



Paper No. SSC12-IV-6

***Moderately Elliptical
Very Low Orbits
(MEVLOs)
A Long-Term Solution
to Orbital Debris***

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Aug. 14, 2012

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Introduction

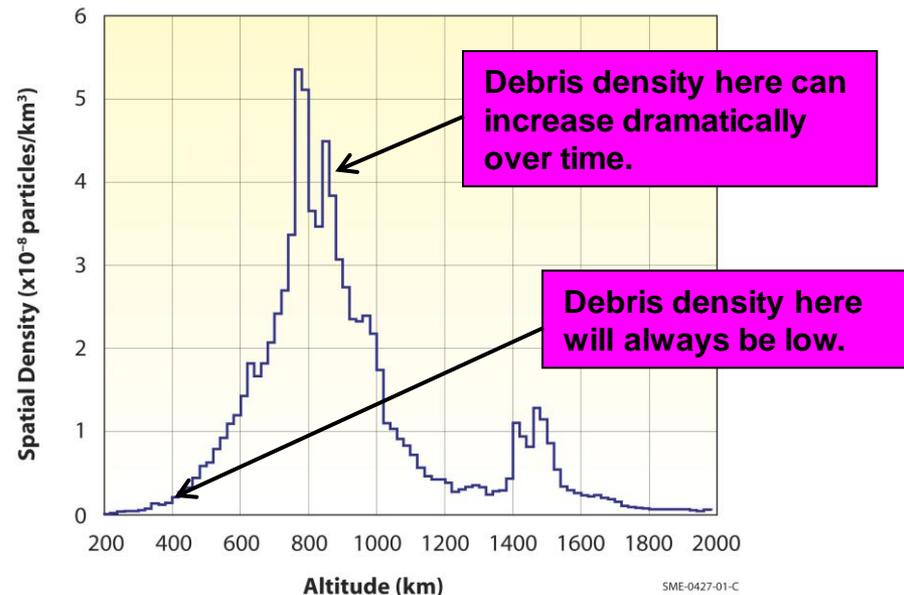
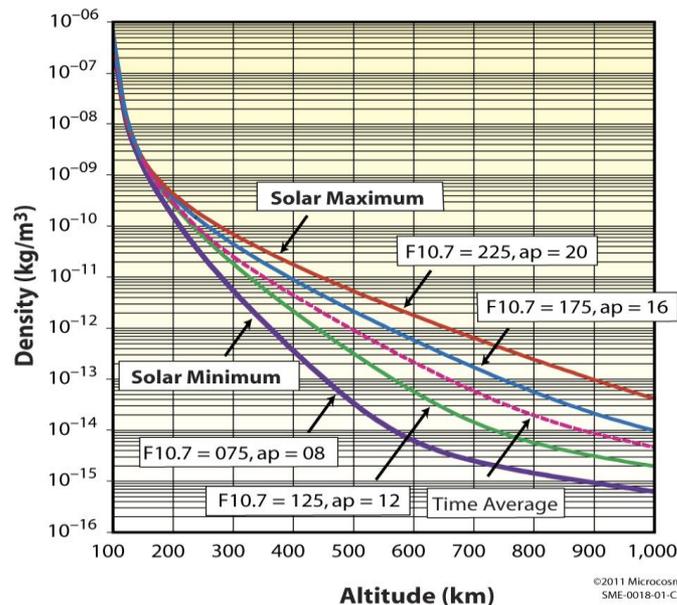
- Long-term man-made debris in Low Earth Orbit (LEO) is a growing problem for current and future space missions
 - Many potential solutions have been proposed— essentially all of which are both challenging and expensive
- Neither Russia nor Iridium LLC are required to clean up or pay for the mess left behind by the Iridium 33/Cosmos 2251 collision
 - Debris from that collision will be with us for ~1000 years
- **A straightforward solution, that can be implemented by individual spacecraft operators, is to put most future LEO spacecraft into *Moderately Elliptical Very Low Orbits (MEVLOs)***
 - Perigees below approximately 300 km
 - Apogees below approximately 500 km
 - Eccentricities in the range of 0.015 to 0.030
- **Orbital debris clouds cannot be sustained in this altitude regime due to high drag**
 - **This means that for MEVLOs the debris population (both now and in the future) is much lower than at higher altitudes and any satellites that die there for any reason will not contribute to the long-term orbital debris problem.**

MEVLOs are an economical, near-term solution to the long-term LEO orbital debris problem.



