IRIDIUM ™ DEBRIS MITIGATION PRACTICES

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ABSTRACT

The IRIDIUM™ Program represents the most exciting prospect in space operations in the world today. However, it also represents one of the biggest engineering challenges as well as one of the best commercial opportunities ever. This paper will describe the trend setting approach Motorola has taken in orbital debris mitigation. It will delineate the attributes of a comprehensive program being implemented during the design phase and to be continued through the operations phase. The challenges are being met head-on and Motorola is aggressively seizing the opportunity to set new standards in debris mitigation.

1. INTRODUCTION

"Outer space is by nature and treaty a global commons, available for use by all nations. With this potential comes responsibility for keeping space safe." (R. A. Williamson, Ref. 1.) The "potential" uses of space have grown over the years and promise to continue to grow. Recognition of this "responsibility" has occurred in varying levels but many would say that the commitment to keep "space safe" has been tepid at best. Motorola is turning up the heat!

2. DISCUSSION

To implement a cost and technically effective debris mitigation plan space operators must commit to debris mitigation in the very first phases of a space program. Debris mitigation must be a part of the Operations Concept that accompanies the basic statement of need or program initiating document. Debris mitigation must be clearly stated policy in the concept definition phase. It must have unambiguous requirements evolve in the requirements generation phase, and it must maintain prominence in the Systems Engineering and Trade-off Analysis phase. Most importantly, it must be a matter of resolve in the operational phase. We at Motorola have made the corporate commitment to ensure debris mitigation is a priority throughout the various phases of our program.

Our initial policy statement was the original Operations Concept which included provisions for debris mitigation, the most dominant of which was de-orbit of spent spacecraft. This first concept also called for selection of orbits that minimized the collision hazard both with our own spacecraft and with other objects, and minimizing debris associated with insertion and deployment. Subsequent updates to the concept have dealt with the explosion hazard and the need for the spacecraft itself to be capable of implementing mitigation techniques autonomously. See Figure 1 for an overview of the IRIDIUM™ System.

The Concept Definition program phase presented the first challenge for debris mitigation policy. Some early size, weight, and power (SWAP) engineers were less than enthusiastic about the fuel costs associated with de-orbit. Clear policy articulation by management during the various design reviews shut down all thoughts of "SWAPing" any of the de-orbit fuel budget for other needs. The Concept definition phase was also the first time we looked at what changes to the basic Adams and Rider constellation (Ref. 2) might be required to avoid colliding with ourselves at the poles and the first time we looked at explosion hazard reduction. We made small adjustments to inclination and argument of latitude to create miss distances of greater than 100 kilometers at the poles (Figure 2 shows the IRIDIUM™ Constellation of 66 satellites) and, based on input from various suppliers, we identified the nickel-hydrogen battery and hydrazine fuel to be our only explosion hazards and deemed them to be extremely low in explosion potential. Management involvement and support throughout the process was highly visible.

The requirements generation phase saw the manifestation of debris mitigation policy. Our top level requirements document (A-Specification) called for minimizing debris. This requirement was flowed down to the space segment (which includes launch) and to the control segment where the Control Center requirements reside. These top level specifications then flow debris mitigation requirements down to segment (product) specifications.

The current challenge is the Systems Engineering and Trade-off Analysis phase which ends at Critical Design Review (CDR). This is the phase where the "Are you sure you really want to do that?" questions abound. As we have investigated alternative orbits and as the spacecraft has grown larger, heavier, and more complex, that question surfaces time and time again.

