RED DRAGON-MSL HYBRID LANDING ARCHITECTURE FOR 2018.
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Introduction: We propose an innovative approach to Safe and Accurate Landing Capability (Challenge Area 2) that: ◆ hybridizes the most advanced contemporary flight-system developments applicable to Mars, ◆ would involve commercial flight systems directly in deep-space exploration, with the potential for significant cost avoidance and schedule acceleration, and ◆ could deliver metric-ton-class payloads to the surface, demonstrating capability critical for eventual human missions. In addition to dramatic benefits to SMD and HEOMD, this hybrid architecture provides a near-term, significant and key role for an affordable, highly visible, Earth-based OCT demonstration flight project.

Hybridizing a variant of the SpaceX Dragon spacecraft (as a Mars lander) with a hypersonic guidance strategy based on the JPL MSL mission (Mars Science Laboratory), the proposed architecture opens a Pathway to commercially provided landing of heavy payloads on Mars with 10-km landing accuracy. The architecture relies on SpaceX SuperDraco engines for supersonic retropropulsion that would decelerate the Dragon-variant spacecraft from supersonic speed to a soft landing on the surface of Mars, thus demonstrating a keystone enabling technology for human exploration.

Landed payloads (e.g., surface science packages) that could take advantage of this capability are open to further study by the science community based on Planetary Science Decadal Survey priorities.

Mission Architecture: A potential mission for the 2018 Mars opportunity would send a Dragon variant to Mars, supported by the SpaceX Dragon trunk module during cruise. The Dragon-variant spacecraft would perform a direct entry into the atmosphere at 6.0 km/s and utilize entry guidance during both hypersonic and supersonic phases of flight. Unlike MSL, the spacecraft would not deploy a parachute decelerator, but rather would transition directly from atmospheric flight to powered descent at Mach 2.24. A high-thrust, powered descent phase would rapidly slow the vehicle to 2.4 m/s 40 m above the surface. From that height the vehicle would descend at a constant rate of 2.4 m/s, performing a soft landing at the same velocity. The Dragon-variant spacecraft would land on a legged subsystem as illustrated in SpaceX vehicle concepts. The conceptual landing sequence is illustrated in Figure 1.

Performance: The Red Dragon-MSL Hybrid landing architecture would be capable of landing a 1000-kg payload on Mars. Table 1 lists key mission parameters. With a 7200-kg entry mass, the vehicle would be configured by a center-of-gravity offset to fly with an L/D of 0.24, matching the MSL L/D. Just prior to powered descent, 120 kg of ballast mass (a potential science-package mission of opportunity) would be ejected to remove this CG offset, thereby balancing the vehicle. During powered decent, 1900 kg of propellant would provide the Δv required for soft landing. System total landed mass would be 5180 kg.

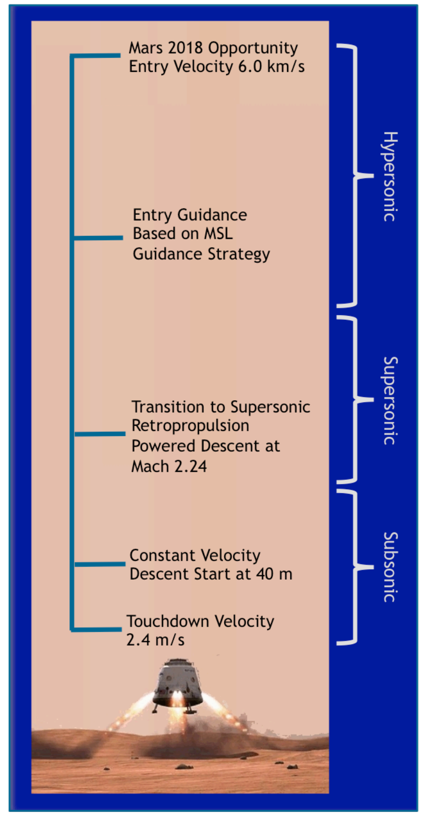

Figure 1. Red Dragon-MSL Hybrid landing architecture concept blends recent commercial and NASA advanced system developments to demonstrate a capability essential for eventual human missions to Mars. (Original Red Dragon graphic credit: SpaceX)

JPL Performance Validation Analysis: We performed a 4001-case Monte Carlo analysis to assess the potential performance, and validate fundamental feasibility of, the hybrid architecture. We determined that an MSL-based bank profile optimized for L/D = 0.24 would provide better landing-site-elevation performance than a Viking-like lift-up entry. The Monte Carlo analysis indicates that the architecture could achieve a maximum landing site elevation of -0.8 km relative

Table 1. Key mission parameters demonstrate significant performance potential of Red Dragon-MSL Hybrid concept.

