ASI/MET
(Chief Engineer, Clayton LaBaw, JPL)

Science and Measurement Objectives.

The Atmospheric Structure Investigation/Meteorology (ASI/MET) experiment is designed to obtain measurements of the martian atmosphere during the entry, descent, and landed phases of the Mars Pathfinder mission. It has been developed at JPL under the supervision of a Science Advisory Team (SAT) with considerable experience in *in-situ* atmospheric measurements and martian meteorology.

The overall scientific goals and measurement objectives of the investigation during the Pathfinder spacecraft Entry, Descent, and Landing (EDL) are to derive a vertical density, pressure and temperature structure profile for the upper atmosphere from measurements of entry vehicle acceleration in three orthogonal axis during the entry phase of the mission; derive a vertical density, pressure and temperature structure profile for the lower atmosphere from measurements of atmospheric pressure and temperature during the descent phase of the mission; and to characterize boundary layer meteorology and accumulate a climatological atmospheric data set at the Pathfinder landing site using measurements of pressure, temperature and wind, during the landed phase of the mission.

ASI/MET Sensors

The ASI/MET experiment is performed by accelerometer and meteorology (MET) instruments using hardware distributed throughout the Pathfinder lander (Figure 6). The accelerometer instrument consists of three science and three engineering accelerometers, with supporting electronics, mounted on two boards in the Pathfinder Integrated Electronics Module (IEM). The MET instrument consists of pressure, temperature and wind sensors and a single IEM electronics board. The pressure sensor is mounted outside the IEM, but within the lander thermal enclosure and is connected to an aperture in the lander vehicle via a pitôt tube. All the temperature sensors and the wind sensor are mounted on a meteorological mast 1 cm in diameter and 1.1 m high, which is deployed after landing. The mast base is located on the end of a lander petal to minimize the thermal contamination of temperature and wind measurements by the spacecraft. In addition to pressure, temperature, and wind sensor electronics, the MET board also carries the signal processing electronics for the temperature sensors of the Aeroshell Instrumentation Package (AIP). Functional block diagrams for both instruments are shown in Figures 21 and 22.

Accelerometers: All six science and engineering accelerometers are Allied Signal QA-3000-003 units. Their location and orientation on the accelerometer board relative to the spacecraft axes is shown in Figure 23. The three science accelerometers are mutually orthogonal and are oriented parallel to the lander X, Y, and Z axes, whereas the three engineering accelerometers are oriented in the X direction and at ±45∞ to the Z-axis in the YZ plane (+YZ and -YZ). Because of limitations imposed by the Pathfinder system design, some accelerometers are displaced significantly from the entry vehicle center of mass.

Each accelerometer signal channel has three gain states giving dynamic ranges of ±40 g, ±800 mg, and ±16 mg. Signals are digitized to 14 bits to provide 5 mg, 100 mg,and 2 mgresolution respectively. During testing, noise levels in each gain state were measured at 1 to 2 counts or less. The accelerometers are expected to be capable of measuring entry vehicle deceleration from the limits of detectability above 160 km, to the maximum pulse of roughly 27 g at 30 km. Low pass filters in the accelerometer electronics attenuate signal frequencies above 5 Hz to suppress the effects of noise and spacecraft dynamic motion.

The primary function of the engineering accelerometers is to monitor and contribute to the timing of important events during entry and descent, such as parachute deployment. They are also used after landing to right the spacecraft and point the lander high gain antenna accurately. Science accelerometer observations focus on measuring atmospheric accelerations throughout entry and descent with maximum resolution, although the optimum measurement strategy has been modified to provide redundancy for the engineering accelerometers. Data from all six accelerometers are sampled at the same rate and will be available to ASI/MET investigators.

Pressure Sensor: The ASI/MET pressure sensor is a Tavis variable reluctance diaphragm device similar to the pressure sensors flown on the Viking mission. This device has proven long-term stability and reliability over four martian years of operation. It is designed to make measurements of dynamic pressure during entry and static pressure on the surface, and is connected to the outside world by a pitôt tube approximately 1 m long and 2 mm inside diameter. Its response time is expected to vary from 1.5 seconds at 3 mbar to 0.45 seconds at 10 mbar. The tube entry port lies in the plane of the aperture between the lander instrument shelf and two petals (Figure 6), and is oriented perpendicular to the anticipated airflow during descent. Because no objects were allowed to extend beyond the lander profile during descent, the entry port location is not ideal.

The pressure sensor obtains data in two ranges simultaneously; 0-12 mbar for descent and 6-10 mbar for surface observations. Signal digitization to 14 bits provides respectively 0.75 mbarand 0.25 mbarresolution over these ranges. Again, system noise levels were measured at 1 to 2 counts or less. As Tavis pressure sensor measurements are temperature dependent, the temperature of the device is monitored in flight by an accurate platinum resistance thermometer (PRT). The PRT covers the 200-335 K temperature range with a resolution of 0.01 K.

