ENHANCING MARS EXPLORATION USING VELOCITY CANCELLATION AND SOFT LANDING TECHNOLOGY. D. C. Folta[1] and F. J. Vaughn[2], G.S. Rawitscher[3] P.A. Westmeyer[4], [1]NASA/GSFC, Greenbelt Md, 20771, Code 595, Navigation and Mission Design Branch, david.c.folta@nasa.gov, [2]NASA/GSFC, Greenbelt Md, 20771, Code 595, Navigation and Mission Design Branch, frank.j.vaughn@nasa.gov, [3]NASA/HQ, Washington DC, 20546, Science Mission Directorate, JWST Program Office, grawitsc@nasa.gov , [4]NASA/HQ, Washington DC, 20546, Office of the Chief Engineer, paul.a.westmeyer@nasa.gov

Introduction: Current Mars landing technology uses various complex means to dissipate the enormous energy of incoming spacecraft, through both propulsive deceleration and thermal protection systems that mitigate the aeroheating of atmospheric entry, to arrive at the surface at a survivable landing velocity. An alternative, straight-forward approach can be implemented using current propulsion designs to cancel all, or almost all, of the forward velocity of a spacecraft either as it enters into orbit or once in orbit, resulting in a unique Velocity Cancellation And Soft Landing (VCASL) concept. The descent segment can be designed and controlled to meet both robotic and human rated deceleration and landing requirements.

Recent Mars transfer analysis [1] shows that this proposed landing method can be economical as well as safe since the technology to accomplish it has been used for decades. Current research has established simulation approaches and estimates of fuel requirements.

This abstract answers Challenge Area 2: Safe and Accurate Landing Capabilities, Mars Ascent, and Innovative Exploration Approaches, specifically the particular interest in analyses of landing techniques.

Justification: NASA requires a flexible and simplified method to land both large robotic cargo masses and humans. Current Entry, Descent and Landing (EDL) approaches based on Viking technology are limited in the amount of mass that they can land on Mars and in the precision with which that limited mass can be landed. Other approaches under consideration, including inflatable aerothermal decelerators, will require significant advances in basic technologies such as materials and deployment mechanisms [2]. Our proposed approach enables large payloads to be landed on Mars or any other solar system body – including Earth -- and does not require any technological breakthroughs, as NASA has utilized rockets to decelerate spacecraft for decades. The only difference in this approach is the amount of deceleration, and thus the total change in velocity that the rockets must provide. More research is needed in the application of VCASL along with low-cost propulsion designs. Analysis is required to optimize the approach and minimize required ΔV along with engineering to develop the rocket systems that can deliver the required ΔV for the lowest cost and risk.

Velocity Cancellation And Soft Landing Description: This method is simply to effectively cancel all, or almost all, orbital velocity via propulsion and allow the spacecraft to come under the influence of Mars gravity to permit a safe landing.

A Sample Case: The example case below uses the current MAVEN orbit insertion design for comparison and initial conditions. This case is important as it provides an incoming v-infinity parameter that is representative of a typical Mars mission. It represents an optimal solution for an operational design and allows us to compare to an actual Delta-Velocity (ΔV) budget. In running a stopping simulation, an impulsive ΔV to target to a Mars periapsis velocity of 50 m/s was used. This target is representative of a residual ΔV that would remain after any propulsive braking maneuver.

Three sample cases are presented, all based on direct entry (not entry from orbit): 1) stop at 585 km altitude, ΔV = 5.67 km/s, landing ΔV = 1.8 km/s; 2) stop at 200 km altitude, stop ΔV = 5.78 km/s, landing ΔV = 1.2 km/s; 3) stop at 50 km altitude, stop ΔV = 5.86 km/s, landing ΔV = 0.7 km/s. Figure 1, 2, and 3 display plots of altitude and velocity vs. the time from full cancellation of the velocity to the landing.

These plots have an x-axis as the time from impulsive stopping ΔV to altitude = 0 km. This duration varies on the stopping altitude; 585 km stop duration = 11 min, 200 km stop duration = 5 min, and 50 km stop duration = 2 min.

Summarizing the results of this example simulation, the ΔV to cancel velocity of the entering trajectory is ~ 5.8 km/s. The landing velocity to be countered after the spacecraft is stopped is dependent upon the selected stopping altitude and varies from ~ 2 km/s to ~700 m/s. The propellant mass fraction for these ΔVs is ~ 0.76.

