Mars Sample Return

How Cutting Edge Technologies, Methods and Minds Will Paint the Path for Red Planet Discovery
Introduction

Much is to learn about our nearest neighbor in the solar system before it plays host to mankind’s next giant leap. While rovers have been exploring the surface Mars for nearly the last two decades – traversing its roughened surface, identifying objects of fascination from ice to craters to myriad minerals, transmitting images and scientifically crucial findings back to Earth for further study – little trumps the goal of returning a sample of Martian minerals to Earth for direct, thorough, and in-depth study. However, while a live sample return might make for an unparalleled advancement in our scientific understanding of Mars, achieving it will take an unparalleled level of technological sophistication and engineering gumption.

The mission designs that follow address both of these needs by amalgamating today’s best tools and techniques in space exploration, adhering to NASA’s overarching timeline for Mars exploration, and maintaining a budget in line with anticipated federal funding through 2024 (Notional NASA budget figures outlined through 2019 are imaged below.)

Mission Architecture

Concretely, we’ll present the following mission architecture:

1. Launch a modified Falcon Heavy with a modified “Red Dragon” 2 capsule, which will carry A) a Mars Ascent Vehicle (MAV) and B) a return rover to collect the Mars 2020 rover’s sample cache and load it onto the MAV.
2. Jettison the Red Dragon 2 into the Mars atmosphere.
3. Land the Red Dragon 2 capsule on the Mars surface.
4. Deploy the return rover to rendezvous with the Mars 2020 rover and retrieve the sample cache.
5. Deploy the MAV and stage it for return launch.
6. Initiate transfer of the sample between rovers, assuring secure storage in a capsule and a successful loading onto the MAV.
7. Launch the MAV from the surface of Mars, returning it to a stable position in High-Earth orbit.
8. Launch a second Red Dragon from Earth to collect the sample from the MAV.
9. Return the sample safely to Earth.
10. Deliver sample to bio-safe facility for secure containment and future, ongoing scientific study.
Falcon Heavy Launch

Launch a modified SpaceX Falcon Heavy Rocket on a trajectory toward Mars.

Red Dragon Capsule Deployment

Configured to land directly on the surface of Mars (via SuperDraco engine retro propulsion), the modified Red Dragon capsule can deliver a payload consisting of a Sample Collection Rover and a Mars Ascent Vehicle (MAV), which will carry the sample on its return toward Earth.

Collection and Ascent

Once deployed, the collection rover will rendezvous with the Mars 2020 rover, acquire its sample cache, and load the cache aboard the MAV. A suite of advanced imaging systems and path planning algorithms will maximize operational effectiveness.

Dragon Retrieval & Re-Entry

With the sample secure, a final retrieval mission will be calculated. A second SpaceX Falcon Heavy will deploy a second Dragon to rendezvous with the returning craft, unload the sample, and return to Earth. The sample will then be offloaded and delivered to a permanent, secure, biosafe NASA test facility.

High-Earth Orbit Suspension

Rather than risking a direct Earth re-entry of the single return vehicle, the MAV will suspend itself at one of the two stable Lagrange points in Low-Earth orbit.
## Scoping Outline

**Project Title:** Mars Sample Return Proposal  
**Date:** April 15, 2014  
**Prepared by:** Brian Sipple, Tobias Kaiser, AJ Burke

### Needs:

1. Address benefits to science of retrieving a sample from Mars.
2. Key milestone in expansion of interplanetary exploration.
3. First-hand knowledge of the surface elements on Mars.
4. Ability to continuously test and experiment with sample.
5. Gain insights into the terrain/substances on Mars in advance of planned human missions in 2030s.
6. Develop a framework that can be adapted for future sample return missions from a variety of bodies in the solar system (planets, moons, asteroids, etc.).

### Goal:

Retrieve Mars 2020 sample container and return sample of minerals from the surface of Mars and deliver them to for future testing and scientific research.

### Objective:

1. Successful retrieval and return of sample.
2. Launch/Completion by 2022.
3. Operate within NASA budget constraints.
4. NASA-owned mission (with the possibility of third-party collaboration)
5. Develop framework for future sample return missions from a wide variety of extraterrestrial environments.

