Extended Abstract

Titan Ballute Aerocapture using the Stochastic TitanGRAM Model

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Abstract:

Aerocapture using a towed, inflatable ballute system has been shown to provide significant performance advantages compared to traditional technologies, including lower heating rates and accommodation of larger navigational uncertainties. This paper extends previous results by designing a ballute aerocapture separation algorithm that can operate in a more realistic Titan atmospheric model based on TitanGRAM. This model incorporates both latitudinal variability as well as noisiness in the density profile.

Introduction:

Aerocapture can potentially significantly lower the propulsive delta-V costs for capturing a spacecraft into orbit about a destination body. Many studies have been made to investigate the feasibility of aerocapture using a variety of techniques, such as a ballistic unguided entry, or using some form of lift or

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drag modulation to help control the spacecraft's atmospheric trajectory to achieve a desired apoapsis altitude. Most of these techniques rely on high dynamic pressures to realize the necessary drag. As a consequence, the heating rates of these techniques are also quite large, forcing the spacecraft to carry massive heatshields to protect the spacecraft during the aerocapture drag pass.

If instead, the spacecraft had a large frontal projected area, then the same drag deceleration could be achieved by flying at a higher altitude, and thus at a lower dynamic pressure. One manner of achieving this is by deploying a ballute (a combination of a balloon and a parachute) that trails behind the spacecraft. Because of the low heating rates, the constraints on the spacecraft design are much reduced and a large heatshield is unnecessary.

The ballute aerocapture possibility offers another attractive advantage: Once the desired drag deceleration has occurred, the ballute can be released from the spacecraft (unlike the spacecraft with the massive heatshield). Since the large ballute is responsible for most of the incurred drag loss, releasing it provides the aerocapture system with a measure of control. The problem now becomes one of finding a robust control that relaxes the other requirements of the aerocapture drag pass, particularly the approach navigation delivery error and the knowledge of the atmospheric density.

Previous work on ballute aerocapture at Titan indicated one promising control law, which said to release the ballute when some specified condition a function of two observable parameters (in this case, integrated drag delta-V and maximum observed drag deceleration) was met. The control law obtained using this technique is dependent on the assumed atmospheric structure. This study uses a higher fidelity model, by incorporating both latitudinal (zonal) variations as well as random perturbations in the atmospheric density model.

Methodology and Results:

TitanGRAM uses the paramater "Fminmax" to describe the density profile over a given location on Titan. This parameter is set to a number between -1 and +1 – A -1 denotes the thinnest density profile expected to be seen, whereas a +1 denotes the thickest density profile expected. The previous research by Lyons and Johnson used a constant Fminmax for any given aerocapture drag pass. We now include the latitudinal variations in density by using the expression:

$$\text{Fminmax} = 0.46 \sin(\text{latitude}) + B$$

where B is some random bias, distributed between –0.54 and +0.54. This bias reflects both atmospheric perturbations as well as model uncertainties.

The nominal approach periapsis altitude is selected so that a 3-sigma high delivery error using the thinnest possible atmospheric profile (B = -0.54) will just barely capture into the desired 1700 km apoapsis orbit without releasing the ballute. Most cases will arrive with a lower periapsis altitude or a higher density, and thus see more integrated drag than that extreme case if the ballute were to remain attached for the entire drag pass. Our control selects to release the ballute when the integrated delta-V exceeds a polynomial function of the maximum observed drag deceleration.

$$\Delta V > f(x) \quad \text{release ballute}$$
$$\Delta V \leq f(x) \quad \text{do not yet release}$$

where

$$f(x) = -284.49x^5 + 4119.49x^4 - 24059x^3 + 70609x^2 - 103903x + 65974$$

This control law was numerically derived to yield a perfect ballute separation time for all possible atmospheric bias terms for the nominal entry state. Other cases could either release the ballute too late, or too early, causing the achieved apoapsis to be too low, or too high. The resulting orbit can be reshaped into the proper 1700 km circular orbit by 2 impulsive maneuvers.

Figure 1 illustrates the resulting apoapsis immediately after the aerocapture drag pass, as a function of the atmospheric bias and arrival osculating periapsis. A green color means the spacecraft successfully achieved a 1700 km apoapsis, yellow and red indicate the spacecraft achieved a lower periapsis (i.e., the ballute was released too late), and blue means the spacecraft's apoapsis is too high (ballute was released too early).

Figure 2 illustrates the required delta-V to circularize the resulting orbit. A blue color indicates little delta-V is required, whereas red indicates a large delta-V is required.

