**RED DRAGON: LOW-COST ACCESS TO THE SURFACE OF MARS USING COMMERCIAL CAPABILITIES.** J. S. Karcz[1] (john.s.karcz@nasa.gov), S. M. Davis[2] (steve.davis@spacex.com), M. J. Aftosmis[1], G. A. Allen, Jr.[3], N. M. Bakhtian[4], A. A. Dyakonov[5], K. T. Edquist[5], B. J. Glass[1], A. A. Gonzales[1], J. L. Heldmann[1], L. G. Lemke[1], M. M. Marinova[1,6], C. P. McKay[1], C. R. Stoker[1], P. D. Wooster[2], K. A. Zarchi[1], [1]National Aeronautics and Space Adminstration (NASA) Ames Research Center, Moffett Field, CA 94035, [2]Space Exploration Technologies Corporation (SpaceX), 1 Rocket Road, Hawthorne, CA 90250, [3]ERC, Inc., Moffett Field, CA 94035, [4]Stanford University, Stanford, CA 94305, [5]NASA Langley Research Center, Hampton, VA 23681, [6]Bay Area Environmental Research Institute, Mountain View, CA 94043.

**Introduction:** We will discuss the feasibility of using a minimally-modified variant of a SpaceX Dragon capsule as a low-cost, large-capacity, near-term, Mars lander for scientific and human-precursor missions. We have been evaluating such a "Red Dragon" platform as an option for a Discovery Program mission concept.

A Red Dragon lander has the potential to be low cost primarily because it would be derived from a routinely-flying spacecraft. Dragon is being developed to ferry cargo and crew to and from the International Space Station (ISS). The cargo variant is currently undergoing test flights, which will be followed by standard ISS cargo missions and, eventually, crewed flights. The human variant, unlike other Earth-return vehicles, appears to also have most of the capabilities necessary to land on Mars. In particular, it has a set of high-thrust, throttleable, storable bi-propellant "SuperDraco" engines integrated directly into the capsule which are intended for launch abort and powered landings on Earth. These thrusters suggest the possibility of a parachute-free, fully-propulsive deceleration at Mars from supersonic speeds to the surface. Concepts for large, human-relevant landers (see, e.g., [1]) also often employ supersonic retro-propulsion; Red Dragon's entry, descent, and landing approach would scale to those landers. Further, SpaceX's Falcon Heavy launch vehicle, currently under development and expected to have its first flight in 2013, will be capable of sending Dragon on a trajectory to Mars.

We will discuss our motivation for exploring a Red Dragon lander, the primary technical questions which determine its feasibility, and the current results of our analysis. In particular, we will examine entry, descent, and landing (EDL) in detail. We will describe the modifications to Dragon necessary for interplanetary cruise, EDL, and operations on the Martian surface. The analysis to date indicates that Dragon is capable of delivering more than one tonne (t) of payload to sites at elevations three kilometers below the Mars Orbiter Laser Altimeter (MOLA) reference, which includes sites throughout most of the northern plains and Hellas.

**Concept:** Red Dragon would be derived from the human variant of the spacecraft. Systems unnecessary for a Mars lander mission, e.g. crew systems and ISS berthing hardware, would be omitted. Some upgrades and modifications would be necessary, e.g. for deep-space communications and navigation, planetary protection, and payload access to the Mars environment. The spacecraft would launch to Mars on a Falcon Heavy rocket. Falcon Heavy is expected to be able to launch more than 10 t, significantly more than Red Dragon's expected launch mass, to a typical Mars trajectory specific energy, $C_3 \sim 10\ km^2 / s^2$. Dragon's existing propulsion system is sufficient for trajectory correction maneuvers during cruise to Mars.

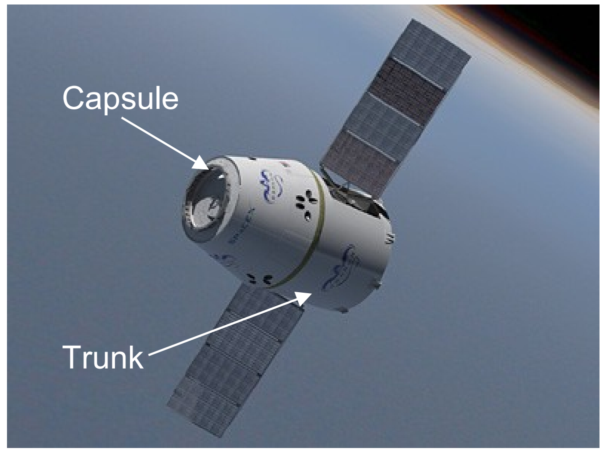

**Figure 1.** Cargo variant of the SpaceX Dragon spacecraft.

Dragon's trunk (Figure 1), which contains its in-space solar arrays and radiators, would be discarded before entering Mars' atmosphere. Dragon's heat shield is designed for hyperbolic entries at Earth and would be capable of withstanding the lower-speed hyperbolic