### Mission Breakdown:

1. Deliver a vehicle to the surface of Mars that contains A) a rover with sample collection capabilities, B) a rover to assist in loading samples for return, and C) a secure Mars Ascent Vehicle (MAV) for both placement and return of the sample.
2. Launch MAV from the surface of Mars back into low-Earth orbit.
3. Suspend MAV in stable Low-Earth orbit at Lagrange Point L4 or Lagrange Point L5.
4. Initiate follow up collection/retrieval mission, using the Dragon delivery system.
5. Develop a framework for planetary sample retrieval that can be abstracted and applied to future missions.
### Constraints:
1. Capability of technology.
2. Requirements of technology (energy, fuel, materials, etc.)
3. Cost vs. NASA Budget

### Budget:
1. Annual NASA budget can support mission objectives (Projections through 2019 listed below)
   - Alternative funding from commercial ventures (SpaceX, Planetary Resources, DSI, etc.)
   - Funding assistance from NSF(CASIS-ISS), other nations space programs (ESA, JSA, Roscosmos).

### Schedule:
1. Must coincide with Mars 2020 rover mission.
2. Complete before focus turns to sending humans to Mars in the 2030s.

### Authority and Responsibility:
1. Primary Authority and Responsibility: NASA
2. SpaceX (providing Falcon Heavy launch vehicle)

### Assumptions:
1. SpaceX to develop Falcon Heavy launch vehicle with capability to deliver rover and return capsule in one launch craft.
3. Mars 2020 rover design is in full gear -- we can adapt from that.
4. Rover will be able to implement AI and machine learning methods to map surface, traverse the surface efficiently, identify optimal samples and safely deposit them on return craft.
5. Return craft will be able to deliver sample back into a sustainable low-Earth orbit.
6. Capability designed to create a bio-safe analysis facility for testing of samples.
7. Capability to analyze the samples in facilities on Earth.
Concept of Operations

SSE101 Red Dragon Too Team - Concept of Operations (ConOps) Document

1. Scope

1.1 Document overview

Provide basis for a hybridizing variant of the SpaceX Dragon spacecraft to perform a MSR (Mars Sample Return) mission as a Mars lander with a hypersonic guidance strategy based on an assumption of a pre-deployed JPL MSR-capable mission rover (NASA Mars 2020) using MSL (Mars Science Laboratory - “Curiosity-tech” rover) derivative that can collect returnable geological samples for analysis back on Earth.

2. Referenced documents

1 NASA SpaceX Red Dragon, Oct 31 2011
2 Red Dragon Approach Concepts
3. OSIRIS-REXX mission
5 Dragon (spacecraft)
6 Curiosity (rover) Wikipedia

3. Current system or situation

3.1 Background, objectives, and scope
Figure 2. Previous Mars orbital and lander/rover missions

With the objective to retrieve and return a sample of minerals from the surface of Mars and deliver them for future testing and scientific research driven by the need to achieve a key milestone in expansion of interplanetary exploration, gain first-hand knowledge of the surface elements on Mars, achieve the ability to continuously test and experiment with these samples it is possible to gain insights into the terrain/substances on Mars in advance of planned human missions in 2030s.

Previous Mars missions have explored the Martian climate, searched for suitable landing sites and water, mapped the surface and done extensive geological work as best as can be accomplished with robotic systems. This mission will attempt to put rocks in the hands of human geologist to perform lab experimentation and analysis before the end of the next decade.

3.2 Operational policies and constraints

3.3 Description of the current system or situation
3.3.1 Mars Exploration Program, the main scientific goals of the MSL mission are to help determine whether Mars could ever have supported life, as well as determining the role of water, and to study the climate and geology of Mars. The mission will also help prepare for human exploration. To contribute to these goals, MSL has eight main scientific objectives given as the modes of operation for current system or situation below.
3.3.2 **Dragon** is a partially reusable spacecraft developed by SpaceX, an American private space transportation company based in Hawthorne, California. Dragon is launched into space by the SpaceX Falcon 9 two-stage-to-orbit launch vehicle, and is capable of both manned and robotic operation. It currently lands in traditional capsule touchdowns at sea in the water. The follow-on Dragon 2 spacecraft will be capable of land touchdowns. It will include side-mounted thruster pods as well as much larger windows, and landing legs which pop out at the bottom of the spacecraft. The Dragon v2 design was originally expected to be unveiled in 2013, but has been moved to 2014. As Dragon 2 will be able to land on Earth 1g gravity, the .6g gravity of Mars should be easy adaptation for the system.

