DPT Architecture & Scenario Groundrules and Assumptions

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Introduction

The Agency's mandate is to ***Discover*** new scientific evidence and new processes which allows to us ***Discover*** our place in the Universe, by exploring existing and new places and phenomena, leading the way for our ultimate expansion beyond LEO while enhancing our quality of life and sharing the adventure of ***Discovery*** with all humanity.

The ability to ***Discover*** is significantly enhanced through the unique contributions of humans in the ***Discovery*** Process. Unfortunately, the current cost and risk of humans beyond LEO is too high to warrant their participation. Through investment in revolutionary and advanced technologies, we can begin to develop capabilities, which will allow a systematic affordable and safe expansion of humans in the ***Discovery*** process beyond LEO.

Such an expansion is envisioned to be accomplished in four phases. The first phase is to routinely leave the Earth's influence and do productive things in space. The second phase is to learn and eventually have voyages lasting up to 100 days in the Earth's neighborhood. As these trip times become routine, humans can then move toward 1000 day trip times with short stays at destinations out to 1.5 AU. Finally, as we grow accustomed to such journeys, we can then establish a permanent presence at an extraterrestrial destination.

The ultimate long-range vision is to enable humans to "go anywhere at anytime" to extraterrestrial destinations.

Purpose

The purpose of this document is to provide a consistent set of groundrules and assumptions for the development and analysis of advanced concepts and the attendant technology requirements and roadmaps, integrated precursor activities, infrastructure development and mission architectures required to meet the Decadal Planning Team (DPT) objective of an integrated human and robotic Exploration Program.

Scope

This document defines the groundrules and assumptions for the approach taken by the DPT to enable an integrated human and robotic program for the exploration of space. This exploration is driven by an Agency set of Exploration Grand Challenges which embrace the Strategic plans for the Space, Earth, and Human Exploration and Development of Space (HEDS) Enterprises and integrate these plans into an overall implementation approach. The DPT has designed an expanding set of capabilities (defined in this document) that allows the gradual expansion of human participation in the science and discovery process and couple it with technology roadmaps to enable these capabilities.

To assess the validity of the Capability approach, mission architectures will be developed for specific cases for the Earth's Neighborhood (Lagrangian points and the Moon), Mars and Asteroids. Groundrules and assumptions for the following cases are included in this document:

- L2 Evolutionary with EELV-H and LEO departure
- L2 Stepping Stone with EELV-H and LEO departure
- Moon with EELV-H and LEO departure
- Mars Midterm
  - LEO departure with:
    - 4a. EELV-H
    - 4b. Big Dumb Boosters
  - HEO departure
    - 4c. EELV-H
    - 4d. Big Dumb Boosters with all chemical in-space propulsion
- Mars Long Stay
  - LEO departure with:
    - 5a. EELV-H
    - 5b. Big Dumb Boosters
  - HEO departure
    - 5c. EELV-H
    - 5d. Big Dumb Boosters with all chemical in-space propulsion
- Mars Short-stay 1 year round trip (Systems Analysis only)
- Asteroid
    - 7a. LEO departure with BDB
    - 7b. HEO departure with BDB

Capability Definitions

Earth's Neighborhood (50 - 100 Day) Human Exploration Mission Capability: The capability to go beyond LEO to nearby solar system points for periods up to 100 days for conducting Science, Discovery or Development of Space investigations. The capability includes all aspects of living and working in space, including transportation (ETO, in-space and ascent/descent from surfaces), habitation, robotic assembly, mission operations, EVA, etc. This capability is the 1st stepping stone from our current capabilities in Low Earth Orbit to the long range objective of going anywhere, anytime.

Accessible Planetary Surface (300 - 1000 Day) Human Exploration Mission Capability: The capability to go out to ~ 1.5 AU for periods up to 1000 days for conducting human-enabled, short-term Science, Discovery or Development of Space investigations of a "visit" nature. The capability includes all aspects of living and working in space, including transportation (ETO, in-space and ascent/descent from planetary surfaces), habitation, robotic assembly, mission operations, EVA, etc. This capability is the 2nd stepping stone to the long range objective of going anywhere, anytime.

Accessible, Sustainable Planetary Surface Human Exploration Mission Capability: The capability to go out to ~ 1.5 AU for conducting human-enabled sustainable Science, Discovery or Development of Space investigations for indefinite periods. The capability includes all aspects of living and working in space, including transportation (ETO, in-space and ascent/descent from planetary surfaces), habitation, robotic assembly, mission operations, EVA, etc. This capability is the 3rd stepping stone to the long range objective of going anywhere, anytime.

Common Groundrules and Assumptions for All Cases

Safety and Mission Levels of Risk (Reliability)

Public safety is mandatory and the highest priority followed by crew safety, NASA employee safety and then system safety.

The appropriate probabilities for mission success of future mission architectures are TBD. For the architecture case studies, the probabilities and risks of scientific mission success and crew survival will be developed for each case to compare the merits and disadvantages of each.

When developing mission architectures:

- Hazards should be eliminated by design wherever possible.
- Known hazards that cannot be eliminated by design should be reduced to an acceptable level by the use of safety devices as part of the system, for example, redundancy, backups, or emergency shutdown.
- When neither design nor safety devices can adequately reduce the risk, use devices to detect the condition and warn personnel of the hazard. Design the warning signals to keep people from reacting incorrectly.
- When neither design, safety or warning devices can adequately reduce the risk, special procedures shall be developed to counter the hazardous condition.

The NASA Planetary Protection Officer has defined the current requirement for back contamination from Mars to be a probability of sample release to the atmosphere of 10^{-6}. Forward contamination requirements are defined as ??????. Forward, back and in-situ contamination requirements for human missions to Mars have not yet been defined.

