Ames Research Center

MSR

Red Dragon

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

2014 IEEE Aerospace Conference
2.0309 Mon. 3/3/2014 Ver. 3.1A

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

Loc C. Huynh
Science and Technology Corp.

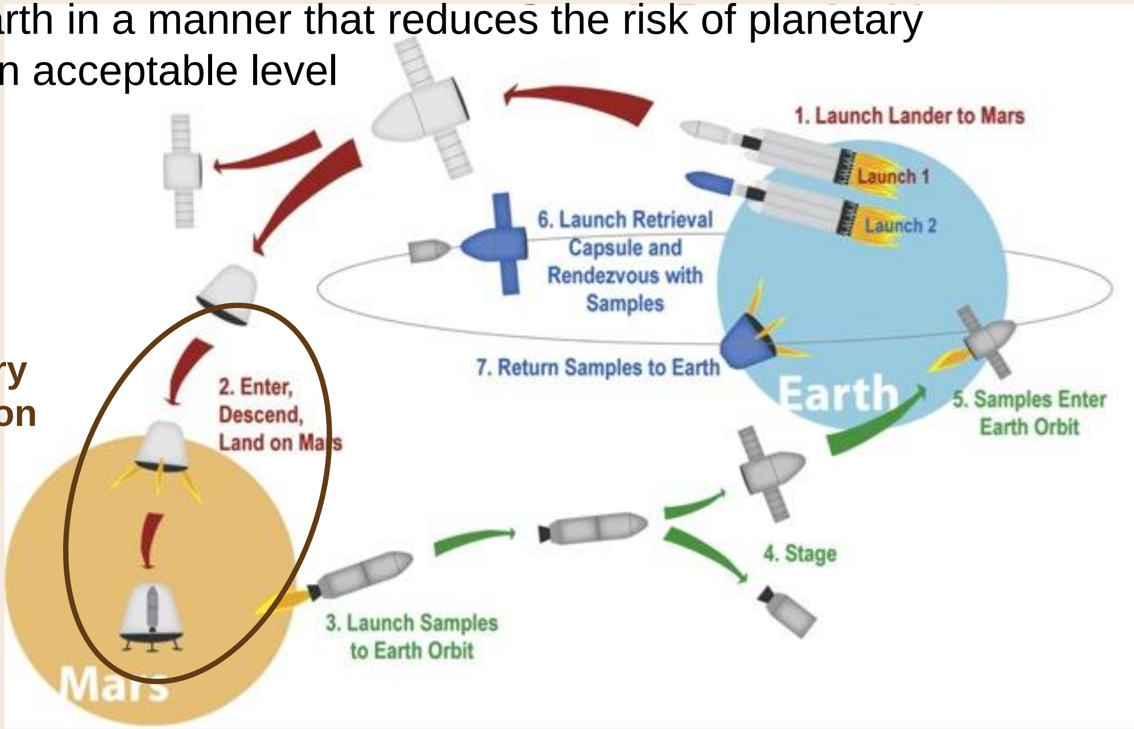
Introduction

- 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.

