Human Spaceflight Architecture Team (HAT)
Mars

Destination Operations Team (DOT)
FY 2013 Final Report

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For Information, contact:
Mr. Larry Toups, NASA Johnson Space Center
Dr. Marianne Bobskill, NASA Langley Research Center

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Introduction

The Human Spaceflight Architecture Team (HAT) was created to inform NASA's Human Exploration and Operations Mission Directorate (HEOMD) regarding possible mission architectures and campaigns beyond Low Earth Orbit (LEO). Following a Capability Driven Framework (CDF) approach, no single destination has been considered, but a roadmap of possible destinations that lead towards an ultimate goal of a human mission to Mars was developed.

The Destination Operations Team (DOT) was created within the HAT in October 2012. The DOT's charter is to develop destination-specific "Point of Departure" Concepts of Operations (ConOps) for HAT Design Reference Missions (DRMs) using a systematic analysis approach. These ConOps then inform more detailed products that are delivered to the HAT Core Team. Using the (July, 2009) *NASA Human Exploration of Mars, Design Reference Architecture 5.0* (NASA/SP-2009-566 and NASA/SP–2009–566-ADD), as a foundation, from April – September 2013, the DOT developed a ConOps for a long-duration (~500 days) crewed Mars surface mission.

By using these ConOps, DOT then assessed exploration destination strategies for human exploration in sufficient depth to: (1) capture the range of capabilities needed to inform near term technology investments, and (2) better understand and inform linkages among the Science Mission Directorate (SMD), HEOMD goals/objectives, Strategic Knowledge Gaps (SKGs) and required functionality.

This Executive Summary provides a description of the key activities of DOT during FY 13 and the key findings from that work.

"Doing Our Homework": Information Gathering in Support of Mars ConOps Development (1 of 3)

An approach was defined to collect and organize information that would serve as the foundation for development of a Point-of-Departure (POD) Concept of Operations (ConOps) for a crewed Mars long-stay surface mission. This information collection approach involved a number of tasks and was carried out by a number of DOT team members prior to beginning development of the ConOps.

1) Two primary reference sources were identified and reviewed in detail. The first reference, the Mars Exploration Program Advisory Group (MEPAG) Human Exploration of Mars-Science Analysis Group (HEM-SAG) document (2008) *Planning for the Scientific Exploration of Mars by Humans*, served as one of the two "foundational" documents for Mars ConOps development. It was reviewed and a detailed summary was created to serve as a working reference during ConOps development. The MEPAG HEM-SAG document contained information regarding Mars science goals & objectives across geology, geophysics, atmospheric & climate science, and astrobiology disciplines; specific science questions to be addressed within each discipline; types of crew and robotic activities that should be conducted; and supporting capabilities to enable these activities. This information was used as primary input into the Mars surface mission ConOps (in particular, the proposed Mars surface traverses). See page 58 of the present report for information regarding Mars scientific goals and objectives as articulated in the MEPAG HEM-SAG document. In addition to the MEPAG HEM-SAG report, the second primary reference source was the set of documents associated with NASA's Mars Design Reference Architecture (DRA) 5.0: *The Mars Surface Reference Mission.*

“Doing Our Homework”: Information Gathering in Support of Mars ConOps Development (2 of 3)

2) The DOT hosted a series of special briefings, where the team was briefed by Subject Matter Experts (SMEs) across three domains related to Mars surface operations. These domains included:
   - Deep Drilling (on Earth and Mars)
   - Biocontainment of Earth and Mars Pathogens, and
   - Mars Planetary Protection

3) A “workbook” was created to provide a mechanism by which the science discipline SMEs from the MEPAG HEM-SAG team could provide answers to a set of questions regarding Mars surface operations within their discipline. The science disciplines for which detailed information was gathered included Mars geology, geophysics, atmosphere & climate science, and astrobiology. The workbook questions related to Mars surface operations driven by science objectives and surface activities, such as drilling and sampling (location, depth, proximity to landing site), data collection (approach, resources, location), data/sample analysis and return, crew + robotic activities across mission phases, contamination control requirements, data rate/frequency, and precursor information requirements. Upon completion of the workbook, a telecon was held for each science discipline where the DOT and science discipline SME’s reviewed their workbook sections and questions or issues were addressed. These “interviews” were then transcribed and used as a primary reference during Mars surface mission ConOps development. See page 72 of the present report for more detailed information regarding the science activities workbook.

Executive Summary

- SME = Subject Matter Expert

“Doing Our Homework”: Information Gathering in Support of Mars ConOps Development (2 of 3)

4) The DOT held an “Educational Forum,” during which SMEs in five fields were asked to brief the team on broad topics of importance to the Mars surface mission ConOps in development. An introduction was given by DOT to the attendees and SMEs to provide a framework for the presentations. The areas briefed by SMEs to the DOT were: EVA and Suit Ports; Crew Medical Issues Regarding Mars Toxicology, Crew Safety, Mars Sample Handling, and Planetary Protection.
5) A number of seminal references were identified as fundamental to the DOT’s understanding of issues related to development of an informed Mars surface mission ConOps. These references were obtained for DOT review and spanned NASA, MEPAG, the National Academy of Science National Research Council (NAS NRC), and organizations responsible for Planetary Protection policy.
6) A series of “guiding questions” was created by the DOT to focus information gathering and discussion around a set of high-level and inter-related issues. These were provided to the SMEs briefing the DOT and were used by the team to provide a framework regarding ConOps-related issues and to provide guidance in shaping the information shared. These guiding questions addressed five topics of interest in Mars ConOps development: (1) returning Mars samples with the crew; (2) crew waste storage, transfer, and disposal; (3) pressurized cabin operations; (4) nominal EVA operations; and (5) sample handling on the surface by the crew. These guiding questions are summarized in greater detail beginning on page 59 of this report.
7) A tour of the Sample Curation Laboratories at JSC B31 was conducted by laboratory personnel for the DOT membership.

- SME = Subject Matter Expert

ConOps Development

- As stated earlier, the goal of this ConOps development was to construct representative surface operations for a DRA 5.0-like crewed mission to the surface of Mars in order to understand the capabilities, assets, and equipment needed to increase fidelity of architecture assessments.
- For this activity, the “Commuter” option described in DRA 5.0 was used as the surface mission template to provide context information, such as mission events, their duration and sequence, for ConOps development. See (February, 2009) *Human Exploration of Mars Design Reference Architecture 5.0 (Summary)*, p. 21, and (2009) NASA/SP-2009-566-ADD *Human Exploration of Mars Design Reference Architecture Addendum*, p. 274, for a description of the “Commuter” strategy.
- Four of the 58 candidate Mars landing sites identified in the HEM-SAG report were selected for study and provided site-specific information and characteristics for analyses of potential surface traverses. One of these four candidate sites, Centauri Montes, was analyzed in detail and served as the basis for development of the ConOps.
- For the present study, the development of the ConOps followed a deterministic approach that was originally defined during a 2012 HAT study to create a crewed Phobos and Deimos mission concept. The process follows an object oriented programming-like process in which smaller segments (called “building blocks”) are developed in detail and then repeated and pieced together to form larger blocks and, eventually, a mission.

Please note that the present report represents one feasible crewed Mars surface mission ConOps and should not be viewed as the only feasible ConOps that could meet mission objectives.

ConOps Development

- Following this process allowed the ConOps developers to add detail where it was needed and to easily update the mission timeline as information and understanding were gained throughout the study. It produced a realistic, representative ConOps that could be traced back to objectives and constraints that could be used as justification for capability needs and element design. This method also produced a final product that can easily be updated in the future as objectives, constraints, and capabilities change.

- Results from this ConOps development activity indicate that the types of exploration activities, including traverses, described in the HEM-SAG report can likely be accomplished using the "Commuter" strategy and can be completed within the 500-day surface stay time available for a DRA 5.0-like mission. A probabilistic assessment (described elsewhere in this report) is being developed to gain an understanding of uncertainties and variability in the nominal building blocks used for assessments thus far.

Functionality Assessment and Special Studies

A Functionality Assessment Team within DOT attempted a Functional Decomposition of the DRA 5.0 surface mission and quickly identified an overwhelming number of potential sub-functions, each potentially spawning a long list of trade studies. In lieu of a more detailed surface mission definition, further functional decomposition was deemed unproductive, because it didn't answer the fundamental question DOT was trying to answer in the functionality assessment: "Did DRA 5.0 miss any functions (and associated mass) ?"

Therefore, the Functionality Assessment Team instead turned its efforts to directed studies of key areas, to better define the surface mission. What was missing from the pure Functional Decomposition approach was the *integrated function* impacts. For example, the analysis could assume the Surface Habitat must provide a glovebox to support science functions…but if the science community wants science samples to remain pristine until they return to Earth (and, therefore, the surface crew would NOT analyze the samples they had gathered) and the Planetary Protection community doesn't want science samples inside Habitable areas, then we've book-kept mass for a function that is not required in the Habitat and — worse -- we've overlooked needed mass for a sample handling area outside of the Habitat. Therefore, instead of decomposing the entire DRA 5.0 functionality, small teams tackled specific portions of the DRA 5.0 surface mission (such as the Commodity Cache concept) and performed limited functional decomposition and subsequent mass estimating, with particular attention to the integrated aspects of each area.

As mentioned, the Functionality Assessment Team of DOT turned its efforts to directed studies of key areas, labeled as "Special Studies." A number of "Special Studies" were conducted that directly informed the creation of the ConOps. An integrated functional analysis was performed early on to focus on how key functions <u>needed to be integrated</u> in order to better understand the overall operational systemic impacts and to inform additional specific studies and operations concept details.

Executive Summary

Functionality Assessment and Special Studies

The *Commodity Cache Feasibility Study* suggested that the DRA 5.0 mass allocation of 1000 kg will likely be exceeded at least 1-fold (perhaps up to 2500 kg for 7 caches of 357 kg each) and that there could be substantial risk to crew. If single fault tolerance is acceptable, a second pressurized rover could rescue stranded crew without benefit of caches at all. However, if subsequent failure of the second rover is not an acceptable risk, one alternative identified is having two reduced capability commodity caches, one that stays with the pressurized rover, and another placed on an unpressurized rover capable of autonomous rescue. The Study Team estimated this “Trigger” concept mass would be less than 244 kg total mass (for both caches), with the added benefit of eliminating laborious cache placement and retrieval, without constraining the second pressurized rover.

The *Traverse Planning and Mobility Study* found that the pressurized rover range may be limited to 100-150 km for 4500 kg and that use of autonomous or tele-robotic small robotic rovers for scouting traverses ahead of crewed traverse during the two-year period after 1st landing is critical. The pressurized rover performance is sensitive to assumptions, such as rolling resistance, battery specific energy, and solar array efficiencies.

Functionality Assessment and Special Studies

The *Mars Laboratory and Sample Handling Study* used the MEPAG HEM-SAG reference document as a starting point in addition to numerous other science sources. The study emphasized that sample handling involves most of the science disciplines and lies at the intersection of a number of key operational areas, such as crew safety, contamination control, and planetary protection and special regions. Representative instrumentation was identified and a "distributed analytical capability" strategy was identified as a way to accommodate numerous diverse sample handling needs, e.g. in the rover, "downhole" during drilling, inside and/or outside of the habitat, and via "handheld" instruments used by the crew during EVA. The habitat and/or habitat area should contain advanced analytical capabilities, such as molecular sequencing , for which sample preparation will likely be a delicate and complex process. A separate astrobiology lab for analyzing Mars subsurface samples is probably required to reduce cross-contamination and to ensure crew safety. If a sample is not in a special region, it may be possible to send humans into the area to collect the samples. Otherwise, alternative methods for sample acquisition may be required for crew safety and planetary protection reasons (e.g., real-time telerobotic sample acquisition and analysis). If contamination can be sufficiently controlled, crew may be able to enter sensitive areas to acquire samples directly.

The *Integrated Surface Power Strategy Study* found that a Portable Utility Pallet (PUP) may be used to sustain a Lander until the Fission Surface Power System (FSPS) is on line, which will help reduce autonomous power mass after landing. Eight smaller units have about 2,000 kg higher mass than two large units, but not all eight may be needed for redundancy. Smaller power units don't have to be as far from crew, can be moved more easily (including to remote sites), and won't drive rover design.

Functionality Assessment and Special Studies

The *Integrated Drilling Strategy Study* noted that drilling will likely invoke Planetary Protection "Special Region" constraints below a certain depth, presently thought to be approximately 5 m (this constraint may be less due to the possibility of shallower subsurface ice). Only one drill from a list of drill technologies in development indicated the possibility of drilling deep to 250-300 m (a "desirement" depth suggested by MEPAG HEM-SAG). If technology plans are realized, dedicated drilling equipment could be under 700 kg, but the study suggests needing at least 2,235 kg total (including mobility) to meet the full breadth of envisioned drilling needs.

The *Statistical Modeling Study* used experience gained from developing an experiment and payload complement for an ISS increment that indicated a deterministic process was not possible. A probabilistic process that provided some guidance regarding the chances of accomplishing a particular complement of experiments with the resources available was the most useful for ISS mission planners. Based on this previous experience, a probabilistic process, implemented using Microsoft Excel and @Risk statistical modeling software, was developed to provide Mars surface mission planners with comparable guidance regarding the chances of a particular complement of investigations and experiments being completed for a specified set of resources. A "benefit" value was introduced that could be assigned to each experiment or investigation. This "benefit" value functions as a weighting factor for the experiments and investigations under consideration. By assigning a weighting factor to the experiments and investigations, the model could be driven to favor certain experiments or investigations, if desired, as the Monte Carlo simulation portion of the model checks the resources usage of randomly selected sets of experiments and investigations. This work suggested an efficient method to examine the feasible combinations in sufficient detail to understand which combinations will satisfy the stated scientific and exploration goals and objectives in an optimal manner.

These Special Studies informed the DOT on their inputs to the Exploration Capability Roadmap Development Team to inform future technology investments that could enhance Mars surface operations.

Executive Summary

Key Findings

- **An integrated Concept of Operations (ConOps) helped identify and understand interdependencies between functional requirements and the capabilities needed to meet these requirements**

- **The nominal 500 Sol surface duration is technically feasible and provides sufficient time to address science and exploration objectives, with several notable caveats**
    1) Feasibility is indicated for the assumed set of systems and operational approach used, both of which contained some low fidelity items. Higher fidelity understanding of these systems and operations, along with the inclusion of obvious contingency situations, could tip the balance in the other direction.
    2) The deep drilling activity, in particular, was problematic in that current drilling technology options and operations do not fit within the mass allocation or time available as stated in DRA 5.0; this requires further analysis to find a solution that will fit within overall mission constraints.

Key Findings

- **The ConOps and Integrated Functionality assessment identified potential missing function and associated mass discrepancies**
  - Based on analyses from this study, the pressurized Rover may not match the HEM-SAG range expectations; additional analysis of systems and operational alternatives is needed to identify a robust solution
  - Potential missing mass from surface manifest:
    - Science Lab external to Habitat
    - Contamination control (e.g., via sterilization) and verification
    - Suit maintenance area
    - Robotic Rovers for exploring "special regions" (including a potential requirement for a dedicated rover to support deep drilling operations)
  - Potential mass savings in surface manifest:
    - Dedicated Drilling equipment may be ~300 kg too high (technical solution dependent)
    - Commodity Cache allocation may be ~750 kg too high (technical solution dependent)
    - Food maybe overestimated (but margins and contingency scenarios must be assessed)
    - Alternative surface power system configurations show potential for additional mass savings

Key Findings

- **As we plan human missions beyond LEO, we encounter a number of new issues not encountered in decades; one of these is the integration of Planetary Protection policy and controls into mission hardware that may be extensible to Mars**
  - Missions to the Moon and other bodies, such as asteroids, can provide useful technology and operational test experience to validate Planetary Protection protocols and controls for use on later Mars missions

- **Deep-diving into selected operations helps validate requirements, identify functional interdependencies, and flush out issues**
  - A special study on the DRA 5.0 Commodity Cache concept (which was derived from Antarctic expedition experience) showed that, while this may be a logical approach in the Antarctic, it was simply not practical on Mars. The study identified an alternative approach that was more time- and mass-efficient, as well as less risky to the crew.
  - A special study of DRA 5.0 Drilling highlighted issues involved with crewed operations that have the potential to bump up against Mars "special region" constraints. The study identified a number of technical and operational concerns, including the time needed to drill to the required depth, and how to handle samples without breaking planetary protection protocols or compromising the integrity of science samples.

DOT FY13 Study Products

TOPIC	ASSOCIATED FILENAME
DRM Summaries: • DRM 8: David Reeves • DRM 8a: David Reeves	• DRM 8 Summary.ppt • DRM 8a Summary.ppt
Expert Briefings • Mr. Roy Long: Drilling • Dr. Kathleen Rubins: Biocontainment of Pathogens • Dr. Catharine Conley: Mars Planetary Protection	• Drilling_RLong.ppt • Biocontainment of Earth and Mars Pathogens_KRubins.ppt • Planetary Protection_Cconley.pdf
Educational Forum • Michelle Rucker: Introduction • Natalie Mary: EVAs and Suit Ports • Dr. Valerie Meyers: Mars Toxicology • Diana DeMott: Crew Safety • Michael Calaway & Dr. Mary Sue Bell: Mars Sample Handling • Dr. Margaret Race: Planetary Protection	• Educational Forum Introduction.pptx • Exploration EVA 101 Overview.pptx • Toxicological Risks from Martian Environment.pptx • Mars Safety & Mission Assurance.pptx • Mars Sample Handling.pptx • Planetary Protection.pdf
MEPAG HEM-SAG Report Summary: David Reeves & Dr. Marianne Bobskill	• MEPAG HEM-SAG Summary.ppt
DOT ConOps Reference Materials: Dr. Marianne Bobskill	• Reference Materials for Mars ConOps Analyses.ppt
DOT Science Activities Workbook: Dr. Steve Hoffman & Dr. Marianne Bobskill	• Mars Surface Science Activities.xlsx
DOT ConOps Groundrules & Assumptions: Kevin Larman & DOT	• Mars Surface Mission Groundrules & Assumptions.docx
CRADLE Mars Crewed Surface Mission Model: Philip Nerren	• CRADLE Mars Crew Operations Model.pptx
Special Studies • Michelle Rucker: Commodity Cache Feasibility Study • David North: Traverse Planning & Mobility Study • Dr. Marianne Bobskill & Dr. Mark Lupisella: Sample Handling & Lab Strategy • Michelle Rucker: Mars Drilling Study	• JSC66626 Commodity Cache Feasibility Study.pdf • Traverse Planning & Mobility Study.pdf • Sample Handling & Laboratory Strategy.ppt • JSC66635 Drilling Study Report.pdf

Section 1 – Introduction

- **Basic Description of a Concept of Operations & Historical Examples**
- **Space-related**
  - ISS SSP 50011, Concept of Operations and Utilization document
- **DOT Charter**
- **DOT Tasks**
- **DOT Team Members**

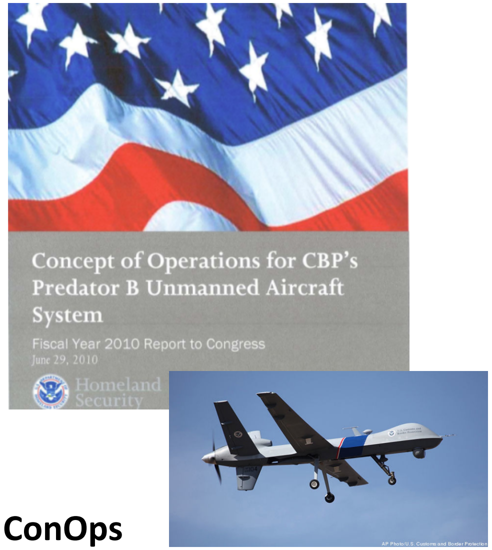
- DOT= Destination Operations Team

Basic Description of a ConOps & Historical Examples

- **An Operations Concept is needed to understand/document how the overall system is expected to perform**
- **An Operations Concept (and early requirements definition) forces engineers and program managers to focus on <u>describing what they need</u>**
- **It's easy to get focused on implementation vs. need too early (particularly in a "Mission Formulation" phase)**

Roald Amundsen
Discovery of South Pole, 1911

Concept Car
2006 Chevrolet Camaro



Concept of Operations for CBP's Predator B Unmanned Aircraft System

Fiscal Year 2010 Report to Congress

June 29, 2010

Homeland Security

2010 ConOps
Homeland Security Predator Systems

Basic Description of a ConOps & Historical Examples

A **Concept of Operations (ConOps)** is a document describing the characteristics of a proposed system from the viewpoint of an individual who will use that system. It is used to communicate both the quantitative and qualitative system characteristics to all stakeholders. ConOps are widely used in the military, government and other fields. A ConOps generally evolves from an initial concept and is a description of how a set of capabilities may be employed to achieve a desired set of objectives or end state.

There are many **Historical Examples** of mission or product success that were based on careful operational planning. Three are included here.

Roald Amundsen was a Norwegian explorer of polar regions. He led the Antarctic expedition (1910-12) to discover the South Pole in December 1911 and he was the first expedition leader to (undisputedly) reach the North Pole in 1926. Amundsen's expeditions benefited from careful preparation, good equipment, appropriate clothing, and a simple primary task plan.

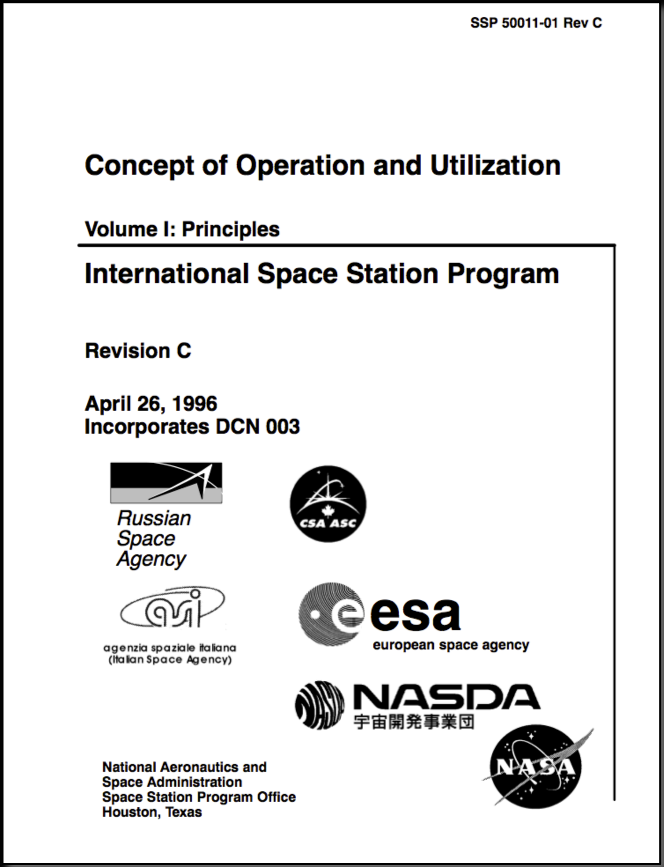
On January 6, 2006, the first official word regarding a fifth generation Chevrolet Camaro from General Motors came at the 2006 North American International Auto Show, where the 2006 **Camaro Concept** was released. This was based on looking at many operational concepts that incorporated various performance and styling options.

In 2010, the U.S. Department of Homeland Security released **a "Concept of Operations for U.S. Custom's and Border Protection's Predator B Unmanned Aircraft System"** which articulated the employment concepts and high-level capabilities required for current and future operations to support U.S. Homeland Security. This was distributed to multiple stakeholders.

Space Related Concept of Operations: ISS COU

International Space Station
Concept of Operations and Utilization (COU)

“ The COU defines the principles of operation of the Space Station. These principles provide the basis for developing more detailed operations processes, and also influence the design of the Space Station through requirements in the Systems Specification document. “



SSP 50011-01 Rev C

Concept of Operation and Utilization

Volume I: Principles

International Space Station Program

Revision C

April 26, 1996
Incorporates DCN 003

Russian Space Agency

CSA ASC

agenzia spaziale italiana
(Italian Space Agency)

esa
european space agency

NASDA
宇宙開発事業団

National Aeronautics and
Space Administration
Space Station Program Office
Houston, Texas

NASA

The International Space Station Concept of Operation and Utilization Initial Document Release occurred on 2/14/94 and was signed by all partners

Space Related Concept of Operations: ISS COU

The importance of creating an early mission definition from an operational perspective is not new within the space community. In 1994, the International Space Station (ISS) Program baselined **SSP 50011, the ISS Concept of Operations and Utilization (COU)** four years prior to first element launch. The purpose of the COU was, and still is, to compile the principles by which the ISS operates.

In its early versions, the COU provided the basis for developing more detailed operations processes, and also influenced the design of the ISS through driving out requirements and identifying trades and analyses and resulting functional assessments.

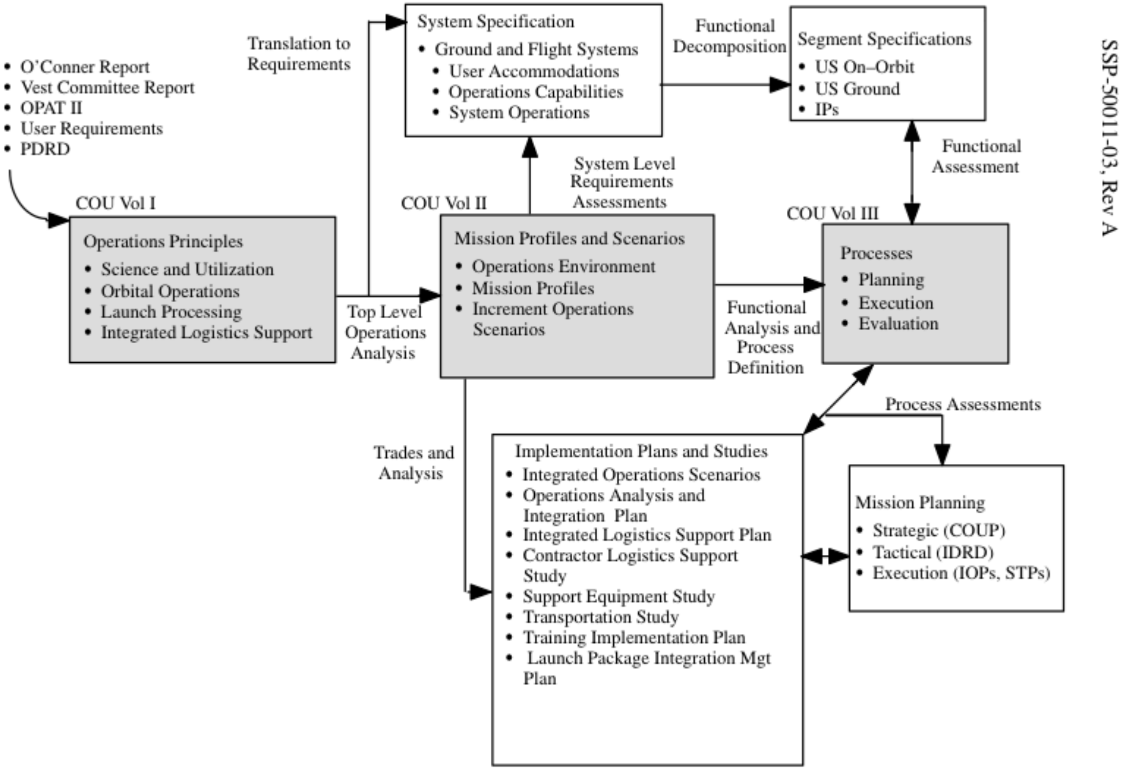


FIGURE 1–1 HOW THE COU RELATES TO THE SPECIFICATIONS

The image above describes how the International Space Station Concept of Operation and Utilization relates to the spacecraft specifications

DOT Charter

DOT Charter & Description of Task

Through a systematic approach, develop a destination-specific “Point of Departure” Concept of Operations for HAT DRMs. This Concept of Operations would then inform more detailed products that would be delivered to the HAT Core Team.

