# BALLISTIC AEROCAPTURE AT VENUS – A CASE STUDY FOR AN ATMOSPHERIC SAMPLING PROBE

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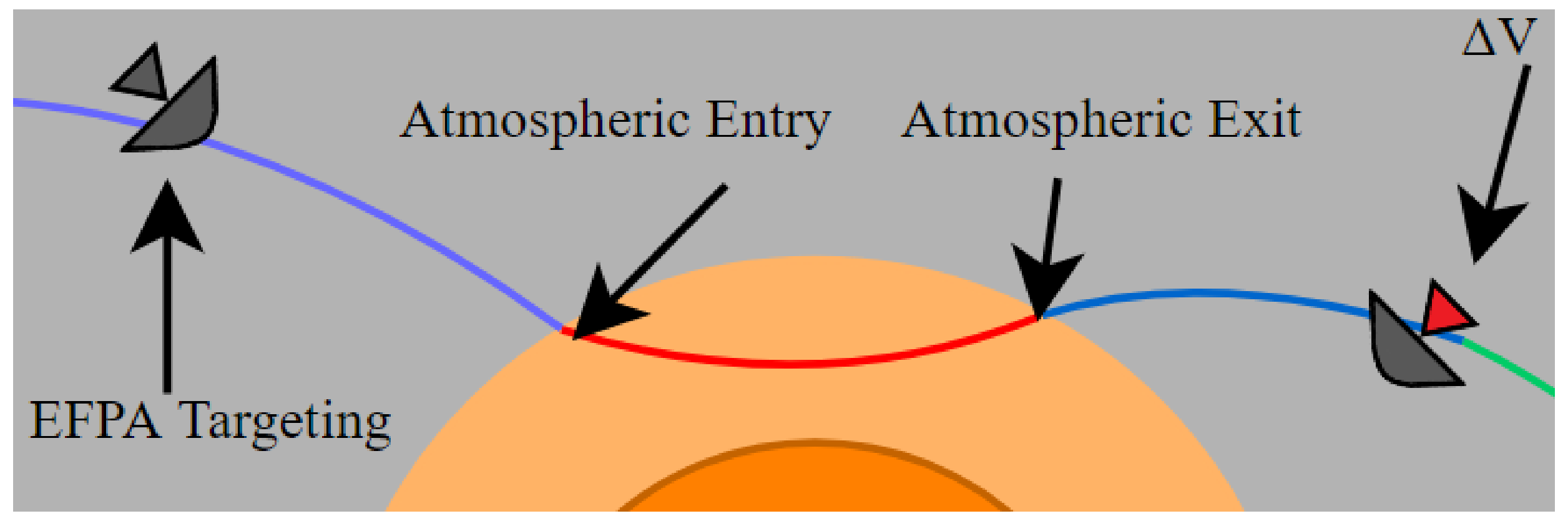
## Overview

Aerocapture is a promising orbit insertion maneuver and prior studies [1-2] have investigated the benefits for delivering a Venus orbiter with lift or drag modulation aerocapture. However, ballistic aerocapture (i.e., no trajectory control) can also be an option for a vehicle with a heatshield, such as a small atmospheric sampling probe (e.g., CUPID's Arrow [3]). Entry condition is the only control variable so it must be properly targeted to ensure 100% non-crash rate. This study uses Monte Carlo analysis to evaluate the feasibility and benefit of ballistic aerocapture.

## Concept of Operations

A ballistic aerocapture vehicle arrives at Venus and enters the atmosphere at a predetermined entry flight-path angle (EFPA). The vehicle flies through the atmosphere to exit and achieve some deceleration. After exiting the atmosphere, a propulsive ΔV is performed to get to the desired orbit (i.e., apoapsis radius). Another small ΔV at apoapsis will correct the periapsis radius.



## Simulation Parameters and Variations

| Parameter | Nominal Value | Variation | 3-σ |
|---|---|---|---|
| $V_\infty$ | 4 km/s | - | - |
| Entry Velocity | 10.9 km/s | Gaussian | 3% |
| Entry Altitude | 180 km | Gaussian | 1500 m |
| Ballistic Coefficient | 200 kg/m$^2$ | Gaussian | 15% |
| L/D | 0 | - | - |
| Nose Radius | 1 m | - | - |
| Density | VERA-model | See note 1 | |
| Target Orbit | 300 x 2,000 km altitude | - | - |

Note 1: [3σ varies linearly at surface from 0% of nominal to 60% at entry altitude.]

The varied parameters help determine the possible conditions that the probe may be subjected to during the maneuver from the simulation results.

## Methodology

### Initilize Parameters

Representative parameters were chosen to demonstrate ballistic aerocapture is possible with 100% capture rate.

