Phoenix – The First Mars Scout Mission (A Mid-Term Report)

Barry Goldstein
Jet Propulsion Laboratory, United States
barry.g.goldstein@jpl.nasa.gov

Robert Shotwell
Jet Propulsion Laboratory, United States
robert.shotwell@jpl.nasa.gov

Abstract

As the first of the new Mars Scouts missions, the Phoenix project was selected by NASA in August of 2003. Over its initial 18 months, the project has completed it's advertised formulation phase activities, and has recently been approved for continuation to formulation, culminating in a launch planned for August 3, 2007. The Mars Scouts missions are Principle Investigator (PI) led, lower cost missions, intended to be responsive to previous discoveries of the Mars Program. Mr. Peter Smith from the University of Arizona is the PI for Phoenix.

Phoenix "Follows the water" responding directly to the recently published data from Dr. William Boynton, PI (and Phoenix co-I) of the Mars Odyssey Gamma Ray Spectrometer (GRS). GRS data indicate extremely large quantities of water ice (up to 50% by mass) within the upper 50 cm of the northern polar regolith. Phoenix will fly the inherited Mars Surveyor program 2001 lander, and will land within this north polar region (65N – 72N) identified by GRS and provide in-situ confirmation of this extraordinary find. Our mission will investigate water in all its phases, and will investigate the history of water as evidenced in the soil characteristics that will be carefully examined by the powerful suite of onboard instrumentation. Access to the critical subsurface region expected to contain this information is made possible by a 3rd generation robotic arm capable of excavating the expected Martian regolith to a depth of 1m.

Phoenix has four primary science objectives:

1) Determine the polar climate and weather, interaction with the surface, and composition of the lower atmosphere around 70° N for at least 90 sols focusing on water, ice, dust, noble gases, and CO2. Determine the atmospheric characteristics during descent through the atmosphere.

2) Characterize the geomorphology and active processes shaping the northern plains and the physical properties of the near surface regolith focusing on the role of water.

3) Determine the aqueous mineralogy and chemistry as well as the adsorbed gases and organic content of the regolith. Verify the Odyssey discovery of near-surface ice.

4) Characterize the history of water, ice, and the polar climate. Determine the past and present biological potential of the surface and subsurface environments.

This paper will cover the mission design, progress made in the formulation phases, key system trades, future plans and challenges.

Introduction

The first of a new series of highly ambitious missions to explore Mars, Phoenix, was selected in August 2003 to demonstrate the NASA Mars Program's effort at responsive missions to supplement the Program's systematic, long term planned exploration of Mars. These competed, PI-led missions are intended to be lower cost missions that are responsive to discoveries made through this systematic program of exploration. Mr. Peter Smith from the University of Arizona is the Principle Investigator for Phoenix. Peter Smith has a long history of Mars science and has been actively involved in the exploration of Mars from the Mars Global Surveyor through the development of the HiRISE telescope being flown on the Mars Reconnaissance Orbiter.

Phoenix "Follows the water" responding directly to the recently published data from Dr. William Boynton, PI (and Phoenix co-I) of the Mars Odyssey Gamma Ray Spectrometer (GRS). GRS data indicate extremely large quantities of water ice (up to 50% by mass, Fig 1) within the upper 50 cm of the northern polar regolith. Phoenix, a reflight if the inherited Mars Surveyor program 2001 lander, will land within this north polar region (65N – 72N) identified by GRS and provide in-situ confirmation of this extraordinary find.

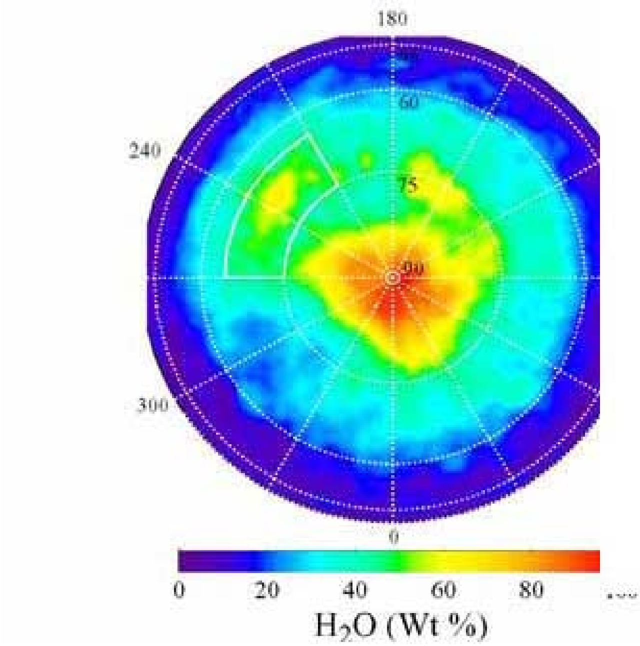
Phoenix will investigate water in all its phases, and will investigate the history of water as evidenced in the soil characteristics that will be carefully examined by the powerful suite of onboard instrumentation. Access to the critical subsurface region expected to contain this information is made possible by a 3rd generation robotic arm capable of excavating the expected Martian regolith to a depth of 1m.

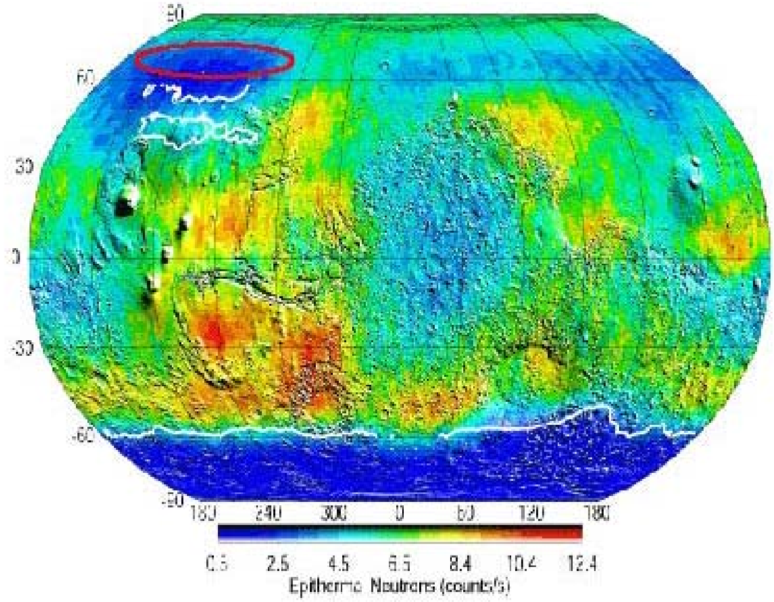
Phoenix has four primary science objectives:

1) Determine the polar climate and weather, interaction with the surface, and composition of the lower atmosphere around 70° N for at least 90 sols focusing on water,

Figure 1. Below left, recent GRS data identifying large quantities of near subsurface ice in the 70 North region of Phoenix interest. To the right, a global distribution of epithermal neutrons indicating water rich sites. The zone identified is a prime candidate site for

Phoenix.





2

ice, dust, noble gases, and CO2. Determine the atmospheric characteristics during descent through the atmosphere.

2) Characterize the geomorphology and active processes shaping the northern plains and the physical properties of the near surface regolith focusing on the role of water.

3) Determine the aqueous mineralogy and chemistry as well as the adsorbed gases and organic content of the regolith. Verify the Odyssey discovery of near-surface ice.