Primary Objective

Assess exploration destination strategies for human exploration in sufficient depth to:

(1) Capture the range of capabilities needed to inform technology investments

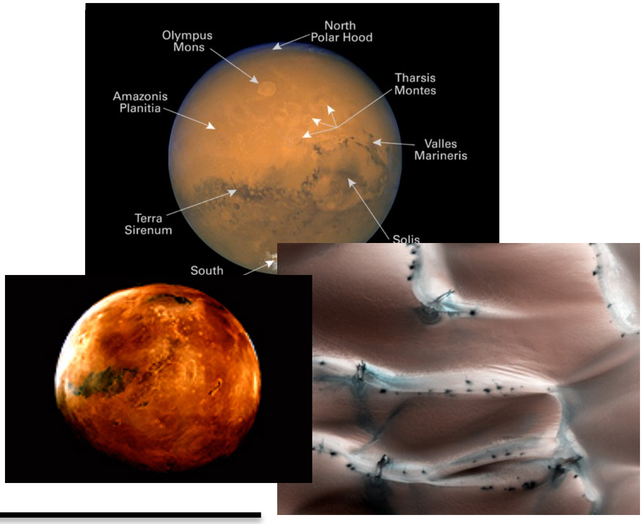
(2) Better understand and inform linkages among SMD, HEOMD goals/objectives, SKGs and required functionality

Late April Re-Direction from HAT

- Original Focus = NEAs, Earth’s Moon, Mars
- Updated Focus = Mars destinations only

Mars DRMs

- DRM 8: Mars Phobos & Deimos Mission
- DRM 8a: Mars Orbital Mission (crew tele-operates surface assets)
- DRM 9: Mars DRA 5.0 crewed surface operations *(Primary focus)*
- DRM 9a: Minimal Mars Mission



HAT = Human spaceflight Architecture Team
NEA = Near Earth Asteroid
DRM = Design Reference Mission

DOT Charter

The Destination Operations Team (DOT) was formed within the Human Spaceflight Architecture Team (HAT) in January, 2013. The primary task of DOT was to evaluate destination-specific operations for HAT DRMs. However, as a team, we first saw a priority to define a clear and concise charter and objective for the DOT.

While the primary product of the DOT's task was to develop "Point of Departure" ConOps for the destination provided, we wanted to make sure we did this in a systematic way, so that this ConOps would then "inform" the additional products DOT would deliver to HAT.

The Primary Objective of our team would then be to have these products inform two very near term, important areas:

1) The capture range of capability needs to inform our investments in technology, and
2) To understand the linkages, and actually the integration, between the different Mission Directorates' goals and objectives and the required functionality to meet these goals and objectives

Again, accomplishing this in a systematic, integrated manner, taking into account multiple stakeholders (within and outside of NASA).

While our original scope in January was to look at multiple DRMs, we were asked in April to focus on the HAT DRM 9 / Mars DRA 5.0 long duration crewed surface mission.

DRA = Design Reference Architecture

DOT Tasks for FY 13 (April – September 2013)

- **DRM 9 / Mars DRA 5.0 surface operations**
  - Re-examine DRA 5.0 (July 2009) *NASA Human Exploration of Mars* + Addendum
  - Use reference: *MEPAG Draft HEM-SAG* report (2008) for Mars surface science definition
  - Perform Functional Decomposition /Capability Audit of DRA 5.0 surface mission
  - Develop "Point of Departure" Surface Concept of Operations
  - Develop representative surface mission system manifest and mass estimate
  - Compare required capabilities & mass estimates to DRA 5.0 baseline

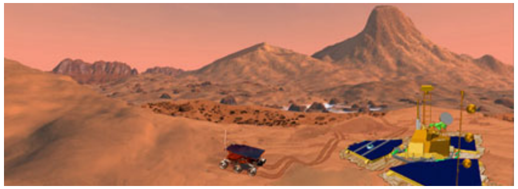
Input from HAT Teams
- Destination Leads
- Campaign Team
- Integrated Performance
- Transportation Team

HAT DRM 9.0
NASA DRA 5.0 +
Addendum

Mars Science
MEPAG
HEM-SAG

- DRM 5.0 Architecture Framework
- Science Objectives & Requirements
- Destination DRM Functional Decomposition
- Initial Capabilities & Technologies

HAT DOT Products
- Mars Surface Mission "Point of Departure" Concept of Operation
- Special Studies Results
- Groundrules & Assumptions
- Enabling Capabilities & Technologies
- Updated Mass Estimates & Comparison
- Recommendations for Further Study



- MEPAG = Mars Exploration Program Analysis Group
- HEM-SAG = Human Exploration of Mars – Science Analysis Group

DOT Tasks for FY 13 (April – September 2013)

Starting in April 2013, DOT undertook multiple tasks related to clearly understanding DRM 9/DRA 5.0 destination surface operations.

This process began with re-examining the source material – the MEPAG Draft HEM-SAG Report, published in 2008, and NASA's DRA 5.0 Human Exploration of Mars (plus its associated Addendum), published in July 2009. We then performed a "capability audit" to determine if the capabilities and referenced elements in DRA 5.0 made sense. We then identified and reviewed documentation and met with a number of Subject Matter Experts, to gather and organize information required to serve as the foundation for developing the ConOps. We then developed a "Point of Departure" ConOps based on what was described in DRA 5.0 and the MEPAG HEM-SAG report (which provided further detail to the science operations described in DRA 5.0). From that operational perspective, DOT was able to develop a representative manifest for the surface mission, then compare these results with the capabilities and mass estimates in DRA 5.0.

Of course, all of these top level tasks not only looked at DRA 5.0 specifically, but, as you'll see, helped "uncover" many other topics and influences to the approach of exploration beyond LEO, regardless of destination.

- LEO = Low Earth Orbit

DOT Membership

Primary DOT Core Membership

Name	Organization	Function
Larry Toups	JSC	Co Lead
Dr. Marianne Bobskill	LaRC	Co Lead
Dr. Steve Hoffman	JSC	ConOps Development Lead
Dave Reeves	LaRC	ConOps Development Lead
Michelle Rucker	JSC	Special Studies Lead
Dave North	LaRC	Special Studies Lead

Science Discipline Leads / POCs

Name	Organization	Function
Dr. Dean Eppler	JSC	Geology
Dr. Mary Sue Bell	JSC	Geology
Dr. Paul Niles	JSC	Geology
John Gruener	JSC	Geology
Dr. Nicholas Schmer	GSFC	Geophysics
Dr. Joel Levine	College of W&M	Atmosphere &Climate Science
Dr. Peter Doran	UI- Chicago	Astrobiology
Dr. Jennifer Eigenbrode	GSFC	Astrobiology
Dr. Craig Kundrot	JSC	Bioastronautics / HRP
Dr. Catharine Conley	HQ	Planetary Protection
Dr. Margaret Race	SETI Institute	Planetary Protection
Michael Calaway	JSC	Sample Collection, Curation, & Contamination Control

Primary DOT Support

Name	Organization	Function
Matt Simon	LaRC	Special Studies - Habitation
Dr. Dale Arney	LaRC	Capabilities Team Interface
Sharon Jefferies	LaRC	Capabilities Team Interface
Roger Lepsch	LaRC	ConOps Development
Kevin Larman	LaRC	ConOps Development
Kevin Earle	LaRC	ConOps Development
Dave Helton (ACL)	LaRC	Graphics
David Coan	JSC	Special Studies - EVA
Horacio de la Fuente	JSC	Special Studies
Steve Rader	JSC	ConOps Development
Natalie Mary	JSC	Special Studies - EVA
Ryan Whitley	JSC	Transportation Team Interface
Alida Andrews	JSC	Special Studies-Statistical Modeling
Rob Mueller	KSC	ConOps Development
Dr. Mark Lupisella	GSFC	Science & ConOps Development
Kendall Brown	MSFC	Mars Lander Interface
Phillip Nerren	MSFC	Special Studies
David Smitherman	MSFC	Special Studies - Habitation
Dr. Brian Wilcox	JPL	Special Studies - Robotics
Scott Howe	JPL	Special Studies - Robotics & Habitation

DOT Membership

The DOT was formed with the understanding that we had limited resources, so much of the participation was leveraged on an "as needed" basis. The primary DOT Core Membership Team consisted of Larry Toups (JSC) and Dr. Marianne Bobskill (LaRC), serving as co-leads; David Reeves (LaRC) and Dr. Steve Hoffman (JSC) leading the ConOps development; with Michelle Rucker (JSC) and Dave North (LaRC) leading the Functionality and Special Studies work.

The list on the right of the chart shows names of those who supported DOT as needed from five NASA centers and JPL. These system and discipline experts were called upon on an as-needed basis by the DOT Core Membership to address specific questions and issues.

On the lower left is the list of Science Discipline Leads and points-of-contact for areas of Mars science considered during development of the Mars ConOps. These Science Discipline Leads were members of the original MEPAG HEM-SAG team that developed the guiding science information and continue as members of the broader MEPAG team. Additionally, some members were experts in science-supporting fields, such as Bioastronautics, Planetary Protection, and sample handling. All of these experts volunteered their time in support of the DOT effort and the DOT Core Membership thanks them for their time; their expertise and information served as the foundation for the DOT Mars ConOps development.

Section 2 – HAT Mars Generic DRMs

- **8: Crewed Mars Moon Mission**
- **8a: Crewed Mars Orbit Mission**
- **9: Crewed Mars Surface Mission**
- **9a: Crewed Mars “Minimal” Mission (TBD)**
  - —Note: DRM 9a is presently being defined and was not considered during this analysis cycle

DRM-8: Crewed Mars Moons Mission

Achievements

- Crewed mission to the Martian system
- Deep-space use of advanced propulsion (NTP, NEP, and/or SEP)
- Multi-year flight of DSH
- Farthest distance that humans have traveled from Earth

Mission Operations

- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Launch of crew and rendezvous with stack and delivery to Martian System
- Total mission duration with direct entry at Earth:
  ~600 day (opposition-class/short-stay) to ~1000 day (conjunction-class/long-stay)

Assumed Element Capabilities

TBD t Class SLS

CPS-1/ CPS-2

MPCV LSS “Block N”

Long Duration DSH

Advanced EVA Systems

tele-operated Robots

Advanced Propulsion (NTP shown)

Mars Orbital Excursion Vehicle (MOEV) (SEV + Transfer Stage)

Cross-Cutting Capabilities

- Advanced propulsion (NTP, NEP, and/or SEP) & trade aerocapture and In-Situ Propellant Production
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- Low-gravity body anchoring systems, proximity ops, & target relative navigation
- Mechanisms for long-duration, deep-space missions

Note: Earth days

NTP	Nuclear Thermal Propulsion
NEP	Nuclear Electric Propulsion
SEP	Solar Electric Propulsion
DSH	Deep Space Habitat

DRM-8: Crewed Mars Moons Mission

- DRM 8 is based on the HAT 2012 Cycle A Mars-Phobos-Deimos Destination Mission Concept Study. This study lead by Dan Mazanek defined a day-by-day timeline for crewed exploration of Phobos and Deimos. The goal of the study was to determine whether an opposition-class mission (short-stay mission of ~30-90 days at Mars) provides sufficient time to meet all or most of the science and exploration objectives at Phobos and Deimos and in Mars orbit, or if a conjunction-class mission (long-stay mission of ~450-540 days at Mars) is required. Throughout the course of the study, science and exploration goals were identified and a point of departure set of capabilities and operations to meet those objectives was defined.
- Key Findings:
  - Preliminary results indicate that a meaningful human orbital mission to explore both Martian moons and robotically retrieve an MSR cache from low Mars orbit could be performed during an opposition-class mission opportunity.
  - The initial destination mission plan indicates that 56 days are required to accomplish all science and exploration objectives (existence proof)
  - Margin and mission reduction opportunities provide confidence that a successful and worthwhile mission could be completed within 60-90 days in the Mars system
  - Preliminary ConOps indicates that sufficient time is available to telerobotically retrieve an orbiting MSR cache if its ephemeris is properly known prior to human arrival

- MEPAG = Mars Exploration Program Analysis Group
- HEM-SAG = Human Exploration of Mars – Science Analysis Group

DRM-8a: Crewed Mars Orbit Mission

Achievements

- Crewed mission to the Martian system
- Multi-year flight of DSH
- Farthest distance that humans have traveled from Earth

Mission Operations

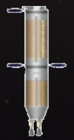
- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Launch of crew and rendezvous with stack and delivery to Martian System
- Teleoperation of robotic surface assets
- Total mission duration with direct entry at Earth: ~600 day (opposition-class/short-stay) to ~1000 day (conjunction-class/long-stay)

Assumed Element Capabilities

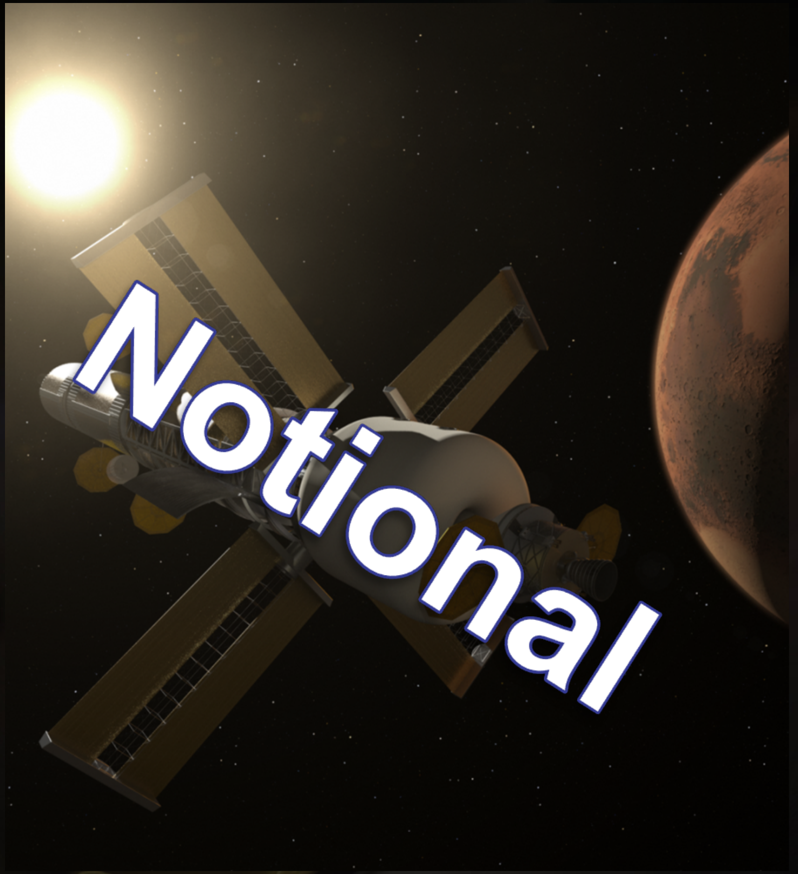

TBD t Class SLS


MPCV "Blk N"


tele-operated Robots


Propulsion (O_2/CH_4 shown)


DSH



Cross-Cutting Capabilities

- Trade advanced propulsion & aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU surface demo
- Mechanisms for long-duration, deep-space missions

Note: Earth days

MPCV	MultiPurpose Crew Vehicle
AR&D	Automated Rendezvous and Docking
ISRU	In-Situ Resource Utilization

DRM-8a: Crewed Mars Orbit Mission

- DRM 8 is derived from the tele-operations portions of the HAT 2012 Cycle A Mars-Phobos-Deimos Destination Mission Concept Study. This task identified Mars surface tele-operated activities that could be performed and would benefit from crew in the Mars vicinity.
- A short additional study was performed by the DOT to look at Mars orbital communication assets and how changing the orbit could impact tele-operations.
- Key Benefits of Crew in Orbit:
  - Increased situational awareness, may reduce risk for more challenging ops.
  - Progress of activities can increase due to multiple decision points per sol.
  - Use of more unconventional scientific platforms (airplanes, hoppers).
  - Transient science acquisition.
- Challenges of tele-operations from Orbit:
  - Much higher operations cost due to large engineering and ops support staff required for crew support.
  - In-system mission periods have limited durations, much shorter than durations available for Earth-controlled operations.
  - Additional crew training requirements for telerobotic operations.

DRM-9: Crewed Mars Surface Mission

DRA 5.0.-Derived

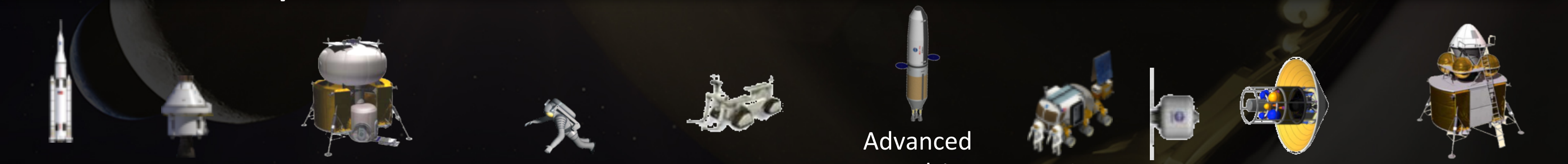
Achievements

- Crewed mission to the Mars surface
- Farthest distance that humans have traveled from Earth
- Extensive exploration of the surface of Mars
- First use of large scale Entry, Descent, & Landing (EDL)

Mission Operations

- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Total mission duration with direct entry at Earth ~1000 day
- Cargo elements are captured in Mars orbit using aerocapture.
- Selected surface assets pre-deployed at the landing site using advanced EDL technology
- Crewed vehicle utilizes propulsive capture at Mars
- 6-crew, ~540-day surface stay
- Crew lives in Deep Space Habitat (DSH) for in-space operations, habitat lander for surface stay

Assumed Element Capabilities



TBD t Class SLS
MPCV “Blk N”
Habitat Lander (crewed descent)
Advanced EVA Systems
tele-operated Robots
Advanced Propulsion (NTP shown)
Surface Systems
DSH
Aeroassist System
MAV Lander (crewed ascent)

Cross-Cutting Capabilities

- Advanced propulsion & trade crew mission aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU
- Mechanisms for long-duration, deep-space missions

Note: Earth days

EVA	Extra Vehicular Activity
MAV	Mars Ascent Vehicle
NTP	Nuclear Thermal Propulsion

HAT DRM 9 / DRA 5.0 Description

- DRM 9 is derived from the Mars Design Reference Architecture 5.0, which describes the systems and operations used for the first three missions to explore the surface of Mars by humans. These first three missions are assumed to occur on three consecutive trajectory opportunities no sooner than the decade of the 2030s. A three-mission set was chosen for this Reference Architecture for several reasons: (1) the development time and cost to achieve the basic capability to carry out a single human Mars mission are of a magnitude that a single mission or even a pair of missions could not be justified and (2) three consecutive missions will require approximately ten years to complete, a period of time sufficient to achieve basic program goals and acquire a significant amount of knowledge and experience, making this a likely point in time to consider new goals and improved architectures to achieve them.

- In addition, these first three human Mars missions are assumed to have been preceded by a sufficient number of test and demonstration missions on Earth, in low Earth orbit, on the Moon, and at Mars (by robotic precursors) to achieve a level of confidence in the architecture such that the risk to the human crews is considered acceptable.

- A crew of six will be sent on each of these missions and each crew will visit a different location on Mars. The rationale for a crew of this size has been judged to be a reasonable compromise between the skill mix and level of effort for missions of this complexity and duration balanced with the magnitude of the systems and infrastructure needed to support this crew. Visiting three different sites is based on a recommendation from a special committee of the MEPAG. The science and exploration rationale for visiting three different sites reflects a recognition that a planet as diverse as Mars is not likely to be adequately explored and understood from the activities that can take place at a single site. However, this three-site assumption does not preclude returning to any of the sites should there be a compelling need to do so.

HAT DRM 9 / DRA 5.0 Description

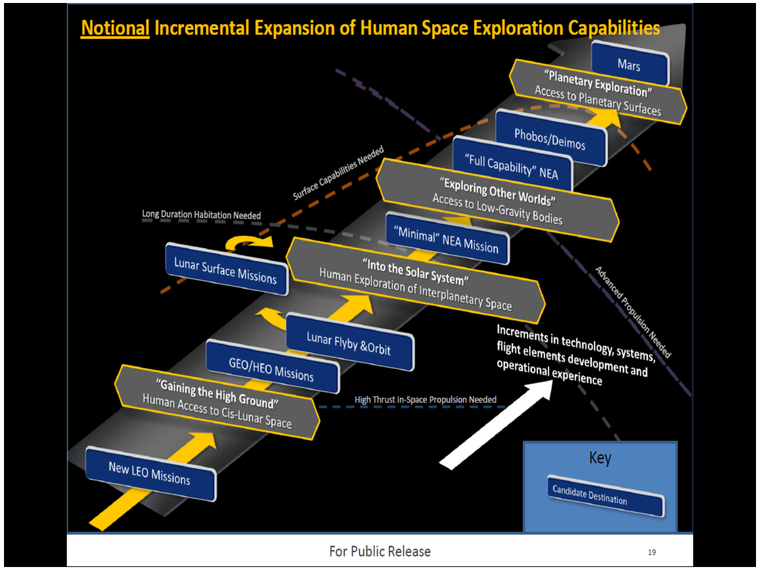
- Each of the three missions will use the conjunction class (long stay) trajectory option resulting in a round trip mission duration for the crew of between 800 and 1000 days. A portion of each mission's assets, specifically the surface habitat and other surface mission equipment as well as the crew ascent vehicle, are sent to Mars one opportunity prior to the crew. In addition, a decision was made to take advantage of the aerocapture technique on arrival at Mars to further enhance the amount of useful payload delivered due to the favorable trade of using the atmosphere of Mars to capture these payloads compared with an equivalent propulsion system. It should be noted that the human crew does not use this aerocapture technique, due primarily to the size of the vehicle transporting them. The decision to preposition some of the mission assets better accommodates the decision to make part of the ascent propellant at Mars, using the atmosphere as the raw material source for this ascent propellant. This use of in-situ resources and the equipment to process it into useful commodities results in a net decrease in the total mass needed to complete a mission. An advanced propulsion system was also recognized as necessary to decrease the total mass needed to complete a mission to acceptable levels. But a decision has not yet been made on which of a number of advanced propulsion system options will be implemented. A surface nuclear power source was found to be better suited, when compared to an equivalent solar power system, for producing this ascent propellant. This choice was further supported by the fact that this power system would be more than adequate to meet the needs of the human crew when they arrive, which occurs after all of the necessary propellants have been produced.

Section 3 – DRM 9 / DRA 5.0 Relationship

- **DRM 9 / DRA 5.0 Relationship**
- **DOT DRM 9-Specific FY13 Tasks**

DRM 9 / DRA 5.0 Relationship

- We are using DRA 5.0 for our initial DRM 9 analysis, since it is the most mature Mars reference architecture and represents a good end goal within a “Capabilities Driven Framework” approach
- By using DRA 5.0, we are developing the fundamental data necessary to understand the linkage among Exploration goals and objectives, functions, capabilities and technologies
- Data, “Building Blocks” and lessons learned can be used to:
  - Evaluate different approaches to explore a given destination (e.g., shorter or longer durations, alternative mission objectives, etc.)
  - Examine exploration of other destinations, including the use of a common (“Building Block”) operational strategy



Notional Incremental Expansion of Human Space Exploration Capabilities

For Public Release

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DOT DRM 9-/DRA 5.0- Specific FY13 Tasks

- **Assess DRA-5.0 Elements & Functionality**
- **Identify Mars Human Mission Groundrules & Assumptions**
- **Summarize DRM-8 and DRM-8a**
- **Develop a detailed Mars crewed surface mission Point-of-Departure (POD) Concept of Operations (ConOps)**
- **Create a Mars Surface Traverse Planning & Mobility Strategy**
- **Create a Mars Drilling (shallow & deep) Strategy**
- **Evaluate the "Commodity Cache" Concept Feasibility**
- **Evaluate a Mars Surface Integrated Power System**
- **Analyze Mars Sample & Laboratory Requirements**
- **Model Mars Surface Crewed ConOps**
- **Perform statistical modeling of crewed surface activities**

- ECLS = Environmental Control & Life Support
- SOWG = Space Operations Working Group

Section 4 – Information Collection Approach: "Doing Our Homework"

- Overview of Information Collection Approach Process
- Additional Information Gathering
- Mars Science Goals & Human Exploration Strategic Knowledge Gaps
- Mars ConOps Guiding Questions
- Review and Summary of Foundational Reference Documents
- Mars Surface Science Activities Workbook

Information Collection Approach Process

- **Purpose**
  - Collect and organize information for use in developing Mars long-duration crewed surface mission POD Concept of Operations

Reviewed Mars Guiding Information

- MEPAG Mars Objectives & SKGs
- DRA 5.0 The Mars Surface Reference Mission + Addendum
- MEPAG HEM-SAG Guidance
  - Geology
  - Geophysics
  - Atmosphere & Climate Science
  - Astrobiology
- NASA Bioastronautics/HRP

Reviewed & Summarized MEPAG HEM-SAG Reference Info

Spoke with Experts Across Multiple Disciplines

- Geology
- Geophysics
- Atmosphere & Climate Science
- Astrobiology
- Bioastronautics/HRP
- Planetary Protection
- Sample Collection, Analysis, Curation, & Contamination Control

Additionally

- Hosted Expert Briefings
- Created Science Information Collection Workbook
- Interviewed Science Discipline Leads / POCs
- Held “Educational Forum”
- Gathered Detailed Info on “Special Topics”
- Reviewed Reference Documentation
- Toured JSC Curation Labs
- Held Weekly Mars ConOps Mtg
- Held 2-day Mars POD ConOps TIM

ConOps Development

SKG = Strategic Knowledge Gap
MEPAG = Mars Exploration Program Analysis Group
HEM-SAG = Human Exploration of Mars – Science Analysis Group
HRP = Human Research Program

Information Collection Approach Process (1 of 2)

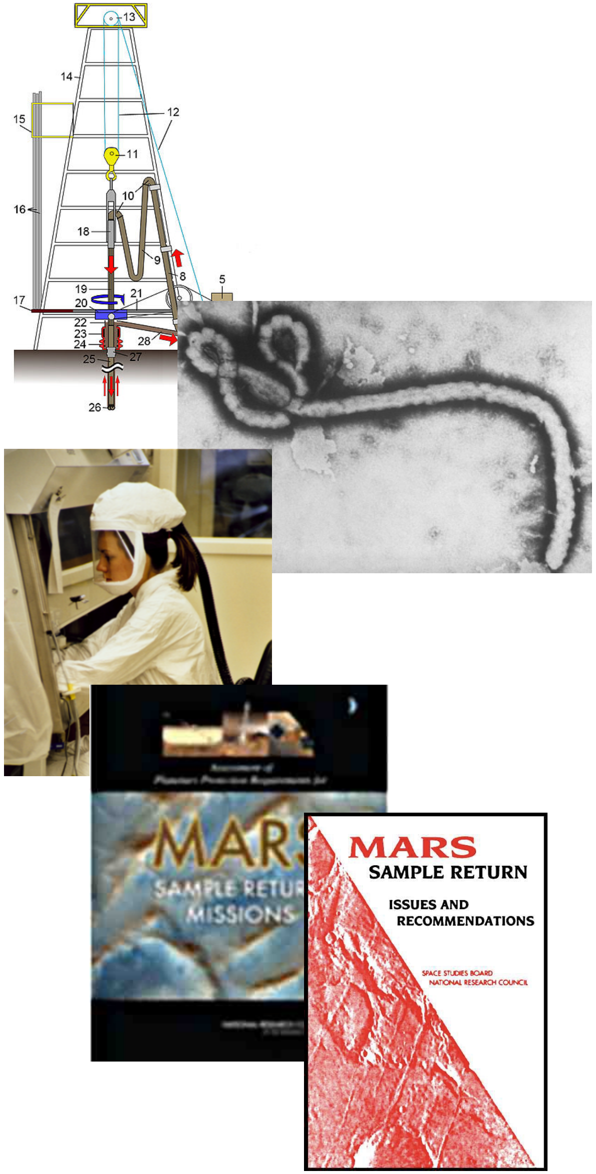
- An approach was defined to collect and organize information that would serve as the foundation for development of a Point-of-Departure Concept of Operations (ConOps) for a crewed Mars long-stay surface mission. This information collection approach involved a number of tasks and was carried out by a number of DOT team members prior to beginning development of the ConOps.
  1) Since the MEPAG Human Exploration of Mars-Science Analysis Group (HEM-SAG) document, (2008) *Planning for the Scientific Exploration of Mars by Humans*, served as one of the two "foundational" documents, it was reviewed and a detailed summary was created to serve as a working reference during ConOps development. See page 58 of the present report for information regarding Mars scientific goals and objectives as articulated in the MEPAG HEM-SAG document.
  2) The DOT hosted a series of special briefings, where the DOT was briefed by experts in a number of fields related to Mars surface operations. These included (1) deep drilling; (2) biocontainment of pathogens; and (3) planetary protection.
  3) A "workbook" was created to gather information from Subject Matter Experts (SMEs) regarding specific questions related to Mars surface operations driven by science objectives and activities (e.g., drilling, sample collection, and traverses). SMEs from the MEPAG HEM-SAG team were identified and asked to complete the workbook within areas of their expertise. These SMEs were then interviewed and the workbook information they provided was discussed and clarified. See page 72 of the present report for more detailed information regarding the structure of the workbook.

