VEXAG Report on High-Priority Technology Development Requirements

Stephen Mackwell, *Chair, Planetary Formation and Evolution Focus Group*
Kevin Baines, *Chair, Atmospheric Evolution Focus Group*

The Venus Exploration Analysis Group held its first public meeting in Pasadena, CA, on November 4, 2005. Together with a broad representation from the Venus science and technology community, the Planetary Formation and Evolution Focus Group and the Atmospheric Evolution Focus Group discussed the status of understanding of the current and past history of the atmosphere, surface and interior of Venus, identifying critical areas in need of further investigation through future robotic missions. In the process of discussing these data needs, we identified key technologies that need to be developed in order to make these measurements. While several potential missions would involve remote sensing from orbit, many important measurements require surface or near surface components that must survive temperatures in the range of 350 to 470°C, transient exposure to corrosive environments in the atmosphere during entry, and static pressures up to around 90 bars for periods of ~1 day to as much as a year. In contrast, prior missions to the surface have only survived several hours. In addition, several key measurement technologies (instruments) must be developed in the near-term that are specific to the Venus environment.

The consensus of the discussion groups was that priority be given for the development of the following technologies for exploration of Venus. This list is not meant to provide any prioritization for mission planning, as there are a number of potential priority missions to study Venus that do not require significant technological development but build on existing capability.

An important aspect of the enabling technologies identified for Venus exploration identified here is that they have applications to the exploration of other solar system bodies. For example, technology challenges of the operation in and communication from the extreme high-temperature and high-pressure environments at or near the surface of Venus are similar to those for deep entry probes at the outer gas-giant planets. Communications microsatellites are equally useful for multiple planetary missions, and in-situ instrumentation (such as chemical analysis tools, and seismometers) may also be useful for other terrestrial planets or icy satellites.

Specific high-priority technologies for **short-duration** (hours to days) missions to Venus:

- Development of passive cooling systems to enable survival of communications systems and instruments for measuring chemical, thermal, mechanical and physical (including seismic) properties at external temperatures of 470°C and pressures of 90 bars for periods of at least 1 Earth day.
- Development of high-temperature electronics for instruments and communication systems that will survive temperatures of up to 470°C for both short- and long-duration missions, so that cooling systems are not required for sustained surface lifetimes. Electronic systems with lower temperature tolerances are still desirable

for passively cooled, short-duration missions, or for high-altitude missions (potentially 350 – 400^{o}C).

- Development of balloons with mobility in both the vertical and horizontal directions. In the vertical, this should include a means to ascend and descend from near the surface to ~ 50 km altitude repeatedly during a week-long mission. Survival of the mission hardware (balloon, gondola, instruments, etc) in corrosive environments (H_2SO_4, HF, HCl, etc.) at warm and hot temperatures (e.g., from 100 to 470^{o}C), and with rapid excursions in temperature (several hundred degrees over periods of several hours).
- Development of precision landing capability, as many scientifically interesting sites for landers have relatively modest landing ellipses.
- Development of autonomous hazard avoidance systems to reduce risk for safely landing spacecraft.
- Development of communications systems to handle large data volumes (requiring potentially expanded capability in Earth-based receivers), multiple in-situ surface or floating platforms, and/or non-ideal landing sites (requiring low-power, light-weight orbiting communication microsatellites).
- For measurements of the chemical composition of rocks at a landing site, technology requirements include high-temperature extraction (potentially including drilling) and handling capability.

Specific high-priority technologies for **long-duration** (months to years) missions to Venus:

- Development of active cooling systems able to enable survival of scientific instruments and communication systems at external temperatures of 470^{o}C and pressures of 90 bars for periods of at least 1 Earth year. Somewhat lower temperature requirements of around 350 - 400^{o}C would be required for high-altitude missions.
- Development of high-temperature power systems capable of providing power for instruments and communications with reduced requirements for active cooling systems.
- Development of long-lived balloons capable of operating within the cloud layer and below the cloud deck for a combination of atmospheric measurements and observations/measurements of the surface (notably at frequencies not available to orbiting spacecraft). Tolerance to high temperatures at lower elevations and potentially corrosive environments (within the clouds and near the cloud deck).
- Development of seismometers capable of operation under Venus surface conditions, with suitable communications systems. Sensitivity requirements are probably similar to Earth systems. Seismometers must be able to be suitably coupled physically to the solid planetary surface and must have a low aerodynamic profile in order to minimize wind-induced noise. Communications systems must be able to deal with relatively high data transfer rates; some rapid triggering of the data recording system at pre-defined levels of ground motion would be necessary.

- Development of heat flow measurement capability for the Venus near surface, perhaps requiring emplacement of thermal sensors after drilling into the near surface below a lander. Requirements would include suitable drilling technologies (may also be used for sample extraction for in situ measurements of chemistry) and potentially high-temperature electronic systems.

The order of these items loosely reflects priority for development of flight hardware, although the development of individual instruments may require significant time (but is also dependent on the items nearer the top of the list), so will need synchronous and coordinated development.