I. Introduction

The Martian atmosphere is the origin of many possible hazards to both humans and equipment. The unknown thermodynamic properties of the bulk gas fluid, including unexpected turbulence in the near-surface boundary layer, represent risks during vehicle entry, descent and landing (EDL). Major dust storms may also affect EDL and adversely affect a human explorers ability to perform extravehicular activities (EVAs). More recent laboratory and terrestrial desert studies indicate that triboelectric effects within dust storms can give rise to large electric fields which might prove hazardous to both explorers and equipment. The Atmosphere Focus Team (AFT) collected such hazards and assessed the likelihood and consequences of their risks. The results are included in this section.

The scope considered by the AFT includes all atmospheric risks from the ground level to the ionosphere. While broad in extent, the initial discussion focused on the atmospheric objectives already in the HEDS portion of the July 04 MEPAG Goals*: 4.A.3. Variations in atmospheric parameters that affect flight and surface activities*, and *4.A.6. Electrical effects of the atmosphere*. The scope then expanded to include photochemistry, dust storms, communication and other topics.

II. Current and Recommended State of Knowledge

Table 1 lists the current and recommended state of for the investigations being considered by the AFT. Note that in most cases, there is a distinct mis-match between the requirements to understand a hazard as represented in the recommended state of knowledge and the current knowledge base.

Table 1. Current and Recommended Knowledge for Atmospheric Investigations

Hazard Investigation	Hazard Description	Current State of Knowledge	Recommended State of Knowledge
1) Fluid variations from ground to >90 km that affect entry, descent and landing (EDL) and take-off, ascent and orbit insertion (TAO)	Turbulent layers in boundary layer (0-20 km) and density anomalies at max dynamics pressure (30-60 km) may alter vehicle trajectory during aerocapture and precision landing. Possibly detrimental if densities underestimated and if instability/turbulence beyond planned tolerances.	To date, less **than < 10 EDLs (is this number correct?)** provide V, T, and ρ profiles use in models. Some remote-sensed atmospheric information from MGS/TES, but limited and not always accurate. Turbulence from dust storm convection/thermal inflation not quantified.	Vertical profiles of V, T, and ρ, especially from 0-20 km and 30-60 km, obtained globally (all lat and long), with high temporal and spatial resolution, obtained over a long baseline (> 1 Martian year).
2) Atmospheric electricity that affects TAO and human occupation	Electric fields in convective dust storm may exceed breakdown, leading to discharge, arcing, RF contamination. Discharge to ascending vehicle is potentially serious issue during take-off (e.g., Apollo 12). High levels of atmospheric electricity may limit EVAs.	Tests limited to lab and terrestrial desert electric field studies of mixing dust. No in situ measurements on Mars, to date.	DC and AC electric fields, and atmospheric conductivity over a Martian year. Package recommended to fly at least once to assess the risk.
3) Dust storm meteorology that affect human occupation and EVA	Local, regional and even global dust storms are likely to occur for a long-stay mission. Storms can last for months. Storm opacity in the cores may be large enough to reduce EVA times and external maintenance of habitat. (e.g., Gulf War II dust storm)	Viking lander provided some opacity information from edge of storm, but no data from inner core region of storm.	Global V,T, ρ, and dust opacity as a function of time and height, over a long (> 1 Martian year) baseline

4) Reactive atmospheric chemistry that creates a toxic or corrosive environment	The Viking LR/GEX experiments indicates that some highly reactive agent is omni-present in the environment, possibly being of atmospheric origin.	Basic atmospheric composition measurements known. Reactive species H2O2, at trace level, just recently detected and bounded.	Mass spectrometer from 2-100 AMU in near surface at many locations and over long durations to detect any isolated pockets of reactive gas buildup.
5) Atmospheric / Ionospheric effects on communication and navigation	Dust storm RF contamination and ionospheric anomalies may adversely affect comm. & nav system	To date, no comm./nav failure, but communication in major dust storms has not been tested.	Ionospheric density as a function of lat, long and height over long baseline, and surface AC E-field measurements in dust storms to determine RF contamination level.

