A Preliminary Investigation of Aerogravity Assist at Triton for Capture into Orbit About Neptune

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Abstract

Previous work by our group has shown that an aerogravity assist maneuver at the moon Triton might be used to capture a spacecraft into a closed orbit about Neptune if a nominal atmospheric density profile at Triton is assumed. The present study extends that work and examines the impact of atmospheric dispersions, especially important in light of the very low density and large degree of uncertainty of Triton's atmosphere. Additional variables that are analyzed in the current study include ballute size and cut time and variations in the final target orbit. Results indicate that while blunt-body, rigid aeroshells penetrate too closely to the surface to be practical, ballutes of modest size show promise for this maneuver. Future studies will examine the application of inflatable aeroshells and rigid aeroshells with higher lift-to-drag ratios such as biconics and lifting bodies.

Introduction

Aerocapture has been studied for numerous missions, primarily focusing on Titan, Mars and Neptune. At the giant planets, these maneuvers inherently involve very high atmospheric entry speeds, severe aerothermal heating rates, and large ablative heat shields. Recent studies indicate that a direct aerocapture at Neptune will typically require aeroshell mass fractions in excess of fifty percent (ref. 1), resulting in a relatively small usable payload. Our group has previously shown that an aerogravity assist maneuver (AGA) using Titan is promising as a means of capturing a spacecraft into a closed orbit about Saturn (ref. 2,3) This method permits much lower atmospheric entry speeds and will likely produce considerably lower aerothermal heating rates than a direct aerocapture at one of the giant planets. The present study considers the use of a similar maneuver at Triton to capture a spacecraft into orbit about Neptune.

Methodology

Atmospheric entry trajectories were calculated using the three degree of freedom version of the Program to Optimize Simulated Trajectories (POST, ref. 4). The atmosphere models used (Fig. 1) were derived from a stellar occultation studies (ref. 5) and have an entry interface at 95 km altitude. While the degree of potential variability in Triton's atmospheric density is not well known, there is evidence that temporal changes in the sub-solar latitude result in greater or lesser amounts of the atmosphere being condensed onto the surface in a frost-like state. The last two decades have seen a general global warming at Triton and a concomitant increase in the atmospheric density (ref. 6,7) This led to our choice of density dispersions which are somewhat greater than are typically used for preliminary aerocapture studies (200% and 50% of the nominal value).

For this investigation, all trajectories were simulated using due east, equatorial entries. A probe mass of 600 kg was used, with the

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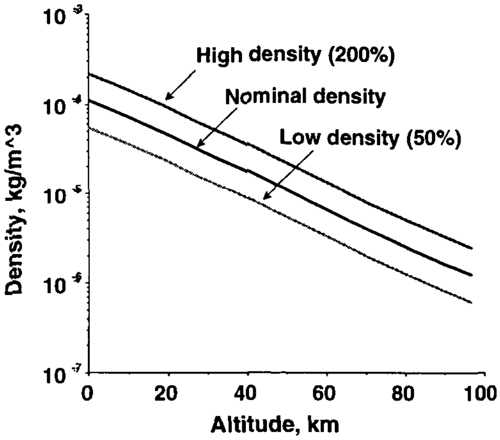

Figure 1 Triton Atmospheric Model

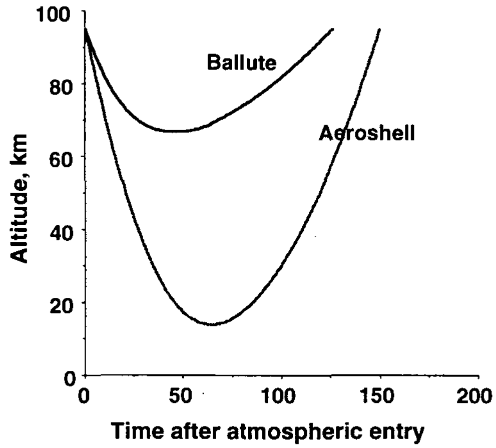

Figure 2. Overshoot trajectory altitude histories for a ballute and a rigid aeroshell entering at 8 km/s

overall mass varying slightly according to ballute size. A toroidal ballute was assumed, using a coefficient of drag (C_D) of 1.25; the ballute reference area was varied from 100 m^2 to 1500m^2. The attached, non-lifting probe had a reference area of 12.56 m^2 and a C_D of 1.25. As a means of comparison, some trajectories were calculated using a blunt body with a lift-to-drag ratio (L/D) of 0.25, a mass of 600 kg and a reference area 12.56 m^2.

