MICROROVER & LANDER-MOUNTED ROVER EQUIPMENT (LMRE) TECHNICAL BASELINE: HIGHLIGHTS AND DESIGN PHILOSOPHY

DESIGN PHILOSOPHY:

1) Develop a microrover which demonstrates key technologies for future Mars rovers.

2) Develop a microrover consistent with MPF mission cost, schedule, and risk constraints.

3) Minimize the microrover's constraints/requirements on the lander, and vice versa. (Decouple microrover and lander design evolutions, consistent with project constraints.)

4) Make microrover adaptable to other landers with minimal microrover or lander redesign.

MICROROVER MISSION HIGHLIGHTS:

The Ares/Tiu Valles is the prime landing site: 19.5°N, 32.8°W. This is a 'grab bag' site so named (and chosen) due to the likelihood of landing near: lots of rocks of a variety of ages, channel deposits, interesting features: 1 km knobs, crater clusters, small young volcanoes and dikes, etched channel floor, and dark halo craters) :

1) The prime microrover mission is within lander camera range.

2) The maximum required microrover radial range from the lander is a few tens of meters with a goal of a few hundred meters.

3) The primary microrover mission is completed at the end of 7 sols (Martian days).

4) Primary microrover mission objectives (not ordered by priority, but loosely chronological):
   a) Exit from lander as early as practical, based on two images: *one of the terrain surrounding the rover petal prior to deployment of the ramps and* one ≈ 120° x 37° lander stereo image *of the rover and early rover activity area on the lander and terrain at 1cm resolution.prior to rover deployment*
   b) Telemeter initial data for mobility, control/navigation, and other technology experiments (wheel/soil interactions, dead reckoning values, etc.).
   c) Move a few meters and telemeter more rover technology data.
   d) Take and return status assessment images of the lander.

e) Take and send "end of sols drive" images for navigation evaluation…or
e´) Encounter a rock or soil patch for APXS, image it, and transmit the image.
f) Deploy APXS and perform a 1 to 10 hr experiment on the rock, or up to a 10 hr experiment on the soil. If solar power fades, rover goes to sleep, but rover's battery will power night phase(s) of APXS experiment if so commanded. (Rover collects & stores or sends interim spectra at (nominally) 1, 2.5, 5.0 and 10 hr intervals.) After 10 hr APXS experiment, rover shuts off APXS. (If at night, rover awakes, shuts off APXS, then goes back to sleep until morning.)
g) The morning after APXS night operation, query APXS for final data, then pass both the interim and the final data to lander.
h) Move on varied terrain, telemeter mobility, control/navigation, and other technology data (wheel/soil interactions etc.) .

5) The extended rover mission begins on sol 8 and continues until terminated. The extended mission goal is 30 sols, but no overt resource consumption precludes continuing indefinitely.

6) Extended rover mission objectives (not prioritized) are:
   a) Telemeter mobility, control/navigation, and other technology data (including pictures) over hundreds of meters of varied, rugged and extreme[1] terrain (slopes, sand, rocks).
   b) Take additional APXS spectra (and associated images) of soil, rocks, *rocks with weathering rind removed (as possible) and ramp magnetic targets*.
   c) Take additional lander assessment images.
   d) Explore "over the horizon" and return pictures.
   e) Extended experiments per the Science/Technology Working Group.

MICROROVER DESIGN ENVIRONMENT HIGHLIGHTS:

1) Delta II (7925) launch vehicle vibration, acoustics, etc.

2) 57 g half-sine pulse, $\approx$ 150 msec duration, actual landing load, with low g-level higher frequency content. Design safety factors of 2.0 (ultimate) and 1.4 (yield) are used for untested equipment, 1.25 (ultimate) and 1.0 (yield) on tested equipment. The structural testing factor is 1.1 (with yielding allowed).

3) 0.1 g^2/Hz design levels for random vib, 80 to 450 Hz, give 114 g peak response (3 sigma) @ Q=20.

[1]Contingent on budget, rugged terrain operations may be without special protective behavior S/W

4) Max/Min actual flight/landed temperature in electronics compartment: +40°/-40°C, operating/non-operating. (15°C qualification margin is added beyond these values.)

5) Max/Min actual flight/landed temperature of equipment external to electronics compartment: +40°/-95°C operating[2] and/or non-operating. (15°C qualification margin is added beyond these values.)

6) Mars atmospheric pressure & primary atmospheric constituent: ≈ 5 torr, CO^2

7) Actual total radiation: ≤ 0.2 K rads behind ≈ 10 mils equivalent aluminum.

8) For rover design purposes, the Mars atmospheric model assumes a worst case of tau=1. The lander designers are assuming a worst case of tau=5. (If tau=5, rover operations could be impacted due to increased periods with ambient temperature < -80°C. Some rover components, such as laser stripe projectors, cannot be operated at such low temperatures.)

MICROROVER OPERATIONS PROCEDURES/CONSTRAINTS

System/External Flight Rules

1) *IMP images of terrain near the rover petal will be required before ramp deployment or rover release.*

2) APXS Deployment Mechanism pyro must be fired within approximately one minute of the rover release pyros. This ensures that the APXS release indicator on the rover can be interpreted as a rover release indicator.

3) The APXS Deployment Mechanism must be fully retracted by the rover before the ramps are released, to avoid ramp contact with the APXS head during ramp deployment. Otherwise, damage to the APXS sensor head may result.

4) The lander petals must not be operated after the rover is released and before the rover has left the ramp.

5) Until the rover stands up, the thermal path between the rover and lander will not be broken. Firing of the rover release pyros will not be sufficient to break this connection. Therefore, the lander must continue to heat *the cold finger attachment between the lander and rover* until the rover has been commanded to stand up.

[2]Some external items needn't operate until heaters or day environment warms them above ≈ -40°C

6) *The APXS shutter will not be opened when the temperature is below -80°C. The APXS sensor head shall be operated only when the surrounding Martian ambient temperature is between -100°C and +25° C.*

7) *APXS experiment targets shall be selected to avoid placing APXS sensor head axis more than 90 degrees from the vertical axis.*

8) *For images associated with rover operations planning, always pan the IMP left-to-right to reach the desired pointing angle for any image. Use the "no-image"setting for right-to-left slewing motions.*

9) *The rover reed relay should not be actuated for more than 30 seconds. Always wait at least TBD minutes between successive actuations.*

10) *When powering-on the LMRE modem, ensure that only one of the two strings is powered-on. During time periods in which the LMRE modem is powered-on, power cycle the modem approximately every hour to clear any possible latchup conditions. The downtime of the modem should be no more than a few seconds to minimize disruption of any ongoing rover-lander communication.*

Internal Flight Rules

1) Before the start of APXS data collection, the time between rover requests to the lander for command sequences (the command query interval) will be set to ≥30 minutes. At the end of APXS data collection, the command query interval will be reset to its default value.

2) Rover rangefinding hazard detection will be turned off whenever the rover is operating on a lander petal or on lander ramps.

External Support of Rover Operations

1) In addition to end-of-day stereo images of the rover, the IMP camera will capture at least one mono image with an azimuth approximately 90° *from the image of the rover*, in order to support re-registration of images *in case of lander orientation shift.*

2) MIPL will perform re-registration of rover end-of-day images to the Mars local level coordinate frame.

3) The lander will have the capability to enable rover command sequences. This

capability will be used only as a “valve” to allow rover sequences to become available to the rover at its next command sequence request, and will never be used to change the order of a set of sequences. The purpose of this capability is to enable tight coordination of rover and lander activities before the rover has been fully deployed onto the Martian surface (e.g., coordinating APXS head retraction with ramp deployment without requiring an additional Earth communications cycle.) The need for lander enables of rover sequences will be disabled after surface operations begin.

RECENTLY BASELINED MICROROVER FEATURES:

This section lists features recently included in the “Technical Baseline.” Rover weight, power, volume tabulations and geometric, electric, thermal interfaces, etc., incorporate these features:

System Level Features/Implementation Revisions:

1) The completion of thermal subsystem and rover system thermal environment tests has shown there is no longer a need:
   a) to retain a thick insulation thermal control option. The baseline design described below addresses all mission environments: operation on Earth during test, integration and test on the lauch pad with the spacecraft, cruise attached to the lander upon delivery to Mars, and Mars surface exploration.
   b) to plan for WEB heating during a nominal sol on Mars. WEB heating capabilities will be retained in the design as margin for off-nominal thermal environment conditions.

Mobility and Thermal Control Subsystem Revisions:

1) A bumper is provided at the connector attachment to external bulkhead, providing a physical contact indication at the front of the vehicle.

2) Monitoring of the motors for short circuit protection has been changed:
   a) the ADM motor is monitored for short circuit protection only. A short circuit is declared if the motor current exceeds 406mA.
   b) the steering motors are monitored so that an ‘overheating’ condition is declared to occur if in any 10sec period, the current*time product exceeds 1.67 amp-sec

3) The low resistence WEB heater has been changed to 26Ω.

