



MSR

Red Dragon

Mars Sample Return Using Commercial Capabilities: Propulsive Entry, Descent, and Landing

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Lawrence G. Lemke *and* Andrew A. Gonzales
NASA, Ames Research Center

Loc C. Huynh
Science and Technology Corp.

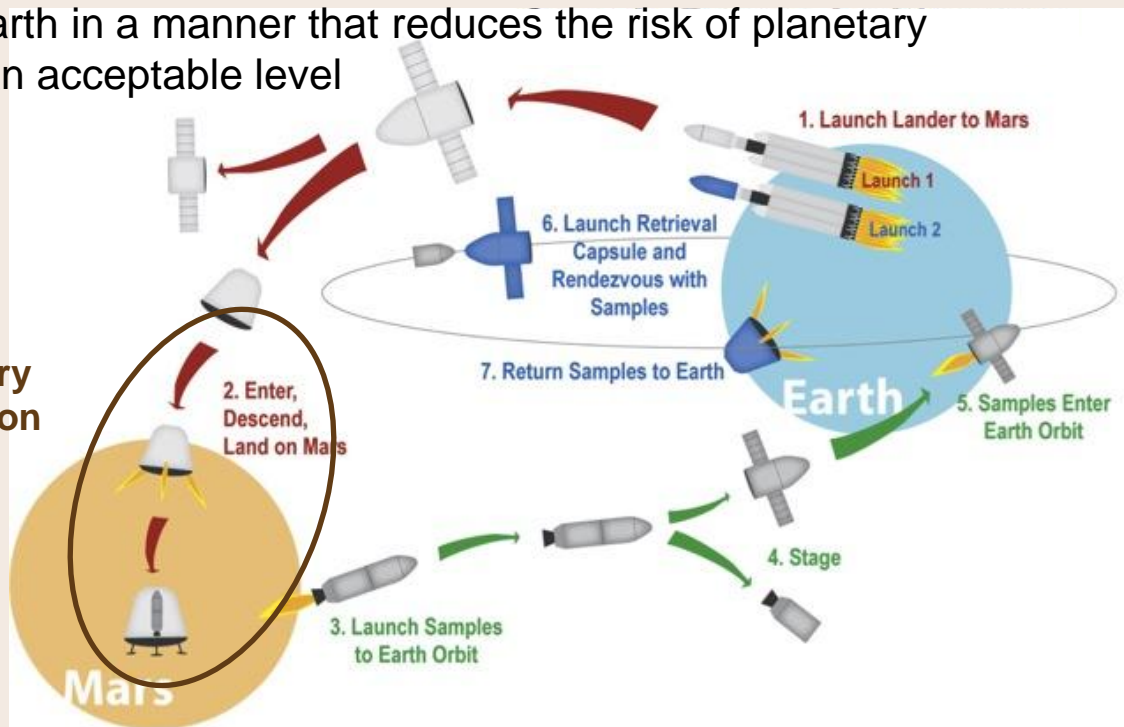
Introduction

- Mars Sample Return (MSR) is the highest priority science mission for the next decade as recommended by the recent Decadal Survey of Planetary Science
- The objective of the study was to determine whether emerging commercial capabilities can be integrated into to such a mission. The premise of the study is that commercial capabilities can be more efficient than previously described systems, and by using fewer systems and fewer or less extensive launches, overall mission cost can be reduced
- This presentation describes an EDL technique using planned upgrades to the Dragon capsule to perform a Supersonic Retropulsion Entry – Red Dragon concept
- Landed Payload capability meets mission requirements for a MSR Architecture that reduces complexity – *Overview paper at this 2014 IEEE Aerospace conference*

Overall Mission Scope

- Mars Sample Return (MSR) is practically the most complex robotic Mars mission that can be envisioned
 - ✓ **Entry Descent and Landing (EDL) in the Martian atmosphere,**
 - ✓ Surface use of dexterous manipulators to acquire a sample from a rover
 - ✓ Mars Ascent Vehicle (MAV) capable of launching a sample from the Martian surface
 - ✓ Transportation of the sample back to the vicinity of Earth
 - ✓ EDL of the sample at Earth in a manner that reduces the risk of planetary back-contamination to an acceptable level

