LANDING MASSIVE PAYLOADS, ACCURATELY, ON MARS: A 25-YEAR ROADMAP. J. T. Bergstralh[1], J. M. Zawodny[1], and R. H. Tolson[2], [1]Mail Code 401, NASA Langley Research Center, Hampton, VA 23681-2199, j.t.bergstralh@larc.nasa.gov, [2]North Carolina State University, Raleigh, NC 27695.

Background: All five spacecraft that have landed successfully on Mars (Viking 1 and 2, Mars Pathfinder, MER-A and -B) employed the entry, descent, and landing (EDL) system developed more than 30 years ago for Viking. Common features of these landings included unguided hypersonic trajectories through the atmosphere, parachute deployments at Mach > 1, landing-error ellipses of order tens of kilometers, landing sites in relatively smooth regions at elevations > 1 km below the MOLA average geoid, and touchdown masses < 600 kg. The principal differences among them were the techniques used for their terminal landing phases (*i.e.* propulsion *vs.* airbags).

Significant progress in future exploration on the surface of Mars will demand precision delivery (< 1 km error) of massive payloads (> 1000 kg) to locations anywhere on the planet (*e.g.* the southern highlands, at elevations above the MOLA geoid). It will become necessary to decelerate massive entry vehicles sufficiently to allow them to deploy their parachutes before they hit the ground (a requirement euphemistically known as the “hypersonic transition problem”), and then to guide them actively to precise landing locations.

The Viking EDL system cannot be scaled up to decelerate massive payloads sufficiently, and work has not yet begun in earnest on precision landing. NASA must begin to invest in new EDL technologies for Mars.

Problem: Large-amplitude variations in the density *vs*. altitude profile, ρ(z), along with winds, wind shear, and turbulence in the boundary layer, are principal sources of uncertainty and risk in Mars EDL operations.

Atmospheric Density Profile. MER-A (“Spirit”) encountered densities that were systematically lower than worst-case predictions in the critical 20 km < z < 50 km altitude range, where maximum aerodynamic deceleration occurs. As a consequence, MER-A landed ~25 km down-range from its nominal target.

Winds and Turbulence. Wind velocities, wind shear, and turbulence in the planetary boundary layer are primary sources of uncertainty and risk in the final phases of landing. For example, a 20 m sec^{-1} wind would create a landing error > 1 km during ~ 1 minute of parachute descent through the boundary layer.

Approach: Improved characterization of the Martian atmosphere will be needed to support definition of trade-spaces for developing new EDL technologies, as well as to reduce risk of EDL operations for upcoming missions (Phoenix and MSL).

Near-term. Over the next 3 to 5 years, characterize the full range of variability of the density profile, ρ(z), as a function of season, time of day, and geographical location. This will require systematic assimilation of remote-sensing atmospheric data from MGS, Odyssey, MEx, and MRO; aerobraking data from MGS, Odyssey, and MRO; and EDL data from Viking, Pathfinder, MER, Phoenix, and MSL into global and mesoscale atmospheric models.

Long-term. Precision landing requirements will demand development of accurate and reliable capabilities to predict the density profile ρ(z), the onset and atmospheric effects of regional and global dust storms, and wind velocities, wind shear, and turbulence in the planetary boundary layer, especially at high-priority locations. A comprehensive suite of remote-sensing measurements will be needed in the next decade to constrain models, to better resolve fundamental processes, and to understand (and predict) short-term and interannual variability. It is likely that *in situ* measurements of temperature, pressure, and wind speed and wind direction will be needed, as well. Accordingly, all future Mars landers should include meteorology packages and, eventually, dedicated meteorology networks may be needed to support precision landing operations in near real time.