Low-Earth Orbit Environment Remediation with Active Debris Removal

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The catastrophic collision between Cosmos 2251 (a defunct Russian communications satellite) and the operational Iridium 33 (a United States commercial communications satellite) in 2009 signaled a potential onset of the "Kessler Syndrome" in the environment, predicted by Donald J. Kessler and Burton G. Cour-Palais in 1978. This event also supports the conclusion of several recent modeling studies: even with a good implementation of the commonly adopted mitigation measures, the debris population in low-Earth orbit (LEO)—the region below 2000-kilometer (km) altitude—will continue to increase. The population growth is driven by fragments generated via accidental collisions among existing satellites. Therefore, active debris removal should be considered to remediate the environment. The need for active debris removal is also highlighted in the National Space Policy of the United States released in June 2010 where, under the Section of "Preserve the Space Environment," NASA and the Department of Defense are directed to pursue research and development of technologies and techniques to remove on-orbit debris.

There are many technical and nontechnical challenges for active debris removal. If the objective is to remediate the environment, then the most effective approach is to target the root cause of the problem—objects that have the greatest potential of generating the highest amount of fragments in the future. These are objects with the highest mass and collision probability products. Figure 1 shows the mass distribution in LEO. It is obvious that the major mass reservoirs are located around 600-, 800-, and 1000-km altitudes. The 600-km region is dominated by spacecraft while the other two regions are dominated by spent rocket bodies. Note the operational spacecraft accounts for only approximately 10% of the mass in LEO. Since the 800- to 1000-km region also has the highest spatial density in LEO, it is expected that many of the potential active debris removal targets will be rocket bodies in that region.

A key element for any active debris removal planning is the ability to quantify the requirements of the operations and the benefits to the environment. Figure 2 shows the latest results from the NASA Orbital Debris Program Office on LEO environment remediation.

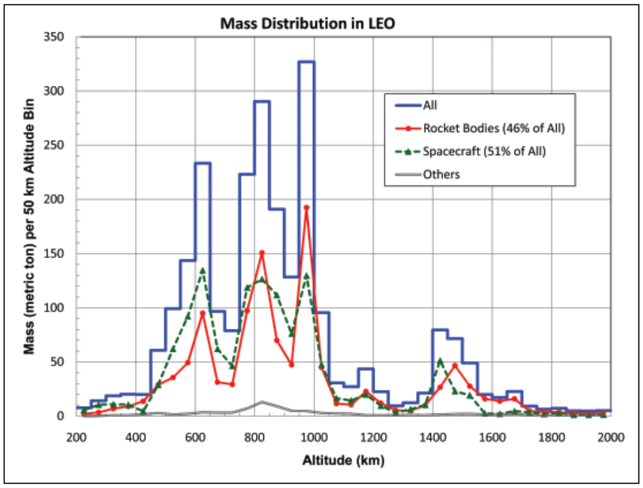

Fig. 1. *Mass distribution in low-Earth orbit. The three major peaks are dominated by rocket bodies and spacecraft.*

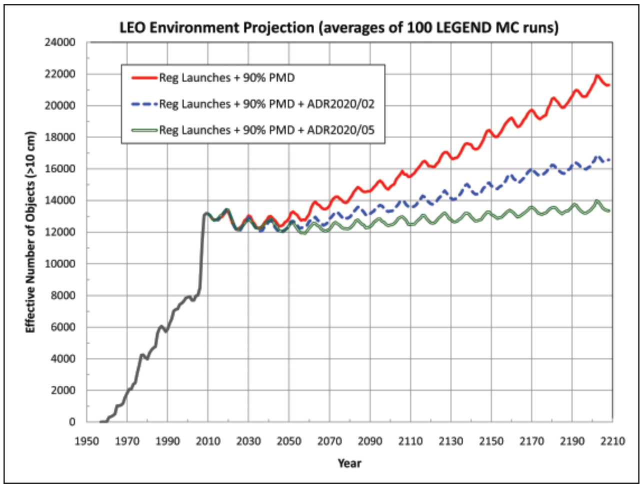

Fig. 2. *Simulated low-Earth orbit (LEO) population growth as a function of time. To maintain the future LEO population at the current level requires a good implementation of the mitigation measures and an active debris removal rate of about five objects per year, starting from the year 2020.*