Temperature Sensors: Atmospheric temperatures during the descent and landed phases of the mission are measured by fine wire chromel-constantan thermocouple sensors mounted on the mast. A typical sensor is shown in Figure 24. It consists of three thermocouples wired in parallel in a fiberglass support structure. The thermocouple wires are 75 mm in diameter and the junction diameter is approximately 200 mm. The fine wires provide conductive isolation for the junctions, and ensure that they reach equilibrium with the tenuous martian atmosphere fairly rapidly, although radiative corrections will have to be modeled to obtain the best results from these sensors. Three wires provide redundancy against damage, either during descent, or due to dust storms during the landed mission. On the surface of Mars, the thermocouple junction time constant is of order 4-5 seconds. All ASI/MET thermocouples are referenced to 'cold' junctions mounted within a small isothermal block located inside the lander petal close to the base of the mast. The temperature of the block is monitored by an accurate PRT with a range of 140 to 330 K and a resolution of 0.01 K. Each thermocouple has a dynamic range of roughly ±100 K about the PRT temperature, and a resolution of 0.01 K.

A single thermocouple is assigned to temperature measurements during the descent phase of the mission, when the entry vehicle is falling by parachute after the heat shield has been jettisoned. The descent sensor is located near the top of the mast (Figure 25), immediately below the wind sensor. Its thermocouple wires are approximately 4 cm from the mast axis and are oriented perpendicularly to it. During descent the mast is stowed and the sensor is close to the center of an aperture in the corner of the lander, although it is set back significantly due to concerns over interference with the lander airbags. Accurate descent temperature measurements rely on undisturbed air flowing through the aperture and over the descent sensor. Wind tunnel measurements on models have shown that this flow is highly disturbed, so that descent temperature measurements are likely to be unreliable. Currently a flexible duct linking the external flow to the sensor is planned to improve the quality of the data.

Three thermocouples are designed for temperature measurements during the landed phase of the mission when the mast is deployed. These sensors are located on the mast 0.25, 0.50 and 1.00 m above the plane of the petal. For each sensor, the thermocouple wires are oriented vertically approximately 2.3 cm from the mast axis. All three sensors and mounts are identical and are clocked at the same angle on the mast. Temperature measurements are subject to thermal contamination when the mast is downwind from the spacecraft or the sensor wires are downwind from the mast. The sensors are therefore oriented away from the spacecraft when the mast is deployed so that these conditions coincide, minimizing the range of unfavorable wind directions.

Wind Sensors: The ASI/MET uses hot wire resistance thermometers to measure wind speed and direction. An isometric drawing of the wind sensor is shown in Figure 26. It consists of six 50 mm diameter platinum-iridium wire elements arranged symmetrically around a cylindrical core approximately 2.6 cm in diameter. Each element consists of a 20 cm wire wound round insulating formers to give eight closely spaced lengths oriented parallel to the axis of the mast roughly 3 mm from the core. All six sensor elements are connected in series and are heated by a constant current source. In still air at typical martian surface pressures, the elements are heated to approximately 40∞Cabove ambient. Wind blowing round the core of the sensor cools the elements, and the cooling produced at an individual element depends on its position relative to the core and the wind direction. Overall cooling is dependent on wind speed and the pattern of cooling for the six elements is a indicator of wind direction. Sensitivity is greatest for low winds and varies roughly inversely with wind speed.

The wind sensor has two operating modes, high and low power. In the high power mode, a current of 51.5 mA flows continuously through the sensor producing the overheat required for wind measurements. In the low power mode, 20.6 mA flows for 3 milliseconds whilst element temperature is being sampled. Low power produces insignificant wire heating and provides an accurate measure of ambient temperature at the sensor. The resolution of the wind sensor element temperature measurement is 0.11∞C for the low power and 0.04∞C for the high power setting. Under martian conditions, the sensor responds to power changes with a short term time constant of 1-2 seconds. Finally, a single chromel-constantan thermocouple junction is mounted within the core of the wind sensor. Its function is to provide a temperature boundary condition measurement needed to interpret the wind measurements.

<u>Sensor Calibration</u>

All the ASI/MET sensors have been subjected to a series of calibration measurements described below. Although preliminary analysis of the calibration data has taken place, it is anticipated that additional reduction of this data will need to be completed by the ASI/MET science team members after selection.

Accelerometers: Accelerometer calibration measurements can be divided into two categories; end-to-end response calibration for each sensor, and alignment and location calibration relative to the lander spacecraft coordinate system.

End-to-end response measurements using the assembled flight accelerometer board (Figure 23) on a precision dividing head have established the linearity, gain and offset of all six accelerometers, at each gain setting over a temperature range of -5∞C to +40∞C. All the sensors are highly linear, and gains and offsets vary linearly with temperature. Calibration measurements are limited to 1 g on the 40 g gain setting, and have not covered the full temperature range expected for the IEM electronics, so that some extrapolation is required. These measurement have also established the relative orientation of the accelerometer heads in the flight board coordinate system to a few hundredths of a degree.