Programmatic

Mission priorities: 1) safety, 2) mission success, 3) cost, 4) schedule

Where possible, science and engineering precursor requirements will be integrated.

Architectures will not be dependent on International partnerships, but this will not preclude future international participation.

Education and public outreach is required for all architectures.

All architectures assume that the Integrated Space Transportation Program (ISTP) and Advanced Space Transportation Program (ASTP) reusable launch vehicle programs will successfully develop technologies and vehicles that perform in accordance with the goals set for those programs.

Technology and Mission Development Guidelines and Assumptions

Enabling technologies are required to reduce the cost and increase the safety of both robotic and human enabled science missions at each specific destination. Prior to inclusion of these technologies in flight hardware, technologies will be flight qualified. Flight qualification may require sub-scale or full-scale testing in space prior to flight hardware development. Technology roadmaps will include all technology demonstrations.

Agency's technology maturation strategy will assure technologies are brought from their initial low TRL levels to at least TRL 6.

Engineering/technology demonstrations may be planned during any phase as appropriate depending on the demonstration objectives.

Technology roadmap timelines are based on past experience as applied to the current state of the technology and anticipated funding levels.

Precursor requirements (knowledge capture and infrastructure) will be derived from the scientific strategy, technology needs and architecture to enhance the mission content and reduce mission risk.

Full-scale mission hardware development (Phase C/D) will not be initiated before TRL 6 is achieved.

Phase C/D begins with completion of NAR and PDR.

Phase C/D duration for system development of human missions (including predeployment missions) is no more than 5 years.

The mission architecture should not be schedule dependent except as noted in these groundrules and assumptions. Phase C/D start and all subsequent activities can be moved later in time if technologies do not mature in time to achieve a TRL 6 by NAR.

Operations Groundrules and Assumptions

Training begins 2 years prior to the launch of the first segment of a human mission whether the launch is for predeployment or not.

Training for robotic missions will begin 1 year before launch including precursor and infrastructure missions.

Launch Vehicle Groundrules and Assumptions

EELV: All cases using the EELV assume that the EELV-H (35MT) will be available in FY10.

RLV*:* For cases with TRL 6 completion dates by 2011, assume that the Integrated Space Transportation Program (ISTP) technologies and flight vehicles are developed and available in accordance with the ISTP goals.

For cases with TRL 6 in the 2020 timeframe, assume that the Advanced Space Transportation Program (ASTP) technologies and flight vehicles are developed and available in accordance with the ASTP goals.

Big Dumb Booster (BDB): The BDB is an optimized (for the optimum mass to orbit per unit cost) launch vehicle for only non-sensitive cargo. The principal criteria for the BDB are lower cost, but lower reliability may be a consequence of this approach.

Development of the launch infrastructure will be the responsibility of and funded by NASA. These costs are not included in the cost per kg factors used for Earth-to-orbit transportation.

Costing Groundrules and Assumptions

Rough order of magnitude costs will be derived for each case as a method for comparing the benefits of each case. Two different cost models will be used: a simple weight based model based on historical $/kg for both human and robotic missions; and the Advanced Missions Cost Model developed by JSC and documented in *Human Spaceflight Mission Analysis and Design.* ***Caution: Since the costs are derived using simple models, the costs should not be used as a valid estimate of the proposed architecture.***

All costs will be in FY00 dollars.

Space Flight Hardware (Deep Sapce)

Robotic system flight hardware development costs, derived from the Aerospace analysis of recent planetary spacecraft costs, are $167K/kg.

Human system flight hardware development costs, based on the only human planetary mission costs, Apollo, are $173K/kg. Comparisons of Apollo to Shuttle are similar to the comparison of robotic planetary spacecraft to robotic earth orbiting spacecraft.

Launch Vehicle

Current launch costs for non-human rated cargo are based on the Delta 2 cost/kg: $11K/kg.

Current launch costs for human rated cargo are based on Shuttle cost/kg: $22K/kg

Future launch costs are:
- Delta IV-H launch costs are $4400/kg based on Boeing current forecasts
- By FY11 non-sensitive cargo, launch costs are $2200/kg (DPT goal)
- By FY11 sensitive cargo, launch costs are $2200/kg (ISTP goal)

Costs are to be applied without consideration of the potential production line costs differences and learning curves.

Ground Infrastructure

TBD

Operations

Current human space flight operations costs are $2M/day (LEO);
Current robotic mission operations are TBD

By FY 11, future human space flight operations costs are $1M/day. Unmanned flight operations costs prior to human occupation are $0.5M/day.
By FY 11, future robotic mission operations costs are $TBD/day

Architecture Case Groundrules and Assumptions

Groundrules and Assumptions, – L_2 Evolutionary and Stepping Stone

Earth-Sun L_2 Program Strategy

The "L2 Evolutionary" strategy assumes that there is no relationship between the technologies and mission components developed for this capability and any future exploration capabilities.

The "L2 Stepping Stone" strategy assumes that the technologies and mission components developed for this capability will be applicable to future exploration capabilities. Initial missions will lay the foundation for more comprehensive follow on missions, both robotic & human.

Integrated human & robotic program to address basic science questions as defined in the Origins Roadmap dated xxxxxxxx.

Scientific objectives and precursor requirements will be integrated to achieve the best mix to meet strategy one above.

Science Objectives

The scientific objectives are to search for life in the Universe; to determine the role of gravity and other fundamental processes in the origin and evolution of life; and to reveal and understand the laws of nature.

These objectives are to be accomplished with ever-larger telescopes at the L2 Sun-Earth lagrangian point.

Mission Operation Objectives

Demonstrate technologies and operations strategies and approaches necessary for distant, long duration human spaceflight. (Stepping Stone Option)

Demonstrate semi-autonomous medical capabilities.

