Efficient Delivery of a Network of Small Probes to the Martian Surface

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Motivation

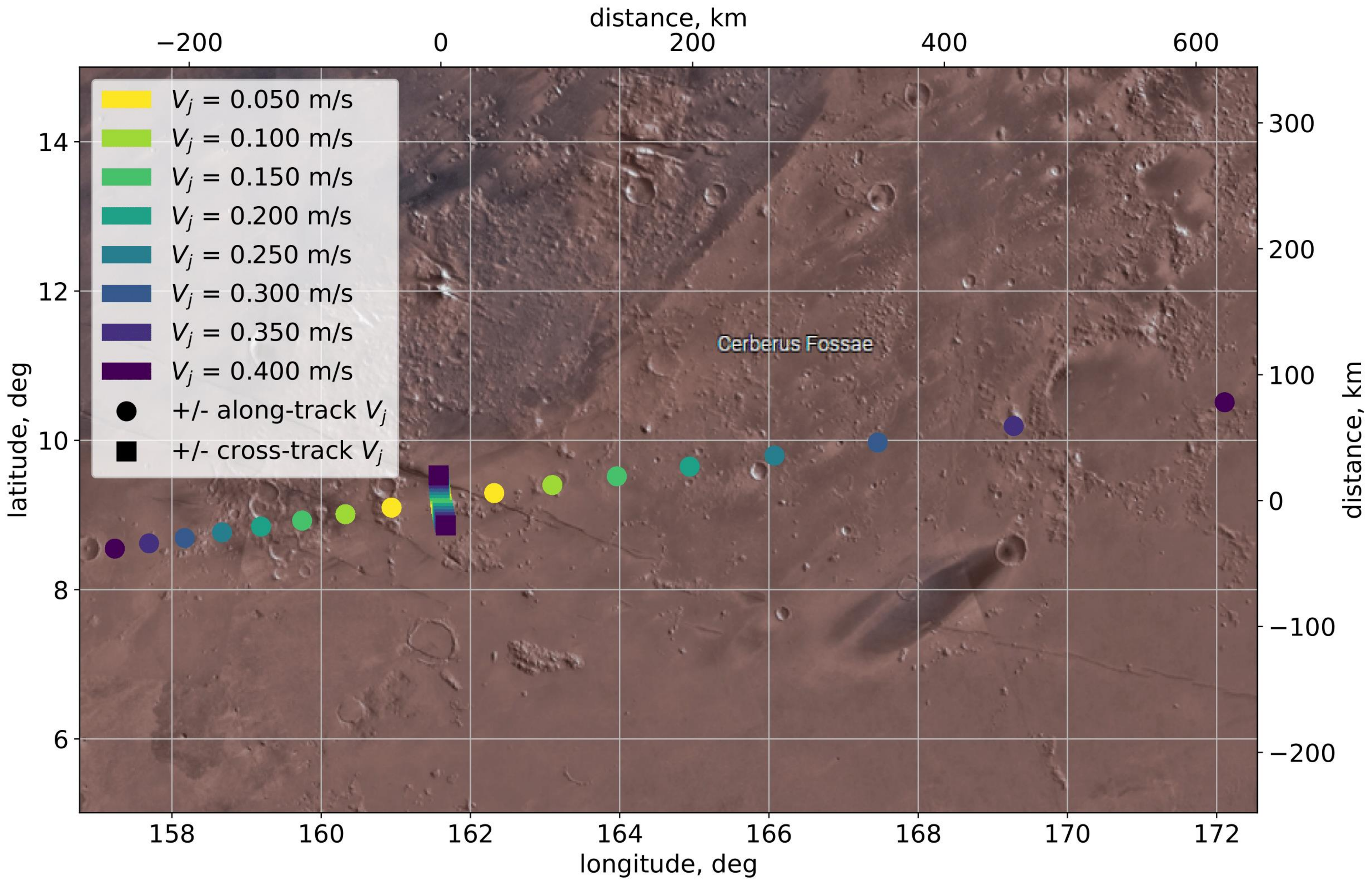
Regional networks of small rough landers on the Martian surface, able to make simultaneous observations across large distances, are a mission class of interest for planetary science. The SHIELD lander, under development at JPL as a simple and robust EDL platform for small missions, could deliver the payloads from atmospheric entry to the surface at reduced cost & complexity. Can these probes all be delivered from a single mothership without the need for in-space maneuvering? When should the probes be released to efficiently target their landing sites with acceptable accuracy?