Calibration measurements with the accelerometer board installed in the IEM on the spacecraft have established the orientation of the heads to a few hundredths of a degree in the lander coordinate system. Further optical measurements on the spacecraft in its cruise configuration have established the shape of the heat shield and the orientation of its symmetry axis in the spacecraft coordinate system with similar accuracy. The relative orientation of these two coordinate systems will not be measured, but they are specified to be coincident to better than 0.25∞ and are expected to be considerably better in practice. During the spin balancing of the spacecraft, the location of each head relative to the entry vehicle center of mass will be determined to about 2 mm in the X & Y directions. In the Z direction, the location of the center of mass will not be measured and will be uncertain to approximately 2.5 cm.

Pressure Sensor: Pressure sensor output voltage has been calibrated against an accurate Baratron gauge in a vacuum chamber for pressures in the range 0-12 mbar, and sensor temperatures from -80∞C to +20∞C. In addition the gain and offset of the pressure sensor electronics has been measured accurately for both pressure channels at ambient temperature (22∞C). Unfortunately data on the variation of gain and offset with electronics temperature are not available.

Temperature Sensors: Both the thermocouple and PRT temperature sensor channels have undergone end-to-end temperature calibration. In addition, independent sensor calibration data is available, and the gains and offsets of the electronics have been measured over a range of -40∞C to +50∞C.

End-to-end temperature calibration was performed with the sensors in a nitrogen atmosphere within an isothermal copper chamber. At a pressure of one atmosphere, chamber temperatures were moved between stable plateaus covering the range 140 to 360 K in 20 K steps whilst data were logged. Spatial temperature variations within the chamber were less than a few hundredths of a degree when data were taken. The thermocouple isothermal block was located outside the chamber at a temperature different from the sensors, to provide representative thermocouple voltages. Both block and chamber temperatures were monitored by NIST-calibrated PRT thermometers, accurate to 0.01 K.

In addition to the end-to-end calibrations, accurate calibration curves are available for the individual PRT sensors used by ASI/MET. The temperature and voltage characteristics of chromel-constantan thermocouples are also well documented and are expected to vary little from thermocouple to thermocouple.

The end-to-end temperature calibration was performed with the flight electronics at ambient temperature. To correct for electronics board temperature variations expected during the mission, the response of each channel to fixed input voltages was measured over the -40∞C to +50∞C temperature range, allowing accurate gain and offset temperature coefficients to be derived. For the thermocouple channels, gain is also dependent on lead resistance. This effect was present in the end-to-end calibrations but was not part of the electronics gain measurements. Lead resistance for each thermocouple was therefore measured at ambient temperature using an AC technique to eliminate errors produced by thermocouple voltages.

Wind Sensors: The wind sensor is effectively an array of PRT temperature sensors and its calibration can be divided into two parts; the calibration of the temperature sensors and the calibration of the temperature response of these sensors to wind speed and direction (wind calibration). In addition the geometrical properties of the sensor elements must be measured accurately.

The temperature calibration of the flight wind sensors is very similar to and was conducted at the same time as the thermocouple and PRT temperature calibration discussed above. It consisted of end-to-end temperature calibration from 140 to 360 K and flight electronics gain and offset calibration over the range -40∞C to +50∞C. In addition the constant currents supplied by the flight electronics to heat the wind sensor windings were measured accurately in both low and high power modes at ambient temperature. In one wind sensor channel, only ambient temperature gain and offset data have been obtained. This is not a serious problem as the temperature dependence of gain and offset variations is very similar for all six channels.

Three nominally identical wind sensors were constructed and subjected to end-to-end temperature calibration measurements. The first was mounted on the flight mast, the second was held in storage as a flight spare, and the third was delivered to the Ames Research Center as a flight test unit for wind calibration investigations. The wind calibration was conducted in the Mars wind tunnel at Ames using nitrogen at pressures of 8, 12, and 18 torr, for wind speeds in the range 0-50 m/s and wind directions covering 360∞in steps of 30∞and 60∞in steps of 5∞. Wind direction changes were simulated by rotating the sensor in the wind tunnel. Wind calibration was not performed directly on the flight sensor to avoid contamination by the fine dust used to measure wind speed in the tunnel experiment chamber. The assumption underlying the wind calibration is that it can be transferred from the flight test unit to the test unit given accurate temperature calibrations and geometrical measurements for both units.

<u>ASI/MET Data Handling</u>

Data from all lander spacecraft subsystems, including the accelerometer and MET instruments, are directed via the Lander Interface Assembly (LIF) to the Lander Remote Engineering Unit (LREU). Whenever they are turned on, data from the accelerometer and MET instruments are sampled continuously by the Pathfinder spacecraft to a schedule defined by a single LREU table. With the exception of the six accelerometer channels, which are sampled 32 times per second, all the measurements are sampled eight times per second. Operational flexibility is provided by the spacecraft Attitude and Information Management (AIM) subsystem which controls instrument operation through a limited set of commands, selects, samples, and processes the instrument data streams, constructs data packets for downlink, and directs data to the spacecraft engineering, housekeeping, and accountability data stream.