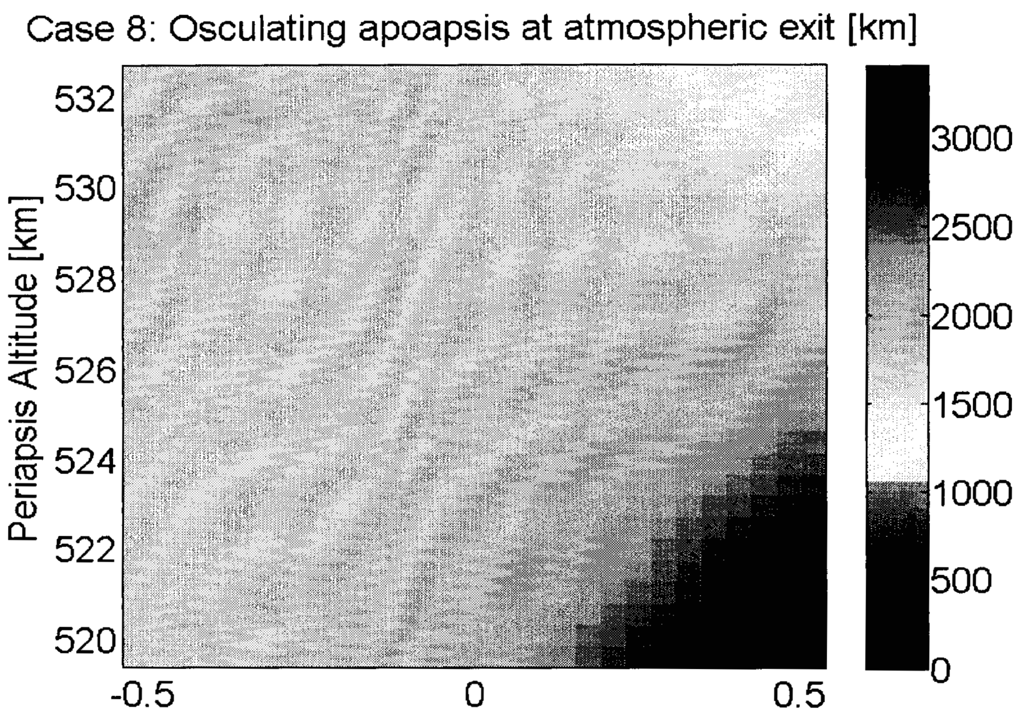

Figure 1: Apoapsis altitude resulting from aerocapture drag pass.

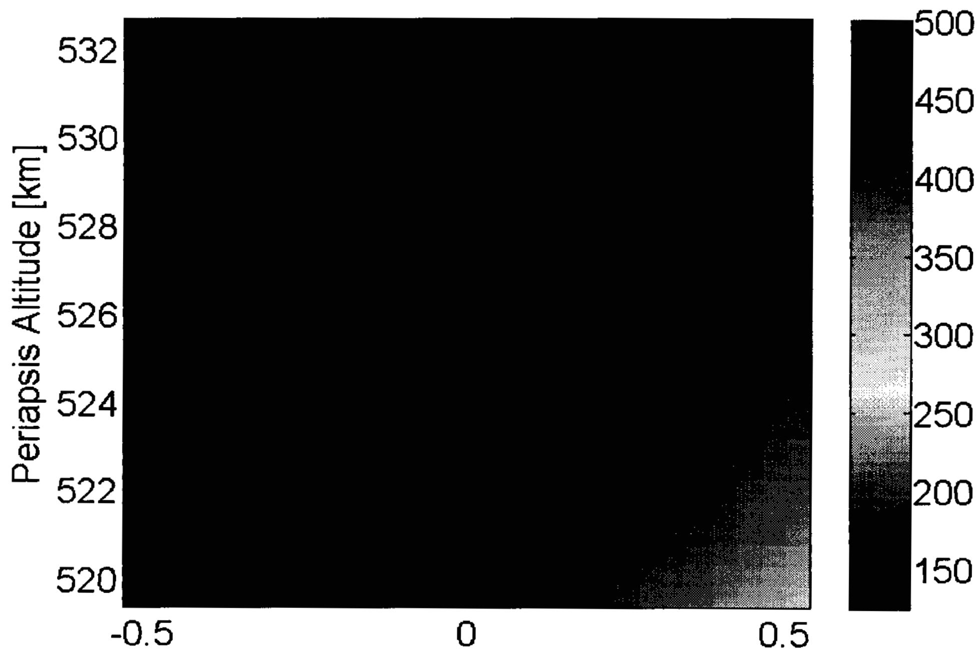

Figure 2: Propulsive delta-V required to circularize orbit.