4) Characterize the history of water, ice, and the polar climate. Determine the past and present biological potential of the surface and subsurface environments.

Additionally, Phoenix will address several key areas in the preparation for human exploration of Mars (MEPAG section IV).

This rich set of investigations is made possible through a selected set of instrumentation previously selected for the Mars Polar Lander and MSP 2001 missions and augmented by a Canadian Space Agency provided Meteorological Station including a Lidar system. The mission timeline for the Phoenix investigation is shown in figure 2. The remainder of this paper will provide more details of the mission, focusing on the project accomplishments over the past two years preparing for the upcoming integration phase leading to launch.

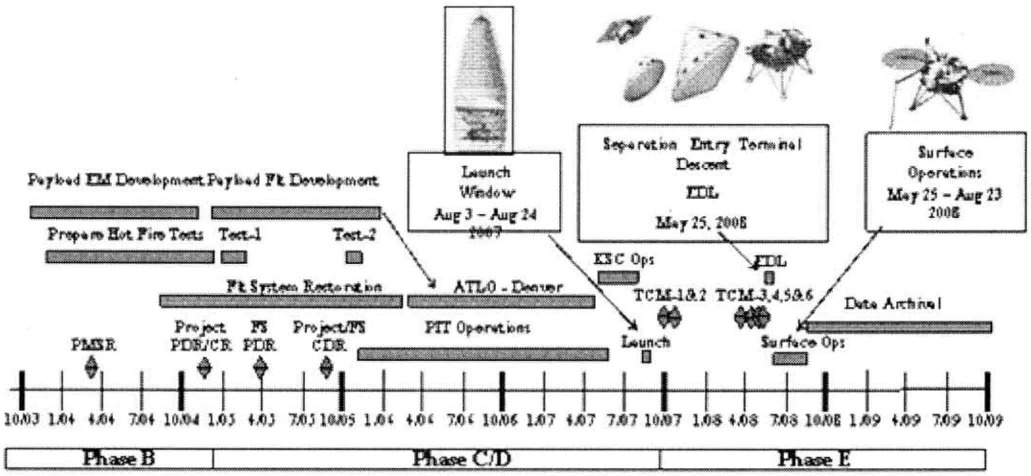


Figure 2 – Phoenix Mission Timeline

Phoenix Science

The rich suite of instruments that will be flown on Phoenix enable a vast array of scientific observations to be made. These measurements have been organized into 5 main themes:

Present Climate
Geomorphology and Physical Properties
Chemistry and Mineralogy
Biological Potential

Present Climate

The surface–atmosphere interaction, particularly the exchange of volatiles—is important to understanding the present and past climate of Mars. The Phoenix mission tests the hypothesis that diffusive transport into the regolith has produced substantial subsurface layers of ice.

Additionally, an important climatic question for Mars is whether the global water cycle is closed on an annual basis. The question stems from the hemispheric asymmetry in the polar caps. The northern cap is three times large than the southern cap and is predominantly water ice, while the southern is comprised primarily of CO_2 ice. Water vapor transport and water ice clouds in the North Polar region of Mars are not well understood. While interannual variations in the appearance of the north polar cap have been interpreted as being caused by dust storms, these variations occur seasonally, indicating possible water ice deposition late in the summer season. Water ice clouds may play a significant climatic role by retaining water in, and scavenging water to, the northern hemisphere. This mechanism may explain the asymmetry observed in the polar caps.

Diurnal changes in the local atmosphere and surface properties are unmeasured at high latitudes. Current observations of opacity suggest the formation of water ice clouds at night and subsequently evaporating during the day as temperatures rise. Direct measurement of many of the key characteristics (Fig 4) that play a role in the northern atmospheric behavior will support developing models of mesoscale atmosphere at Mars by providing ground truth and empirical data.

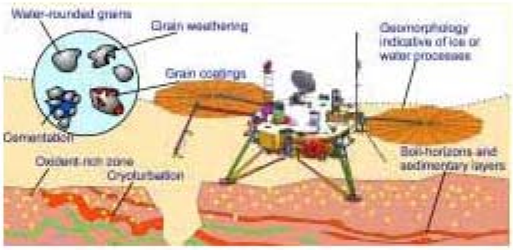


Figure 4. Phoenix retrieves and analyzes atmospheric, surface and subsurface samples. Imagery will show surface features from km to sub-mm scales. Images of samples acquired by the arm will detail grain structure down to micron scales assisting physical interpretation of water interaction processes.

Geomorphology and Physical Properties

The history of water may be written in the soils. Chemical and geological evidence allows us to read this record of water and the processes that control its distribution and phases. What is the origin of the ice layer, and how does it interact with the atmosphere? Once emplaced, has it gone through freeze–thaw cycles? How do local processes link with the global water cycle?

The surface is both source and sink for water, depending on local conditions. The atmosphere transports the water vapor, removing it from some sites and depositing it at others. The details depend on a complex interplay of surface characteristics (porosity, composition, albedo, stratigraphy), atmospheric properties (temperature, circulation patterns, humidity), and insolation (variable on daily, seasonal, and geological time scales). Adding further complexity to the history of water in the northern hemisphere are geologic processes that may have contributed stochastically to the cycle by introducing large amounts of water at specific locations through outflow channels, perhaps even creating oceans. The fate of the water released by the outflow channels—even if "oceans" did not form—is unknown. Did the water evaporate away or percolate to aquifers under the surface? Because the upper meters of soil undergo saturation/desiccation cycles on 10' [illegible]

As shown in Figure 5, shallow subsurface ice could result from several processes:

- Diffusive transport into the regolith from the atmosphere
- Seepage of subpolar liquid water (e.g., from groundwater or basal melting) into the circumpolar regolith
- A remnant of an older, larger ice sheet
- Residual surface snow or remnant high-latitude snow deposits
- The frozen residue of an ancient ocean

Figure 5. Four leading hypothesis explain the presence of shallow subsurface ice: imported by diffusion from the atmosphere, remnant of a receded ice front, subglacial melting, or residue from an ancient water body.

Diffusive transport into and out of the regolith is a seasonal process that occurs on both Mars and Earth. Therefore, expectations are high that volatiles will be found in the polar regions a few tens of cm below the surface. Finding this volatile layer was a primary goal of the Mars Polar Lander (MPL), although the enormity of the ice signature seen by Odyssey brings the diffusive model into question. Another possibility is that a blanket of ice or snow has retreated, subliming to a depth where it comes to equilibrium with the atmosphere. In this case, we might find solid ice intermixed with dust below a transition region. Neither diffusive transport nor retreat of an ice cover requires large amounts of liquid water.

The landing site for Phoenix is in an area also hypothesized to have been a deep ocean basin in the planet's distant past. The salinity of such an ancient ocean or the amount of dissolved CO_2 is unknown, but the eventual evaporation or sublimation of this water body might have left sedimentological evidence accessible to Phoenix. However, ice-rich regions also occur in the south where past oceans are not suspected. Excavating the trench allows Phoenix to search for several clues to the origin of the circumpolar ice:

- Possible layering relationships between the ice and the soil
- Depth at which the ice is encountered
- Relationship between the ice volume and the soil porosity
- Density and "solidity" of any ice layers ("fluffy" versus "compact")
- Post depositional distortions to the ice/soil layers

Indications of abundant liquid water on early Mars might come from fine, clastic sediments, such as layers of indurated mud and silt. Coarser clastic sediments (such as sand) might indicate water transport, particularly if the sediments are well sorted and the grains rounded. Phoenix measurements can distinguish between subaqueous and aeolian grains. Well established techniques using grain sorting, shape, and surface textures can determine the provenance, transport history, and diagenetic history of sedimentary clasts. For standing bodies of liquid water to have been stable on ancient Mars, a dense CO_2 atmosphere would have been required to bring average temperatures above freezing. Much of this early atmosphere should have chemically combined with the surface, forming carbonates.