Below 500 km There is No Orbital Debris Problem

- Traditionally we have launched satellites at altitudes of 700 to 900 km because they could live there more-or-less indefinitely at little or no propellant cost
 - This implies that debris will also live there almost indefinitely
 - Running into a 10 cm piece of debris (the smallest that can be tracked) is equivalent to being hit with a bowling ball at 2,000 mph — the spacecraft doesn't work well afterward



Data from *Space Mission Engineering*, ©2011, Microcosm, Inc.

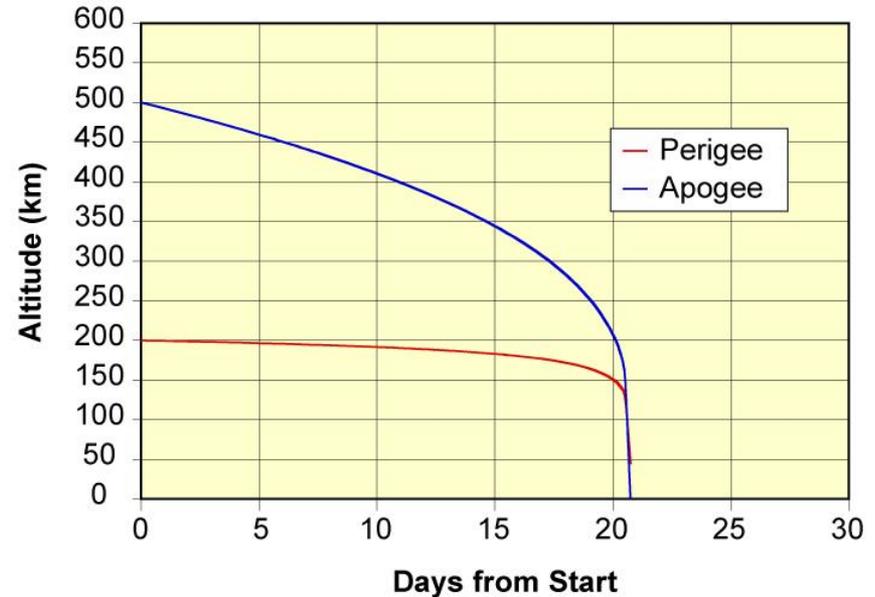
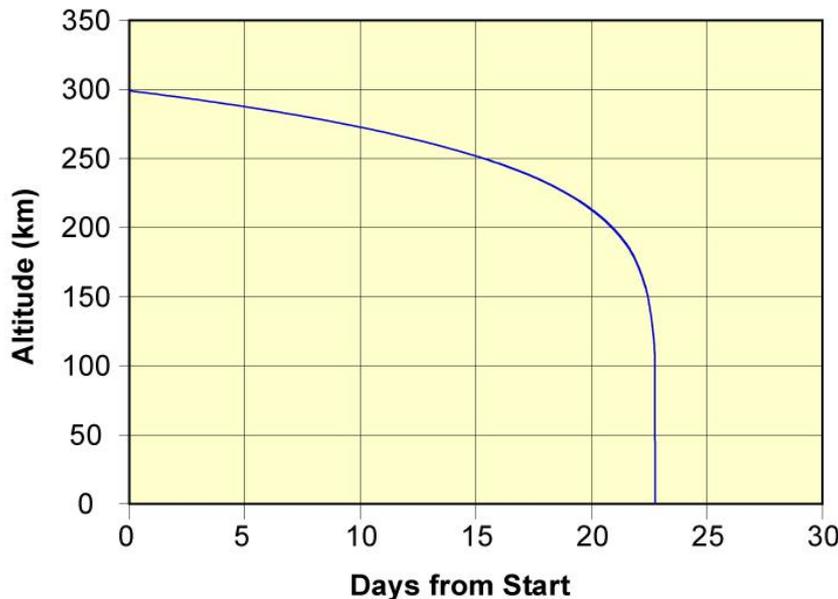
If a debris cloud is created below 500 km, it will last anywhere from a few weeks to, at most, the time until the next solar maximum.



