AEROCAPTURE DEMONSTRATION AND MARS MISSION APPLICATIONS. M. M. Munk, NASA Langley Research Center (1 N Dryden Street, M/S 489, Hampton, VA; michelle.m.munk@nasa.gov)

Challenge Area Summary: Aerocapture is an aeroassist technology that can enable large robotic payloads to be placed into Mars orbit, facilitate access to Phobos and Deimos, and support human Mars exploration. This abstract addresses Challenge Area 2; in particular, ***Concepts for low-cost demonstration of aeroassist technologies***. The information herein presents the state-of-the-art (SOA) in aerocapture technology, outlines an established Earth flight demonstration concept, and offers specific uses for aerocapture at Mars.

Introduction: Aerocapture, shown in Fig. 1, is the use of aerodynamic forces to slow an approaching vehicle and put it into a closed orbit about a planet. In contrast to aerobraking, aerocapture occurs in a single atmospheric pass, so orbit establishment is immediate. By accomplishing over 95% of the orbit insertion delta-V with drag, aerocapture saves significant propellant mass, allowing the use of smaller, more inexpensive launch vehicles, faster trip times, or increased payloads. The heating and aerodynamic loads on the spacecraft require that a heatshield, like that used for entry, descent and landing (EDL), be used for protection. The heatshield must also provide the aerodynamic shape required for autonomously controlling the vehicle to a specified target altitude upon exit, after which the heatshield is ejected and adjustments can be made to achieve the final orbit.

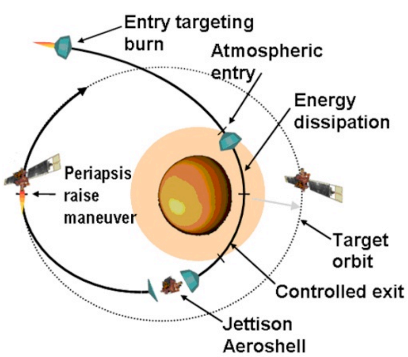

Figure 1. The Aerocapture maneuver is accomplished in a single atmospheric pass to eliminate propellant.

The Aerocapture maneuver has never been proven in flight, but the theory and benefit of using a planet's atmosphere to effect a change in velocity has been studied for decades. Aerocapture was once part of the Mars Surveyor Program 2001 Orbiter design and the Mars Sample Return architecture for 2003-2005; Aerocapture saves multiple Earth launches for human Mars DRA5[1], when coupled with high-thrust propulsive transfers. Aerocapture's mass benefits for historical Mars missions have not been compelling due to small scale and low arrival velocities. As we strive to emplace more massive assets at Mars to support humans or explore Phobos and Deimos, Aerocapture can play a significant, beneficial role.

Aerocapture SOA: Aerocapture occurs in only one flight regime (hypersonic) and there are no required configuration changes during the maneuver, making it much less difficult than EDL. Small timing errors during EDL can result in loss of mission; during aerocapture, they mean a little more propellant is needed to adjust the final orbit. Monte Carlo simulation is used to ensure system performance is robust even with realistic navigation, atmospheric, and aerodynamic uncertainties. Aerocapture utilizes the same analysis, hardware and systems engineering methods as EDL systems, so much of what is needed for Aerocapture already exists and has been flown in space. In fact, the Mars Science Laboratory (MSL) entry GN&C algorithm has the same foundation as aerocapture guidance, so some argue that once MSL maneuvers successfully and Orion accomplishes a skip entry, Aerocapture is essentially proven.

Specific technology maturation for Aerocapture has received NASA investments continuously for over 10 years through the Science Mission Directorate's (SMD) In-Space Propulsion Technology (ISPT)[2] program. Through ISPT, Aerocapture has been matured to a TRL of 5+ for use at Mars, Earth, Titan, and Venus. SMD is so confident in the Aerocapture TRL that in the New Frontiers-3 Announcement of Opportunity, the use of Aerocapture or Aerocapture hardware components matured by ISPT were incentivized, and proposers taking advantage of the incentives were not subject to more stringent risk reviews. Specific investments have included detailed systems studies and models for SMD missions, lightweight ablator and structure manufacture and testing, aerothermal tool validation, heatshield instrumentation development, and guidance, navigation and control (GN&C) flight software and hardware-in-the-loop testbed development. Mars Aerocapture can utilize either existing Mars entry system hardware (the 70-degree sphere cone rigid aeroshell with SLA-561V or PICA heatshield material), enhanced structures and materials developed through ISPT, or take advantage of NASA's more recent developments in deployable decelerators, depending on the mass and volume of the payload.

Extensibility to Human-Scale Missions: As shown in DRA5 and in the EDL Systems Analysis (EDLSA) effort[3], Aerocapture is effective using both high- and low-ballistic-coefficient vehicles. These span the range of EDL configurations currently envisioned for humans, and include the rigid, slender, mid-L/D vehicle, the hypersonic inflatable aerodynamic decelerators (HIADs), and the mechanical deployable systems (such as ADEPT). Aerocapture can deliver payloads from 1 to over 100 mt to both 500 km circular and 1-Sol orbits, including orbits from which to explore Phobos and Deimos.