Chemistry and Mineralogy
Phoenix will also assess the relationship of the ice to the soil chemistry—Phoenix will determine the relationship of the ice to oxidants, organics, the deuterium/hydrogen (D/H) ratio, and other chemical/compositional gradients and horizons (such as concentrations of salts or hydrated minerals). These phenomena should provide insight into whether the ice is relict or is interacting with the atmosphere, and whether it has been liquid in the past.

Although chemical models indicate that clays should occur in Martian soil, they have so far eluded detection. Recent spectroscopic data could imply clays in the soil ,or conversely, andesitic lavas underlying the northern basin. Possibly, some of the hydrogen signal seen in the Odyssey GRS results may be from such minerals, since we would expect to find clays in a region that may have been subject to wetting.

Isotopic ratios help determine the origin of water deposits—an important Phoenix goal for Phoenix makes comparative mass spectroscopy measurements of atmospheric gases and soil volatiles to determine the isotopic ratios of evolved gases from the samples, which indicates the long time-scale interaction between the surface and atmosphere. The D/H ratio of atmospheric water vapor increases rapidly over time as H preferentially escapes to space; it decreases when "new" water is injected into the atmosphere from a reservoir. Any differences between the D/H ratio of the atmosphere and subsurface ice will reflect the degree of mixing between them. The same is true for the isotopes of O and C.

Wetted soil would not be in equilibrium with the atmosphere; therefore, the regolith and atmosphere should exchange water. Upward percolation of water through capillary action can leach compounds and leave them in concentrated soil horizons as the saturation level changes or as the water evaporates. Thus, vertical compositional fractionation of the soil (as occurs in many terrestrial soils) might be detectable. Soil horizons might exhibit concentrations of salts, carbonates, iron compounds, and other soluble materials. The concentration of compounds at certain horizons should be evident from the chemistry, from spectroscopic (color) variations with depth, and from changes in soil induration— hardpans, duricrusts, and nodules are typical products of the cementation of soil horizon minerals. This implies that soil horizons can be detected by imaging the trench and monitoring soil resistance during digging, and that they can be confirmed by chemical measurements.

The wet chemistry laboratory detects water soluble minerals such as salts, carbonates, and evaporitic compounds.

Biological Potential
Phoenix assesses the biological potential of near surface ice and determines its habitability. A habitable environment is one that allows life to grow and reproduce, even if such conditions only occur infrequently. Does liquid water occur on Mars that might sustain life at the landing site? Are there energy sources that can sustain life? Is the environment hazardous to life?

Mars' rotational dynamics force periodic soil-warming phases as the longitude of perihelion precesses, completing a full cycle in 51,000 years. Thus, cyclically, perihelion occurs during northern summer. Runs of the Global Climate Model (GCM) similar to those reported in show that seasonal warming at high northern latitudes allows near-surface ground ice to melt. In addition to changes in peak insolation resulting from orbital precession, obliquity variations can dramatically increase average insolation at high latitudes over timescales of 10^5 and 10^6 years, perhaps leading to greater warming over longer periods.

An environment in which liquid water occurs briefly and infrequently might still be habitable. Many terrestrial organisms survive in a dormant state for long periods, returning to a growing state when conditions allow. Dormant live bacteria are found encased in salt crystals or amber drops as old as 40 million years.

In addition to liquid water and the basic biogenic elements [C, H, N, O, P, S], all detectable by Phoenix, life requires an energy source as well. Sunlight on the surface can be converted by a chromophore, such as chlorophyll, into a usable form. Underground, where sunlight does not penetrate, life must rely on other sources. Organic compounds are a plausible energy source for such life underground, and these form the basis for the bulk of the terrestrial subsurface biosphere. In addition, subsurface life forms exist on Earth that derive energy from reacting hydrogen produced in the decomposition of basalt with CO_2. Metabolizing energy under oxygen free conditions derived from other material substrates may also be possible.

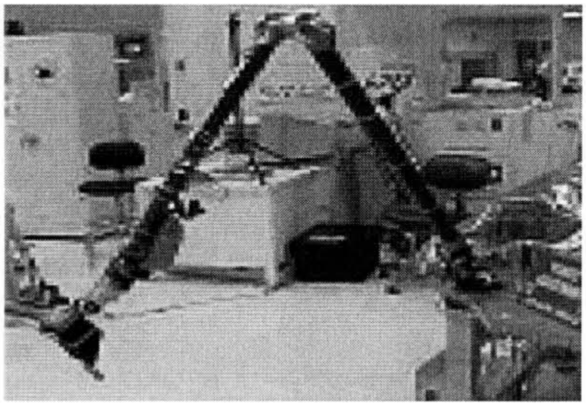
Phoenix searches for organic compounds and minerals that could provide energy for subsurface metabolism. Identified by chemical analysis, reduction-oxidation (redox) pairs may determine whether the potential chemical energy of the soil can sustain life. Moreover, gradients in redox potential often indicate biological activity. Finally, Phoenix characterizes key fundamental soil properties, such as pH and saltiness that relate to habitability.

Even with energy sources and liquid water present, hazards can prevent growth. Powerful oxidants that can break apart organic molecules are expected in a dry environment that is bathed in UV light and has trace oxygen available. Such oxidants are proposed as the most likely explanation for the Viking biology experiments not detecting any traces. The MECA chemistry laboratory can determine the depth and nature of many such oxidants. After adding water to a soil sample, the dissolved oxygen electrode can detect oxygen produced by the reaction of superoxides and similar species with water. Weaker oxidants, such as peroxides, determine the redox potential of the system, as measured by the platinum redox potential electrode. Solid potassium iodide will be added to measure oxidants that convert iodide to iodine. The iodide electrode measures the iodide added, while the redox electrode measures the ratio of iodide to iodine. Cyclic voltammery provides additional information about specific oxidation and reduction processes in the solution.

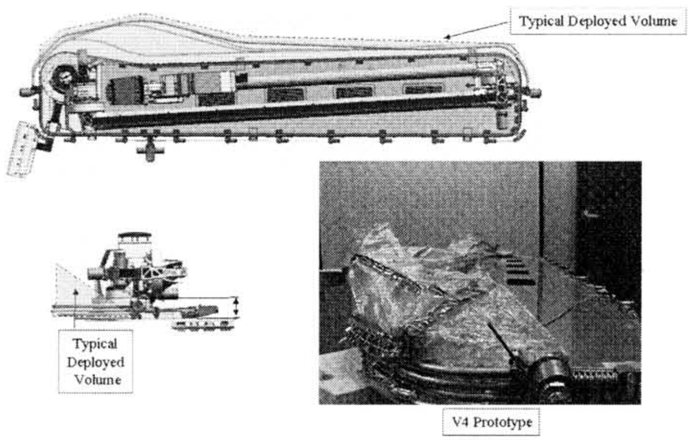
Science Payload

Phoenix carries a large and diverse instrument suite selected to broadly characterize the surface, subsurface and atmosphere at the landing site. These instruments exhibit a great deal of heritage, including instruments already built (for MSP'01), instruments previously flown that will be modified slightly, and new instruments with some flight heritage. Many of the instruments are either derived from the Mars Polar Lander mission or the Mars 2001 mission recovering many of the science objectives not yet achieved.