III. Impact on MEPAG Goal IV and Changes in Criticality

The primary AFT investigations, those of understanding the fluid properties of the atmosphere and atmospheric electricity, remain high priorities in both original and latest version of the MEPAG goals. The criticality of both has increased slightly, with fluid variations being considered the highest priority in the overall Goal IV investigations (Investigation 1B). One reasons for the change of criticality was the difficult EDLs experienced by the robotic MERs, which punctuated the need for timely and accurate measurements of the atmospheric state at descent.

IV. Risks and Priorities

IV. 1 Risk Mitigation and Reduction

The AFT derived 5 major categories of risk to a human exploration to Mars, and a description of the category and mitigation strategy is presented.

1.Wind shear, turbulence, and density anomalies that may create uncompensatable trajectory offsets during EDL and TAO. Unexpected fluid variations are a concern, primarily in two regions: between 30-60 km and 0-20 km. The regions between 30-60 km is a critical region for aerocapture, where the dynamic pressures of an incoming body are the greatest, and maximum acceleration occurs. A density miscalculation in this regions can lead to both an offset in anticipated landing location and/or higher than expected descent velocities. Given a direct entry scenario for a human mission, accurate densities in this region are critical to the safety of the crew. The region between 0-20 km contains the highly variable planetary boundary layer. During daytime, the surface heats the lower atmosphere (with cooler air above) creating a naturally unstable situation. These instabilities can manifest themselves as convective systems with both turbulence and shear wind flows. As a result, the incoming vehicle (now moving relatively slowly for precision landing) may experience oscillations, a change in orientation, and/or large wind drift offsets. During the MER/Spirit EDL, lower-than-modeled middle atmosphere densities and unexpected oscillations near parachute deployment occurred that nearly exceeded safe ranges.

To mitigate this situation, the AFT suggests a strategy parallel to the study of terrestrial weather, where forecasts are derived based upon advanced modeling, but using timely measurements to both set the initial conditions and in validation. The primary objective is to improve and enhance the Martian global circulation models (GCMs), so that forecasting can occur to derive the mean state and variability in atmospheric conditions for EDL. First**, in situ meteorological V, T, and ρ during EDL and at the surface (lander package)** should be a standard measurement obtained on every future landed mission. This recommendation extends to the upcoming MSL opportunity in 2009. The information from these packages is critical for initializing and validating the GCMs. The number of EDL profiles obtained between the present and a 2030 human mission will greatly improve the data set already available (by a factor of 2). Long-term measurements from surface packages are critical in setting accurate model initial conditions of the surface heat energy driver responsible for lower/middle atmosphere instabilities. Second, to obtain complete coverage in space and time, an **orbital remote-sensing weather station** is recommended to obtain vertical profiles of V, T, and ρ around the globe with high temporal and spatial resolution, particularly emphasizing heights between 0-20 km and 30-60 km. Remote sensing tools to derive the atmospheric state at ground and regions from the ground to 20 km currently do not exist, requiring a development effort.

Implicitly incorporated into these recommendations is the collection of atmospheric state and variability during unstable dust storms. Such storms give rise to lower/middle atmosphere temperature increases that inflate the atmosphere (even measured at 100 km altitude) and are a source of instability-related fluid waves and turbulence. GCMs need to predict the turbulence within and in the vicinity of more violent, unstable dust storms.

During any actual human EDL, the AFT suggests bringing all available assets to bear, with an orbital platform providing the most timely density and wind profiles, along with GCM's which fill in coverage and identify potentially unstable atmospheric situations based on the recent remote-sensed profiles in the landing site region. Finally, in analogy to launch preparation at KSC, the AFT suggests a pre-descent "weather sounding probe" be deployed just prior to human entry, this sent along the identical path anticipated for the human-containing vehicle. For the return trip, pre-ascent weather probes can be sent from ground upward to derive high altitude MET conditions before launch from Mars.