Orbit Decay Profile for Satellites in Very Low Orbits

- With the circular orbit, the satellite begins immediately going deeper and deeper into the atmosphere, the decay rate increases, and the satellite may or may not be recoverable at a later date, but, even in the best case, will have a substantial delta V penalty
- With the moderately elliptical (MEVLO) orbit, decay is a 2-step process with apogee decreasing nearly uniformly until the orbit circularizes and spirals into the atmosphere
 - **Nearly any time prior to re-entry, recovery is possible without a large delta V penalty**

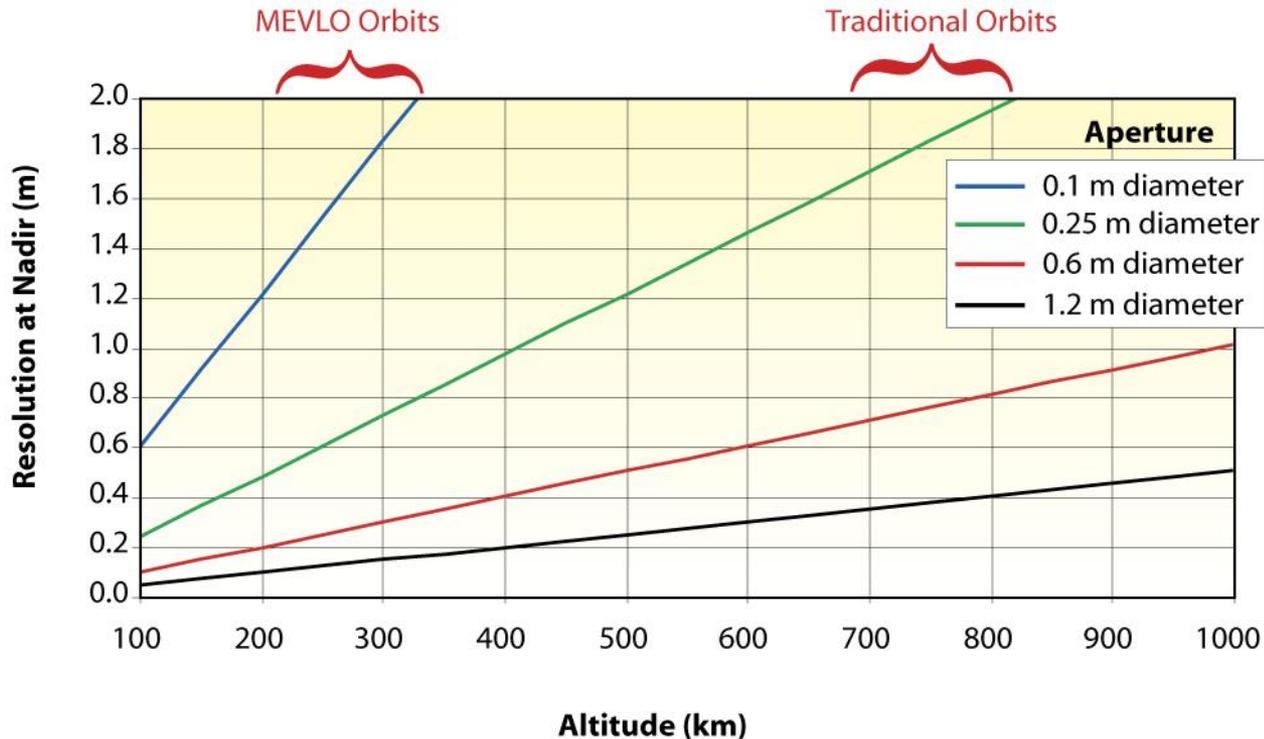
Both plots show orbit decay at solar max with no orbit maintenance



MEVLO is a fail-safe orbit. In the event of an orbit maintenance failure, nothing bad happens until relative near the time that the satellite re-enters. This gives us time to recover.