Robotic Arm (RA)



MSP'01 RA

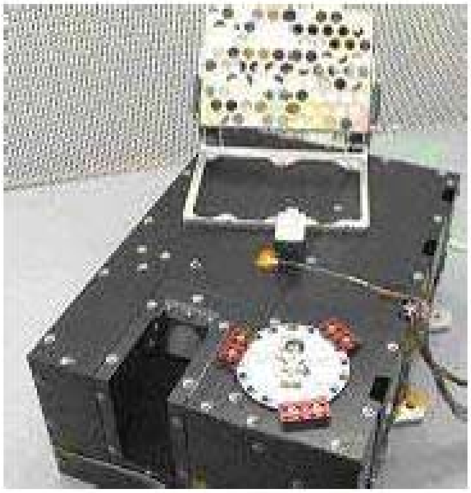


Phoenix RA CAD drawing along with Planetary Protection Bio-Barrier

The robotic arm is a key and critical part of the Phoenix science plan. The RA is required to acquire surface and subsurface samples and provide them to the MECA and TEGA instruments for analysis. The Phoenix RA is a 3^{rd} generation 4-degree of freedom arm and draws heritage from the MPL and MSP'01 arms. The Phoenix arm will be lengthened by 0.35m over the MSP'01 arm to increase the available workspace and to ensure the ability to dig to 1m depth. This arm is also being strengthened in order to dig successfully in the frozen, tundra like soil that may be present at the Phoenix landing site. To assist digging in this potential terrain, improved serrated blades and ripper tines are being added. The RA also points the Robotic Arm Camera (RAC) and positions the TECP probe (part of MECA) into the soil.

During the formulation phase, further analysis was conducted on the design and materials of the robotic arm design and materials. This analysis focused on the ability of the design to meet the Phoenix requirements specifically driven by predicted environments and life time. The results of this effort lead the project to a significant implementation shift. Since the scoop of the RA will be placed below the top of the regolith, all living earthborn spores must be destroyed. The approved modality for this process is to conduct a dry heat sterilization process on the arm. The existing RA materials would not survive this process. In addition, life time requirements for digging in high compressive strength material indicated a need to strengthen the actuators for Phoenix. The team was fortunate in that we could leverage off of the actuator designs in the development of the Instrument Deployment Device (IDD) from the Mars Exploration Rover (MER) mission. The project has redirected this effort, and is now on course to deliver a much more robust mechanism for spacecraft integration in June of 2006.

Microscopy, Electrochemistry and Conductivity Analyzer (MECA)



MECA will be modified slightly from the MSP'01 Mars Environmental Compatibility Assessment instrument that was delivered and remains in bonded storage. MECA is comprised of four main parts:

Wet Chemistry Lab (WCL)
Optical Microscope
Atomic Force Microscope
Thermal, Electrical, Conductivity Probe (TECP)

The patch plate for Phoenix has been removed (shown above).

The WCL contains four, single use wet chemistry cells. Each beaker assembly contains reagents and pure water for conducting the experiments. Each beaker contains 26 sensors. A partial list of the measurements capable are:

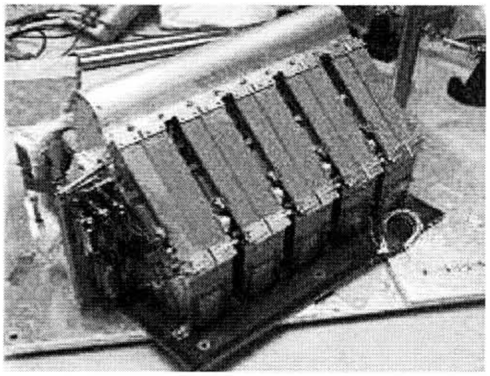
Conductivity Silver/Sulfide
pH (3 sensors) Cadmium
Reference (3 sensors) Cl^- (2 sensors)
Dissolved O2 Br^-
Dissolved CO2 I^-
ORP (redox potential) Na^+
Cyclic voltammetry K^+
Anodic stripping Mg_2^+
NO3– ClO_4
NH_4^+ Ca_2^+
Temperature

Soil samples are placed into a sample wheel that provides imaging opportunities for the two microscopes. The fixed focus, 6X optical microscope uses a 256 x 512 CCD array and achieves 4μm/pixel resolution providing an optimal compromise between resolution and depth of field. Samples can be illuminated by Red, Green, Blue and UV LED's. The AFM can image a 40μm x 40μm area at sub-micron resolution.

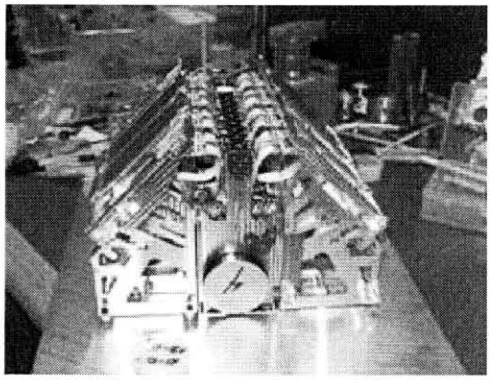
The TECP is mounted on the heel of the scoop and replaces the original MECA electrometer. The 4-pin probe determines electrical conductivity by a two-pin LC approach and a redundant 4-pin van der Pauw technique. Thermal conductivity is measured by a pulse decay method using a heater and a thermocouple pair.

The MECA development has been proceeding smoothly. New WCL cells have been developed and tested. The MECA electronics have been redesigned, and simplified, as per the Phoenix implementation plan. Environmental testing of the MECA is planned before the end of calendar 2005, with delivery still scheduled for March of 2006.

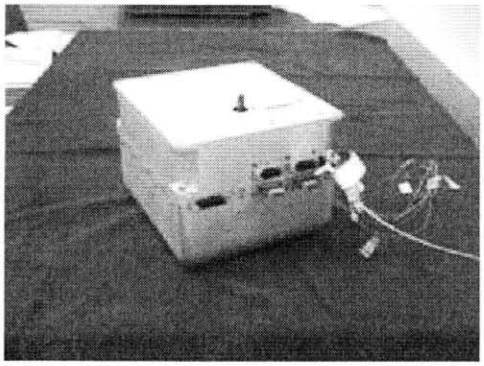
Thermal Evolved Gas Analyzer (TEGA)



MPL TEGA Thermal Analyzer



Phoenix EM Thermal Analyzer Structure



Phoenix EM Evolved Gas Analyzer (Mass Spectrometer)

The Thermal and Evolved Gas Analyzer is a modified version of the MPL TEGA maintaining the differential scanning calorimeter and replacing the tunable diode laser with a mass spectrometer. The DSC will perform calibrated thermal analysis of the Martian soils while the Mass spec will analyze the volatiles released by the heating of the soil samples. The mass spec can also ingest atmospheric samples thus enabling detailed atmospheric composition analysis. Soil samples are delivered to one of the eight, one time use DSC cells and hermetically sealed. The DSC uses precise heat delivery and measurement to elevate the temperature of the samples observing both endothermic and exothermic phase transitions. The volatiles driven off through this process can then be passed to the EGA to measure volatile abundances and isotope ratios. This data will be correlated with the DSC data providing the capability of detecting 0.2% ice abundances and 0.5% calcite ($CaCO_3$) abundances.

