# *Overview of Mars Technology Program*

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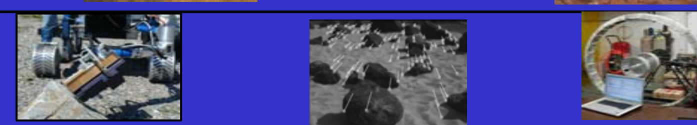
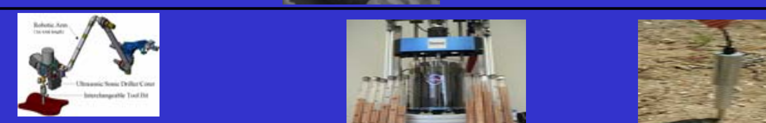
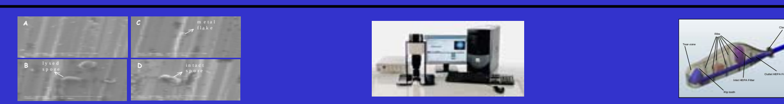
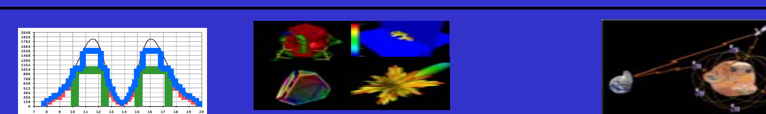
# *Outline*

- *Goals of technology program*
- *Elements of technology program*
- *Program metrics*
- *Major accomplishments*
- *Examples*
- *Information about Mars Technology Program*

# *Technology Program Objectives*

- *Develop a technology program for future Mars missions*
- *Develop required technologies for future Mars missions*
- *Develop technologies to enable new types of missions currently not possible*
- *Acquire technologies for Mars missions via competition and when appropriate through direct assignments*


| Capabilities | Examples |
|---|---|
| Land more payload mass on higher altitudes more accurately |  |
| Access to sites with terrain too complex for landing current rovers |  |
| Increase mobility and autonomy |  |
| Access the subsurface and acquire samples for in-situ analysis |  |
| Enable improved science instruments |  |
| Protect Mars via planetary protection techniques |  |
| Enable Mars sample return |  |
| Develop capabilities for in-situ sample acquisition, preparation, and distribution systems |  |
| Develop proximity telecommunication technologies |  |

# *Mars Technology Program (MTP)*

- *MTP is an integral part of Mars Program (all funds are provided by Mars Program). It is managed at JPL within the Mars Exploration Program for NASA.*
- *MTP funds technology developments that are specific to Mars*
- *MTP leverages other technology programs such as:*
  - *In-Space Propulsion Technology Project*
  - *IS Program*
  - *ESMD technology program*
  - *ASTEP, PIDDP, ASTID, ESTC, etc.*
- *Program is comprised of four elements:*

Focused Technology

Base Technology

Studies

Technology Testbeds

# Technology Planning Process

**Science Office** → **Science Goals, etc.** → **Advanced Studies Office** → **Technology Needs** → **Technology Office**

- *MEPAG*
- *SAG'S*

*Candidate Program/ Mission Sequences*

- *Mission Concepts*
  - *Technology*
  - *Mission Development*
  - *Mission Ops*
  - *LV*

*Tech Plans*

- *Focused Tech Program Plans*
- *Base Tech Plans*

Review by
Mars Program Systems Engineering Team (MPSET)

# *Focused Technology*

- ***Focused Technology*** *is aimed at advancing enabling technologies to TRL 6 by the PDR of specified missions.*
- *Missions will manage focused technologies, with MTP oversight, with flight project discipline, including cost, schedule, and reviews.*
- *Technology plans are aligned as project's needs are consolidated*
- *Technologies deemed no longer required for a particular mission are continued if significant investments were made and future missions are beneficiaries.*
- *Focused technology programs have start and end dates and allocated funds*
- *Technology validations are performed within focused technology tasks*

# *Base Technology*

- ***Base Technology*** *addresses technology advances for multiple missions including technologies that will enable new mission types*
- *The following technology areas were selected by consulting an "expert" team and with the agreement of Mars program manager and NASA HQ (see next page)*

# *Base Technology*

*Eight areas have been identified as high priority technology areas for Mars missions*