For the nominal case, the vehicle is targeted to an exit velocity of 3.0 km/s. If this velocity is directed opposite to Triton's orbital velocity vector, it will result in a spacecraft orbit about Neptune with an periapse radius of 29000 km and an apoapse at Triton's orbital distance (355,000 km). This design is consistent with previously established mission profiles and reflects current science objectives (ref. 1). Triton entry speeds from 4.7 km/s to 22 km/s were examined in this paper, corresponding to the hyperbolic excess speeds required for Neptune entries over the previously established range of 24 to 34 km/s (ref. 1).

Our initial approach was to determine if the proper amount of energy could be dissipated by a given vehicle during an atmospheric pass. For a rigid, lifting aeroshell, the maximum energy loss for a given entry state will be achieved by flying the vehicle on a full lift down trajectory. The entry angle which achieves the target exit energy for such a full lift down pass is known as the overshoot boundary. This is the shallowest angle at which the vehicle can enter and execute a successful maneuver. For a ballute (which has no lift), the shallowest entry will be achieved when the ballute is held throughout the atmospheric pass, rather than being released at some intermediate time. Steeper entries will require the ballute to be released earlier, and the steepest allowable angle is set either by heating constraints on the probe or (more probably) on the ballute material or possibly by minimum altitude constraints on the probe after the ballute releases.

Results

Rigid Aeroshell

Trajectory simulations reveal that the rigid aeroshell penetrates quite low in the atmosphere, even for the overshoot trajectory entering the nominal atmosphere at 8 km/s (Fig. 2). For the low-density atmosphere, steeper entries would be required, and these would result in closer approaches to the ground, leaving an inadequate margin for error. At entry speeds of 10 km/s or more, capture to the target orbit was impossible since steeper flight path angles were required and these lead to vehicle crashes. These results indicate that blunt body, rigid aeroshells are not suited for this application.

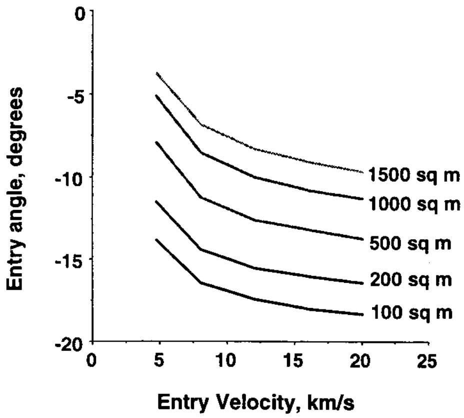

Figure 3 The required atmospheric entry angle as a function of atmospheric entry speed for a range of ballute sizes. The ballute is not released during the atmospheric passage. A nominal density profile is assumed

Ballutes

Figure 3 illustrates that throughout the range of potential entry speeds, the correct amount of energy can be dissipated by a wide range of non-releasing ballutes. Figure 3 also shows the sensitivity of the entry angle with respect to the ballute size. Figure 4 shows the relationship of atmospheric exit velocity to the entry angle for a non-releasing, 500 m^2 ballute at several specific entry speeds. While it is clear that the exit velocity becomes increasingly sensitive to entry angle as entry speed goes up, it must be noted that these sensitivities will be significantly reduced by allowing for a releasing ballute.

