AN INTERPLANETARY CUBESAT MISSION TO PHOBOS.
J. Thangavelautham[1], E. Asphaug[1], G. Dektor[2], N. Kenia[2], J. Uglietta[2], S. Ichikawa[2], A. Choudhari[2], M. Herreras-Martinez[2], S. R. Schwartz[1], [1]School of Earth and Space Exploration, Arizona State University, 781 E Terrace Rd, Tempe, Arizona, 85283 (jekan@asu.edu), [2]School of Energy, Matter and Transport Engineering, Arizona State University.

Introduction: Martian moon Phobos may hold vital clues to the origin of Mars. The moon exhibits several unique features such as surface striations, arguably due to its being within Mars' Roche limit [1, 9]. Phobos has been suggested as a low delta-v stop-over site and staging base for human missions to Mars. It is feasible to teleoperate Mars surface assets via a base on Phobos. In order to one day take advantage of Phobos as a strategic location for future human exploration to Mars, much more needs to be known about the moon's origin, composition and surface-properties [1, 9]. This data is critical towards designing feasible missions and working towards the eventual goal of developing a staging base on Phobos. To date, missions with a major Phobos focus, such as Phobos I & II, Nozomi, and Phobos-Grunt, have all failed prematurely. Phobos has been proposed as the target of several Discovery missions [2], showing that there is an important need to have a dedicated mission to Phobos.

CubeSats offer the opportunity to perform low-cost focused science exploration, with rapid turn-around times between multiple missions [3]. The high failure rate of past Phobos missions must be considered when developing future missions, and the cost/risk involved in large missions needs to be carefully weighed. An alternative option is to have multiple small spacecraft that focus on simple tasks instead of a single, large spacecraft with very complex, multitasking functionality. A reasonable option is to utilize CubeSats as stepping-stones to exploring Phobos, uncovering its mysteries and contributing towards long-term human exploration of Mars.

Science Mission: We propose development of a 6U, 14-kg interplanetary CubeSat called LOGIC (Low Orbit Geology Imaging CubeSat) that would perform thermal and visible imaging of Phobos at resolutions of 25 m/pixel and 5 m/pixel, respectively. The mission concept of operations is shown in Figure 1. LOGIC is inspired by JPL's INSPIRE and MarCO CubeSats [4-6]. This CubeSat mission would be a pave the way for a subsequent, larger Phobos surface lander mission. This CubeSat mission to Phobos would provide an unprecedented view of the moon, including coverage of more than 50% of the surface. The spacecraft will obtain detailed images of striations, crater rims, surface boulders and material composition. To complete these science objectives, LOGIC will for the first time demonstrate a CubeSat achieving a capture orbit around Mars.

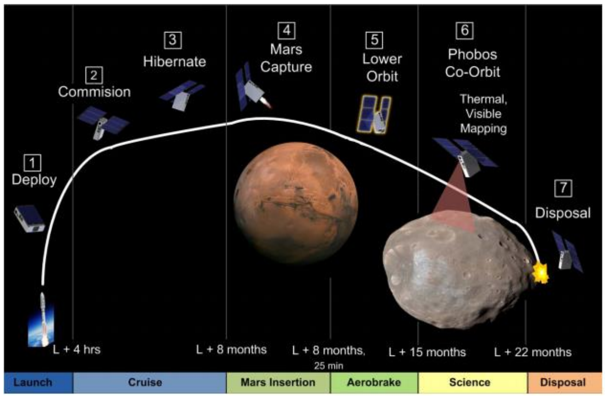

Figure 1. Mission Concept of Operations.

Spacecraft Bus: Figure 2 shows the spacecraft layout. The spacecraft contains two science instruments, namely the e2V Cires Visible camera and FLIR Tau thermal camera. The spacecraft is powered using a pair of onboard deployable solar panels such as the E-HaWK from MMA Design. The solar panels have 1 DoF of gimballing. The back side of the solar panels contains an X-band reflect-array for communication and will utilize JPL's IRIS v2 X-band radio [5-6]. The spacecraft will charge 2 Gomspace NanoPower BPX lithium ion batteries with a total energy capacity of 154 Wh.

