IMPROVED MARS GRAVITY AND MAGNETIC MAPPING FOR MINERAL EXPLORATION

Research and Technology Development Annual Report

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A. OBJECTIVES

The objective was to examine required accuracy and plausible deployment scenarios for regional gravity and magnetic surveys on Mars, in support of eventual mineral exploration and mining of local resources.

Continued operation of human colonies on Mars will require the finding and use of local mineral resources. On Earth, mineral exploration usually begins with geophysical surveys, in which gravity and magnetic fields are measured.

At present, the global gravity and magnetic fields of Mars are reasonably well known, from spacecraft observations. However, this present knowledge falls far short of the fidelity and spatial resolution which will be required as input to geophysical exploration for mineral resources, to be mined on Mars. We propose to pursue two related tasks which are intended to move us closer to having useful levels of both quality and quantity for geophysical input to mineral exploration and extraction.

Our basic premise is that a network of small, robust geophysical sensors will be deployed on the surface of Mars, and they will measure and communicate values of the gravity and magnetic field vectors at their locations. We will examine the required performance, and evaluate some deployment strategies.

Recent on-surface measurements of Mars gravity and magnetic fields, by Mars Curiosity Rover and Insight, have shown that such data provide information well beyond what can be obtained from orbital platforms.

B. STRATEGIC FOCUS AREA

Innovative Spontaneous Concepts:

[X] Innovative Spontaneous Concepts

C. RELEVANCE TO STRATEGIC FOCUS AREA

N/A

D. APPROACH AND RESULTS

summary of approach

In the first task, we perform simulations to assess how the sensor grid geometry (spatial extent, density, homogeneity etc.) and sensor measurement accuracy both map onto improvements in knowledge of the regional and/or global fields. Higher accuracy measurements and higher density grids will obviously yield better results, but at greater cost. We seek to understand the trade-off curves. Also, the accuracy and spatial resolution required for traditional scientific investigations is very different from what is required to guide mineral exploration activities.

In the second task, we make an initial assessment of feasible deployment strategies. If sufficiently sensitive instruments were sufficiently robust, in terms of impact shock survival, then hard delivery would be feasible, and much less expensive than soft landings. However, we expect that even relatively robust sensors (such as exist in current generation cell phones) would not survive 3-5 km/s impacts, and some accommodation will be required.

Our current notion is that, from a polar orbiting “mother ship”, packets of sensors could be propulsively slowed enough to lie on orbits which intersect the surface of Mars. If the along-track orbital speed were completely removed, the “stop and drop” delivery would still result in impacts at 1-2 km/s, unless atmospheric drag were significantly exploited. An attractive option, in that direction is to use biologically motivated rotors, known as samaras, such as those used by elm and maple trees to disperse their seeds.

summary of results

measurement accuracy

The criterion we use for assessing required measurement accuracy at each location within a regional grid is that the error of the measurement needs to be substantially smaller than the expected RMS variation between values at adjacent grid nodes.

Based upon orbital measurements, we currently have estimates of the long wavelength variance spectra of gravity and magnetic fields at Mars. In both cases, the shortest wavelengths measured this way are roughly 100 km, whereas the regional grids we are investigating will have inter-node spacing of 1-10 km.

For planetary gravity fields, the RMS amplitude of the spherical harmonic coefficients of the external potential are known to follow the Kaula rule [1, 2], in which the RMS amplitude is inversely proportional to the square of the harmonic degree. Using that template, we have computed the single station measurement accuracy required, as a function of mean inter-node spacing, as shown in **Figure 1**.

For planetary magnetic fields, the situation is somewhat more complex. On Earth, the long wavelength variations are dominated by the core field, and shorter wavelength features are dominated by crustal remanent magnetization [3]. On the Moon and Mars, there are no core contributions, and current observations [4, 5] are well approximated by crustal sources, with a flat source spectrum and depth for Mars of 80 km. **Figure 2** shows the corresponding measurement accuracy, as a function of inter-node spacing.

The derivation of these results is documented in a publication currently under review.

surface deployment

The premise of our deployment strategy is that aerobraking can be used to slow the orbital motion of sensor packages sufficiently to allow relatively soft landing on the surface.