Earth Demonstration Mission: Despite the evidence that Mars aerocapture is low risk and can be performed immediately, there are some advantages to performing an Earth flight validation. An Earth flight may be fiscally feasible before a Mars aerocapture mission, and will open the door earlier, for aerocapture use at multiple destinations in the Solar System. In addition, a flight dedicated to technology validation will be designed to include thorough instrumentation to validate the computational models underlying the aerodynamics, aerothermodynamics, and GN&C disciplines. In 2004-06, an Earth validation of Aerocapture was one of the 5 Space Technology 9 (ST9) proposals to NASA's New Millennium Program (NMP). Although not ultimately selected (NMP was cancelled shortly thereafter), the Aerocapture proposal received high marks from the reviewers and independent peers, and was widely supported by the technical EDL community. The ST9 concept definition[4] was important for establishing consensus that an Earth flight demo was actually applicable to other planets, and it established the requirements for ensuring infusion readiness. The estimated mission cost was $107M, excluding launch vehicle. The 1.1-m diameter, 60° sphere cone launched on an expendable rocket to an apogee >10,000 km to achieve an entry speed >10 km/s, needed to fully exercise and validate the GN&C system.

Recent studies aiming to reduce the cost of an Earth Aerocapture demonstration have focused on only validating the GN&C system with minimal instrumentation, and on minimizing the launch vehicle cost. A vehicle diameter of 0.8 m or greater is still required to match the flight characteristics of applicable missions, and this scale, coupled with the need for an initial 10 km/s entry speed, makes most sounding rockets unusable. The Sandia Super-Strypi is a low-cost suborbital rocket that can accommodate the aerocapture vehicle plus a propulsive stage to "pile-drive" the vehicle into the atmosphere at the desired 10 km/s velocity. An approach of this type might be feasible for accomplishing the aerocapture demonstration at Earth for about $75M including launch, within 3 years.

Mars Missions: The use of Aerocapture at Mars provides an endless number of possible missions. In a 2006 ISPT-funded Mars systems analysis study[5], an opposition-class mission design was used to return a Mars sample one year sooner than current architectures, once the sample was cached and in Mars orbit. The shortened mission profile reduced cost and risk; Aerocapture enabled the 7-mt Earth Return Vehicle to achieve Mars orbit and retrieve the orbiting sample while carrying the fuel necessary for both trans-Earth injection and a deep-space maneuver. Another use for an aerocaptured high-mass orbiter may be to deploy multiple weather GPS-type satellites in 2 orbit planes for global and diurnal coverage.

Aerocapture was also an integral technology in the ESMD Flagship Technology Demos (FTD-4), proposed in 2010. FTD-4 outlined both Mars and Earth demonstrations using either Mid-L/D or HIAD entry vehicles to demonstrate Aerocapture and EDL. Although not low-cost, large-scale demonstrations will be critical mid-term steps to maturing the systems for eventual human use. Payloads of ~2 mt placed on Mars after Aerocapture could include ascent vehicles, ISRU plants, power generators, weather stations, advanced drilling platforms, or portable laboratories. The Exploration Feed-Forward study[6] also showed that aerocapture with a HIAD, followed by EDL, could put 2.5-3.5 mt on Mars within today's launch capabilities.

Concluding Remarks: Aerocapture technology is beneficial to both SMD and HEOMD missions, and is ready to be added to the Agency's toolbox. Demonstrating Aerocapture at Earth, or using it on a Mars mission in the near term, will benefit that mission, advance technologies needed for human exploration of Mars, and open the door for its use on missions throughout the Solar System. Mars mission planners are strongly encouraged to utilize Aerocapture at Mars in the coming opportunities.

References: [1] Drake, B. G., editor (2009). *NASA/SP-2009-566; Human Exploration of Mars Design Reference Architecture 5.0*. [2] Anderson, D. J. et al (2012). *IEEEAC Paper #1037; In-Space Technology Products Ready for Infusion on NASA's Future Science Missions.* [3] Cianciolo, A. M. et al (2010). *NASA/TM-2010-216720; Entry, Descent, and Landing Systems Analysis Study: Phase 1 Report.* [4] Keys, A. et al (2006). *AIAA-2006-4518; Overview of a Proposed Flight Validation of Aerocapture System Technology for Planetary Missions.* [5] Wright, H. S. et al (2006). *NASA/TM-2006-214522; Mars Aerocapture Systems Study.* [6] Cianciolo, A. M. et al (2011). *NASA/TM-2011-217055; Entry, Descent, and Landing Systems Analysis Study: Phase 2 Report on Exploration Feed-Forward Systems.*