Assumptions

- Passive ballistic rough landers (SHIELD)
- Landing sites 10-200 km apart, in 2 directions
- Precision landing not required
- Probes approach Mars on a single carrier spacecraft on an entry trajectory
- Probes separate from carrier mechanically and in balanced pairs
- Jettisons occur between 5 and 0.25 days before atmospheric entry
- Desirable to separate probes with equal jettison speeds

Problem Characterization

The figure below shows landing locations for four probes jettisoned from the mothership in the along-track and cross-track directions at 1 day prior to entry, varying the jettison speed. As shown, the landing locations move roughly linearly as jettison speed increases, and along-track separation is far more sensitive. Similar results are shown in the paper for varying jettison time with a fixed speed of 10 cm/s.

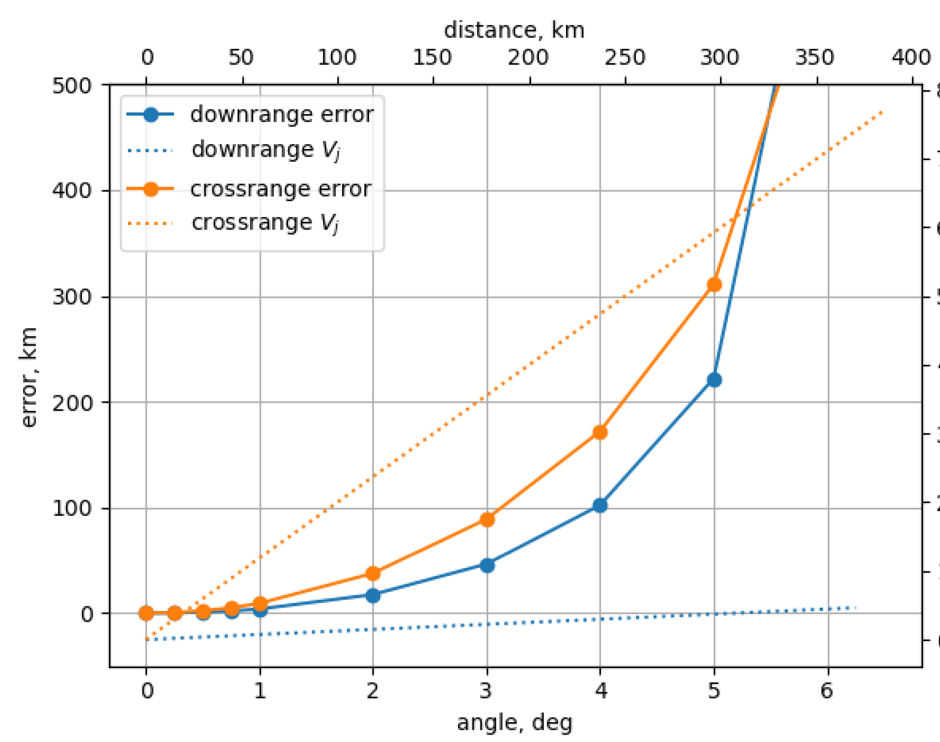


Linearized Targeting

A numerical linearized targeting scheme is used to design minimum maneuvers to target desired lat/lon changes, akin to B-plane targeting. The linearization fails when desired separation becomes large.

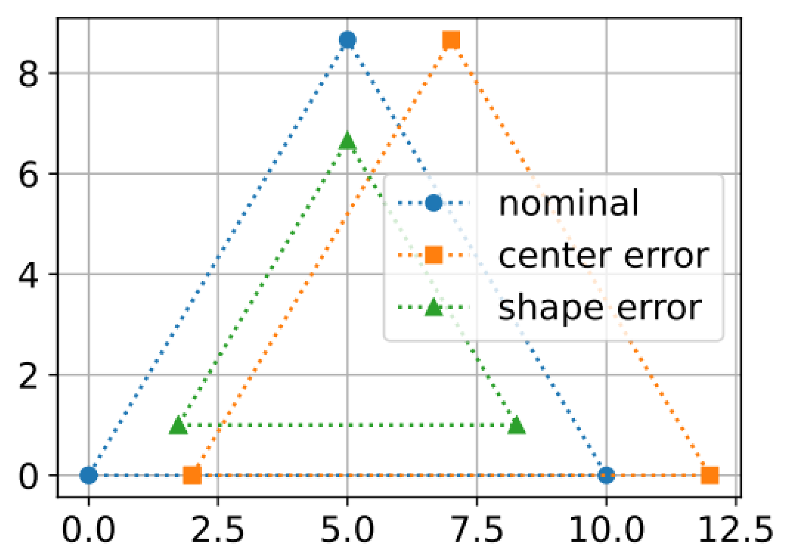
$$\Delta \boldsymbol{x}_{\theta\phi} \approx \left.\frac{\partial \boldsymbol{x}_{\theta\phi}}{\partial \boldsymbol{V}}\right|_{*} \boldsymbol{V}_j = [\boldsymbol{J}]\boldsymbol{V}_j \qquad [\boldsymbol{J}] = \begin{bmatrix} \frac{\partial\theta}{\partial V_x} & \frac{\partial\theta}{\partial V_y} & \frac{\partial\theta}{\partial V_z} \\ \frac{\partial\phi}{\partial V_x} & \frac{\partial\phi}{\partial V_y} & \frac{\partial\phi}{\partial V_z} \end{bmatrix}_{*}$$