As a “proof-of-concept” case, we examine trajectories of sensors released at low relative speed from a “mother ship” spacecraft in circular orbit about Mars at a mean altitude of 200 km. The initial along-track speed is 3.5 km/s. The trajectory is computed using a monopole model for Mars gravity, and an along-track deceleration proportional to the product of speed squared times atmospheric density, projected area, and inversely proportional to mass [7]. The atmospheric density is an exponentially decaying function of altitude, with scale height of 11.8 km [8].

If the along-track speed were completely eliminated, the trajectory to the surface would simply reflect a balance between gravitational attraction and atmospheric drag. **Figure 3** shows the resulting variations of speed with height, with different values of the area/mass ratio. The black curve shows motion under the influence of gravity alone. When starting from 200 km altitude, the impact speed is nearly 1.2 km/s, which is too high for our purposes. The blue and red curves show trajectories corresponding to area/mass ratios of 1 and 10 m^2/kg. The solid curves are integrated solutions of the equations of motion, as given above. The dashed curves use the "terminal velocity" expressions for speed, and integrate that to yield height. The upper elevation parts of the trajectories are dominated by the gravitational acceleration, and the lower elevation parts are dominated by drag. The "terminal velocity" estimate yields a good approximation to the integrated trajectory speed at impact.

Figure 4 shows how the time from release to impact varies with initial elevation and area-to-mass ratio. Similarly, **Figure 5** shows how impact speed varies with area-to-mass ratio. It is independent of initial altitude.

As part of a third task, we have begun considering design for the delivery package. **Figure 6** shows a nominal design, in which there is a central module, which contains the gravity and magnetic field measurement instruments and telecommunication system. The outer ring contains batteries. The disk connecting them provides large projected area to slow the orbital motion, and has small slots which act as a propellor to spin the package, maintaining orientation stability.

E. SIGNIFICANCE OF RESULTS

Our work has succeeded in obtaining quantitative results in two key areas related to geophysical surveys of gravity and magnetic fields of Mars as part of a mineral exploration program.

We have found how the measurement accuracy scales with the inter-node spacing in the surface grids, as shown in Figures 1 and 2. We have also found how impact speed scales with area-to-mass ratio, assuming that aero-braking is used to slow the initial along-track orbital speed. The results are shown in Figure 5.

F. NEW TECHNOLOGY

None

G. FINANCIAL STATUS

The total funding for this task was $45,000, all of which has been expended.

H. ACKNOWLEDGEMENTS

None

I. PUBLICATIONS

[A] Bills, B.G. and K.M. Gorski, Measurement accuracy requirements for Mars surface gravity and magnetic field sensors

in review at Planetary and Space Sciences.

J. REFERENCES

[1] Kaula, W. M. (1963). Determination of the Earth's gravitational field. *Reviews of Geophysics*, 1(4), 507– 551

[2] Ermakov, A.I. et al. (2018), Power laws of topography and gravity spectra of solar system bodies, J. Geophys. Res., 123, 2038-2064.

[3] Maus, S. (2008), The geomagnetic power spectrum, Geophys. J. Inter., 174, 135-142.

[4] Langlais, B. et al. (2019), A new model of the crustal magnetic field of Mars, J. Geophys. Res., 124, 1542-1569.

[5] Tsunakawa, H. et al. (2015), Surface vector mapping of magnetic anomalies over the Moon, J. Geophys. Res., 120, 1160-1185.

[6] Roshko, A. (1955), On the wake and drag of bluff bodies, J. Aeronaut. Sci., 22, 124-132.

[7] Smith, M. D. (2008), Spacecraft observations of the Martian atmosphere. Ann. Rev. Earth Plan. Sci. 36, 191--219.