2. Dust storm electrification may cause arcing, affecting TAO. Based on laboratory studies and terrestrial desert tests, there is a growing body of evidence that dust devils and storms may develop dipole-like electric field structures similar in nature to terrestrial thunderstorms. Further, the field strengths may approach the local breakdown field strength of the Martian atmosphere, leading to discharges. A hazard during the vulnerable human return launch from Mars would be a lightning strike to the ascending vehicle. Apollo 12 suffered a lightning strike at launch, upsetting the onboard computer. During human occupation of Mars, dust storm discharges and induced electrostatic effects may also force human explorers to seek shelter, reducing EVA time, habitat maintenance, etc. Mitigation strategies include avoidance of aeolain dust clouds both at launch and during human EVA periods. However, to date, there are no measurements of Martian atmospheric electricity to evaluate the consequences of the proposed risk. The AFT suggests placing an atmospheric electricity (DC and AC E-fields, conductivity) package on at least one future landed missions to assess the risk.

3. During crew occupation and EVA, dust storms may affect visibility, limiting EVAs and regular habitat maintenance. As demonstrated by the dust storm during the recent US-Iraq conflict, operations in a major dust storm can be stalled due to obscured visibility and adhering dust. On Mars, global dust storms can last for 3 months, with possible crew internment for long periods (especially with the passage of high opacity core regions). Mitigation strategies include designing low maintenance habitats and EVA systems and/or avoid human occupation at times when storms are expected. The ability to predict the large seasonal storms has greatly improved with MGS/TES, but regional and local storms appear quasi-random. To assess the risk, lander MET packages (like those suggested in point 1 above) should also have the capability to assess dust density/opacity. A remote-sensing orbital weather station (like that described in point 1 above) would have the capability to monitor dust storm frequency, size, occurrence and thermodynamic characteristics over a long baseline.

4. Photochemical reactions in the atmosphere may create chemically-reactive gases that lead to corrosive or toxic environments. Landed missions have yet to fail because of a corrosive/reactive agent, but certain locations and seasons may favor the increased production of reactive chemicals. A mitigation strategy is to avoid occupation and EVA during chemically active periods and/or active locations. Special non-reactive coverings may have to be designed for EVA suites and habitats. Mass spectrometers placed at various locations on the surface can monitor the presence of reactive chemicals that are produced beyond trace levels. Orbital platforms are not considered effective since measured columnar densities do not indicate concentration levels at the surface.

5. Atmospheric conditions on Mars, at times, may lead to communication losses and navigation anomalies. Ionospheric variations/scintillations can disrupt RF propagation and electrical activity (discharges) in dust storms can be a source of RF interference. Strategies are already applied to mitigate ionospheric disruption by transmitting at frequencies well above the peak ionospheric plasma frequency. Mitigation strategies in electric dust storms may also be the application of judicious choice in frequency selection to avoid noisy, contaminated frequency bands. However, fundamental information of dust storms RF emission is suggested to make this choice. An atmospheric electricity package with AC E-field sensing capability (like that suggested in point 2) is capable of deriving the intrinsic RF emission within a dust storm.

IV 2. Precursor Investigations

Table 2 lists the precursor investigations, in order of their relative priority, and their associated measurements. Note that the measurements are consistent with mitigating the risks described in Section IV 1.

Table 2. Investigations and associated measurements.

Hazard Investigation	Measurements
1) Fluid variations from ground to >90 km that affect EDL and TAO	1a. Measure v, P, T and ρ in the upper, middle and lower atmosphere during EDL. Obtain as many profiles at various times and locations as possible (requested for ALL landed missions). Measurement resolution should be high enough (~ 100 Hz) to quantify turbulent layers. Specific direct or derived measurements include: - Density from 120 km to surface ranging from high altitude values of 10^{-9} to near-surface values of 10^{-1} kg/m^3, $d\rho$ = 1% of local ambient, rate= 100 Hz