4) The batteries are allowed to be stored at 50°C for as long as 2 weeks without degradation.

Control Subsystem Revisions:

1) The four outboard lasers have been changed from stripers to spot projectors and the hazard avoidance algorithm modified to operate on a short history of projected spot locations developed during rover movements. This corrects a problem with reflected light returned to the cameras in Mars sun illumination conditions. In addition, to enhance laser light intensity, the power delivered per laser is increased, requiring that lasers be operated one at a time.

2) To reduce error in dead reckoning due to gyro drift and instability during power-up, the gyro is allowed to remain powered-on during traverse sequences while the rover is stopped.

3) The programming resident in the 16KB rad-hard PROM controls power-on reset and invokes a reduced-functionality control program, if the main programming in EEPROM is determined to be invalid. The functionality retained includes:
   a) communication through the modem (but no latch-up checking or modem heating logic)
   b) support for running motors, driving and contact sensor induced aborts (no dead reckoning estimation or camera/laser system hazard avoidance)
   c) health checks that report sensor outputs only (no checking while motors/heaters or most devices powered-on)
   d) read/write at I/O ports

Power Subsystem Revisions:

1) The current limiter has been adjusted to allow the vehicle to operate at range of voltages between 13.5V and 14V under solar panel power.

UHF Radio Communication Subsystem Revisions:

1) Thermal testing of the radio modems revealed that BER performance is sensitive to low temperature. Heating of the radio modem on the rover is required when the temperature is below -15°C to obtain a BER less 10E-4. When modem temperature is below -10°C and a failure in communication with the lander occurs, the modem is heated for 15min if solar panel power is available or 30min under battery power. In addition, batteries are enabled for use for modem heating

throughout the mission.

2) The heater on the rover modem has been changed to 78.5Ω (2.5W @ 14V).

Science and Technology Experiments Revisions:

1) In support of APXS operation:
   a) after power-off of the APXS there will be a delay of at least 10sec before a subsequent power-on.
   b) after power-on of the APXS there will be a delay of at least 30sec before a command is issued to the APXS to begin collecting spectra data.

Lander/LMRE Mechanical Interface Revisions:

1) The LMRE ramps are modified with a cut in each stem near the edge of the petal. This gives the ramps a preferential bend at deployment.

2) The LMRE rover tiedowns include mechanical latches for restraining vehicle motions perpendicular to the wheel turning axis.

Lander/LMRE Electrical Interface Revisions:

1) The heater of the 'coldfinger' (a thermal strap which is part of the LMRE and thermally connects the interior of the WEB to the lander panel and coolant loop) has been changed to a 225Ω (5.76W @ 36V) heater on the lander.

2) The LMRE modem is relocated in the lander integrated electronics module (IEM) attached to the rechargeable battery. Lander thermal models ensure that the temperature of this battery will not fall below 0°C during a sol. Hence the default power-up mode of the LMRE modem is to power-up with the converter which does not power the modem heater.

MICROROVER REFERENCE DESIGN: FEATURES AND IMPLEMENTATION:

System Level Features/Implementation:

0) See also, “Recently Baselined Features” (all are not duplicated in this section).

1) The rover utilizes a UHF lander/rover communication link which has a clear-field radial communication range of ≈ 500 m. “RF link checks” are made approximately every rover-length of travel so the rover does not become lost in an

area where it's unable to communicate with the lander. During traverses, the rover stops every 0.6 meters ($\approx$ *90sec*) sends a signal to the lander and receives an echo back. If RF contact is not made, the rover performs a recovery behavior which may include: turning in place, backing to the last point(s) of successful RF contact, etc., in an attempt to regain lander communication.

2) Rover large-scale navigation is commanded from the ground, based on lander-generated stereo images supported by on-board tilt and heading sensors. Rover terminal guidance (rock approach, etc.) can use lander & rover stereo images, rover ranging sensors and/or rover contact sensors.

3) Rover power is supplied by a solar panel, primary batteries, and GSE power for test on Earth. The rover can accomplish all mission objectives (except night temperature measurements) with all batteries dead. (With dead batteries, APXS night activity is shifted to day.) The rover can also accomplish virtually all of its primary objectives with the batteries good but the solar panel dead. In the event of solar panel failure, batteries are used to conduct surface operations/experiments as quickly as possible (not to heat the rover). In this "dead panel scenario" the WEB interior is allowed to cool (below -55°C) at night rather than use batteries for heat, and operations are moved to the warmth of late afternoons.

4) The rover employs power management sequencing to maximize power margin. For example, motor start ups are done sequentially to minimize surge current demands, steering is not done while drive wheel motors are running. and the CCD/Light-Striper rangefinding system, and UHF modem are both off during motor operation.

5) Electronics are single point grounded, and ground is floated above chassis with $\approx$ 1KΩ resistance and *a* $0.1\mu F$ *capacitance*.

6) The rover's thermal control design requires no electrical heating during the Martian night. Daytime power from the solar panel and continuous RHU heat is used to heat the "Warm Electronics Box" (WEB). Insulation keeps the WEB warm through the night.

7) To minimize system weight and WEB volume, cables between WEB equipment and external equipment are typically pigtailed at their source. Flex cable connects the board set to all bulkheads; from these cables are pigtailed to electronic subassemblies. A connector panel is provided outside of the "igloo tunnel" and WEB-equipment-to-external-equipment connectors mate at that panel. Also, a direct access test connector (capped for launch) is provided outside the WEB on the solar panel for system test and diagnosis.

8) "Unacceptable- modes-when-latched-to-lander" (power to motors, etc.) are locked out by software flags until rover sensors indicate the rover release sequence has occurred.

9) The rover can take and store a full frame CCD image in 1 minute, compress it in 6.25 minutes, and send the compressed image to the lander in 5 minutes. [The lander can send it toward earth in ≈ 9 minutes (at 1200 BPS) to 35 minutes (at 300 BPS).] Prior to taking each image, rover requires ≈ 60 seconds to take a pre-image and set the exposure time for the "real" image.

10) Rover can compress images (compression ratio 4.9:1) with Block Truncation Coding (BTC) at 0.52 MBits/min (8.7 Kbits/sec).

11) Mass of rover, *including payload as measured at delivery to the MPF flight system, is 10.5 kg. The current best estimate of the mass of the rover including uncertainty associated with any future modifications is 11.0kg.*

12) Mass of LMRE ("red carpet" ramps, rover release latches, UHF antenna/mechanism, UHF modem, uncertainty, etc.) is *4.9 kg*.

13) Mass of the mobile payload is 1.35 kg, (1.2 kg for the APXS plus mobile portion of its latching/positioning mechanism, and 0.15 kg for MAE-plus-WAE).

14) Mass allocation for the rover, mobile payload and LMRE is *16.0 kg*.

Mobility Subsystem Features/Implementation:

See also, "Recently Baselined Features" (all are not duplicated in this section).

Mechanical Portion Of Mobility Subsystem:

1) The Mobility Chassis has 6 wheels (130 mm dia, 60 mm footprint width), in the Rocky IV rocker-bogey configuration. It can turn in place, provides a traverse rate of ≈ 0.4 meter/minute, climbs vertical steps somewhat higher than the tops of the 130 mm wheels, and crosses soft sand with a Mars surface pressure of ≈ 0.3 psi (@ ≈ 10 mm sinkage).
   a) The "Stowed Rover Static Envelope", is 650 mm long, 480 mm wide, & 190 mm high, with an approximately 100 mm trapezoidal extension in the long direction. (The trapezoidal height tapers from 200 mm to ≈ 170 mm.) The rover unstows to 300 mm high. The "Unstowed Rover Envelope" is 650 mm long, 480 mm wide, 300 mm high
   b) All steering, APXS mechanism and wheel-drive actuators are non-back-

driveable through magnetic detents and are configured with 2000 to 1 gearboxes powered by Maxon REO16-039-14 motors (*14 V* to 18 V nominal operating range, winding resistance: 84 Ω @ +20°C, 64 Ω @ -40°C, torque factor: 44 mNm/amp). With actuators powered at 15.5 V typical Rover performances are:

i) Actuator output is ≈ *1.5 RPM at 0°C* at no-load, *0.8 RPM* at high working load (9 in-lb @ *-80°C*).
ii) Rover speed is ≈ 0.4 m/min over nominal terrain (essentially no load).
iii) Rover speed is ≈ 0.25 m/min over extreme terrain (actuator output of ≈ 9 in-lb).
iv) Stall Torque is ≈ *75 to 110 in-lb, (7 to 10 times* the torque required for extreme terrain).
v) Wheel steering rate is ≈ 7 deg/sec.