K. APPENDIX

None

L. FIGURES

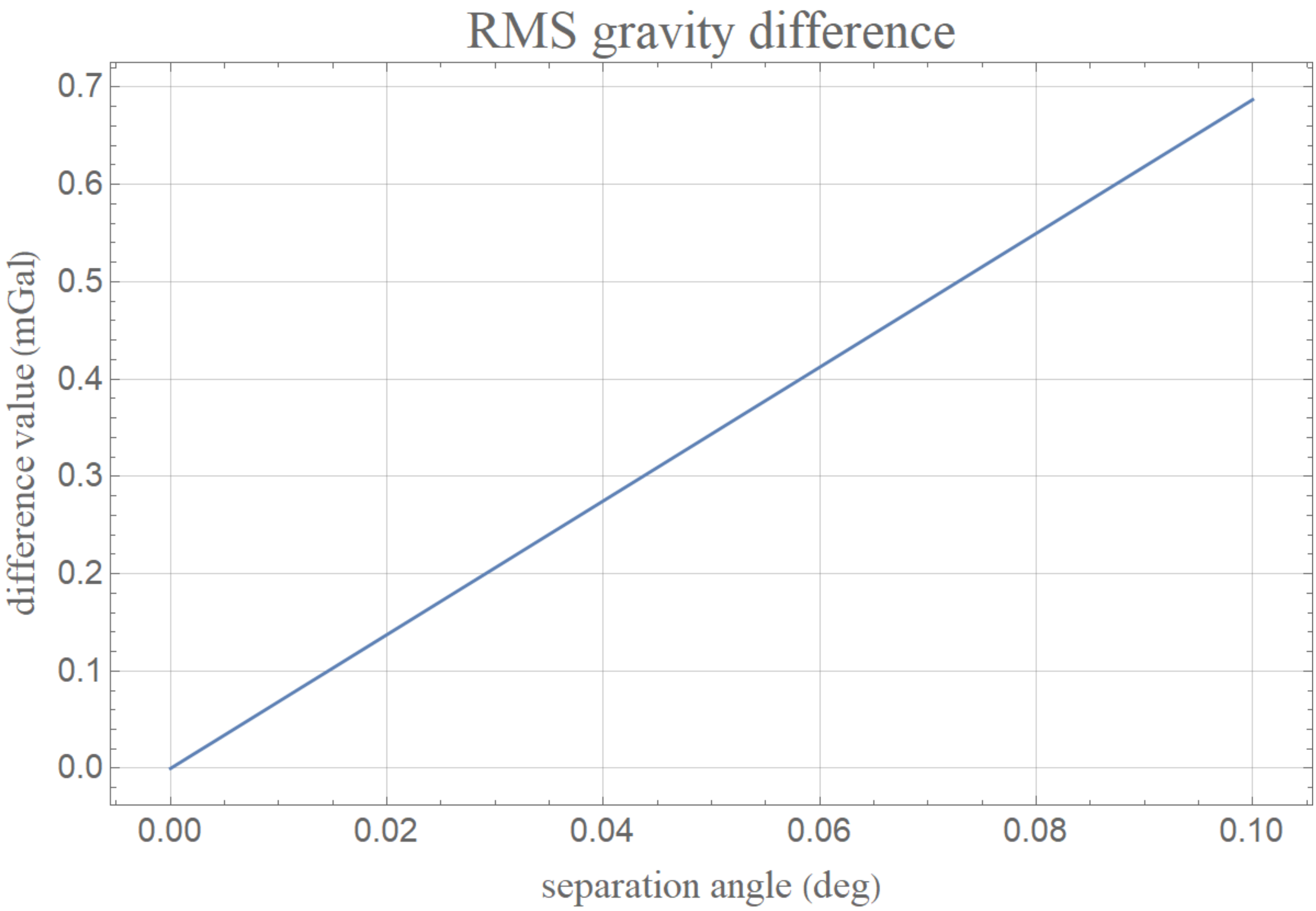

Figure 1. Mars RMS gravity difference versus station angular separation.