Key Mission Parameters	Value
Launch Opportunity	2018
Entry Velocity	6.0 km/s
Entry Vehicle L/D	0.24
Entry Vehicle Ballistic Number	450 kg/m^2
Entry Mass	7200 kg
Propellant Mass	1900 kg
Total Landed Mass	5180 kg
Landed Payload Mass	1000 kg
Est. Landing Accuracy	10 km
Est. Max. Landing Site Elev.	-1.3 km MOLA

to the MOLA areiod. However, entry guidance (which this initial analysis did not include) would provide ~10-km landing accuracy, at a cost of approximately 0.5 km in landing-site elevation performance. We estimate the maximum landing site elevation capability (with entry guidance) is ~1.3 km with respect to the MOLA areiod. The bottom-line performance of an integrated system could therefore be ~1000 kg of payload delivered to -1.3 km and lower, with 10-km landing accuracy.

Launch: 7200 kg is at or above the capability of Delta IVH (the largest launch vehicle in our stable) to deliver to Mars. SpaceX is developing a Falcon Heavy launch vehicle, essentially three Falcon 9 first stages strapped together with propellant crossfed. Such a vehicle could launch 7200 kg on to Mars with significant margin. SpaceX is currently planning the first Falcon Heavy launch for 2013 and quotes launch cost at $128M [1].

Application to Programmatic Goals: The value of the Red Dragon-MSL Hybrid landing architecture we propose would be as a commercially-leveraged, constrained-cost delivery system to the Mars surface, that could enable pursuit of Decadal Survey science objectives on a continuing basis. Combining a Dragon vehicle modified from the commercial production line with the Falcon Heavy's potentially low cost and high performance yields the possibility of delivering 1000-kg payloads to the Mars surface for ~$250M. Even at twice this cost, the value proposition would be very strong. This is made possible by accepting very low mass efficiency (MSL delivers 1000 kg with a 3800-kg launch mass), but combining it with a very low cost launch vehicle that can handle that mass. Such a system could provide up to 7 m^3 of cargo volume [2], in which strategic Decadal-Survey science payloads might be stowed for delivery onto Mars. In so doing, the architecture would also promote into implementation the key technology of supersonic retropropulsion, commonly identified as enabling for eventual human mission architectures requiring 20-30-metric ton payloads.

Technical Challenges: Given the strategic promise of this hybrid approach as a delivery system to the Mars surface, it is worth investigating in detail four principal technical challenges. (1) As conceived, the architecture would require deep throttling of the SuperDraco thrusters (to 5% or less) during the final constant-velocity phase just prior to touchdown. This technical challenge would both require and provide an opportunity to push the state-of-the-art of deep-throttled engines. (2) The Dragon aeroshell configuration, with very shallow 15° aftbody sidewall angle [1], would require additional suitability assessment for flying with L/D = 0.24. (3) The legged landing system and surface-payload deployment method would both require engineering development before they could deliver robust function in the Mars landing and egress environment.

Finally, supersonic retropropulsion would have to be demonstrated. Herein lies a key partnership role for OCT, which could take on an Earth-based supersonic-retropropulsion flight test as a Technology Demonstration Mission. Such a demonstration test flight could use the Earth re-entry capability already designed into the SpaceX Dragon, providing valuable insight into the viability of this key capability in a flight environment analogous to what it would experience at Mars and thus advancing a key step of the OCT EDL technology roadmap [2] and the NASA Exploration Technology Development and Demonstration Program [3].

Summary The Red Dragon-MSL Hybrid Landing Architecture, when coupled with the Falcon Heavy launch vehicle, could comprise an innovative, cost-effective architecture for delivering payloads to the surface of Mars. By leveraging the commercially available SpaceX Dragon spacecraft and hypersonic guidance from JPL's MSL, such an approach could deliver 1000-kg payloads to -1.3 km and lower elevations. In addition to becoming a workhorse for accomplishing NRC science objectives, the hybrid architecture could demonstrate an enabling technology for eventual human missions, and provide a foundation for near-term and sustained partnership among SMD, HEOMD, and OCT.

References: [1] Space Exploration Technologies, http://www.spacex.com/falcon_heavy.php. [2] Space Exploration Technologies, SpaceX Brochure V12, p6. [3] Adler, M, et al., NASA TASR TA09, TA09-3. [4] Edquist, K.T., et al., AIAA-2010-5046, p9.