Programmatic and Hardware Development

First human mission to the Sun-Earth libration point (L2) no earlier than ~2011.

Total mission duration (Earth-L2-Return) should be minimized.

Crew size should be minimized but sufficient to meet science requirements and mission flight rules

Transits to and from L2 will be in zero-g (no artificial gravity).

L2 injection will take place from low Earth orbit.

Shuttle equivalent capability will be available to delivery sensitive cargo and humans to orbit.

ELVs up to EELV-H will be available for payload/vehicle delivery.

Precursor Requirements and Infrastructure

Knowledge Capture

Robotic precursor missions are required to characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology. Specific knowledge includes:

Engineering Design Information:

Radiation Measurement, Characterization, & Modeling and Radiation Effects on Materials & Humans

Operations Information & Experience

Experience in autonomous operations (multiple EVA & habitat crew, vehicles, telescope facilities); large team coordination (Crew size >2 EVA astronauts); human / robotic-assisted operations / teleoperations; extended duration operations; and operations traversing over extended distances

Infrastructure Emplacement

Unique infrastructure is needed to provide the physical and operational foundation at the L2 (in-space) to support first arrival and on-going operations of an integrated human/robotic science mission. This includes:

- Communications / Navigation (coupled to Earth)
- Space weather monitoring / “sentinels”
- LEO-Based mission staging capability and capacity
- Earth surface-to-LEO and return capability

Specific infrastructure related to the architecture is defined as part of that architecture.

Technology Requirements

Critical Enabling Technologies (with technology goals)

Human Support

- Advanced health care systems
- Radiation protection
- Closed loop life support (air and water (physical/chemical) only)
- Space environmental assessment, control & countermeasures
- Advanced habitation
- Advanced EVA systems

In-Space Propulsion

- Advanced chemical propulsion (restartable, reusable)
- Advanced electric propulsion (50 KW thrusters; Isp 3500 – 4000)
- Aeroassist (aerocapture @ Earth)
- Cryogenic fluids management (zero boil off)

Power Systems

- Advanced solar power generation (500W/Kg)
- Advanced power storage (fuel cells)
- Power management and distribution

Miscellaneous

- High bandwidth telecom (HDTV)
- Advanced materials (factor of 3 improvement in strength to weight ratio over Al)
- Integrated vehicle health maintenance
- Micro/Nano avionics for improved system reliability
- In-space assembly
- Automated docking and rendezvous
- Aggressive IT

Unique L2 Steppingstone Technologies (with technology goals)

Human Support

- Closed loop life support (air and water (bioregenerative) only)

In-Space Propulsion

- Advanced electric propulsion (MWs total power)

Power Systems

- Space Nuclear Power

Groundrules and Assumptions, Lunar

Program Strategy

Integrated human & robotic program to address basic questions of geologic age and evolution as defined in the Solar System Exploration Roadmap dated xxxxxxxx

. This suggests that two classes of HUMAN missions to the Moon might be justified:

(I) Short surface stay (i.e., Apollo class -- < 7 days at appropriate times) tactical studies of selected local sites in which evidence of volatiles or very recent geological activity has been directly identified via robotic reconnaissance

2) Highly mobile, long-stay missions (< 100 days) on the lunar surface the purpose of conducting field geological, geophysical, and sampling traverses

Scientific objectives and precursor requirements will be integrated to achieve the best mix to meet strategy one above.

Initial missions will lay the foundation for more comprehensive follow on missions, both robotic & human.

Human lunar missions will serve as a vital operational and engineering testbed for future human exploration activities.

Science Objectives

"Informed" sampling of lunar surface and near-surface materials for the purpose of calibration of surface ages by means of radiometric age determination ==> requires at least 3-4 samples from different sites consistent with major lunar epochs, including samples of impact melt or debris from Tycho, Copernicus, and other major impact events (for return to Earth)

In situ experiments to search for and potentially identify lunar volatiles, especially within polar regions, and ultimately sampling of such potential materials for return to Earth

Mobile subsurface E-M sounding to quantify vertical stratigraphy of key areas within the more recent context of lunar geological evolution, and to facilitate deep subsurface sampling, if warranted, via drilling.

Long range (circa 1000 km) mobile field exploration for sampling major geologic units and their contacts and measuring stratigraphic relationships in the context of lunar geological evolution

In situ search for and analysis of introduced, hermetically sealed examples of active biological materials (ie., final quest for organic molecules on the Moon)

Science Requirements

Global surface access, as well as access to complex, rugged sites identified on the basis of next-generation orbital remote sensing.

Mobility consistent with focused in sit*u science to be accomplished at* a given site. Sub-surface access to at least a depth of 3 m, and 10 m ideally

Surface residence time consisten*t with tactical in situ science* chosen beforehand on the basis of robotic reconnaissance

Power availability consistent with activities r*equired to accomplish* science drivers

Surface access to complex, rugged terrains, *including rim regions of large* impact features such as Tycho

Maximum EVA time per day of ~ 7 hours, *consistent with crew health and* safety

Mission Operation Objectives

Demonstrate technologies and operations strategies and approaches necessary for distant, long duration human spaceflight.

Demonstrate semi-autonomous medical capabilities.

Programmatic

First human mission to the Moon will occur no earlier than ~ 2011 with cargo pre-deployment prior to crew departure (as necessary).

Total mission duration (Earth-Moon-Return) should be minimized.

Crew size should be minimized but sufficient to meet science requirements and mission flight rules

Transits to and from the Moon will be in zero-g (no artificial gravity).

Lunar injection will take place from low Earth orbit.

Do not assume the need to return crews to the same site for next mission; i.e. want to achieve global access (*not restricted to equatorial landing sites*).

