Surveying Martian Surface using Balloons: an Open-Architecture Mission Concept

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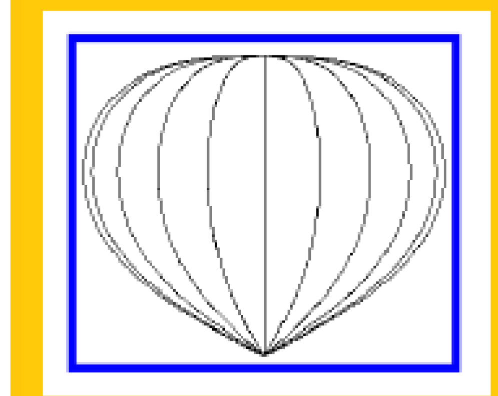
Motivation and Summary

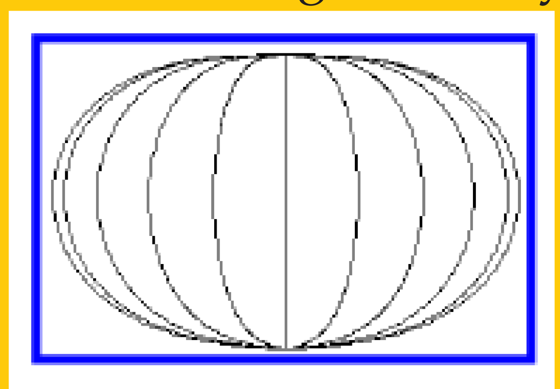
Surface mobility is one of the primary limiting factors in planetary exploration[1][4]. Recent advances in materials and instrumentation has renewed interests in using balloons to explore larger areas of the Martian surface. We propose an open architecture approach using solar-heated balloons. Using a weighted guide rope, the balloon system can autonomously select an operating altitude to find wind moving in a direction of interest, land for closer inspection of an area, and dispatch of small rovers to gather samples from a wide area, facilitating eventual Mars sample return to the Earth. This study presents modeling results of balloon dynamics on Mars.

Balloon & Atmosphere Model

We considered two balloon models: a zero-pressure balloon and a supper-pressure balloon. The balloon skin material is black PE and the gas is hydrogen.

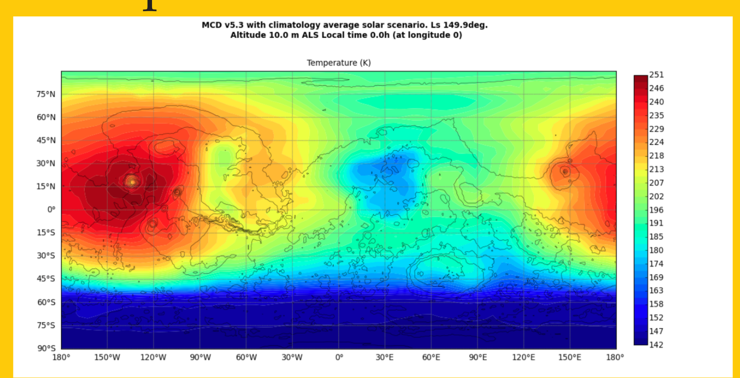


a) Zero-Pressure[2]



b) Super-Pressure[2]

The Mars atmosphere model is based on the time-dependent MCD database[3][6].



MCD contour for Mars atmosphere temperature distribution at 1000m height

Assumptions and Approximations

- Payload mass: 1kg-100kg.
- Balloon volume: $105m^3$-$10500m^3$. Balloon skin mass: 0.02246 $\frac{kg}{m^2}$.
- All thermal constants: based on that of the Black PE properties at 225K temperature.
- No clouds in the Martian sky

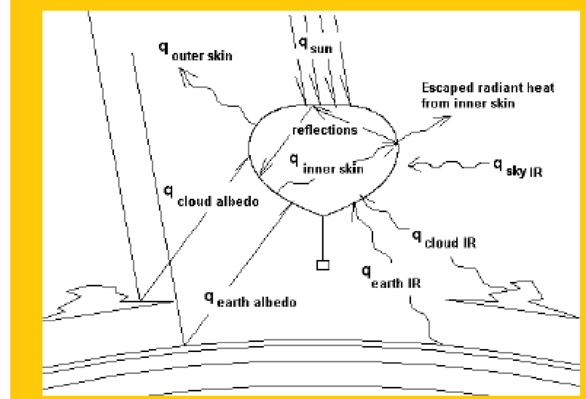
Equations and Coefficients

We use the time-dependant Newton equations to describe the trajectory of the Balloon.
In order to simulate the volume change of the balloon,