- SME = Subject Matter Expert

Information Collection Approach Process (2 of 2)

5) The DOT held an “Educational Forum,” during which SMEs in five fields were asked to brief the team on Mars mission-related information within their area of expertise. The areas briefed were: EVA and Suit Ports; Crew Medical/Mars Toxicology, Crew Safety, Mars Sample Handling, and Planetary Protection.
6) Reference information was gathered on a number of “special topics” (e.g., “Mars special regions,” sample analysis) and guiding reference documents were identified and obtained for DOT review.
7) A series of “guiding questions” was created by the DOT to focus information gathering and discussion around a set of high-level (and inter-related) issues. These “guiding questions” are summarized beginning on page 59 of this report.
8) A formal tour of the Sample Curation Laboratories at JSC B31 was conducted by laboratory personnel for the DOT membership.
9) A weekly DOT Mars ConOps meeting was held, during which the reference information, special topics of interest, and potential Mars surface activities were discussed.
10) A two-day Mars ConOps Technical Interchange Meeting was held at JSC, during which DOT members briefed the team on their tasks and a draft Mars crewed surface mission concept of operations was created.

Additional Information Gathering



SUBJECT MATTER EXPERT LECTURES

- **Drilling**
  - Mr. Roy Long, Ultra-Deepwater Technology Manager, Strategic Center for Natural Gas and Oil, US Department of Energy, National Energy Technology Laboratory
- **Biocontainment of Earth & Mars Pathogens**
  - Dr. Katharine Rubins, JSC, Pathogen , JSC Astronaut Office, Molecular & Cancer Biology
- **Planetary Protection**
  - Dr. Catharine A. Conley, NASA Planetary Protection Officer, HQ, Plant Biology

DOT "EDUCATIONAL FORUM"

• **Introduction**	**Michelle Rucker/NASA JSC**
• **EVA 101 & Suit Ports 101**	**Natalie Mary/NASA JSC**
• **Crew Medical (Toxicology)**	**Dr. Valerie Meyers/NASA JSC**
• **Crew Safety**	**Diana DeMott/NASA JSC**
• **Mars Sample Handling**	**Michael Calaway & Dr. Mary Sue Bell /NASA JSC**
• **Planetary Protection**	**Dr. Margaret Race, SETI Institute**

Additional Information Gathering (1 of 2)

- Subject Matter Experts across three domains were asked to brief the DOT members on topics in their discipline, particularly with regard to Mars surface operations. These three domains included Drilling, Biocontainment of Earth & Mars Pathogens, and Planetary Protection (particularly regarding Mars).
  - The US Department of Energy has an ongoing R&D program in advanced drilling technologies, and Mr. Roy Long (Ultra-Deepwater Technology Manager, Strategic Center for Natural Gas and Oil, as DOE's National Energy Technology Laboratory) briefed the DOT members on the history of drilling and ongoing development in advanced drilling technologies.
  - Dr. Kathleen Rubins (of NASA's Astronaut Office) is a molecular biologist and an expert in the biocontainment of Earth pathogens. Dr. Rubins described to DOT Biosafety Levels 1 through 4 and discussed issues regarding methods of containment for Mars samples potentially containing extant Mars life.
  - Dr. Catharine Conley is a plant biologist and serves as the NASA Planetary Protection Officer at Headquarters. Over two presentations, Dr. Conley described current planetary protection issues, concerns and laws, and discussed potential operational approaches for managing both forward and back contamination during a crewed Mars surface mission during which surface and subsurface samples may be collected via drilling (and which, therefore, may contain extant Mars life). Dr. Conley also put the DOT in contact with Dr. Margaret Race of SETI (the Search for Extraterrestrial Intelligence Institute), an expert in Planetary Protection; Dr. Race represented Dr. Conley and served on the DOT as a Planetary Protection consultant throughout the development of the Mars mission ConOps.

Additional Information Gathering (2 of 2)

- A DOT "Educational Forum" was organized and held for the DOT members to address a set of five broad topics of interest and importance to the Mars surface mission ConOps in development. An introduction was given by DOT to the attendees and Subject Matter Experts to provide a framework for the presentations and for discussion. The presentations given by these SMEs are provided in the files associated with this report.
- The five topics addressed by the SMEs included:
  - Introduction
  - EVAs and Suit Ports
  - Crew Toxicology Issues
  - Crew Safety
  - Mars Sample Handling
  - Planetary Protection

Mars Science Goals & Strategic Knowledge Gaps (SKGs)

- **Mars Goals (from: *MEPAG Mars Science Goals, Objectives, Investigations, and Priorities: 2010*)**
  - Goal I: Determine if life ever arose on Mars
  - Goal II: Understand the processes and history of climate on Mars
  - Goal III: Determine the evolution of the surface and interior of Mars
  - Goal IV: Prepare for Human Exploration

- **Mars Strategic Knowledge Gaps (from: *Analysis of Strategic Knowledge Gaps Associated with Potential Human Missions to the Martian System, P-SAG, May 2012*)**
  - Upper Atmosphere
  - Atmospheric Modeling
  - Orbital Particulates
  - Technology
    - To/From Mars System and Mars Surface
    - Sustained Presence
    - Phobos/Deimos
  - Lower Atmosphere
  - Back & Forward Contamination
  - Crew Health & Performance
  - Dust Effects on Surface Systems
  - Atmospheric ISRU
  - Landing Site and Hazards
  - Phobos/Deimos Surface Science & Surface Ops
  - Water Resources

Mars Science Goals & Strategic Knowledge Gaps (SKGs)

- The Mars Exploration Program Analysis Group (MEPAG) developed prepared a reference document describing the Mars science and human exploration goals, objectives, investigations and priorities, (2010) MEPAG (Johnson, J.R., Chair) *Mars Science, Goals, Objectives, Investigations, and Priorities*. Three science goals identify the primary guiding questions regarding Mars exploration (life, climate, surface, & interior) across geology, geophysics, atmospheric & climate science, and astrobiology disciplines. A fourth goal specifically addresses the human exploration of Mars and requirements to enable such a mission. These four goals, and their associated objectives, investigations, and priorities, were addressed in greater detail within the MEPAG HEM-SAG documentation and, thereby, guided DOT ConOps development.

- NASA's Human Exploration & Operations Mission Directorate (HEOMD) Human Spaceflight Architecture Team (HAT) has identified a set of Strategic Knowledge Gaps (SKGs) regarding a number of potential destinations for future human exploration missions (including Earth's moon, Earth-Moon cis/translunar space, Near Earth Asteroids, and Mars). The latest set of HEOMD HAT SKG's has been documented and reviewed by a number of expert groups, including the MEPAG's Precursor Strategy Analysis Group (P-SAG). The P-SAG document their findings in the report, (2012) Analysis of Strategic Knowledge Gaps Associated with Potential Human Missions to the Martian System, and this reference was used by the DOT during ConOps development. The specific P-SAG identified Mars SKGs are listed.

Mars ConOps Guiding Questions

- Prior to the DOT Educational Forum, and also to guide DOT ConOps development, a set of "guiding questions" was identified and issues/concerns related to these questions were identified. These guiding questions were provided to the team and to the SMEs briefing the DOT at the educational forum, to provide a framework regarding ConOps-related issues and to provide guidance in shaping the information shared.
- It was felt by the DOT that the issues within these guiding questions were significant determinants of Mars crewed surface operations and that a ConOps needed to understand and address these issues and their interactions.
- The guiding questions identified issues regarding the following five topics:
  1) Returning Mars samples with the crew
  2) Pressurized cabin operations
  3) Crew waste storage, transfer, and disposal
  4) Nominal crew EVA operations
  5) Sample Handling (on the surface by the crew)
- A summary of each of these topics and their associated guiding questions and issues is provided in the following charts.

Guiding Questions: Returning Crew and Surface Samples

- **The crew will land/live in one vehicle (habitat), but leave Mars in a different vehicle (MAV, Mars Ascent Vehicle)**
  - The two vehicles will be approximately 1 km apart on the surface
- **Notionally, the crew would EVA from the Hab/Lab to a rover, drive the 1 km to the MAV, and EVA again from the rover to the return vehicle — likely carrying the sample container (s) as much as 20 feet up an external ladder to the MAV hatch.**
  - Both the crew's EVA suits and the sample container will have been exposed to the surface

- **Questions to Ponder:**
  - How do we "break the chain" and get dusty, EVA-suited crew into the ascent vehicle?
    - Is it required that crew bring their EVA suits into the ascent vehicle?
    - Can a "layered dust control/containment" system be built into the ascent vehicle?
    - Current suit port design will still have some dust on the PLSS hatch
    - If dust gets into the suits over their 500+ sol surface usage period, it may adhere to the crew's skin or inner garments and be carried into the return vehicle cabin; may require a "crew decontamination" process
  - If we put suit ports on the MAV, do we need one for every crew member (large mass penalty) or can we downsize to 2 or 3 and discard suits before the next crew member goes in?
  - Do we need to provide decontamination (e.g., suit, crew) before or after leaving the surface? Can materials "self-clean"?
    - Could suits be left behind on Mars surface? What about transit EVA needs?

PLSS Portable Life Support System

Guiding Questions: Pressurized Cabin Operations

- **Pressurized cabins (habitat, rover, ascent vehicle) will have overpressure protection that vents overboard**
- **Pressurized cabins will have some nominal leakage of cabin atmosphere + likely off-nominal leakage of fluids**
  - Note that ISS, Mir, and Shuttle all experienced leakage of cooling fluid lines, cabins, etc.

- **Questions to Ponder:**
  - Is venting cabin atmosphere overboard or to a closed container required while on Mars' surface?
    - If Mars landing site assessment is adequately done prior to crew landing and transport mechanisms are understood and limited, it might be able to vent while on Mars' surface
    - Otherwise, habitat venting may need to be contained – *precursor landing site data could make the difference in strategy*
  - Does the entire habitat external surface have to be sterilized/cleaned before leaving Earth or just parts the crew may brush against going in/out of the habitat or not at all?
    - If so, how?
      - Habitat will likely be 7- 9 m diameter and may be partially inflatable…can it be sterilized/cleaned in pieces, then assemble?
      - Can the external surfaces be cleaned while the habitat is part of the launch stack?
    - If fluids are inadvertently leaked from lander systems while on Mars' surface (e.g., liquid oxygen propellant; thermal control fluids, such as ammonia or wax; water), does the spill have to be cleaned up?
      - Potentially, yes, at least in the case of water spill or activities that increase local temperatures, to avoid creating a "special region" in the landing zone. Details depend on environment and contamination transport.

Guiding Questions: Waste Storage, Transfer, and Disposal

- **Most of the logistics (e.g., food) will arrive on the Cargo Lander and will be later transferred to the Crew Lander when it arrives**
  - Logistics will be stowed in TBD cargo containers inside a rover or ascent vehicle cabin

- **Questions to ponder:**
  - If we have to take the logistics cargo containers outside to transfer from one vehicle to another, do the containers need to be sterilized?
    - If so, when?
    - If so, how?
    - Probably doesn't require sterilization
  - Can some logistics supplies be buried for storage on Mars (e.g., food) to protect it from radiation
    - If so, what kind of container do we need to use?
    - How do we verify it's safe to bring containers into the Habitat later?
  - 6 Crew x 500 sols = a lot of empty food containers and a lot of crew waste; since there's not enough room to keep all waste and containers inside, can we dispose of them outside?
    - If so, do we have to do something to them first?
    - Store outside but with TBD cleanliness spec?

Guiding Questions: Nominal EVA Operations

- **Boots**
  - EVA crews will likely walk around the landing zone and surface elements
  - Crew may also walk in areas where science operations are being conducted (e.g., drill rig)
- **Gloves**
  - EVA crews will likely pick up tools, manipulate surface samples (e.g., rocks, core samples), repair equipment (e.g., stalled drill string), and climb up/down ladders/steps to access rovers, habitat, and return vehicle

- **Questions to Ponder:**
  - Do the EVA suits need to be sterilized or cleaned to certain levels before walking on Mars?
    - Requires that sufficient assessment of area can be made prior to crew landing that indicates "lifeless area" and/or consequences of contamination are acceptable?
    - EVA suits will be stowed external to the surface elements (e.g., habitat) and will be exposed to Mars environment (e.g., UV); is this sufficient to "sterilize/clean" the suit surface? How long do suits need to be exposed for sufficient "sterilization/cleaning"?
    - If yes, where? When working in areas where crew collects science samples or do we need to sterilize/ clean before walking around surface elements?
    - If yes, does the entire suit need to be sterilized, or just the parts that nominally touch the surface?
      - Actual contact with Mars is the most important consideration; however, there may be deposition between surface and suit that needs to be addressed.
    - If yes, when/how often? Suits will be stowed inside crew habitat enroute to Mars, so sterilizing on Earth won't help much. Prior to doing first EVA?
    - If yes, how? Can the outside surfaces be "wiped down" with wet wipes or is it required that the whole suit be "heated"? Note that cleaning may damage the suit, will require a "cleaning capability" and power
    - If yes, do we need to verify cleanliness on Mars? Most probably, yes.

- UV = Ultraviolet

Guiding Questions: Sample Handling

- **EVA suits leak internal atmosphere and organic contaminants and may pick up contaminants during crew operations**

- **Questions to ponder:**
  - How close can EVA-suited crew member get to surface samples?
    - If contamination can be controlled to acceptable levels, then physical contact with samples should be possible
  - How close to the habitat can samples be transported/stowed?
    - Contamination from habitat may be hard to control, so many samples may need to be kept and analyzed some TBD distance from habitat (e.g., in a separate facility some TBD distance from the habitat accessible by crew or tele-operated)
  - Do we return science samples inside the ascent vehicle's crew cabin or outside?
    - If sample containment is adequate, then sample containers may be stowed inside the return vehicle
      - If inside, does the return container need to be "sterilized" or cleaned prior to transporting to the vehicle without exposing it to the Mars environment again?
    - If outside, the sample containers need to be transported to the return vehicle (e.g., via a crew EVA or robotic transfer)

Review & Summary of Foundational Reference Documents

1) **Reviewed in detail and summarized MEPAG *Human Exploration of Mars Science Analysis Group* (MEPAG HEM-SAG) information as primary science reference for POD ConOps development**
   - *Planning for the Scientific Exploration of Mars by Humans* (January 2008) http://mepag.nasa.gov/reports/index.html
   - Addressed activities to be conducted by crew within four science disciplines:
     - Geology
     - Geophysics
     - Atmospheric & Climate Science
     - Astrobiology

2) **Mars Long-Stay Surface Mission Architecture**
   - Hoffman, S., Ed. (2001) *The Mars Surface Reference Mission: A Description of Human and Robotic Surface Activities,* NASA/TP-2001-209371.
   - Drake, B.G. (2009) *Human Exploration of Mars Design Reference Architecture 5.0*.
   - Drake, B.G., Ed. (2009) *Human Exploration of Mars Design Reference Architecture 5.0 Addendum;* NASA/SP-566-ADD.
   - Architecture includes long-stay (~500 sols) with central hub near landing site + multiple long (~100-300 km) traverses

- POD = Point od Departure

Review & Summary of Foundational Reference Documents

- A number of seminal references were identified as fundamental to the DOT's understanding of issues related to Mars surface science and exploration and to development of an informed Mars mission ConOps.

- These references were collected and organized and were made available to the DOT membership for review.

- The references spanned NASA, MEPAG, the National Academy of Science National Research Council, and a number of organizations responsible for Planetary Protection policy.

- On completion of this DOT FY13 final report, these references will be placed on the ICE Windchill HAT DOT Portal in a special References section for future reference by the DOT members and other HAT personnel interested in Mars science and planetary protection reference information.

Review & Summary of Foundational Reference Documents

- As noted earlier, the <u>primary science guiding document</u> for development of the DOT Mars surface mission Concept of Operations was the MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

- This document contained information regarding goals & objectives across geology, geophysics, atmospheric & climate science, and astrobiology science disciplines. Also within this reference are described the specific questions to be addressed within each science discipline, the types of crew and robotic activities that should be conducted to address these fundamental questions, and supporting capabilities to enable these activities.

- In the following pages, the goals, investigations and associated approaches, planned analyses, and consensus and general conclusions across all science disciplines addressed are briefly described. This information is summarized in greater detail in a supporting file accompanying this report.

- These science discipline investigations and approaches and the MEPAG HEM-SAG team conclusions were used as inputs into the Mars surface mission ConOps. In particular, across a number of the science disciplines, Mars' surface traverses were provided and a subset with detailed accompanying crew and robot activities was modeled within the ConOps.

- In the following section, a high-level summary of the geology, geophysics, atmospheric & climate science, and astrobiology investigations and approaches and the MEPAG HEM-SAG team conclusions is provided for reference.

MEPAG HEM-SAG Science: Geology

- **Addresses *MEPAG Goal III: Determine the evolution of the surface and interior of Mars***

- **Top level questions addressed:**
  1. What is the volcanic history of the planet, and is Mars volcanically active today?
  2. What is the nature and evolution of the Martian magnetic field?
  3. What is the climate history of Mars?
  4. What is the hydrologic history of Mars?
  5. Is Mars hydrologically active at the present time?

- **Three major periods of Mars geologic history: Noachian, Hesperian, Amazonian**
  - Sites and samples must span all three geologic periods
  - Potential landing sites of Geology interest
    - Jezero Crater
    - Mangala Valles
    - Arsia Mons Graben

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Suggested Investigations and Approaches to Address Mars Geology Science Questions

Objective: Determine the Nature and Evolution of the Geologic Processes that Have Created and Modified the Martian Crust and Surface

Investigation (in priority order)	Approaches
1. Determine the present state, 3-dimensional distribution, and cycling of water on Mars.	• Drilling • Surveying for groundwater seeps • GPR • MET Stations
2. Evaluate fluvial, subaqueous, pyroclastic, subaerial, and other sedimentary processes and their evolution and distribution through time, up to and including the present.	• Sampling along traverses • MET stations • In-situ composition analysis
3. Calibrate the cratering record and absolute ages for Mars.	• Thorough sampling of diverse rocks • Cosmogenic age dating of samples
4. Evaluate igneous processes and their evolution through time, including the present.	• Extensive sampling traverses • In-situ composition analysis
5. Characterize surface-atmosphere interactions on Mars, including polar, Aeolian, chemical, weathering, mass-wasting and other processes.	• MET stations • Traverse sampling along glaciers • Sampling of diverse mineralogy
6. Determine the large-scale vertical structure and chemical and mineralogical composition of the crust and its regional variations. This includes, for example, the structure and origin of hemispheric dichotomy.	• Drilling • Seismic stations • GPR • Compositional comparison of fresh/weathered samples
7. Document the tectonic history of the Martian crust, including present activity.	• Seismic stations • Observations of graben and other tectonic features
8. Evaluate the distribution and intensity of hydrothermal processes through time, up to and including the present.	• Stratigraphic sample collection • Compositional analysis at multiple sites
9. Determine the processes of regolith formation and subsequent modification, including weathering and diagenetic processes.	• Sample collection a multiple latitudes/environments • MET stations
10. Determine the nature of crustal magnetization and its origin.	• In-situ magnetometer analysis. • Traverses in areas of magnetic anomalies
11. Evaluate the effect of impacts on the evolution of the Martian crust.	• Ejecta sampling • Mapping of crater-wall outcrops

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

MEPAG HEM-SAG Science: Geophysics

- **Also addresses *MEPAG Goal III: Determine the evolution of the surface and interior of Mars***
- **Geophysics investigations are organized into two categories**
  1. *Planetary scale geophysics*: Determine the structure and dynamics of Mars' interior and determine the chemical and thermal evolution of the planet
     - Goal: Determine the structure and dynamics of Mars' interior and determine the chemical and thermal evolution of the planet
     - 1,000s of km
     - Characterizes the structure, composition, dynamics, and evolution of the Martian interior
  2. *Exploration / regional- & local-scale geophysics*
     - Goal: To characterize the structure, composition, and state of Mars' near-surface crust
     - Regional: 10s – 100s of km
     - Local: <10 km
     - Characterizes the structure, composition, and state of the crust, cryosphere, hydrologic systems, and upper mantle

- **Potential landing sites of Geophysics interest**
  - Chasma Boreale
  - Nili Fossae
  - Centauri Montes
  - Arsia Mons

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Planetary Scale Geophysics Investigations & Approaches

MEPAG Goal III science investigations that are relevant to Mars planetary scale geophysics

Investigation (in priority order)	Approaches
1. Characterize the structure and dynamics of the interior	• Seismology • Heat flow • Gravity • ULF EM induction (conductivity profile) • High-precision geodesy
2. Determine the origin and history of the magnetic field	• High-precision, high-resolution magnetic field measurements • Measurements of the magnetic properties of samples
3. Determine the chemical and thermal evolution of the planet	• Seismology • Heat flow • ULF EM induction (conductivity profile) • Gravity • High-precision geodesy • High-precision, high-resolution magnetic field measurements

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Regional and Local Scale Geophysics Investigations & Approaches

MEPAG Goal III science investigations that are relevant to Mars regional and local scale geophysics

Investigation (in priority order)	Approaches
1. Evaluate fluvial, subaqueous, pyroclastic, subaerial, and other sedimentary processes and their evolution and distribution through time, up to and including the present	• Reflection seismology, ground penetrating radar, gravity, EM induction (conductivity profile), neutron spectroscopy
2. Characterize the composition and dynamics of the polar layered deposits	• Reflection seismology, ground penetrating radar, gravity, EM sounding (conductivity profile)
3. Evaluate igneous processes and their evolution through time	• Reflection seismology, ground penetrating radar, gravity, EM induction (conductivity profile)
4. Characterize surface-atmosphere interactions on Mars, including polar, aeolian, chemical, weathering, mass-wasting and other processes	• Active seismic, EM, NS
5. Determine the large-scale vertical and horizontal structure and chemical and mineralogical composition of the crust; this includes, for example, the structure and origin of hemispheric dichotomy	• Passive, active seismic, gravity, active EM, passive low-frequency EM
6. Determine the present state, 3-dimensional distribution, and cycling of water on Mars	• Active seismic, active EM, passive low-frequency EM, instrumented drilling or wireline sensors
7. Document the tectonic history of the Martian crust, including present activity	• Gravity, passive and active seismic, active EM, passive low-frequency EM, instrumented drilling or wireline sensors
8. Evaluate the distribution and intensity of hydrothermal processes through time, up to and including the present	• Passive and active seismic, active EM, passive low-frequency EM, instrumented drilling or wireline sensors
9. Determine the processes of regolith formation and subsequent modification, including weathering and diagenetic processes	• Passive, active seismic, active EM, passive low-frequency EM, NS for hydrogen
10. Determine the nature of crustal magnetization and its origin	• Mobile magnetometry, heat flow, passive low-frequency EM
11. Evaluate the effect of impacts on the evolution of the Martian crust	• Subsurface mapping via active seismic, EM sounding

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

MEPAG HEM-SAG Science: Atmosphere & Climate Science

- **Addresses MEPAG *Goal II: Understand the processes and history of climate on Mars***
- **Focus: Planetary Boundary Layer (PBL, surface to ~10 km)**
  - Surface-atmosphere interactions impart fundamental influences on the dynamical, chemical, and aerosol characteristics of the global Mars atmosphere

Investigation	Key Objectives for Human Missions
Atmospheric Objectives	• **Surface-atmosphere interactions: Dynamics, heat and mass balance, non-equilibrium trace gases** • **Search for sources of volatiles and trace gases**
Polar Cap Objectives	• **Baseline chronology and characterization of the climate history of the north polar dome (deep core)** • **Horizontal sampling of the North polar layered deposits (NPLD)**
Early Climate Evolution	• **Long-term climatic evolution of the planet (billion-year temporal scale); implications of early climatic conditions in the emergence of early potential habitats and/or Life, which includes inference in the atmosphere chemical state** • **Sampling of Noachian to Amazonian deposits through soft drilling (around 1 meter deep) along outcrops or deep drilling to capture information in the sedimentary record**

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Atmosphere & Climate Science Investigations & Approaches

1. Atmosphere-surface interactions: Dynamics, heat and mass balance

1.1	Monitor basic atmospheric state at reference height above surface (2m?)	MET station: • Instrumented mast –sonic anemometer (3 heights), temperature (3 heights), pressure, humidity, radiation (net, LW, SW), dust particle counter • Soil heat and conductivity probes • Soil temperature profile
1.2	Monitor the radiation and heat balance for surface-atmospheric exchange and solar forcing	
1.3	Monitor temperature, wind, dust and cloud through the depth of the boundary layer (2 scale heights ~20 km)	• Upward looking thermal IR spectroscopic sounder (water vapor, dust, temperature) • Tethered balloon & winch & gondola – sonic anemometer, temperature, pressure, humidity, camera • Radiosonde balloon – temperature, pressure, wind, humidity • Portable doppler lidar (wind) • Portable Raman/imaging lidar (dust) • DC electric field sensors • Portable DIAL (water vapor) • Surface accumulation measurements (dust/ice) • Microscope analysis of dust
1.4a	Monitor the mass balance for dust and volatile components	
1.4b	Investigate processes that influence the mass balance for dust and volatile components	
1.5	Assess the impact of latitude, longitude, season and local time	• Diurnal cycle campaign: tethered balloon sounding each two hours, portable instrumentation deployment • Seasonal cycle campaign: 3 sols of diurnal cycle campaigns, 6 times over mission, radiosonde release midday/midnight

2. Atmosphere-surface interactions: Atmospheric volatiles & chemistry

2.1	Measure atmospheric composition (trace, isotopes)	• Isotope mass spectrometer (2-10 amu) • Sample processing system • pH, wet chemistry, microscope
2.2	Measure physical and chemical properties of the regolith	
2.3	Measure the deposition of chemically-active gases, such as ozone and hydrogen peroxide, to the Mars surface.	
2.4	Search for gases of biogenic (methane, ammonia, etc.) and volcanic (sulfur dioxide, hydrogen sulfide, etc.) origin and determine their source(s).	• Portable laser diode system or FTIR for ~100 pptv detection limits
2.5	Search for sources of atmospheric water vapor.	
2.6	Assess the impact of latitude, longitude, season and local tim on atmospheric composition and on the photochemistry of trace atmospheric gases.	• Chemistry campaign: 3 sols, 6 times over mission

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Nominal Deep Drilling Robotic Polar Mission

- Mars' polar regions pose unique technical challenges due to cold temperatures and polar night – therefore, it was assumed that a polar mission would be robotic only and no further analysis was performed
- North polar dome targeted for a deep drilling mission
- *Robotic polar mission only*: Following robotic polar drilling operations, crew traverses to lower latitude for launch prior to onset of polar night
- Access to ancient ice and the North polar layered deposit (NPLD) region will also be of interest for Geology and Astrobiology investigations