Instrument Commands: Accelerometer and MET instrument commands are summarized in Table 5. For the accelerometer, only the power and gain change commands act directly on the instrument. The remaining commands call these commands and control AIM data handling. Spacecraft accelerations are calculated in real time by AIM for use during the entry, descent and landed phases of the mission. Three commands are used to set, save and dump the accelerometer head gain and offset parameters required for these calculations. If one or more accelerometer heads fail before entry, the accelerometer use command is available to flag the problem, so that the AIM software can respond appropriately. Finally, the attitude update command allows AIM to update spacecraft attitude knowledge automatically during the landed phase of the mission using accelerometer data.

Four commands act directly on the MET instrument or hardware. These control instrument power, MET mast deployment, the wind sensor power state, and the switch that determines whether MET housekeeping or spacecraft AIP data are multiplexed into the MET data stream. The two remaining commands call these commands and control AIM data handling. The DO_MET_SESSION command is used after landing to execute a data taking session. Its parameters control session duration, the time delay between power on and data collection, the averaging interval for science data, the averaging interval for housekeeping data, the data sampling interval, the wind sensor power mode and the duration of low and high wind power operation if the wind sensor cyclic power mode is selected. Through this command AIM is able to support considerable observational flexibility for the landed part of the MET investigation. In addition to averaging sampled MET data, the AIM also calculates standard deviations for each channel. It compares these with a predetermined table of standard deviations which it uses to generate a 2-bit flag indicating whether the standard deviation is less than 2, greater than 2, greater than 4, or greater than 8 times larger than the table value. To reduce data volume the flag, rather than the standard deviation, is downlinked. The contents of the standard deviation table can be updated at any time in the mission using the UPDATE_MET_PARAMS command, which also downlinks the current table contents.

Instrument Data Summary: The data generated by the accelerometer and MET instruments are summarized in Table 6. The science and engineering accelerometer instruments each supply 3 acceleration and 13 supporting measurements to the spacecraft. As the instruments are essentially identical, engineering parameters are equivalent to the science parameters, except for accelerometer axis orientations. In addition to accelerations and housekeeping voltages and temperatures, both boards return measurements from a simple solid-state hygrometer. As these hygrometers are isolated from the atmosphere of Mars within the IEM, they are unlikely to produce useful data on water in the martian atmosphere, and should be regarded as an engineering experiment. The MET instrument generates 12 science and 12 housekeeping/AIP parameters. When the multiplexer control switch is set to AIP, 12 AIP temperatures are substituted for the MET housekeeping parameters. Science data however is unaffected. All accelerometer and MET data are digitized to 14 bits and incorporated into a 16-bit data word for packetizing by the AIM. The additional 2 bits are used to store accelerometer gain information and the standard deviation flags generated for the MET data averages.

Observation Strategy

The Pathfinder mission can be divided into cruise, EDL (entry, descent and landing), and landed phases. Nominal plans for ASI/MET observations during these mission phases are summarized below.

Cruise operations: No ASI/MET science observations are planned during cruise. However various health check measurements will be made. The accelerometer instrument will be turned on during all the Pathfinder thrust correction maneuvers (TCMs), to measure offset signal levels in zero-g, detect the axial accelerations produced by the TCMs, and provide instrument functional health checks. The MET instrument will perform two cruise health check sequences, one about a week after launch and the other just over two weeks before EDL. These sequences will exercise the housekeeping and AIP data modes, collect data packets, and direct data to the EH&A (Engineering, Health and Accountability) telemetry stream. In addition to establishing the functional health of the instrument, they will also establish accurate zero offsets for the pressure sensor. Both instruments will be turned on immediately before EDL to establish final offset calibrations. This is particularly important for the accelerometer, which requires time to stabilize. Offset data will be taken for each accelerometer head at all three gain settings.

Entry, Descent and Landing (EDL) measurements: During EDL both ASI/MET instruments will be powered on and collecting data (Table 7). Data sampling will vary dramatically with EDL telemetry phase and will be controlled by the AIM subsystem. There will be no real-time data transmission during EDL. Instead, data packets will be directed to three separate memory locations. These are 'Critical EEPROM', which will contain a bare minimum of science and engineering data, 'Science EEPROM', which will contain fairly complete science data set sampled at a lower than optimum rate, and RAM, which will contain the full science and housekeeping data set. After landing, the contents of critical EEPROM will be downlinked first, followed by Science EEPROM and ultimately RAM. This approach ensures that key data will be returned in the event of rapid deterioration of the spacecraft after landing.

The mission entry phase covers the period before parachute deployment when the entry vehicle is experiencing ballistic deceleration by the atmosphere. Entry is divided into two telemetry phases, freefall and entry. Freefall starts 15 minutes after cruise stage separation and is used to collect instrument offset data at low rates before significant atmospheric accelerations are encountered. Entry starts 29.5 minutes after cruise stage separation, contains the main atmospheric deceleration pulse, and is dedicated to high rate accelerometer measurements. As decelerations increase during entry, the gains of all three science accelerometers are allowed to switch independently from the 16 mg to the 800 mg and finally to the 40 g ranges. Gain switching occurs automatically when accelerations reach 15/16 of the full scale at a given gain setting, although Z-axis gain may be forced prematurely to the 40 g range to provide backup for the engineering accelerometer sampling of the deceleration peak, which is used for parachute deployment timing. The MET instrument is in AIP data mode throughout entry so that no housekeeping data are collected. However, all science data are sampled at a low rate to provide context and offset data for the mission descent phase.