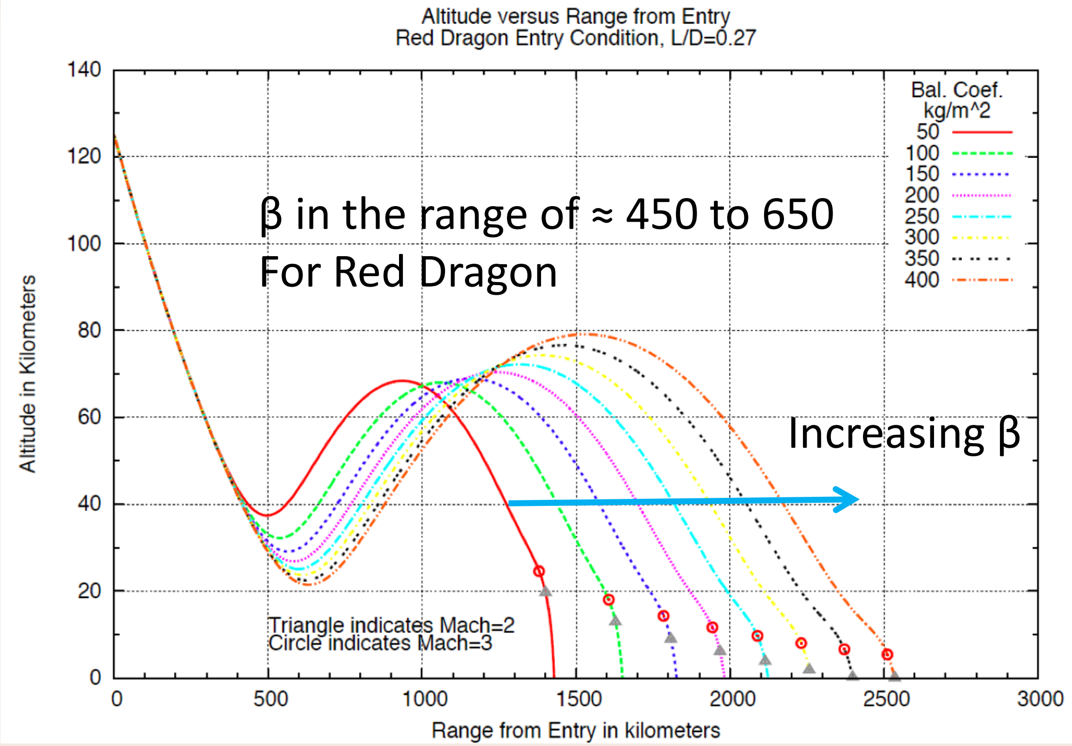
  - ✓ Terminal Descent Phase beginning at altitude and velocity that matches the descent system's capabilities, typically at ≈ M 2 and between 9 to 12 km AGL

  - ✓ 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 a 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

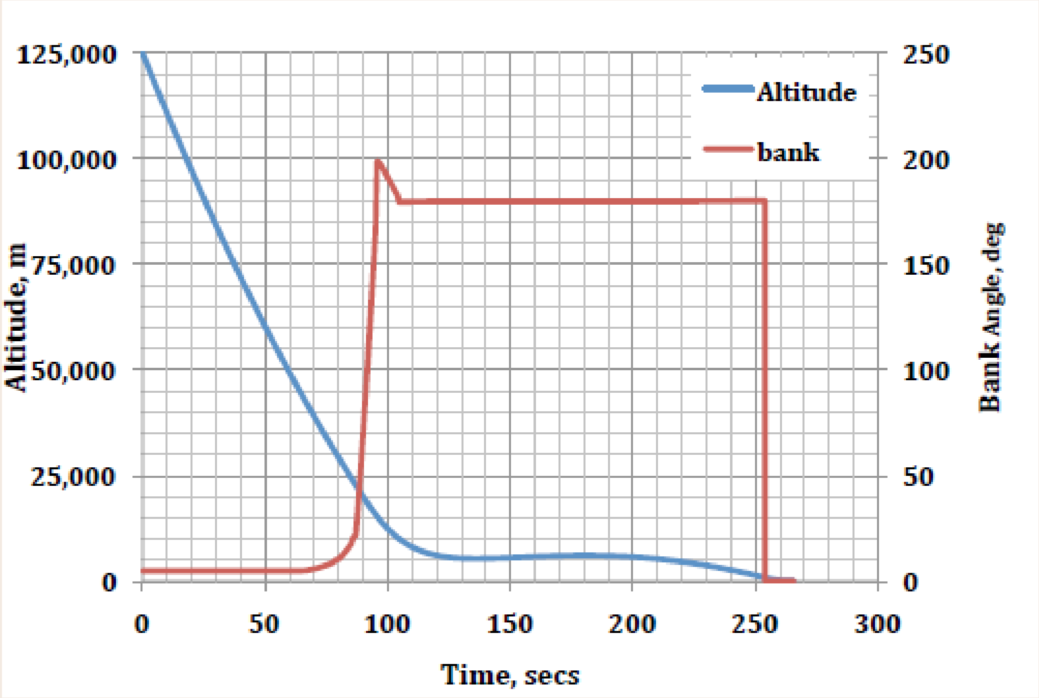
Use of Lifting Trajectory During Entry Phase