c) The total of 6 drive motors (1 per wheel) draw an average raw power of ≈ *5.9 W /1.0 W* on nominal terrain and ≈ *7.5 W / 2.3 W* in rugged terrain, at temperatures of -40°C/0°C @ *14 V*.
d) The total of 4 steering motors draw an average power of ≈ *6.0 W / 2.4 W* at -40°C/0°C when steering on rugged terrain, and provide a wheel steering rate of ≈ 7 deg/sec.
e) Each steering motor, each wheel-drive motor, and the APXS motor is independently on-off controlled in least time increments of 0.1 seconds (no pulse width modulation speed control). An individual turning command to each of the 4 steering motors moves it to the desired angle. (Each steering motor or APXS motor is turned on until its potentiometer reaches the commanded position, then the motor is turned off during the following 0.1 seconds.) After any steering or wheel-drive motor is turned on, its commandable turn-off control options include “wheel encoder counts,” “time from turn-on,” or “on-board dead-reckoning-based computer command.”
f) Total current to the suite of motors/heaters is limited as necessary to maintain the core bus at *14 V*. This protects the solar panel powered Rover from brown outs in the case of dead batteries, and protects the motors from being overheated in the face of global overloads (climbing in deep sand, accidental turn-on while latched to lander, etc.)
g) A switch-controlled bypass power-line (directly from the batteries) is diode-connected to the Motor/Heater Power Bus, downstream of the Current Limiter. When ON, this bypass automatically augments solar panel power to the motors, assuring a Motor/Heater Power Bus voltage no lower than the battery voltage (≈ 8 V to 10 V). (8 V can provide up to 0.75 A of current to the six drive motor array at -40°C, for a total Rover thrust of ≈ 30 lbf.) Because the bypass is diode isolated from the core bus, it can be switched onto the Motor/Heater Bus with no risk of core bus (CPU) gray-out.
h) *Each wheel-drive and steering motor is individually protected from overheat and short circuit by software current monitoring. The APXS mechanism*

motor is protected from short circuit. If the current-time product to any wheel drive motor exceeds 6.7 amp-seconds during any 40 second period (e.g., 166 mA for 40 secs, or 240 mA for 28 secs, etc.) the motor will be shut off to avoid overheat, then turned back on after an appropriate cooling time (≈ 300 secs). *If the current-time product of any steering motor exceeds 1.67 amp-sec in any 10sec period, the motor will be shut off to avoid overheat*. If the steady state current draw of *wheel-drive or steering motor* is above the limit of 316 mA, the motor is considered shorted and shut-off. *If the steady state current draw of the APXS deployment mechanism motor is above the limit of 406 mA, the motor is considered shorted and shut-off.*

i) The wheels, drive motors, and drive gear boxes are designed and qualified to support at least 100 meters actual travel on earth, followed by 100 meters actual travel on the surface of Mars.

j) The steering system permits steering angles on each steered wheel of ± 55°.

k) Mobility technology experiment instrumentation (1 bit/rev optical motor encoders and associated externally mounted dropping resistors, temp sensors, bogie and steering potentiometers) are in the mobility subsystem and have data/electrical interfaces negotiated with the control subsystem. Motor power switching, current monitors and voltage monitors are provided by the computer I/O board.

l) Wheel motor encoders are 1-bit per motor revolution optical encoders with an approximately linear transition from full on to full off during 30° of motor rotation.

m) The LED's for each "left-side/right-side" set of wheel motors are wired in series with an externally mounted current limiting resistor (10 mA). The 2 motor LED strings are paralleled with 2 similar APXS contact sensor strings and the entire LED array is fed from a single 5 V/return wire pair. The LED resistors and similar resistors for the associated detectors are externally mounted to minimize wire count through the WEB wall, and they belong to their associated subsystems (Mobility or APXS).

n) There are three "high resolution" bogey/rocker position potentiometers (full 12 bit A/D conversion used--low bits may be noisy) , one high resolution pot is on the rocker differential and one is on each wheel bogey. There are also four "low resolution" pots (8 bits used), one on each steering assembly. (An additional low-res pot, not part of the Mobility Subsystem, is on the APXS positioning mechanism).

2) The Mobility Chassis supports the Warm Electronics Box (WEB), an insulated enclosure that houses all equipment which must be kept above -40°C during the Martian night.

3) The Mobility Chassis also supports the cabling, the hazard-detection/navigation sensors, the solar panel, the UHF antenna and latch/deploy-mechanism, one side of

the Rover/Lander tie downs, and etc.

4) Based on tests with the motors and gear box configurations, motor heater usage is formally removed from the baseline operations. However, the heaters and all accommodation for cabling, switching electronics and software support for control of motor heaters are retained pending final motor configuration and thermal test results. As such, the design provides four independently switchable strings of motor heaters fed from the current limiter. They are designed to preheat motor-actuators for $\approx$ 60 minutes before operating, thereby reducing the required actuator power by as much as 8 W and enabling solar-panel-only extreme terrain driving in mid morning. The actuator heaters in a string are wired in parallel, and each heater *is 157 Ω (1.2 W @ 14 V*. The heater strings are:
   a) String-1, heats one rear steering actuator and the APXS actuator.
   b) String-2, heats the remaining three steering actuators.
   c) String-3, heats the three "minus-Y" wheel drive actuators.
   d) String-4, heats the three "plus-Y" wheel drive actuators.

5) The heater strings connect to the output side of the current limiter. If too many heaters are turned on before the panel can fully support their current draw, the limiter automatically increases its resistance, and all power unconsumed by equipment upstream of the limiter is shared between the limiter (WEB heat) and the downstream loads (actuator heat).

6) The "Jeff" (main rocker) axle is configured as a low thermal conductivity structural tube which penetrates the WEB from one side to the other (parallel with the rover and lander Y-axes when the rover is stowed on the lander petal. +Z is down for both rover and lander coordinate systems).

7) The +Y end of the "Jeff" tube (toward the Lander petal outboard end when the Rover is latched to the petal) is open and accepts direct insertion of a 3 RHU "bayonet capsule." This permits late installation of the RHU's in one quick step without opening the rover WEB at the ETR (flight batteries are pre-installed at JPL). If desired, RHU bayonet capsule installation can be done without unlatching the rover from the lander petal.

8) The rover differential is all lever action, using one high resolution pot to monitor position state. Differential-pot-to-running-gear backlash is held as small as practical, especially on the side nearest the potentiometer. The differential is at one end of travel with the rover in the stowed position on the petal, and slews to the mid-travel position when the rover is fully "stood up" on the petal, thus the pot directly monitors the height the rover achieves during stand-up.

9) The "standard" electrical connector on the rover is the pre-wired Cannon "Micro-

D" (or equivalent). A flex harness will be used to connect circuit boards to external bulkheads, and will route through the WEB tunnel. The standard wire in all other cables is 28 gauge high strength copper (not a special order for Micro-D's). Exceptions to wire size standards are made on a case by case basis. Where possible, standard cabling has been replaced with flexprint.

10) The rover incorporates positive means of bleeding electrostatic charge from rover elements to the Mars surface (conductive brushes to wheels or equivalent), and to the Mars atmosphere (pointed "discharge spines," or possibly just take advantage of existing APXS radiation source ionization)

11) Paint markings on the vehicle have been added to enhance determination from the lander camera images of rover position and orientation. The locations for the markings are on:
    a) the solar panel port and starboard edges with 115 mm long alternating color tape segments *against a background of alternating black and white stripes*.
    b) the wheels with paint markings to show their relative state of rotation,
    d) the collision bumpers *with alternating black and white markings*.

12) There are four rover tie-downs to the lander petal: one for the APXS sensor head and APXS deployment mechanism and 3 for the rover proper.

13) The design of cable runs and location of equipment on the rover have been revised to provide ease for assembly and replacement during integration and test. Highlights include:
    a) introduction of both internal and external bulkheads for cable/connector attachment
    b) pigtails from all components, in particular the CPU & I/O and power electronics boards
    c) standoffs in place between the CPU & I/O and power electronics boards and attachment of the WEB internal bulkhead to the boards.
    d) use of flex print cable as the implementation of the wire run from the internal bulkhead to the external and APXS bulkheads for all wire except coax.