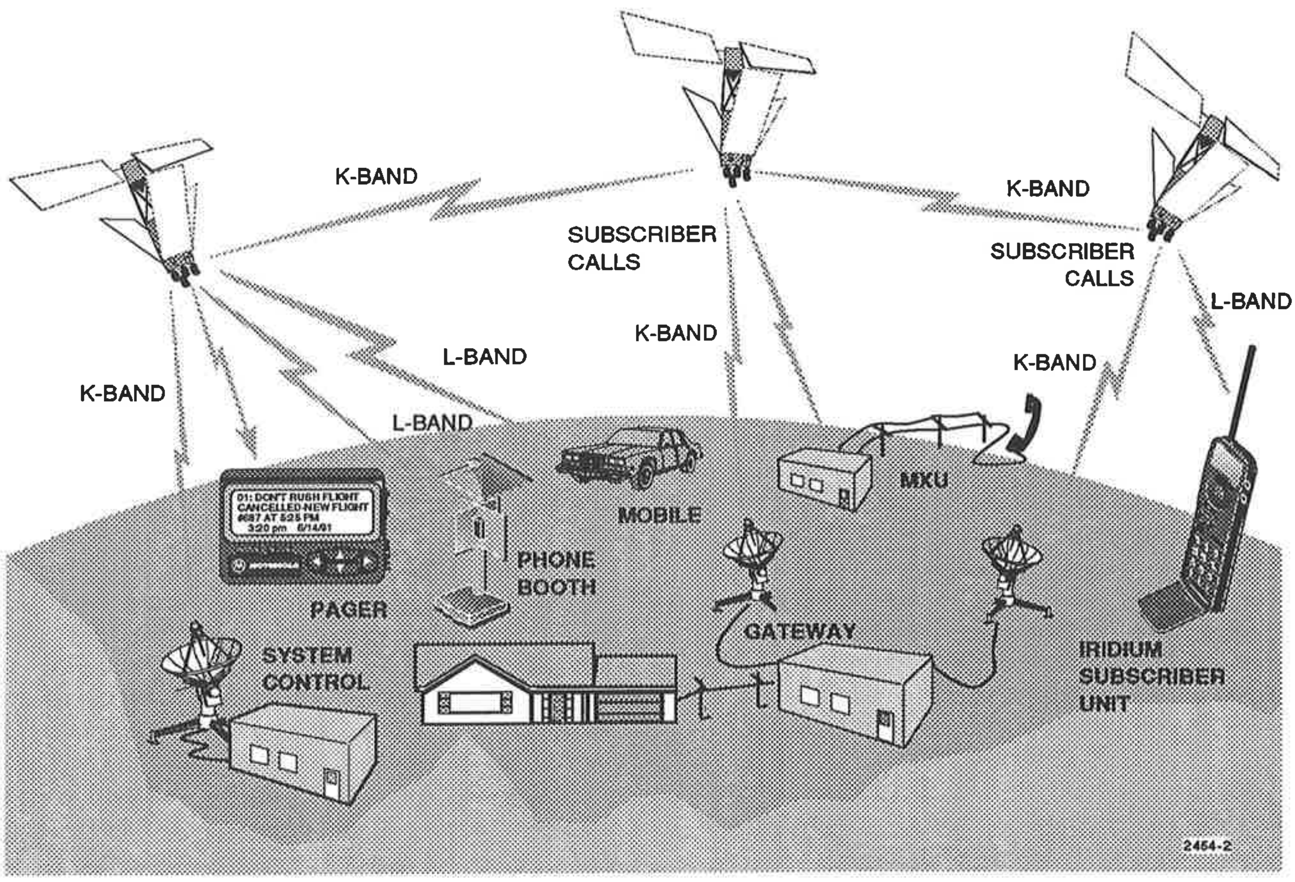

Figure 1. IRIDIUM™ System Overview

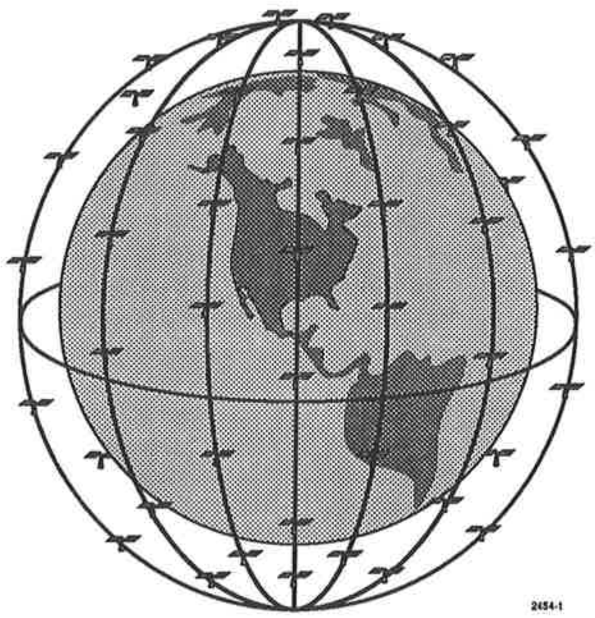

Figure 2. IRIDIUM™ Constellation

Most often, debris mitigation policy is so widely known that engineers themselves throw out solutions that abrogate or might abrogate the policy. As an example, higher orbits were eliminated from consideration because of the well known higher debris density in the 800-1200 kilometer regime. Trade-offs involving spacecraft weight often include the very appealing mass of less de-orbit fuel. But the corporate commitment is firm. Motorola continues to include the de-orbit fuel in our weight budget and engineers have become resigned to the fact that they must look elsewhere for potential weight savings. The various autonomous capabilities (initiated by ground controllers) we envision for de-boost and fuel depletion burns are inherent in most processor designs and the added functionality is negligible...trade-offs haven't really been necessary. Trade-offs of "dirty" deployment schemes such as explosive bolts and untethered shrouds against explosive nuts, pin pullers, and tethered shrouds have been virtually painless from both a design and a cost standpoint, especially since we've done them before CDR.