Shuttle equivalent capability will be available to delivery sensitive cargo and humans to orbit.

ELVs up to EELV-H will be available for payload/vehicle delivery.

Precursor Requirements and Infrastructure

Knowledge Capture

Robotic precursor missions are required to characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology. Specific knowledge includes:

Engineering Design Information:

Radiation Measurement, Characterization, & Modeling and Radiation Effects on Materials & Humans

Landing Site Characterization & Preparation

Operations Information & Experience

Experience in autonomous operations (multiple EVA & habitat crew, vehicles, telescope facilities); large team coordination (Crew size >2 EVA astronauts); human / robotic-assisted operations / teleoperations; extended duration operations; and operations traversing over extended distances

Infrastructure Emplacement

Unique infrastructure is needed to provide the physical and operational foundation to support first arrival and on-going operations of an integrated human/robotic science mission. This includes:

1. Communications / Navigation (coupled to Earth)
2. Space weather monitoring / “sentinels”
3. LEO-Based mission staging capability and capacity
4. Earth/Moon L1 staging capability and capacity
5. Earth surface-to-LEO and return capability

Specific infrastructure related to the architecture is defined as part of that architecture.

Technology Requirements

Critical Enabling Technologies (with technology goals)

Human Support

- Advanced health care systems
- Radiation protection

- Closed loop life support (air and water (bioregenerative) only)
- Space environmental assessment, control & countermeasures
- Advanced habitation
- Advanced EVA systems

In-Space Propulsion

- Advanced chemical propulsion (restartable, reusable)
- Advanced electric propulsion (50 KW thrusters up to MWs total power; Isp 3500 – 4000)
- Aeroassist (aerocapture @ Earth)
- Cryogenic fluids management

Power Systems

- Advanced solar power generation (500W/Kg)
- Advanced power storage (fuel cells)
- Power management and distribution
- Space Nuclear Power

Miscellaneous

- High bandwidth telecom (HDTV)
- Advanced materials (factor of 3 improvement in strength to weight ratio over Al)
- Integrated vehicle health maintenance
- Micro/Nano avionics for improved system reliability
- In-space assembly
- Automated docking and rendezvous
- Aggressive IT

Groundrules and Assumptions, Midterm to Mars

Mars Program Strategy

The Mars Program strategy is to use an integrated human & robotic program to address basic questions of life, resources and climate as defined in the Solar System Exploration Roadmap dated xxxxxxxx through a strategy of "follow the water. "

The overall science strategy is to conduct ever harder remote sensing, in-situ, and sample return missions as we seek to answer the scientific questions at Mars. The specific scientific investigation sequence will be developed to allow a systematic approach that builds on each successive investigation. The initial science strategy for the first human Mars mission is to:

- Follow the water to search for evidence of past or present life
- Do so with tactical geologic/biologic field studies of a region <5km in radius
- Use Mars-adapted field methods including geophysics, geology and biology
- Exhaustively assess best candidate landing sites before human visits

- Pre-deploy higher-mass equipment as needed

The first human visit is intended to be the first of multiple visits as we continue our quest for understanding of Mars.

Scientific objectives and precursor requirements will be integrated to achieve the best mix to meet strategy one above.

Initial missions will lay the foundation for more comprehensive follow on missions, both robotic & human.

Science Objectives

The first human mission has the primary scientific objective of “intelligent” sample of diversity of materials in a pre-selected local area to accomplish:

(1) Discovery of, access to, and sampling of Martian volatiles, rock materials, and localized fines both on the surface and subsurface with at minimum some form of in situ analysis;

(2) Multi-km scale field geophysical surveys conducted by human science explorers;

(3) A variety of human-tended active experiments, including "inside" sample laboratory analysis of selected samples for screening, analysis, and packaging for return to Earth.

(4) Teleoperated regional science using robots to conduct human-controlled surveys in order to focus and pathfind the most useful field study sites.

Science Requirements

Human mobility must extend at least 200 m by foot, and several km’s by vehicle.

Subsurface access is required to at least 10 m and preferably 100 m.

In situ sample screening and assessment is required.

Science instrument capabilities must address Martian water in whatever state it can be found and isolated (frozen, in hydrates, etc.).

Humans will facilitate “active” scientific experiments while on the surface of Mars.

Landing site will be pre-determined prior to launch of the human mission through robotic surveillance.

Landing requires a precision of < 1 km to the pre-selected landing site.

Capacity for return of 50 kg of samples in various forms is required.

Specific scientific investigations will include:

1. Local geophysical traverses using heat flow sensors, active seismic refraction and ground penetrating radar;
2. Subsurface core drilling in locations isolated from surface operations;
3. Elemental analysis such as laser induced mass spectrometry (LIMA)
4. Measurement of isotropic fractionation of volatiles;
5. Surface metrology
6. Sample acquisition and analysis with 20X magnification, mechanical desegregation, and screening;
7. Sample acquisition and handling to preserve bio-barrier between humans and Martian materials;
8. Tele-operated robotic devices with mm to cm scale imaging
9. Digital imaging and voice recording of all scientific activities; and
10. Set-up of scientific devices for post-human mission monitoring

Programmatic

First human mission no sooner than ~ 2018 with cargo pre-deployment prior to crew departure. Alternate cases should include 2020 and 2026 (worst case)

Total mission duration (Earth-Mars-Return) should be minimized regardless of mission opportunity.

Short Duration Mission is defined as a surface stay time with a goal of less than or equal to 30 days.

Crew size should be minimized but sufficient to meet science requirements and mission flight rules.

Interplanetary cruise will be in zero-g (no artificial gravity).