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

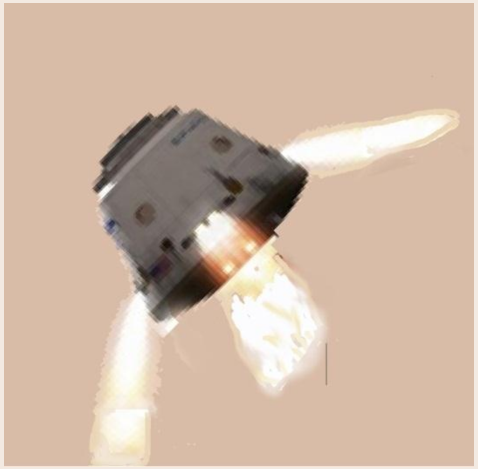


- Red Dragon strategy is to modulate α during the hypersonic deceleration phase. When the probe reaches the inflection point, α is reversed to limit the lofting.
- Red Dragon roll reversal changes direction of lift vector and flattens the loft – to fly the approach, scrubbing velocity horizontally and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

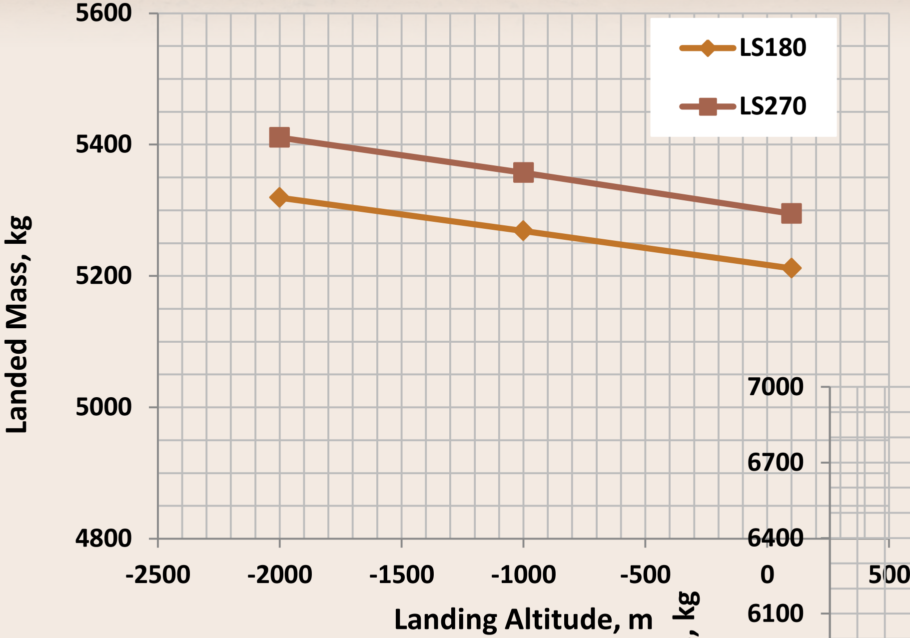


Use of Retropropulsion Continues During Landing Phase

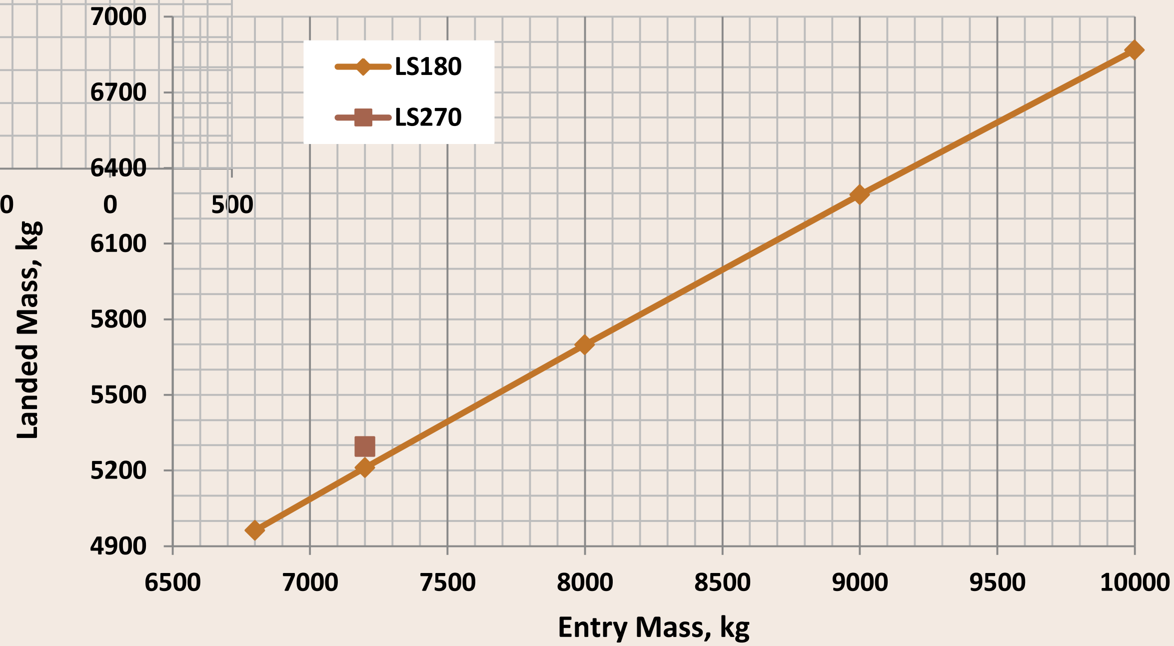
- Terminal Landing Phase as a constant descent rate of 3 m/s.
- Hazard avoidance capability of 100 m provided

Overall propellant mass fraction for entire EDL ~ 0.31

Landed Mass Performance



Landed Mass vs. Landing Site Elevation and Season

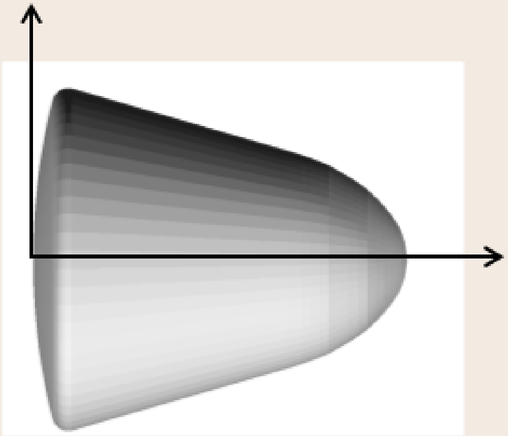


Landed Mass vs. Entry Mass

MSR
Red Dragon

Analysis Methodology

- 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 ≈ 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

Acknowledgements & Disclaimer

Author Contributions

Lawrence G. Lemke, Entry, Descent, and Landing integration
Andrew A. Gonzales, Systems Engineering
Loc C. Huynh, Entry, Descent, and Landing analysis

Acknowledgements