All entry phase data sampled by AIM are directed to RAM, but only a subset is diverted to science EEPROM. This includes all accelerometer parameters, sampled at a reduced rate, and the four MET parameters that are essential for descent pressure and temperature measurements, sampled at an unaltered rate. No MET data are sent to critical EEPROM, and science accelerometer data are limited to low rate sampling of the Z-axis acceleration and two supporting housekeeping parameters.

The mission descent phase covers the period when the lander is descending by parachute through the lower martian atmosphere, starting 20 seconds after the parachute mortar firing when the heatshield separation pyro firing occurs, and ending 0.5 seconds after the lander bridle is cut. It is divided into descent and terminal telemetry phases. The terminal telemetry phase starts when the radar altimeter is turned on.

ASI/MET observations throughout descent center on high rate MET temperature and pressure measurements, although accelerometer data are also taken at a reduced rate. There is no difference in data sampling rates between the descent and terminal telemetry phases. All the science accelerometer channels are commanded to the 800 mg range about 2 seconds after the start of the descent phase and stay there until 8 seconds before the end of the terminal phase, when they are commanded to the 40 g range to monitor the accelerations associated with airbag deployment, rocket firing, and landing. As with the entry data, all sampled telemetry is directed to RAM, a subset at lower sampling rates is sent to Science EEPROM, and only science accelerometer Z-axis data is directed to critical EEPROM.

The final EDL landing telemetry phase starts about 1.5 seconds before impact, and is designed to monitor the lander for about a minute as it falls to the surface, bounces, and comes to rest. During the landing phase MET observations continue to be made at reduced rates, whereas the frequency of accelerometer measurements is sustained. In the science EEPROM and critical EEPROM data streams, accelerometer sampling rates are increased relative to those used during descent.

Landed Operations: Once it has come to rest, the Pathfinder lander begins to open autonomously. Over a period of roughly three hours, the airbags are deflated and retracted, the lander petals are opened, the spacecraft is righted, and the high gain antenna (HGA) is pointed at Earth. In the nominal mission plan, landed data taking then begins, and the MET mast, the IMP camera head, and the rover are deployed by command when it is judged safe to do so.

ASI/MET landed operations center on the MET instrument. The accelerometer will still take data occasionally to determine the acceleration due to gravity at the surface accurately and monitor small changes in spacecraft orientation for HGA pointing, but this data is expected to become less and less variable with increasing time. The MET instrument, in contrast, will begin surface observations that will last until the instrument or the spacecraft fails or the spacecraft is turned off. The nominal Pathfinder landed mission lasts for 30 days but, once it has survived landing, there is no reason why the MET instrument should not function for as long as the lander survives.

MET observations can be divided into two types; repetitive atmospheric sampling that is repeated day after day, and individual experiments that are performed a few times per day. Repetitive sampling will be implemented without uplink using command sequences stored on the spacecraft, and both types of measurements will make use of the flexibility provided by the DO_MET_SESSION command. In practice MET data sampling is limited by lander power and data volume restrictions, so that continuous high rate data can not be taken, particularly at night. The repetitive daily sampling scenario, described below, has been used to develop a MET landed investigation within these restrictions. It is by no means a final scenario, and can be changed both before and after launch, subject to resource restrictions.

In the current MET observational scenario, data is taken for equally spaced 5 minute intervals 25 times per day, and for 1 hour at 3 pm local time. Data will be sampled twice per second and averaged over periods of 4 seconds for science and 32 seconds for housekeeping to reduce total volume by a factor of 14. Wind sensor power will be cycled, but the optimum duty cycle has not yet been defined. It is also probable that 4 second averaging will be replaced by 4 second point sampling, to reduce aliasing of the wind measurements.

Mission Operations and Data Analysis

Pathfinder mission operations activities will occur at JPL, and investigators will be expected to be present at JPL during EDL and the early part of the landed mission. Some of the facilities available at JPL for both ASI/MET commanding and preliminary data processing and display are summarized below.

Commanding: Software tools will be available to generate MET commands in a form suitable for merging with spacecraft sequences, and to assess the impact of changes in instrument operation on spacecraft resources. As there will be minimal ASI/MET activity during cruise, and as EDL activities are entirely autonomous, most instrument commanding from Earth will occur during the landed phase of the mission.

It is envisioned that the science team will decide how the instrument is to be operated and produce a set of command requests on a daily basis. These requests will be presented to the spacecraft mission operations planner who will assess their impact on spacecraft resources. If there is little impact, the commands will be incorporated into the spacecraft command load for the following day. If there are resource issues, the planner will either not include the commands in the load or will modify them in consultation with the science team. There is no formal review cycle in place to regulate this process. Success relies on co-location and good, informal communications between the team leader and the planner.