Two options for Mars injection will conducted: Low Earth orbit and High Earth Orbit

Do not assume the need to return crews to the same site for next mission; i.e. want to achieve global access (*not restricted to equatorial landing sites*). The first mission is constrained to 5 South and 65 North degrees latitude and –5500m - 0 m altitude.

Shuttle equivalent capability will be available to delivery sensitive cargo and humans to orbit.

Two options for Earth-to-Orbit will be conducted:

a. Combination of RLVs and ELVs up to EELV-H
b. Combination of RLVs and Big Dumb Boosters

A communication and navigation infrastructure will be in place at Mars as a result of the Mars Surveyor and follow-on robotic scientific missions.

Precursor Requirements and Infrastructure

Knowledge Capture

Robotic precursor missions are required to characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology. Specific knowledge includes:

Engineering Design Information:

1. Radiation Measurement, Characterization, & Modeling and Radiation Effects on Materials & Humans
2. Landing Site Characterization & Preparation
3. Mars Environmental Data:
   A. Mars Atmosphere
   B. Surface Dust and Soil
   C. Martian Surface Characterization
   D. Subsurface Soil & Physical Characteristics
   E. Crew Biomedical Concerns

Operations Information & Experience

Experience in autonomous operations (multiple EVA & habitat crew, vehicles, telescope facilities); large team coordination (Crew size >2 EVA astronauts); human / robotic-assisted operations / teleoperations; extended duration operations; and operations traversing over extended distances.

Infrastructure Emplacement

Unique infrastructure is needed to provide the physical and operational foundation to support first arrival and on-going operations of an integrated human/robotic science mission. This includes:

- Communications / Navigation (coupled to Earth)
- Space weather monitoring / “sentinels”

- LEO-Based mission staging capability and capacity
- Earth surface-to-LEO and return capability
- Non-Contaminating Sample Collection

Specific infrastructure related to the architecture is defined as part of that architecture.

Technology Requirements

Breakthrough Technologies

1. Earth-to-Orbit Transportation
   Significant improvement in launch vehicle performance in accordance with ASTP goals
2. Interplanetary Propulsion
   Option 1 - Nuclear Thermal Propulsion
   Option 2 – SEP/Chemical Propulsion
   Aerocapture
3. Advanced materials (factor of 9 improvement in strength to weight ratio over Al)

Evolutionary Technologies

1. Human Support
   - Advanced health care systems
   - Radiation protection
   - Closed loop life support (air and water)
   - Space environmental countermeasures
   - Advanced habitation
   - Advanced EVA
2. Power Systems
   - Nuclear surface power
   - Power conversion including solar
   - Regenerative fuel cells for surface power (adequate to conduct science activities)
   - Power management and distribution
3. Miscellaneous
   - Micro-lab science instruments
   - Locally deployable, teleoperated "mini-bots" for local site characterization
   - Integrated vehicle health maintenance
   - Free form fabrication for maintenance and spares
   - Micro/Nano avionics for improved system reliability
   - Robotic aggregation and assembly in LEO
   - Self repairing/ self-configuring systems

- Aggressive IT
- Cryo-fluid management

Groundrules and Assumptions, Long stay to Mars

Mars Program Strategy

The Mars Program strategy is to use an integrated human & robotic program to address basic questions of life, resources and climate as defined in the Solar System Exploration Roadmap dated xxxxxxxx through a strategy of “follow the water. “

The overall science strategy is to conduct ever harder remote sensing, in-situ, and sample return missions as we seek to answer the scientific questions at Mars. The specific scientific investigation sequence will be developed to allow a systematic approach that builds on each successive investigation. The initial science strategy for the first human Mars science mission is to:

1. Follow the water to search for evidence of past or present life
2. Do so with tactical geologic/biologic field studies of a region <5km in radius
3. Use Mars-adapted field methods including geophysics, geology and biology
4. Exhaustively assess best candidate landing sites before human visits
5. Pre-deploy higher-mass equipment as needed

The first human visit is intended to be the first of multiple visits as we continue our quest for understanding of Mars.

Scientific objectives and precursor requirements will be integrated to achieve the best mix to meet strategy one above.

Initial missions will lay the foundation for more comprehensive follow on missions; both robotic & human.

Science Objectives

Same as for short surface stay, but allows for regional access in an area of Mars specifically pre-selected to require mobility beyond the 5-10 km limits of the short surface stay and deep subsurface exploration.

MOBILE science exploration should consider a pressurized rover capable of > 100 km traverses, with ultimate goal of 250 km. Thats far enough on Mars to traverse major geochemical and geomorphological unit boundaries if the landing site is preselected carefully.

In situ laboratory equipment for adaptive studies and ideally such analyses as Mass Spectroscopy, SEM, XRD/XRFS, and other sample screening methods should be available INSIDE an isolated lab for the crew (with suitable bio-isolation).

In summary, the Long Surface Stay" mission should address similar science issues as the short stay version, but in greater depth (in situ) and facilitate the following:

(1) discovery of, access to, and sampling of martian volatiles, with at minimum some form of in situ analysis (ideally oxygen isotopic analysis?)

(2) capacity for multi-km scale field geophysical surveys conducted by human science explorers, including GPR, Seismic refraction, gravity gradiometry or at minimum gravimetry.

(3) capability for multi-unit regional human access at traverse distances of at minimum 100 km, and ideally to 250 km.

(4) capacity for a variety of human-tended active experiments, including a suite of those related to future human exploration such as ISRU (but not just the usual hydrolysis, etc. varieties).

(5) Capacity for "inside" sample laboratory analysis of selected samples for screening, analysis, and packaging for return to Earth.

(6) capacity for teleoperated regional science using microrovers, martian blimps, etc. to conduct human-controlled surveys in order to focus and pathfind the most useful field study sites.