**Proximity Telecom/Navigation**

Rover Technology

Subsurface Access

Planetary Protection

Advance EDL

Low Cost Mission Technologies

Mars Science Instruments

Advanced Electronics

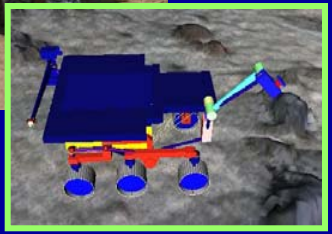
*Currently, 95 tasks are within the Base Program*

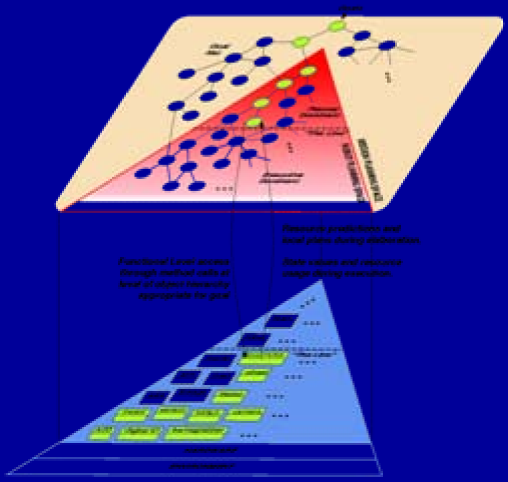
# Studies

- *Technology planning is also supported by studies for better understanding of:*
  - *State of the art*
  - *Determining feasibility and technical approach*
  - *Cost and schedule*
- *Many of these studies are co-funded and co-managed by MTP and Advanced Studies Office*
  - *Examples are:*
    - *Pin-point landing*
    - *Increased mass landing on Mars*
    - *Night driving*
    - *ISRU*
    - *Aeroshell measurement sensors*
    - *MSR technology*
    - *Etc.*

# Technology Testbeds

- Technology Testbeds are physical or software testbeds designed to integrate component technologies to develop capabilities and provide a facility for validation
- Examples are:
  - CLARAty/Dsend/ROAMS software environments
  - Technology rovers (at Ames/ JPL/ CMU)
  - Drill specific planning and control software
  - Controlled environment for testing drilling technologies
  - Rover facility for MIDP instrument testing in the field





# *Program Performance*

- *Three metrics have been selected to assess MTP performance:*
  - *Technology infusion into Mars missions*
    - *Focused Technology*
    - *Base Technology*
  - *Technology Readiness Levels (TRL)*
    - *TRL advancements*
  - *Publications, NTRs, Patents*

# *Major Accomplishments*

- *Four new technologies are being infused into MER, if successful, this brings the total technologies infused into MER to 14*
- *All three focused technologies developed for MRO have been successfully infused to the project*
- *Three technologies are infused into Phoenix Project (mostly from Base technology program)*
- *MSL focus technology has been very successful in developing relevant technologies that have very high probability of infusion. Current best estimate is that 60% funds used in MSL technology will be used by the mission.*