SpaceX is additionally developing a crewed variant of the Dragon called **DragonRider**. DragonRider will be able to carry up to seven astronauts, or some combination of crew and cargo, to and from low Earth orbit. SpaceX has received several U.S. Government contracts to develop its crewed variant, including a Commercial Crew Development 2(CCDev 2)-funded Space Act Agreement in April 2011, and a Commercial Crew integrated Capability (CCiCap)-funded space act agreement in August 2012. The spacecraft's heat shield is furthermore designed to withstand Earth re-entry velocities from potential Lunar and Martian spaceflights.

3.4.1 Modes of operation for current system or situation for MSL/Curiosity

**Biological**

1. Determine the nature and inventory of organic carbon compounds
2. Investigate the chemical building blocks of life (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur)
3. Identify features that may represent the effects of biological processes (biosignatures).

**Geological and geochemical**

1. Investigate the chemical, isotopic, and mineralogical composition of the Martian surface and near-surface geological materials
2. Interpret the processes that have formed and modified rocks and soils

**Planetary process**

1. Assess long-timescale (i.e., 4-billion-year) Martian atmospheric evolution processes
2. Determine present state, distribution, and cycling of water and carbon dioxide

**Surface radiation**

1. Characterize the broad spectrum of surface radiation, including galactic and cosmic radiation, solar proton events and secondary neutrons. As part of its exploration, it also measured the radiation exposure in the interior of the spacecraft as it traveled to Mars, and it is continuing radiation measurements as it explores the surface of Mars. This data would be important for a future manned mission.

3.3.2 Modes of operation for current system or situation for SpaceX Dragon/Earth landing mode

Dragon 2 is just entering extensive development and testing at the time of this review and could have technological problems with its lander mechanisms.

3.5 End-user classes and other involved personnel

Use of Dragon 2 in other commercial projects my develop a civilian astronaut corps for projects such as Space Based Solar Power (SBSP) and asteroid mining / orbital manufacturing projects by the time that Red Dragon is ready to return from Mars making retrieval of the sample canister of Martian rock samples almost a trivial on-orbit activity that could be completed by a commercial spaceflight.

3.6 Support environment

On the other hand, if commercial interests do not develop the Dragon 2 lander capability then direct government funding for such an effort may be required. This is all contingent on commercial use of space becoming the norm.

4. Justification for and nature of changes

4.1 Justification of changes


Red Dragon concept for a low-cost, un-crewed Mars lander that would utilize a SpaceX Falcon Heavy launch vehicle and a modified Dragon capsule to enter the Martian atmosphere. The concept will be proposed for funding in 2013 as a NASA Discovery mission, for launch in 2018. The mission would search for the
biosignatures of past or present life on Mars. Red Dragon would be able to drill about 1 meter (3.3 ft) underground in an effort to sample reservoirs of water ice known to exist in the shallow Martian subsurface.

A Dragon capsule is capable of performing all the entry, descent and landing (EDL) functions required to deliver payloads of 1 tonne (2,200 lb) or more to the Martian surface without using a parachute. Preliminary analysis shows that the capsule's atmospheric drag will slow it sufficiently for the final stage of its descent to be within the capabilities of its SuperDraco retro-propulsion thrusters. Thus, if a ascent vehicle and robotic retrieval robot rover where placed on-board a Red Dragon configuration then the basic elements of a Mars Sample Return (MSR) would be in place.

4.2 Description of desired changes

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.

4.3 Priorities among changes

Entry guidance would provide need to provide 10-km landing accuracy, at a cost of approximately 0.5 km in landing-site elevation performance. Estimate the maximum landing site elevation capability (with entry guidance) is of 1.3 km. 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 for the Red Dragon-MSL Hybrid landing architecture.

4001-case Monte Carlo analysis was used to assess the potential performance, and validate fundamental feasibility of the hybrid architecture as a delivery system to the Mars surface. It is requires investigating in detail four important four technical challenges given in priority. (1) The architecture requires deep throttling of the SuperDraco Earth-lander 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 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. (4) Supersonic retropropulsion would have to be demonstrated in a key partnership role with SpaceX for 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 technology roadmap and the NASA Exploration Technology Plan.