Science Requirements

The landing site must be pre-selected and surveyed at scales of 100 Km to ensure it offers a quiltwork of possible discoveries.

Human mobility must extend at minimum 100 km, and ideally to 250 km.

Subsurface access is required to at least 100 m.

In situ sample screening and assessment is required.

Science instrument capabilities must address Martian water in whatever state it can be found and isolated (frozen, in hydrates, etc.).

Humans will facilitate "active" scientific experiments while on the surface of Mars.

Landing site will be pre-determined prior to launch of the human mission through robotic surveillance.

Landing requires a precision of <1 km to the pre-selected landing site.

The mission should return on the order of 100 kg of samples, some of which should be preserved in context, and at least one of which should include martian volatiles (frozen)

Specific scientific investigations will include:

1. Local geophysical traverses using heat flow sensors, active seismic refraction and ground penetrating radar;
2. Subsurface core drilling in locations isolated from surface operations;
3. Elemental analysis such as laser induced mass spectrometry (LIMA)
4. Measurement of isotropic fractionation of volatiles;
5. Surface metrology
6. Sample acquisition and analysis with 20X magnification, mechanical desegregation, and screening;
7. Sample acquisition and handling to preserve bio-barrier between humans and Martian materials;
8. Tele-operated robotic devices with mm to cm scale imaging
9. Digital imaging and voice recording of all scientific activities; and
10. Set-up of scientific devices for post-human mission monitoring

Programmatic

First human mission no sooner than ~ 2018 with cargo pre-deployment prior to crew departure. Alternate cases should include 2020 and 2026 (worst case)

Total interplanetary transits (Earth-Mars and Mars-Earth) should be minimized, with a goal of less than 180 days, regardless of mission opportunity.

Time spent on Mars can be varied in order to minimize total propulsive requirements.

The surface stay should be minimized as determined by orbital mechanics.

Crew size should be minimized but sufficient to meet science requirements and mission flight rules.

Interplanetary cruise will be in zero-g (no artificial gravity).

Two options for Mars injection will conducted: Low Earth orbit and High Earth Orbit

Do not assume the need to return crews to the same site for next mission; i.e. want to achieve global access (*not restricted to equatorial landing sites*). The first mission is constrained to –5 to 65 degrees latitude from the equator and 0 to -5500 km altitude.

Two options for Earth-to-Orbit will be conducted:

- Combination of RLVs and ELVs up to EELV-H
- Combination of RLVs and Big Dumb Boosters

Capabilities of the RLVs will be in accordance with the ASTP goals.

A communication and navigation infrastructure will be in place at Mars as a result of the Mars Surveyor and follow-on robotic scientific missions.

Precursor Requirements and Infrastructure

Knowledge Capture

Robotic precursor missions are required to characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology. Specific knowledge includes:

Engineering Design Information:

1. Radiation Measurement, Characterization, & Modeling and Radiation Effects on Materials & Humans
2. Landing Site Characterization & Preparation
3. Mars Environmental Data:
   A. Mars Atmosphere
   B. Surface Dust and Soil
   C. Martian Surface Characterization
   D. Subsurface Soil & Physical Characteristics
   E. Crew Biomedical Concerns

Operations Information & Experience

Experience in autonomous operations (multiple EVA & habitat crew, vehicles, telescope facilities); large team coordination (Crew size >2 EVA astronauts); human / robotic-assisted operations / teleoperations; extended duration operations; and operations traversing over extended distances.

Infrastructure Emplacement

Unique infrastructure is needed to provide the physical and operational foundation to support first arrival and on-going operations of an integrated human/robotic science mission. This includes:

- Communications / Navigation (coupled to Earth)
- Space weather monitoring / “sentinels”
- LEO-Based mission staging capability and capacity
- Earth surface-to-LEO and return capability
- Non-Contaminating Sample Collection

Specific infrastructure related to the architecture is defined as part of that architecture.

Technology Requirements

Breakthrough Technologies

1. Interplanetary Propulsion
    - Nuclear Thermal Rocket
    - Solar Electric Propulsion
    - Advanced Chemical Propulsion
    - Other concepts per the Transportation Team assessment such solar sails
    - Aerobraking
2. Advanced materials (factor of 9 improvement in strength to weight ratio)

Evolutionary Technologies

1. Earth-to-Orbit Transportation
    - Evolutionary advancement of current launch systems to meet ETO mission requirements
2. Human Support
    - Advanced health care systems
    - Radiation protection
    - Closed loop life support (air and water)
    - Space environmental countermeasures
    - Advanced habitation
    - Advanced EVA
3. Power Systems
    - Nuclear surface power (30KW)
    - Power conversion including solar (light-weight arrays @ 18% efficiency)
    - Regenerative fuel cells for surface power (adequate to conduct science activities)
    - Power management and distribution
4. Miscellaneous
    - Micro-lab science instruments

- Locally deployable, teleoperated “mini-bots” for local site characterization
- Integrated vehicle health maintenance
- Free form fabrication for maintenance and spares
- Micro/Nano avionics for improved system reliability
- Robotic aggregation and assembly in LEO
- Aggressive IT
- Cryo-fluid management (Same)

Groundrules and Assumptions, 1 Year Round Trip, Short stay to Mars

Mars Program Strategy

The Mars Program strategy is to use an integrated human & robotic program to address basic questions of life, resources and climate as defined in the Solar System Exploration Roadmap dated xxxxxxxx through a strategy of “follow the water. “

The overall science strategy is to conduct ever harder remote sensing, in-situ, and sample return missions as we seek to answer the scientific questions at Mars. The specific scientific investigation sequence will be developed to allow a systematic approach that builds on each successive investigation. The initial science strategy for the first human Mars science mission is to:

1. Follow the water to search for evidence of past or present life
2. Do so with tactical geologic/biologic field studies of a region <5km in radius
3. Use Mars-adapted field methods including geophysics, geology and biology
4. Exhaustively assess best candidate landing sites before human visits
5. Pre-deploy higher-mass equipment as needed

The first human visit is intended to be the first of multiple visits as we continue our quest for understanding of Mars.