Thermal Control Portion Of Mobility Subsystem:

1) The Warm Electronics Box (WEB) is constructed using solid SiO_2 aerogel as insulation, lining an epoxy sheet and spar box. The insulation is of density approximately 20 mg/cc with additional 20 mg/cc aerogel crushed into Nomex honeycomb for the top (solar array portion of the WEB). A high emissivity gold coating is planned for the exterior of the WEB. Its average thermal loss is targeted not to exceed 2 W (50 W-hr per sol) beyond the RHU supplied heat. The WEB is

heated each sol with a combination of 3 RHUs, electronics waste heat and resistor array heat. Thermal capacity and RHU heat keeps the WEB above the minimum operating temperature of -40°C through the night.

a) Cabling is routed out of the WEB through a long (200 mm to 400 mm) insulated "igloo entrance tunnel" to minimize conductive heat leakage to the exterior.
b) The *26 Ω* WEB resistor heater array is a set of 3 heaters attached to each of the three battery cases.
c) A heater is attached to the modem for prewarming selected components prior to transmitting under cold (less than *-15°C*) temperature conditions.
d) Redundant thermostats provide failsafe control of the WEB heaters and are mounted near the internal bulkhead
e) WEB resistive heater control is based on two sets of temperature sensors: one set (of 3) associated with the batteries and the remainder (4 of the 7 total sensors). WEB heating is discontinued either if a sensor associated with the batteries reads above 50°C or if one of the remaining sensors reads above 40°C. The failsafe thermostats remain set at 55°C.
f) The power output of the RHU's is 0.97W each, or 2.91W total.
g) A thermal strap (approximately 0.7 sqcm in diameter and weighing 0.04 kg) is run from the RHU Jeff tube to the 'Y' restraint to transfer heat from the WEB to the lander petal and coolant loop during cruise.
h) The 'coldfinger' (a thermal strap which is part of the LMRE) thermally connects the interior of the WEB to the lander panel and coolant loop. This strap (approximately 1.4 sqcm in diameter) is separated from the thermal conductive path to the WEB when the rover stands up. This strap is warmed by a *225Ω (5.76W @ 36V)* heater on the lander after landing while the rover remains attached to the lander petal.
i) A high emissivity gold coating is planned for the exterior of the WEB. A black coating is planned for the interior of the WEB.
j) The 7 temperature sensors within the WEB are now assigned as:
    i) One to each of the battery cases for a total of 3
    ii) One to the modem
    iii) One to the power board (considered the warmest of the two electronics boards)
    iv) One to the WEB wall
    v) One to the CPU board, with the board designed to maintain the option to reassign the temperature sensor to the gyro, if later determined to be necessary.

2) Prelaunch battery temperatures during the 3 months when RHU's are installed are targeted not to exceed 37°C (with an ambient environment of 22°C). *However, the batteries may be stored at 50°C for as long as 2 weeks without degradation.* Cruise temperatures on the batteries in the WEB are targeted not to exceed 30°C (0°C

goal) for more than 100 cruise hours.

3) Equipment mounted outside the WEB is not actively temperature controlled, and is designed for the cruise and Martian ambient temperatures (Mars ≈ -95°C/+10°C, Cruise ≈ -95°C/+40°C).

4) Based on the lander heat rejection system design concept and the three RHUs for the rover, the rover equipment temperature is expected to range from 10°C to 20°C during Cruise, with a possible excursion to near 30°C during the hottest condition such as TCM near Earth. For this reason, no heater power is necessary for the rover during cruise.

5) Aluminum thermal straps (approximately weighing 0.04 kg) are run from *the RHU Jeff tube to the accelerometer tray and the Y-pin thermal strap to spread RHU heat*.

Control Subsystem Features/Implementation:

0) See also, “Recently Baselined Features” (all are not duplicated in this section).

Traverse Behavior/Dead Reckoning Portion Of Control Subsystem:

1) From earth, the Control Subsystem gets high-level information (“Rover location is A with a heading Ø”) and takes high-level commands (“go to locations B then C, quit if lapsed time exceeds t”). The rover executes the commands via onboard capabilities which involve: a) Dead Reckoning (based on gyro, tilt-sensing accelerometers, & wheel revolution counters, etc.) and b) Traverse Behaviors (based on rangefinders, contact sensors, wheel bogey angle sensors, etc.).

2) Since rate gyro output is affected by rover tilt angle, the accelerometers are used to compensate gyro readings. Accelerometer values are also used to assess vehicle attitude in order to prevent tipover.

Rangefinder Portion Of Control Subsystem:

1) The rover has two forward looking triangulation rangefinders that are based on point-and-shoot camera technology. (Range is found by flashing *spots and* stripes of light onto the ground, then noting which pixels along a CCD array line are brightened.) The rangefinding system consisting of two CCD cameras, *four laser spot projectors and one laser light striper* are mounted external to the WEB, (no fiber optics).

2) Each rangefinding CCD (768 pixels wide, 484 pixels high, 8 bits/ pixel), looks through a ≈ 4 mm wide-angle lens with a 127.5 degree horizontal by 94.5 degree vertical FOV (resolutions are ≈ 2.897 mrad/pix horizontal, and 3.409 mrad/pix vertical). Each lens includes a 0.85 micron filter which enhances signal return from the laser *spot projectors*_ and stripers through the CCDs . The rangefinder CCD boresights are ≈ 22.5 deg below the horizon. The lasers are pointed 6 deg below the camera boresight.

3) For rangefinding, the CCD is electronically shuttered with ≈ 1/4 sec exposure, then the selected lines of interest are read out in about 1 sec. The scanlines of interest are determined by the rover's attitude with respect to vertical, as measured by the accelerometers.

4) The cameras, *spot projectors* and light stripers detect hazards within a meter-wide swath by stopping ≈ every 60° of wheel rotation (i.e., every ≈ 10 secs, 7 cm of travel) and doing *(as needed)* "differenced ranging".

5) For imaging, the CCD is electronically shuttered with ≈ 1 sec exposure, then all, or a windowed portion of, the lines are read out in less than 60 seconds. Prior to taking each image, the rover requires ≈ 60 seconds to take a pre-image and set the exposure time for the "real" image. If necessary, less memory can be used by repeatedly taking, reading out, and sending complementary sections of the CCD's view.

6) In addition to the two front-looking CCDs, a third (rear-looking, FOV rotated 90°) CCD is used for imaging in support of the APXS placement (no light stripers or rangefinding), and for imaging of soil mechanics wheel spin and navigation technology experiments (including tracks). This rear camera is now baselined to use a color CCD.

7) Color camera: The camera optics pass blue poorly, so red and green pixels in an image will generally be properly exposed, but blue pixels will be very dark. Data compression cannot be performed on color images without loss of color information. Better color images can be produced by taking two exposures on the rover, one normal, and one overexposing the red and green; on the ground, MIPL can combine the two images, using the blue pixels from the overexposed image to replace the underexposed blue pixels in the first image. If problems develop with the color camera before launch, it will be replaced with a black and white camera.

8) The rover uses the CCDs sequentially, powering all, but reading only one at a time.

9) The CCD's and supporting power supplies draw ≈ 2.8 W of raw power during exposure and readout. Each light-striper (0.2 W light output) draws 1.0 W (raw

power) during CCD exposure. (*Stripers and spot projectors are used singly*).

Computer/Power-Switching Portion of Control Subsystem:

1) Computing for all rover behaviors is done on-board the rover with an 80C85 CPU. No rover-specific computing is done by the lander (except routine communication protocol, data storage, and data forwarding).

2) The rover bulk RAM memory size is 512 KBytes. It can store an uncompressed image from one of it's CCDs (≈ 372 KBytes), all "Health Status" data from a sol's activities (≈ 7 KBytes uncompressed), all "Traverse Status" data from a sol's travel (10 m ≈ 12 KBytes uncompressed), and all the engineering/image-patch data from a soil mechanics wheel spin experiment (≈ 93 KBytes uncompressed). Nominally, however, these data are sent to the lander as soon as they are taken.

3) The CPU is an 80C85 (≈ 100 Kips) having 64 KBytes of addressable memory space at any one instant. Of the 64 KBytes, 32 KBytes is Cassini approved IBM 2568 radiation-hard RAM (half of which shadow maps 16KBytes of IBM 6617 Cassini-approved, class-B ROM), and 32 KBytes is composed of any two 16 KByte pages called from a total of forty-two available pages. The forty-two available pages are composed of 10 pages, (160 KBytes, five SEEQ 28C256 chips) of non-volatile EEPROM for program/patch storage, and critical state data, and 32 pages (512 KBytes) of commercial RAM selected for SEU/SEL resistance.

4) The I/O is composed primarily of Cassini-approved (but class-B) parts, except selected power switches, op-amps, crystals, and the bulk RAM. The I/O provides:
   a) power switching, sensor excitation/read-out, A/D conversions, and output drivers (motors, modem, instruments, CCD's etc.).
   b) a power-based morning wake-up circuit, a time-based wake-up circuit (alarm clock), an under-voltage tripped load shedding circuit (CPU gray-out protection), and a current limiter for the motor/heater power bus. These circuits function as follows (see also Power Subsystem section for details):
      i) The "power-up monitor circuit" removes its finger from the CPU reset button when the core bus voltage rises above the 5.25 V level which assures adequate power for the digital portion of the CPU-I/O.
      ii) After landing, the independently powered, settable (up to) 36 hr alarm clock provides real-time data to the Rover, and can turn on the CPU at any specified time for night health checks, (or emergency day operations if morning power-up fails to occur). This alarm clock can be supplied power from either the solar array or batteries after closure of the 3BSS switch. This timer supports all wakeup and failsafe timing functions for the rover. Time-tagging is provided through a combination of lander supplied time and relative time offsets derived

from the watch-dog timer circuit.

iii) The "load shedding circuit" sheds all loads except the CPU from the power bus if core bus voltage sinks below 5.75 V level.

iv) The current limiter ensures that motors and heaters are run at *14 V* which during normal operations is near the solar panel peak power point.