Red Dragon performs lifting trajectory EDL with Supersonic Retro Propulsion



EDL Phases

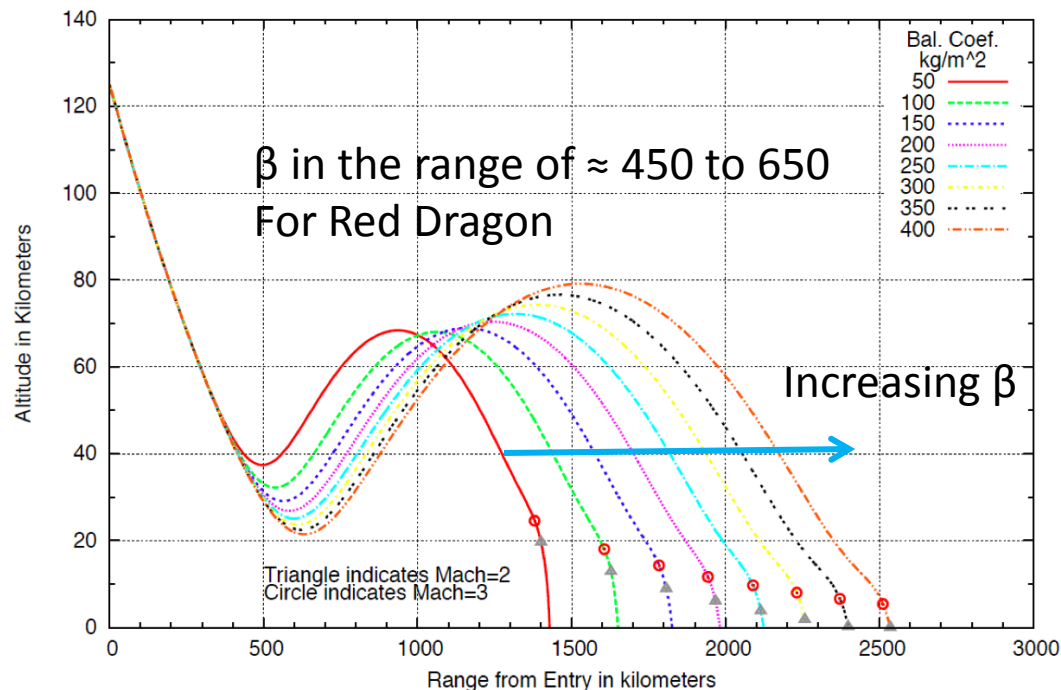
- Entire EDL sequence consists of 3 distinct phases
 - ✓ Entry Phase where probe enters the atmosphere with the excess velocity from launch. Atmospheric friction decelerates probe – A Mars probe's velocity would be above Mach 1 if it simply impacted.
 - ✓ Terminal Descent Phase beginning at altitude and velocity that matches the descent system's capabilities, typically at $\approx M 2$ and between 9 to 12 km AGL
 - ✓ Landing Phase beginning at a point within the landing system's capability and typically ending with a touchdown with vertical velocity ≈ 2.4 m/sec and horizontal velocity ≈ 1.0 m/sec

Red Dragon Approach Retro Propulsion

- How can a capsule designed for re-entry into an Earth atmosphere that is 100X thicker than the Mars atmosphere, still perform a successful EDL entry phase at Mars ?
- Analytical approach, similar to Braun & Manning, and later by investigators at ARC and JPL required for high β capsules.
 - Purely ballistic trajectory cannot be used
 - Modest amount of lift required – with bank angle modulation

Use of Lifting Trajectory During Entry Phase

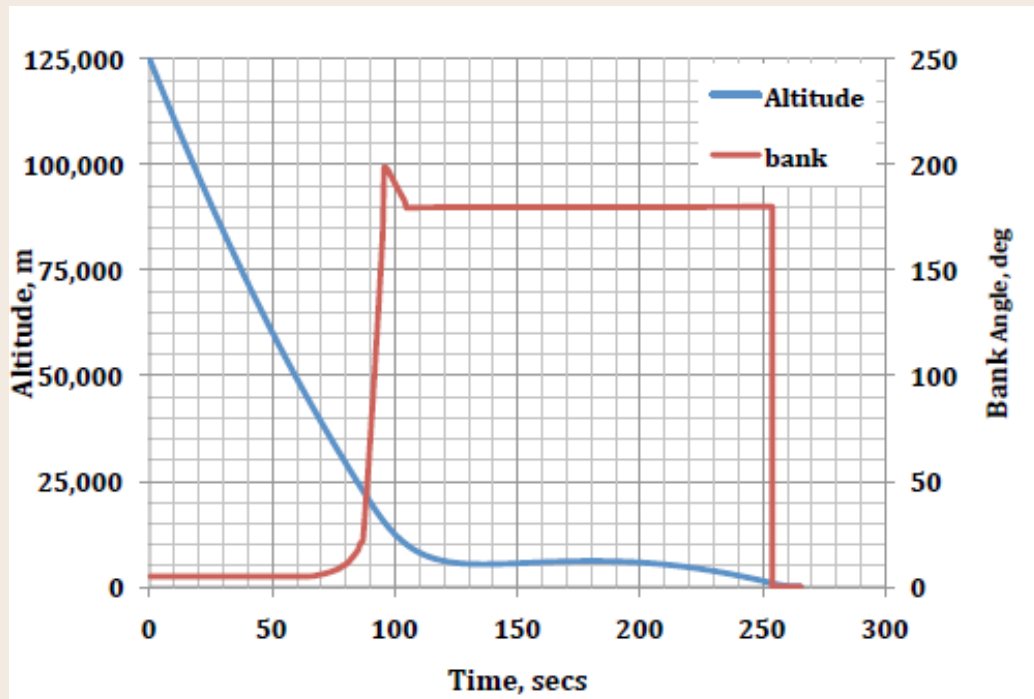
Altitude versus Range from Entry
Red Dragon Entry Condition, $L/D=0.27$