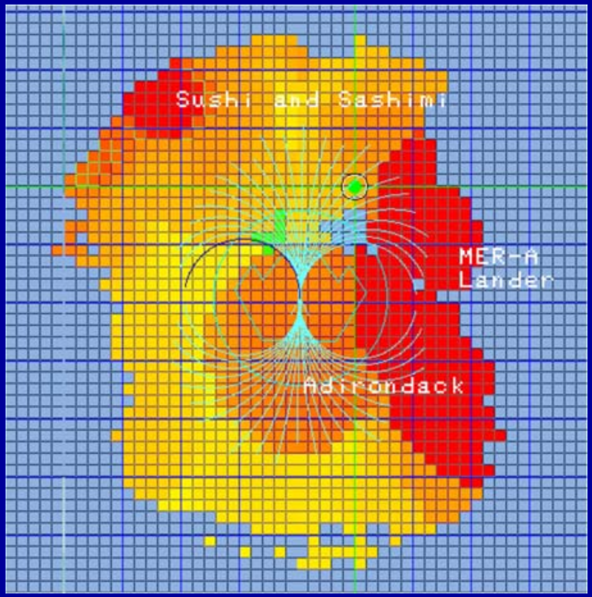
# MER

| | Technology | Funding Source | Description | PI/Technologist |
|---|---|---|---|---|
| 1 | Long Range Science Rover | NASA (Code R and MTP) | Provides increased traverse range of rover operations, improved traverse acuracy, landerless and distributed ground operations with a large reduction in mass | Samad Hayati<br>Richard Volpe |
| 2 | Science Activity Planner | NASA (Code R and MTP) | Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists | Paul Backes<br>Jeff Norris |
| 3 | FIDO: Field Integrated Design and Operations Rover | NASA (MTP) | Developed TRL 4-6 rover system designs, advancing NASA capabilities for Mars exploration; demonstrated this in full-scale terrestrial field trials, Integrated/operated miniaturized science payloads of mission interest, coupling terrestrial field trials to flight requirements | Paul Schenker<br>Eric Baumgartner |
| 4 | Manipulator Collision Prevention Software | NASA (MTP) | Computationally efficient algorithm for predicting and preventing collisions between manipulator and rover/terrain. | Eric Baumgartner<br>Chris Leger |
| 5 | Descent Image Motion Estimation System (DIMES) | NASA (Code R and MTP) | Software and hardware system for measuring horizontal velocity during descent, Algorithm combines image feature correlation with gyroscope attitude and radar altitude measurements. | Andrew Johnson<br>Yang Cheng<br>et al. |
| 6 | Parallel Telemetry Processor (PTeP) | NASA (Code R and MTP) | Data cataloging system from PTeP is used in the MER mission to catalog database files for the Science Activity Planner science operations tool | Mark Powell<br>Paul Backes |
| 7 | Visual Odometry | NASA (MTP) | Onboard rover motion estimation by feature tracking with stereo imagery, enables rover motion estimation with error < 2% of distance traveled | Larry Matthies<br>Yang Cheng |
| 8 | Rover Localization and Mapping | NASA (MTP) | An image network is formed by finding correspondences within and between stereo image pairs, then bundle adjustment (a geometrical optimization technique) is used to determine camera and landmark positions, resulting in localization accuracy good for travel up 1 km | Ron Li<br>Clark Olson<br>et. al. |
| 9 | Grid-based Estimation of Surface Traversability Applied to Local Terrain (GESTALT) | NASA (Code R and MTP) | Performs traversability analysis on 3-D range data to predict vehicle safety at all nearby locations; robust to partial sensor data and imprecise position estimation. Configurable for avoiding obstacle during long traverse or for driving toward rocks for science analysis | Mark Maimone |
| 10 | Lithium-Ion Batteries | NASA (Code R and MTP), Air Force (AFRL) | Significant mass and volume savings (3-4 X) compared to the SOA Ni-Cd and Ni-H2 batteries. | Richard Ewell<br>Rao Surampudi |
| **New Technology Infusion (in Progress, passed flight upload gate review, Jume 2006)** | | | | |
| 11 | Automated instrument placement | MTP Base (JPL) | Enable final target approach and instrument placement within single command cycle | Chris Leger |
| 12 | Automated tracking to approach designated rocks autonomously | MTP Base (JPL/ARC) | Enable flight demonstrations of 10-m target tracking on Martian surface using MER navcam stereo cameras. | Won Kim |
| 13 | On-Board global path planning | MTP Base (CMU/JPL) | Smarter negotiation around extended obstacles (added capability to GESTALT) | Arturo Rankin<br>Tony Stenz |
| 14 | Autonomous science to detect dust devils | IS Program, NMP, MTP | Onboard detection and tracking of dust devils and clouds | Steve Chien<br>Ronald Greeley |

# MER

## *GESTALT*

*Visualization of map with color-coded traversability and candidate driving paths for evaluation*