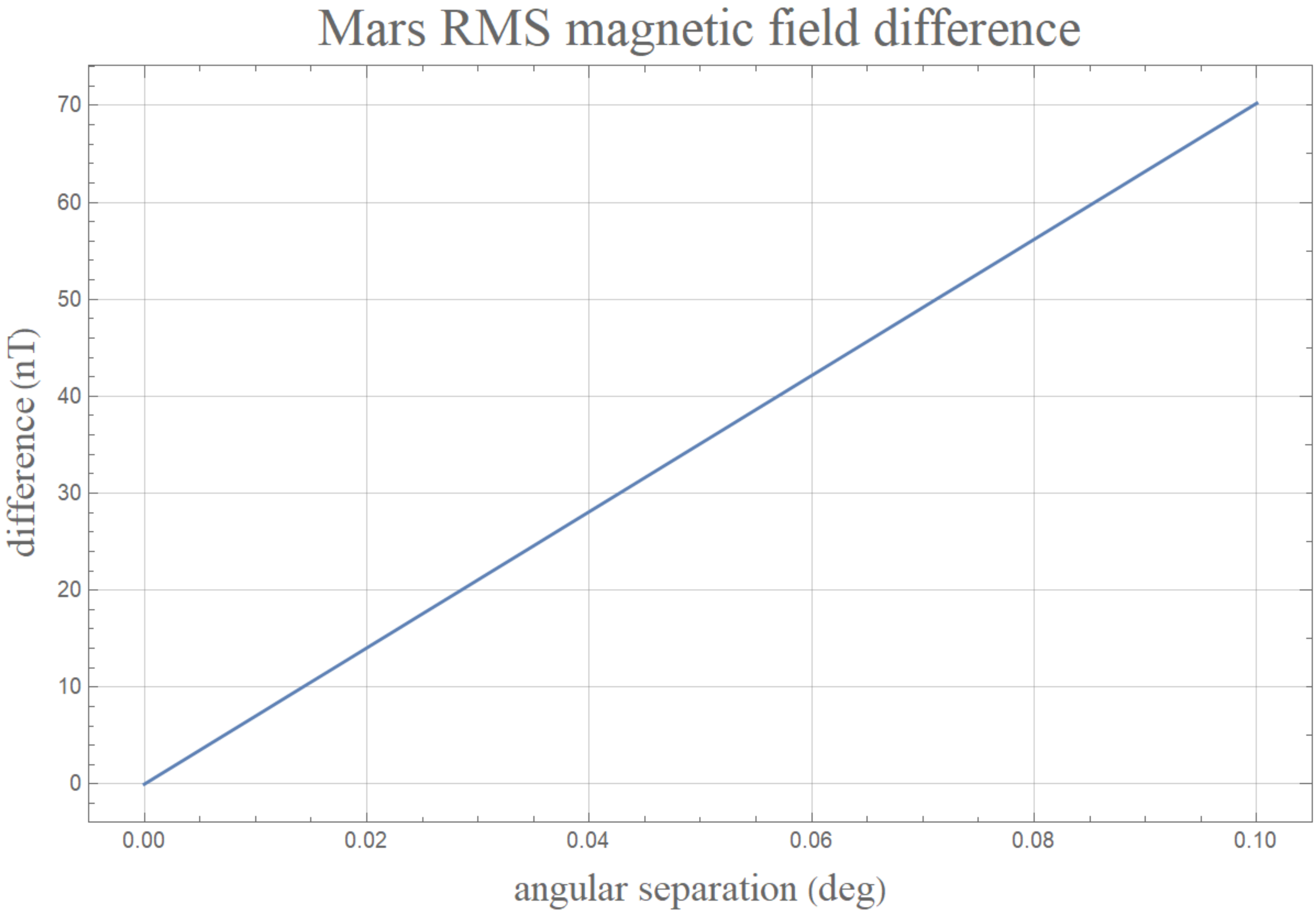

Figure 2. Mars RMS magnetic field difference versus station angular separation.