Simplest strategy is to give the probe a constant angle-of-attack α from the atmospheric interface through the entire hypersonic deceleration phase. The probe will reach an inflection point and begin to loft.

- Higher β probes lose kinetic energy slower than lower β probes
- Higher β probes arrive at the inflection point later than lower β probes
- Higher β probes pull-up at lower altitudes but with greater velocity than lower β probes .
- Higher β probes loft higher than lower β probes

Flying the Approach to Descent Phase



- Red Dragon strategy is to modulate α during the hypersonic deceleration phase. When the probe reaches the inflection point, α is reversed to limit the lofting.
- Red Dragon roll reversal changes direction of lift vector and flattens the loft – to fly the approach, scrubbing velocity horizontally and minimizing DV requirement during Descent Phase.

Use of Supersonic Retropropulsion During Descent Phase

- Parachutes not feasible for capsules with the entry mass of Red Dragon, 9 to 10 mt.
- Rocket retropropulsion, starting at supersonic speeds used
 - Super Draco thrusters being developed for Earth launch abort and possibly Earth landing applications
 - Placement on perimeter as opposed to a single central thruster, makes technique tractable
 - Propulsive energy requirement minimized by velocity scrub off during horizontal flight as previously noted



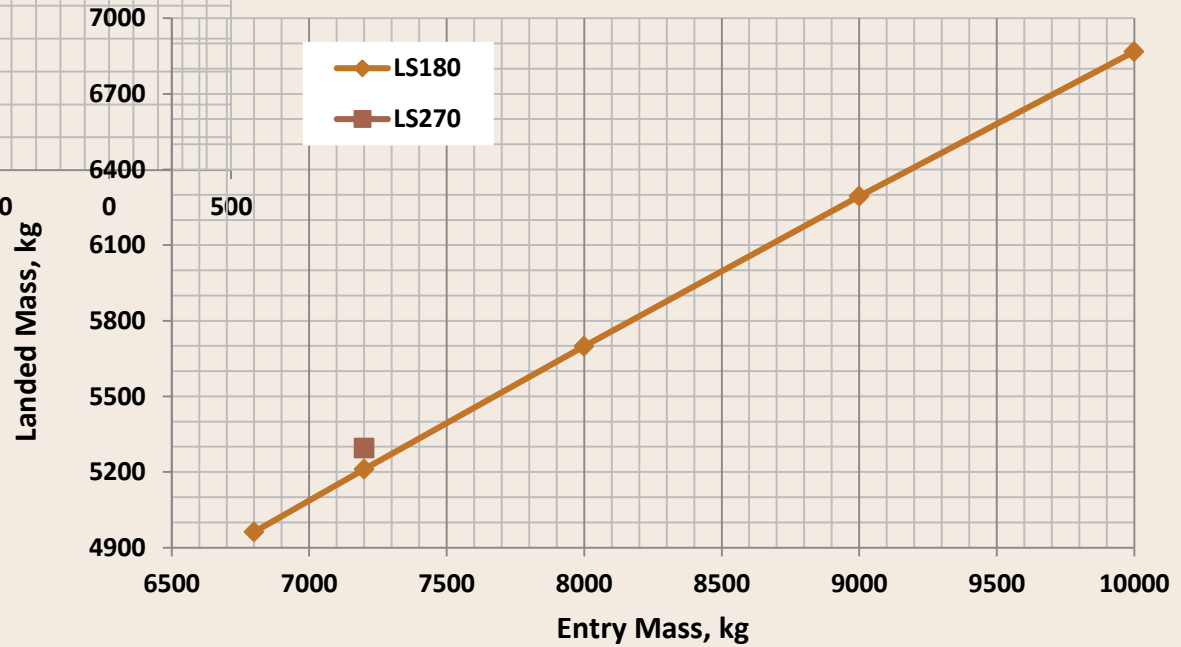
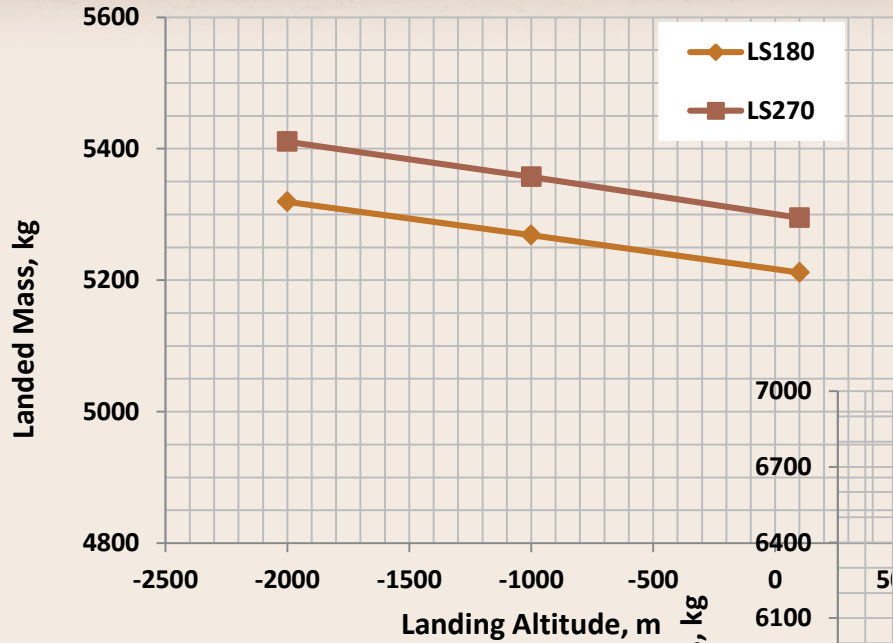
Use of Retropropulsion Continues During Landing Phase