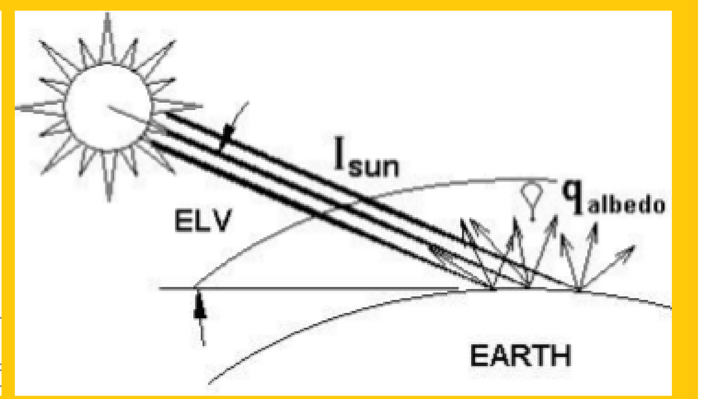
$$\frac{dT_{gas/film}}{dt} = C \cdot \frac{Q_{convection+radiation}}{c_f \cdot m_{gas/film}} \quad (1)$$

For the convection we consider the convection induced by both the internal gas flow and external gas flow[5] For the radiation, we consider 4 sources[2]:

1. Absorbed sunlight heat
2. Absorbed albedo
3. Absorbed planetary IR heat and IR from sky
4. IR heat from the interior/exterior of the skin

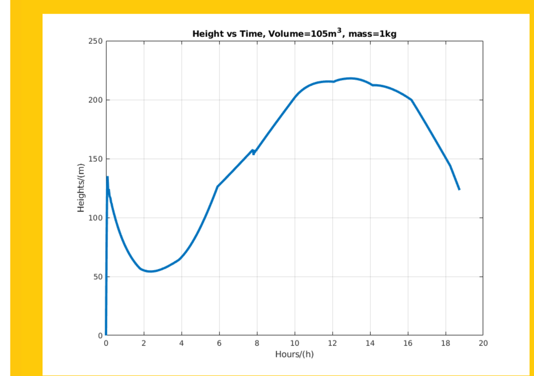


a) Heat sources[2]

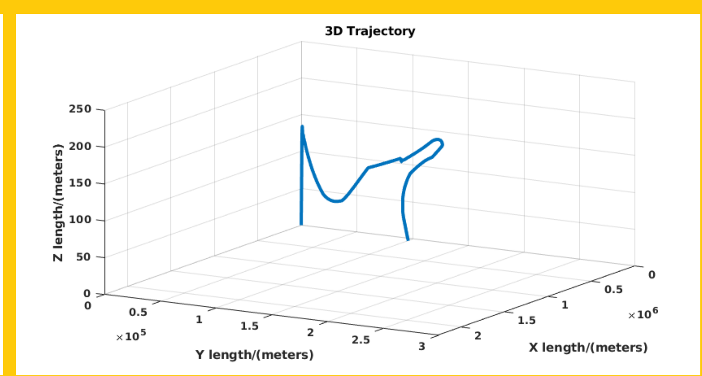


b) Albedo[2]