Scientific Goal	Approach
Baseline chronology and characterization of the climate history of the north polar dome	• Deep core preferably to bedrock and baseline chronology • Polar cap mass and energy balance for current climate state and seasonal cap formation processes • Shallow cores to investigate heterogeneity • Emplace geophysical sensors (heat probe and seismic sensors)

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

MEPAG HEM-SAG Science: Astrobiology

- **Addresses *MEPAG Goal I: Determine if life ever arose on Mars***
  - Objective A: Characterize past habitability & search for evidence of *ancient* life
  - Objective B: Characterize present habitability & search for evidence of *extant* life
  - Objective C: Determine how long-term evolution of Mars affected the physical & chemical environment critical to *habitability & the possible emergence of life*
- **Astrobiology strategy based on: (2007) "*An Astrobiology Strategy for the Exploration of Mars*." NAS NRC SSB Board of Life Sciences, Division of Earth & Life Sciences.**
- **Potential landing site of Astrobiology interest**
  - Centauri Montes
- **High Priority Target Locations**
  - Note: Top 5 meters of surface are extremely limiting for life = requires sub-surface access (e.g., high UV radiation levels, oxidants, below limits of water & temperature for life)
  - Surface, interior, and margins of polar caps
  - Cold, warm, or hot springs or underground hydrothermal systems
  - Source or outflow regions associated with near-surface aquifers (responsible for "gullies")
  - Mid-latitude deposits of shallow ground ice
  - Source/outflow regions for catastrophic flood channels
  - Ancient highlands formed during widespread surface water (e.g., Noachian)
  - Mineral deposits associated with surface/ /subsurface water; ancient hydrothermal systems; or cold, warm, or hot springs

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Astrobiology Investigations & Approaches

INVESTIGATIONS	APPROACH
Characterize complex organics	• Raman Spectroscopy & GCMS • Screen for biomolecules using life marker chips and other "life on a chip" assays • Nucleic acid extraction (assuming Mars life has nucleic acids) and sequencing • Microscopic staining for biomolecules
Characterize the spatial distribution of chemical and/or isotopic signatures	• Isotope MS and GC • Tabletop SEM
Characterize the morphology or morphological distribution of mineralogical signatures	• XRD, LIBS • FTIR + Raman Spectroscopy • Bright field microscopy • SEM
Identify temporal chemical variations requiring life	• Basic metabolic analysi • Analysis of major cations and anions and metals associated redox couples

GC = Gas Chromatography
MS = Mass Spectroscopy
SEM = Scanning Electron Microscope
XRD = X-Ray Diffraction
LIBS = Laser-Induced Breakdown Spectroscopy

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

MEPAG HEM-SAG Science Operations Consensus Conclusions (1 of 2)

- ***Consensus Conclusions*** **= Cross-cutting findings related to specific attributes of potential human missions required to enable science priorities**

- <u>Sample mass to Earth and return mechanism</u>
  - Sample conditioning and preservation essential for some samples
  - 250 kg+ driver (Science) [400 kg max]
  - 250 EVA sols at 1-1.5 kg / EVA-sol vs. Apollo 17 threshold
  - Astrobiology requirements are subset of 250kg+ minima (must-have)
  - Astrobiology hab-lab requirements on Mars are essential for sample selection (for in situ analysis)
  - Atmospheric / ice samples as well (subset of total for Earth return)
  - Independent robotic return path to Earth would be required for some samples

- <u>Horizontal Mobility</u>
  - Science theme dependent
    - Astrobiology deep drilling requires least horizontal mobility, but remains in ~100 km class
  - Geophysics station spacing requirements dictate (antipodal node emplaced): 200-400 km radial from initial landing position
  - Affects regional lithospheric structure, seismicity, thermal structure via geophyscial stations
  - Spacing from orbit of magnetic striations now 200 km — rove to ensure high magnetization > 200 km
  - Supports requiref atmosphere/climate network sampling
  - Astrobiology / life requires geology-related context mobility (for sampling)

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

MEPAG HEM-SAG Science Operations Consensus Conclusions (2 of 2)

- Vertical Subsurface Access (drilling)
  - Astrobiology (extant life): ~300 m for access to subsurface liquid water zones (if available)
  - 5-50 m for traverse sampling
  - Ionizing radiation/super-oxidant zone is 2-5 m
    - ✓ minima is 2 m from neutron interaction path length
  - Geology/climate > 100 m access is likely essential (site dependent)
  - Selective Coring (recoverable) vs. pure drilling to depth z (cuttings recovered)
  - Polar climate coring-recovery also at 300 m depth (anywhere deep ice)

- Hab-Lab Requirements (sample analysis) (multidisciplinary)
  - Facilitates high-grading of "sample return to Earth" mass
  - Enables biology-unique (and climate) measurements that cannot be done on Earth
  - Examples of key aspects include: e.g., extant life tests (productivity, labeled radio-C etc.)
  - Monitor environmental isolation (contamination and hab isolation, curation…)
  - Decisions on basis of samples analysis and directs future sample collections and science

- Additional Conclusions
  - Some network stations (geophysical/meteorological/climate) to be emplaced and operated after human departure (e.g., ALSEP-like, LDEF-like, etc.)
  - Crew emplacement of short-lived monitoring assets are critical climate/atmospheric sampling and analysis
  - Robotic assistants/adjuncts required to serve as "science mule" for information capture and transport of samples, equipment, etc.
  - Telecommunications support for science required for navigation, including GPS-like or inertial reference (includes inertial reference for science documentation)
  - Ensure separation of Astrobiology experiments from human life sciences biology conducted for crew

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

- ALSEP = Apollo Lunar Surface Experiments Package
- LDEF = Long Duration Exposure Facility

MEPAG HEM-SAG Science Operations Generalized Conclusions (1 of 2)

- ***Generalized Conclusions*** **= Essential for any science-driven program of human exploration**
  - Requires multiple, independent sites for long-stay for science-driven missions
  - Sample mass to Earth > 250 kg, however this is achieved (may include robotic & human return approaches)
  - Human horizontal mobility is > 200 km radial (may be up to 500 km radial)
  - Vertical mobility must be capable of ~ 300 m (at one site, less at multiple sites on traverses)
  - Extant biology is not off-limits, including in situ analysis via special lab equipment
  - Requires lab instruments to address multiple objectives (Astrobiology, Geology, etc.)
  - Emplacement of network stations for interior, meteorological, climate and astrobiology essential beyond initial landing site (to be operated during mission & after crew leaves)
  - Science after humans return to Earth is essential for monitoring climate, interior, & astrobiology (if found)
  - Some key human science activities on Mars must be demonstrated on the Moon and maybe some on Earth in Mars analogue settings
  - Navigational and telecom infrastructure needed to support human science
  - Humans on site bring scientific improvisation, adaptability, agility, and increased cognition for solving major problems

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

MEPAG HEM-SAG Science Operations Generalized Conclusions (2 of 2)

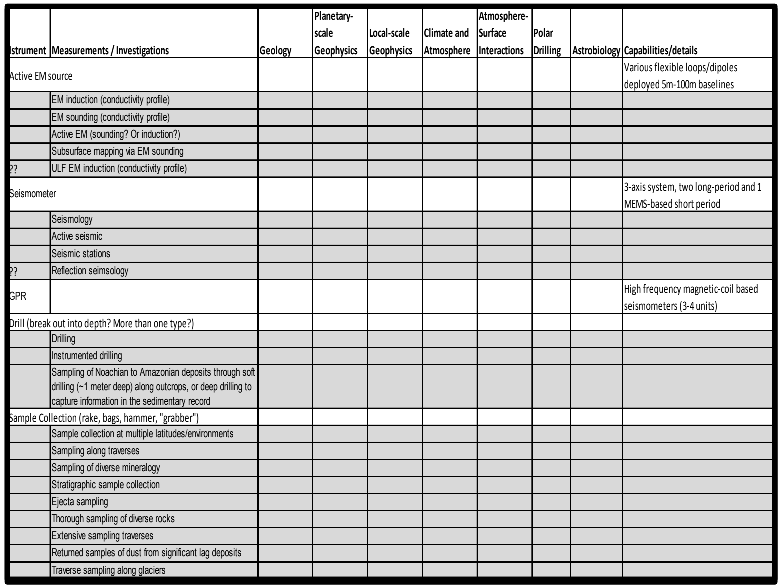
- ***Generalized Conclusions*** **= Essential for any science-driven program of human exploration**
    - ○ Humans must have equipment to conduct analyses so they can iterate to perform well-adapted science to what they discover as they go
    - ○ HEM missions to Mars are not Apollo-like (less rush, more time to think and adapt)
    - ○ Careful consideration of contamination control and isolation for astrobiology-relevant samples is essential to prevent a “false positives”
    - ○ There are HEM mission science precursors that would enable better, smarter, and less costly science that need to be developed
    - ○ Deep Drilling and long-range pressurized mobility are essential for science-driven HEM missions to Mars
    - ○ Robotic assistants are required on field traverses and short-lived monitoring assets
    - ○ There may be programmatic reasons for a sustained, stable Mars Exploration Program with related research and analysis, field analogues, etc. to keep HEM missions on track for the 2030s after an era of Human Lunar Exploration (‘20s)
    - ○ The public must be engaged in the scientific exploration of Mars by humans! EPO strategy leading to humans on Mars (HEM missions) must start now

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

EPO = Education & Public Outreach

Mars Surface Science Activities Workbook

- **Approach**
  - — MEPAG HEM-SAG investigations were identified + cross referenced between disciplines
  - — Key information about each investigation (e.g. samples, drilling, location, number or repetitions, sample return, etc.) was identified
  - — Investigations were mapped to instruments and equipment needed
  - — Mass, power, and volume estimates are being collected
- **Science Disciplines Considered, Organized by “Approaches”**
  - — Geology
  - — Geophysics
    - Planetary-scale
    - Regional & Local-scale
  - — Atmospheric & Climate Science
    - Atmosphere and Climate
    - Atmosphere-Surface Interactions
    - Polar Deep Drilling
  - — Astrobiology
- **Workbook Information Categories**
  - Sampling location: Fixed site, many sites
  - Drilling depth (meters)
  - Landing site proximity: Local (<10 km), Regional (>10 km)
  - Data collection approach: Stationary, traverse
  - Data collection resources: Passive, active
  - Data analysis location: In-situ surface, in-situ subsurface, surface lab, Earth lab
  - Data/sample return: Data returned, sample returned (in sealed container), sample returned (requires special environment)
  - Mission Phase 1 through Phase 6: Robot only, Crew + robot, Crew only
  - How clean
  - Data rate/frequency
  - Precursor measurements required?
  - Operational notes/recommendations



strument	Measurements / Investigations	Geology	Planetary-scale Geophysics	Local-scale Geophysics	Climate and Atmosphere	Atmosphere-Surface Interactions	Polar Drilling	Astrobiology	Capabilities/details
Active EM source									Various flexible loops/dipoles deployed 5m-100m baselines
	EM induction (conductivity profile)								
	EM sounding (conductivity profile)								
	Active EM (sounding? Or induction?)								
	Subsurface mapping via EM sounding								
??	ULF EM induction (conductivity profile)								
Seismometer									3-axis system, two long-period and 1 MEMS-based short period
	Seismology								
	Active seismic								
	Seismic stations								
??	Reflection seimsology								
GPR									High frequency magnetic-coil based seismometers (3-4 units)
Drill (break out into depth? More than one type?)									
	Drilling								
	Instrumented drilling								
	Sampling of Noachian to Amazonian deposits through soft drilling (~1 meter deep) along outcrops, or deep drilling to capture information in the sedimentary record								
Sample Collection (rake, bags, hammer, "grabber")									
	Sample collection at multiple latitudes/environments								
	Sampling along traverses								
	Sampling of diverse mineralogy								
	Stratigraphic sample collection								
	Ejecta sampling								
	Thorough sampling of diverse rocks								
	Extensive sampling traverses								
	Returned samples of dust from significant lag deposits								
	Traverse sampling along glaciers								

Key Takeaway: Discipline Experts helped us build the Mars ConOps

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

Mars Surface Science Activities Workbook

- The science disciplines for which detailed information was gathered included geology, geophysics (both planetary- and regional/local-scale), atmosphere and climate science (atmosphere and climate, atmosphere-surface interactions, and polar deep drilling, and astrobiology.
- The science discipline SMEs were asked to answer a set of specific questions regarding a number of operations categories, related to such topics as drilling, sampling, data collection and analysis, activities across mission phases, and precursor information requirements.
- Each science SME was provided the workbook with a set of detailed instructions, and they were given approximately two weeks to review and complete their science discipline information. After completion, each workbook was returned to the DOT members, who reviewed the information and identified questions and issues for discussion.
- A discussion telecon was established for each science discipline, such that the DOT members met with the science discipline SME's and discussed their MEPAG HEM-SAG information. A detailed review of the science discipline-associated sections of the workbook was carried out at this time and all identified questions and issues were addressed.
- These discussion telecon "interviews" were then transcribed and the transcribed information was provided to the DOT membership, which was then reviewed and used as a primary reference during Mars surface mission ConOps development.

REF.: MEPAG HEM-SAG (2008) *Planning for the Scientific Exploration of Mars by Humans*.

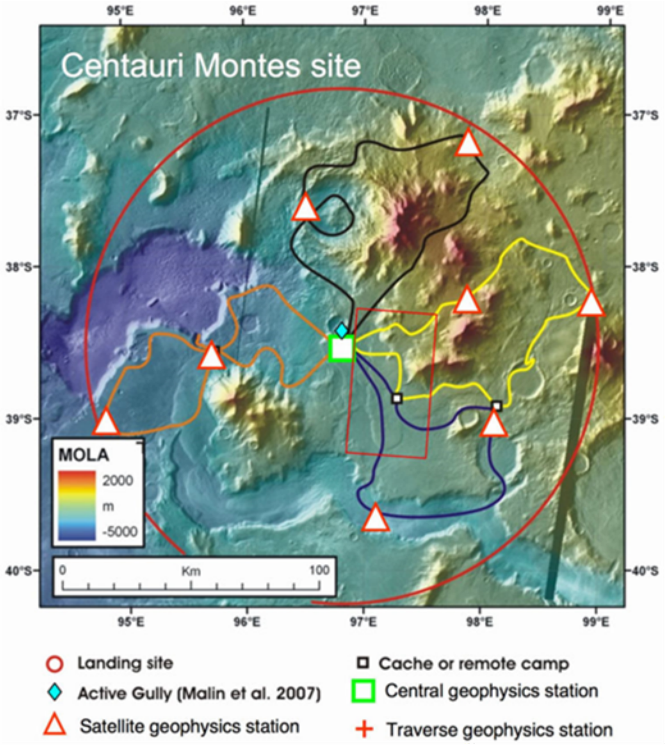
Section 6 – Destination Concept of Operations Outline

- Objectives & Approach
- Groundrules & Assumptions
- Crewed Mission Phases
- Detailed ConOps by Phase
- CRADLE Crew Activities Model

ConOps Development Objectives

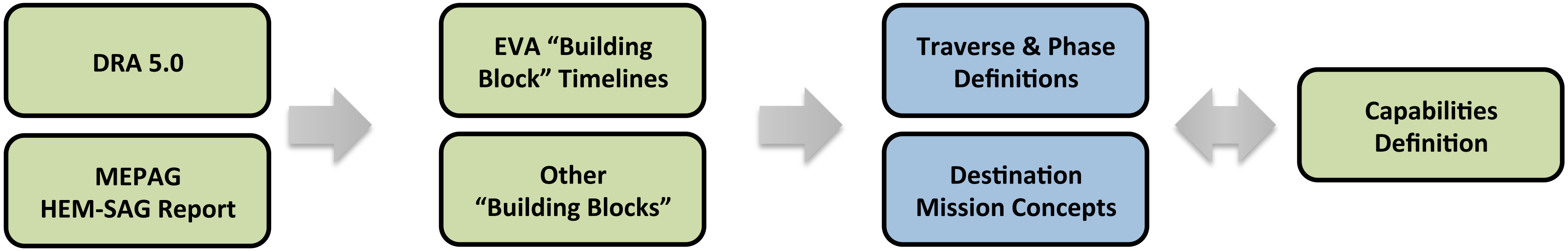
***Goal*: Develop representative surface operations for a DRA 5.0-like crewed mission to Mars in order to understand the capabilities, assets, and equipment needed to increase fidelity of architecture assessments.**

- **Understand Mission Objectives and Constraints**
  - Use DRA 5.0 and HEM-SAG report as a starting point
  - Integrate with Objectives team to understand additional objectives
  - Work with NASA Planetary Protection Officer to develop potential crewed operations that follow planetary protection protocols
- **Develop Operations**
  - Use HEM-SAG sites and proposed traverses
  - Develop high level time based on desired exploration and science activities in each mission phase
  - Identify vignettes to look at in more detail (e.g. deep drilling, maintenance, sample collection from uncharacterized locations, asset deployment, etc.)
  - Work with EVA, Science, and Planetary Protection communities throughout the process to ensure operations are viable and meet objectives



Potential traverses for human exploration

Deterministic ConOps Development Approach



DRA 5.0

MEPAG HEM-SAG Report

EVA "Building Block" Timelines

Other "Building Blocks"

Traverse & Phase Definitions

Destination Mission Concepts

Capabilities Definition

"Doing Our Homework"
- Science Activities Workbook
- Expert Briefings
- Educational Forum
- Special Studies

Objective activities / payloads converted into building blocks. Single building block could map to multiple objectives and payloads. EVA building blocks included detailed EVA timelines.

Mission timelines developed, constraining total surface mission time and defining capabilities needed.

Results

- **A representative ConOps, driven by realistic science and engineering activities and constraints, that is traceable to objectives**
- **Supporting detail for the operations that provides a flexible foundation for updating the ConOps if objectives, constraints, and/or mission parameters change in the future**
- **Justification for capability needs and preliminary performance metrics**

Key Takeaway: ConOps ties requirements & capabilities together

DRM 9 Deterministic ConOps Development Approach

- The development of the ConOps followed a deterministic approach that was developed during a 2012 HAT study on a crewed Phobos and Deimos mission. The process follows an object oriented programming-like process in which smaller segments (called “building blocks”) are developed in detail and then repeated and pieced together to form larger blocks and, eventually, a mission.

- The process starts by decomposing the objectives into activities that need to be performed. For this study, that involved reviewing the DRA 5.0 and the HEM-SAG report, consulting with the science community and other subject matter experts, and performing detailed special engineering studies on topics that needed further clarification.

- Once the activities were identified, building blocks were developed that detailed the operations required for each of the identified activities. For ease of integration, the building blocks were limited to two-hour minimums which required the combination of some activities into a single building block. Based on the uncertainty of the operations required, some building blocks are more detailed than others. This is a key aspect of this process. It provides the flexibility to include as much definition as available at the time to each building block and allow for easy updates as knowledge increases. Examples of the detailed EVA building blocks can be found in Appendix A.

- After developing the building blocks, they were then laid out to form larger blocks, such as traverses; then, a combination of those larger blocks and the original building blocks were used to form the mission phases and, finally, the full mission operations.

- Following this process allowed the ConOps developers to add detail where it was needed and easily update the mission timeline as information and understanding was gained throughout the study. It produced a realistic, representative ConOps that could be traced back to objectives and constraints that can be used as justification for capability needs and element design. This method also produced a final product that can easily be updated in the future as objectives, constraints, and capabilities change. It represents one feasible ConOps but should not be viewed as the only feasible ConOps that could meet mission objectives.

Mars DRA 5.0 Surface Strategy Options

- **Multiple strategies were developed, stressing differing mixes of duration in the field, exploration range, and depth of sampling**
  - Mobile Home: Emphasis on large pressurized rovers to maximize mobility range
  - Commuter: Balance of habitation and small pressurized rover for mobility and science
  - Telecommuter: Emphasis on robotic exploration enabled by teleoperation from a local habitat
- **Mobility, including exploration at great distances from landing site, as well as sub-surface access, are key to science community**
- **In-situ consumable production of life support and EVA consumables coupled with nuclear surface power provides greatest exploration leverage**
- **Development of systems which have high reliability with minimal human interaction is key to mission success**

Mobile Home

Commuter

Telecommuter

Mars DRA 5.0 Surface Strategy Options

- As discussed elsewhere, scientific exploration of the Martian surface will rely on the ability of the crew to investigate surface features, subsurface features, and the atmosphere. Candidate sites will be selected based on (a) the best possible data available at the time of the selection, (b) the operational difficulties associated with the site, and (c) the collective merit of the science and exploration questions that can be addressed at the site. From an operational perspective, candidate surface sites are likely to have a relatively broad, relatively flat, centrally located area where the (robotic) cargo elements can land in relative safety. However, this places these systems and the crew at potentially large distances from the features that are of interest, making mobility a key capability to achieve mission goals and objectives.
- During the development of DRA 5.0, three alternative strategies were created for satisfying the desired combination of horizontal and vertical exploration. These three options, which were given the working titles of “mobile home,” “commuter,” and “telecommuter,” were constructed to focus on different approaches to accomplish these two exploration “directions.” The “mobile home” scenario assumes that surface exploration by the crew will be primarily a mobile operation. Thus, this scenario assumes no central fixed habitat but rather the use of two (for mutual support) large, capable, pressurized rovers for extended traverses that would spend between two and four weeks away from the landing site. These rovers will have space and resources allocated for on-board science experiments. The landing site is assumed to retain infrastructure elements not needed for the extended traverses (e.g., the crew ascent vehicle, a large nuclear power plant, ISRU plant, crew consumables and spares, etc.).
- In addition to the internal science experiments that are mentioned above, the pressurized rovers will also bring two small robotic rovers; two small unpressurized rovers (comparable to the Apollo Lunar Rover Vehicle/LRV) to carry EVA crews, and a drill. The two robotic rovers can be tele-operated from the pressurized rover or be given a set of instructions and allowed to carry out these instructions in an automated fashion. The unpressurized rovers will allow the EVA crews to move relatively quickly between sites within walk-back range of the pressurized rovers once the latter have stopped for extended operations at a given location. (Note that it is assumed the pressurized rovers will not be very nimble and, thus, will serve as a “base camp” from which local traverses will be staged.)

Mars DRA 5.0 Surface Strategy Options

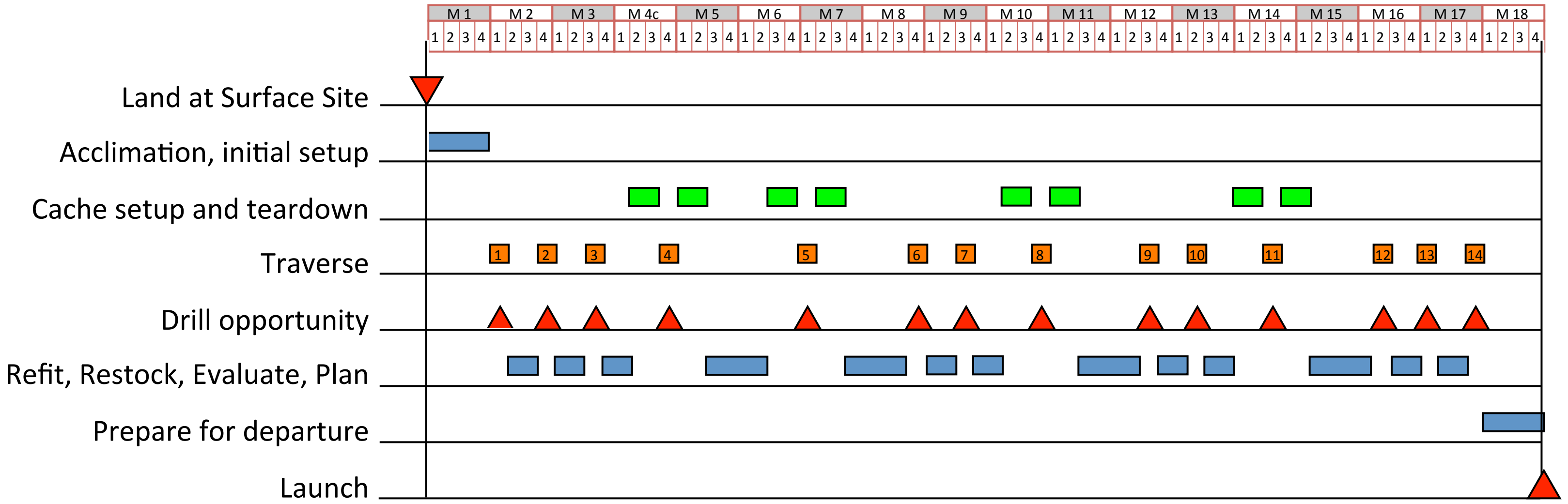
- The “commuter” surface mission scenario, which was adopted as the nominal scenario for DRA 5.0 based primarily on feedback from the HEM-SAG, assumes a centrally located, monolithic habitat, two small pressurized rovers, and two unpressurized rovers roughly equivalent to the Apollo LRV. Details of this scenario are discussed below. The last case, the “telecommuter” scenario, assumes that the crew will be based in a centrally located, monolithic habitat and that only unpressurized rovers (Apollo LRV equivalents) will be used for EVAs. This implies traverses by the crew of no more than walk-back distances (~15 km radial distance). The long-range traverses will be handled by very capable robotic rovers (notionally a considerably improved Mars Science Laboratory/MSL rover) that are tele-operated (or possibly just supervised) by the surface crew members from their habitat.

- The primary habitat will have space and resources allocated for on-board science experiments. The unpressurized rovers and EVA crews will carry only the minimal scientific equipment that is deemed essential for field work; samples will be returned to the primary habitat and its on-board laboratory for any extensive analysis. The robotic rovers will carry a more extensive suite of instruments suitable for long-range and long-duration traverses, but will have the capability to acquire and return samples to the primary habitat for further analysis and, possibly, for return to Earth. The human crew’s primary EVA job will be to set up a drill that is capable of very deep drilling (thousands of meters?), if desired, and for operating that device.

- In all three scenarios, there will be a large (assumed to be nuclear) power plant and an ISRU plant at the landing site/habitat site that will make commodities, such as O2, CH4, H2O, and ECLSS/EVA buffer gases. These systems will be operational for just over two years prior to the arrival of the crew and for the duration of the crew’s surface mission, making high reliability and minimal spares key features for mission success.

Surface Mission ConOps Option 2: "Commuter"

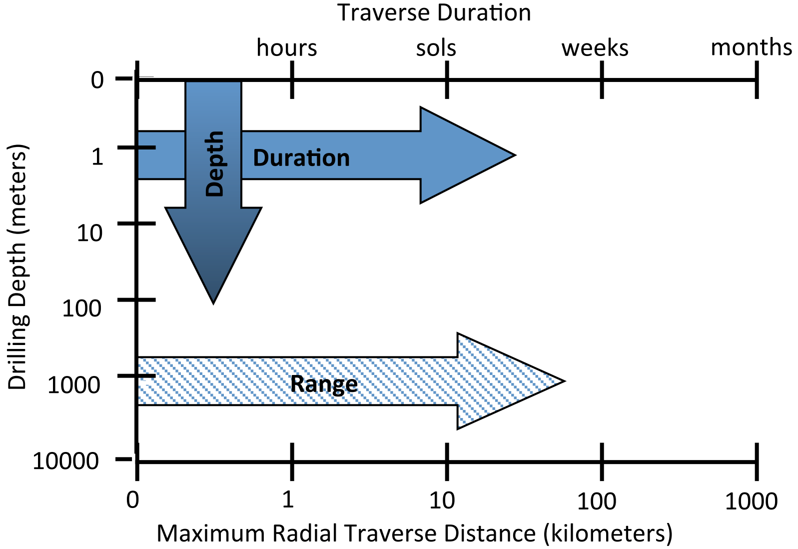
Notional Surface Mission Activities



Surface Assets

Item	Mass
Primary Habitat	15 MT (estimated)
Sm. Press. Rover x 2	6 MT (estimated)
Crew Consumables	7.5 MT (estimated)
Drill	1 MT (estimated)
Science Equipment	1 MT (allocation)
ISRU and Power Plant	2 MT (estimated)
Robotic Rovers x 2	0.5 MT (allocation)
Total	33 MT

MT = Metric Tons



Surface Mission ConOps Option 2: “Commuter”

- This description of the “Commuter” scenario is based on the assumed operations described in DRA 5.0.