Data Processing: Data from the spacecraft and instruments will be dowlinked and archived in the project data base. Tools will be available to extract realtime or archived data from the database in packet form. For EH&A data packets, the data management and display (DMD) tool will generate displays of raw and calibrated data, together with simple line plots. For EDL and landed ASI/MET data packets, simple software tools will be available to perform ASCII dumps of the packets and generate line plots of raw and calibrated data.

The tools that will be in place by launch are intended to provide access to the project data base for investigators and insight into instrument health and the success of command uplinks, as well as generating material of immediate interest to the general public. It is assumed that most investigators will develop their own software to address their specific science goals. To this end, the project will supply all available calibration data to investigators on request, together with calibration and data display software.

MICROROVER EXPERIMENTS

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General Goals of the Investigation

A fundamental philosophy of the Rover Team is to develop a microrover which demonstrates key technologies for future Mars rovers, which is consistent with mission costs, schedule, and risk, and which has minimum interference with lander design. The technology experiments planned by the rover team (see below) are designed to demonstrate technologies for future Mars rovers. The rover also carries the chemical analysis instrument (alpha proton X-ray spectrometer or APXS) and the mechanism that deploys the APXS.

Rover Description and Measurement Techniques

Six wheels powered by six separate motors, four steerable wheels powered by four separate motors, and the rocker system form a versatile rover that can turn around in-place and climb a step with a rise somewhat greater than the diameter of a wheel (Table 8). Figure 27 shows a diagram of the rover. Vehicle motion control is accomplished through the on/off switching of the drive or steering motors. An average of motor encoder (drive) or potentiometer (steering) readings determines when to switch off the motors. When motors are off, the computer conducts a proximity and hazard detection function, using its laser striping and camera system to determine the presence of obstacles in its path. The vehicle is steered autonomously to avoid obstacles but continues to achieve the commanded location. While stopped, the computer also updates its measurement of distance traveled and heading using the average of the number of turns of the wheel motors and an on-board gyroscope. This provides an estimate of progress to the goal location and distance to the lander.

Initially, rover operations will probably be within 10 meters or less of the lander. Duration of the Primary Mission is 7 sols and the Primary Mission objectives are: (1) exit from the lander as early as practical, from analysis of monochromatic stereoscopic panoramas from IMP, (2) send initial vehicle performance and technology experiment data to the lander, (3) move a few meters and send more vehicle performance and technology experiment data to the lander, (4) acquire images showing the condition of the lander and transmit them, (5) acquire images at the end of daily traverses for navigation purposes, and encounter, acquire, and transmit an image or images of a rock or "soil" patch for subsequent APXS analysis, (6) deploy APXS on a (or the imaged) rock or "soil" patch for 1 to 10 hours duration (may occur at night) for chemical analysis, (7) query the APXS for final data and transmit interim and final data to the lander, and (8) traverse diverse terrains and send vehicle performance and technology experiment data to the lander. If spacecraft, rover, and site related factors permit, objectives and requirements may be exceeded by deploying the APXS for additional analyses of soillike materials and rocks and the acquisition of more data for the technology experiments.

The duration goal of the Extended Mission is 30 sols, but a longer duration is possible. Extended Mission objectives are like those of the Primary Mission, but they also include exploration of diverse terrains on Mars well beyond the lander - perhaps as far as a few hundred meters.

There are three cameras aboard the rover (Table 9). Two broadband monochrome cameras are located on the forward part of the rover and provide stereoscopic images. A third camera is located on the aft part of the rover near the APXS, which has a pixel array that allows imaging in three colors. For every 4 x 4 block of 16 pixels, 12 are green, 2 are red, and 2 are infrared. Spectral response of the camera for each of the three types of pixels is shown in Figure 28. The response of the infrared pixels is low, compared to that for the red and green. Unfortunately, increasing the exposure time to improve the dynamic range of the infrared pixels results in bleeding of light from the red and green pixels into the infrared pixels. Thus, the color camera will primarily be useful only for red and green color information.

Data Collection Procedures

Several rover images will probably be acquired each day, the actual number depending on mission plans. APXS targets and technology experiments will have different requirements for imaging. Options for image collection include selection of a rectangular subset of pixels, automatic or selected exposure time, and compression. For an idea of what and how engineering data will be collected, see the Vehicle Performance experiment description.

Nature of Available Data Sets

Rover images will be stored in a database with query and image browse capability. Raw engineering data (e.g., accelerometers, gyroscope, temperature sensors, power current, rover heading and position, contact sensors, etc.) will be stored in the project database.

Technology Experiments Planned by the Rover Team

(1) Terrain characterization: Rover and IMP images will be used to determine terrain feature classes ("soils," rocks, hills, etc.) and statistical size and location distributions of the feature classes.