### Identify Nominal Entry Condition

A bisection method was used to find the nominal EFPA for successful aerocapture using a target apoapsis radius (50,000 km).

### Determine Entry Condition for 100% Success

At nominal EFPA the capture rate was found to be below 100% with variations with Monte Carlo Analysis. An EFPA close to the nominal value was found to achieve 100% success.

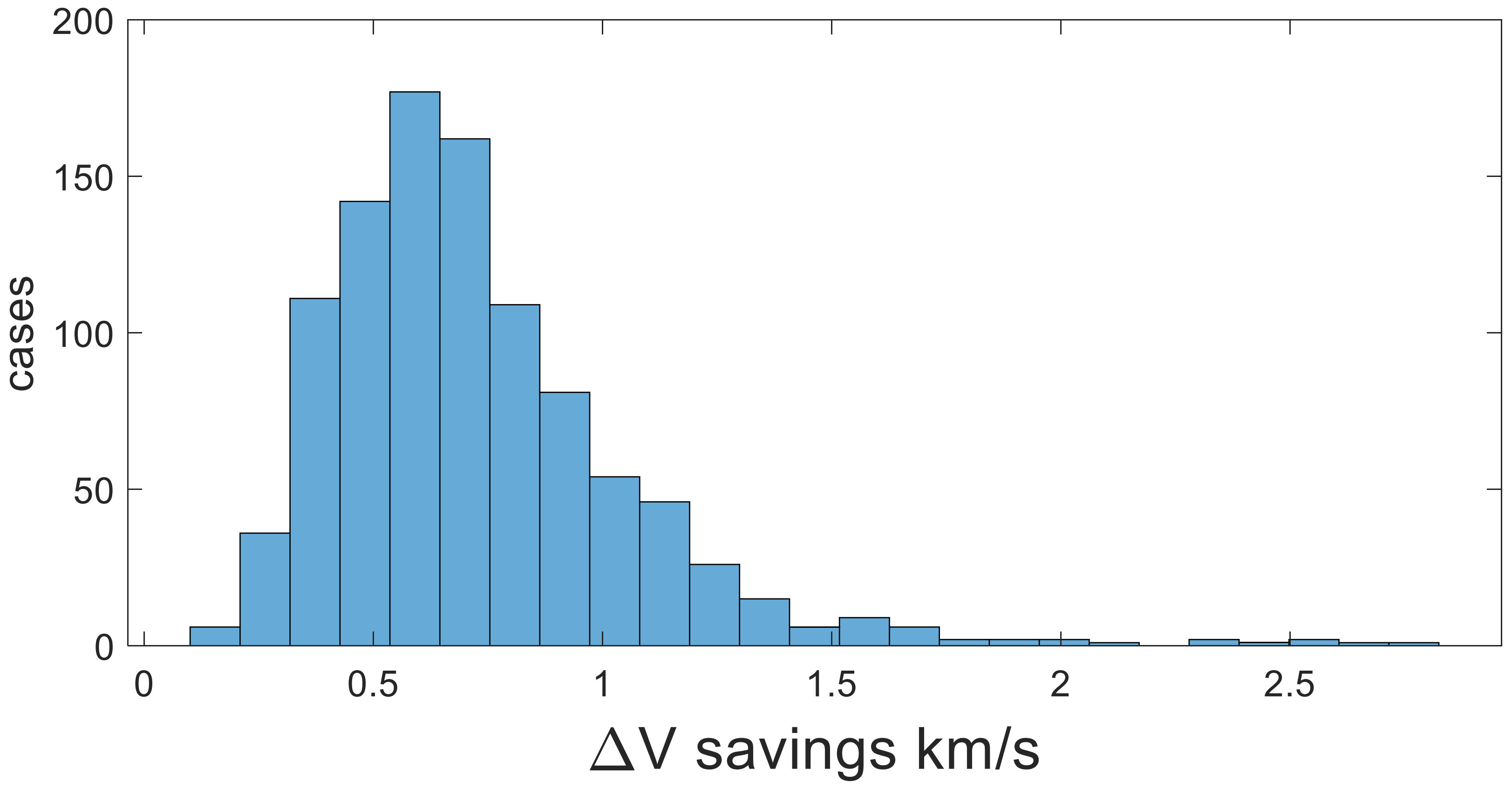
### Monte Carlo Analysis

The cases are simulated 1000 runs by varying the nominal parameters to determine the sensitivity of aerocapture.