- This scenario will have a centrally located, monolithic habitat and two small pressurized rovers. Traverses will not be as long as the “mobile home” scenario (notionally 100 kilometers total distance) and no more than one-week duration. Thus, on-board habitation capabilities will be minimal in these rovers. However, these rovers are assumed to be nimble enough to place the crew in close proximity to features of interest (that is, close enough to view from inside the rover or within easy EVA walking distance of the rover). Not all crew will deploy on a traverse, so there will always be some portion of the crew in residence at the habitat. The pressurized rovers will carry (or tow) equipment that will have the capability to drill to moderate depths – 100s of meters – at the terminal end of several traverses.

- The primary habitat will have space and resources allocated for on-board science experiments. The pressurized rovers will carry only minimal scientific equipment deemed essential for field work (in addition to the previously mentioned drill); samples will be returned to the primary habitat and its on-board laboratory for any extensive analysis.

Surface Mission ConOps Option 2: "Commuter"

- Long traverses will be accomplished by the pressurized rovers (or possibly robotic rovers) prepositioning supplies in caches along the proposed route of travel prior to the "full duration" traverse. Thus, a typical traverse will begin with the crew (or robotic rovers) traveling a nominal distance (approximately 15 kilometers, or EVA walk-back distance) and establishing a cache of commodities for life support and power (possibly emergency habitation) before returning to the habitat. Some amount of exploration-related activities may be accomplished, but the primary purpose is route reconnaissance and cache establishment. The crew then makes another traverse, establishing a second cache a like distance beyond the first cache. This process continues until all caches in this chain are built up sufficiently for the crew, in the two pressurized rovers, to make the entire round-trip traverse for the time duration needed to accomplish traverse objectives. The amount of time required to set up and retrieve these supply caches will depend on the specific conditions for a traverse. However, the timeline on the facing page illustrates how much can be accomplished if approximately two weeks are allocated for establishing this string of caches and another two weeks to retrieve them. In addition, not all traverses will be long enough to require this type of support. A mixture of cache-supported and unsupported traverses has been illustrated. Finally, some amount of time will be required to repair and restock the pressurized rovers after each traverse, as well as conduct any local experiments and plan for the next traverse. A notional two weeks between short traverses and four weeks between long traverses has been illustrated.

- As in Option 1, there will be an ISRU plant at the landing site/habitat site making the same kinds of commodities. The habitat will serve as the pantry and maintenance/repair facility described in Option 1.

Groundrules & Assumptions Summary

- In the process of this study, and prior to developing the POD ConOps, a Groundrules and Assumptions document was developed by the DOT. The full set of G&A's were specific to this study and were used during ConOps development.
- The G&A's developed for this study were organized into the following categories:
  - General Crew Constraints
  - General EVA Operations
  - Special Regions Operations
  - Non-Special Regions Operations
  - Science Sample Handling
  - Traverse
  - Mission Planning
  - Drilling Protocols
  - Logistics
  - Mars Surface Habitat
  - Crew Support
  - Surface Infrastructure
- The following pages highlight a few assumptions that served as *driving constraints* during the ConOps development. These assumptions were made with the assistance of EVA, mobility, and mission operations Subject Matter Experts, in order to ensure that best current practices were being followed and to provide a realistic operations estimate.

Key Groundrules & Assumptions (1 of 2)

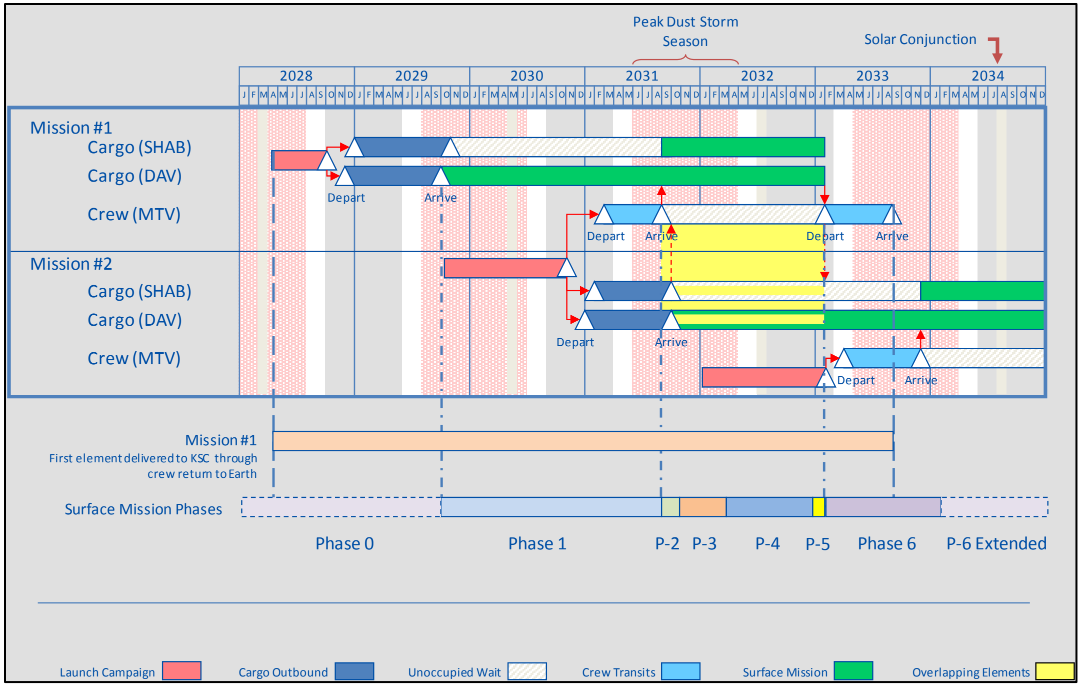
- **Crew Conditioning:** For 30 (TBR) sols after landing, crew will perform minimal physical tasks and follow TBD conditioning protocols to adjust to gravity environment. Rationale: Phase 2 planning will allow crew to adjust to Mars gravity after long duration exposure to microgravity environment during transit. This period of time is considered sufficient to encompass the majority of (anecdotally observed) recovery times for STS and ISS crews.
- **EVA Limits:** Each crew member is limited to no more than 8 hours of EVA in a 48 hour period and 24 hours [TBR] of EVA per 7 sol period with at least one full sol of rest within that same 7 sol period. Rationale: Current HAT EVA limit. The EVA project may increase this limit for consumables planning due to the ability to perform shorter, more frequent EVAs from the suitports on SEVs or from a hybrid concept on a habitat. The limit increases to greater than 24 hours for short duration missions. The capability for short, frequent EVAs also allows crewmembers to go EVA on back to back sols with a sol of rest after 24 hours of EVA.
- **Work Day:** Nominal work-day plans are no longer than 8 hours to allow for other activities (i.e. sleep, meals, exercise, maintenance, daily briefs, public engagement, etc.) This may need to be shortened for Crew acclimation phase. Rationale: Conservative assumptions to limit strenuous planning and allow for known and unknown overhead activities.

Key Groundrules & Assumptions (2 of 2)

- **Buddy System:** During all EVA activities, each EVA crew member will be able to be reached by another crew member within 45 (TBR) minutes. This could be achieved by two EVA crew members in proximity or by an IVA crew member having the ability for quick egress from habitat or rover. Rationale: Increase crew safety.
- **Pressurized Driving:** The Pressurized Rovers are assumed to be able to drive at an average rate of 20 km/h. Driving time is assumed be part of the 8 hour crew day. Rationale: Based on HAT lunar assumption.
- **Post-nominal Mission EVAs:** No nominal EVAs will be performed past the nominal surface stay and any logistics to support EVA in this time period would come out of contingency supply. Rationale: This time will be short due to launch and departure windows. It is also assumed that all nominal tasks will be completed prior to this time and any EVAs will be focused on addressing the contingency that is preventing launch.

Mission Phases for Notional DRM 5/DRM 9-based Mars Exploration

- **Phase 0 – Prior to Cargo Landing**
  - Observations and investigations of the landing site by previously deployed orbital and surface assets
  - Characterize habitability, including potential special regions
- **Phase 1 – Post Cargo Landing (~2.25 Years)**
  - Cargo Landing
  - FSPS and ISRU deployment
  - Exploration by robotic assets, micro-climate monitoring
  - Final crewed landing site selection
- **Phase 2 – Crew Landing & Acclimation (~30 Sols)**
  - Crew Landing and acclimation to Mars gravity environment
  - Additional deployment of assets and local science investigations as time and capabilities permit
- **Phase 3 – Local Exploration (~30 Sols)**
  - EVAs within local area (~10 km) to set up central stations and complete initial science objectives
  - Deployment of Deep drill system
- **Phase 4 – Regional Exploration (~410 Sols)**
  - Up to 19 separate 15-sol traverses with 2 SPRs
  - Mobility extends up to ~200 km from landing site
  - Sample analysis and follow-on local investigations continue
- **Phase 5 – Preparation for Ascent (~30 Sols)**
  - Final curation of samples and preparation of MAV
  - Crewed Launch with contingency window
- **Phase 6 – Post Crew Departure**
  - Robotic assets continue exploration



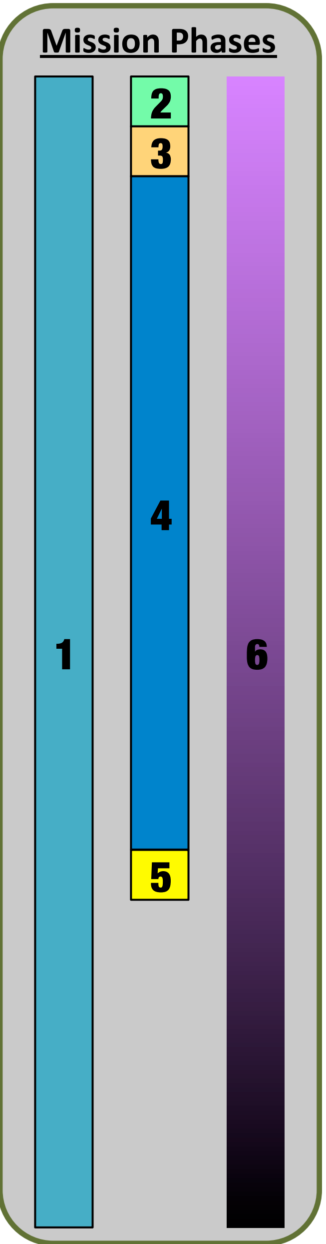
The figure above illustrates the relative sequence of each phase with trajectory data for a Mars surface mission set to occur in the early 2030 time frame.

Mission Phases for Notional DRA 5.0-/DRM 9-based Mars Exploration

- Previous sections have discussed the types of scientific investigations thought to be necessary at each of the landing sites that will be visited by human crews. In addition to these investigations and their associated hardware systems, certain infrastructure elements necessary to complete the surface mission must also be delivered. All of these elements – science and infrastructure – will be delivered on one of two landers assumed in DRA 5.0. Each of these landers will deliver a primary payload – the first delivers the ascent vehicle for the crew along with the ISRU plant and power plant, the second delivers the surface habitat – there will be additional payload capacity for other surface elements in each lander’s manifest. To help determine which of the remaining surface elements should be manifested on each of the cargo landers, the surface mission was divided into a series of phases divided by key mission milestones.

- The upper portion of the diagram illustrates a notional timeline for the first two of the three missions assumed in DRA 5.0 if the first human crew lands on Mars in the early 2030’s. The lower portion of the diagram illustrates a six-phase surface mission that begins with the arrival of the first cargo lander at the designated landing site. A phase zero was also added to capture necessary planning activities prior to the arrival of the first cargo mission. Key events and approximate durations for each of these surface mission phases are also shown here. The following pages describe each of these surface mission phases in more detail.

Notional Phase 0 Definition: Prior to Cargo Landing



Phase 0 Activities

- (High science value location already selected by the yet to be created Mars Landing Site Selection Board)
- Identify potential deep drill sites
- Identify potential crewed landing sites
  - Cargo lander within 1 km of crewed site
- Identify cargo landing site
  - Potential FSPS sites
  - ISRU location
- Identify potential "Special Regions"
- Identify potential deep drill sites- remove
- Map preliminary traverse routes
- Identify potential sites for central scientific station(s) deployment
- Deploy orbital communications relay in areostationary orbit
  - Consider other orbiting assets that could potentially help with navigation and communications?

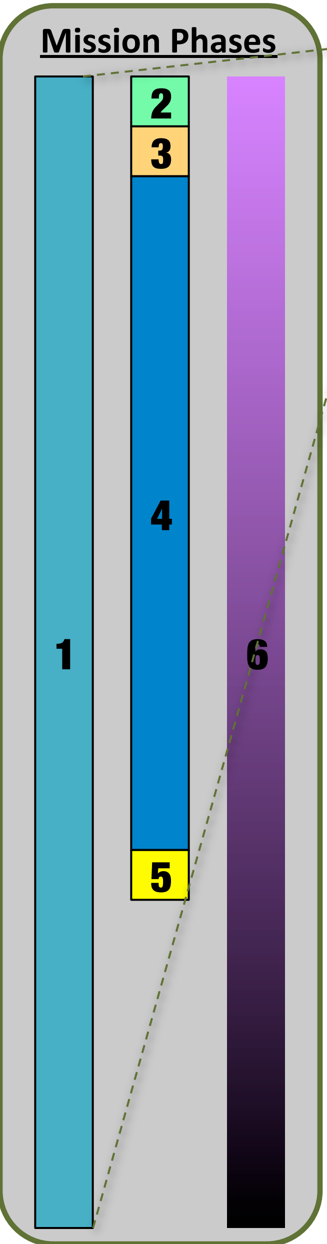
FSPS = Fission Surface Power System
ISRU = In-Situ Resource Utilization

Notional Phase 0 Definition: Prior to Cargo Landing

- **Phase (0)** This phase begins after the site has been selected by the yet to be created Mars Landing Site Selection Board and ends when the first cargo lander arrives. The selection of this site will be based on a set of scientific questions, and investigations designed to address these questions, that will be more compelling than those associated with other proposed sites. These site-selection-driving questions and investigations will form the basis of a site exploration plan that will guide the selection of specific instruments, plans for the emplacement or usage of these instruments, and identification of surface features that will become the target of surface traverses and subsurface investigations (by means of drilling, ground penetrating radar, and other exploration techniques). Activities during this phase will include at least the use of remote assets (e.g., sensors on orbiting spacecraft that could include imagery, altimetry, radar, other multi-spectral instruments, etc.) or surface assets if a previous landed mission has been sent to this site (not necessarily a prerequisite for site selection) to improve the knowledge of the site and facilitate planning for the activities carried out during the surface mission.
- **Key Assumptions**
  - Appropriate data sets to complete the Phase (0) Required Mission Events exist, or
  - Robotic spacecraft are in orbit at Mars that can be tasked to gather appropriate data sets to complete the required Phase (0) Required Mission Events
- **Required Mission Events**
  - Prepare a "Site Exploration Plan," documenting science investigations to be accomplished, sites identified to support these science investigations, (preliminary?) traverse routes and objectives to be accomplished along these routes, etc.
  - Prepare a landing site plan, indicating (a) key terrain features to be used by the lander guidance and hazard avoidance system (i.e., features to avoid or to use as guidance landmarks), (b) primary (and backup?) landing sites for the first and second landers, (c) primary (and backup?) sites for the surface power system (selected to be within the range of the power cable between the power system and the first lander, as well as for useful features that can mask the inhabited areas of the landing site from radiation, etc.)
  - Conduct a TBD assessment (robotic precursor activity? part of the site selection process?) indicating that this site is not a "special region" as defined by planetary protection policy
  - Gather local weather data and identify potential locations for MET station deployment
- **Possible / Optional Mission Events**
  - None at this time

MET = Meteorology Station

Notional Phase 1 Definition: Post-Cargo Landing



Phase 1 Activities (~ 2.25 years)

- **Post landing safing of propulsion systems**
- **Verify and test of payload unloading system**
- **Deploy PUP and PUP array**
  - Provides keep alive power to cargo lander prior to FSPS start up
  - Provides initial charging and recharging for FSPS mobility system
- **Deploy FSPS mobility system**
- **Charge FSPS mobility system**
- **Scouting of potential FSPS sites and final selection (~1 sol)**
- **Offload, move, deploy, and start up FSPS, including cable runs**
  - FSPS deployment and operation is a required activity
- **Start ISRU plant**
- **Produce, deliver, and store MAV propellant**
- **Scout potential crewed landing sites and make final selection**
- **Deploy mobile environmental monitoring stations at notional crewed landing site**
- **Initial scouting of deep drilling location**
- **Site/traverse scouting, mapping, and initial exploration**
  - Are there any initial surface sampling or measurements that need to be made prior to crew arrival?
  - Any science system checkout?

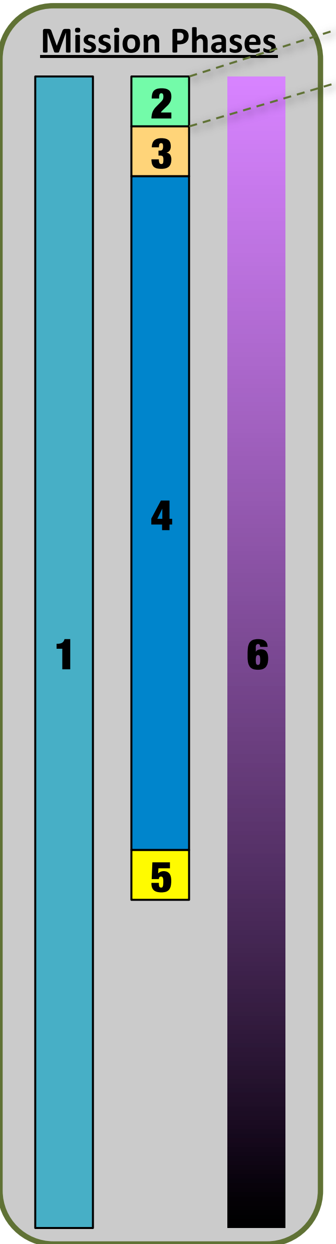
PUP = Portable Utility Pallet
ISRU = In-Situ Resource Utilization
MAV = Mars Ascent Vehicle

Notional Phase 1 Definition: Post-Cargo Landing

- **Phase (1)** This phase begins when the first cargo lander arrives at the mission's surface location and starts activities, such as setting up the (mission critical) surface power reactor and ISRU plant to make LOX. This phase ends with the arrival of the crew. At this point in the mission there are no humans present at the landing site, but elements are active and remote operations of some/all of these landed elements by people on Earth will be possible. The surface site will also be uncontaminated by the presence of a human crew (this assumes all elements on this first cargo lander are sterilized per planetary protection protocols) at this point, so any "before humans" data or samples will need to be collected during this phase. There are likely to be some science investigations that can or should be started (and completed?) during this phase (e.g., robotic field reconnaissance of specific sites of interest or emplacing a weather station so that the local "micro-climate" and weather can be monitored and modeled – to facilitate EDL by the crew in addition to purely scientific objectives).
- **Key Assumptions**
  - Robotic assets from Phase 0 (if used) and Phase 1 deployed assets are sterile and will not provide "human" contamination
- **Required Mission Events**
  - Autonomous landing
  - Determine distance of the actual landing site from the planned site and from planned surface power system sites; update landing site plan accordingly
  - Deploy and activate the communication system
  - Off-load the surface power system from the lander and move it to its operational site
  - Deploy and connect the power cable from the surface power system to the lander
  - Activate, check out and begin operations of the ISRU plant
- **Possible / Optional Mission Events**
  - Reconnaissance of candidate surface power system sites to ensure that site properties are satisfactory for the power system (e.g., is the path from the lander to the site free of hazards or obstacles?; is the soil bearing strength at the operational site for the power system consistent with the power system's design specifications?)
  - Set up one or more meteorological monitoring stations and gather local weather data
  - Survey the landing site (i.e., confirm previous assessments indicating this landing site is not a "special region", meets conditions for astronaut safety)
  - Survey the landing site for evidence of extinct or extant life signs (i.e., confirm previous assessments indicating this landing site is not a "special region")
  - Reconnaissance of planned traverse routes and science investigation sites (as specified in the "Site Exploration Plan") that are within the range of robotic rovers
  - Deploy the "special regions" robotic rover to the first (as specified in the "Site Exploration Plan") candidate special region
  - Deploy the sterilizable robotic rover to the first (as specified in the "Site Exploration Plan") exploration site/candidate special region

LOX = Liquid Oxygen

Notional Phase 2 Definition: Crew Acclimation



Phase 2 Activities (~ 30 sols [TBR])

- Crewed landing
- No nominal EVA activities
- Crew exercise and acclimation activities
- Medical life science tests (baseline and on-going)
- Connect newly delivered surface assets to pre-existing power grid
  - Assumed to be telerobotic
- Check out habitation systems
- Check out science systems
- Final outfitting and setup of habitation/lab equipment
- Check out and deploy initial surface systems (performed IVA)
  - EVA handrails/ladders
  - Communications / Navigation systems
  - Etc., that can be performed IVA or telerobotically
- Perform telerobotic scouting
- Test for clearance of crew for EVAs by crew health officer

Crew acclimation time and activities are currently being studied by NASA's Human Research Program (HRP). Thirty sol allocation is a conservative recommendation to be updated in the future.

Notional Phase 2 Definition: Crew Acclimation

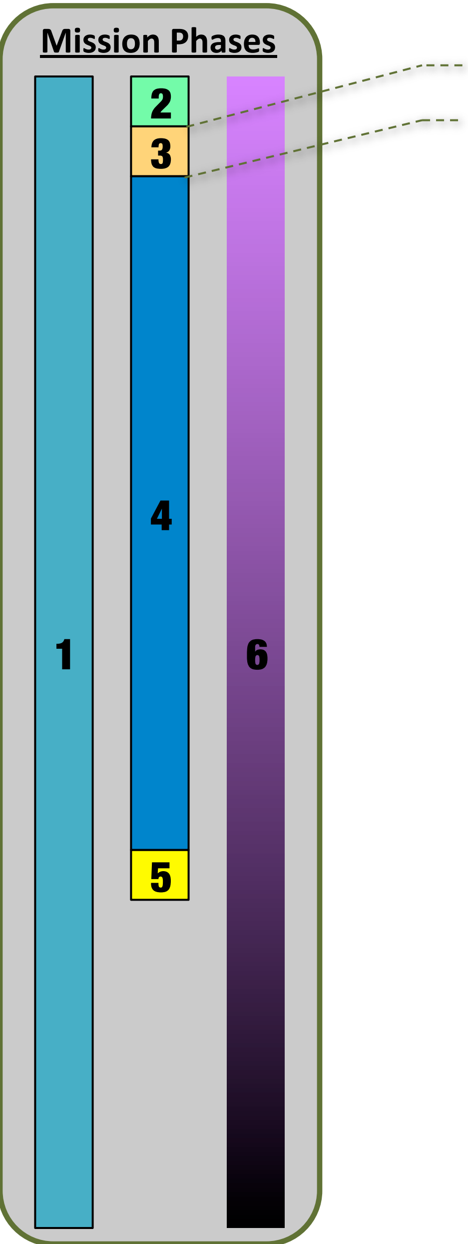
- **Phase (2)** This phase begins with the arrival of the crew at the landing site and lasts for several weeks. The crew will re-acclimate to living and working in a gravity field and will learn the differences in working in the reduced gravity field of Mars compared to Earth's gravity. Stowed systems in the habitat will be unpacked, activated, and confirmed to be operating in a mode that is satisfactory for the long surface mission. Other surface mission elements delivered on the two landers that have not been previously deployed will be unpacked, activated, and confirmed to be operating satisfactorily. Links to and interaction with any of the previously deployed scientific instruments will be established and tested as required. Scientific investigations begun in Phase (1) will continue as appropriate. Crew activities (including limited EVAs) to support scientific investigations will be added as crew re-acclimation allows and as crew involvement with the deployment and activation of surface systems necessary for the surface mission is completed.

- **Key Assumptions**
  - FSPS was deployed successfully and confirmed to be working prior to crew descent
  - ISRU was deployed successfully and confirmed to have produced enough propellant and filled the MAV prior to crew descent

- **Required Mission Events**
  - Autonomous landing
  - Connect habitat to surface power system deployed from the first lander
  - As required, deploy, activate and connect habitat to backup surface power system
  - Configure habitat for nominal surface operations
  - Configure all remaining surface elements for nominal surface operations
  - Crew acclimation activities

- **Possible / Optional Mission Events**
  - Begin tele-operating robotic devices or interacting with other science payloads

Notional Phase 3 Definition: Local Exploration



Phase 3 Activities (~ 30 sols)

- Deploy central science station(s) (geophysics, atmosphere, etc.)
- Perform initial atmospheric & climate science activities
  - Initial balloon campaign
  - Initial "chemistry" campaign
  - Lab analysis to calibrate future measurements
- Test crew mobility systems
- Deploy communications tower
- Check out MAV
- Perform initial exploration and mapping of local area
  - Geologic context
  - Shallow drilling
  - Geophysics
- Select deep drill location
- Deploy deep drill system

Notional Phase 3 Definition: Local Exploration

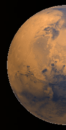
- **Phase (3)** This phase begins when (a) all surface elements have been activated and confirmed to be operating satisfactorily and (b) the crew is determined to be sufficiently re-acclimated to conduct exploration activities outside of the habitat and away from the immediate vicinity of the landing site. These exploration activities are also assumed to be limited to the "local" area around the landing site, characterized by (a) nominal time limits on a single EVA (e.g., approximately 8 hours), and (b) distances that are within "walk-back" range of the habitat (e.g., 10 – 15 kilometers). Activities during this phase will guided by "local" scientific questions and investigations described in the exploration plan, discussed in Phase 0, as well as by discoveries made in the "local" area (during the current and prior mission phases)that result in new or modified activities compared with the original exploration plan. These activities will also be guided by expanding the "operational envelope" of surface elements (e.g., rovers) and the crew.