Another major concern in performing such a maneuver is whether or not trajectories can be achieved while allowing for potential atmospheric dispersions. Figure 5 shows the variation in the required entry angle for a non-releasing, 500m^2 ballute in all three atmospheric density profiles. The extreme density atmospheres do cause some appreciable differences in the required atmospheric entry angles for a non-releasing ballute, but again, this impact will be minimized by allowing for an early ballute release. This approach is illustrated in Fig. 6 where it is clear that a wide range of entry angles can be accommodated using a single ballute simply by varying the release time.

Conclusions

Aerogravity assist at the Triton-Neptune system is probably not feasible using blunt body, rigid

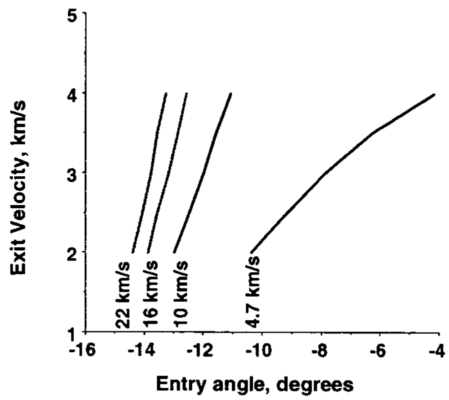

Figure 4 Exit velocity vs entry angle for a non-releasing 500 m^2 ballute entering at various speeds

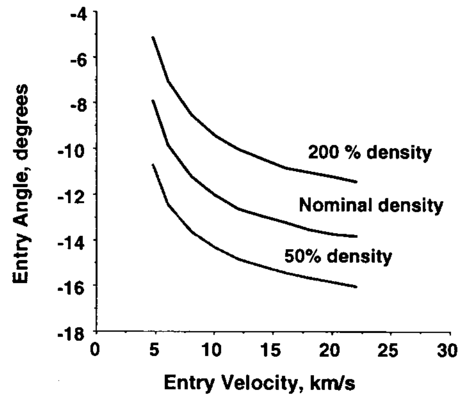

Figure 5. Impact of atmospheric dispersions on required entry angle for a 500 m^2 non-releasing ballute

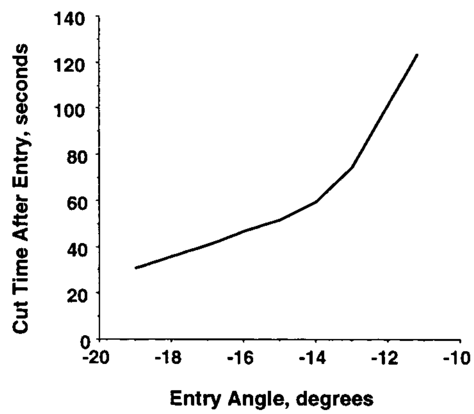

Figure 6. Cut time for a 500 m^2 ballute entering the nominal atmosphere at 8 km/s

aeroshells with low lift-to-drag ratios. The significant potential variability in the atmospheric density coupled with the low altitudes reached during the aeroshell trajectories are likely to result in a catastrophic failure. However, it appears that modest sized ballutes stay high enough in the atmosphere and offer adequate corridor widths to warrant further study.

Future Work

More work must be done to more clearly determine the appropriate degree of atmospheric variability for dispersion studies. Once this is accomplished, it will be necessary to examine the aeroheating environment and design trajectories for both nominal and off nominal atmospheric conditions that meet the constraints of inflatable materials.

Another interesting area to examine will be the use of high L/D, rigid aeroshells (biconics or lifting bodies) and low ballistic coefficient aeroshells, such as those with inflatable skirts to perform the maneuver.

The approach and departure geometry with respect to both Triton and Neptune must be more fully evaluated to determine desirable encounter turn angles.

Acknowledgements

The work described in this paper was funded in whole or in part by the In-Space Propulsion Technology Program, which is managed by the NASA Science Mission Directorate in Washington, D.C., and implemented by the In-Space Propulsion Technology Projects Office at Marshall Space Flight Center in Huntsville, Ala. The program objective is to develop in-space propulsion technologies that can enable or benefit near and mid-term NASA space science missions by significantly reducing cost, mass or travel times.