- Terminal Landing Phase as a constant descent rate of 3 m/s.
- Hazard avoidance capability of 100 m provided



Overall propellant mass fraction for entire EDL ~ 0.31

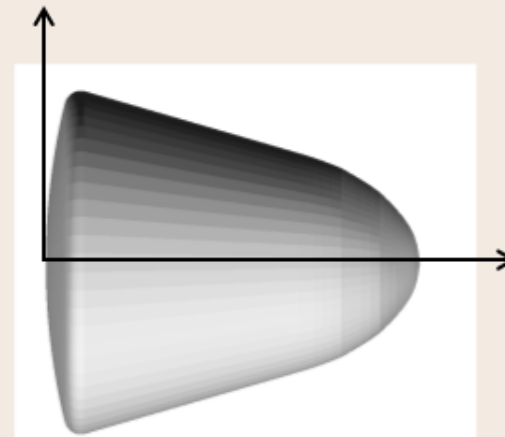
Landed Mass Performance



Landed Mass vs. Landing Site Elevation and Season

Landed Mass vs. Entry Mass

- Super Draco Thrusters modeled based on publicly available data
- Ames Research Center independently develop geometry Model based on publicly available data
 - ✓ Red Dragon CFD
 - ✓ Red Dragon Aerodynamic Engineering Analysis
- EDL trajectory simulated with bank angle modulation
- Tools used
 - ✓ CART3D
 - ✓ CBAERO
 - ✓ POST II 3-DOF
- Factors considered and varied
 - Entry mass
 - Entry angle
 - Hypersonic L/D
 - Landing site elevation
 - Atmosphere density at arrival





Conclusions & Future Work



- EDL capabilities of a Red Dragon capsule have been investigated using publicly available data and best established engineering techniques.
- Among the EDL parameters considered
 - ✓ Entry mass is the most important.
 - ✓ Entry flight path angle has negligible effect on the landed mass.
 - ✓ Landing elevation has a modest influence on the landed mass.
 - ✓ The effect of the atmosphere is also modest.
 - ✓ Entry mass / landed mass relation is highly linear over a wide range of entry mass.
- An entry mass of $\approx 9,000$ to $10,000$ kg is
 - Deliverable by the Falcon Heavy launcher
 - Can successfully perform all EDL phases with capabilities intrinsic to or planned for the Red Dragon
 - Supports the overall MSR mission architecture studied
- Detailed CFD testing of Supersonic Retropropulsion will be the next step
- Flight test in an Earth re-entry test can provide additional confirmation

Author Contributions

Lawrence G. Lemke, Entry, Descent, and Landing integration

Andrew A. Gonzales, Systems Engineering

Loc C. Huynh, Entry, Descent, and Landing analysis

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Backup

Companion Overview Paper at 2014 IEEE Aerospace

Gonzales, A. A., et al “Mars Sample Return Using
Commercial Capabilities: Mission Architecture Overview”

Session 2.06, paper 2514

Describes complete architecture concept