**A MULTIPURPOSE PENETRATOR PROBE FOR HEAT-FLOW, THERMAL PROPERTIES, AND CLIMATIC-CYCLE STUDIES ON MARS**: Paul Morgan[1], Suzanne E. Smrekar[2] and Theodore C. Clarke[2], [1] Dept. Geology, Box 4099, Northern Arizona University, Flagstaff, AZ 86011-4099; [2]California Institute of Technology, Jet Propulsion Laboratory, Mail Stop 183-501 (SES) 264-744 (TCC), 4800 Oak Grove Drive, Pasadena, CA 91109.

**Introduction.** Shallow, sub-surface temperature data can be used to determine heat flow (a critical parameter for understanding the thermal structure of a planet), thermal properties (required for heat-flow determinations, used as calibration for thermal remote sensing studies, and very sensitive to the presence of water or ice in the regolith), and a record of past-surface temperature variations (typically for the last annual cycle before measurement). Measurements of this type were made on the Moon at the Apollo 15 and Apollo 17 landing sites by drilling holes and placing temperature sensors into the holes[1-4]. Penetrator probes (free-falling missiles that penetrate up to a few meters into the regolith) were first developed for military purposes to emplace sensors to monitor troop movements and have the advantage that no drilling equipment is required to access the subsurface. We are developing of multipurpose penetrator probes for subsurface temperature and thermal property measurements with special reference to application to Mars.

**Instrumentation.** With reference to spacecraft restrictions on probe dimensions and mass, we have developed a three-part penetrator missile which is proposed for release from an entry vehicle backshell at altitudes of 2-5 km, and is accelerated by gravity as a single unit until impact. On impact the probe deploys into its three components: 1) the head section, which is 300 mm in length and 50 mm diameter, contains majority of the probe mass(~1 kg), has temperature sensors at its tip and along its length, and gives maximum penetration of the probe; 2) a wire tether with temperature sensors along its length connecting the head section to the tail section; and 3) a tail section which remains at the surface and includes a UHF transmitting antenna. Present plans are to deploy two or more penetrators from a single entry vehicle and for the probes to transmit their data to a surface lander for relay to an orbiting satellite and back to Earth, although communications direct to orbit are possible. We tentatively plan to use the probes to deploy about six subsurface temperature sensors (thermistors or thermocouples) from the surface to the maximum depth of penetration of the probe (2-3 m). An additional temperature sensor will be mounted on the tail section to measure air temperatures, and an accelerometer in the probe will measure penetration depth. Temperatures will be measured over a period of one martian year with a sample rate decreasing from once every few seconds immediately after impact to once per day at the end of the mission. Data at these low rates can easily be stored within the probe until a convenient time for relay to Earth in conjunction with data from other experiments. Probes are currently being considered for temperature/thermal property measurements only as well as in combination with other instruments, such as seismometers and chemical sampling systems.

**Theory of Operation.** The same subsurface temperature data will be used for three objectives: 1) measurement of heat flow from Mars; 2) determination of the thermal properties of the martian regolith with special reference to the presence of water or ice in the regolith; and 3) investigation of the annual climate (temperature) cycle on Mars. Heat flow from Mars is expected to be generated by radiogenic isotopes (mainly $^{232}Th$, $^{235}U$, $^{238}U$, and $^{40}K$) within Mars and is important because heat is the energy source for planetary volcanism and tectonics. Conductive heat flow is defined as the product of the vertical thermal gradient and the thermal conductivity of the medium in which the gradient is measured. The thermal gradient will be calculated directly from the subsurface temperatures and their spacing with depth; thermal conductivity is one of the regolith thermal properties to be determined. Regolith thermal properties are important not only for understanding the thermal processes in the regolith, but also for detecting water or ice in the regolith, and for extrapolating the presence or absence of water to other locations globally.

The thermal conductivities of the main rock-forming minerals vary by about a factor of 5 from about 1.5 to 7.5 W $m^{-1}$ $K^{-1}$ and the thermal conductivities of massive, consolidated, low-porosity rocks has a similar range. Unconsolidated material, however, has a much wider range in conductivity because of the effects of intergranular thermal resistances and the wide range of thermal conductivity of possible intergranular fluids (liquid or gas). Measured thermal conductivities of the lunar regolith were very low ($0.0225 \pm 0.0075$ W $m^{-1}$ $K^{-1}$ [1,2]) because of the very low conductivity of the intergranular near-vacuum. In contrast, water-saturated terrestrial sediments have thermal conductivities at the low end on the range of mineral conductivities as water has a very high thermal conductivity for a common fluid. Thus, the measured thermal conductivity of the regolith will be very sensitive to the presence of intergranular water. If ice is present in the regolith, conductivity is increased by a significant, but smaller amount than if water is present. However, if transient probe temperatures exceed the melting temperature, the strong effects of latent heat of melting will be reflected in the transient thermal response. The transient thermal response of the penetrator probe emplaced in regolith is similar to that of marine heat-flow probes which has been well studied [5,6], and can be used to determine both thermal conductivity and thermal diffusivity of the medium surrounding the probe if the probes thermal parameters are known. In marine probes, as with the lunar heat-flow probes, a thermal transient is introduced using an electrical heater in the probe. Experiments using gas-gun emplaced penetrator probes into dry sand suggest that the conversion of the kinetic energy of penetration to heat provides a strong thermal transient from which thermal properties may be determined without the need for an electrical heater in the probe [7].

The annual climatic temperature cycle is recorded in subsurface temperatures as a transient propagating temperature-wave, attenuated with depth, and superimposed on the background thermal gradient. The propagation of this wave gives not only an independent measure of the regolith thermal properties (wave length depends on thermal diffusivity) but also allows the surface temperature history to be reconstructed for the past one or more temperature cycles. This information is somewhat redundant if the actual surface temperature is monitored for a full year, but it can also be used to monitor exchange of gases between the regolith and the atmosphere during the annual cycle through the non-conductive effects of this exchange on the subsurface temperatures.

**Experiment Status.** Preliminary experiments on the thermal behavior of penetrator probes have been completed using gas-gun launched penetrators into a dry-sand target. Work currently in progress to test the penetration of free-fall penetrators in the Mohave Desert. Opportunities for launch of these penetrators include the Mars Surveyor Program and InterMarsnet in 2001.

**References**: [1] Langseth, M. G. *et al.* (1972) *Apollo 15 Prelim. Sci. Rpt., NASA SP-289*, 11-1. [2] Langseth, M. G. *et al.* (1973) *Apollo 17 Prelim. Sci. Rpt., NASA SP-330.* 9-1. [3] Langseth, M. G. *et al.* (1976) *PLSC, 7,* 3143. [4] Langseth, M. G. and Keihm, S. J. (1977) *Soviet-American Conf. on Geochem. of the Moon and Planets, NASA SP-370,* 283. [5] Bullard, E. C. (1954) *Proc. R. Soc. Lond., A 222,* 408. [6] Hyndman, R. D. *et al.* (1979) *Marine Geophys. Res., 4,* 181. [7] Wolff, E. D. *et al.* (1995) *Eos, Trans. Am Geophys. Un., 76(46),* F330.