



SmallSat Venus Aerocapture Demonstrator

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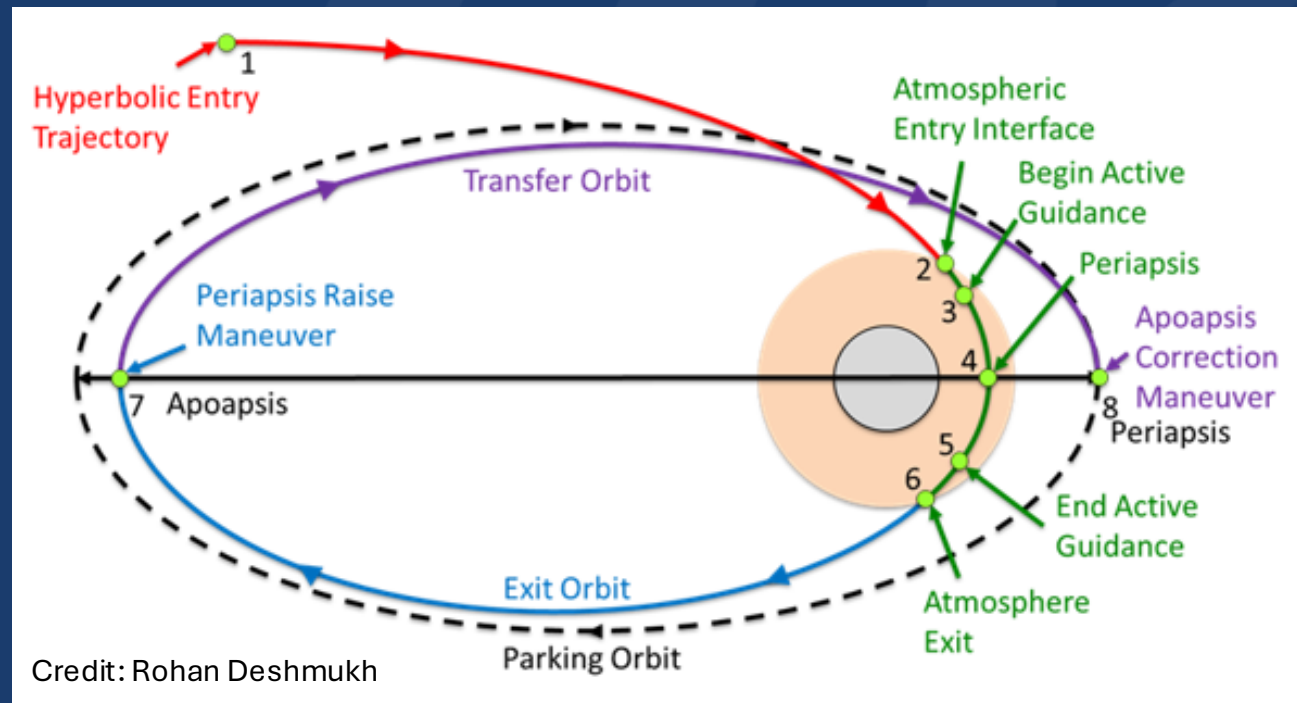
Introduction

Background

Aerocapture Background

Aerocapture is the process of utilizing a target planet's atmosphere to decelerate into a closed orbit within a single pass. After atmospheric exit, the spacecraft performs a periapsis raise and an apoapsis correction. Aerocapture is highly dependent on the following:

- Arrival Velocity
- Ballistic Coefficient
- LD Ratio



Motivations

Benefits and Advantages

Compared to similar maneuvers, such as aerobraking, aerocapture can increase deliverable payload mass and shorten arrival time. These benefits are greatly enhanced for the outer planets, such as Uranus.

Aerocapture has not been flight tested despite sufficient TRL for guidance, TPS, and spacecraft. Prior to implementation on a flagship-class mission, a flight demonstration is necessary.

Flight Demonstration

A SmallSat rideshare mission can significantly reduce the cost of a flight demonstration. Venus is chosen for the following:

- High heating and control challenges
- 3 upcoming NASA and ESA missions
- Scientific gain

Modeling and Simulation

Vehicle and Mission Design

Vehicle Configuration

- Similar mission setup as JPL MarCO probes
- Approximately 12U size, flying SAGEIV instrument
- Two science orbits, 463km circular and a 100,000km x 1,000km elliptical
- Two sphere-cones: 60-deg and 70-deg

Table 4: Theoretical Corridor Width for Mission Design

Parameter	Genesis (60-degree aeroshell)	MSL (70-degree aeroshell)
Velocity	11 km/s	11 km/s
LD	0.11	0.11
Ballistic Coefficient	132 kg/m ²	117 kg/m ²
Lifting-Up Crash Boundary	-5.992°	-5.971°
Lifting-Up Escape Boundary	-5.358°	-5.333°
Lifting-Down Crash Boundary	-5.417°	-5.391°
Lifting-Down Escape Boundary	-5.261°	-5.237°

Guidance and Steering Algorithms

Fully Numerical Predictor Aerocapture Guidance (FNPAG)

FNPAG is implemented for guided aerocapture, which utilizes bang-bang control. In phase 1, the vehicle commands lifting-up and calculates a switching time to switch to lifting-down in phase 2. The version of FNPAG used also has a phase 3 which stops calculating switching times to help the guidance converge on a solution.