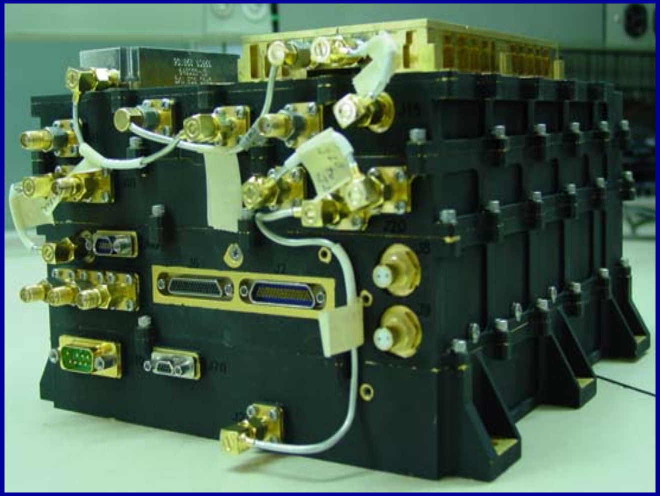

*Actual map built from MER Spirit imagery*

- ***PRODUCT DESCRIPTION***
  - *<u>**G**</u>rid-based <u>**E**</u>stimation of <u>**S**</u>urface <u>**T**</u>raversability <u>**A**</u>pplied to <u>**L**</u>ocal <u>**T**</u>errain*
  - *World modeling and autonomous driving software used onboard MER flight rovers and in MER ground operations*
  - *Performs traversability analysis on 3-D range data to predict vehicle safety at all nearby locations; robust to partial sensor data and imprecise position estimation*
  - *Configurable for avoiding obstacle during long traverse or for driving toward rocks for science analysis*
- ***CURRENT and FUTURE USERS/APPLICATIONS***
  - *MER'03: used on Spirit and Opportunity rovers*
  - *MSL' 09 and any future rover mission*
  - *Potential defense and commercial use for collision avoidance*
- ***Sponsorship***
  - *Mars Exploration Program since 1999 (developed for MER, building on prior, NASA-funded, university research in the 1990's)*
- ***Key Technologist***
  - *Dr. Mark Maimone, JPL*
- ***Licensees***
  - *Carnegie Mellon University, NASA Ames Research Center for use in NASA-funded R&D*

# *MRO*

***Electra***

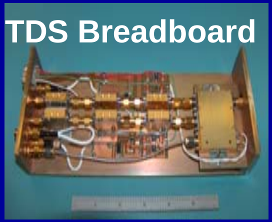
- *Developed and delivered an EM as part of Electra Payload project. This constitutes MTP's first successful hardware development that will be used by baselined and future Mars missions.*
- *Electra radio is currently on MRO and will be used on MSL*



***Optical Navigation Camera***

- *Developed and delivered a flight unit conducted experiments successfully*
- *The Optical Navigation Camera experiment successfully acquired and processed 480 images during MRO's approach phase.*
- *Analysis of the data residuals indicates that objective of nav error  to be less than 1-2 km has been achieved.*
- *Data analysis is in progress and will complete this FY*

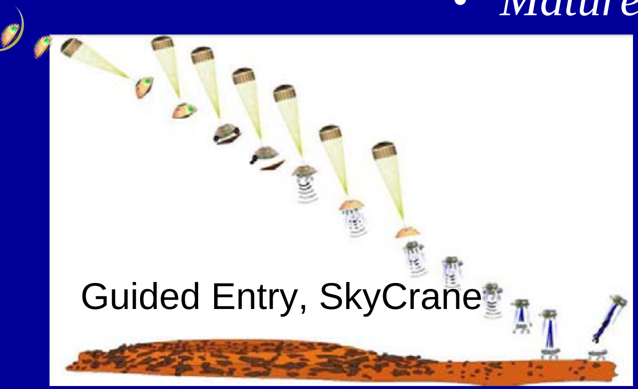
# *MSL*



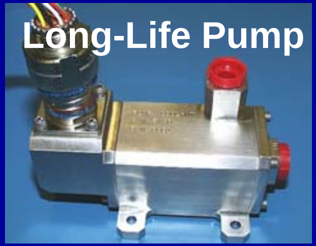



## ***Program Objectives***

- *Develop technology for MSL Entry, Descent, and Landing (EDL) and Surface Systems which will enable new capabilities including:*
  - *Precision Guided Entry*
  - *Robust Touchdown System*
  - *Long-lived Mobility Asset*
  - *Efficient Surface Ops*
  - *Sample Acquisition & Distribution*
- *Mature technologies to TRL 6 by MSL PDR*





- ***Completed "Development" program for Mars Lander Engine (including new throttle valve assembly)***
  - *Completed Design Verification Test (nearly equivalent to full flight qualification test program)*
  - *3 development engines tested—DEV3R meets all performance requirements with margin*

- ***SOA: Viking engine***
  - *Updated to SOA materials and catalyst bed retention for MSL*
  - *MSL single nozzle modification produces higher performance*
  - *New "cavitating" throttle valve design achieves <1% to >100% thrust range*