### Performance Assessment

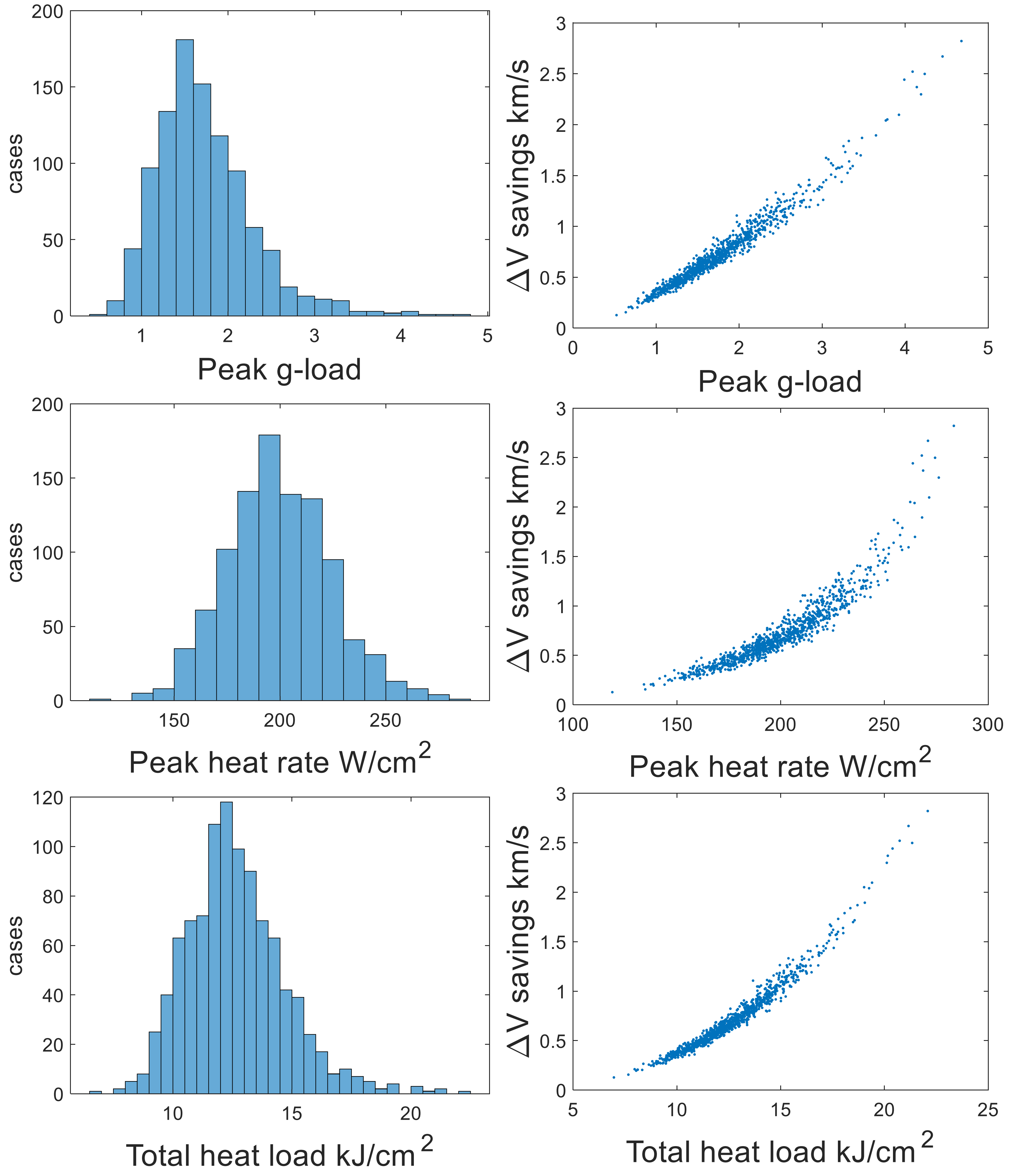
Post-aerocapture ΔV is minimized and compared with the fully propulsive case. Peak g-load, peak heat rate, and total heat load are also evaluated.

## ΔV Savings



| | | | |
|---|---|---|---|
| Minimum | 127 m/s | Mean | 724 m/s |
| Maximum | 2.8 km/s | σ | 334 m/s |

## Variation and Performance



The values seen in the plots for peak g-load, peak heat rate, and total heat load are the range of possible conditions the probe may encounter due to the variations in entry conditions, atmosphere, and vehicle properties.

## Conclusion

- Targeting a proper entry condition results in100% success rate
- The loads on the probe are within survivable limits.
- Moderate ΔV savings are observed.

## References

[1] Girija, A. P., et al. (2020) Journal of Spacecraft and Rockets, 57, 1. [2] Saikia, S. J., et al., (2017) OPAG Meeting. [3] Sotin, C. et al., (2018) *49th Lunar and Planetary Science* (LPI Contrib. No. 2083).