Ad Astra Rocket Company's VASIMR® Near Earth Asteroid (NEA) Deflection Mission

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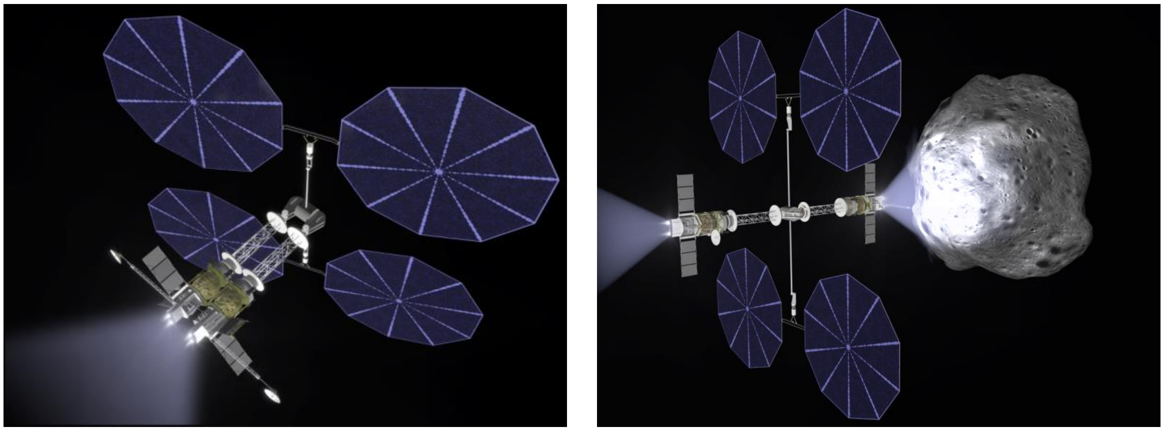


Ad Astra's ***Viento*™** spacecraft is configured in 2 modes: additive propulsive mode for fast transit to asteroid (left) and opposing tandem mode (right). The 400 kW solar electric propulsion spacecraft is equipped with 2, VF-200-class VASIMR® engines.

Ad Astra Rocket Company has evaluated the applicability of its 400 kW solar electric propulsion (SEP) "space tug" concept, ***Viento*™** to successfully deflect an imaginary medium-sized asteroid in a direct impact scenario with Earth. ***Viento*™** is equipped with two dual-core, VF-200-class engines operating at 200 kW each in: 1) additive ***translation mode*** to provide high speed translation capability to the target asteroid and 2) ***deflection mode*** with its two nacelles oriented in opposing tandem to utilize the plasma exhaust of one of the engines to gently "blow" on the asteroid to impart momentum and alter its trajectory, while the other engine, with proper gimballing and auxiliary spacecraft attitude control, maintains the spacecraft in a stable position, hovering adjacent to the asteroid without actually landing.

Viento™ Mass Budget

- **Power & Propulsion: 4.0 t**
- **Propellant: 35.6 t**
  - **L1- NEA: 5.0 t**
  - **Deflection: 30 t**
  - **Return to L1: 0.6 t**
- **Tank & Structure: 5.4 t**

Total (IML1): 45.0 t

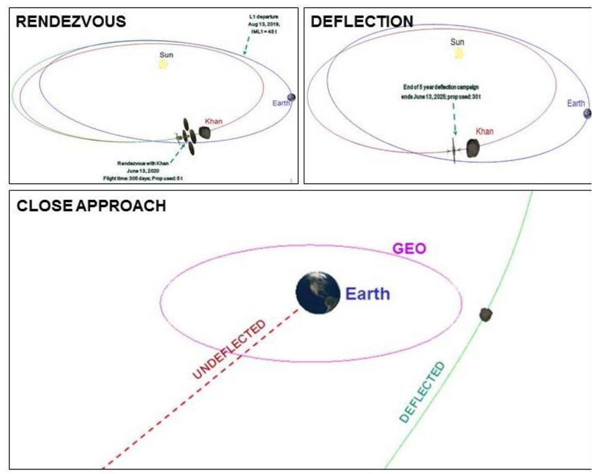
The imaginary asteroid, which we call "Khan," is a 7 million ton, 150 m diameter body in an Apophis-like[1] orbit, slightly modified to set up a direct impact[2] with Earth on April 13, 2029, versus the near-miss that will actually occur with Apophis. Khan is in a nearly circular orbit with a period of 323 days. Each year, Earth crosses Khan's orbit on April 13 as Khan heads inbound toward perihelion. Khan is large enough to pose a major threat to our planet and, in our imaginary scenario, if not deflected, Khan will impact Earth with an energy release of 131 megatons, causing a major regional disaster.