5) Total computer + I/O including ±12 V analog electronics and supporting power supplies draw 3.8 W of raw power.

6) The computer/power-switching and sensor support elements provide Mobility Subsystem and APXS mechanism switching, current limiting & sensors described in the Mobility Subsystem section, items 1-e), 1-f), and 1-h).

7) Packaging of the computer electronics is done on ≈ 300 sqcm of two sided board space, (1 cm total thickness), using JPL approved surface mount technology. Mil Spec packaging fabrication is used. Additionally , the “power board” for the electronics occupies ≤ 200 sqcm of double sided surface ≈ 2.5 cm thick in selected areas.

8) The control system does not support fixed and/or multiple rate groups. Instead, control loop(s) execute at the speed dictated by the code execution time, a significant S/W simplification. Analysis is performed to insure that worst-case loop time does not threaten the vehicle’s safety in hazardous terrain.

Computer/Software Portion of Control Subsystem :

1) Upon reset the computer begins execution from rad hard PROM. The programming stored in PROM loads programs into rad hard RAM along with selected programs in the non-volatile RAM and any program patches. Then:
   a) The conditions which caused the reset to occur are determined based on the current state of selected memory locations and power conditions: the alarm clock and lander actuated battery switches, the solar panel wakeup circuit, the auxiliary power source (used during test) and load shed interrupt state. Adequate power is either made available through battery switch engagement (closing switch CCBS) or is assumed available from the solar panel or auxiliary power source.
   b) Program loading into rad hard RAM continues from the non-volatile RAM, including correction/scrubs of any detected bit errors and any commanded program patches.
   c) I/O device hardware, watchdog timer and software error state counters are initialized.
   d) The rover clock is reset based on a successful communication with the lander

requesting the current mission time.

e) The current mission state is determined from the state of hardware flags and/or a determination of the gravity vector from the accelerometers
f) A 'no-load' health check is performed to certify the state of the I/O and power system. Upon success of the health check the basic control loop of the rover software system can be performed. Results of the health check or error conditions encountered during the reset process are placed into telemetry packets and transmitted to the lander.

2) The main rover control loop executes until shutdown. Execution of this loop occurs at the rate of about once every 2 seconds (nominally, the watchdog timer cycle). Within this loop:
   a) Power and thermal management is performed. This includes: a determination if WEB heating can be performed, what power is available from the array, and an update of the battery use monitor - an estimate of energy available from the battery.
   b) If a load shed has occurred an extensive health check is performed to determine the device(s) which caused this condition.
   c) If no commands are queued for execution, the lander is checked for command loads.
   d) If commands are queued for execution and if no pending command loads are available on the lander, the next command is readied for execution. Prior to execution, error state conditions, timeout conditions and power availability are checked and parameters set to control the command execution. This setup includes identifying the telemetry collected during the execution.
   e) Once a command is executed successfully, the telemetry is packaged and sent to the lander. If an error occurs during the command an error report is prepared as telemetry and this report is sent to the lander.
   f) With no command available for execution, the lander is periodically interrogated for new command loads. In this control loop the timer (nominally 10 min) for this interrogation is updated.
   g) If it is time for shutdown, the shutdown process is executed.

3) Shutdown occurs as the consequence of a timeout or a reduction in solar panel power output below the threshold level required for operation. Prior to shutdown, the next wakeup time is set on the alarm clock. Shutdown is accomplished with the opening of the battery power backup switch CCBS. If the rover is operating under battery power, this switch opening causes execution to cease immediately. If the rover is operating under solar power, shutdown will occur when solar power above a sufficient threshold ceases to be available. In the meantime, the computer is placed in an idle loop in which the watchdog timer is serviced.

4) All rover functions result from the execution of commands. All commands result

in the generation of telemetry. Details are available in the Command and Telemetry dictionaries. Included are commands which set parameters controlling the execution of the rover software. These parameters set timeout conditions, establish ranges on acceptable sensor values, adjust rates of execution and command resource utilization (e.g., batteries, use of failed devices). The current set of these parameters is listed in the Command dictionary.

5) When commands are executed the appropriate programming from non-volatile RAM is loaded into rad hard RAM for execution. These programs are grouped into the following categories, called contexts: navigation (supporting all driving commands), science (APXS, WAE, MAE), Health (health checks), Imaging (capture image). These grouping avoid a reloading of software during command execution, saving time and computer execution cycles.

6) A principle function for rover control is navigation which coordinates dead reckoning, sensor monitoring, hazard detection, motion control and telemetry collection during driving. These vary by navigation mode which include:
   a) Direct drive: control motion to a specified encoder count
   b) Turn in place: steer to a heading
   c) Go to waypoint: drive is a specified X/Y coordinate
   d) Find rock: use proximity detection in a spiral search pattern to center on a rock
   e) Position APXS: drive backward until contact is made between the APXS deployment mechanism and a rock
   f) Unstow: drive the rover forward with rear wheels locked to lock bogeys prior to deployment

7) Auxiliary functions representing subroutine calls during command execution include:
   a) Dead reckoning: determine rover 'X/Y' position during traverses
   b) Motion control: start motors and monitor motor performance for short circuits and overheating
   c) Soil mechanics: behaviors associated with this technology experiment
   d) APXS control: handle interfaces with the APXS instrument and control the deployment mechanism
   e) Material adherence experiment: control the MAE hardware and gather data
   f) Wheel abrasion experiment control: behavior associated with a special WAE wheel driving experiment
   g) Contingency mission: command and monitor rover actions due to loss of communications
   h) Communication: handle the data management and protocol associated with the 4 lander communication sessions: time request, heartbeat, command and telemetry

i) Imaging: perform auto exposure processing and image compression
j) Proximity sensing and hazard detection: evaluate the results of the rangefinding operation of the lasers and CCDs
k) Sink/slip sensing: monitor articulation and proximity sensor data to determine a 'sinking' hazard condition and adjust for slip measured odometry
l) Time management: control the watchdog timer, alarm clock, and produce telemetry time stamp
m) Health monitoring: control the conduct of health checks and assemble diagnostics for use in flagging devices as failed
n) Power and thermal management: control the WEB, motor and modem heaters

8) Additional functions within the software handle interfaces to the sensors, actuators and I/O devices serviced by the computer. The powered and controlled state of these devices, implemented in the form of power switches, is generally not visible to the software. These states are maintained in software 'shadow' registers. These states are not stored across power-off cycles since a power-off resets all power switches. The exception are the two relays associated with APXS night-time operation. These relay states are maintained in non-volatile RAM.

Control Station Portion of Control Subsystem:

1) The rover control workstation (RCW) hardware consists of a Silicon Graphics Incorporated (SGI) Crimson Reality Engine with 21-inch multisync monitor, 1.2GByte disk drive, CD ROM drive, Spaceball multi-DOF input device, and stereo view glasses and emitter. A duplicate SGI machine is available during mission operations in case the primary machine fails. Either machine provides the following capabilities:
   a) The monitor allows both monoscopic and stereoscopic viewing of images. More than one image can be displayed on the monitor.
   b) A 3-d cursor and overlay graphics capability is provided. The cursor can be adjusted automatically to create a correct perspective in the image view. The cursor can be moved in the scene by the spaceball.
   c) The cursor implementation allows the operator to designate a point in the view, automatically calculate the coordinates of that point and transfer those coordinates to a file, such as the command sequence file. Designation is used by the operator to select waypoints, locations for imaging and sites for APXS experiments.
   d) When overlaid on the rover in an image display, the cursor allows the operator to locate the position of the rover.
   e) The operator can use the overlay graphics to test for clearances in the image. This represents a preview capability, allowing the operator to test rover path traversals.

2) The RCW allows the operator to build command sequences using all commands defined in the Command Dictionary. The control station generates rover command uploads in the form of RASFs (Rover Activity Sequence Files) in binary format. RASFs are sent by Ethernet to the MGDS (Mars Pathfinder Ground Data System), which incorporates the file unchanged into the uplink data stream.

3) To facilitate imaging of the rover by the lander, the rover control workstation through its operator provides :
   a) Location of the rover in lander-centered local level coordinates.
   b) Time window in local (Martian) standard time (LST) during which the rover will be situated at the specified location.