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3rd International Planetary Probe Workshop
Anavyssos, Greece
June 27- July 1, 2005

Motivation

Atmospheric entry speeds at Neptune are inherently very high (typically 28-30 km/s)

As a result, recent studies have shown that direct aerocapture at Neptune will require aeroshell mass fractions in excess of 50%

Previous work by our group has shown that an aerogravity assist (AGA) at *Titan* has promise as a means of capturing a vehicle into orbit about *Saturn*

Such a maneuver would entail much lower entry speeds than a direct aerocapture and would result in a less severe aerothermal environment

Objectives

Present study seeks to determine if an aerogravity assist at Triton is feasible as a means of capture into orbit about Neptune

Evaluate entry corridors as a function of atmospheric entry speed

Determine the characteristics of a vehicle necessary to accomplish the proposed maneuver

Determine the impact of off-nominal atmospheric conditions on vehicle design and maneuver feasibility

Triton - Basics

A diameter of 2700 km - by far the largest of Neptune's moons

Near-circular, retrograde orbit at 355,000 km radius with a 157 degree inclination

Orbital speed about Neptune of 4.4 km/s

Extremely tenuous atmosphere, primarily nitrogen with a small percent methane

Surface pressure of approximately 0.016 *millibar* with a large temporal variation

Mission Assumptions

Triton entry speeds from 4.7 to 22 km/s (corresponding to Neptune entry speeds of 24 to 34 km/s)

Target orbit about Neptune 355,000 km apoapse and 29,000 km periapse (based on previous Neptune aerocapture studies by Lockwood et al)

A nominal target for the Triton atmospheric exit velocity of 3.0 km/s (if the outbound trajectory is opposite to Triton's orbital velocity, this gives a periapse at the specified 29000 km radius)

Methodology

Trajectory simulations carried out with 3D POST

Due east, equatorial entries

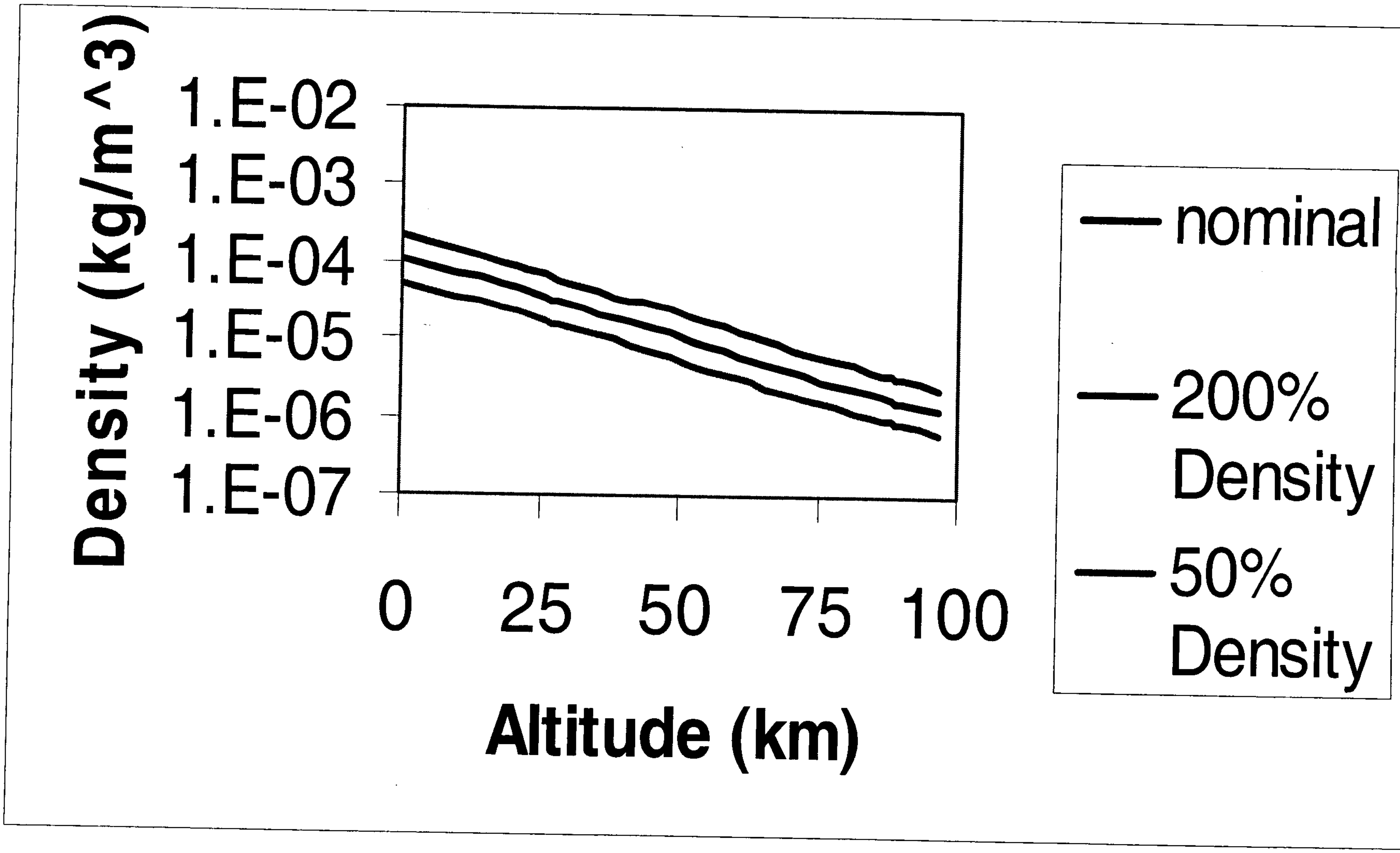
No winds or horizontal density dispersions were considered