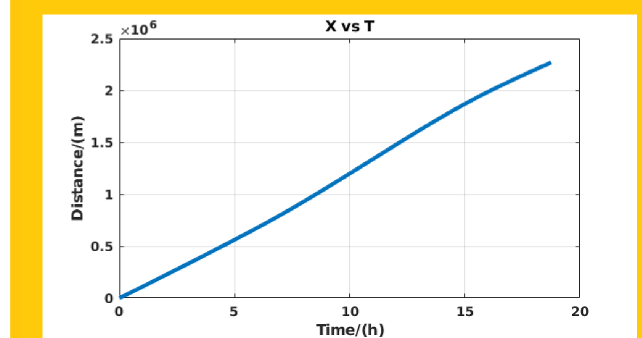
Typical Balloon Trajectory



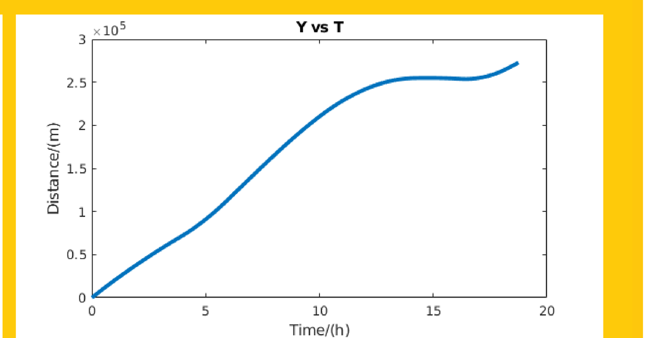
a) Z vs T



b) 3D Trajectory



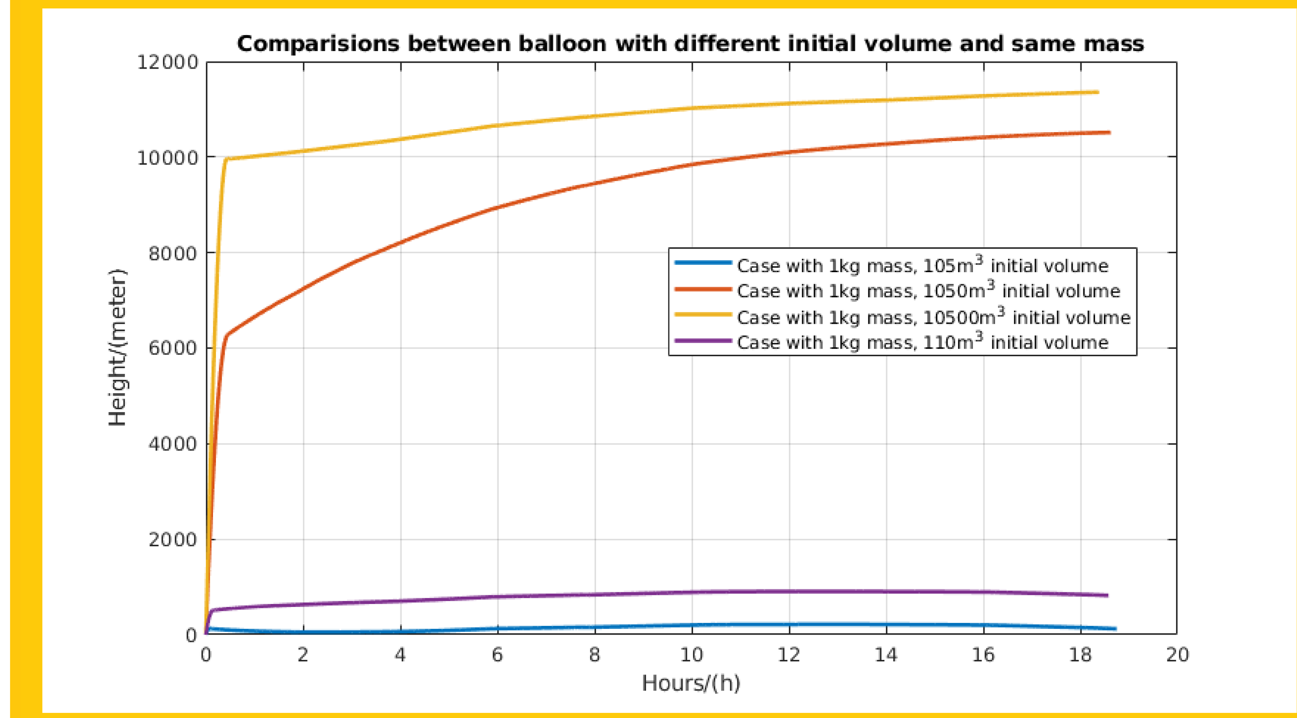
a) X vs T



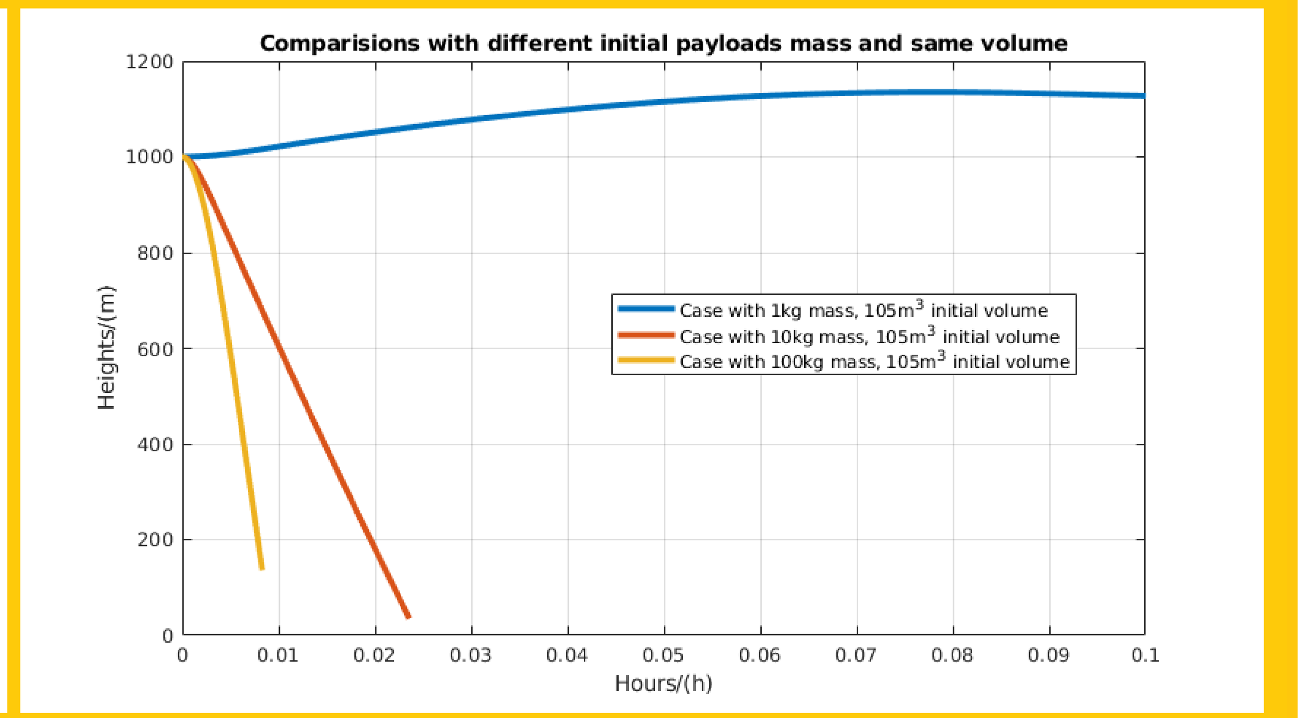
b) Y vs T

The above plots shows a typical balloon trajectory in 18 hours. This simulation considers a super-pressure balloon with a 1kg payload. The balloon system is designed to ascend during the day and descend during the night to survey the Martian surface.