Other Advantages of MEVLOs

- The radiation environment is more benign at low altitude
- **For observation missions, a low perigee altitude provides better resolution at much lower cost than a higher orbit with a larger aperture instrument**

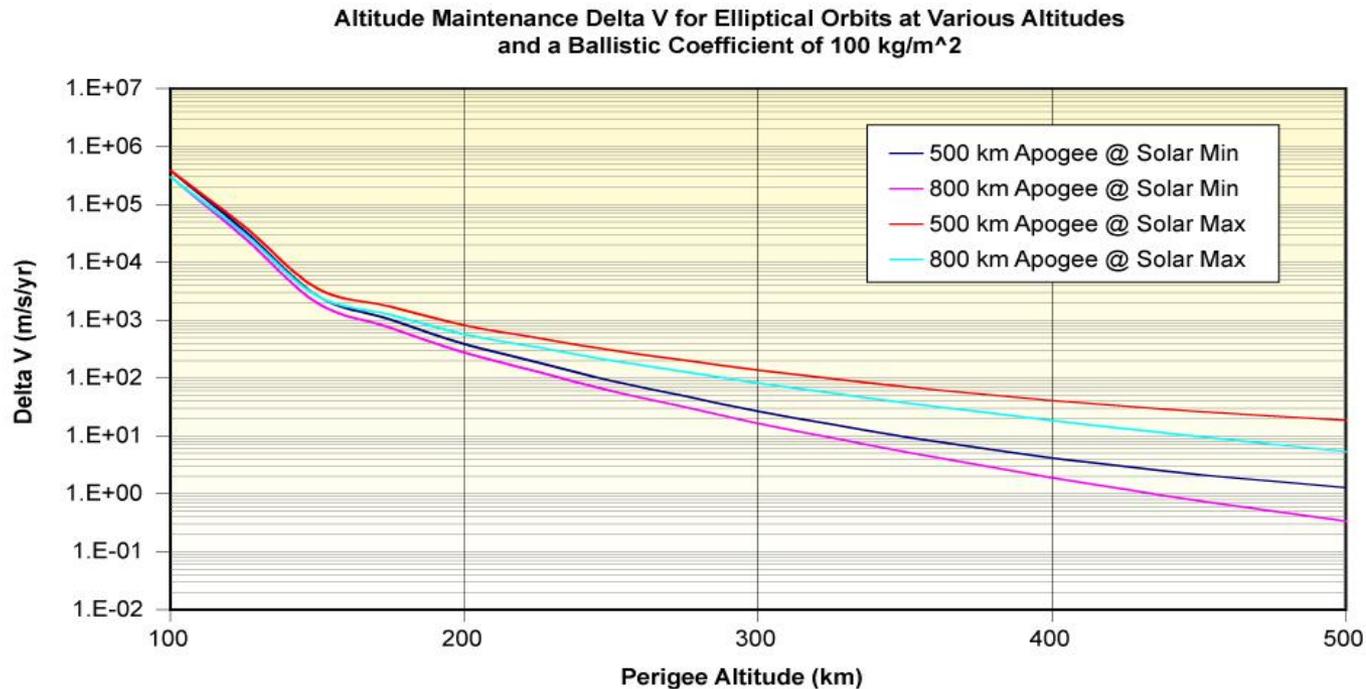


Low Altitude is much cheaper than large aperture for improving resolution.