Entry interface at 95 km altitude

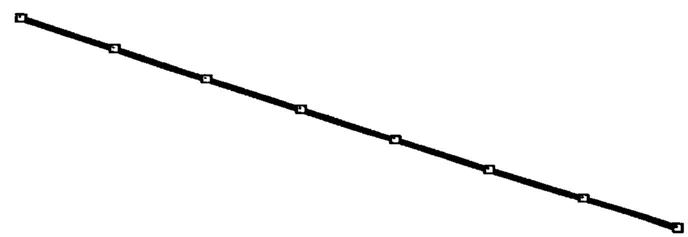
Assumed probe mass is 600 kg

Toroidal ballute used with $C_D = 1.46$ and area ranging from 100 to 1500 m^2

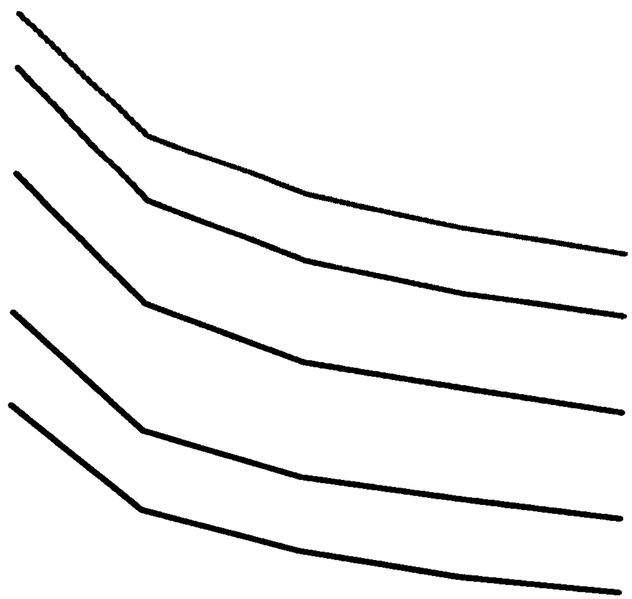
Triton Atmospheric Model Based on Stellar Occultation Studies