4.4 Changes considered but not included

5. Concepts for the proposed system

5.1 Operational policies and constraints

Mars missions need to run on a 18 month window that places the planet in optimal orbit for launch.

5.2 Description of the proposed system

See architecture outlines above

5.3 Red Dragon is a modified SpaceX Dragon capsule for low-cost Mars lander missions using Falcon Heavy rockets. Plans call for a sample return rover to be delivered to the Martian surface while also testing techniques to enter the Martian atmosphere with equipment a human crew could eventually use.

5.4 Modes of operation

5.4.1 Modes of operation for current system or situation for MSR/Red Dragon

Scientific goals
1. Search for evidence of life (biosignatures), past or present
2. Assess subsurface habitability
3. Establish the origin, distribution, and composition of ground ice
4. Understand past climate using ground ice record

Human precursor goals
1. Conduct human-relevant entry, descent and landing (EDL) demonstrations
2. Assess potential hazards in dust, regolith, and ground ice
3. Characterize natural resources
4. Demonstrate access to subsurface resources
5. Conduct in-situ resource utilization (ISRU) demonstration
6. Operational scenarios

6.1 User goal use case diagram

6.2 User goal use case descriptions

Provide basis for a hybridizing variant of the SpaceX Dragon spacecraft to perform a MSR (Mars Sample Return) mission as a Mars lander with a hypersonic guidance strategy based on an assumption of a pre-deployed JPL MSR-capable mission rover (NASA Mars 2020) using MSL (Mars Science Laboratory - “Curiosity-tech” rover) derivative that can collect returnable geological samples for analysis back on Earth.

6.3 Data flow diagrams (optional)

7. Summary of impacts

7.1 Operational impacts
7.2 Organizational impacts
7.3 Impacts during development

8. Analysis of the proposed system

8.1 Summary of improvements
8.2 Disadvantages and limitations

8.3 Trade Studies of Alternatives to Mission Design

8.3.1 Return to ISS-based geological lab instead of direct return to Earth
The mission design team had considered an alternative of the return to Earth directly for an expanded ISS geological lab but determined that this was probably not the best use of resources.

8.3.2 Trade-Off Study on idea to just ‘re-launch’ the Red Dragon instead of using Mars AV

<table>
<thead>
<tr>
<th>Separate MAV</th>
<th>Figure of Merit</th>
<th>Super-Draco ascent burn</th>
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<tr>
<td>Low</td>
<td>Fuel/Mass</td>
<td>High</td>
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<tr>
<td>Medium</td>
<td>Complexity</td>
<td>High</td>
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<td>Same</td>
<td>Retrieval Rover Impact</td>
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<tr>
<td>Low</td>
<td>Probability of Loss of Mission</td>
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<tr>
<td>Low</td>
<td>Mission Flexibility</td>
<td>Medium</td>
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Figure 8.3.1 Figure of Merit diagram for re-launching the Red Dragon versus separate ascent vehicle (MAV)

8.3.3 Trade-Off Study between Active Thrusting and Aerobrake during High-Earth Orbit slowdown
Aerobrake | Figure of Merit | Active Thrusting
--- | --- | ---
Low | Fuel/Mass | High
Medium | Complexity | High
High | Reliability | Medium
Low | Additional Cost | Medium
High | Mission Flexibility | Low

Figure 8.3.1 Figure of Merit diagram deciding between Aerobrake and active thrusting as a mechanism for High-Earth Orbit slowdown.  
*Reference: IEEE Standard 1362-1998*
Key Product Breakdown Structures

- **Falcon Heavy Launch Vehicle with Dragon Mars Lander Payload**

- **Mars Ascent Vehicle**
• Sample Return Rover

• Second Dragon (High-Earth Orbit Intercept Component)
### Project Life Cycle

#### NASA Life Cycle Phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>KDP A</th>
<th>KDP B</th>
<th>KDP C</th>
<th>KDP D</th>
<th>KDP E</th>
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<tr>
<td>PrePhase A: Concept Studies</td>
<td>Preliminary Project Requirements</td>
<td>Preliminary Project Plan</td>
<td>System Design &amp; Fabrication</td>
<td>System Assembly, Integration &amp; Test, Launch &amp; Operations</td>
<td>Operations &amp; Statement</td>
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<td>Phase A: Concept &amp; Technology Development</td>
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<td>Phase B: Preliminary Design and Technology Completion</td>
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<td>Phase C: Final Design &amp; Fabrication</td>
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<td>Phase D: System Assembly, Integration &amp; Test, Launch &amp; Operations</td>
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<td>Phase E: Operations &amp; Statement</td>
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<td>Phase F: Closeout</td>
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#### Project Life-Cycle Gates, Documents, and Major Events

