BALLISTIC AEROCAPTURE AT VENUS – A CASE STUDY FOR AN ATMOSPHERIC SAMPLING PROBE. Oswaldo Santana[1] and Ye Lu[2], [1]osantana@kent.edu, [2]ylu16@kent.edu, College of Aeronautics and Engineering, Kent State University, Kent, OH, 44240.

Introduction: Aerocapture has been studied to be feasible for getting a probe to a capture orbit while allowing for significant mass savings [1]. Special consideration must be taken to ensure that given the mission requirement, there is enough margin for uncertainties and errors for a successful aerocapture [2]. A ballistic aerocapture can only vary the entry flight path angle as a means of trajectory control and no guidance or control will be available during the maneuver. It is therefore important to select the entry parameters that can ensure that the probe will not crash or burn in the atmosphere.

An important requirement for ballistic aerocapture is that the probe has a heatshield. An example Venus atmospheric sampler probe is used in the study to determine the benefit and feasibility of ballistic aerocapture. Generally, ballistic aerocapture can be incorporated to help increase mass margins in smaller probes which tend to be more mass constrained. The effectiveness and reliability of using aerocapture is dependent on each mission requirement, but it is a beneficial option that is available for applicable cases.

Results and Analysis*:* In order to investigate the possibility of using ballistic aerocapture, selected cases were studied using various entry velocities, vehicle ballistic coefficients, and different target orbits. It was first determined if it was possible to use aerocapture with only entry flight path angle as a control. An entry flight path angle for all cases studied was found that allowed for orbit capture of the probe. Limiting cases for ballistic aerocapture were identified from the initial analysis of finding entry flight path angles.

In some cases, we observed that aerocapture is not possible due mainly to the excessive high heat rates which are consistent with previous studies [2]. A high limiting survivable heat rate would have the probe experiencing heat rates of a few 100 W/cm^2 for ballistic coefficients of the same magnitude. Heat rates increase with increasing ballistic coefficients and entry velocity. Heat rate limitations provide a high limiting entry velocity of around 12 km/s. Probes with a higher entry velocity were seen to experience heat rates of a few kW/cm^2. In the ballistic coefficient range of interest heat rates allow for ballistic aerocapture below the high limiting entry velocity. Adding thermal protection systems to protect against the extremely high heat rates at higher than 12 km/s entry velocity would diminish from the benefit of using ballistic aerocapture for reducing mass.

The sensitivity of successfully executing ballistic aerocapture to each of the variables is also investigated in the study [3]. Small deviations from entry velocity and ballistic coefficient were used to determine the proper entry flight path angles for a target capture success rate (99% is used, as shown in Figure 1). It is important to note that 100% may also be achieved. Using the nominal entry flight path angles found for each case, an overall capture rate when targeting a low apoapsis radius was near 60% and near 90% for apoapsis radii that are tens of thousands of kilometers in altitude. The results show that a 99% capture rate is possible for all cases by having the probe enter at a shallow angle that may result in an escape orbit. The change in entry flight path angle increases post-capture ΔV needed to enter the target orbit, but it is significantly reduced compared to a fully propulsive capture.

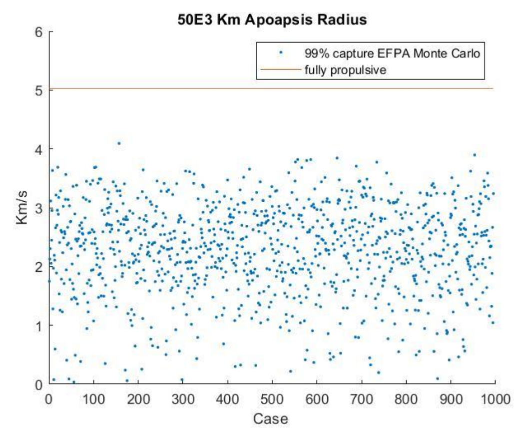

Figure 1. ΔV *needed post Aerocapture*

Figure 1 shows the result for a case studied with ballistic coefficient of 200 kg/m^2, entry velocity of 12 km/s (i.e., equivalent V_∞ of 7.5 km/s), target orbital period of 8.3 h, and a target apoapsis of 50,000 km. Using a Monte-Carlo analysis by varying ballistic coefficient and entry velocity, we observe a maximum value of near 4 km/s for the required ΔV post-aerocapture. In a fully propulsive maneuver, 5 km/s of ΔV is needed to reach the target orbit. Figure 1 shows the distribution of ΔV post aerocapture of the analysis. The difference in ΔV between ballistic aerocapture and fully propulsive option shows that there is a possible significant reduction in ΔV, leading to mass savings.

References: [1] Saikia, S. J., et al., (2017) OPAG Meeting. [2] Girija, A. P., et al. (2020) *Journal of*

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