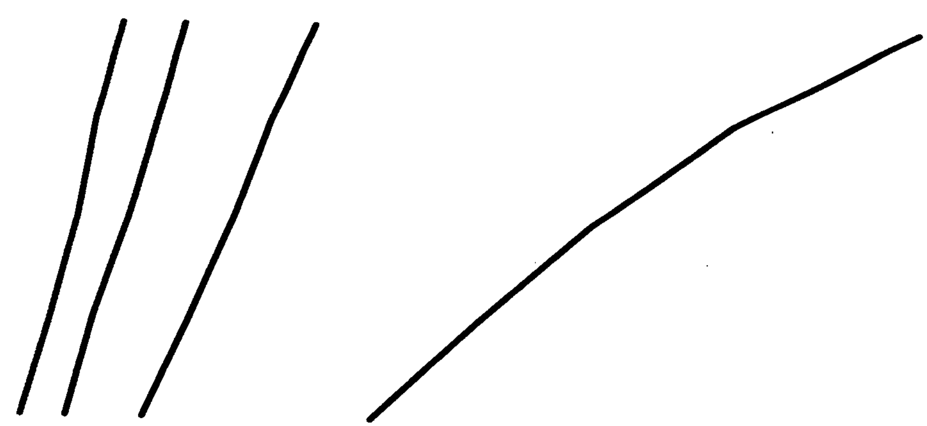
Minimum Altitude of Rigid Aeroshell and Ballute During Overshoot Trajectory



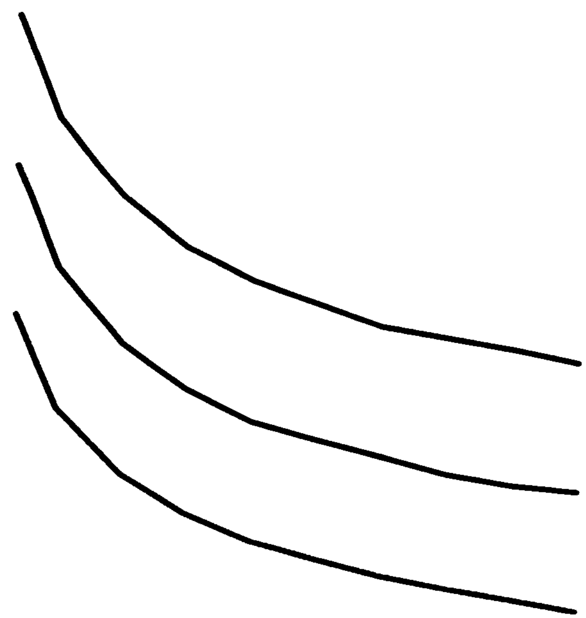
Influence of Ballute Size on the Required Entry Angle for a Non-Releasing Trajectory