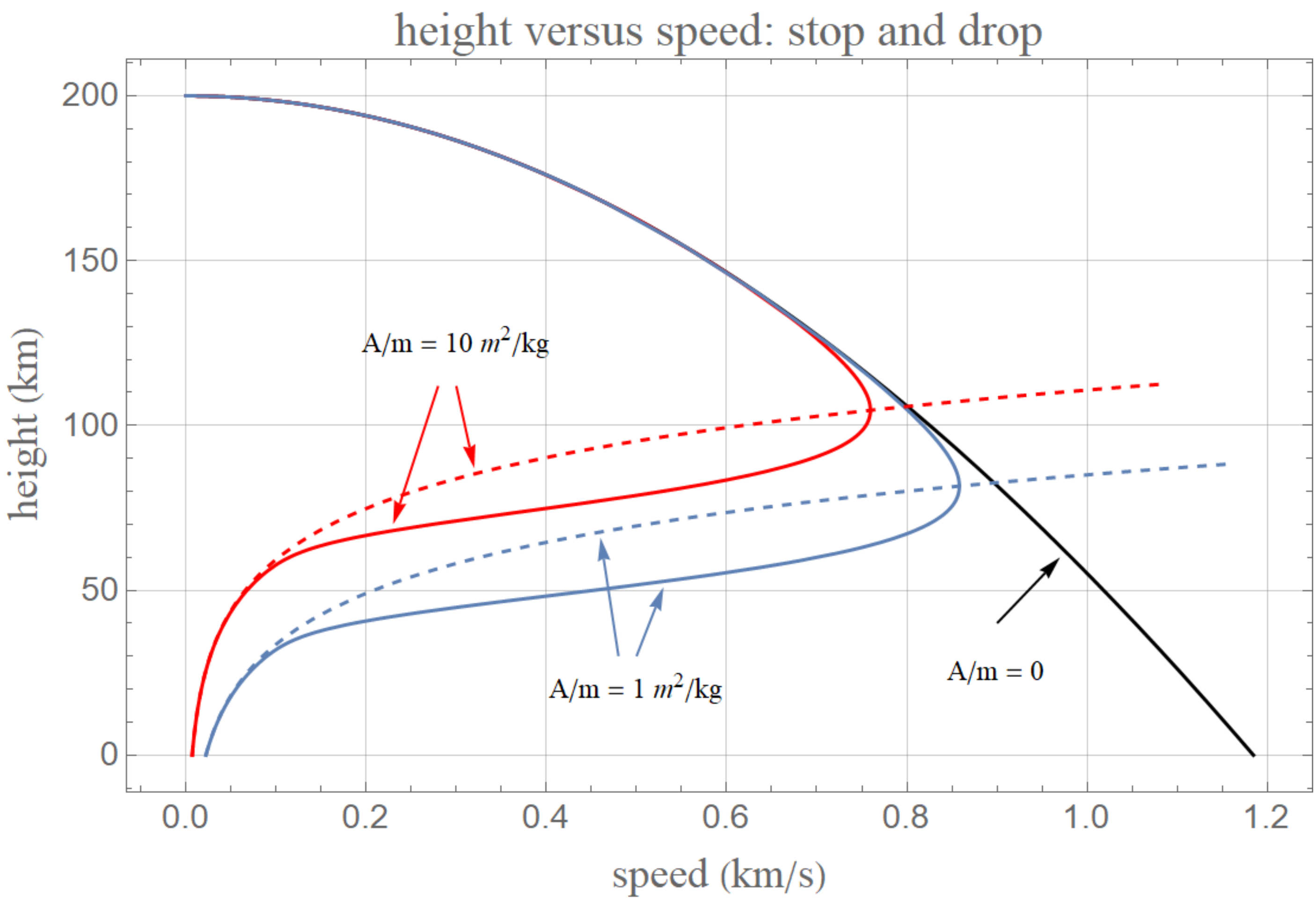

Figure 3. Height versus speed with zero initial speed.