4) To support coordination of rover and lander operations, the control station provides an ASCII file, associated with a particular RASF, containing the following information to the MGDS. This file, called a RAIF (Rover Activity Inspection File) may be used as an input to SEQGEN:
   a) mnemonic versions of the command sequence, suitable for interpretation by members of the rover team.
   b) "Comment" lines interspersed at appropriate points in the command sequence. These are marked with a SEQGEN-recognizable header to identify them as comments, and will include a machine-readable time tag and a text message.

   The comments in the file may be read by SEQGEN and incorporated into the Predicted Events File (PEF) to confirm coordination of rover and lander activities. These comment lines are inserted by the rover operator.

5) At present two coordination requirements between the rover and lander have been identified:
   a) The rover must be in the appropriate location at the time when the lander will be imaging it. The corresponding comment line text for this condition might be: "ROVER READY TO HAVE ITS PICTURE TAKEN".
   b) The rover must transmit to the lander all telemetry necessary to support the planning of the next day's command sequence in time for the lander to transmit this data to Earth. The corresponding comment line text for this condition might be: "ALL ROVER CRITICAL TELEMETRY DATA HAS NOW BEEN SENT TO THE LANDER".

6) A rover-dedicated GDS workstation (SPARC 20) station uses the MGDS database query facility and DMD (Data Monitor and Display) tools to acquire and display rover telemetry messages. A selected set of these messages is stored at the control station for use in analysis and display.

7) MIPL (Multi-mission Image Processing Laboratory) de-compresses rover images from the BTC compressed rover image telemetry. The rover control workstation queries the database for these uncompressed rover images as well as lander images for display. MIPL warps the lander and rover images to linearize them, and provides the appropriate camera model in the header of each image. MIPL can also provide 3x2 linearized image mosaics to support rover path designation.

Power Subsystem Features/Implementation:

0) See also, "Recently Baselined Features" (all are not duplicated in this section).

1) The rover power subsystem includes ≈ 0.22m^2 of flat GaAs solar panel, a lithium primary (non-rechargeable) battery pack, three DC/DC converters, *two switching down regulators, one linear regulator*, two inverters, and one current limiter. Switched bypass of the current limiter is provided for battery powered driving and modem heating when solar panel power is inadequate.

2) The rover's solar array is composed of 13 diode-isolated strings of 18 GaAs cells, 5.5 mil thick, 2 x 4 cm per cell, with 3-mil cover glass, *14.9 W* maximum on Mars noontime power @ ≈ *14 V*.
   a) Available panel power, any time during a clear-day (tau = 0.5) 6 hour period (20° N, untilted) exceeds ≈ 11 W (≈ *14.9 W* at mid-day). This power could be attenuated by approximately a factor of two during severe dust storms (optical depth ≈ 4, the worst that Viking experienced).
   b) The rover's maximum unregulated DC power needs during key functional modes are (see rover power modes):
      i) ≈ *7.5 to 11.3W* for motor preheat prior to driving.
      ii) ≈ *6.8 to 12.4 W* traversing nominal/rugged terrain [≈ 0.4 m/min with motors at -40°C]
      iii) ≈ 7.3 W long-range (≈ 3 m) range-finding/hazard-detection [≈ 10 sec, Rover stopped]
      iv) ≈ 4.5 W reading a picture from a CCD [≈ 1 min/full picture]
      v) ≈ 3.7 W compressing data [≈ 12 min/sol per stereo pair]
      vi) ≈ 3.7 W (CPU) plus 0-to-12.0 W (heater), thermal maintenance [≈ 7 hours/sol]
      vii) ≈ 6.3 W to communicate with the Lander [typically ≈ 17 min/sol, 2 Mbits data].
      viii) ≈ 1.0 W APXS (10 hours, selected nights) plus 3.7 W CPU for brief data read outs.

3) The Lithium main battery pack contains ≈ 150 W-hrs of energy and is diode connected to the unregulated DC power bus in such a way that battery power is

drawn only when solar panel power is unavailable or inadequate to support the power load. The pack is configured in 3 strings of 3 $LiSOCl_2$ D-cells. Each string is diode isolated from the others. Output voltage is ≈ 8 to 11 V (temp/load dependent) downstream of diodes.

a) Primary battery energy consumption in the nominal mission is less than 32 W-hr total comprised of :
   i) ≈ 8.00 W-hr supporting the night portion of APXS spectra [10 night hours]
   ii) ≈ 0.04 W-hr supporting cruise health checks [two periods of 10 sec each]
   iii) ≈ 14.00 W-hr of traversing contingency, if panels are shadowed [1 hr allocated]
   iv) ≈ 2.24 W-hr/week for ≈ 112 (1 per hour for 16 hour per night, 10 sec each) night health-data and communication sessions to the Lander
   v) ≈ 0.7 W-hr supporting the first post-landing health check-data and communication session to the lander (assuming modem heating)
   vi) ≈ 3.9 W-hr supporting the second post-landing imaging-data and communication session to the lander (assuming modem heating)
   i) ≈ 2.40 W-hr supporting the pre-sunrise calibration of the APXS on sol 1[3 night hours]

4) The regulated power-supplies maintain their output voltages over an input range of 8 to 24 V. This permits operation of rover electronics at nominal voltages even though:
   a) the solar panel output swings from ≈ *14 V* to ≈ 18.0 V (due to load/temperature variations), and
   b) the rover battery supplies ≈ 8 to 11 V.

   The DC/DC converters are operated at no less than ≈ 10% of rated power (to maintain regulation), and no more than ≈ 90% of rated power (to avoid over stress).

5) The unregulated DC bus supplies power only to converters, regulators, & current limiter.

6) To maximize the available current for driving, many rover actions are sequential, rather than simultaneous, for example:
   a) Steering motors are run only when wheel drive motors are stopped, and vice versa.
   b) All motors are stopped when laser range-finding/hazard-detection is done (approximately once every wheel radius of travel).
   c) RF communication with the lander is not done when motors are running.
   d) A bank of motors (6 drive-wheel-motor bank, or 4 steering-motor bank) is

ripple started, one motor at a time on ≈ 50 msec centers, to assure maximum available startup surge current for each motor.

7) The MOSFET current limiter (feeding motors and heaters) senses core bus voltage and limits motor/heater current draw if the core bus starts to drop below *14 V*. (limiter resistance increases from ≤ 0.5 Ω to ≈ 1 MΩ as core bus voltage drops from *14 V to 13.5 V*). This precludes CPU brownout by loads downstream of the limiter. Placing a heavy heater load downstream of the limiter will hold the solar panel at essentially its peak-power point throughout the day (with no active monitoring).

8) GSE power (≈ 18 V) can be supplied via DA Cnctr-1 which is dioded onto the Core Bus. Protection against electrostatic discharge or GSE power overvoltage to the DA Cnctr-1 pins is provided *by active filter protection in the GSE*.

9) Solar panel powered WEB heating is done whenever the sun is shining and motors/motor-heaters are off. WEB heating is accomplished by connecting the low resistance (*26 Ω)* WEB heater to the output of the current limiter. The limiter then clamps the solar panel output voltage at *14 V*, and all solar panel power unconsumed by equipment upstream of the limiter is automatically shared between the limiter (heating the WEB) and the WEB heater (also heating the WEB). This approach delivers nearly all possible solar panel energy to the WEB throughout the day (essentially independent of sun angle, solar intensity, etc.).

10) To minimize energy loss, power for the motors and heaters is routed directly from the core bus through only a "low on-impedance" current limiter (no power converters). So long as the solar array can provide adequate current to support motor or heater loads, the limiter remains fully "on" (≤ 0.5 Ω). Anytime the core bus voltage begins to sink below the panel peak-power-point voltage of *14 V*, the limiter resistance increases until the core bus voltage stabilizes above *13.5 V*, or until the current limiter resistance reaches maximum (≈ 1 MΩ). When the core bus voltage begins to sink below the *13.5 V* the following occurs:
   a) If the core bus voltage sinkage continues to below ≈ 10 V, it is propped up by the 3 strings of 3 D-cell lithium thionyl chloride batteries which are diode connected to the core bus during normal operations.
   b) If the core bus voltage sinkage still continues and drops below ≈ 5.75 V, an automatic load-shedding circuit drops all loads from the core bus, except for the dedicated 5 V DC/DC converter and its CPU-I/O.
   c) Further sinkage to ≈ 5 V toggles-on the CPU RESET circuit and holds the CPU in RESET (until core bus voltage returns and rises above ≈ 5.25 V).
   d) If the core bus level sinks below ≈ 4.5 V it ceases to support the 5 V DC/DC converter and dedicated CPU-I/O. At this point, the CPU quits, and the Rover lies dormant until the next day's solar intensity produces enough solar

power for CPU activity. (The CPU starts automatically whenever the solar panel brings the core bus to ≈ 4.5 V and can supply ≈ 450 mA of current.)

