# Ad Astra's VASIMR® Space Tug
# Low Earth Orbit (LEO) Space Cleaner

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**Ad Astra Rocket Company**
**http://www.adastrarocket.com/aarc/**
**141 W. Bay Area Blvd, Webster, TX 77598, Tel: 281 526 0500**

Ad Astra Rocket Co (Ad Astra), developers of the VASIMR® electric propulsion engine, presents the advantages of its propulsion technology to remove orbital debris from low Earth orbit (LEO) by means of a high power, solar electric propulsion (SEP) space tug. The company has examined the capture and controlled deorbit of 19 known large pieces of orbital debris, drifting in various high inclination orbits. The chosen objects are mainly spent Zenit rocket upper stages 4 m diameter by 10 m long, weighing approximately 8 t. Figure 2 shows the specifics of the Zenit rocket and the orbital characteristics of the chosen targets.

Figure 1: Powered by a 200 kW VASIMR® engine, Ad Astra's solar electric LEO Space Cleaner approaches a spent Zenit upper stage for capture and disposal

This mission concept utilizes the company's multipurpose, 200 kW VASIMR® solar electric space tug to lower the orbital altitude of the Zenit targets for a controlled chemical deorbit over the Pacific Ocean. To accomplish this, the reusable tug is fitted with a specialized service module (SM) consisting of a solid rocket motor (SRM) tray, loaded with 20 SRM units (19 plus a spare) and a detachable, short-range, "chemical robotic pod" (CRP) for proximity operations near the target body. For each of the 19 targets, the tug first climbs to the orbit of the drifting Zenit (~800 km) where the CRP is released to capture, stabilize, and bring the target back to a hard docking with the tug. At capture, the CRP also robotically installs a fresh SRM unit onto the Zenit rocket nozzle. With the Zenit attached, the tug brings it down to approximately 400 km for release at a point where the newly fitted

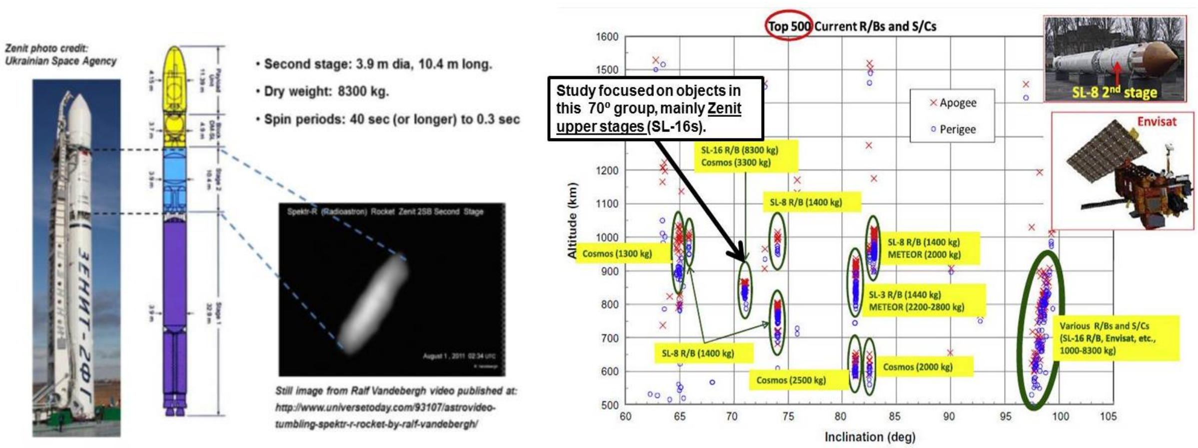
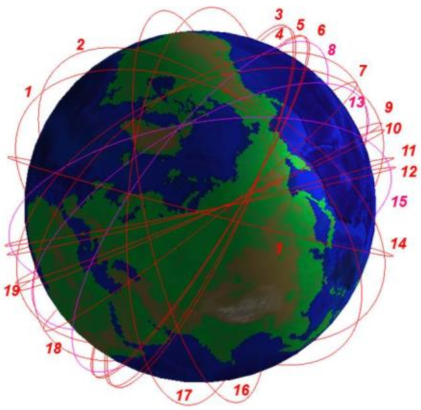
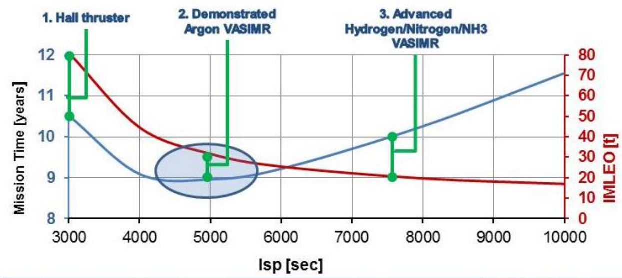