The LOGIC CubeSat would launch as a secondary payload much like JPL's MarCO CubeSats [5-6] on a Mars-bound spacecraft and is expected to be ejected once it is on an Earth-escape trajectory. The spacecraft will be propelled using a green monopropellant system developed by Aerojet Rocketdyne that will insert it into a Martian orbit. Green monopropellant provides the most practical option for a high-thrust, high-delta-v CubeSat propulsion system [7]. The key will be to reduce capture-orbit burn time to avoid having the plume overheat the spacecraft as may have hapenned with the CONTOUR mission [8]. The spacecraft will enter into a highly elliptical orbit and perform aerobraking to enter into a co-orbit with Phobos. This propulsion system consists of 4 one-newton GR-1 thrusters. This system allows LOGIC to capture, perform corrections and desaturate the reaction wheels. The system utilizes 3.3 kg of total fuel with 1.8 kg of thruster components.

The Attitude Determination and Control System (ADCS) consists of the Blue Canyon Technologies

XACT. It combines a suite of sensors such as a star tracker and sun sensor to perform deep-space inertial measurements. For attitude control, the system contains 3-axis micro-reaction wheels which are periodically desaturated using the GR-1 thrusters.

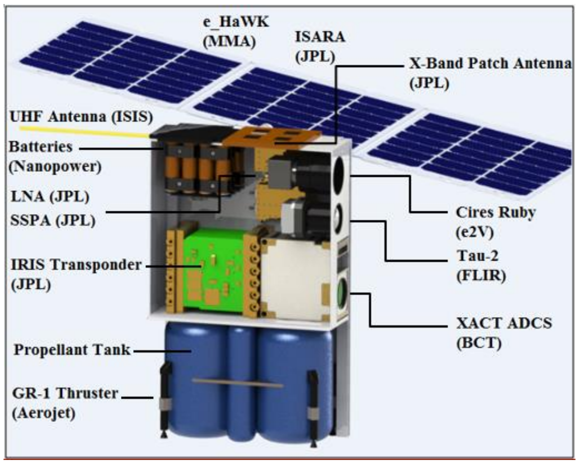

Figure 2. LOGIC spacecraft layout. The spacecraft is expected to be a 14 kg, 6U CubeSat with a visible and thermal camera, onboard green monoprop propulsion system, X-band radio and Blue Canyon XACT attitude determination and control system suite.

Mission Analysis: The proposed mission will be testing several new technologies that, if shown to be successful, could further the capabilities of future interplanetary CubeSats. One is to perform aerobraking around Mars to get into the desired co-orbit around Phobos. Due to the limited mass and volume of the spacecraft, there is a critical need for aerobraking. The proposed technique for aerobraking is no longer something new for large spacecraft, but, until now, the implications for CubeSats are not well understood. The team has analyzed options for further simplications and mission descopes that would avoid aerobraking. The result would be a highly elliptical orbit around Mars that would allow periodic "close" flybys of Phobos at 6-month intervals or longer.

In addition, the mission would be testing a combined solar-panel X-band reflector array antenna technology in deep space. This provides both opportunities and challenges when trying to balance the positioning requirements to maximize power while also exhibiting good communications capabilities.

Planetary Protection drives the requirement for disposal of the satellite after the mission. In order to adhere to planetary protection laws, the satellite must have less than a 1 % probability of impact for 20 years and less than a 5% probability in 50 years. The disposal orbit has been carefully designed such that the spacecraft does not degrade into a collision with Mars for at least 50 years.

Interplanetary CubeSats offer a compelling path forward towards short, focused science missions that act as trailblazers for larger, longer missions. Even if one fails, a CubeSat mission may be assembled with a relatively short turn-around time. Phobos is an excellent target to better understand small-bodies, their origins and compositions, and could be crucial for making a future human mission to Mars a reality.

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