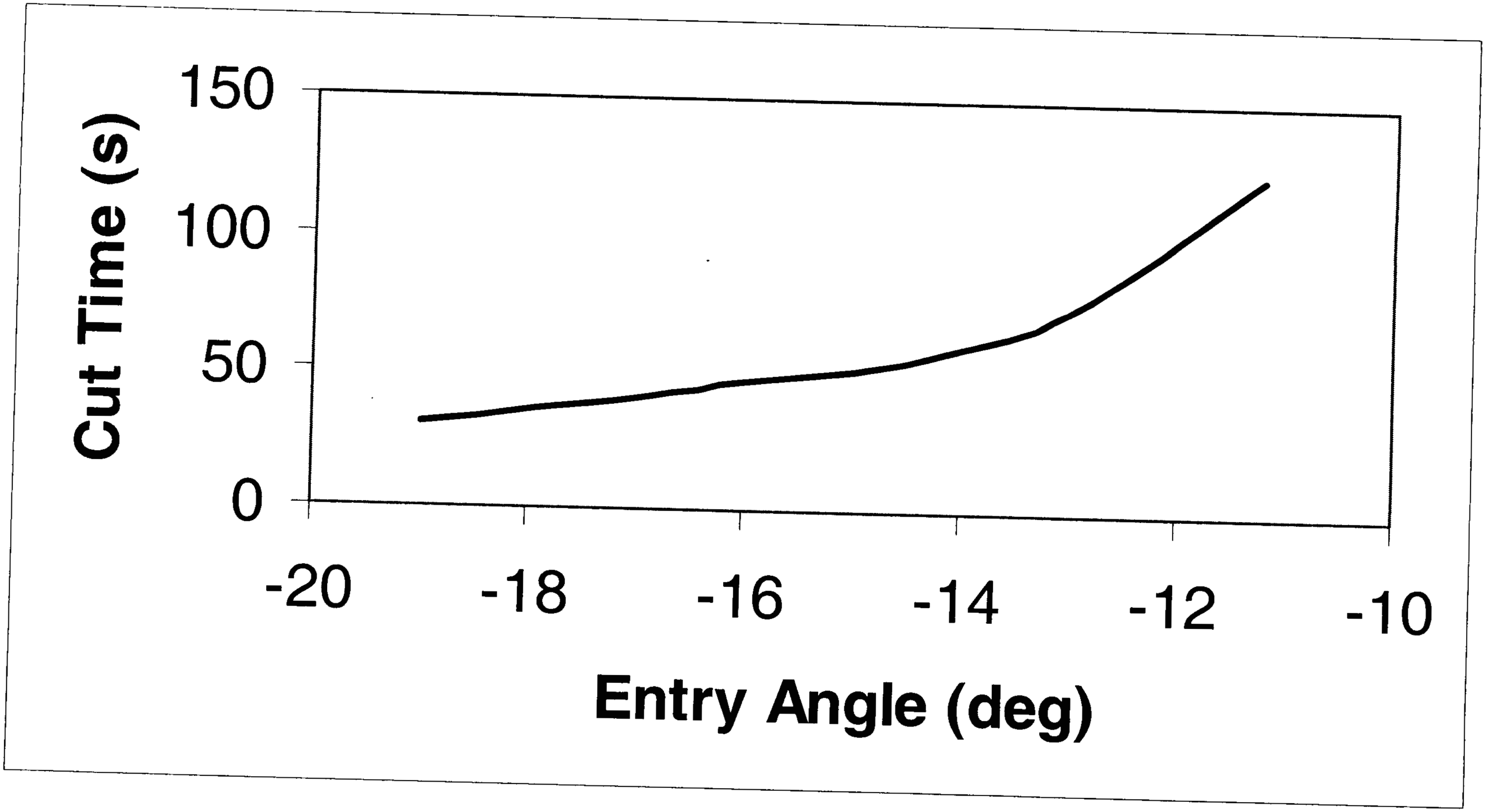
Exit Velocity Vs Entry Angle for a Non-Releasing 500 m^2 Ballute Entering at Various Speeds



Impact of Atmospheric Dispersions on the Required Entry Angle for a Non-Releasing 500 m^2 Ballute



Cut Time for 500 m^2 Ballute
Entering at 8 km/s



Cut Time for 500 m^2 Ballute Entering at 12 km/s

Conclusions

Aerogravity assist at Triton/Neptune is probably not feasible using a rigid aeroshell because of the significant potential variability in the atmospheric density, coupled with the low trajectories expected under nominal conditions *(i.e. crash probable)*

Ballutes offer substantial corridor width and high enough trajectories to merit further study

Future Work

An evaluation of aerodynamic heating and the design of nominal and off-nominal trajectories which meet the constraints of inflatable structures

Aeroshells with very low ballistic coefficients (such as designs using inflatable skirts) for Triton/Neptune AGA

More work is required in collaboration with atmospheric scientists to determine the probable range of variability in Triton's atmospheric structure

Acknowledgements

We would like to thank Bonnie James and the In-Space Propulsion Program at NASA Marshall Space Flight Center for supporting this work under NASA Research Grant NNM05AA17G