The mass spec (EGA) is sensitive to ~ 10 ppb and covers the AMU range of 2-140 AMU. Gases are admitted from the ovens or from the atmosphere through a leak or from a gas concentrator. (To prevent detection of adventitious organics from Earth, TEGA cells will be carefully sterilized and tested before sealing.) The concentrator removes essentially all the CO_2 to improve sensitivity (by 30 times) for lower-abundance species. The electron beam ionizer is controlled by a microprocessor to produce two emission currents (25 µA and 250 µA) and four electron energies (from 75 eV to 20 eV). This extends the dynamic range by a factor of 10 and helps identify molecular constituents by varying their fragmentation and charge states. Pumping consists of a non-evaporable getter to maintain the analyzer section at < 1×10^{-7} Torr and a mini sputter-ion pump.

Progress has been steady of the TEGA development. A significant goal for the TEGA instrument is the detection of organics. Toward that end, cleanliness of the Thermal Analyzer (TA) is of paramount consideration. Concerns over implicit cleanliness during fabrication and assembly, and cross contamination during tests and operations have been addressed. Assembly cleaning processes were successfully developed and demonstrated ~0.01 micrograms/cm^2 of low volatility residue for the TA. To address cross contamination issues, the TA has been modified to include covers over each pair of four ovens. Recent tests of the TA and electronics have shown a very quite, and accurate signal (see figure 6).

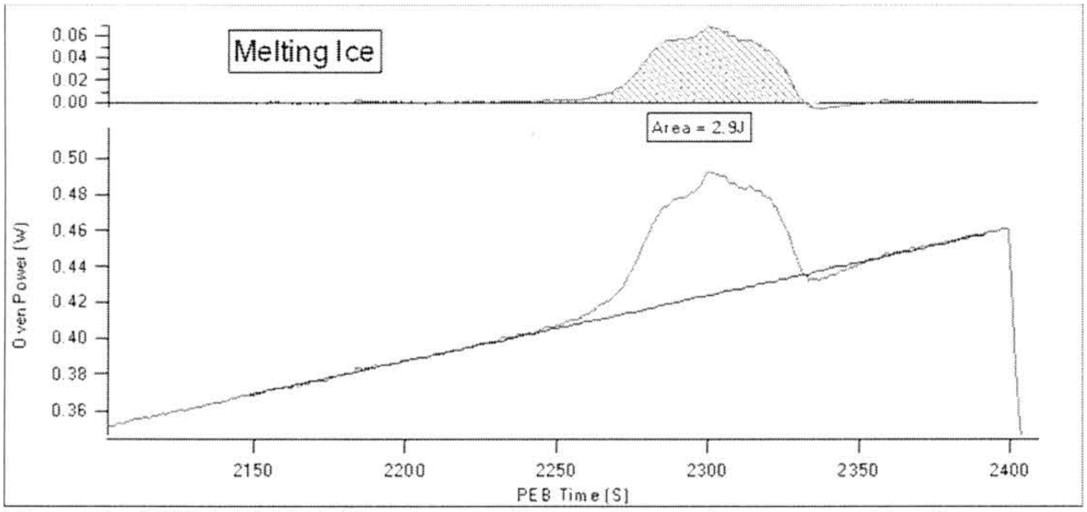
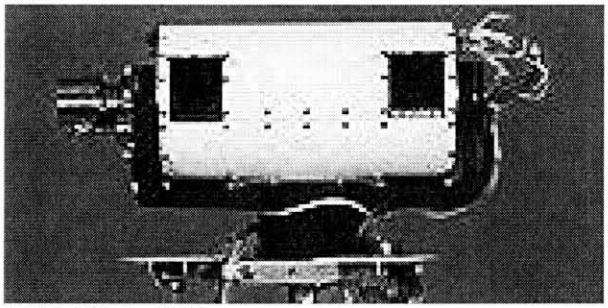
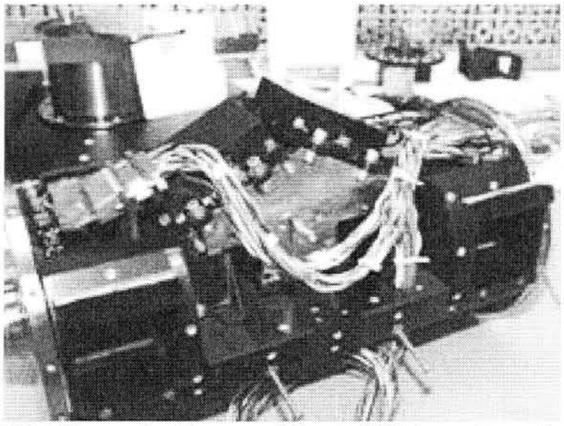


Figure 6 – TEGA EM TA Temperature/Energy Ramp Spectrum melting ice

Surface Stereoscopic Imager (SSI)



MPL Flight SSI



EM Phoenix Camera Head (Without housing)

Phoenix uses the MPL SSI, with upgraded MER CCDs, allowing higher resolution geologic mapping, RA range mapping, multi-spectral analysis, and atmospheric observations. SSI surveys the landing site for geological context, provides range maps in support of RA digging operations, and makes atmospheric dust and cloud measurements from its location 2 m above the ground. Two "eyes" allow stereoscopic imaging in blue, red, and near infrared. Filters allow imaging at 12 wavelengths of geologic interest and

8 of atmospheric interest. Sun images will be used to obtain opacity; sky images will be used for aerosol and dust/cloud properties. Lander images will be used to assess dust deposition rates.

The engineering model SSI has completed its functional tests, and is nearing environmental qualification. Assuming remaining activities go as planned; the flight SSI will be ready for spacecraft integration next summer.

Robotic Arm Camera (RAC)

The RAC is used for high-resolution viewing of trench walls and of samples in the scoop and was delivered for the MSP'01 spacecraft. It is currently in bonded storage at JPL. Attached to the wrist of the RA, RAC images all collected samples, the soil at the tip of the scoop, the trench dump pile, and the trench walls (unseen by SSI). Images are used to analyze grain sorting and size. RAC can focus from 10mm to infinity at a resolution of 2 mrad/pixel and illuminate samples with Red, Green and Blue LED's.

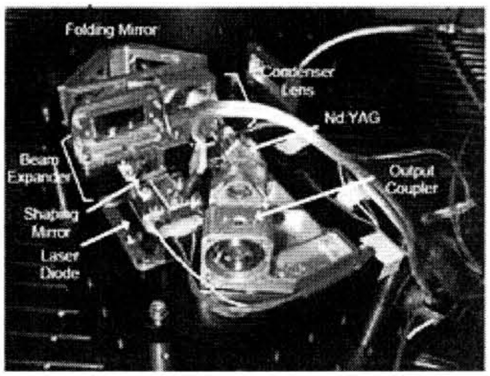
As the RAC is mounted on the RA, it is subjected to bio-reduction requirements. To accomplish this, the team was very concerned about the materials. Detailed analysis has given the team confidence that the camera will survive, and no unacceptable degradation of performance would occur. The flight RAC has recently completed it first round of dry heat processing, and post processing performance tests have confirmed the team's analysis.

Mars Descent Imager (MARDI)

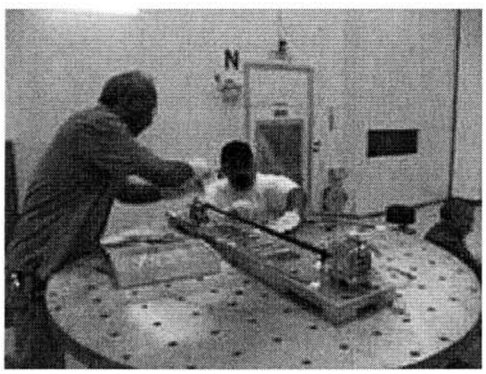
MARDI will provide geologic context of the landing site for Phoenix by acquiring images during descent. MARDI was developed and delivered for the MSP'01 mission and is in bonded stores at JPL.