- **Key Assumptions**
  - TBD

- **Required Mission Events**
  - Set up / deploy any science payloads not deployed during Phase (1) as described in the "Site Exploration Plan"
  - Test pressurized and unpressurized rovers for operational readiness
  - Carry out local scientific investigations and traverses as described in the "Site Exploration Plan," using tele-operations, EVA suits, unpressurized rovers, or pressurized rovers

- **Possible / Optional Mission Events**
  - tele-operate rovers further along the traverse paths to characterize environments "over the horizon" e.g. to avoid inadvertent trespass into special regions

Notional Local Exploration (Phase 3) ConOps (1 of 2)



Sol	Crew 1 & 2	Crew 3 & 4	Crew 5 & 6
1	Local EVA Exploration @ Landing Site	IVA Test/Maintain/Stock Mobility Systems	Local EVA Deploy Communications Tower
2	IVA Test/Maintain/Stock Mobility Systems	Local EVA Exploration @ Landing Site	IVA Test/Maintain/Stock Mobility Systems
3	Local EVA Deploy central science station	IVA Lab Analysis / Maintenance	Local EVA Exploration @ Landing Site
4	IVA Lab Analysis / Maintenance	Local EVA Checkout/Maintain ISRU	IVA Lab Analysis / Maintenance
5	Local EVA Test/Maintain Mars Ascent Vehicle	IVA Lab Analysis / Maintenance	Local EVA Test/Maintain Mars Ascent Vehicle
6	IVA Lab Analysis / Maintenance	Local EVA Habitat Maintenance	IVA Lab Analysis / Maintenance
7	Rest Sol	Rest Sol	Rest Sol
8	Local EVA Rover Maintenance	IVA Maintain/Stock Mobility Systems	Local EVA Rover Maintenance
9	IVA Crater Traverse Planning & Prep	IVA Crater Traverse Planning & Prep	IVA Crater Traverse Planning & Prep
10	IVA Lab Analysis / Maintenance / Mission Ops	Crater Traverse (< 10 km of Landing Site)	Crater Traverse (< 10 km of Landing Site)
11			
12			
13			
14	Rest Sol	Rest Sol	Rest Sol
15	Local EVA Rover Maintenance	IVA Lab Analysis / Maintenance	IVA Lab Analysis / Maintenance

▨ Other Ops

🟦 IVA Activities

🟩 Traverse

🟩 EVA Local

⬜ Rest Sol

IVA = Intravehicular Activity
EVA = Extravehicular Activity

Notional Local Exploration (Phase 3) ConOps (2 of 2)

Sol	Crew 1 & 2	Crew 3 & 4	Crew 5 & 6
16	IVA Lab Analysis / Maintenance	IVA Lab Analysis / Maintenance	Local EVA Rover Maintenance
17	Rest Sol	Rest Sol	Rest Sol
18	IVA Local Exploration Planning & Prep	IVA Local Exploration Planning & Prep	IVA Lab Analysis / Maintenance
19	IVA Maintain/Stock Mobility Systems	IVA Maintain/Stock Mobility Systems	
20 - 23	Local Exploration (< 10 km of Landing Site)	Local Exploration (< 10 km of Landing Site)	IVA Lab Analysis / Maintenance / Mission Ops
24	Rest Sol	Rest Sol	Rest Sol
25	IVA Deep Drill Planning & Prep	IVA Lab Analysis / Maintenance	IVA Lab Analysis / Maintenance
26	IVA Maintain/Stock Mobility Systems	IVA Lab Analysis / Maintenance	IVA Balloon Campaign Planning & Prep
27 - 29	Deploy/Test of Deep Drill	IVA Lab Analysis / Maintenance / Mission Ops	Local EVA Balloon Campaign
30	Rest Sol	Rest Sol	Rest Sol

- ▨ Other Ops
- 🟦 IVA Activities
- 🟩 Traverse
- 🟩 EVA Local
- ⬜ Rest Sol

IVA = Intravehicular Activity
EVA = Extravehicular Activity

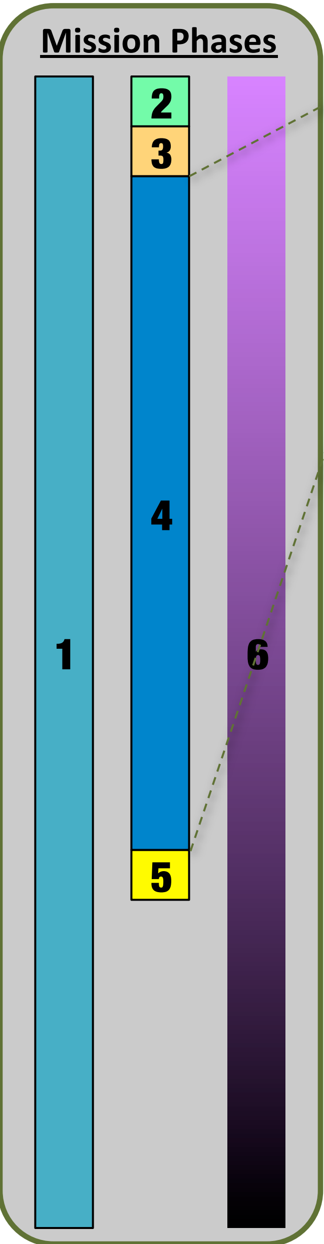
Key Activities Building Block Definitions

- Building Blocks Definition: A detailed operations segment that captures one or more activities that is treated as fundamental unit for building larger ConOps segments, such as EVAs and traverses. A detailed description of the EVA Building Blocks is provided in Appendix A.
- Local Exploration: EVA exploration of the landing site which is assumed to be scientifically interesting location that can provide context for the rest of the mission.
- Crater Traverse: For the Centauri Montes site, the HEM-SAG report identified a short traverse near the landing site that would explore a crater rim on which signs of liquid water have been observed. This short traverse would involve shallow drilling, deployment of geophysics instruments (e.g. geophones, sounders, etc.) to verify and locate a subsurface water source (e.g., aquifer). The results of this traverse would help identify the deep drill location for Centauri Montes. This would not be a part of Phase 3 operations for other locations and would be replaced by more local exploration and deep drill location identification.
- Deep drill deployment: Once the drill site has been determined, two crew will traverse to the drill site while towing or carrying the drill equipment (with the rover). The crew will stay at the drill site and live in the rover for 3 sols during the deployment.
- First balloon campaign: The balloon campaigns perform atmospheric & climate science studies using tethered and un-tethered balloons that need to be deployed periodically throughout the mission. The deployment time and operations were outlined in the HEM-SAG report and summarized in the Appendix with the Atmospheric & Climate Science information.
- IVA lab analysis and maintenance: The remainder of the time is allotted to IVA maintenance and lab analysis. These activities will occur on as an as needed basis, so they were combined into a single building block.

Post-Analysis Observations of Phase 3 Key Activities

- **Test and maintain the rovers. One rover was delivered on the cargo lander and has been on the surface ~2.5 years performing some short range scouting. The other was delivered with the crew.**
    - 14 IVA crew-days, includes maintenance required from previous surface time and short Phase 3 traverses, outfitting and traverse switch-out activities, and contingency following accepted HAT maintenance assumptions.
    - 8 EVA crew-days of maintenance required from previous surface time and short Phase 3 traverses following accepted HAT maintenance assumptions.
- **EVA maintenance that couldn’t be performed in Phase 2: MAV and Habitat**
- **EVA deployment of surface assets: Communications Tower & Central Science Station**

Representative Notional Phase Definition:
Phase 4 – Regional Exploration



Phase 4 Activities (~ 410 sols)

- **Traverses**
- **Balloon and chemistry campaigns**
- **Lab analysis and sample curation**

- Over the course of Phase 4, four different paths are traversed. Each traverse involves two pressurized rovers, each rover carrying two crew.
- An *initial characterization* (recon) traverse is completed for each traverse path with nine other 15-sol traverses available for more in-depth investigations.
- *Follow-on traverses* are planned and finalized after all initial traverses are complete.
  - *Geophysics* focused
  - *Shallow-drilling* focused

SUMMARY

- Traverse 1: Route Characterization (23 sites, 2 hours each)
- Potential Follow-on #1:
  - In-Depth Investigations
  - Geophysics-focused (6 sites, 8 hours each)
- Potential Follow-on #2:
  - In-Depth Investigations
  - Shallow drilling-focused (3 sites, 16 hours each)

Representative Notional Phase Definition: Phase 4 – Regional Exploration

- **Phase (4)** This phase begins when all local science equipment required for Phases (2) and (3) have been deployed, required Phases (2) and (3) science investigations have been completed, and it has been determined that sufficient experience with surface elements and by the crew is sufficient to allow exploration activities in the "regional" area around the landing site, characterized by (a) total time away from the habitat greater than that of a single EVA (e.g., greater than approximately 8 hours), and (b) distances that are greater than the nominal "walk-back" range to the habitat (e.g., greater than approximately 10 – 15 kilometers). Activities during this phase will be guided by "regional" scientific questions and investigations described in the exploration plan, discussed in Phase 0, and by discoveries made in the current and previous mission phases, as well as in the "regional" area that result in new or modified activities compared with the original exploration plan. Between long regional excursions there may be extended periods of time spent at the landing site conducting a variety of activities, such as: (a) analyzing samples collected along a traverse, (b) conducing follow-on local investigations based on previous investigations and Earth-based science support team recommendations, (c) performing routine maintenance of surface elements, (d) conducting science investigations that need multiple dispersed (in time and location) measurements, and (e) planning for future activities (in particular, traverses).

- **Key Assumptions**
  - Pressurized rovers traverse in a manner such that one may rescue the other in a contingency scenario

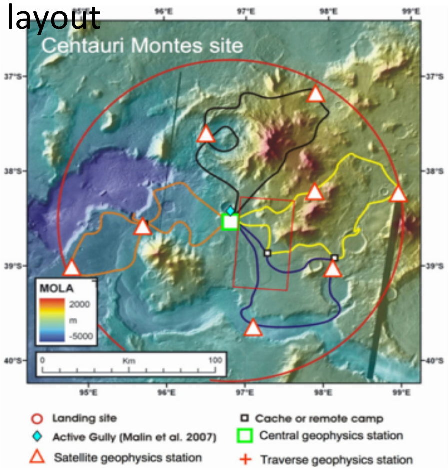
- **Required Mission Events**
  - Continue to conduct scientific investigations from Phase (1), as necessary
  - Carry out regional scientific investigations and traverses as described in the "Site Exploration Plan," using tele-operations, EVA suits, unpressurized rovers, or pressurized rovers

- **Possible / Optional Mission Events**
  - TBD

Traverse Planning

- **Initial Recon Traverse**
  - Objective
    - Drive the entire traverse route
    - Collect initial context samples and imagery for general route characterization
    - Deploy MET stations
  - Methodology
    - Drive between sites while collecting imagery and other rover-mounted measurements
    - 2 hour (TBR) short stop EVAs to collect samples, perform targeted imagery and spectrometry, and deploy MET stations
    - Actual drive times and number of EVA sites is TBD
    - The following shows the maximum number of EVAs based on EVA constraints
      - 15 sols
      - 23 x 2-hour EVAs
      - 4 MET station deployments
      - ~300 km traversed

- **Follow On Traverses**
  - “Flexecution”
    - Flexible execution: Hypothesis-driven objectives and mission plans are defined, but are subject to continual modification throughout the mission as warranted by samples and information gathered
  - Follow on traverses will be defined based on the finding of the initial recon traverses
  - Multiple example traverses were defined in order to understand EVA times and possible equipment needs
    - Two samples follow the Recon traverse layout



Potential Centauri Montes traverses (from MEPAG HEM-SAG)

Traverse Planning

- For each of the representative landing sites identified in the HEM-SAG report, several (4 to 5) traverse loops were proposed. The distance along these loops ranged from a few 10's of kilometers to several hundred kilometers. The diagram on the facing page illustrates four long-range traverses suggested for the Centauri Montes site. In the HEM-SAG report, several specific investigations were identified that could be made on these long-range traverses (e.g., emplacing satellite geophysical stations) but otherwise, activities were discussed that could occur anywhere along each traverse route, depending on conditions found or features observed.
- A strategy to explore these routes was proposed to allow estimates of the number of traverses, time spent performing EVAs, etc. to be developed. The first step in this strategy was for the crews to conduct a "reconnaissance" traverse along the entire length of each long-range traverse route to identify interesting locations or features for subsequent detailed exploration. Thus only short duration (approximately two hours in length) stops would be made at these interesting locations for limited activities, such as (a) emplacing satellite geophysical stations or meteorological stations, or (b) gathering a limited number of images and samples (e.g., to help inform sites to which the crew should return for detailed investigations). The number of short stops that could be made was limited by the total distance of the traverse loop and the driving speed of the rovers. For one of the example routes at the Centauri Montes site, 23 sites could be investigated along a loop of approximately 300 kilometers' distance.
- After all long-range traverse routes had been "mapped" in this reconnaissance mode, sites designated for detailed exploration would be prioritized and as many as possible would be carried out during the remainder of the surface mission. This phase of the exploration traverse was dubbed "flexicution," indicating a phase during which original mission objectives and hypotheses would guide subsequent traverses and the duration spent at specific sites. But the specific activities associated with these subsequent traverses would be subject to continual modification based on data and knowledge gained during previous traverses and investigations. Several examples of these more detailed traverses were developed, again to help estimate the amount of EVA time that was available, activities to perform, etc.
- The following pages illustrate details associated with the reconnaissance traverse and two examples of detailed traverses.

Initial Recon Traverse: Route Characterization

23 Sites, 2 Hours EVA at each site

Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6	Sol 7	Sol 8
Traverse	EVA Local Site Sweep: (MET Install)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	Rest Sol	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)
Traverse	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization
Traverse	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (MET Install)	Rest Sol	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)
Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization

Sol 9	Sol 10	Sol 11	Sol 12	Sol 13	Sol 14	Sol 15
EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	Rest Sol	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (MET Install)
Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse
EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (MET Install)	Rest Sol	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	EVA Local Site Sweep: (Spectrometer)	Traverse
Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse

▨ Other Ops
🟩 Traverse
⬜ Rest Sol
🟦 IVA Activities
🟩 EVA Local

In-Depth Investigations: Geophysics Focus

6 Sites, 8 Hours Each

Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6	Sol 7	Sol 8
Traverse	EVA Wrap	IVA Characterization	EVA Wrap	IVA Characterization	Rest Sol	EVA Wrap	IVA Characterization
Traverse	EVA Local Seismometry	Traverse	EVA Local Seismometry	Traverse	Rest Sol	EVA Local Seismometry	Traverse
Traverse	EVA Local Surface Sampling	Traverse	EVA Local Surface Sampling	Traverse	Rest Sol	EVA Local Surface Sampling	Traverse
IVA Characterization	EVA Local Surface Measurements	IVA Characterization	EVA Local Surface Measurements	IVA Characterization	Rest Sol	EVA Local Surface Measurements	IVA Characterization

Sol 9	Sol 10	Sol 11	Sol 12	Sol 13	Sol 14	Sol 15
EVA Wrap	IVA Characterization	Rest Sol	EVA Wrap	IVA Characterization	EVA Wrap	IVA Characterization
EVA Local Seismometry	Traverse	Rest Sol	EVA Local Seismometry	Traverse	EVA Local Seismometry	Traverse
EVA Local Surface Sampling	Traverse	Rest Sol	EVA Local Surface Sampling	Traverse	EVA Local Surface Sampling	Traverse
EVA Local Surface Measurements	IVA Characterization	Rest Sol	EVA Local Surface Measurements	IVA Characterization	EVA Local Surface Measurements	Traverse

▨ Other Ops
🟦 IVA Activities
🟩 Traverse
🟩 EVA Local
⬜ Rest Sol

In-Depth Investigations: Shallow Drilling Focus

3 Sites, 16 Hours Each

Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6	Sol 7	Sol 8
Traverse	EVA Wrap	Rest Sol	EVA Wrap	IVA Characterization	Traverse	EVA Wrap	Rest Sol
Traverse	EVA Local Seismometry	Rest Sol	EVA Local Surface Measurements	Traverse	Traverse	EVA Local Seismometry	Rest Sol
IVA Characterization	EVA Local Set-up Drill	Rest Sol	EVA Local Target of Opportunity	Traverse	IVA Characterization	EVA Local Set-up Drill	Rest Sol
IVA Characterization	EVA Local Surface Sampling	Rest Sol	EVA Local Retrieve Drill and sample	Traverse	IVA Characterization	EVA Local Surface Sampling	Rest Sol

Sol 9	Sol 10	Sol 11	Sol 12	Sol 13	Sol 14	Sol 15
EVA Wrap	IVA Characterization	Traverse	EVA Wrap	Rest Sol	EVA Wrap	IVA Characterization
EVA Local Surface Measurements	Traverse	Traverse	EVA Local Seismometry	Rest Sol	EVA Local Surface Measurements	Traverse
EVA Local Target of Opportunity	Traverse	IVA Characterization	EVA Local Set-up Drill	Rest Sol	EVA Local Target of Opportunity	Traverse
EVA Local Retrieve Drill and sample	Traverse	IVA Characterization	EVA Local Retrieve Drill and sample	Rest Sol	EVA Local Retrieve Drill	Traverse

▨	Other Ops	🟩	Traverse	⬜	Rest Sol
🟦	IVA Activities	🟩	EVA Local		

At-Habitat Activities During Surface Phases

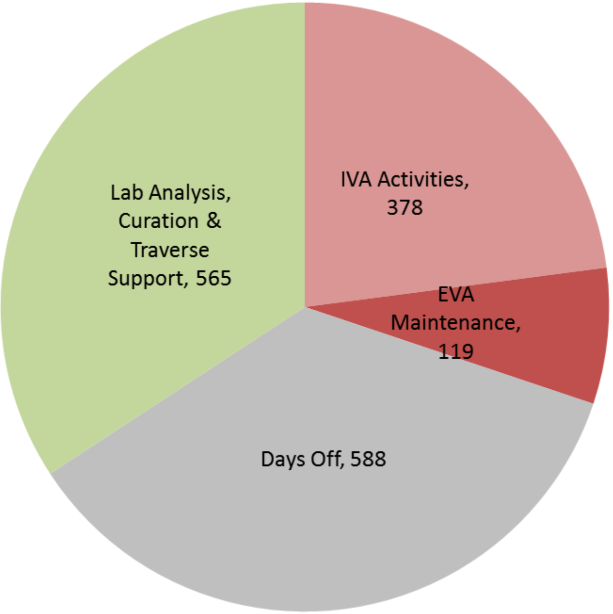
- **2 Crew at habitat during traverse**
  - Perform lab analysis and sample curation
  - Perform habitat maintenance
    - 3d printing for spare parts?
    - Requires times and specific activities
  - Perform repairs
  - Perform housekeeping
  - Monitor deep drill operations and provide occasional support, as required
  - Perform EVA suit maintenance
  - Support traverse crew
  - Check out and monitor ISRU plant/MAV cryo
    - Maybe ground monitored and use crew only in contingency
  - Conduct routine medical diagnostics
  - Conduct HRP investigations
  - Perform exercise
  - Perform telerobotic operations
  - Enhance existing infrastructure, as needed
  - Continue local exploration
- **All 6 crew at habitat between traverses**
  - Perform rover maintenance
  - Perform suit maintenance
  - Perform rover preparations
    - Unload waste, trash
    - Reload logistics & tools
    - Unload samples
  - Conduct EPO
  - Perform training
  - Support traverse debrief
    - Share results and context found
    - Discuss integrated results
  - Plan next traverse(s)
  - Perform lab analysis and sample curation
  - Perform telerobotic operations
  - Accommodate solar conjunction ConOps
    - Nominal IVA activities
    - Limited local EVA, as needed
  - Monitor and maintain local instrumentation
  - Adjust / relocate communications terminal
  - Retrieve logistics from cargo lander and transfer to habitat
  - Perform periodic checkout of MAV (same time as logistic resupply)

EPO = Education and Public Outreach

Phase 4 Summary (1 of 2)

- **Assumptions**
  - 1 week off after 3 weeks of activity
  - 15-30 sols without gathering samples at the end of Phase 4 in order to finalize analysis and curation
  - Only 4 crew on traverse at a time (at least 2 crew at habitat at all times)
  - ~2 week period where all crew are at the habitat to cover solar conjunction
- **High-level Sequence of Events**
  - 15 sol traverse
  - 3 sol balloon and chemistry campaign for Atmospheric & Climate Science
  - 7 sols of rest
  - 7 sols of analysis and traverse preparation
  - Sequence is repeated (~13 times)
- **Results**
  - 13 Traverses: 4 Recon + 9 Follow-up
  - 5 Balloon and Chemistry Campaigns (1 completed during Phase 3)
  - 1,650 crew-sols in the habitat for analysis, curation, maintenance, house keeping, planning, local exploration, etc.
  - 14 full weeks “off”
  - 28 sols after final traverse for final analysis and curation

Phase 4 Habitat Operations (crew-sols)



The figure above shows Mission Phase 4 Operations, including lab analysis, curation & traverse support (564 sols); IVA activities (378 sols); EVA maintenance (119 sols); and crew days off (588 sols).

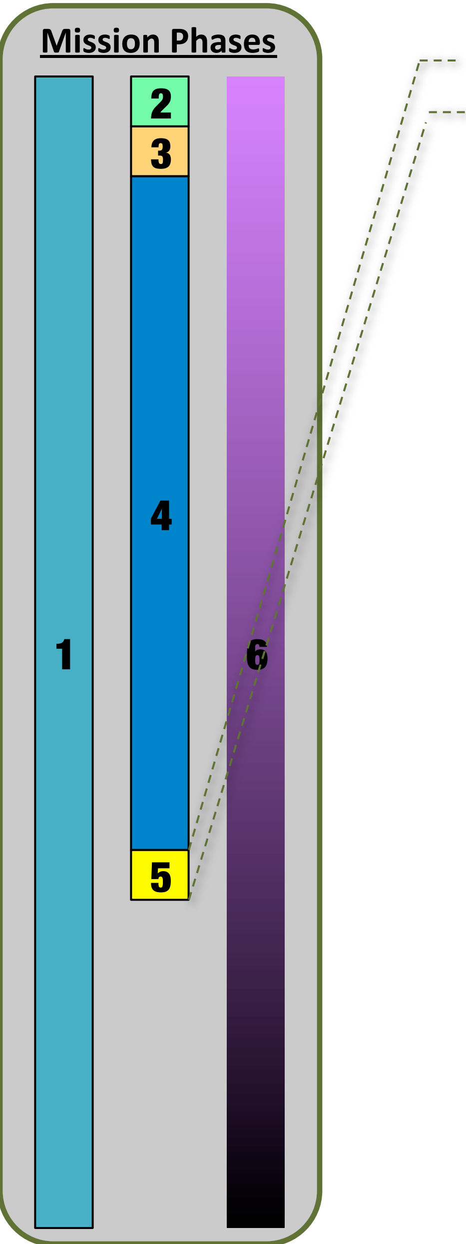
<u>Key Takeaway</u>: 500 Sol surface duration provides sufficient time to address objectives with margin

7 sols	Initial traverse preparation
15 sols	Recon Traverse 1
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Recon Traverse 2
3 sols	2nd Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Recon Traverse 3
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Recon Traverse 4
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 1
3 sols	3rd Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 2
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 3
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 4
3 sols	4th Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 6
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 7
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 8
3 sols	5th Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 9
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Traverse or further analysis
7 sols	Week off
3 sols	6th Balloon campaign
11 sols	Final analysis and curation
7 sols	Week off

Phase 4 Summary (2 of 2)

- Initial planning reveals 1,650 crew-sols of work time at the habitat during the 410-sol Phase 4.
  - Based on accepted HAT crew-time modeling, ~380 crew-sols will be required for IVA maintenance, housekeeping, and training activities and ~120 crew-sols for EVA maintenance activities.
  - Based on a conservative assumption of 588 crew-sols of rest, there are ~565 crew-sols for utilization activities that are defined above.
- If both crew that are not on excursions are required to support the traverse full-time, that could require an additional 390 crew-sols, reducing the utilization time to 198 crew-sols.

Notional Phase 5 Definition: Preparation for Ascent



Phase 5 Activities (~30 sols)

- **Final sample curation (3 crew – 7 sols)**
  - Final selection and preparation of samples to return
- **Preparation of the MAV for launch (3 crew – 7 sols)**
  - MAV power up and checkout, power down
  - Assumed multiple crewed visits
- **Transfer all samples to be returned to MAV (2 crew – 1 sol)**
- **Prepare surface assets for uncrewed operations (2 crew – 3 sols)**
  - Prepare rovers for uncrewed exploration
  - Manage trash/waste
  - Lock up and shut down habitat
- **Crew transfer to MAV**
  - Release latches
  - Remove tank insulation
  - Ingress MAV
- **Launch**
- **Contingency launch window**

Notional Phase 5 Definition: Preparation for Ascent

- **Phase (5)** This phase begins at some TBD time before the crew needs to launch and return to the MTV. This time is likely to be driven by the duration of the launch window determined to be necessary to allow for returning to the MTV and then departing from Mars orbit (estimated to be approximately 30 sols), plus the activities required to put the surface systems into the necessary state for Phase (6). These activities and the associated time needed are likely to be driven by the surface systems more than the science investigations. However, there will be some science investigations that will continue through this phase and we need to account for the time and resources needed for these activities, in addition to those we need for the crew to prepare for departure.

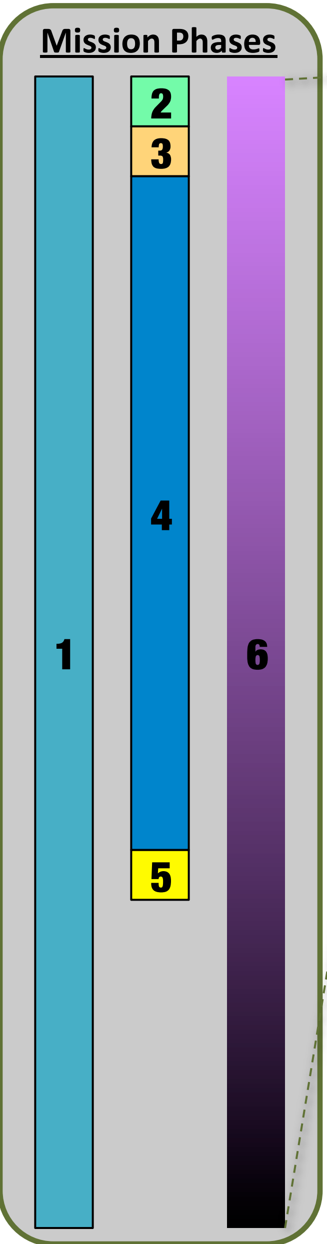
- **Key Assumptions**
  - TBD

- **Required Mission Events**
  - Physical samples to be returned to Earth are identified and packed in appropriate containers
  - Surface elements are prepared for uncrewed operation
  - Surface elements are placed in a safe state/location to protect against plume and debris during crew launch

- **Possible / Optional Mission Events**
  - TBD

MTV = Mars Transit Vehicle

Notional Phase 6 Definition: Post-Crew Departure



Mission Phases

Phase 6 Activities (~TBD sols)

- **Record ascent**
- **Continued exploration with rovers until end of life**
  - Remotely operated from Earth
  - Possibly operated by crew on return transit
- **Continued operation of deployed instruments and science stations**
- **Potential for sample caching**
- **Potential operation of sample analysis capabilities**
- **Long traverse away from landing site**
  - Relying on PUP power to use visual and spectral imagers, GPR, etc. to extend reach until end of life of rovers
- **Public/educational outreach**

GPR = Ground Penetrating Radar

Notional Phase 6 Definition: Post-Crew Departure

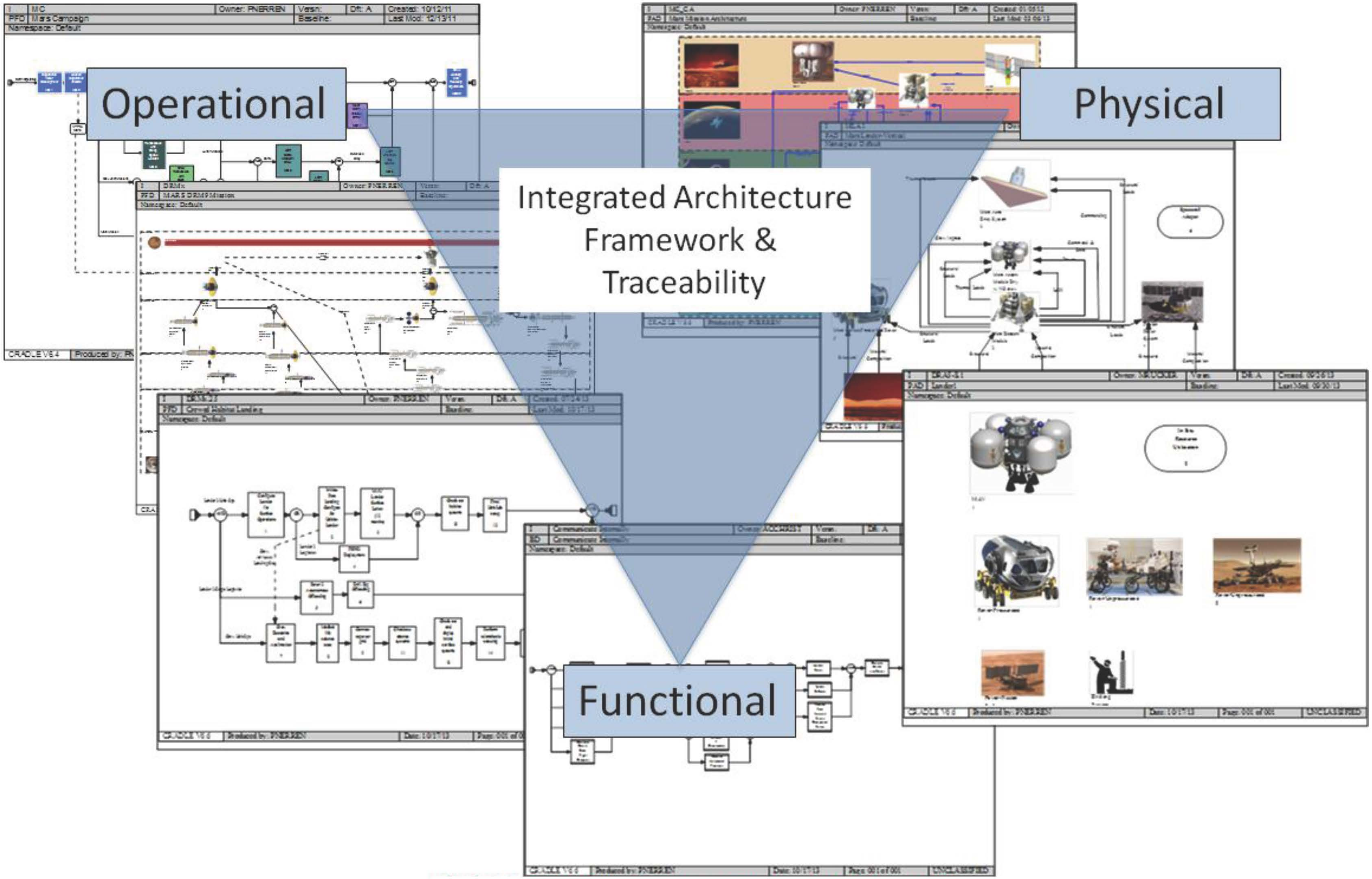
- **Phase (6)** This phase begins after the crew leaves the surface of Mars. Assuming the crew is not leaving due to some emergency, there should still be a functioning power reactor, communication system, habitat, and rovers (both robotic and crewed). There are likely to be science investigations that can/should continue after the crew departs (e.g., weather monitoring, seismic activity monitoring, tracking what happens to human contaminants at the landing site, etc.). Hence, some of the activities in Phase (5) will be associated with the crew preparing these surface elements so that these Phase (6) investigations can be carried out. Certain investigations are also likely to continue to take advantage of instruments emplaced at this site and at this time (e.g., one node in a seismic network that must be operational during the surface mission of subsequent crews in order to gather global seismic characteristics). These long-term science activities constitute what amounts to an "extended mission" phase for Phase (6).