- **Agency Reviews**
  - ASM
  - MRR
  - SDR
  - SIR
  - ORR
  - FRR
  - PLAR
  - DR
  - DRR
- **Human Intercept Mission Project Life-Cycle Reviews**
  - MCR
  - SRR
  - SIR
  - PDR
  - CDR
  - SRR
  - SIR
  - ORR
  - FRR
  - PLAR
  - CERR
  - DR
  - DRR
- **Robotic Mission Project Life-Cycle Reviews**
  - MCR
  - SRR
  - MDR
  - PDR
  - CDR
  - MRR
  - ORR
  - FRR
  - PLAR
  - CERR
  - DR
  - DRR
- **Other Reviews**
  - SAR
  - SMSR, LRR (LV)
  - PLAR
  - CERR
  - DR
  - DRR
- **Supporting Reviews**
  - FAD
  - FA
  - Preliminary Project Requirements
  - Project Plan
  - Launch #1
  - Launch #2 (Sample Interception)
  - End of Mission
  - Ongoing Archival of Sample Data

#### Timeline

**ASPM Timeline**: Jan 2015 - Jul 2026

- **Jan, Apr, Jul 2015**
- **Dec 2015**
- **Mar 2016**
- **Sept 2016**
- **Jan 2017**
- **Oct 2020**
- **Oct 2023**
- **Dec 2023**
- **Mar 2024 (T+0 days)**
- **Apr 2024**
- **Mar 2025**
- **Feb 2026**

#### ACRONYMS:

- **ASPM** – Acquisition Strategy Meeting
- **CDR** – Critical Design Review
- **CEER** – Critical Events/Readiness Review
- **DR** – Decommissioning Review
- **FA** – Formulation Agreement
- **FRR** – Flight Readiness Review
- **KDP** – Key Decision Point
- **LRR** – Launch Readiness Review
- **LV** – Launch Vehicle
- **MCR** – Mission Concept Review
- **MDR** – Mission Detention Review
- **MRR** – Mission Readiness Review
- **ORR** – Operational Readiness Review
- **PFAR** – Post-Flight Assessment Review
- **PLAR** – Post-Launch Assessment Review
- **PRA** – Production Readiness Review
- **SAR** – System Acceptance Review
- **SIR** – System Integration Review
- **SMSR** – Safety and Mission Success Review
- **SRR** – System Requirements Review
- **SRB** – Standing Review Board

#### Footnotes

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is present at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle reviewed objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5.
3. PRR may require an SRB. Timing is optional.
4. CERRs are established at the discretion of the program.
5. For robotic missions, the SRR and MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASRM is determined by the MDAA. It may take place at any time during Phase A.
8. The Baseline Project Plan will be conducted at the end of 2020 and factor in the success of the Mars 2020 rover mission, mainly to determine optimal landing locations and the expected sample composition.
9. The projected timeline between launch and return to Earth Orbit is based on the “Short-Stay” approach, which consists of 620 days in flight and 30 days operating on the Martian surface.

Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.
Work Breakdown Structure

1.0 Concept Studies
   1.1 Requirements Analysis & Development
      1.1.1 Determine sample size / weight
      1.1.2 Determine launch payload weight
      1.1.3 Determine return payload weight
      1.1.4 Determine technological specifications
   1.1.5 Trade Studies
      1.1.5.1 Alternative Vendors for System
      1.1.5.2 Evaluate rover component proposals
      1.1.5.3 Weight timelines against Delta-V and resource estimates
      1.1.5.4 Construct project schedule and assign project roles
      1.1.5.5 Locate facilities for testing and sample storage
   1.2 Finalize constraints
   1.3 Reconcile constraints with feasibility studies
   1.4 Finalize requirements and sign-off with stakeholders

2.0 Concept and Technology Development
   2.1 Acquisition of operating components
   2.2 Periodic review of in-development system
      2.2.1 Computer simulation and modeling
      2.2.2 Isolated component testing
   2.3 Final system definition
   2.4 Final requirements review