Even when a program becomes comfortable with its design in regard to debris mitigation, designers and management must maintain vigilance for changes in thinking, technology, or operational experience. In evaluating the explosion hazard, the team had been advised from several sources that nickel-hydrogen batteries simply did not "blow up". Then there appeared in the media a report that three (three!) alleged explosions of satellites employing that type battery had occurred. We immediately started digging to find out if, indeed, there had been an explosion associated with nickel-hydrogen batteries and why. The investigation led us to the noted Russian scientist Boris Tsenter. Motorola brought him on from Israel (he had emigrated from Russia) to assist us with our design to mitigate the explosion hazard for our satellites. In the three days he spent in Chandler he confirmed that, in fact, one of the explosions was caused by the nickel-hydrogen battery. He provided a wealth of information on battery design that avoids the problems that caused the one explosion. In addition to the design input, he presented us many procedural recommendations that will end up in our Operations Plan. In short, Mr. Tsenter boosted our already high confidence that our mitigation program will result in a virtual "debris free" operation.

This past fall the media reported that the Russian "PROTON" rocket was suspected to have been the cause of orbital debris that caused damage to a Soviet satellite. Motorola raised the issue during discussions with the Russians as potential launch suppliers and received assurances that the equipment intended for use on our satellites would **not** be a source of debris. To shore up verbal agreements the language was reviewed in the Statement of Work (SOW) for all suppliers and wording was developed to clearly prescribe orbital mitigation needs. The following is a sample of such wording:

"Subsequent to deployment of all of the IRIDIUM™ space vehicles, the launch vehicle upper stage must perform a de-orbit maneuver placing the upper stage in a decay orbit."

"Design analyses shall also be performed to demonstrate that the Launch Vehicle or related hardware does not generate any debris on orbit in excess of the limitations specified in the IRIDIUM™ Space Segment Specification."

The final challenge will be during the Operational phase. The team has already begun writing the operational procedures to be used when launching begins in 1996. These procedures include supporting software that will direct (under specified conditions) the spacecraft to execute fuel depleting, perigee lowering burns with whatever capability it can muster. The procedures emphasize the need for ailing spacecraft to be taken out of the operational orbit and "safed" with regard to explosion hazard. Our customer, Iridium Inc., has been briefed on our plans, notably the de-orbit philosophy which will occasionally result in de-orbiting perfectly healthy spacecraft because the fuel remaining is only enough for that de-orbit. Their response has been totally supportive. As the design is finalized and the training for operations is set up, debris mitigation will be ingrained in the process and live on with the operational system.

3. CONCLUSION

This paper has described how corporate Motorola has dealt with debris mitigation from the earliest phases of our program. The attribute that has been evident from the beginning and prevails today is corporate commitment. Initial commitment endorsed acceptance of the attendant costs (although they can be minimized when included early in the process) and inclusion of mitigation requirements in the design. Commitment through the design phase was consistent in fending off the alluring options to reduce size, weight, and power by trimming mitigation requirements. And finally, commitment in the operational phase will maintain resolve and execute the plan even when an otherwise healthy spacecraft must be de-orbited because there is only enough fuel left for that de-orbit.

Motorola SATCOM was very happy to see the AIAA identify "... four categories of debris mitigation measures that are the most promising candidates for near-term standardization..." (Orbital Debris Mitigation Techniques:

Technical, Legal, and Economic Aspects, SP-016-1992) They are:

1) Venting of residual fuel and pressurants from discarded rocket bodies

2) Boosting of GEO satellites into disposal orbits

3) De-orbiting spent hardware

4) Reducing operational debris

The IRIDIUM™ program has already implemented all three measures applicable to our particular orbits!

Motorola is committed to mitigating orbital debris. We hope other satellite operators will join us in committing to help preserve that "...global commons, available for use by all nations."

4. REFERENCES

1. Williamson, Ray A., The Growing Hazard of Orbiting Debris, *Issues in Science and Technology*, Vol VIII, No 1, Fall 1991.

2. *Journal of Astronautical Sciences*, Vol 35, No 2, Apr-Jun 1987, pp 155-192.