- **Key Assumptions**
  - TBD

- **Required Mission Events**
  - TBD

- **Possible / Optional Mission Events**
  - Post-crew measurements
  - Follow-on science investigations as identified during crewed mission or by Earth-based science support team

CRADLE “Mars Crew Activities Model” Modeling Framework



The figure above shows the Operational, Physical, and Functional portions within an Integrated Architecture Framework & Traceability of a system

CRADLE = Computerized Requirements Analysis Design Logistics and Execution

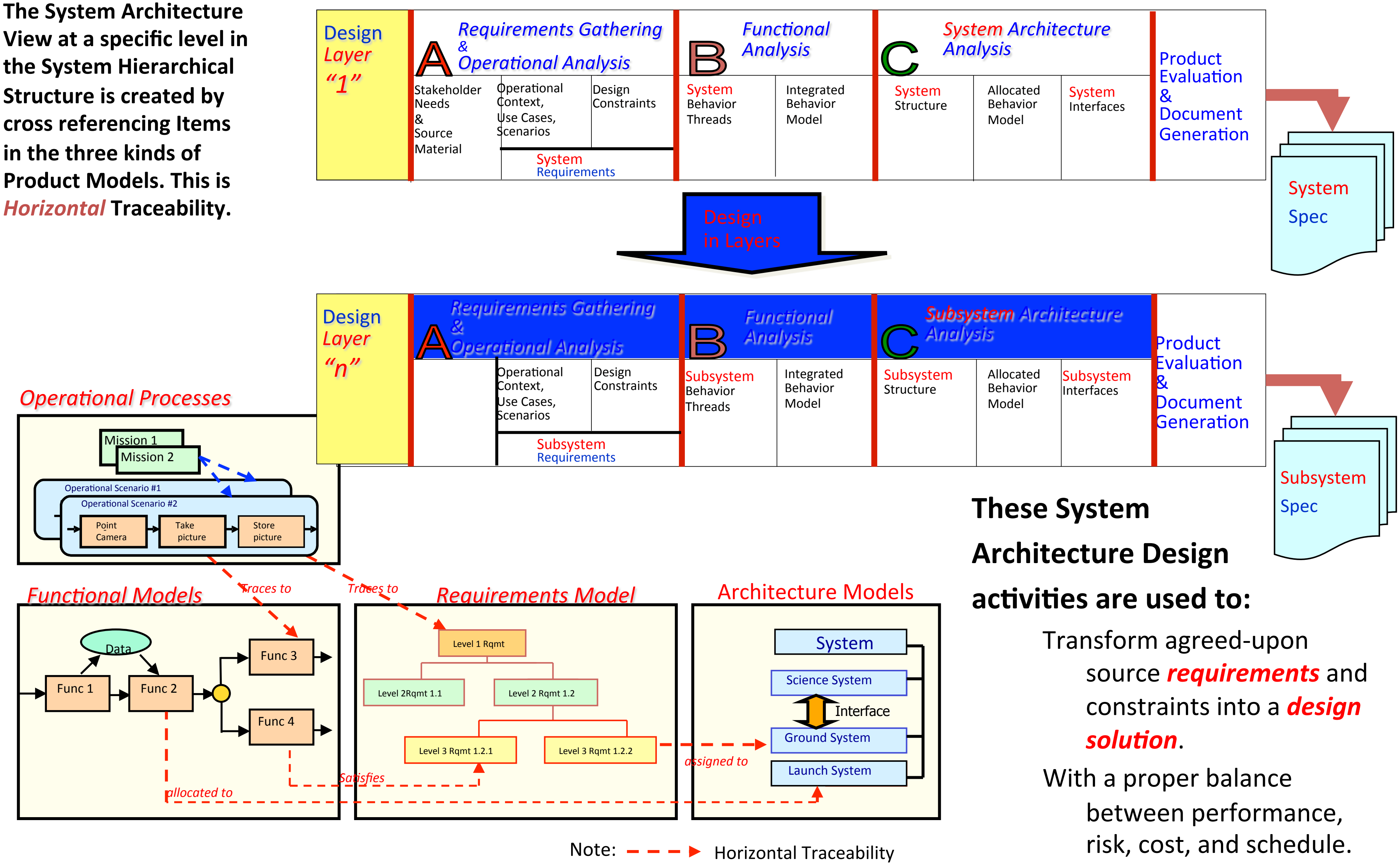
CRADLE MBSE Process

- **Objective**
  - —Establish architecture framework to provide a structured information environment for assessment and analysis
  - —Capture/define a basic modeling framework
    - Operational, functional and physical
  - —Define data schema for categorization and characterization of the framework data as well as supporting information
  - —Integrate framework content with relational cross reference schema
  - —Provide contextual reports for visibility and analysis of relational data

MBSE = Model-Based Systems Engineering

Traceability Between Models

The System Architecture View at a specific level in the System Hierarchical Structure is created by cross referencing Items in the three kinds of Product Models. This is *Horizontal* Traceability.



Note: Horizontal Traceability

These System Architecture Design activities are used to:

Transform agreed-upon source ***requirements*** and constraints into a ***design solution***.

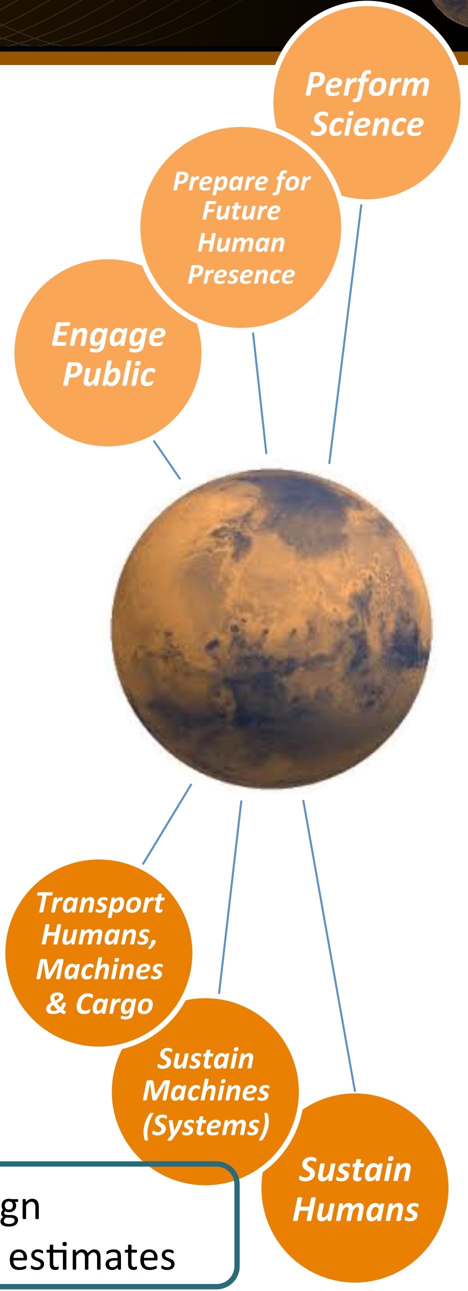
With a proper balance between performance, risk, cost, and schedule.

Section 7 – "Special Studies"

A. Functionality Analysis / Iterative Decomposition & ConOps
B. Commodity Cache Feasibility
C. Traverse Planning & Mobility
D. Sample Handling & Laboratory Strategy
E. Integrated Surface Power Strategy
F. Drilling: Shallow & Deep
G. Statistical Modeling
H. Capability & Technology Requirements

A. Functionality Analysis

- **Task: Identify potential DRA 5.0 missing functions & associated mass discrepancies**
- **Discrepancies identified so far:**
  - ↑ Potential missing mass for Science Lab/Area external to habitat (increasing mass)
  - ↓ Dedicated drill equipment may be ~300 kg too high (decreasing mass)
    - *Depends on where mobility & dual use equipment is booked*
  - ↑ Potential missing mass for sterilization & verification (increasing mass)
  - ↑ Potential missing mass for dusty suit maintenance area (increasing mass)
    - *Can't bring dusty suits inside Habitat for maintenance*
  - ↓ Commodity Cache allocation may be ~750 kg too high (decreasing mass)
  - ↑ Potential missing mass for rovers exploring potential special regions (increasing mass)
    - *Dedicated rover or sterilize it before going back to Habitat*
  - ↓ Food mass may be over-estimated based on HDU numbers (decreasing mass)
  - ↓ Potential mass savings for alternative power system configurations (decreasing mass)



<u>Key Takeaway</u>: DOT helps validate Design Reference Architecture (DRA) 5.0 mass estimates

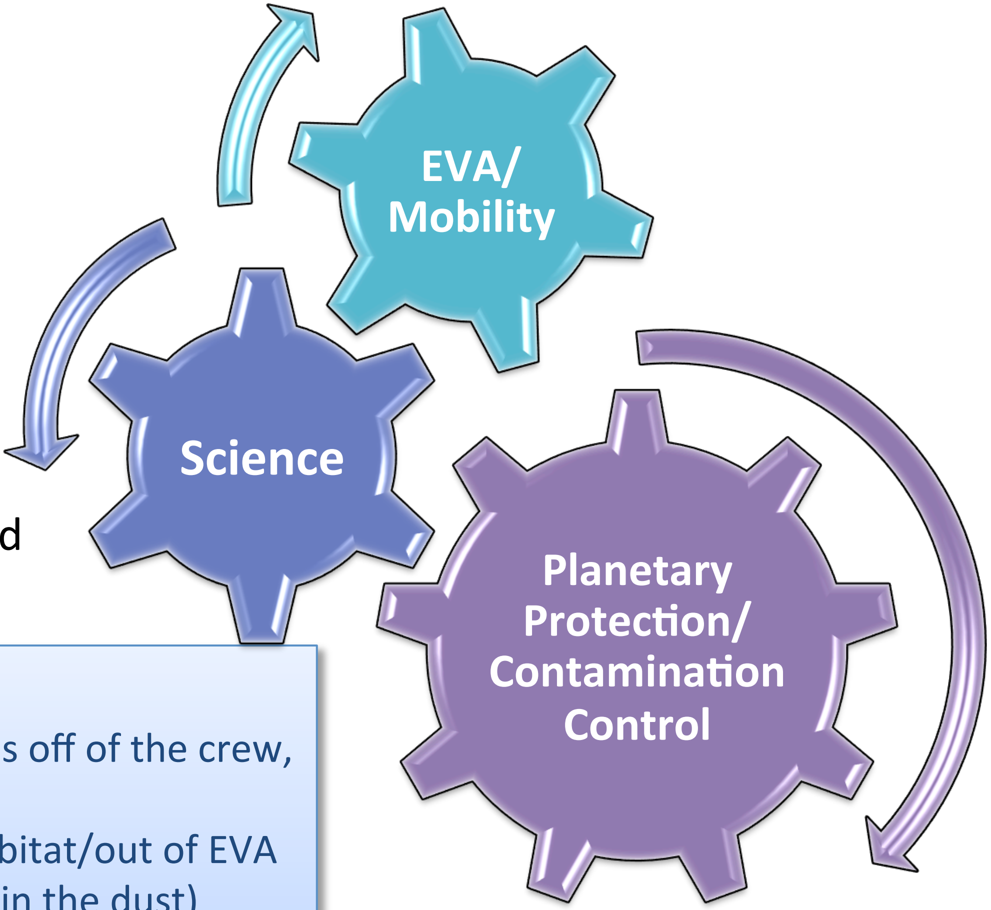
HDU = Habitat Demo Unit

A. Functionality Analysis Description

- The Mars surface mission as described in DRA 5.0 requires possibly the broadest range of capabilities envisioned for any of the human planetary exploration missions now being considered. The graphic on the facing page shows the top level of a functional breakdown developed for the surface mission portion of DRA 5.0.
- The Functionality Assessment Team attempted a Functional Decomposition of the DRA 5.0 surface mission, but quickly identified an overwhelming number of potential sub-functions--each potentially spawning a long list of trades. In lieu of a more detailed surface mission definition, further functional decomposition was deemed unproductive, because it didn't answer the fundamental question: "did DRA 5.0 miss any functions (and associated mass)?"
- The Functionality Assessment Team instead turned its efforts to directed studies of key areas, to better define the surface mission. What was missing from the pure Functional Decomposition approach was the *integrated function* impacts. For example, we could assume the Surface Habitat must provide a glovebox to support science functions…but if the science community wants science samples to remain pristine until they return to Earth, and the Planetary Protection community doesn't want science samples inside Habitable areas, then we've book-kept mass for a function that we don't really need in the Habitat and — worse — we've overlooked needed mass for a sample handling area outside of the Habitat.
- Instead, small teams tackled specific portions of the DRA 5.0 surface mission, such as the Commodity Cache concept, and performed limited functional decomposition and subsequent mass estimating, with particular attention to the integrated aspects of each area.
- The top-level functional decomposition results can be found in the Appendix B of this document.

Iterative Functional Decomposition & Con Ops

- **Can only take Functional Decomposition so far without knowing more about Planetary Protection-Crew Safety-Contamination Control ops con**
  - Impacts *how* we do Science
  - Which in turn impacts our EVA and Mobility Strategies and architectures
  - All of which impacts Habitat design and drives overall mission mass



The figure above shows that EVA/Mobility, Science, and Planetary Protection / Contamination Control are interconnected.

Three related but distinct issues:

1) **Planetary Protection**: Keeping Mars organisms off of the crew, and vice versa
2) **Crew Safety**: Keeping toxic dust out of the Habitat/out of EVA suits (regardless of whether there are "bugs" in the dust)
3) **Good Science**: Keeping crew/equipment contamination off of Mars science samples

Key Takeaway: NASA's Human Exploration Architecture Team is the only group performing this integration function

B. Commodity Cache Feasibility

Technical Challenge

- Up to a 6-sol Walk-Back
- Crew has to open EVA suit to eat, replenish drink bag, change diaper, or sleep comfortably
  - — Drives shelter to be pressurized, large enough to get out of suit, and dust controlled

Approach

- Developed concept of operations
- Cache functional decomposition
- Estimated mass needed for each function

Findings

- Mass exceeds 1,000 kg allocation
  - — 7 caches x 357 kg/each = 2,499 kg
- Laborious: takes at least 4 sols to deploy caches; same to retrieve
  - — If caches are activated, crew will spend 11 sols collecting and refurbishing before they can get back to science excursions
- Risky: loss of crew if…
  - — PLSS fails during up to 6-sol walk-back
  - — Rover has to be abandoned shortly after nominal EVA (e.g., fire, no time to recharge EVA suits)
- Lower mass, lower risk option identified
  - — Deploy "Life Raft" cache from rover, triggers unpressurized rescue rover to deploy
  - — Crew remain in EVA suits, ride back on unpressurized rover

Commodity	Mass (kg)	Volume (m^3)	Power (W)
EVA Resupply	99.02	0.347	564
Communication	4.30	0.060	15
Shelter and Comfort	215.02	0.628	0
Power System	25.00	0.400	600
Content Per Cache	343.34	1.435	600 W
Stowage Case	13.65		
Single Cache Total	357 kg		

Advantages of "Trigger" Option

- Enables crew to return to the Habitat much faster
  - — 1 sol instead of up to 6 sols
  - — Critical if crew is injured during rover disabling event
- Can keep crew in their suits, which reduces mass
  - — *Mass savings is equivalent to 3+ Apollo rovers*
- Keeps crew together, even if one has PLSS failure or injury
- Riding vs. walking results in lower consumable rates
- Allows two concurrent excursions
  - — Position one unpressurized rover between two pressurized rovers
- Streamlines operational timeline
  - — Reduces wear & tear on rovers and EVA suits

- **Study Participants:** Michelle Rucker (Lead), Molly Anderson, Jason Norcross, Robert Howard, Stephanie Sipila, David Coan, Natalie Mary, Pat Loyselle, Steve Rader

PLSS = Portable Life Support System

C. Traverse Planning & Mobility Study

Technical Challenge

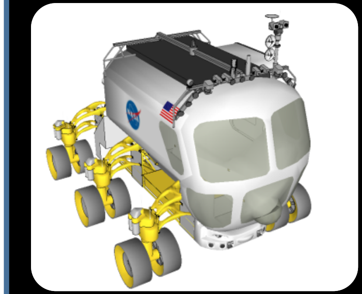
- Long traverses with pressurized rovers and 4500 kg rover+PUP landed mass allocation
- Transport of large FSPS unit up to 1 km

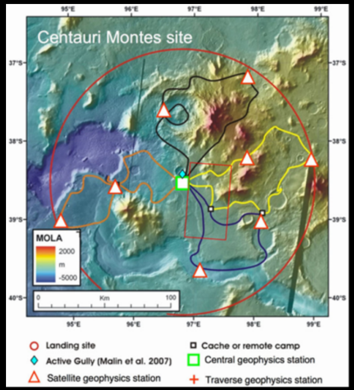
Approach

- Pressurized rover analysis spreadsheet built by Andrew Abercromby (LER/MMSEV AES Team)
- Start with lunar rover mass assumptions (Sharon Jefferies)
- Analyze HEM-SAG traverses, starting with Centauri Montes

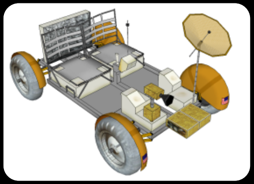
Findings

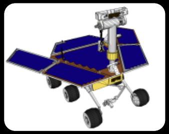
- Initial sizing analysis shows that pressurized rover range may be limited to 100-150 km for 4500 kg
  - Additional sensitivity analyses show potential for range improvement
- Use of autonomous or tele-robotic small robotic rovers for scouting traverses ahead of crewed traverse during two-year period after 1st landing is critical
- Smaller FSPS (2-4 mT vs. 7 mT) will prevent non-optimal design of rover chassis
- Pressurized rover performance is sensitive to assumptions, such as rolling resistance, battery specific energy, and solar array efficiencies
- Other traversing strategies need to be investigated (e.g., quick traverse to science area of interest with local non-PUP roving, 2 crew + 2 rovers)
- Very reliable pressurized rovers are needed


Pressurized Rover



Potential traverses for human exploration


Unpressurized Rover


Robotic Rover

Issues & Future Work

- Full sensitivity analysis of key pressurized rover parameters
- Analysis of alternate traverse strategies

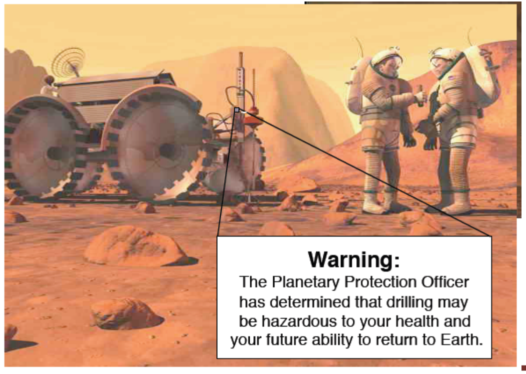
Key Takeaway: DRA 5.0 Pressurized Rover may not match HEM-SAG range expectations

- **Study Participants:** Dave North (Lead), Michelle Rucker, Andrew Abercrombie, Steve Chappell, Sharon Jefferies, David Smitherman, Brand Griffin

LER = Lunar Electric Rover
MMSEV = Multi-Mission Space Exploration Vehicle

AES = Advanced Exploration Systems

D. Mars Laboratory & Sample Handling Study



Warning:
The Planetary Protection Officer has determined that drilling may be hazardous to your health and your future ability to return to Earth.

Technical Challenge

- Mars Samples
  - *How to collect & contain?*
  - *How to handle & how to transport?*
  - *How & what to analyze?*
  - *Sample curation needs?*

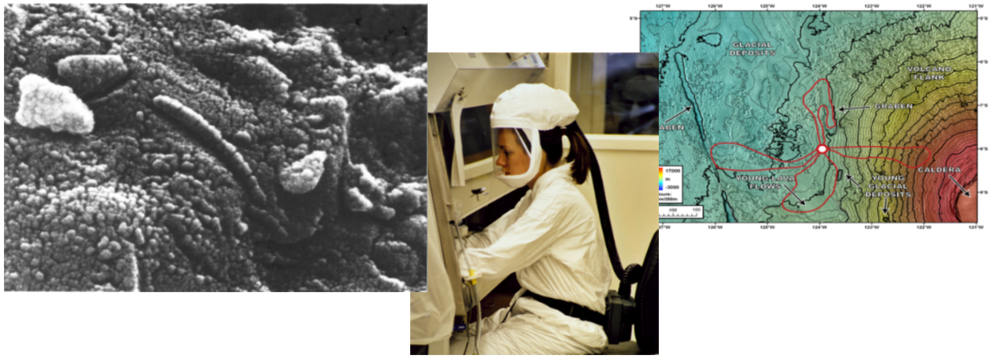
- Mars Analytical Laboratories
  - *Types?*
  - *Located where?*
  - *How do labs fit into science strategy?*
  - *Lab outfitting?*
  - *Special Issues: e.g., maintain contamination control, manipulate samples*

Approach

- Review MEPAG HEM-SAG for needs
- Review overall Mars surface mission ConOps strategy
- Derive analytical laboratory requirements
- Identify representative instrumentation for mass, volume, & power estimates
- Develop overall strategy

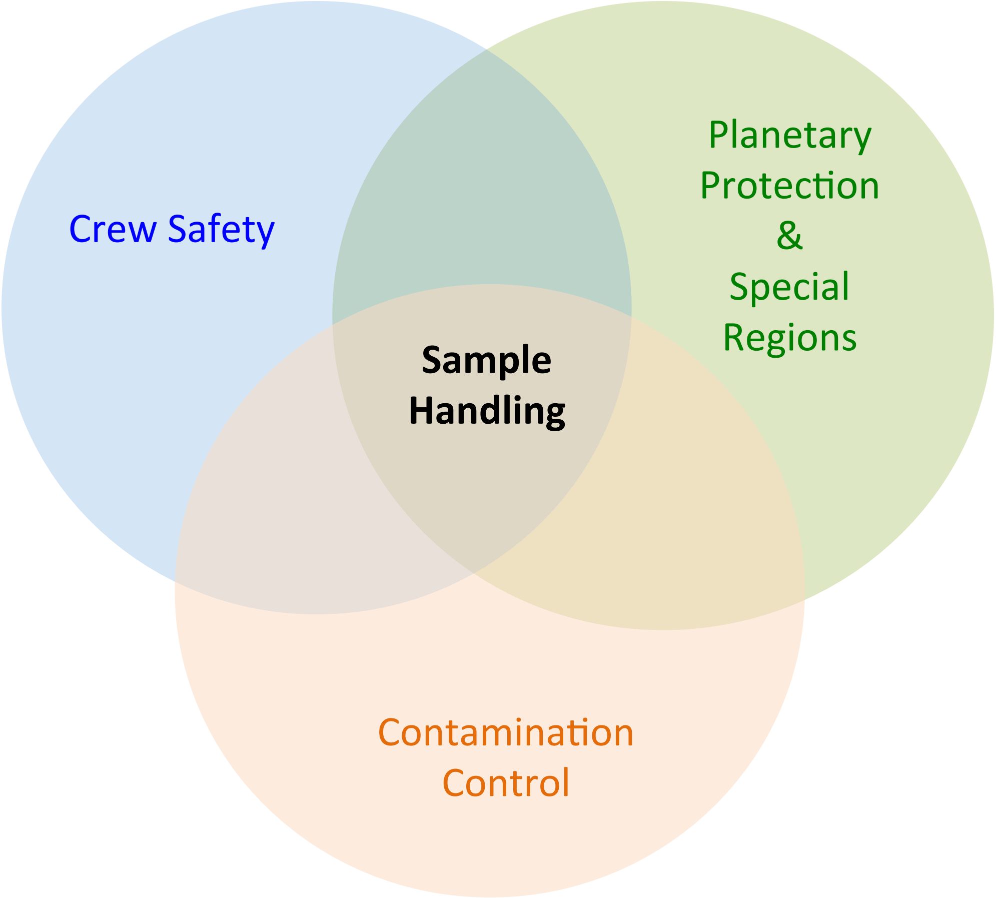
Findings

- **MEPAG HEM-SAG reference document provides good starting point for establishing analytical laboratory requirements**
  - Unequal treatment across science disciplines; will require further definition
- **Samples are required across science disciplines**
  - Geology requires surface and shallow subsurface samples
  - Atmospheric & Climate Science requires atmosphere & surface samples (some at altitude)
  - Astrobiology has most difficult sampling requirements: 250 – 300 m subsurface (requires drilling) to subsurface aquifer (potential for Mars extant life)
  - Geophysics requires emplacement of instrumentation & data returned
- **Representative instrumentation was identified**
  - Some sensors and analytical instrumentation development may be required
  - Microminiaturized analytical instrumentation from biotechnology industry may be leveraged
- **Distributed analytical capability required in rover, downhole during drilling, at habitat area, and "glove-size" for EVA crew**
  - Small analytical laboratory in rover, used during traverses
  - Downhole sensors required for data collection during drilling for subsurface samples
  - Small handheld instruments by EVA-suited crew
  - More capable analytical capability at habitat area: Separate astrobiology lab for analyzing Mars subsurface samples probably required
- **Issues to be addressed**
  - Sample handling: collection, containment, transport, analysis, curation
  - Contamination control: specifications & protocols required; in-situ cleaning
  - Planetary Protection & Special Regions operations: Leakage, transport, inducing special regions
  - Crew Safety: protocols required, impact on surface element design.
- ***Study is in early stages***



- **Study Participants:** Marianne Bobskill (Lead), Mark Lupisella

D. Mars Laboratory & Sample Handling Study



The figure above shows that Crew Safety, Planetary Protection & Special Regions, and Contamination Control are inter-connected, with Sample Handling at the intersection.