Scientific objectives and precursor requirements will be integrated to achieve the best mix to meet strategy one above.

Initial missions will lay the foundation for more comprehensive follow on missions; both robotic & human.

Science Objectives

The first human mission has the primary scientific objective of “intelligent” sample of diversity of materials in a pre-selected local area to accomplish:

(1) Discovery of, access to, and sampling of martian volatiles, rock materials, and localized fines both on the surface and subsurface with at minimum some form of in situ analysis;

(2) Multi-km scale field geophysical surveys conducted by human science explorers;

(3) A variety of human-tended active experiments, including "inside" sample laboratory analysis of selected samples for screening, analysis, and packaging for return to Earth.

(4) Teleoperated regional science using robots to conduct human-controlled surveys in order to focus and pathfind the most useful field study sites.

Science Requirements

Human mobility must extend at least 200 m by foot, and several km's by vehicle.

Subsurface access is required to at least 10 m and preferably 100 m.

In situ sample screening and assessment is required.

Science instrument capabilities must address Martian water in whatever state it can be found and isolated (frozen, in hydrates, etc.).

Humans will facilitate "active" scientific experiments while on the surface of Mars.

Landing site will be pre-determined prior to launch of the human mission through robotic surveillance.

Landing requires a precision of <1 km to the pre-selected landing site.

Capacity for return of 50 kg of samples in various forms is required.

Specific scientific investigations will include:

1. Local geophysical traverses using heat flow sensors, active seismic refraction and ground penetrating radar;
2. Subsurface core drilling in locations isolated from surface operations;
3. Elemental analysis such as laser induced mass spectrometry (LIMA)
4. Measurement of isotropic fractionation of volatiles;
5. Surface metrology
6. Sample acquisition and analysis with 20X magnification, mechanical desegregation, and screening;
7. Sample acquisition and handling to preserve bio-barrier between humans and Martian materials;

8. Tele-operated robotic devices with mm to cm scale imaging
9. Digital imaging and voice recording of all scientific activities; and
10. Set-up of scientific devices for post-human mission monitoring

Programmatic

First human mission no sooner than ~ 2028 with cargo pre-deployment prior to crew departure.

Total mission duration (Earth-Mars-Return) should be minimized, with a goal of less than one year, regardless of mission opportunity.

Short Duration Mission is defined as a surface stay time with a goal of less than or equal to 30 days.

Crew size should be minimized but sufficient to meet science requirements and mission flight rules.

Interplanetary cruise will be in zero-g (no artificial gravity).

Do not assume the need to return crews to the same site for next mission; i.e. want to achieve global access (*not restricted to equatorial landing sites*). The first mission is constrained to 5 South and 65 North degrees latitude and –5500m - 0 m altitude.

Shuttle equivalent capability will be available to delivery sensitive cargo and humans to orbit.

Two options for Earth-to-Orbit will be conducted:

- Combination of RLVs and ELVs up to EELV-H
- Combination of RLVs and Big Dumb Boosters

A communication and navigation infrastructure will be in place at Mars as a result of the Mars Surveyor and follow-on robotic scientific missions.

Education and public outreach is required for all human and robotic Mars missions.

Precursor Requirements and Infrastructure

Knowledge Capture

Robotic precursor missions are required to characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology. Specific knowledge includes:

Engineering Design Information:

1. Radiation Measurement, Characterization, & Modeling and Radiation Effects on Materials & Humans
2. Landing Site Characterization & Preparation
3. Mars Environmental Data:
   A. Mars Atmosphere
   B. Surface Dust and Soil
   C. Martian Surface Characterization
   D. Subsurface Soil & Physical Characteristics
   E. Crew Biomedical Concerns

Operations Information & Experience

Experience in autonomous operations (multiple EVA & habitat crew, vehicles, telescope facilities); large team coordination (Crew size >2 EVA astronauts); human / robotic-assisted operations / teleoperations; extended duration operations; and operations traversing over extended distances.

Infrastructure Emplacement

Unique infrastructure is needed to provide the physical and operational to support first arrival and on-going operations of an integrated human/robotic science mission. This includes:

- Communications / Navigation (coupled to Earth)
- Space weather monitoring / “sentinels”
- LEO-Based mission staging capability and capacity
- Earth surface-to-LEO and return capability
- Non-Contaminating Sample Collection

Specific infrastructure related to the architecture is defined as part of that architecture.

Technology Requirements

Breakthrough Technologies

1. Earth-to-Orbit Transportation
   Significant improvement in launch vehicle performance in accordance with ASTP goals
2. Interplanetary Propulsion
   Option 1 - Nuclear Thermal Propulsion
   Option 2 – SEP/Chemical Propulsion
   Aerobraking
3. Advanced materials (factor of 40 improvement in strength to weight ratio)

Evolutionary Technologies

1. Human Support
    - Advanced health care systems
    - Radiation protection
    - Closed loop life support (air and water)
    - Space environmental countermeasures
    - Advanced habitation
    - Advanced EVA
2. Power Systems
    - Nuclear surface power
    - Power conversion including solar
    - Regenerative fuel cells for surface power (adequate to conduct science activities)
    - Power management and distribution
3. Miscellaneous
    - Micro-lab science instruments
    - Locally deployable, teleoperated “mini-bots” for local site characterization
    - Integrated vehicle health maintenance
    - Free form fabrication for maintenance and spares
    - Micro/Nano avionics for improved system reliability
    - Robotic aggregation and assembly in LEO
    - Self repairing/ self-configuring systems
    - Aggressive IT
    - Cryo-fluid management

Groundrules and Assumptions, Asteroids

Program Strategy

The program strategy is to use an integrated human & robotic program to address basic questions about the formation and evolution of the solar system and the characterization of asteroids as defined in the Solar System Exploration Roadmap dated xxxxxxxx. The existing strategy for asteroidal science calls for understanding compositional and assembly history, as well as diversity.