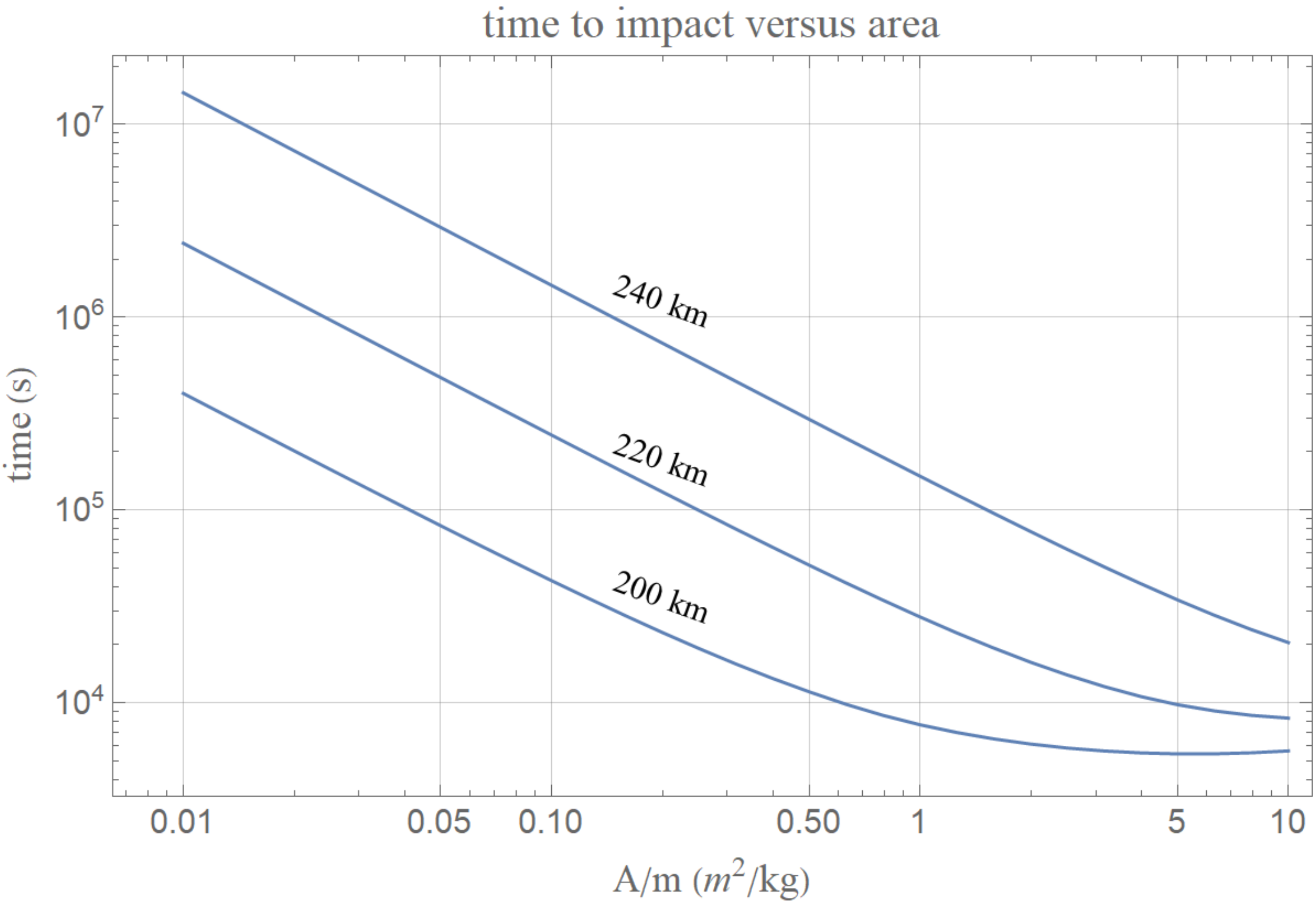

Figure 4. Time to impact as function of area-to-mass ratio, for a range of initial altitudes.