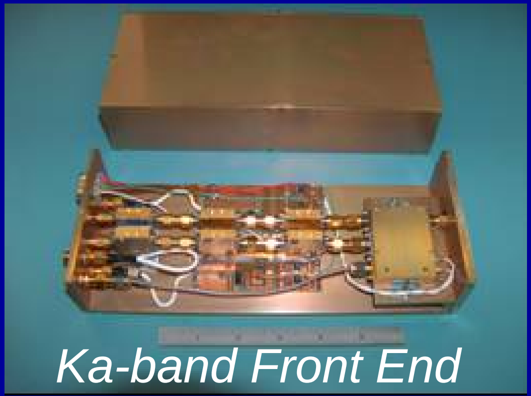

Mars Lander Engine


Viking Engine

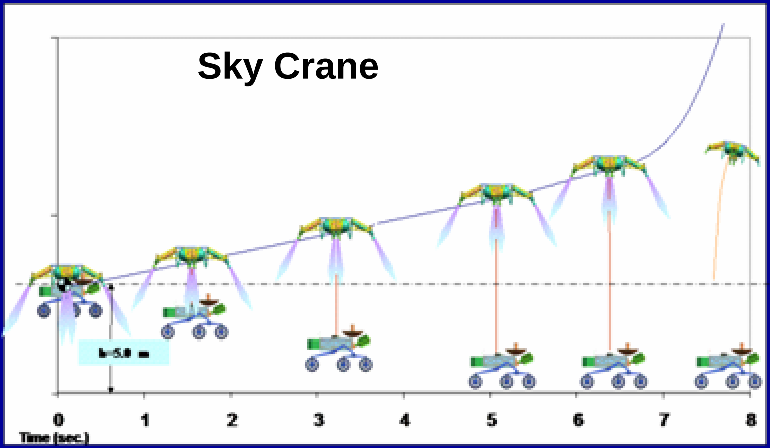

MSL Throttle Valve Assembly

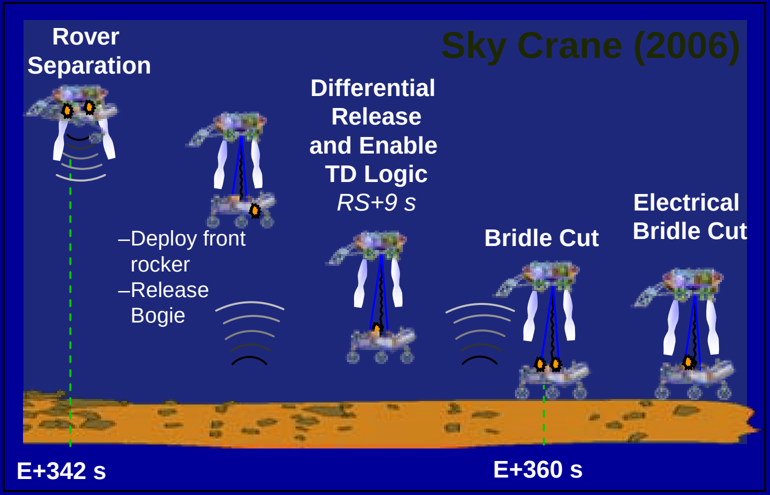
- ***Completed fabrication and testing of Terminal Descent Sensor Breadboard***
  - *Ka-band radar with electronics and real-time processing heritage to MSLFT Phased Array Terrain Radar program (FY03-FY04)*
  - *Better than 10cm/s velocity and 10 cm range performance*
  - *Matured design and operations concept for MSL flight unit development*
- ***SOA: Wide-beam altimeter/velocimeter (Phoenix) or helicopter velocity sensor***
  - *Performance improved by more than 10x over Phoenix sensor and 2x better than helicopter sensors (which lack ranging)*
  - *Ka-band narrows beamwidth (reducing velocity & ranging errors) and improves velocity precision*


TDS Breadboard Rack


Ka-band Front End

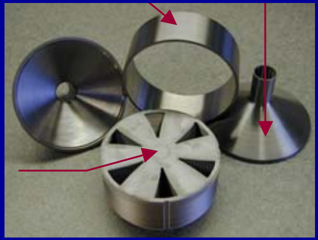
- ***Matured the Skycrane concept (in close collaboration with Project)***
  - *Successfully realized a robust Skycrane design through comprehensive analysis/testing and numerous external/peer reviews*
  - *Contributed to designs of testbeds including development of 1 d.o.f. motion control and mini-TDT*
- ***SOA: Airbag or Legged Landing***
  - *Airbag landing can not support MSL size rover*
  - *Legged landing poses complications with engine shutdown, landing on sloped terrain, and egress*



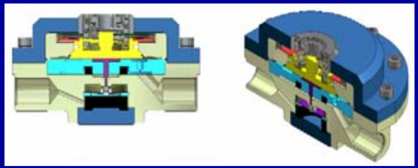



# *Propulsion Technologies**

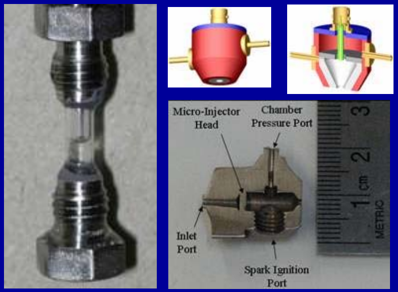
*Develop the capability to manufacture an ultralight diaphragm tank, cut the mass of a diaphragm tank in half (JPL/ATK/PSI)*