Figure 2: Zenit upper stages are orbiting debris in a cluster of objects drifting in diverse orbital planes, located at roughly 70° orbital inclination and 800-900 km altitude

SRM ignites, bringing the Zenit to a controlled atmospheric re-entry. The VASIMR® tug then climbs back, making a plane change, as required, to capture the next target and repeat the process.






| | technology | Propellant | $I_{sp}$ | Mission time | IMLEO | Cost |
|---|---|---|---|---|---|---|
| 1 | Hall Thruster | Xenon | 3000 | 10.5 y | 80 t | $800M |
| 2 | VASIMR | Argon | 5000 | 9 y | 30 t | $300M |
| 3 | VASIMR | NH3 | 7500 | 10 y | 20 t | $200M |

Figure 3: VASIMR® tug maneuver sequence (left); performance and estimated cost tradeoffs of the propulsion system

As shown in Figure 3, the mission involves a sequence of 19 altitude change maneuvers, in multiple orbital planes optimized for minimum fuel use and minimum time for a given power and specific impulse ($I_{sp}$). The mission shows an absolute minimum time at an $I_{sp}$ of 4500-5000 seconds, well suited for a VASIMR® propulsion system operating with low-cost argon propellant. Lower $I_{sp}$ results in a large increase in the initial mass in low Earth orbit (IMLEO) and therefore increased cost. We can conclude that **VASIMR's measured high power performance for this application is both faster and cheaper than other EP technologies.**

Going to even higher $I_{sp}$ may also be attractive, as it further reduces the initial launch cost to LEO with only a modest increase in mission time. Ad Astra will be exploring the potential of VASIMR® engines operating with other propellants, such as hydrogen, and ammonia to further expand the high $I_{sp}$ envelope of the technology in the same manner it has been exploring the use of krypton for applications benefitting from lower $I_{sp}$. Ad Astra presently maintains a VASIMR® rocket prototype, the VX-200, running with argon propellant at 200 kW with greater than 70% thruster efficiency[1] in its Houston vacuum chamber. The company has executed more than 10,000 reliable firings of this engine to date (See Figure 4). Initial operation of VX-200 with krypton propellant was also demonstrated in 2012.

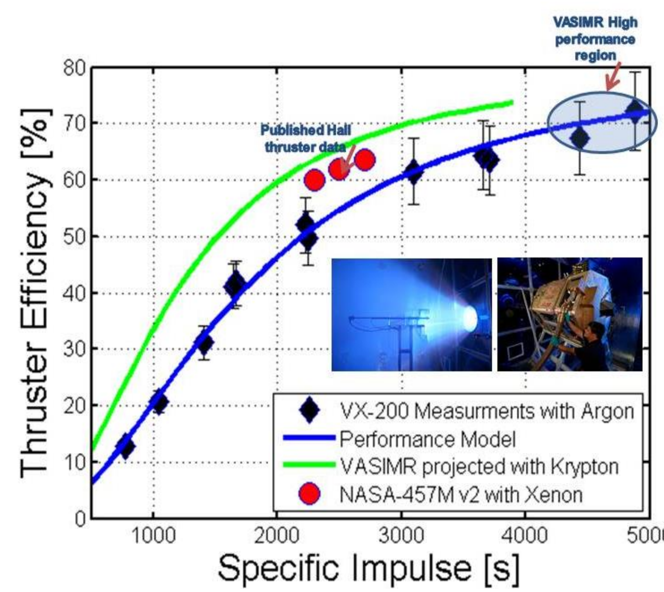



Figure 4: 2011 VX-200 performance data, VX-200 engine, and VX-200 plume at 200 kW

[1] B. Longmier, et al. VASIMR VX-200 Performance Measurements and Helicon Throttle Tables Using Argon and Krypton, IEPC-2011-156, 32nd International Electric Propulsion Conference, Wiesbaden, Germany, Sept 11-15, 2011.