3.0 System Design and Technology Completion
   3.1 Finalize Project Baseline Plan
   3.2 Preliminary Design and Technology Reviews
   3.3 Production Readiness Review
      3.3.1 Form product alignment and integration plan
   3.4 Critical Design and Technology Review

4.0 Final System Testing
   4.1 Propulsion Testing
      4.1.1 SuperDraco Mars Descent Simulation
      4.1.2 Mars Ascent Vehicle escape testing
   4.2 Falcon Heavy Testing
      4.2.1 Long-range Mars delivery tests
      4.2.2 High-Earth orbit intercept tests
   4.3 Train engineers for mission operation
   4.4 Train crew for second launch and high-Earth orbit sample transfer.

5.0 Launch #1
   5.1 Prepare Launch facilities
   5.2 Assemble launch support team
      5.2.1 Ascent Guidance
      5.2.2 Performance Assurance
   5.3 Finalize launch procedures and protocols
5.3.1 Final Rundown
5.3.2 Distribute launch sequence outline and protocols
5.4 Mission Control
5.4.1 Liftoff
5.5 Launch System Integration

6.0 Mars Operations
6.1 Calculate optimal landing site for rendezvous with 2020 rover.
6.2 Ensure safe landing of Red Dragon capsule
   6.2.1 Check stability
   6.2.2. Check sensor feedback
6.2 Deploy sample return rover
   6.2.1 Activate rover’s remote guidance systems
   6.2.3 Establish and maintain secure connection with 2020 rover
   6.2.4 Assist remote operating team with algorithmic guidance calculation
   6.2.5 Ensure optimal surface condi
6.3 Transfer sample from 2020 rover cache to return rover cache.
   6.3.1 Rendezvous
   6.3.2 Ensure optimal surface conditions and robotic arm functionality
   6.3.3 Ensure stable storage of capsule upon loading
6.4 Return rover sample to the landing site
6.5 Deploy and stage Mars Ascent Vehicle (MAV)
   6.5.1 Activate Red Dragon deployment systems.
   6.5.2 Verify optimal surface conditions and calculate optimal launch time.
   6.5.2 Offload MAV
   6.5.3 Guide rover onto MAV via extendable ramp
       6.5.3.1 Safely load capsule onto MAV and guide rover away from launch site.
6.6 Launch MAV on trajectory to optimal Lagrangian point in high-Earth orbit.

7.0 Sample Return to High Earth Orbit
7.1 Set approach vector and calculate arrival date
7.2 Execute deceleration sequence
   7.2.1 Execute Initial Maneuver
   7.2.2 Perform Trajectory Corrections
   7.2.3 Plan and execute Braking Maneuver (Trade study will decide between active
       thrusting and Aerobrake?)
7.3 Ensure safety and accessibility of position (high Earth Orbit with low chance for collision with debris)

8.0 Launch #2 (Falcon / Dragon system for sample interception)
8.1 Conduct preliminary analysis of sample orbital state
8.2 Prepare launch facilities
8.3 Assemble launch support team
   8.2.1 Ascent guidance
   8.2.2 Performance assurance
8.4 Finalize launch procedures and protocols
   8.4.1 Final rundown
   8.4.2 Distribute launch sequence outline and protocols
8.5 Mission Control
   8.5.1 Liftoff
8.6 Launch System Integration

9.0 Sample Transfer and Processing
  9.1 Re-entry Guidance
    9.1.1 Burn Stage Progression
  9.2 Sample Transport
    9.2.1 Return Vehicle Recovery
    9.2.2 Transport to Laboratory
  9.3 Bring laboratory to fully operational state
  9.4 Orbital Intercept and Sample Transfer

10.0 Closeout
  10.1 Implement recovery/disposal plans for remaining system components
  10.2 Final Archival of Mission Data
    10.1.1 Define Key Performance Indicators
    10.1.2 Implement data quality and storage policy
  10.3 Define plan for ongoing analysis and investigation of sample data
  10.4 Document operational plans for contingency
  10.5 Document training plans
  10.6 Determine proper allocation of mission assets
  10.7 Lessons Learned
    10.7.1 Analyze adaptability of mission framework for future planetary excavations
### FY 2015 President’s Budget Request Summary

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