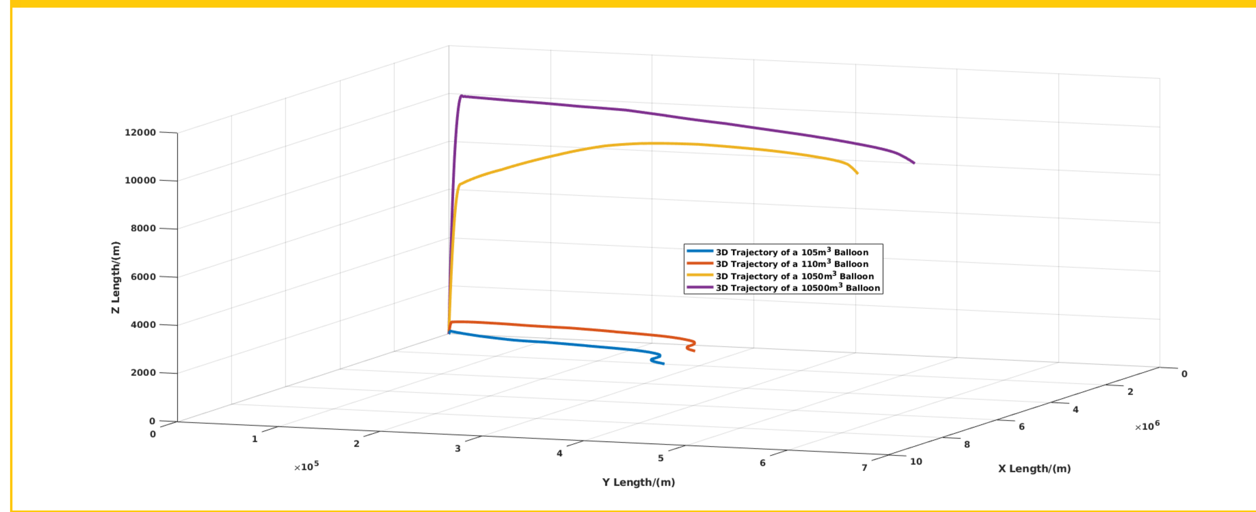
Effects of Balloon Volume and Payload Mass



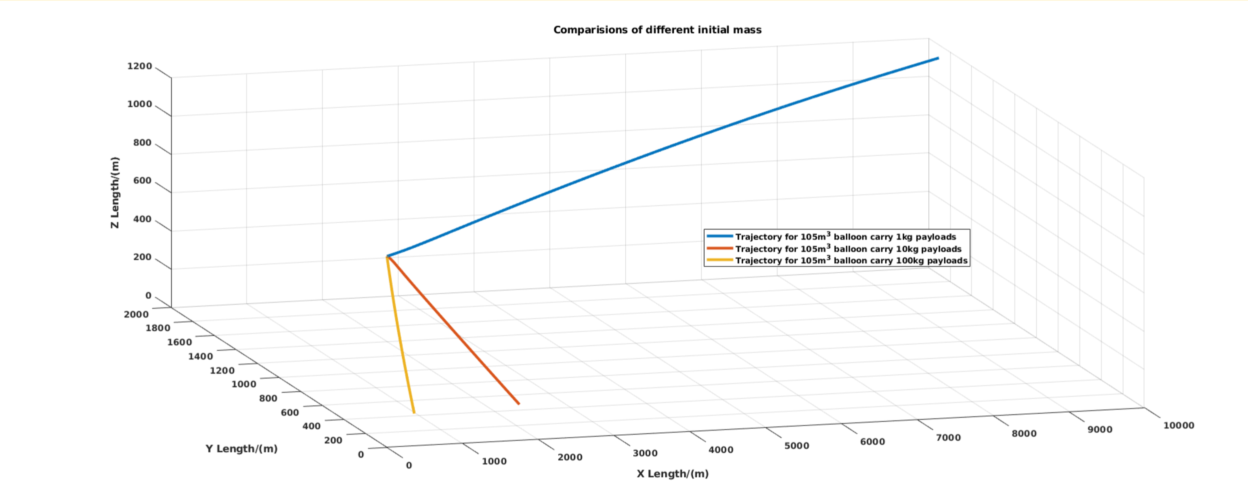
a) Balloons with different initial volume



b) $103m^3$ Balloons with different initial mass



a) Balloons' Trajectory with different initial volume



b) Balloons' Trajectory with different initial mass

The above plots compare the effects of the initial balloon volume and payload mass. The simulation results show that the balloon trajectory is greatly influenced by both the initial balloon volume and payload mass. Too big a balloon will cause the balloon to ascend too high and not descend during the night. Too heavy a payload will cause the balloon to descend too quickly to ground. Hence, the balloon volume and payload mass must be chosen carefully to achieve the cruising trajectory required for the survey mission.

Conclusions

1. A Martian surface survey mission is designed using a zero-pressure and a super-pressure balloon. The balloon ascends during the day and descends during the night.
2. The feasibility of the mission design is sensitively influenced by the balloon volume and payload mass.
3. A $105m^3$ super-pressure balloon with a 1kg payload is proposed as a baseline model for Martian surface survey mission design.

References

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