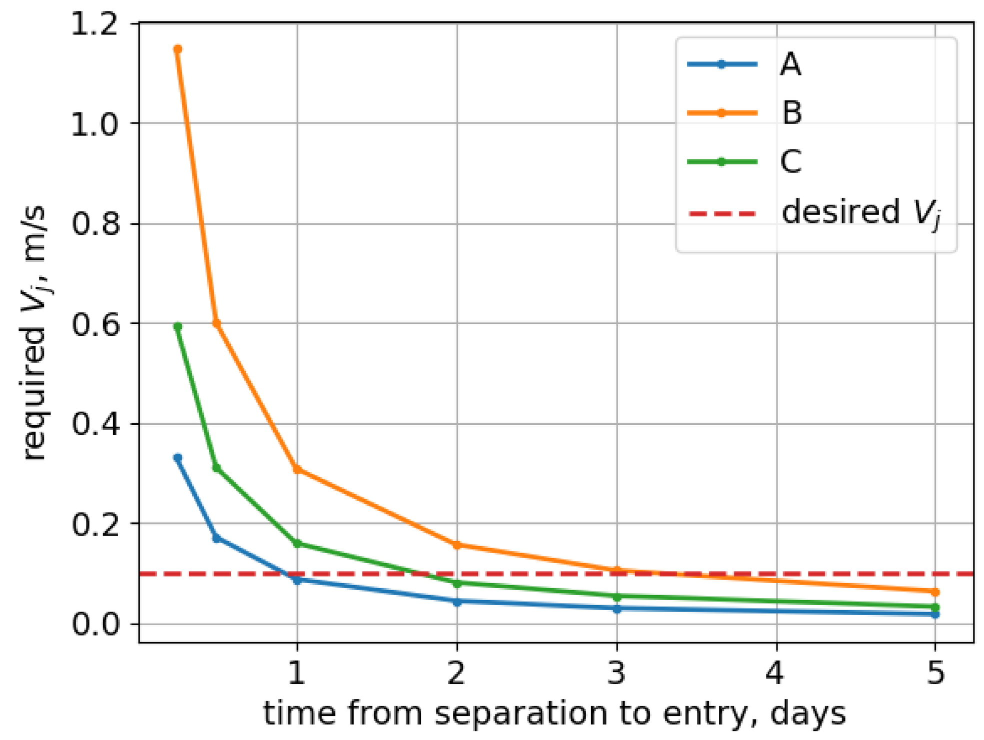
$$\boldsymbol{V}_j = [\boldsymbol{J}]^T \left([\boldsymbol{J}][\boldsymbol{J}]^T\right)^{-1} \Delta \boldsymbol{x}_{\theta\phi}$$



Network Design

A notional network is designed to place six seismic stations in the Cerberus Fossae region. Because probes are assumed to jettison mechanically, the maneuvers are designed for a common magnitude of 10 cm/s, enabling a common jettison system for all three pairs. The figure below and on the right shows how jettison time was tuned accordingly.