The overall science strategy is to conduct ever harder remote sensing, in-situ, and sample return missions as we seek to answer the scientific questions about asteroids. The specific scientific investigation sequence will be developed to allow a systematic approach that builds on each successive investigation.

The initial strategy for the first human asteroid mission has not yet been defined. However, the first human visit is intended to be the first of multiple visits as we continue our quest for understanding of the solar system.

Scientific objectives and precursor requirements will be integrated to achieve the best mix to meet strategy one above.

Initial missions will lay the foundation for more comprehensive follow on missions; both robotic & human.

Science Objectives

The first human mission has the primary scientific objective of “intelligent” sampling of diversity of materials to accomplish:

(1) Asteroidal surface material diversity and absolute age relationships

(2) internal structure and assembly history

(3) Compositional diversity from samples of competent materials

(4) Regolith thickness and development/evolution time (from samples) Long-term (1 year?) monitoring of asteroidal surface and internal environments

(5) Measure 3D stratigraphy of asteroidal surface layer and sample materials necessary for calibrating absolute surface ages and ultimately the evolutionary history of the object (requires Samples...)

(6) Conduct long-term measurements of environmental (space) conditions on asteroidal object on the basis of human-emplaced infrastructure ("leave behind").

Science Requirements

Access to any surface location on an asteroidal surface (global access); Human mobility must extend at least 200 m by foot.

Tools to access and measure aspects of the subsurface, especially that region beneath any regolith layer

Local mobility consistent with pre-human reconnaissance that enables visitation of key surficial units

Surface residence times of at least 20-30 days to achieve the real-time in situ science and the time necessary to set up 'leave-behind' robotic systems for sustained (post-human) measurements (i.e., of local asteroidal environmental conditions and internal responses to an orbital cycle)

Pre-landed reconnaissance by the human surface descent or orbiting return vehicle to evaluate additional landing site conditions

In situ sample screening and assessment is required.

Humans will facilitate “active” scientific experiments while on the surface of asteroids.

Landing site will be pre-determined prior to launch of the human mission through robotic surveillance.

Capacity for return of 50 kg of samples in various forms is required.

Programmatic

First human mission no sooner than ~ 2017.

Total mission duration (Earth-Mars-Return) should be minimized regardless of mission opportunity.

Surface stay time with a goal of less than or equal to 30 days.

Crew size should be minimized but sufficient to meet science requirements and mission flight rules.

Interplanetary cruise will be in zero-g (no artificial gravity).

Two options for asteroid injection will conducted: Low Earth orbit and High Earth Orbit

Do not assume the need to return crews to the same asteroid for next mission.

Shuttle equivalent capability will be available to delivery sensitive cargo and humans to orbit.

Only one option for Earth-to-Orbit will be conducted: Combination of RLVs and Big Dumb Boosters

Precursor Requirements and Infrastructure

Knowledge Capture

Robotic precursor missions are required to characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology. Specific knowledge includes:

Engineering Design Information:

1. Radiation Measurement, Characterization, & Modeling and Radiation Effects on Materials & Humans
2. Landing Site Characterization & Preparation
3. Surface Environmental Data:
   A. Surface Dust and Soil Characterization
   B. Subsurface Soil & Physical Characteristics
   C. Crew Biomedical Concerns

Operations Information & Experience

Experience in autonomous operations (multiple EVA & habitat crew, vehicles, telescope facilities); large team coordination (Crew size >2 EVA astronauts); human / robotic-assisted operations / teleoperations; extended duration operations; and micro-g operations on rotating asteroid surfaces...

Infrastructure Emplacement

Unique infrastructure is needed to provide the physical and operational foundation to support first arrival and on-going operations of an integrated human/robotic science mission. This includes:

- Communications / Navigation (coupled to Earth)
- Space weather monitoring / "sentinels"
- LEO-Based mission staging capability and capacity
- Earth surface-to-LEO and return capability
- Non-Contaminating Sample Collection

Specific infrastructure related to the architecture is defined as part of that architecture.

Technology Requirements

Breakthrough Technologies

1. Earth-to-Orbit Transportation

Significant improvement in launch vehicle performance in accordance with ASTP goals

2. Interplanetary Propulsion
   - Nuclear Thermal Propulsion
   - Aerobraking
3. Advanced materials (factor of 9 improvement in strength to weight ratio)

Evolutionary Technologies

1. Human Support
   - Advanced health care systems
   - Radiation protection
   - Closed loop life support (air and water)
   - Space environmental countermeasures
   - Advanced habitation
   - Advanced EVA
2. Power Systems
   - Nuclear surface power
   - Power conversion including solar
   - Regenerative fuel cells for surface power (adequate to conduct science activities)
   - Power management and distribution
3. Miscellaneous
   - Micro-lab science instruments
   - Locally deployable, teleoperated "mini-bots" for local site characterization
   - Integrated vehicle health maintenance
   - Free form fabrication for maintenance and spares
   - Micro/Nano avionics for improved system reliability
   - Robotic aggregation and assembly in LEO
   - Self repairing/ self-configuring systems
   - Aggressive IT
   - Cryo-fluid management