Total launch mass required to deliver a 5-metric-ton payload from LEO to the Mars surface using this approach would be approximately 130 metric tons, which is the equivalent of about 3 Falcon Heavy launchers or one evolved SLS launcher, assuming fully propulsive landing techniques are utilized and 320s I_{sp} for all in-space legs.

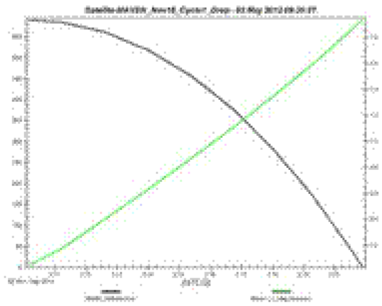

Figure 1 – 585 km Altitude (black/left vertical axis) and velocity magnitude (green/right vertical axis)

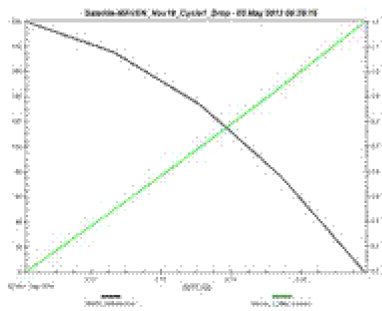

Figure 2 - 200 km Altitude (black/left vertical axis) and velocity magnitude (green/right vertical axis)

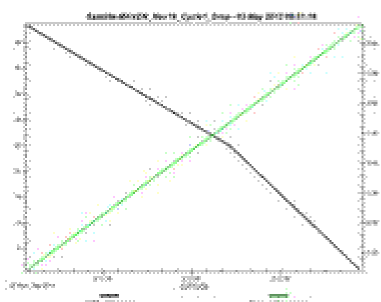

Figure 3 - 50 km Altitude (black/left vertical axis) and velocity magnitude (green/right vertical axis)

In the first, low-I_{sp} example above, simple, state-of-the-art storable propellant systems could be used (either solids or hypergolics). To minimize technical complexity, propulsion modules could be aggregated in-orbit as independent stages (i.e., no propellant transfer is required), simplifying the assembly process. The aggregation systems need be no more complex than the robotic arms used by STS and ISS, and could be teleoperated from the ground. Moreover, once this infrastructure capability was established in Earth orbit, it could be utilized for multiple missions to destinations throughout the solar system.

One concern in modeling this approach is the finite maneuver duration. Long pre-periapsis maneuvers can be inefficient and one may not be able to actually cancel all the ΔV in one maneuver. Further analysis will need to be performed to verify these assumptions and to determine the propulsion system types and sizes that can be used. Also, the finite maneuver inefficiencies must be tallied.

Additional Scenarios: Additional scenarios must be simulated to determine ΔVs and accelerations required for various entry velocity conditions and, if VCASL from orbit proves more efficient than a direct approach from an overall mission standpoint, to determine candidate orbital velocities once an orbit has been achieved. In particular, the use of a staging method to enhance efficiency and to reduce the required ΔV in each segment needs to be analyzed. For example, a capture into orbit can be achieved using a smaller ΔV of ~ 1.3 km/s. Once the spacecraft has reached this capture orbit, the required stopping ΔV is reduced (and can be reduced further by applying and staging several braking ΔVs). Follow-on analysis would seek the optimal approach from a total mission perspective.

Landing Considerations: Mechanisms to permit the deceleration during the free-fall segment need to be analyzed and engineered as well, but countering Mars' relatively low gravity should be well within the current state of the art for several possible approaches. In fact, after the stopping maneuver, the requirements are very similar to landing a suborbital vehicle on Earth. There are no aerothermal issues to mitigate, thus no need for heat shields. Using current technology, one can envision the use of either, or more likely a combination of: simple rocket propulsion as was done by Apollo on the Moon, or DC-X on Earth; an aerodynamic approach using either regular wings or the shuttlecock design of the type used by Spaceship One/Virgin Galactic; or parachutes/parafoils such as those currently used by the military to deliver large payloads to the surface.

By use of any of these approaches VCASL permits increased landing accuracy as there is minimal forward velocity, and the potential for positive control of the flight path. Based on decades of experience in terrestrial applications, both the forward and descent velocities should be able to be controlled easily, thereby enabling precisely targeted landings at very low risk compared to current landing approaches.

References:

[1] Folta. D.C. et al, (2005), Enabling Exploration Missions Now: Applications of On-Orbit Staging", AAS 05-273

[2] Wright, M. J., et al., (2011) "Overview of Entry Descent and Landing Investments in the NASA Exploration Technology Development Program", IEEEAC paper #1097