(2) Basic soil mechanics and sinkage in each soil type: The physical-mechanical properties of interest are: (1) grain characteristics (size, distribution of sizes, shape, etc.), (2) density, (3) cohesion, (4) friction angle, and (5) compressibility. This experiment will evaluate the mechanical properties of the martian surface

materials (e.g., soil energy loss, shear strength, sinkage, shear strength as a function of sinkage, adhesion, and abrasion) using the results of the Vehicle Performance experiment and rover and IMP images. Experimental techniques include measuring vehicle performance (motor torque, bogie positions, etc.) during traverses and special experiments. One such experiment will involve rotating one wheel while others are held fixed, and deriving "soil" shear force from the measurements. Sinkage is obtained from IMP images of rover tracks and experiment wheel patches and from rover images of a wheel in the "soil."

(3) Wheel abrasion: This experiment will assess abrasive wear on a rover wheel using thin films of Al, Ni, and Pt, (200 to 1000 angstroms) deposited on black, anodized Al strips that are attached to the rover wheel. As the rover moves across the martian surface, a photocell will monitor changes in film reflectivity. These changes will indicate the amount of abrasion of the metal films by martian surface materials. Data on wear will be accumulated. In a special experiment, all of the rover wheels will locked to hold the rover stationary while the test wheel is rotated and digs into the surface in order to provide more severe conditions than simple rolling. Laboratory experiments using terrestrial materials and a rover wheel will be used to evaluate the results.

(4) Material adherence: The goal of this experiment is to measure the change in performance of the solar array caused by dust deposition on the array. The experiment employs a reference cell with a memory-metal actuated transparent dust cover. Comparison of the output of the reference cell with and without the transparent dust cover will be a measure of the degradation of the array due to dust deposition. The oscillation frequency of the quartz crystal changes as mass is deposited on its surface. The sensitivity is 4 nanograms/cm^2 with 10 nanograms/cm^2 drift. Expected atmospheric dust deposition (1.7-5 micrograms/cm^2/day) is well above the sensitivity and drift. Maximum loading is about 177 micrograms, which corresponds to 35 days of operation for a rate of dust deposition of 5 micrograms per day.

(5) Thermal characterization: The rover has seven temperature sensors internal to the warm electronics box and six external ones. Temperature will be monitored during both day and night each sol to track the thermal characteristics of the vehicle.

(6) UHF link effectiveness: The radio signal strength and noise will be monitored as a function of distance between the rover and lander, for various conditions of terrain occlusion and temperature (of the equipment). This experiment will provide measurement of the performance of the radio modems (e.g., bit error rate).

(7) Vehicle performance: All engineering status data will be logged with time tags, including measurements of solar array power output, voltage and current from the batteries, voltage and current from the power regulation equipment, temperature, data transfer performance (between the rover and lander), inertial sensor and location estimation, and motor performance. During traverses, the rover also

measures steering and bogie potentiometers, wheel encoder counts, motor current, hazard/obstacle detection from the camera/laser system and contact sensor state. Sampling is normally every ten minutes during the day and every hour at night. During traverses, the rover samples data every two seconds.

(8) Dead reckoning and path reconstruction: The objective is to determine the error in the rover on-board position estimator by comparing predicted vehicle positions with positions derived from the dead reckoning sensors (wheel encoders and gyroscope) and with the positions determined by the end of sol lander image.

(9) Vision sensor performance: The rover and IMP cameras will image the tracks produced by the vehicle in the soil after traverses. These images, taken once per sol, can be correlated with the vehicle telemetry and the reconstructed paths to develop and refine the hazard avoidance and navigation algorithms used on the rover.

DEEP SPACE TRANSPONDER

Science Objectives

By two-way X-band range and Doppler tracking of the Mars Pathfinder lander by the Deep Space Network, a variety of orbital and rotational dynamics science objectives can be addressed. Tracking the Pathfinder lander allows determination of the location of the lander. Knowledge of the location of the lander enables the pole of rotation of the planet to be determined. Knowledge of the orientation of the pole of rotation allows calculation of the precession rate to a fraction of a percent by comparing with similar measurements made with the Viking landers about 20 years ago. Measurement of the precession rate (regular motion of the pole with respect to the ecliptic) allows direct calculation of the moment of inertia, which is governed by the density distribution with depth of the planet. At present, the moment of inertia of Mars is poorly known and interior models with and without a metallic core cannot be distinguished. Measurement of the moment of inertia by Pathfinder tracking will provide strong constraints on possible interior models and will likely distinguish between these competing interior models. The present day moment of inertia is also a strong constraint on potential obliquity variations in the past, which could have been large for Mars. Constraining possible obliquity variations is important for understanding long term climatic fluctuations. The seasonal variations in rotation rate (changes in length of day) are also indicative of the cycling of volatiles between the atmosphere and poles and can be addressed if Pathfinder can be tracked for a significant fraction of an Earth year. Finally, the ranging data can be used to address scientific questions regarding asteroid masses (from the improved martian ephemeris), the time variability of the gravitational constant, and can be used to test general relativity.