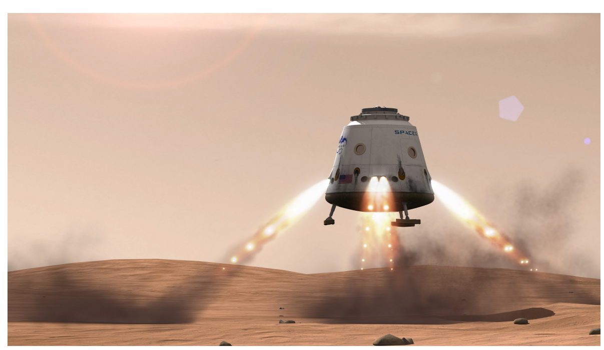
**Figure 2.** Artist's conception of a Red Dragon landing on Mars.

entries at Mars. After entering the atmosphere, the vehicle would decelerate through a guided, lifting trajectory. Dragon would propulsively decelerate from supersonic speeds to touchdown, taking advantage of its high-thrust retro-propulsion system and obviating the need to develop new parachutes or other aerodynamic decelerators for the vehicle. SpaceX plans to include legs on a version of the human variant of Dragon; Red Dragon would land on those legs (Figure 2), modified as necessary for the Mars environment.

The vehicle would have a large volume (~ 10 $m^3$) for payload. After landing, payload could access the Mars environment using certain existing pathways. The top of the capsule, where the ISS berthing hatch would otherwise be, is protected by a disposable fairing and can be opened or host a payload deck. A side bay which otherwise holds ISS mission sensors and equipment—located near the heat shield and protected by an actuated door—is another route. Payload systems could also access the environment through new, custom pathways. Dragon's structure is designed to contain the high forces of an Earth sea-level atmosphere; for unpressurized missions, the structure can accommodate large doors, fairings, or other routes to the outside environment. During surface operation, payload services such as power and communications could be provided by the capsule or by the payload itself; we are exploring the range of options.

**Feasibility:** The primary question determining whether it would be feasible to use Dragon as an inexpensive Mars lander is whether it can successfully enter, descend, and land with little or no modification. Specifically, the question is whether Dragon, which was designed for Earth reentry, can decelerate and land safely in Mars' thinner atmosphere. The efficacy of aerodynamic deceleration is determined by an entry vehicle's ballistic coefficient, $\beta = M / C_d A$, where $M$ is the mass of the vehicle, $C_d$ is its drag coefficient, and $A$ is its aerodynamic reference area, as well as the vehicle's lift-to-drag ratio, $L / D$. Higher ballistic coefficients correspond to higher final speeds when approaching the surface. After slowing as much as possible aerodynamically, some other method must be used to decelerate through the remaining speed to landing. All previous Mars landers have used supersonically-deployed parachutes followed by subsonic retro-propulsion for terminal descent. However, since Dragon is designed for Earth entry it has a significantly higher ballistic coefficient, $\beta > 300$ kg / $m^2$, than previous Mars landers. Its aerodynamic characteristics are at the edge of the range for which using parachutes is currently considered feasible [2]. Even if parachutes were feasible, adopting them would require a major development and qualification effort. Instead, we have examined whether Dragon's launch-abort system has sufficient capability to decelerate through the final phase of flight using propulsion alone.

To determine whether the capsule has sufficient propulsive capability, we compared the final speeds attainable through unpowered aerodynamic deceleration to the propulsive capacity of the launch-abort system. Our analysis to date has focused on landing sites relevant to our Discovery Program mission concept; in particular, it has focused on landing at an elevation three kilometers below the MOLA reference, which addresses much of the Northern Hemisphere. Also, for the analysis so far, entries followed unguided, lift-up trajectories. We varied entry conditions (speed, flight-path angle, and atmospheric density) and vehicle parameters (L/D and entry mass) and found that Dragon is capable of landing more than one tonne of payload to our target sites for a broad range of conditions. Analysis of EDL continues, including considering guided entries to increase payload capacity, continuing detailed examination of the supersonic-retro-propulsive phase of the flight, and assessing whether a combination of guided entry and fully-propulsive descent would allow improved landing accuracy compared with previous landers. Although Dragon's ballistic coefficient is higher than previous Mars landers, it is still less than those suggested for future human landers. Red Dragon's EDL approach is scalable to those vehicles, and a Red Dragon mission would advance the readiness of supersonic retro-propulsion and other aspects of EDL for human missions.

**Summary:** SpaceX's Dragon capsule and Falcon Heavy rocket present the possibility of delivering large scientific and human precursor payloads to Mars within the Discovery Program's cost cap. The capsule's design already includes most of the capabilities necessary for Mars missions. Options exist to integrate payloads with the vehicle and for them to access the Mars environment. Current analysis indicates that entry, descent, and landing of the capsule at Mars is feasible, and the capsule's descent technique would lead on a path toward future human-mission landers.

**References:** [1] B. G. Drake, editor (2009) Human Exploration of Mars: Design References Architecture 5.0, *NASA-SP-2009-566*. [2] R. D. Braun and R. M. Manning (2007) *Journal of Spacecraft and Rockets, 44*, 310–323.