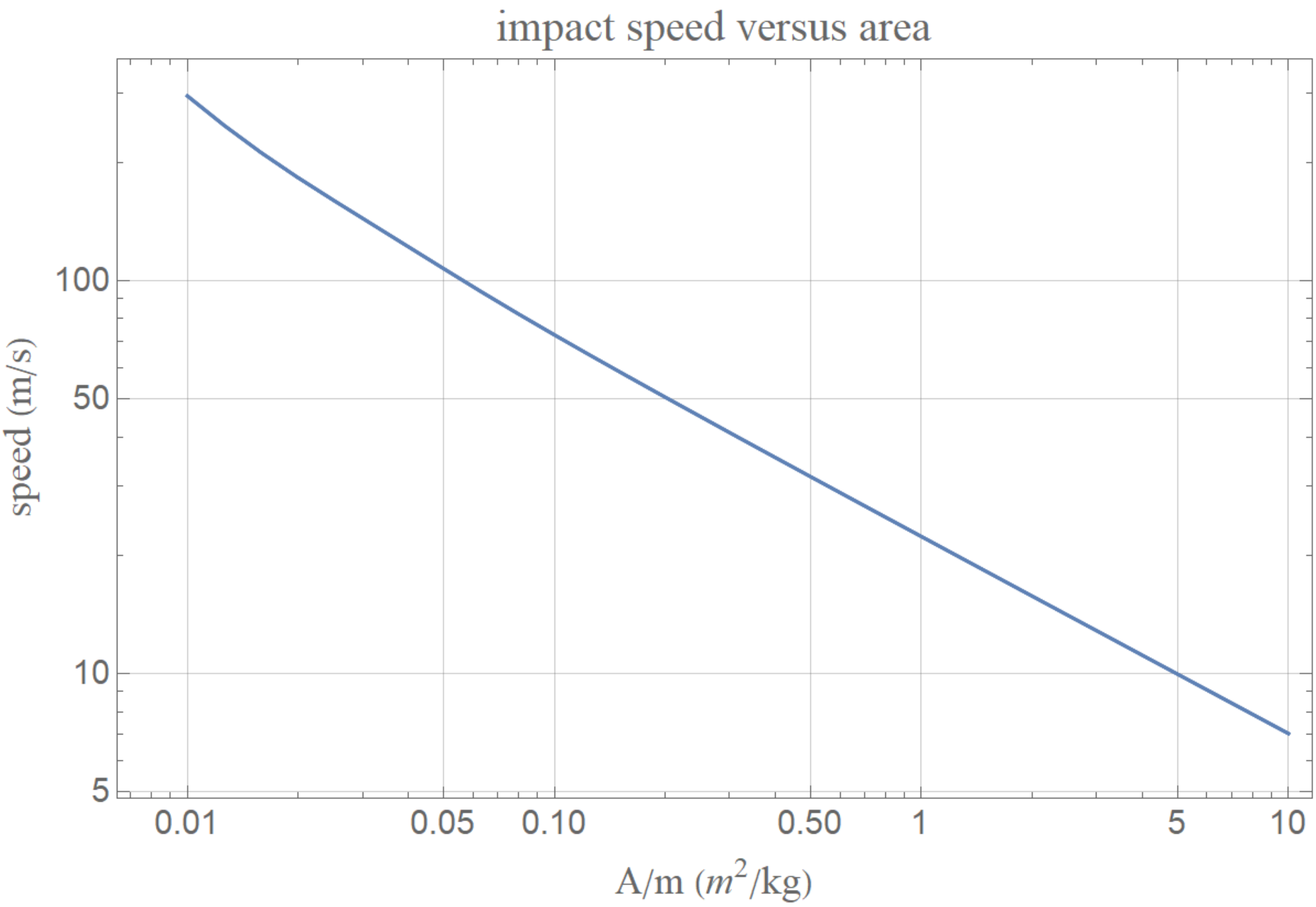

Figure 5. Speed at impact as function of area-to-mass ratio.

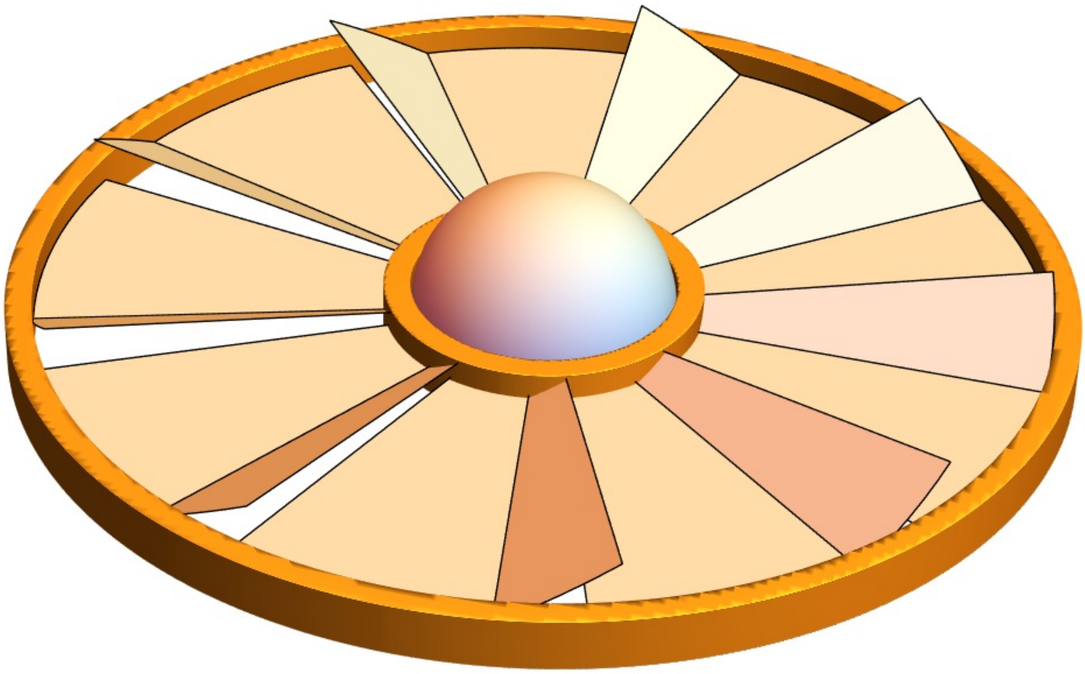

Figure 6. Nominal configuration of instrument delivery package.

M. COPYRIGHT STATEMENT