Evaluation of Potential Landing Sites for Surface Rover Missions on the Planet Mercury

Elizabeth A. Fisher, 2015

Methods:
First, estimates conditions needed for a successful rover mission were made based on publically available operating specifications for the MESSENGER spacecraft [1], and Mars Rovers Spirit and Opportunity [2,3]. Assumptions
The spacecraft needs a flat area to land (>5° slope)
The rover may bounce up to 1 km on Mercury’s surface at high speed after initial impact [4]
The rover will be solar powered and can be designed to last for up to 90 sols if sunlight is available [2,3].

The rover’s safe operating temperatures range from -40°C-40°C (this has been considered unsuitable for landing areas, are highlighted in Figure 3. Results of temperature modeling for 1 Mercury orbit (~90 sols), are reported in Figure 4-5.

Introduction:
NASA’s MESSENGER Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) spacecraft impacted with the surface of Mercury on April 30th, 2015, signaling the end of NASA’s first mission to Mercury. MESSENGER made several unexpected discoveries during its three years on Mercury’s orbit, the most incredible of these being strong evidence for the presence of water ice in permanently shadowed craters on Mercury’s poles, despite the intense temperature conditions characteristic of much of the planet. Investigating the origin and extent of these ice deposits could reshape our understanding of how our solar system formed, making further observation of Mercury’s poles a priority in the planetary science community. A successful rover mission to Mercury could both verify the existence of postulated ice deposits and provide round-truth calibrations for remote sensing data, opening the door for decades of novel research like that conducted on Mars and the Moon. This study presents an attempt to identify potential sites on Mercury’s North Pole where a rover could safely land and conduct ~80 sol (Earth day) mission without being disabled by steep terrain or excessive temperatures. This was achieved by 1) Utilizing elevation data to determine the extent of low-slope areas on Mercury’s surface (>5°), 2) Instating a 1.5 km buffer around areas around areas of >5° slope, 3) Utilizing a temperature model to find areas with rover-safe temperatures (-50°C-50°C) for >80 sol of Mercury’s orbit, and 4) Estimating levels of insolation on Mercury’s surface throughout this period to determine the location that would provide the most sunlight over this period of time.

Elevation:
A digital elevation model of Mercury’s northern hemisphere, generated using MESSENGER’s Laser Altimeter data [5], was acquired from NASA’s Planetary Data system and imported into ArcGIS at 500x500m/pixel resolution in a north polar stereographic projection (source 1). Slope (degrees) was calculated using the slope tool, then classified as either >5° (value=1) or <5° (value=0) using raster algebra. Raster cells with slope >5° were converted to polygons, and a 1.5 km buffer added to these polygons using the buffer tool. polygons were returned to raster format, and the raster reclassified such that slope/buffer areas=0, and remaining areas safe for a rover landing =1. Areas determined to have both a safe slope and sufficient distance from surface features (safe for landing), are highlighted in Figure 3.

Temperature:
A temperature model for the surface of Mercury at its perihelion (longitude 0 at subsolar point) generated by the European Space Agency BepiColombo science team [5], was plotted as x-y data in north polar stereographic projection and interpolated between 175°E-W and 85°N-S using a cubic spline interpolant (spline tool). The resulting raster was then rotated to estimate Mercury’s maximum surface temperatures at 10, 20, 50, 70, and 90 sols into orbit after perihelion (sol 0). Rotation rate was estimated as 2.045°/day (Fig. 1) (6)
Sunlight levels estimated using Fig.1 in combination with modeled surface temperature as a proxy [5, 6].

Results:
Results of slope analysis are reported in Figure 2. Areas of low slope buffered from Mercury surface features at a distance of 1.5 kilometers, classified as safe landing areas, are highlighted in Figure 3. Results of temperature modeling for 1 Mercury orbit (~90 sols), are reported in Figure 4-5.

Discussion:
1. Temperature is the largest constraint on the success of a Mercury Rover mission

Temperature constraints of -50°-50°C severely limits the time a rover can spend even at high latitudes, models indicate that rovers may be restricted to poles, but further temperature modeling/extrapolation is required (Fig. 4).

Increasing rover temperature limits up to 125°C significantly increases latitude range available to rover to ~85°N for ~80 sols (Fig. 5).

-Modeled temperatures are conservative due to the fact they were estimated at orbital perihelion

Heat shields capable of resisting up to 173°C exist (MESSENGER technology [1])

-Placing a rover at >90°E at perihelion in this study allows for up to 80 sols of unbroken sunlight, facilitating rover travel of minimum ~6 km, maximum 25 km [average and top speeds estimated from Spirit/Opportunity, 4.5].

-Wide swaths of low slope area capable of facilitating a safe rover landing exist at Mercury’s north pole near 85°N (Fig. 3).

Conclusions/Implications:
Extended rover operations (~80 sols) are likely feasible at high northern latitudes on the surface of Mercury using existing rover and heat shielding technology. Rover missions in these locations are ideally located to study crater ice deposits discovered on Mercury’s poles.

Figure 3. Slope analysis showing areas of <5° slope that are not within any Mercury surface feature with relief of <5° slope. Areas shaded in teal are considered safe for rover landing mechanism utilized by Spirit and Opportunity rovers on Mars [4]. North polar stereographic projection.

Figure 1. Diagram showing 1 year of Mercury’s orbit around the sun and planetary rotation relative to daylight on surface (modified from [6]).

Figure 2. Slope analysis conducted for Mercury’s north pole, with >5° slope considered unsuitable for landing outlined in red. North pole stereographic projection.

Figure 4. Mercury Surface Temperature predicted from model [5] with rotation of 2.045°/day estimated from [6], plotted at various times in Mercury’s orbit between 0 sol (perihelion), and 90 sol. North polar stereographic projection.

Figure 5. Mercury Surface Temperature predicted from model [5] at sol 0 (perihelion), indicating extension of rover range to ~85°N with operating temperature range of -50°-125°C (shaded in blue). North polar stereographic projection.