EXPLORING MARS WITH SMALL SPACECRAFT ORBITERS AND LANDERS. N.J. Barba, T.A. Komarek, V. Stamenkovic, L. Giersch, R.C. Woolley and C.D. Edwards, Jet Propulsion Laboratory, California Institute of Technology 4800 Oak Grove Drive, Pasadena, California 91109. nathan.j.barba@jpl.nasa.gov.

Introduction: The Mars Exploration Directorate at the Jet Propulsion Laboratory sponsored a recent study to examine the capabilities of small spacecraft missions for Mars exploration. The purpose of the study is to examine the technical feasibility of sending small spacecraft to Mars to conduct compelling science for a total mission cost, including launch costs, of below $250 million. The study is focused on three key areas: identification of high-priority science investigations consistent with MEPAG goals that could be performed by small spacecraft; investigation of methods of transport for small spacecraft from Earth to Mars; and determination of the technical feasibility and mission cost of small spacecraft mission concepts.

The study began by surveying science instruments suited to meet the mass, volume, power, and cost constraints of a small spacecraft. The survey led to the identification of several science themes for orbiter and landers, see Figure 1.

Figure 1: Small Spacecraft Science Themes for Orbiters and Landers.

The themes identified were used to develop key science questions, objectives, and investigations that are traceable to MEPAG goals. Special attention focused on science goals that are related to (1) fundamental and new “high-science-impact” measurements, (2) global observations and global context, allowing the derivation of a 3D map of Mars properties from orbit and on ground (3D networks and “mini-scouts”) and particularly (3) global 4D (3D in space + time = 4D) observations of fast varying processes with changes occurring over periods of less than a few sols. The latter does not only provide a global context but would allow to constrain causality between processes on the planet [1].

It should be mentioned that the low cost point of small spacecraft missions can enable unique mission concepts with higher than normal mission risk. This increase in risk can create opportunities for low-cost, compelling science missions in regions that may be otherwise unexplored by higher-cost, high-risk-averse missions.

Getting to Mars: To get small spacecraft from Earth to Mars, three methods were identified: (1) hosted payload or “piggyback”, (2) rideshare as a secondary payload on a traditional launch vehicle, and (3) primary payload on one of an emerging class of small launch vehicles (e.g., Firefly Alpha, Relativity Terran 1, ABL Space RS1) with advertised pricing ranging between $10 and $15 million for a dedicated launch. The rideshare investigation of the study concluded that a spacecraft in a secondary payload configuration could reliably count on 10 - 12 launch opportunities per year to geosynchronous transfer orbit (GTO). Assuming a 200 kg dry mass, approximately 10 km/s delta V would be required to get to from GTO to Mars. Conceptual mission design indicates that a small spacecraft flight system utilizing solar electric propulsion could achieve the required velocity while meeting the mass and volume constraints of an EELV secondary payload adapter (ESPA) [2].

SmallSat Orbit Science: Aside from a survey of applicable science instruments, several mission architecture concepts were developed. The study focused on high (~17,000 km) and low orbit (250 km) concepts capable of delivering up to 20 kg of science instrument payload to Mars using solar electric propulsion.

Areostationary Orbiter Concept: One of those missions was an Areostationary SmallSat orbiter called LOKI (LOcalizing Key Ingredients), see figure 2.

Figure 2: Areostationary Small Spacecraft Concept.

The science goal of the concept was to localize the sinks and sources of trace gases using a multi-channel nadir-pointed spatial heterodyne spectrometer (SHS) in order to better constrain the processes that form and destroy methane and oxygen on Mars as observed with the Curiosity rover. In contrast to current and past trace gas monitoring assets, the areostationary orbit would allow to observe a constant and large field of view.
Low Altitude Mars Orbiter: Another orbiter concept investigated was a low-orbit mission concept. The reference instrument for the orbiter was a high-resolution multi-spectral imager capable of 30 cm/px ground sampling at a 300 km altitude. A high-resolution capability <30 cm/px would enable science investigations that explore geologic and climatic processes. In parallel to science investigations, the imager could also support hazard avoidance and entry descent and landing support for robotic and human missions to the Martian surface.

Small Spacecraft Orbiter Constellations: In the context of an areostationary orbit a constellation of three small orbiters placed equidistant from each other in areostationary orbits can provide continuous scientific observation of most latitudes of Mars. Areostationary constellations are also well-suited to provide continuous telecom downlinking of data while acting as a relay for space-based and ground-based assets at Mars.

Mars Impact Lander: In order to reduce the cost of landing small payloads on Mars, a new technology is being developed: the Small High Impact Energy Landing Device concept (SHIELD) see Figure 3.

The purpose of SHIELD is to provide a low-cost option to deliver up to 6 kg of science payload to the surface of Mars. The cost target for a SHIELD lander concept is <$50M per lander or <$200 million for up to three SHIELDs, a transit stage, and launch. The limitations of SHIELD are that the landing decelerations are significantly higher than more conventional Mars EDL technologies, roughly 9,800 m/sec², or 1000 g. As a result, not all payloads will be compatible with SHIELD. To provide context to a 1000 g deceleration, product-level drop impact tests of cellular phones indicate that a cell phone dropped from 1 m can experience decelerations up to 1.2 ms with magnitudes as high as 1400 g [3]. The SHIELD lander can be deployed as a single lander or in a network configuration of landers. SHIELD can be delivered to Mars as a surface only mission or can be coupled with an orbiter to provide context and confirmation to remote sensing missions. Several mission concepts have been developed such as the TH₂OR mission concept, see Figure 4, which would search for for subsurface liquid water using a time-domain electromagnetic sounder down to depths of many kilometers [4, 5].

Figure 3: SHIELD Lander Concept.

Figure 4: TH₂OR concept using SHIELD to search for liquid groundwater. Credit NASA/JPL by Corby Waste.

Conclusion: Small spacecraft missions can conduct traceable and compelling science. Within the cost and launch constraints considered here, small spacecraft can offer science payload capability of up to 20 kg for orbiters and up to 6 kg of for landers. A first order analysis on cost indicated a single spacecraft in areostationary orbit would be under the $250 million cost target and a constellation of three small orbiters estimate cost could fit within the current $500 million Discovery class mission cost cap. The cost target for a SHIELD lander is estimated to be <$50M per lander or <$250 million for up to three SHIELDs, a transit stage, and launch.


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