Monte Carlo Analysis

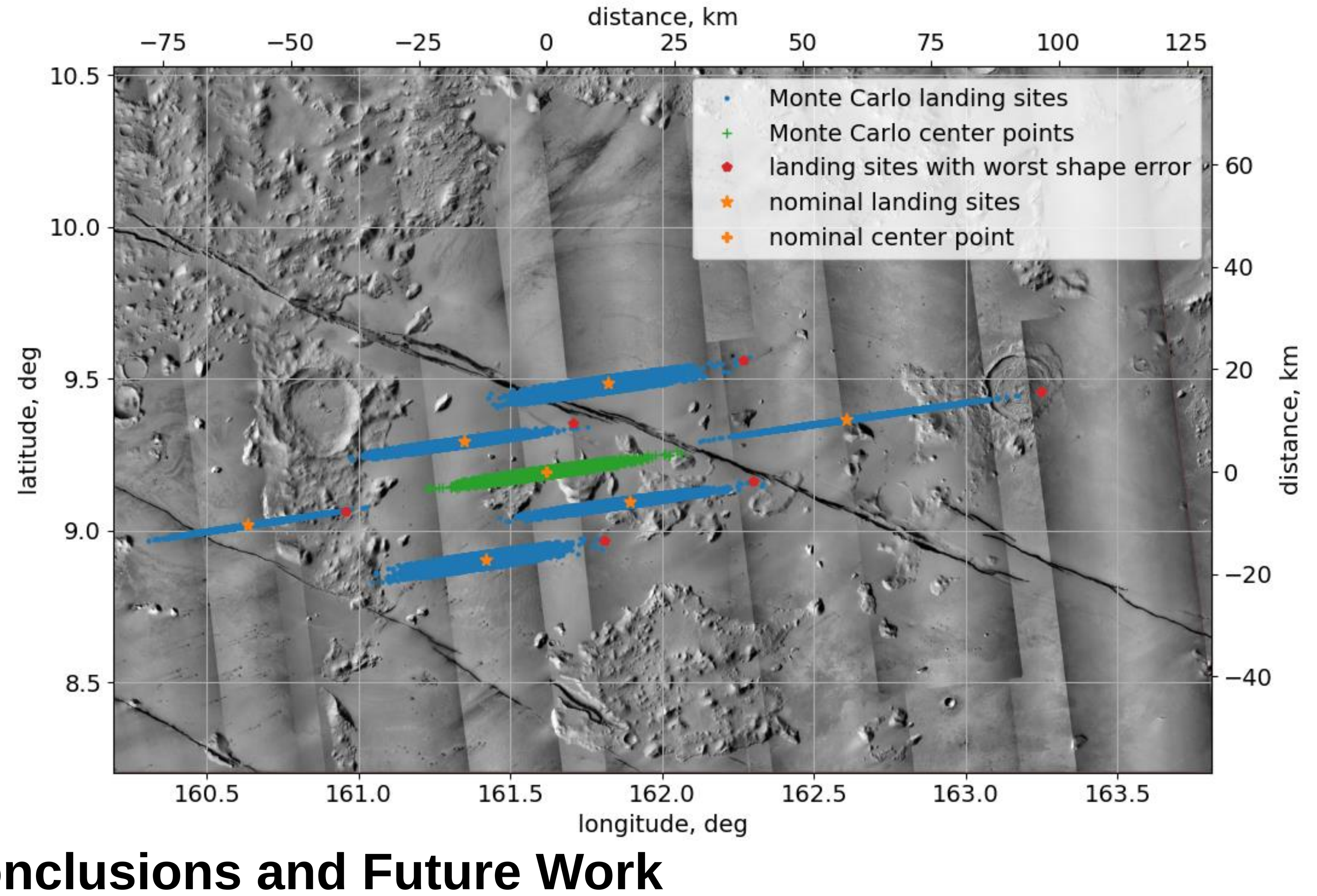
The input dispersions and results of a 5000-trial Monte Carlo analysis are shown below. Density and the mothership's entry flight-path angle and velocity were the same for all probes each trial, but the probe ballistic coefficient and jettison speed error were dispersed independently for each probe for each trial.

Table 3 Monte Carlo analysis input dispersions

Parameter	Dispersion
atmospheric density ρ	MarsGRAM
entry velocity magnitude V_0	$3\sigma = 2$m/s
entry flight-path angle γ_0	$3\sigma = 0.2°$
probe ballistic coefficient β	±5%
jettison speed V_j	±10%

Table 4 Statistics of relative landing site separation distances

Parameter	Mean	Min.	Max.	3σ
center error ε_c, km	5.309	0.012	26.344	12.102
shape error ε_s, km	2.285	0.366	6.055	2.859
min. separation, km	21.741	20.000	24.113	2.363
max. separation, km	118.808	103.312	137.478	17.011
avg. separation, km	52.168	46.583	59.441	5.924



Conclusions and Future Work

Though individual targeting accuracy is poor, the landing site dispersions are highly correlated between probes. As a result, the overall network size and shape is maintained within requirements under relevant dispersions. Future work includes nonlinear targeting approaches for larger networks and using smart deploy of a subsonic drag skirt to improve probe targeting.

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