The most significant scientific challenge, and perhaps the most significant operational challenge on Mars, will be effectively dealing with Mars science samples, which requires an integrated approach at least across the following areas: (a) sample handling (b) contamination control (c) planetary protection and “special regions” operations, and (d) crew safety.

Sample handling rests at the intersection of many considerations. Sample handling includes a number of activities, including acquisition, containment, transport & delivery, and analysis, all of which are affected by contamination control, planetary protection, and crew safety. Sample acquisition is the beginning of the process and methods of acquisition can be heavily influenced by precursor data. For example, if the sample is not from a potential special region, it may be possible send humans into the area to collect the samples. Otherwise, alternative methods (e.g., real-time telerobotic sample acquisition and analysis) may be required to avoid the threat of introducing terrestrial biota into the special region. Or, if contamination can be sufficiently controlled, crew may be able to enter sensitive areas to acquire samples directly.

D. Mars Laboratory & Sample Handling Study

The MEPAG HEM-SAG reference document provides a good starting point for establishing sample handling and analytical laboratory requirements. It indicates the need for different treatment across science disciplines , which requires further definition for higher fidelity operations assessments. Mars samples are required across multiple science disciplines, but the sample type and acquisition requirements vary. Geology requires surface and shallow subsurface samples. Atmospheric & Climate Science requires atmosphere (some at altitude) & surface samples to evaluate atmosphere/surface interactions. Geophysics requires distributed emplacement of instrumentation & returned data. Astrobiology arguably has the most significant sampling challenges, e.g. sampling at depths perhaps 250 – 300 m down to a subsurface aquifer, data collection during drilling, and in-situ detection of unknown forms of life.

During this initial study, representative instrumentation was identified. Sensors and analytical instrumentation development is likely to be required, e.g. miniaturized biotechnology instrumentation for rapid in-field measurements during traverses. It would be advantageous to distribute analytical capability across numerous surface assets, such as in the rover, downhole during drilling, at the habitat area, and via “handheld” instruments used by the crew during EVA. The habitat and/or habitat area should contain advanced analytical capabilities, such as molecular sequencing , for which sample preparation will likely be a delicate and complex process. A separate astrobiology lab for analyzing Mars subsurface samples is probably required to reduce cross-contamination and to ensure crew safety.

This study is in the early stages and a number of key areas remain to be investigated in more detail. These include, for example, (a) crew safety protocols and their impact on surface element design, (b) operational details for sample collection, containment, transport, analysis, curation, (c) contamination control protocols and in-situ cleaning, and (d) planetary protection compliance and special regions operations strategies, including addressing contaminant leakage and transport and the potential for creating special regions , such as by melting ice or leaking water into the environment.

E. Integrated Surface Power Strategy

Technical Challenge

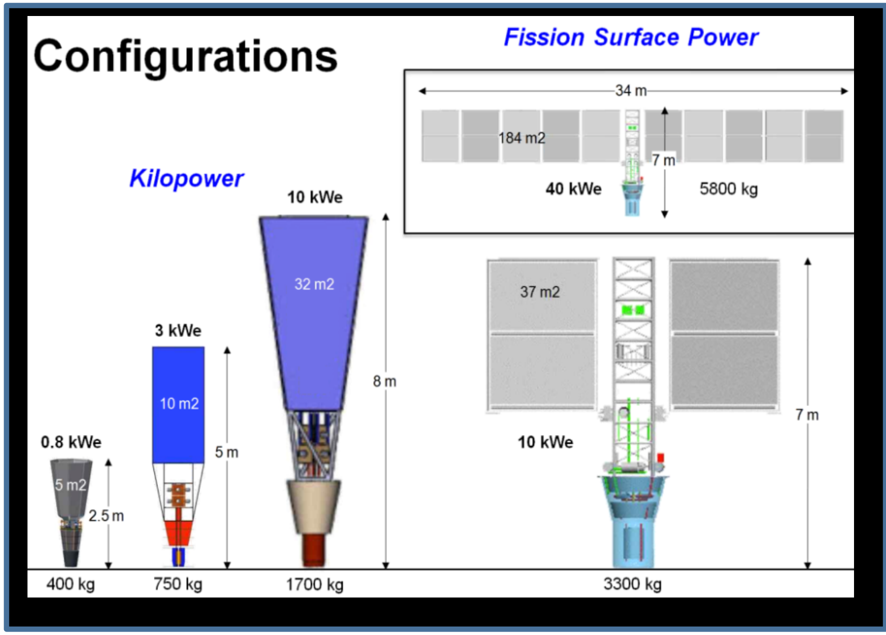
- FSPS is the heaviest item that needs to be moved around Mars' surface
  - Design driver for surface mobility (rover)
- Landers must be autonomous until the FSPS comes on-line
  - Drives Lander mass/power and rover speed
- Nominally, spare 40 kWe FSPS on Crew Lander *is never used*
  - 5,800 kg allocation would be nice to use elsewhere

Approach

- Evaluate alternative approaches to DRA 5.0 strategy
- Develop surface Powered Equipment List (PEL)
  - Who needs power, how much, when, how long?

Findings

- May be able to use PUP to sustain Lander until FSPS is on line
  - Minimizes Lander autonomous power mass after landing
- 8 each 10 kWe kilopower systems = more landed mass than 2 each 40 kWe FSPS's (13,600 kg vs. 11,600 kg), however…
  - May not need 8 of the smaller units for redundancy
  - Smaller units don't have to be as far from crew (lower cable mass) and are easier to bury so crew can be even closer (even lower cable mass), shorter rover drive
  - Smaller units can easily be moved with small rovers
  - Multiple smaller FSPS's offer more ops flexibility and redundancy, and won't drive rover design
  - Smaller units could be deployed to remote sites (drill site, for example) without impacting Habitat



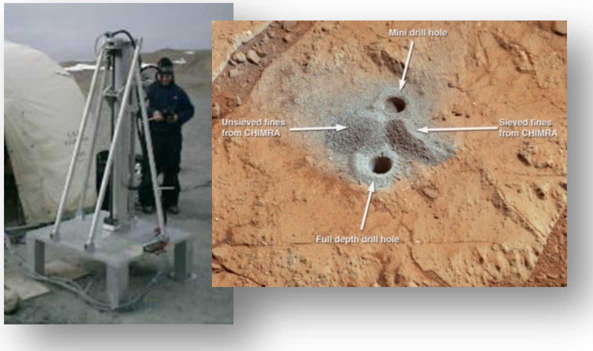
The figure above shows different configurations and classes of planetary surface power systems.

Issues & Future Work

- *Study is still in early stages*
- Complete Power Equipment List
- Develop detailed integrated mass estimates for various options, including flow-down effects to rovers, Hab, and portable equipment

- **Study Participants:** Horacio de la Fuente (Lead), Michelle Rucker, Dave North, Don Palac, Pat Loyselle

F. Integrated Drilling Strategy Study



Technical Challenge

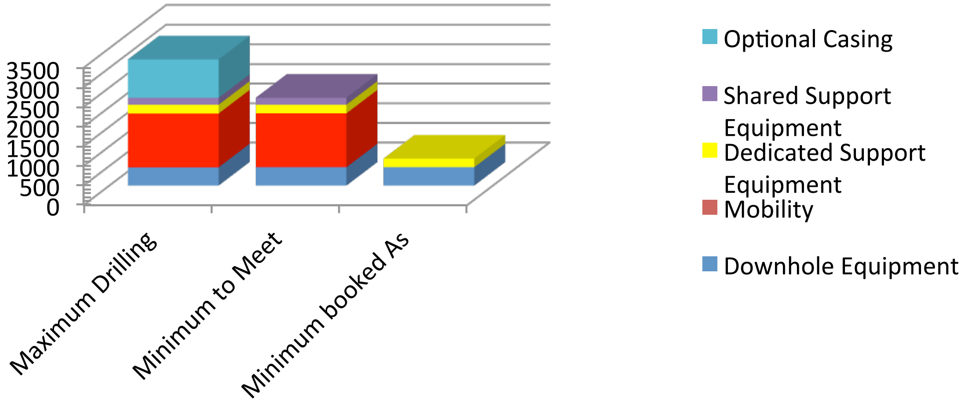
- DRA 5.0 specifies 1,000 kg of drilling equipment, but gives few details
  - *How many holes?*
  - *How deep?*
  - *How far apart?*
  - *Are we drilling into “habitable zones”?*

Approach

- Survey science community for needs
- Identify issues and constraints
- Develop Drill System requirements
- Develop integrated drilling ops con
- Make operational point of departure assumptions, and drilling system mass

Findings

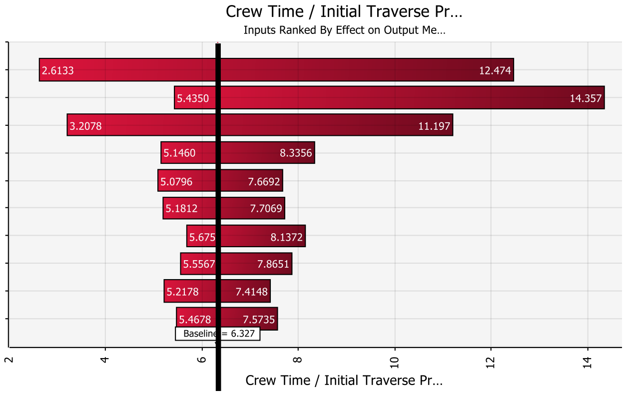
- **Drilling >5m invokes “Special Region” considerations**
  - — DRA 5.0 focus is “Zones of Minimum Biological Risk” …should we be deep drilling?
- **Subsurface planetary protection guidelines need review/update/mission specific interpretation**
  - — Per COSPAR: surface is self-sterilizing, so no constraints down to 5 m depth
  - — But per JPL, *ice may be only 3-5 m below surface w/in 30^o of equator*
- **None of 53 drill technologies surveyed are a sure thing for 300m target depth**
  - — Only 5 drills are advertised >100 m (none demonstrated beyond 3m)
  - — Only 1 drill is advertised to 300 m target depth (demo to 3 m, TRL 2)
- **At demo drilling rates, it may take more than 500 sols to drill 300 m**
  - — Solvable with tech dev, more power, or autonomous drilling before crew arrives
- **If technology pans out, dedicated drilling equipment is only 689 kg**
  - — *IF we don’t case the borehole (risk of borehole collapse, no sample return)*
  - — *AND we book-keep mobility & dual-use equipment under other allocations*
- **Need *at least* 2,235 kg total (including mobility) to meet requirements**
  - — Add more mass if you decide to stabilize the borehole (recommended)



The figure above shows masses associated with multiple (minimum to maximum) drilling strategies.

- **Study Participants:** Michelle Rucker (Lead), Mark Lupisella, Brian Glass, Dean Eppler, Steve Hoffman, Steve Rader, Michael Wright, Lana Miller, Roy Long (DOE), Margaret Race (SETI)

G. Statistical Modeling Study: Mars Operations Modeler (MOM) Background

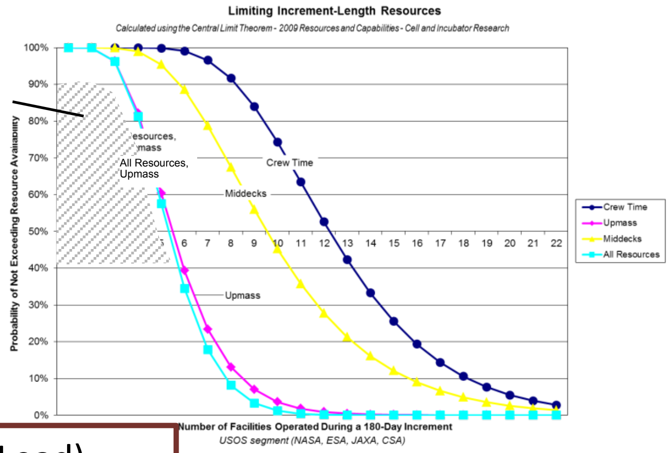


Most Likely Resource Values

- **A Mars surface mission, as described in DRA 5.0 and the HEM-SAG report, has several scientific and exploration investigations/activities that could be repeated numerous times within the time available**
  - Each of these scientific and exploration activities will place demands on other mission resources (e.g., delivered mass, power, bandwidth to Earth, etc.)
  - Numerous feasible combinations (i.e., does not exceed any mission resource) of these scientific and exploration activities can be assembled.
- **What is an efficient method to examine these combinations to gain a better understanding of the scientific and exploration activities and mission capabilities that will result in a robust surface mission?**

- **The ISS Program has been faced with a similar situation since its inception**
  - The ISS Payloads Office developed a modeling capabi to look at the impact of different payloads and priorities on the ability of the ISS to achieve its scientific mission
- **This ISS Payloads Office experience has been used to develop a prototype model that is intended to provide similar insight for the Mars surface mission**

Most Likely Ops Space



- **Study Participants:** Alida Andrews (Lead)

G. Statistical Modeling Study: MOM Background

- Previous sections of this report have described how a Mars surface mission will be made up of several scientific and exploration investigations. The HEM-SAG report describes the investigations that would be carried out by several different scientific communities. These investigations could be one-time events (e.g., deployment and activation of a meteorological measurement station) or could be repeated as many times as time and resources allow (e.g., surface traverses). In addition, the investigations described by the various science communities can, in some circumstances, be easily integrated or coordinated and in other circumstances may require dedicated activities by the crew. All of these science investigations must occur on top of a background of routine crew activities (e.g., sleep, meals, exercise, etc.) and expected operating overhead (e.g., planned maintenance and random repair of surface equipment and infrastructure). All of these activities will place demands on mission resources such as crew time, delivered mass, power, or communication bandwidth between Earth and Mars. Because none of these activities consumes all of the mission resources, there will be numerous feasible combinations of activities that could be assembled that satisfy minimum scientific goals and objectives.

- The challenge then becomes finding an efficient method to examine these feasible combinations in sufficient detail to understand which combinations will satisfy the stated scientific and exploration goals and objectives in a robust manner. In this context, “robust” means that a particular combination satisfies not only the minimum number (or duration) of the investigations described in the HEM-SAG report but makes full use of available mission resources (crew time, delivered science mass, power, etc.) to accomplish the greatest number of investigations in a balanced manner.

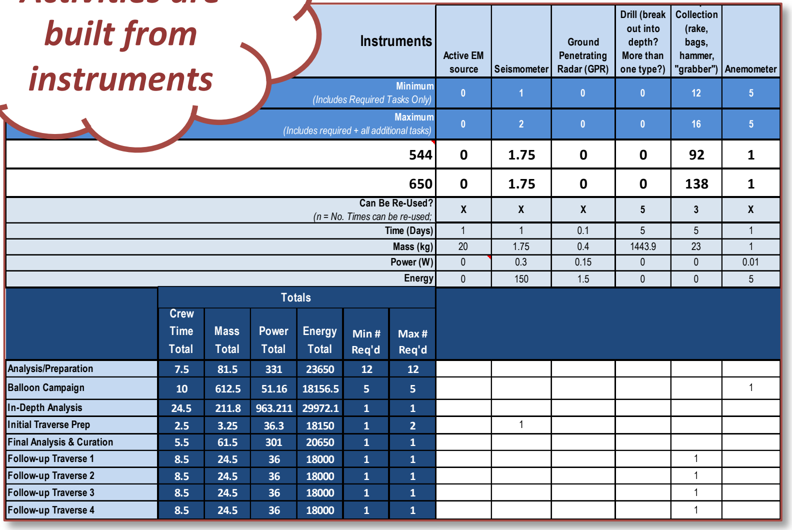
- The International Space Station (ISS) has been faced with a similar need since its inception to sort through a large number of potential experiments in a constrained resource environment for each increment. The ISS Payloads Office developed a methodology and a modeling capability to look at the impact of different payload combinations and priorities on the ability of the ISS to achieve its scientific mission. This ISS Payloads Office experience has been used to develop an appropriate methodology and an associated prototype model that is intended to provide similar insight for the Mars surface mission.

G. Statistical Modeling Study: MOM Methodology

- **Developed with MS Excel and @Risk statistical modeling software**
- **Performs a Monte Carlo simulation to randomly select sets of activities then check each set's overall resource use**
  - **Activities/Tasks (for example, investigations or traverses) are built from instruments and other resources; the required resources are totaled per activity**
    - Current Resources being evaluated are Crew Time, Mass, Power, and Energy
    - Because resource requirements are still fluid, a distribution over a range of likely resource values is used where exact values are unknown
  - **Verifies that the selected mission tasks/building blocks can be completed without breaking resources**
    - Each activity is given a maximum and minimum number of "runs" to be made during the time period being studied
      - Some activities may need multiple runs to get the needed data; others could get enhanced results from multiple runs, or may achieve their goals with only one run

@RISK 6

Activities are built from instruments



Instruments	Active EM source	Seismometer	Ground Penetrating Radar (GPR)	Drill (break out into depth? More than one type?)	Collection (rake, bags, hammer, "grabber")	Anemometer
Minimum (Includes Required Tasks Only)	0	1	0	0	12	5
Maximum (Includes required + all additional tasks)	0	2	0	0	16	5
544	0	1.75	0	0	92	1
650	0	1.75	0	0	138	1
Can Be Re-Used? (n = No. Times can be re-used;	X	X	X	5	3	X
Time (Days)	1	1	0.1	5	5	1
Mass (kg)	20	1.75	0.4	1443.9	23	1
Power (W)	0	0.3	0.15	0	0	0.01
Energy	0	150	1.5	0	0	5

	Totals											
	Crew Time Total	Mass Total	Power Total	Energy Total	Min # Req'd	Max # Req'd						
Analysis/Preparation	7.5	81.5	331	23650	12	12						
Balloon Campaign	10	612.5	51.16	18156.5	5	5						1
In-Depth Analysis	24.5	211.8	963.211	29972.1	1	1						
Initial Traverse Prep	2.5	3.25	36.3	18150	1	2		1				
Final Analysis & Curation	5.5	61.5	301	20650	1	1						
Follow-up Traverse 1	8.5	24.5	36	18000	1	1					1	
Follow-up Traverse 2	8.5	24.5	36	18000	1	1					1	
Follow-up Traverse 3	8.5	24.5	36	18000	1	1					1	
Follow-up Traverse 4	8.5	24.5	36	18000	1	1					1	

- **If the available resources are not exceeded, a "benefit" score is calculated**
  - Goal is not to maximize the number of runs per activity, but to maximize the benefit of the entire suite of activities to provide the "best" science data possible within our resource budget
  - Initially all activities will have equal benefit
- **Once all iterations are completed, two plots are generated:**
  - The percent of time that each activity got at LEAST n runs
  - The number of successful runs per activity

Maximum Benefit
98.3025851

Mars Operations Modeler (MOM) Methodology

- Experience gained from developing an experiment and payload complement for an ISS increment indicated that a deterministic process was not possible. Rather, a probabilistic process that provided some guidance regarding the chances of accomplishing a particular complement of experiments with the resources available was the most useful for mission planners. With this experience in mind, a probabilistic process, implemented using Microsoft Excel and @Risk statistical modeling software, was developed to provide Mars surface mission planners with comparable guidance regarding the chances of a particular complement of investigations and experiments being completed for a specified set of resources.

- The facing page (above) describes the steps in this process.

- A "benefit" value was introduced that could be assigned to each experiment or investigation. This "benefit" value functions as a weighting factor for the experiments and investigations under consideration. By assigning a weighting factor to the experiments and investigations, the model could be driven to favor certain experiments or investigations, if desired, as the Monte Carlo simulation portion of the model checks the resources usage of randomly selected sets of experiments and investigations.

H. Capability & Technology Requirements

- **DOT met with the Exploration Capability Roadmap (ECR) Development Team**
  - DOT presented the notional DRM9/DRA5.0 ConOps
    - The ECR team agreed that the level of detail was more than sufficient to inform the Systems Maturation Team and the Architects.
  - The ECR team presented the current Systems Maturation Team (SMT) data collection template
    - This informed the DOT of the current level and type of data being collected to close capability gaps within the Exploration Capability Roadmap development.
- **High-level categories of capability improvements were identified and supporting information was provided, for the following categories:**
  - Extra-Vehicular Activity
  - Human-Robotic Mission Operations
  - Crew Health and Performance
  - Autonomous Mission Operations
  - Communications and Navigation
  - ECLSS (including Environmental Monitoring)
  - Entry, Descent, and Landing
  - Power and Energy Storage
  - Radiation
  - Thermal (including Cryogenic operations)
  - SKG Measurement Instruments & Sensors
  - Fire Safety
  - Propulsion
  - In-Situ Resource Utilization

Exploration Capability Roadmap Worksheet Categories

Extra-Vehicular Activity

Human-Robotic Mission Operations

Crew Health and Performance

Autonomous Mission Operations

Communications and Navigation

ECLSS (incl. Environmental Monitoring)

Entry, Descent, and Landing

Power and Energy Storage

Radiation

Thermal (incl. Cryo)

SKG Measurement Instruments & Sensors

Fire Safety

Propulsion

In-Situ Resource Utilization

Other

- **Study Participants:** Kevin Larman (Lead), DOT

Key Findings

- **An integrated Concept of Operations (ConOps) helped identify and understand interdependencies between functional requirements and the capabilities needed to meet these requirements**

- **The nominal 500 Sol surface duration is technically feasible and provides sufficient time to address science and exploration objectives, with several notable caveats**
    1) Feasibility is indicated for the assumed set of systems and operational approach used, both of which contained some low fidelity items. Higher fidelity understanding of these systems and operations, along with the inclusion of obvious contingency situations, could tip the balance in the other direction.
    2) The deep drilling activity, in particular, was problematic in that current drilling technology options and operations do not fit within the mass allocation or time available as stated in DRA 5.0; this requires further analysis to find a solution that will fit within overall mission constraints.

Key Findings

- **The ConOps and Integrated Functionality assessment identified potential missing function and associated mass discrepancies**
  - Based on analyses from this study, the pressurized Rover may not match the HEM-SAG range expectations; additional analysis of systems and operational alternatives is needed to identify a robust solution
  - Potential missing mass from surface manifest:
    - Science Lab external to Habitat
    - Contamination control (e.g., via sterilization) and verification
    - Suit maintenance area
    - Robotic Rovers for exploring "special regions" (including a potential requirement for a dedicated rover to support deep drilling operations)
  - Potential mass savings in surface manifest:
    - Dedicated Drilling equipment may be ~300 kg too high (technical solution dependent)
    - Commodity Cache allocation may be ~750 kg too high (technical solution dependent)
    - Food maybe overestimated (but margins and contingency scenarios must be assessed)
    - Alternative surface power system configurations show potential for additional mass savings

Key Findings

- **As we plan human missions beyond LEO, we encounter a number of new issues not encountered in decades; one of these is the integration of Planetary Protection policy and controls into mission hardware that may be extensible to Mars**
  - Missions to the Moon and other bodies, such as asteroids, can provide useful technology and operational test experience to validate Planetary Protection protocols and controls for use on later Mars missions

- **Deep-diving into selected operations helps validate requirements, identify functional interdependencies, and flush out issues**
  - A special study on the DRA 5.0 Commodity Cache concept (which was derived from Antarctic expedition experience) showed that, while this may be a logical approach in the Antarctic, it was simply not practical on Mars. The study identified an alternative approach that was more time- and mass-efficient, as well as less risky to the crew.
  - A special study of DRA 5.0 Drilling highlighted issues involved with crewed operations that have the potential to bump up against Mars "special region" constraints. The study identified a number of technical and operational concerns, including the time needed to drill to the required depth, and how to handle samples without breaking planetary protection protocols or compromising the integrity of science samples.

Key Findings

- "Doing Our Homework" and having stakeholders (i.e., science discipline experts) involved early and, to some degree, throughout the ConOps-development process was beneficial in the analysis of surface activities and in the development of the ConOps. Their participation helped DOT understand the integrated surface operations more fully and identify potential "previously unrecognized challenges."
- Using Mars DRA-5.0 as a starting point for ConOps development will enable human exploration definition to inform and trace operations and functionality requirements to precursor destinations.
- Looking at the Mars DRA 5.0 surface strategy in more detail provides material that will inform the HAT in future mission approaches (DRMs). As described in Section 6, the DOT developed the ConOps and related functionality against "Mission Phases" for the surface mission itself. These mission phases can be used as "building blocks" to inform possible future approaches to HAT DRMs.
- Mission Phases 0 and 1 define the characteristics of a DRM that incorporate a "Pre-deployment of cargo" prior to a crew arrival at the destination. Phase 0 and Phase 1 activities, key assumptions, required mission events, and any optional mission events will help drive (and inform) a campaign perspective that may incorporate this approach.
- Mission Phases 2 and 3 define the characteristics of the "Initial crew surface operations" required for DRA 5.0. Even though these phases are part of a longer duration surface stay, the activities, key assumptions, required and optional mission events identified by DOT will help in deriving mission needs for a short stay approach to a human mission to Mars or other destination.

Key Findings

- Planetary Protection
  - As we plan human missions beyond Earth orbit, we encounter a number of new issues not previously encountered in LEO. One of these is the integration of Planetary Protection policy and controls into missions to the Moon and other celestial bodies. (Planetary Protection is not required in Earth orbit.)
  - There are formal COSPAR principles and implementation guidelines in place for human missions to the Moon and other celestial bodies, but not defined protocols, technologies, or operations details yet.
  - Integrating Planetary Protection information and policies early in mission planning will take advantage of synergies and cross-cutting efforts in many development activities.
  - Planetary Protection controls have been studied extensively in coordination with both NASA and International agencies over the past decade and it is recognized that such controls must be integrated into mission protocols and are often synergistic with other mission needs. In addition, these controls have implications for many aspects of crewed Mars missions and impact both robotic and human aspects of such missions, including:
    - Forward and backward contamination
    - Chemical pollutants detection and measurement
    - Biological monitoring, including microbial identification
    - Equipment decontamination and sterilization
    - Sample containment and handling
    - Advanced life support systems (ALS), including closed-loop recycling capabilities and waste handling & disposal
    - Extravehicular Activities (EVA) equipment, including suits & associated ALS and ingress/egress
    - Subsurface drilling equipment and operations
    - ISRU systems
    - Laboratory – Habitat separation
    - Quarantine
  - Missions to bodies like the Moon and asteroids, which are not habitable or likely to have putative indigenous extraterrestrial life, are not constrained by Planetary Protection considerations, but they can nonetheless provide useful testbeds for technology and operations and may serve as stepping stones to overall mission success for missions to Mars.

Follow-On Focused Studies

These analyses showed the importance of a set of special topics that could be implemented as forward work. These analyses would address issues that would impact how the Mars DRA 5.0 may be modified to increase mission success and reduce risk. These forward work issues include:

- Mars Drilling (shallow and deep) operations and options
- Sample Strategy / In situ sample analysis requirements
- "Minimal" crewed mission definition (as a subset of DRA 5.0 work)
- TBD Contingency Operations
- Quarantine Protocols
- “Special Regions” strategy
- Crew Waste Management
- Mars Precursor Missions
    - Precursor knowledge is important for human Mars missions. For example, NASA has identified a number of “Strategic Knowledge Gaps” requiring data to be gathered prior to fielding a crewed Mars mission. The NRC recommends “conducting a precursor in situ experiment at a location as reasonably close to the human mission landing sites as possible to determine if organic carbon is present.” The DOT, during ConOps development, considered some plausible mitigation strategies. However, the DOT chose to explicitly NOT address potential contingencies during this first round of analysis, but to focus on nominal surface operations. Note that pre-delivered cargo assets (such as robotic assets/rovers) could be used to conduct sample analysis prior to human landing, if there is sufficient time within the ConOps to conduct such sampling. If there is no sampling at or near the TBD landing site prior to crew landing, then initial crew surface operations could be conducted via IVA telerobotics. The focus of these operations would be to obtain biologically relevant data outside the habitat to inform mitigation strategies for crew safety and to address Planetary Protection concerns. This could be done during a planned period of crew acclimation that is already accounted for in our present ConOps.