MARDI begins operation after the heat shield is jettisoned and acquires up to 20 images during the terminal descent phase. The camera has a 65.9 degree FOV and uses a Kodak KAI-1001 (1024 x 1024) detector with 9μm pixels.

Meteorological Station (MET)



EM Phoenix Lidar optical bench



Flight MET Mast in vibration test

Contributed by the CSA, MET is the only newly designed instrument for Phoenix. It is comprised of two parts, a fixed, upward pointed Lidar and a temperature and pressure station that can operate continuously. The pressure and temperature measurements derive heritage from Mars Pathfinder. Using a similar deployable mast, three type-E thermocouples will be placed at stages going up the 1m mast providing profiles of the near surface temperatures. The pressure transducer will be mounted within the Payload Electronics Box (PEB) which will maintain the temperature of the sensor within necessary limits. Temperature and pressure measurements will be used to characterize the local atmosphere.

The Lidar system will provide the first ever measurements of the Planetary Boundary Layer (PBL). The Lidar will provide data on the depth, location, structure and optical properties of clouds, fogs and dust plumes within the PBL. A better understanding of the PBL is key to understanding surface atmosphere interactions at Mars, particularly the exchange of volatiles.

The EM Lidar and MET electronics have been completed. The integration plan for the MET is to deliver the flight MET electronics, flight MET mast and flight sensors for spacecraft integration in the summer of 2006. The flight Lidar, which is lagging the balance of the development, will be integrated on the lander deck after spacecraft environmental test, in the late fall time frame.

Spacecraft

Shown in **Fig 7**, Phoenix is architecturally similar to the Mars Polar Lander spacecraft. The Phoenix spacecraft uses a powered descent system for a soft landing on the surface of Mars. Much of the detailed design work follows directly from the MPL and MSP'01 efforts and also takes into account some of those changes can be seen in the Table 1. Some of the most significant changes involve the upgrade of both the cruise and landed solar cells for Phoenix. Since the Mars-Sun range is greater for Phoenix, increased cell efficiency is necessary to provide sufficient power at arrival.

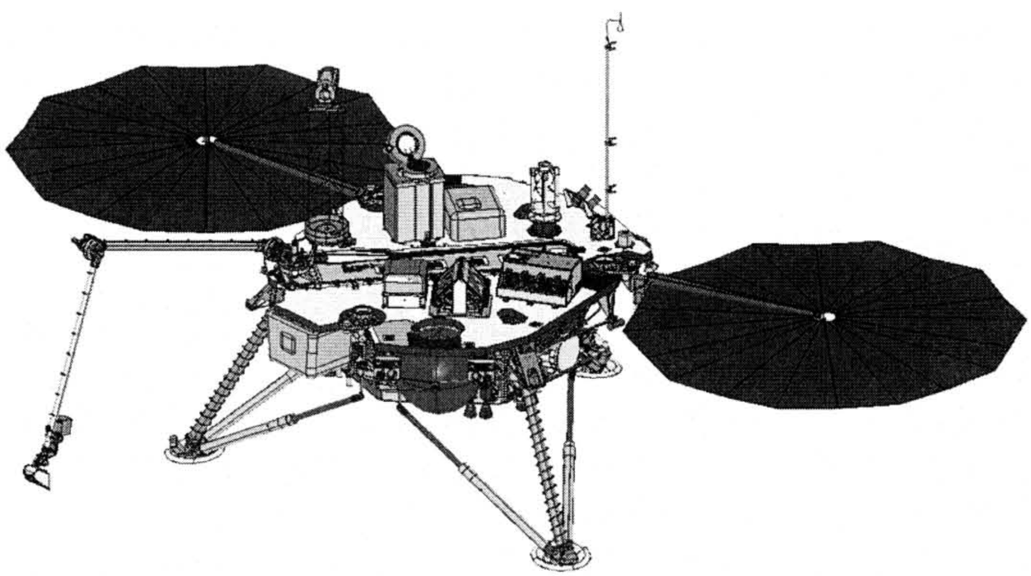


***Figure** 7. Phoenix Lander in deployed state on surface of Mars*

many of the important lessons learned during those missions.

At the point of termination, MSP'01 was about 70% complete and much of the hardware had already been procured. There are, however a number of issues that still exist. First, some of the Lander hardware was taken to benefit other programs, especially MRO. In addition, there are a number of changes recommended by the Return to Flight report generated by the failure review boards that must be assessed and potentially implemented. Lastly, there are some fundamental differences in the MSP'01 mission for which the lander was initially designed and the requirements for the new application that is Phoenix.

Complicating matters further, the surface mission is now landing at very high northern latitude hence increasing the solar incidence angle on the landed arrays. In both cases, the double junction cells from the MSP'01 arrays will be de-populated and repopulated with newer Spectrolab advanced triple junction cells as used by MER. The landed Ultraflex arrays will be modified to operate with the added weight of the triple junction cells. Offsetting the sun angle incident on the arrays in the northern latitude is the fact that the sun will actually be visible by the lander almost continually for the initial part of the landed mission, though very low on the horizon.

Many spacecraft system trades have been conducted during the Phoenix formulation phase. Due to several resource constraints, most notably, landed mass capability, the X-Band communication system for surface operations was removed. This enabled the Project to remove the mass, and associated development challenge of an articulated high gain antenna on the lander deck. This provided significant mass, accommodation and cost margins for the system. The recent significant success of UHF operations, and Entry Descent and Landing (EDL see figure 8) telemetry by MER, made this implementation feasible. The addition of an additional, small monopole UHF antenna on the lander deck, provides for robust communication architecture, and assures the helix UHF antenna is not a project single point failure.

In the Phoenix proposal, the team has incorporated hypersonic guided entry as a feed forward technology for the Mars Program, however, the Project has always assumed it would be an option, which if it incorporated more risk than it retired, we would descope. This is indeed what happened over the past 12 months. The science team, working with the Phoenix landing site selection team, has identified, to date, no compelling reason to incorporate this capability into the system. This fact, compounded by the concern of implementing this first time at Mars technology, and the possibility of a UHF EDL communication black out induced by plasma fields surrounding the entry vehicle, have lead the team in this new direction. The current EDL plan calls for the entry vehicle to enable a lifting trajectory, holding attitude, during the hypersonic phase. There are many advantages to this approach, including the elongation of the entry timeline. By lengthening this time period, the EDL team can more effectively balance system risk. A recent approved change has reduces the size of the Phoenix parachute by 10%, thus reducing the inflation loads on the vehicle, and the parachute, by a corresponding 10%. This margin increase was enabled by additional time on the parachute, which now has a corresponding reduction in atmospheric drag.