*The primary objective is to develop a propulsion filter component design with reliable, high efficiency and especially low mass filtration technologies (VACCO)*



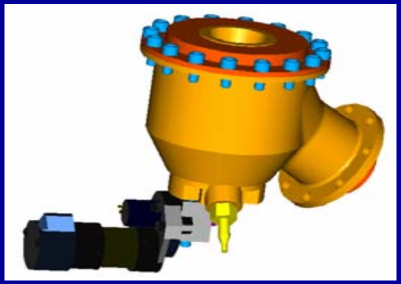
*Develop a low mass breadboard design TRL 3-4 of a helium feed propulsion system regulator/filter module to TRL 6 in 2 ½ years (VACCO)*




*Produce a ~300s Isp monopropellant blend that is low cost, non-toxic, self-pressurizing, deep-space-storable (JPL, Firestar Engineering, Colorado School on Mines)*

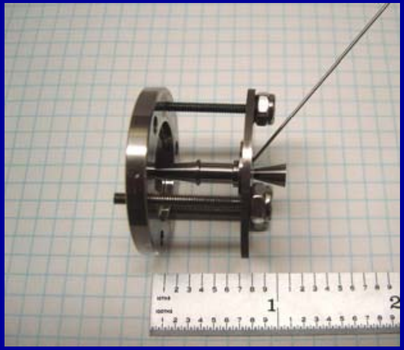
***** *(For further Information contact Ron Reeve at JPL)***

# *Propulsion Technologies**



*Develop clean, high energy, vacuum- & space-compatible solid propellants; optimize physical properties for cold temperature operation; demonstrate the selected propellant in a heavyweight gas generator (ATK)*

*Develop a quad piston propellant pump with the following characteristics: high liquid throughput, low mass, high pressure rise, low gas consumption, and long lifetime (Lawrence Livermore National Laboratories, Aerojet)*



*Develop a milli-Newton class hydrazine thruster that will replace reaction wheels, providing: Mass savings of ~ 10 kg., 3x – 5x reduction in system peak power (Watts), and average energy consumed (W-hrs). Cost savings of $0.5M - $2M per (JPL)*

***** (For further Information contact Ron Reeve at JPL)***

*For more information: http://marstech.jpl.nasa.gov*

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    - Subsurface Access
    - Low-Cost Mission Technologies
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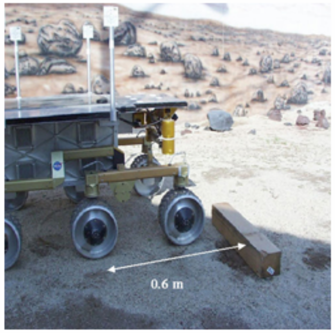
- PARTICIPANTS

## OVERVIEW

NASA is pursuing an aggressive, science-driven agenda of robotic exploration of Mars with a series of orbiters and landers. These missions carry science instruments selected to answer questions the planetary science community has posed to better characterize the planet (See Mars Exploration Program Analysis Group, MEPAG). The overarching objective is increased understanding with regard to Life, Climate, Geology, and Preparation for Human Exploration.

Many new technologies need to be developed and infused into future Mars missions, which demand the following capabilities:




Rover Navigation Algorithm Validation

- Better landing accuracy, with active hazard-detection-and-avoidance capability.
- Access to high-priority sites with terrain too complex for landing current rovers.
- Increased mobility to sample diverse geological sites and reach targets of interest.
- Longer-lived, more robust and higher-output energy systems to allow year and longer surface operations in a greater range of adverse conditions.
- Technologies to access the subsurface and acquire samples for in situ analysis.
- New and improved science instruments.
- In situ sample acquisition, preparation, and distribution systems.
- Increased autonomy to enable increased return of high-priority science.
- Planetary protection techniques.
- Technologies for possible return of samples to Earth for analysis.

The Mars Technology Program (MTP) is responsible for technology-development plans that are consistent with NASA's Mars Exploration vision, and implementing and infusing those technologies into future missions.

Technologies are selected for development funding by competitions via NASA Research Announcements (NRA) and by direct funding when appropriate.