Simulations were carried out with the NASA long-term debris evolutionary model, LEGEND. The future projection part of the top curve assumes a nominal launch cycle and a 90% compliance of the post-mission disposal measures (e.g., the 25-year rule). The average of 100

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continued

Monte Carlo LEGEND runs indicates that the LEO population will continue a steady increase in the next 200 years. With the addition of active debris removal operations of two objects per year, starting from the year 2020 (the middle curve), the population growth is approximately reduced by half. If the active debris removal rate is increased to five objects per year, then the LEO population in the next 200 years can be maintained at a level similar to the current environment (bottom curve). However, if the objective is to restore the environment back to the level prior to January 1, 2007, (before the Chinese anti-satellite test), then a removal rate of more than five objects per year must be implemented.

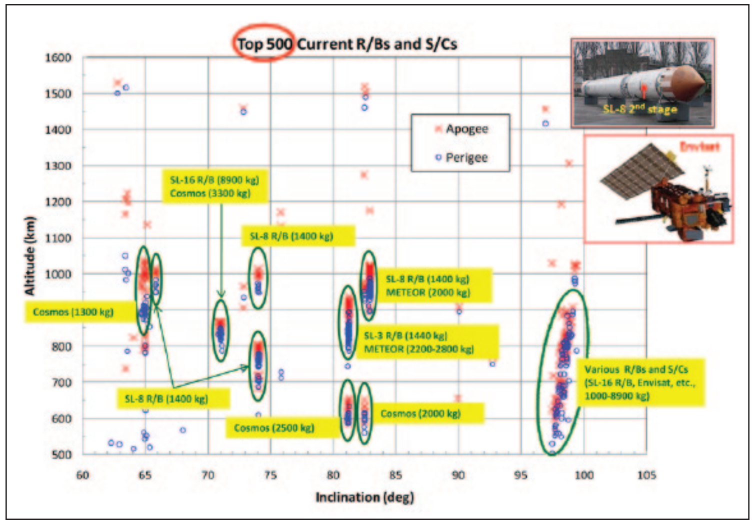

Fig. 3. *Apogee altitude (crosses) and perigee altitude (open circles) versus inclination distributions of the existing low-Earth orbit rocket bodies and spacecraft that have the highest mass and collision probability products. Only the top 500 are shown. These are potential targets for active debris removal.*

The active debris removal target selection criterion used in the LEGEND simulations was the [mass × collision probability] value of each object. This criterion can be applied to objects in the current environment to identify potential targets for removal in the near future. The altitude-versus-inclination distribution of the top 500 objects identified via this selection criterion is shown in figure 3. The prograde group is dominated by several well-known classes of vehicles: SL-3 rocket bodies (Vostok second stages; 2.6 meter [m] diameter by 3.8 m length; 1440 kilogram [kg] dry mass), SL-8 rocket bodies (Kosmos 3M second stages; 2.4 m diameter by 6 m length; 1400 kg dry mass), SL-16 rocket bodies (Zenit second stages, 4 m diameter by 12 m length; 8900 kg dry mass), and various Meteor-series (Russian meteorological satellites) and Cosmos spacecraft (masses ranging from 1300 to 2800 kg). Below 1100-km altitude, the total mass of all SL-3, SL-8, and SL-16 rocket bodies is about 500 tons, which accounts for close to 20% of the total mass in LEO. Objects in the retrograde region are more diverse. They include, for example, Ariane rocket bodies (1700 kg dry mass), CZ-series rocket bodies (1700 to 3400 kg dry mass), H-2 rocket bodies (3000 kg dry mass), SL-16 rocket bodies and spacecraft such as Envisat (8000 kg) and meteorological satellites from various countries.

If active debris removal is to be conducted in the near future, objects in figure 3 should be high on the target list for removal. In general, rocket bodies ought to be considered first because they have simple shapes and structures, and belong to only a few classes. However, some of the rocket bodies may carry leftover propellant in pressurized containers. Any capture operations of those rocket bodies will have to be carefully conducted. A potential problem to capture and remove objects shown in figure 3 is the nontrivial tumble rates of the targets. New ground-based observations on those objects are needed in the near future to identify their tumble states. As the international community gradually reaches a consensus on the need for active debris removal, the focus will shift from environment modeling to technology development, engineering, and operations. It is clear that major cooperation, collaboration, and contributions at the national and international levels will be needed to move forward to implement active debris removal for environment remediation.