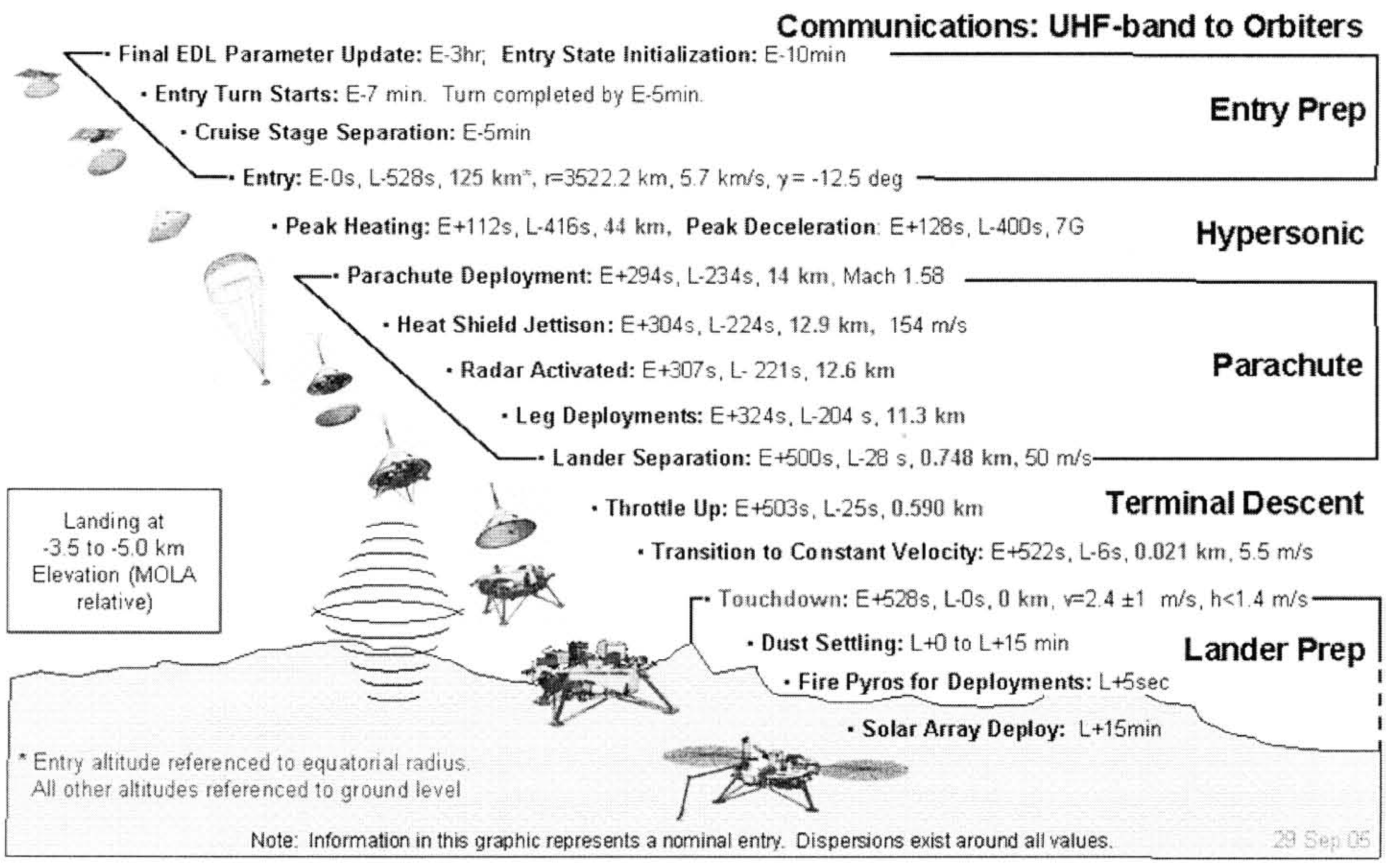


Figure 8 – Phoenix EDL Timeline

Table 1. Key differences between MSP'01 and Phoenix

Parameter	MSP'01	Phoenix
Launch Period	April, 2001	August, 2007
Launch Vehicle	Delta II 2425-9.5	Delta II 2925-9.5
Mars–Sun at arrival	1.5 AU	1.665 AU
Mars-Earth at arrival	1.8 AU	1.95 AU
Approach V∞	<4.92 km/s	<3.5 km/s
Atmospheric Entry Velocity	6.5 km/s	~5.75 km/s
Landing Site	Equatorial (-12 to+3)	North Polar (65-72N)
Landing Altitude	<2.5 km	<-3.5 km
Surface Temperature Diurnal variation	181 to 277K	191 to 257 K
Payload (including heritage)	66 kg MIPP MARIE MARDI APEX w/PEB MECA w/Electrometer on RA RA/RAC Marie Curie	55 kg MET SSI (MPL, Pathfinder) MARDI (MSP'01) TEGA w/PEB (MPL) MECA w/TECP on RA (MSP'01) RA (MPL, '01) RAC (MPL, '01)

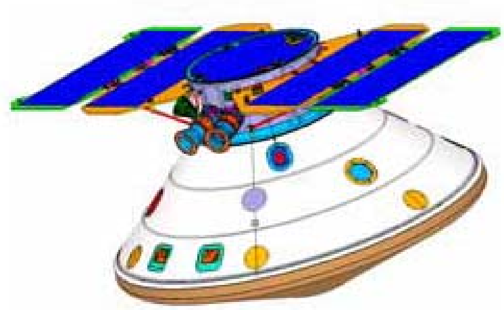


Figure 9 Spacecraft in Cruise configuration with antennas and thrusters clearly visible.

Another enhancement to landing safety comes from an upgrade to the MSP'01 landing radar. The Honeywell HG9550 radar will be upgraded to use separate Tx and Rx antennas and will also get a firmware upgrade. These enhancements substantially improve the radar performance and increase the landers robustness to slopes at all scales and provide better horizontal and vertical velocity resolution enabling lower speeds at touchdown.

Phoenix uses the same pulsed propulsion system for descent as that designed for Mars Polar Lander. This system includes eight thrusters (4 RCS and 4 ACS) scarfed through the backshell (Fig 9)for operations during cruise and EDL, as well as 12 68lbf thrusters pulsed off for terminal descent. The team has conducted a series of tests over the past year to assess the performance of the propulsion system, as well as characterize the performance of the overall lander as a consequence of induced loads from the pulsing systems. A detailed flight like mock up of the vehicle, along with flight quality propulsion components were constructed (see figure 10) The test set is highly instrumented to measure multiple dynamic responses of the system. Two tests were conducted. First, the prolusion tanks were filled with water, which has almost identical specific gravity to flight hydrazine. During this test, the thruster's catalysts were removed, and the team purposely over drove the system to examine for unwanted "water hammer" effects, which the flight control system would be unable to tolerate. After this test series was successfully completed, the thrusters were reconfigured, and hydrazine added to the propellant tanks. In this configuration, several tests were run mimicking the terminal descent phase simulations. The intent of this test was to empirically correlate the dynamics the team uses in its multiple thousand EDL simulations. These statistical runs are utilized to determine the robustness of the overall EDL system. Figures 11 and 12 shows some of the results of this test, specifically indicating the tight correlation between the models, and the measured responses. This accomplishment by the team at Lockheed Martin has significantly increased the project confidence in the pulse mode propulsive descent phase of the mission.

Once landed, Phoenix has the benefit of numerous orbiter passes in the northern polar environment for UHF data relay. Mars Odyssey is the primary relay asset for Phoenix, but Phoenix is also planning coverage by the recently launched Mars Reconnaissance Orbiter (MRO). Both assets use the Proximity-1 protocol and are compatible with Phoenix. This plethora of options ensures substantial data return (Fig 13).