[1] 99942-Apophis is a 270 m diameter boulder weighing approximately 40 million tons and discovered on June 19, 2004.

[2] In a direct impact (vs. a "keyhole" impact) an asteroid is on an orbital track that will result in a certain collision with Earth on a specific date. A keyhole impact also results in a collision with Earth, but only following a prior near-miss, during which the asteroid passes through a keyhole, a small region near Earth where the gravitational force of the planet causes a change in the asteroid's orbit, setting up a subsequent direct impact. Avoiding a keyhole is less demanding than a direct impact and could potentially be accomplished using a Gravity Tractor. Avoiding a direct impact requires a robust deflection capability.

VX-200 engine (left), 200 kW argon plume (center) and measured and predicted performance data for Argon and Krypton

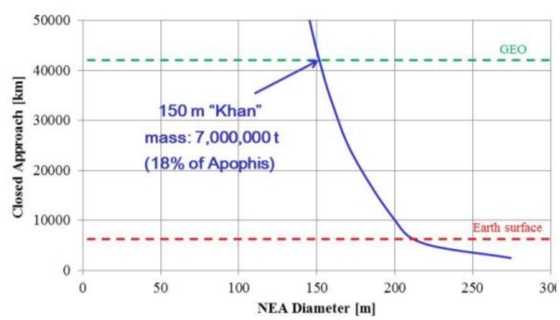
Ad Astra's ***Viento***™ carries out the deflection campaign in four phases: 1) **departure** on August 13, 2019 from Earth-Moon L1 (EML1) and a 305 day propulsive translation to a rendezvous with Khan on June 13, 2020; 2) a five-year active **deflection** period, ending on June 13, 2025, where the spacecraft is configured to hover adjacent to the asteroid while pushing on it with the other engine; 3) a four-year passive **loiter** period at Khan, ending on March 19, 2029, while ***Viento***™ awaits an optimal return opportunity and 4) a 40 day **return** maneuver, which brings ***Viento***™ back to its point of origin a the EML1.



Deflection trajectories and close approach geometry before and after deflection

The high power scalability of the technology forms the basis of an attractive mission. The VASIMR® propulsion system is electrodeless (expected to reduce component wear and increase lifetime) and has an inherent high power density and high specific impulse (I_{sp}), with no thruster scalability concerns at total power of up to 1 MW. VASIMR® systems use more efficient, economical propellants, such as argon (~$5/kg) and krypton (~$300/kg), than conventional Hall and ion thrusters, which operate with much rarer and expensive xenon (~$1000/kg). Such flexibility results in significant operational cost savings. The 200kW VASIMR® engine is in a high state of technical maturity. A full scale prototype running with argon propellant and called VX-200 has executed more than 10,000 reliable high-power firings to date with greater than 70% thruster efficiency[3] in Ad Astra's 150 m^3 Houston vacuum chamber.

The VASIMR® deflection capability is determined by the power level, the deflection time and the size and mass of the asteroid. At the 400 kW level used in this study, the deflection of a 150 m asteroid is readily facilitated within the allotted time from a direct impact at the center of the Earth out to several Earth radii. Larger asteroids, up to ~200 m in diameter may be deflected just enough to avoid a collision.



Deflection capability for a given power level decreases with asteroid diameter

[3] 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.