e) Start-up sequence from solar panel power includes:
   i) core bus current capability from panel reaches ≈ 450 mA @ 4.5 V and the 5 V DC/DC Converter pops on to feed the CPU-I/O,
   ii) Core bus voltage pops up to ≈ 18.4 V,
   iii) "Power Monitor Circuit" withdraws RESET after a 9 sec delay due to filtering as the Core Bus exceeds 5.25 V,
   iv) "Load Shed circuit" withdraws LOAD SHED after a 0.2 sec delay due to filtering as the Core Bus exceeds 5.75 V,
   v) the CPU boots up and connects Battery Bus to Core Bus (closes CCPS),
   vi) CPU is on for the day

11) Power supply types and output voltages are :
   a) 5 V DC/DC Converter: supports CPU, I/O, and 3 V power to CCD clocks.
   b) 5 V Switching Down Regulator: supports lasers, MAE-QCM/MAE-cover-actuator, APXS fail-safe release, APXS contact sensors, motor encoders, gyro, and -5 V inverter
   c) -5 V Inverter: supports gyro.
   d) 9 V DC/DC Converter: supports RF modem, -7.5 V inverter and 7.5 V *linear* regulator.
   e) 7.5 V *linear* regulator and -7.5 V inverter: supports the APXS
   f) ±12 V DC/DC Converter: supports CPU, I/O, CCD's, CCD clocks, pots, accelerometers, and temp sensors.
   g) 3.3 V regulator: supports the laser diodes
   h) Current Limiter: supports all motors, all motor heaters, and WEB heater
   i) Switchable bypass lets batteries directly support Motor/Heater Bus

UHF Radio Communication Subsystem Features/Implementation:

0) See also, "Recently Baselined Features" (all are not duplicated in this section).

1) The rover/lander UHF radio link utilizes a commercial RF modem operating at ≈ 459.7 MHz. It provides a 500 m clear-field range, delivers 100 mW RF power, and with its supporting power supplies draws 2.5 W of raw DC power. The UHF signal strength a few tens of meters from the Lander is on the order of 1,000 times the minimum strength for reliable communication.
   a) Communication rates are at 9600 baud (≈ 2 Kbits/sec net data rate with protocol overhead).
   b) When deployed, ≈ 1 m high "Whip" antennas on the rover and the lander permit line-of-sight broad-casting over the top of 0.5 meter high rocks.

c) The bit error rate (BER) for the modem is expected to be 10E-5 within the nominal operating range of the lander.

2) Until the Lander petals open on Mars, the rover and lander UHF antennas are stowed. The traditional, "spec level" is ≤ 2 V/m RF field at 460 MHz while both the rover and the lander are operating. Without attenuation, an RF field strength of ≥ 22 V/m is theoretically possible for equipment mounted ≤ 10 cm from either UHF antenna. The rover and lander are designed to accept these fields.

3) The rover and the lander (LMRE) modems are identical single string (non-redundant) Motorola units. The lander (LMRE) modem is packaged with redundant DC/DC power converters whose outputs are electrically isolated from their inputs (compatible with lander grounding). The lander separately switches power to each redundant DC/DC +9V converter in the LMRE modem package. When one of the two supplies is turned on a small *(628Ω)* heater is also powered to heat the modem in cold (morning) *contingency* conditions. *The LMRE modem is relocated in the lander integrated electronics module (IEM) attached to the rechargeable battery. Lander thermal models ensure that the temperature of this battery will not fall below 0°C during a sol. Hence the default power-up mode of the LMRE modem is to power-up with the converter which does not power the modem heater.*

4) A *78.5Ω* heater is powered-on for nominally *15 min (30min under battery power)* at the first daytime wakeup during surface operations to warm the rover modem prior to communications with the lander. The modem heater is allowed to use battery energy. Also, the modem heater is powered-on for communication sessions after landing but prior to release and at any time under command.

5) The rover-mounted UHF antenna assembly is stowed along the +Y (right, starboard) edge of the rover solar panel with the hinge at +X (forward) end and the antenna at the -X (aft) end of the stowed assembly. RG 178 coax (0.085 diameter, 14 grams, 1.2 dB loss) is routed approximately 1.5 meters from the WEB to the base of the rover UHF antenna assembly, and up the antenna assembly's mast . The assembly is sized to put the base of the deployed antenna approximately 650 mm (one wavelength) above the Martian surface (the mast height may be adjusted slightly to simplify mechanical mounting/latching without large impact on RF performance).

6) The lander-mounted LMRE UHF antenna assembly is attached to the lander low-gain antenna (LGA). Rover-supplied (lander-routed) coax ("STORM 421-010," 0.21 inch diameter, 65 gram/meter, 0.25 dB loss/meter) is routed approximately 2 m to the base of the LMRE UHF antenna assembly from the LMRE modem in the lander thermal enclosure (TE). This antenna is mounted in a 2.5 cm standoff

configuration from the LGA and is attached 30 cm below the antenna's radiating element.

APXS (and APXS Mechanism) Related Features/Implementation:

0) See also, "Recently Baselined Features" (all are not duplicated in this section).

1) APXS experiment with associated power supplies draws 0.8 W of raw power. Non-volatile APXS memory stores a maximum of 64 Kbits of data (even with Rover power off), and plays back a maximum of 16 Kbits per query at 9600 baud (RS 232) when turned on. The rover CPU need not run during APXS operation (except for on/off commands, & APXS data playback).

2) The APXS sensor head is roughly cylindrical $\approx$ 50 mm diam by 50 mm long. The cylinder's flat end is pressed against the surface to be analyzed, with a maximum allowable sensor face to sample face misalignment of $\pm$ 20° and a gap from the sensor head to surface not larger than 50 mm . (Large misalignment may require integration times greater than 10 hours.) The sensor head, mounted on a positioning mechanism is provided to the rover by the MPF project, and the rover supports the sensor/mechanism assembly. Total mobile APXS instrument and mechanism mass is 1.2 Kg. Additional highlights of the interfaces to the rover include:
   a) All coax and electrical cable connection are made at the APXS mechanism shelf. Pigtailed cable is routed from this shelf into the WEB to the APXS electronics and rover CPU and I/O board.
   b) The above cabling strategy facilitates the installation of APXS curium sources (9 sources of Cm-244 totaling from 50-75 millicurries) at the cape through the replacement of the APXS sensor head.
   c) Mass allocations of 0.46 kg for the APXS electronics and 0.18 kg for the APXS sensor head (both numbers include cable and connector mass)
   d) A motor actuated shutter is baselined with the APXS sensor head allowing commanded control of both the open and close shutter states.
   e) The communication protocol provides acknowledgement by the APXS electronics of receipt of each command issued by the rover. A new command is added which allows data accumulation without power-off of the APXS electronics.
   f) Power drawn by the APXS electronics is identified by mode: one mode for the nominal operation of spectrum accumulation of as much as 1 W and the other mode for shutter open/close of as much as 1.9 W. Ripple of 20 mV peak-to-peak is required for the power supplied during the nominal operation of the electronics. Shutter open/close power may be reduced pending a design which would allow much of the APXS electronics to be powered off

during shutter operation. 1 W power for APXS electronics is the maximum allocated and may be reduced pending final electronics design.

g) Double capacitors incorporated within the APXS electronics on the input power lines are provided as protection against a short in these electronics causing a cascade failure in rover power conditioning and electronic components.

3) Provision to mount the APXS electronics is made in the rover's WEB.

4) Rover mechanically supports the APXS mechanism and provides electrical interfaces (identical to the rover steering drive) for one motor, one 8-bit position pot, and four contact sensors which are part of the APXS mechanism. Additional highlights of this mechanism interface to the rover include:

a) Accommodation for cable connection to the APXS sensor head and electronics at the APXS deployment mechanism shelf. The mechanism electrical and data cable connector is separate from that of the APXS electronics.
b) Accommodation of as much as 2 A (10 W for 10 min) to the failsafe release mechanism.
c) Mass allocation of 0.49 kg (including cable and connector mass).
d) 4 LED contact sensors spaced 90° apart are required at the end of the mechanism.
e) Less than 10 N required for engagement of the contact sensor(s).
f) A single tie-down is required to latch the APXS sensor head and APXS deployment mechanism to the lander petal for launch/landing.