Selecting the Right MEVLO

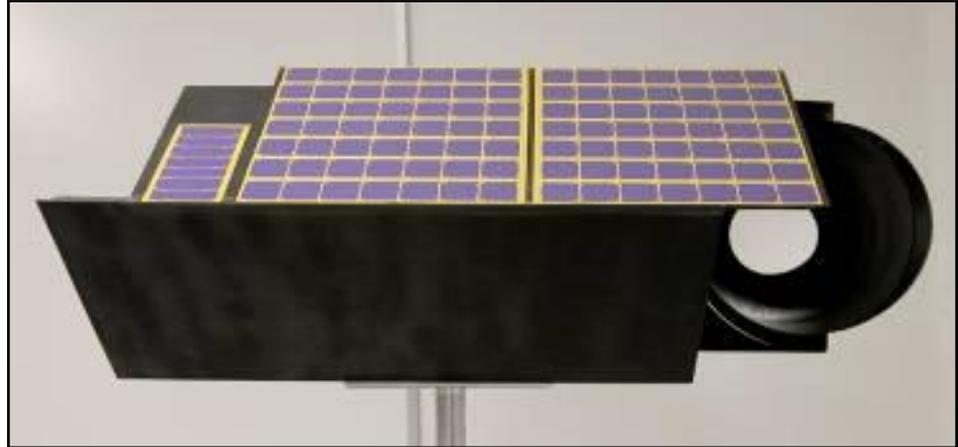
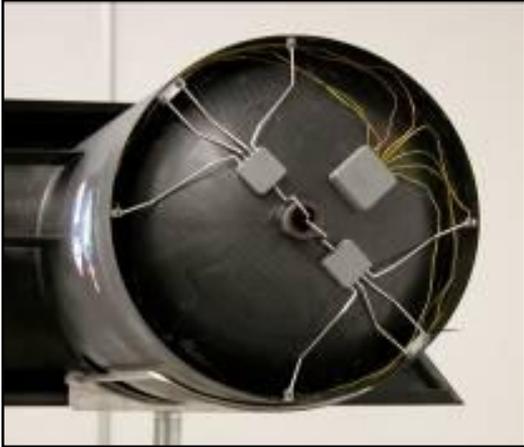
- Final orbit selection is a balance between:
 - Advantages of going lower = Good resolution, reduced instrument (and spacecraft) size and cost, and reduced orbital debris problems
 - Disadvantages of going lower = Required delta V (and, therefore, propellant) and reduced coverage



Design life of MEVLOs will typically be shorter, which allows us to take advantage of continuous improvements in technology, such as the performance of small electronics.



NanoEye Full-Scale Mock-Up — A Spacecraft Designed for MEVLO Operation



**No deployables.
Propellant tank is the
spacecraft structure**



Spacecraft configuration designed to minimize drag and torque with large propellant volume.



NanoEye Accommodation for Low Altitude Orbits

- **NanoEye physical configuration is specifically designed to minimize both aerodynamic drag and aerodynamic torque**
- **It has very large margins in both force and torque to accommodate inevitable uncertainties in atmospheric density and structure**
 - The maximum available thrust is over 10 N, which is 500 times the maximum expected force due to drag of 0.02 N
 - The maximum available torque is 450 mN-m [and could easily be made larger], compared to the worst case torque of 1 mN-m
- **The spacecraft also allows very fine orbit and attitude adjustments with a minimum thruster on-time of only 1 msec, corresponding to a delta V of 0.06 mm/s**
- **The relatively frequent orbit control burns that are required at low altitude are done autonomously using Microcosm's autonomous orbit control software**
 - Successfully flown on UoSAT-12 and TacSat-2
- There is ample delta V available to adjust both the perigee and apogee altitudes as often as desired by large amounts
 - The spacecraft can fly at a higher altitude if atmospheric conditions cause operational problems or lower altitudes if needed to respond to mission needs

NanoEye is designed to fly at low altitudes to achieve better performance at much lower cost and to minimize the issue of orbital debris.



Conclusion

- **With MEVLOs, if the spacecraft stops working for an extended period for any reason, it will re-enter the atmosphere**
 - That's what we want to happen
 - If spacecraft functionality returns in a reasonable time, the orbit can be recovered with little or no loss in the total delta V used
- Observation spacecraft in MEVLOs provide improved resolution at much lower cost
- Generally, MEVLOs favor:
 - Small spacecraft which use smaller solar arrays because of the smaller volume to area ratio
 - Shorter design lives, which allow taking advantage of advances in microelectronics
- **With MEVLOs the orbital debris problem goes away, both now and in the future**
- The only substantive demerit is the added launch mass needed for additional propellant for orbit maintenance
 - The propellant itself is cheap

Spacecraft flying in Moderately Elliptical Very Low Orbits (MEVLOs) will have less debris problems both now and in the future and cannot contribute to the long-term orbital debris problem for other spacecraft.