	- Pressure from 120 km to surface ranging from high altitude values of 10^{-7} to near-surface values of 15 mb, dP= 1% of local ambient, rate =100 Hz - Temperature 60-300 K, dT = 0.5K, rate= 100 Hz (direct measurement may be slower) - Directional Wind Velocity, 1-50 m/sec, dv = 1 m/s, rate= 100 Hz Particular emphasis on measurements between 0-20 km to quantify boundary layer turbulence and 30-60 km where vehicle dynamic pressure is large. 1b. Monitor surface/near-surface v, P, T, and ρ as a function of time. Used to define barometric fronts and surface features and quantify the surface heating driver responsible for atmospheric instabilities. Data sets initial conditions for high altitude modeling of instabilities. Obtain data from as many locations as possible (requested for all landed missions). Surface/near surface packages should measure directly: - Pressure 0.005 mb to 15 mb, dP = 0.005 mb, rate= 10 Hz - Velocity 0.05-50 m/sec, dv = 0.05 m/s, horizontal and vertical, rate= 10 Hz - Temperature 150-300 k, dt = 0.04k, rate= 10 Hz - Opacity depth 0.2-10, dtau = 0.1, once every 10 min 1c. Make long-term (>> 1 Martian year) remote sensing observations of the weather (atmospheric state and variations) from orbit, including a direct or derived measurement of: - Aeolian, cloud, and fog event frequency, size, distribution as a function of time, over multi-year baseline. - Vertical temperature profiles from 0-120 km with better than 1 km resolution between 0-20 km, 1-3 km resolution between 20-60 km, 3 km resolution > 60 km and with global coverage over the course of a sol *[Development work required for T from surface to 20 km]* - Vertical density/pressure profiles from 0- 120 km with better than 1 km km resolution between 0-20 km, 1-3 km resolution between 20-60 km, 3 km resolution > 60 km and with global coverage over the course of a sol *[Development work required for ρ from surface to 20 km]* - 3-D winds as a function of altitude, from 0-60 km with better than 1 km resolution below 20 km, and 1-3 km resolution between 20-60 km, and with global coverage over the course of a sol *[Development work required at all altitudes for an independent means to derive V, with special emphasis from surface to 20 km]* Particular emphasis on measurements between 0-20 km to quantify boundary layer turbulence and 30-60 km where vehicle dynamic pressure is large. 1d. At time of human EDL and TAO, deploy ascent/descent probes into atmosphere to measure P,V, and T just prior to human descent/ascent at scales listed in 1a.
2) Atmospheric electricity that affects TAO and human occupation	2a. Basic measurements: – DC E-fields 0-80 kV/m, dV=1 V, bandwidth 0-10 Hz, rate = 20 Hz – AC E-fields 10 uV/m – 10 V/m, Frequency Coverage 10 Hz-200 MHz, rate = 20 Hz, with time domain sampling capability – Atmospheric Conductivity 10^{-15} to 10^{-10} S/m, ds= 10% of local ambient value – Ground Conductivity > 10^{-13} S/m, ds= 10% of local ambient value – Grain charge >10^{-17} C – Grain radius 1-100 um 2b. Combine these with surface MET package to correlate electric forces and its causative meteorological source over a Martian year, both in dust devils and large dust storms. Combine measurements from 1b with 2a above.
3) Dust storm meteorology that affect human occupation and EVA	3a. P, V, T, n, and dust density (opacity) as a function of time at the surface, for at least a Martian year, to obtain an understanding of the possible MET hazards inside dust storms. Surface Package measure directly: – Same as measurement of 1b with added: – Dust size 1-100 um – Dust density 2-2000 grains/cc 3b. Orbiting weather station: optical and IR measurements to monitor the dust storm frequency, size and occurrence over a year, & measure terrain roughness and thermal inertia. Climate sounder would enable middle atmosphere temperature measurements. In situ density or spacecraft drag sensors monitor the dust storm atmosphere inflation at high altitudes. Same recommendation as measurement 1c.
4) Reactive atmospheric chemistry that creates a toxic or corrosive environment	4. Mass spectrometer from 2-100 AMU in near surface, multiple locations, and over long durations to detect any isolated pockets of reactive gas buildup.
5) Atmospheric / Ionospheric effects on communication and navigation	5a. Ionospheric density as a function of lat, long and height over long baseline. 5b. Surface AC E-field measurements in dust storms (same as requirement 2a) to determine RF contamination level.

The AFT Recommends R&T investments in remote sensing meteorological tool, particularly methods for remote-sensing (1) atmospheric winds from orbit at all atltitudes independently of temperature/density-derived methods and (2) the surface and near surface (0-20 km) V, T, and ρ, especially in the turbulent boundary layer.