The work described in this paper was performed with funding support from the Ames Center Investment Fund. The contributions of the study team including the following individuals are gratefully acknowledged:
Carol R. Stoker, Study Principal Investigator
Steven Hu, Project Management
Jeffrey V. Bowles, MAV parametric design
Joseph A. Garcia, ERV parametric design
Cyrus J. Foster, Trajectories
Nicolas T. Faber, sample transfer in Earth orbit and Planetary Protection
David Willson, sample transfer on Mars and mechanical engineering
Michael Soulage, mechanical engineering
Eddie A. Uribe, Red Dragon internal systems
Bernardus P. Helvensteijn, ISRU and cryogenics
Charles J. Hatsell, Red Dragon internal systems
Jeffrey R. Feller, ISRU and cryogenics
Ali Kashani, ISRU and cryogenics
Sasha V. Weston, trade studies and engineering research
John Love, propulsion
We also appreciate management support from Dr. Simon (Pete) Worden, Dr. Michael D. Bicay, Dr. George L. Sarver, and Chad R. Frost.

Disclaimer

The work described in this paper was performed internally by NASA's Ames Research Center using information in the public domain and without the assistance of any commercial organization. There is no endorsements of any particular commercial organization by NASA. There is also no endorsement of this work by any particular commercial organization.

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