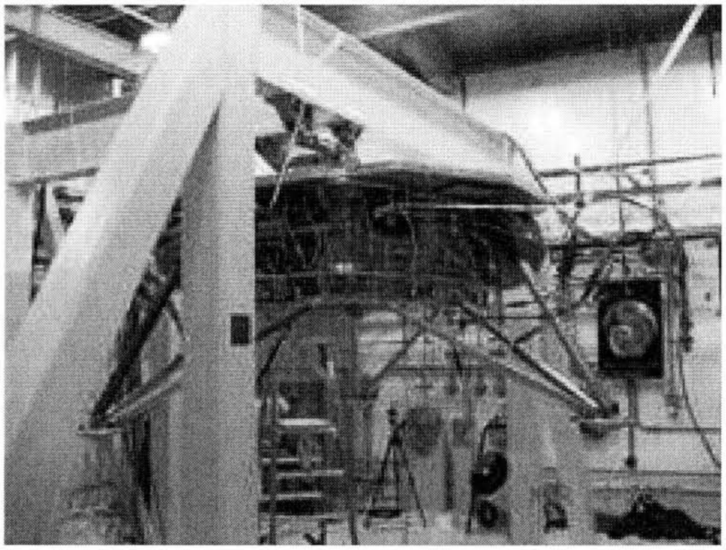


Figure 10 – Flight-like Lander for Phoenix Hot Fire Testbed

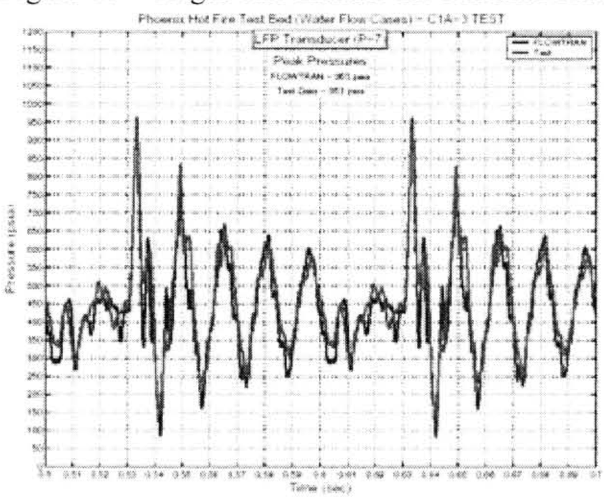


Figure 11 - Time-domain correlation between Flowtran model (blue) and test data (red)

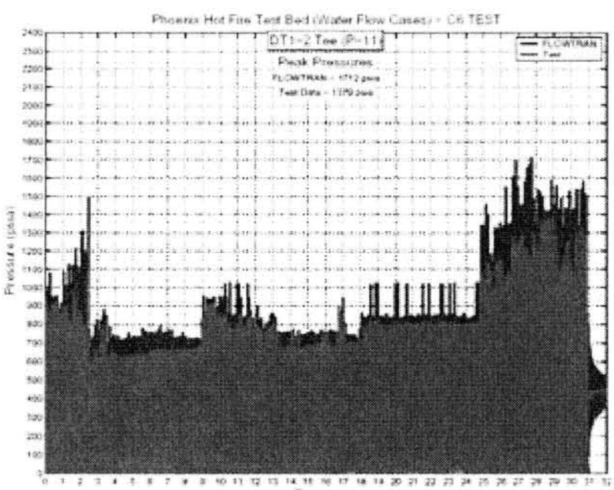


Figure 12 - Peak pressure during EDL simulation shows correlation between model (Blue), and test data (Red)

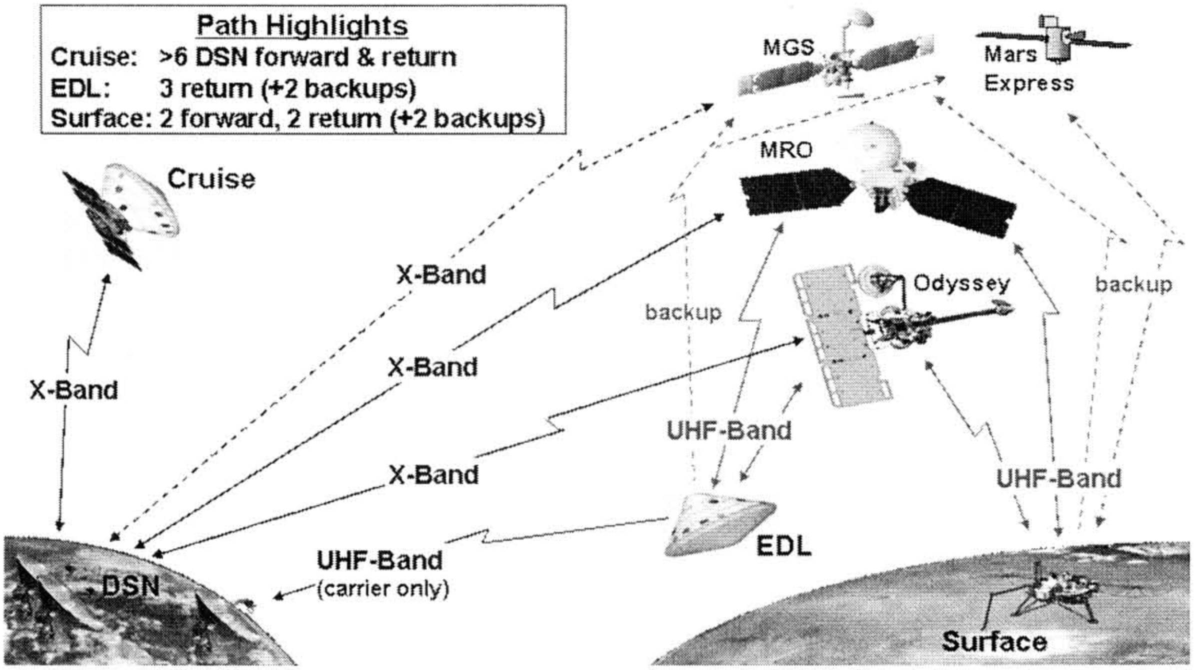


Figure 13 – Multiple communication options for the Phoenix Mission

Operations

Phoenix will be operated primarily through a new Science Operations Center (SOC) being built at the University of Arizona. This newly developed facility is being constructed especially for Phoenix and will incorporate a Payload Interoperability Testbed (PIT). The PIT is a mockup lander with Engineering Model (EM) instruments incorporated in order to test interaction between the instruments and overall payload interoperability. It will provide a testbed for payload and payload software development, as well as sequence testing and verification during landed operations. The PIT will incorporate a Spacecraft Test Lab (STL) which houses identical hardware to the Lander C&DH system for real time execution testing.

The prime mission will be operated from the SOC at UA. This center will house most of the Phoenix science team for the mission duration. There will also be members of both the JPL and LM mission team co-located for the mission duration, in addition to members residing at their home institutions. JPL and LM both serve as potential backup operations centers.

The mission team will operate on Mars time and will be working on a daily sequence turnaround time (tactical plan) while also coordinating multi-week planning (strategic planning). Special coordination will be executed to ensure smooth operations with the missions providing data relay support on a regular basis (Odyssey and MRO).

Conclusion

Phoenix is a science rich, relatively low risk kickoff to an exciting series of new NASA missions to Mars. Phoenix has the capability of obtaining key critical science information that could write whole new chapters in our current understanding of Mars. Much progress has been made enabling the team to proceed out of formulation and into the implementation phases. The next two years leading to launch prove to be both exciting and challenging, as we ready for the all important landing on May 25, 2008.