Doppler

The Mars Pathfinder lander makes use of the Cassini-designed Deep Space Transponder (DST), capable of generating two-way X-band Doppler and range data via the Deep Space Network (DSN). Two-way (or coherent) Doppler is produced by measuring the received frequency of the downlink carrier and comparing it to the uplink carrier frequency, which is stable and well known. As the lander moves relative to a tracking station, the velocity between the two causes a shift in the observed frequency. This observed frequency shift in the downlink carrier provides a means of accurately measuring the range rate from the station to the lander. Typical Doppler noise at X-band is 0.003 - 0.006 Hz for a 60-second count, equivalent to a range rate measurement uncertainty of 0.05 - 0.1 mm/s (1- sigma). Collecting two-way Doppler requires an X-band uplink from the DSN station and the transponder's two-way non-coherent (TWNC) switch be in the 'OFF' position. Additional information on ranging using the DSN can be found in "DSN/Flight Project Interface Design Handbook", DSN 810-5, Rev. D, Chg. 1, Vol. I, Section TRK-20 (DSN TRACKING SYSTEM: DOPPLER AND SIGNAL LEVEL), Mar. 15, 1990, which is accessible on the World Wide Web at URL (http://deepspace1.jpl.nasa.gov/dsndocs/810-5/tr20/tr20.html)

Range

Range data is collected by the DSN using the Sequential Ranging Assembly (SRA) installed at all three DSN complexes. The SRA acquires range data by modulating the uplink carrier with a digital code and measuring the time for that code to make a round-trip from the station to the spacecraft. This digital code is configured by a series of squarewave signals (known in the SRA as components), with frequencies varying from 1 Hz to 2 MHz. Before the tracking pass, DSN personnel perform a ranging calibration procedure to characterize the electronic delay from the SRA to the antenna collection point. After two-way coherent tracking is established, the uplink carrier is modulated with the ranging tone from the SRA. A round-trip light time later, the range signal is received on the downlink carrier. Correlating the uplinked signal with the received downlinked signal over a selected integration time (typically 10-20 minutes) provides an accurate measurement of time delay and therefore the distance from the station to the spacecraft. The procedure continues to collect range data points until the pass is over or it is decided to cease ranging for other reasons. Typical range data exhibit noise levels of 1-10 meters (1-sigma), depending on the signal-to-noise ratio of the range channel and the desired integration time.

Operational Constraints

Two-way ranging requires a coherent signal (i.e. TWNC=ON) and the transponder's range channel must be on. Additionally, there needs to be a sufficient signal-to-noise ratio of the ranging signal in the downlink, which is achieved by utilizing the lander's high gain antenna and a 34-meter High Efficiency (HEF) DSN station. In some cases the uplink or downlink signal-to- noise ratio may be too low to simultaneously support ranging with commanding and/or high-rate telemetry. Coordination of ranging activities with other mission activities is required to ensure sufficient uplink and downlink signal levels. Presently, the project expects to have sufficient signal to noise link margin to allow two-way ranging during all communication sessions. Additional information on ranging using the DSN can be found in "DSN/Flight Project Interface Design Handbook", DSN 810-5, Rev. D, Vol. I, Section TRK-30 (DSN TRACKING SYSTEM: RANGING), Nov. 15, 1993, which can be accessed directly on the World Wide Web at URL (http://deepspace1.jpl.nasa.gov/dsndocs/810-5/tr30/tr30.html).

Temperature fluctuations, such as those expected during the surface phase, are known to introduce errors in the range measurement. This phenomena has been measured for Pathfinder, but only for the conditions of the transponder expected during interplanetary cruise, where precise range data is required for navigation. For ranging from the surface, it will be necessary to determine and calibrate the temperature effect by utilizing measurements of the transponder temperature and observed behavior of the range data. Additional data on this effect during cruise will also be available as the project expects to use two-way ranging during cruise to track the location of the spacecraft.

The Pathfinder spacecraft has an X-band receiver, which requires use of the 34-m HEF antennas for uplink (for commanding the spacecraft from Earth). Current project plans are to use two-way ranging during most, if not all uplink sessions. During the prime mission, the project has extensive use of the DSN 34-m and 70-m antennas (4-8 hours per day). Project plans call for one or two uplink sessions per day of order one hour duration. Available power on the spacecraft allows downlink (return of data from the spacecraft to the Earth) on the high-gain antenna for 2-4 hours per day. Downlink into the 70-m DSN antennas improves the data rate by a factor of 4, so that the 70-m antennas will be used whenever possible during downlink. Nevertheless, the spacecraft is capable of uplink, downlink and two-way ranging at the same time. As a result, it is possible to uplink using a 34-m HEF antenna at the same time that downlink occurs into a 70-m antenna, although as stated earlier, this requires a slightly higher margin for any given link over one way incoherent downlink. Evaluation of this margin during surface operations will be done to optimize data return (using the highest data rate possible) from the spacecraft, while still maintaining enough two-way ranging time to successfully track the lander. During the extended mission (after the first 30 days), the use of DSN antennas decreases sharply and the exact time allocation has not been set. Nevertheless, preliminary analysis indicates at least 2-3 uplink sessions per week of roughly 1 hour each will be possible. Additional downlink time may be available, but likely without two-way ranging.