5) In operation, the rear-mounted APXS sensor head and APXS deployment mechanism are used as follows:

a) For rock sampling, the APXS sensor head extends at least far enough aft to mate against a vertical wall (without the rover solar panel contacting the wall) when the rover is on level terrain and within $\pm$ 25° of perpendicular to the wall
b) For rock sampling, the APXS mechanism extends the APXS sensor head aft and provides $\pm$ 20° of head compliance, the rover then drives forward to the target rock, squares up with the target surface, turns 180°, backs at $\approx$ 0.7 cm/sec, and stops (within $\approx$ 0.3 sec, 0.2 cm) after the mechanism's optical encoder contact sensors indicate APXS sensor-head-bumper contact. At this point the head's internal APXS detector is spaced $\approx$ 40 mm from the rock surface, and the collection of 1 to 10 hours of rock sampling spectra is begun. (Optional pictures from the rear CCD camera may be used to document the site & APXS position).
c) For soil sampling, the APXS mechanism points the APXS Sensor head downward, at the target soil patch, and extends the sensor head downward to

within 1.5 cm, or less, of surface contact. At this point the collection of 1 to 20 hours of soil sampling spectra begins. The APXS mechanism is single-fault tolerant where practical, uses one motor-actuator and one heat actuated (nominally, 7.9 W for $\approx$ 10 min) failsafe retraction mechanism.

d) For rover traversing, the APXS mechanism tucks the APXS sensor head against the rear of the rover such that the rover can turn within a 385 mm diameter circle (up to 500mm, worst case, when the failsafe mechanism has been used).

6) Rover is able to store 1 interim APXS spectra overnight. The APXS is capable of storing an interim and a final spectra overnight.

7) *In support of APXS operation:*
   a) *after power-off of the APXS there will be a delay of at least 10sec before a subsequent power-on.*
   b) *after power-on of the APXS there will be a delay of at least 30sec before a command is issued to the APXS to begin collecting spectra data.*

Technology Experiments:

1) LeRC MAE (Materials Adherence Technology Experiment, Solar Cell/QCM): Around noon each sol the MAE draws: $\approx$ 150 mW regulated 5 V for $\leq$ 1 minute for QCMs, and $\approx$ 5.9 W regulated 5 V DC for $\leq$ 1 minute for cell nitinol-actuated dust cover opening. MAE requires open-cell current and shorted-cell voltage readings each sol around noon, and one temperature measurement immediately before and after each QCM reading and Solar Cell reading.

2) LeRC WAE (Wheel Abrasion Technology Experiment):
The WAE consists of 10 g of abradable materials bonded along a central circumference on one rover center wheel, viewed by a photocell. (Photocell requires no power), A/D readouts of photocell analog output are made at least once every 16 encoder counts ($\approx$ every 30° of wheel rotation, $\approx$ every 0.5 seconds) during dedicated WAE wheel spin experiments.

Ramp Magnetic Experiment (RME)

1) Once deployed, the RME magnets at the end of each ramp will collect magnetic materials throughout the surface mission. The magnets will be observed by the IMP (lander) camera. Rover involvement in the RME experiment will be considered if the following conditions are satisfied:
   a) the ramps remain deployed on the surface after 20 sols

b) the rover is still functioning at this time
c) one of the RME magnets is accessible to the rover without imposing undue hazard to the rover

2) If there is agreement to support the RME experiment (there is no requirement to do so), the rover will be positioned to perform an APXS data collection on one of the magnets.

LMRE Description, Mechanical Interfaces With Lander & RME Magnets:

0) See also, “Recently Baselined Features” (all are not duplicated in this section).

2) The mobile portion of the rover has direct mechanical interfaces only with the lander-mounted tracks and with the rover-provided lander-mounted separation devices.

3) Lander-mounted (non-mobile) rover electronic equipment (Power Regs/RF Modem/Antenna) are essentially duplicates of their rover-mounted counterparts (except for Pwr Regs, Antenna mounting details). See “UHF Radio Communication Subsystem” above, for details.

4) Lander mechanical interfaces with lander-mounted (non-mobile) rover mechanical equipment & cabling are negotiated as simple “bolt-on” interfaces of pre-checked-out rover supplied equipment. Wherever practical, field joints are different than mechanism functional joints. [These comments apply to antenna assembly, rover latches, guide tracks, ramps, etc.]

5) The rover attaches to its LMRE pyro release latches at four points, one at each external end of “Jeff” tube, one at the front of the rover WEB and one at the APXS sensor head.

6) RME magnets are attached to the LMRE ramps. These magnets are flat squares, approximately 10cm x 10cm, one mounted to the batten and wire mesh at the end of each ramp.

7) The lander provides Mars surface images for the planning (way point selection) of rover traverses. The rover requires that all images used for rover way point selection be in a common Mars-fixed coordinate system. (The rover does not provide the service of coordinating lander pictures taken from a shifting lander.)

8) The LMRE ramps each consist of two stem mechanisms connected by battens, with a wire mesh between the stems; *a cut is provided in each stem giving a*

preferential bend at deployment; a track, which provides the rolling surface for the rover, is mounted outboard of each stem. When released by pyro-activated cable cutters, the stems unroll like a spring-steel tape measure *then drops to the surface*. Fully extended, each stem has a circular cross-section, which forms a guide rail running along the inside of each rover track. The wire mesh is intended to prevent hazards (e.g., airbag material) from protruding above the tracks between the stems. A color calibration target is mounted on the ramp structure, such that it will be visible from the rear rover camera when the rover is in its stowed configuration prior to ramp deployment.

LMRE & Rover Electric Interfaces With Lander (& With Rover LCE via T-0 Umbilical):

0) See also, "Recently Baselined Features" (all are not duplicated in this section).

1) Rover electrical interfaces with the lander /LMRE include:
   a) actuation of the rover internal power-on switch,
   b) firing connections for LMRE pyros to release petal mounted rover "red carpet" ramps, APXS sensor head and APXS deployment mechanism, and the rover itself.

   There is no electrical connection between the rover electronic equipment and the lander electronic equipment.

2) The lander is reserving support for power to heaters for the relays to all 9 petal-mounted pyros.

3) The LMRE UHF modem redundant power supplies are +9 V DC/DC converters having isolated secondary and primary circuitry. The outputs of the +9 V converters are dioded together to the single LMRE UHF modem, and power to each converter is independently switched/fused by the lander.

4) Redundant bimetallic thermostats are configured with the LMRE modem and heater. When open these thermostats disconnect power to the modem heater. The thermostats are set to open at 40°C and close at 30°C. The modem heater resistance is 628Ω (2W @ 36V).

5) A latch-up protection circuit is incorporated with the LMRE. This circuit samples the current drawn by the modem. If the current drawn is above 200 mA for greater than 1 second, the modem is powered-off for 700 msec then powered-on. These specifications are derived from tests of the latch-up characteristics of the modem and are designed to prevent burn-out of the +9V converters.

6) The rover/lander separation connector (and associated weight and "hang-up" failure

mode) is eliminated. The functions it supported are dealt with as noted in the items below. The rover/lander electrical interface baseline is as described below:

a) All LMRE and APXS mechanism pyro release devices are electrically on the lander side of the separation interface. No lander/rover separation connector is required for pyro functions.
b) Lander control of the rover “turn-on” switch (LCPS) is via parallel redundant lander-mounted (LMRE) electromagnets which activate parallel redundant rover-mounted “reed-switches.” (The lander powers the two electromagnets via a single power circuit.) No lander/rover separation connector is required for the rover turn-on function.
c) The rover deduces it is released from the lander by
    i) noting that the APXS contact sensor loses contact with its stowage seat (due to APXS mechanism snap-back), then
    ii) waiting 2 additional minutes for the lander to complete all other rover/LMRE/APXS pyro-releases. (Lander sequencing and flight rules assure that all rover/LMRE/APXS release pyros are fired by that time.)

   No lander/rover separation connector function is required to notify the rover it has been released from the lander.
d) Disconnecting Battery Strings B & C from the Battery Bus (opening the 3BSS relay) is only possible by applying GSE current to 3BSS’s “opening coil” via the manual GSE direct access connector. Connecting Battery Strings B & C to the Battery Bus (closing the 3BSS relay, is exclusively controlled by the rover CPU) No lander/rover separation connector is required for battery disconnect functions.
e) No rover-mounted status indicator switches are monitored across the rover/lander interface. No lander/rover separation connector is required for monitor functions.
f) Lander equipment temperature control requirements are expected to result in a satisfactory thermal environment for the rover. No lander/rover separation connector functions are baselined to support lander-powered rover temperature control.
g) GSE power to the rover for system testing is via a GSE cable which is manually mated/demated to the rover-mounted “Direct Access Connector-1” (DA Cnctr-1). The last opportunity to externally (GSE) power the rover is just before the lander petals are latched up for launch final buildup. No lander/rover separation connector is required for this GSE power function.

7) To ensure that the rover "turns-on", the lander powers the 'reed switch' electromagnets for 10 sec (a programmable parameter ranging from 1 sec up to *30sec*).

8) The rover’s external power access port is internally protected so that

a) application of reverse voltage cannot damage the rover, and
b) shorting the port cannot drain rover batteries or disable the rover.