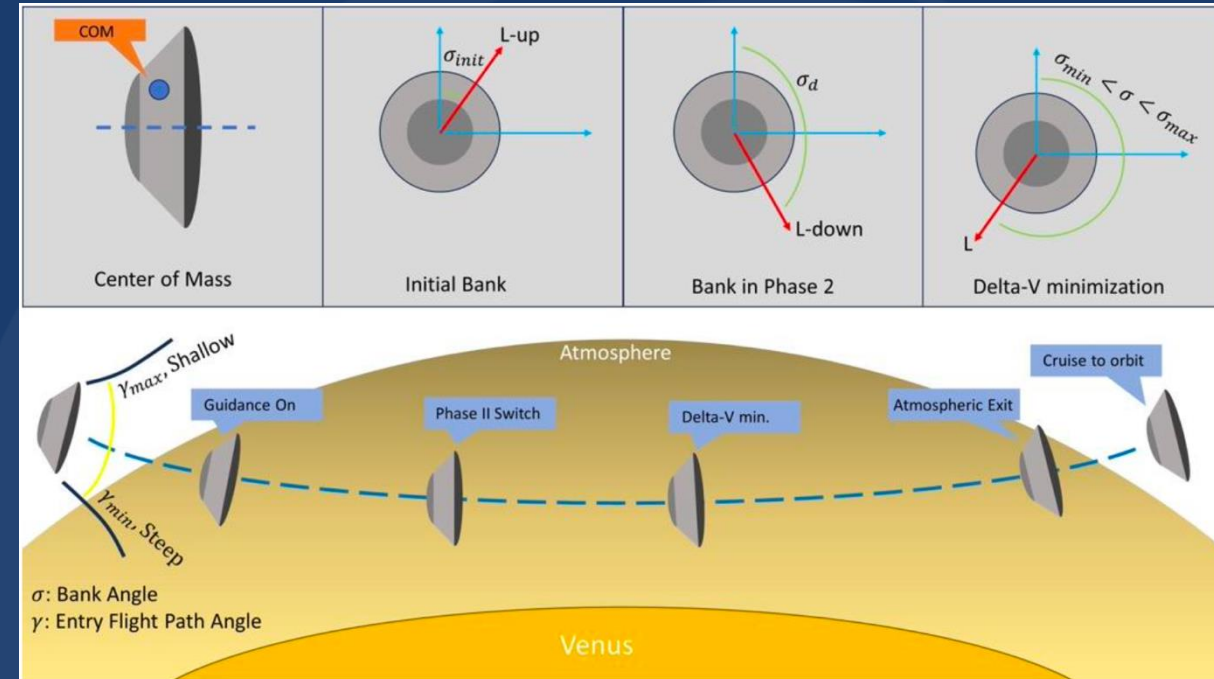
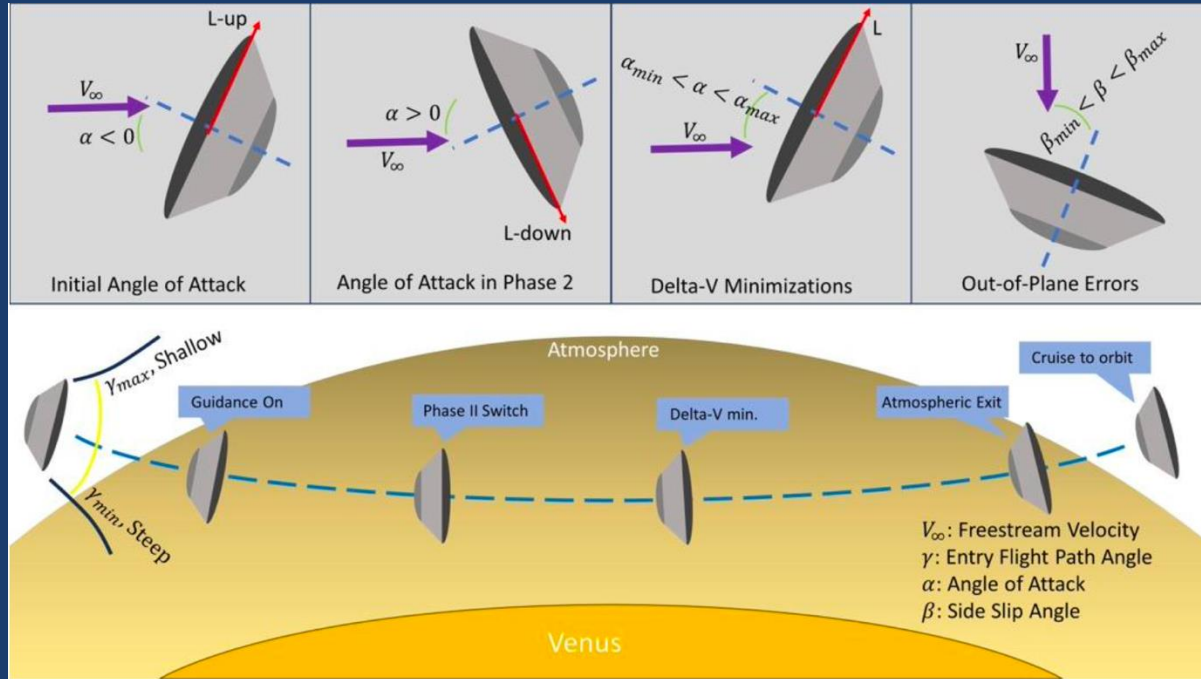
Steering Algorithms

- Bank Angle Modulation (BAM)
- Direct Force Control (DFC)

Simulation Environment

- NASA's Program to Optimize Simulated Trajectories II (POST2)
- VenusGRAM2005

Guidance and Steering Algorithms



Results

Verification

Replication of Existing Results

To ensure guidance was converging properly, simulations were replicated and compared to previous studies.

- Results for BAM and DFC were completed
- Small differences, likely due to no lateral logic used in this study
- Results were close enough to conclude that guidance was working

Baseline Results

Simulation Workflow

Nominal simulations are first tuned for single case. Then, an 8000 run Monte Carlo analysis is performed to determine performance under uncertainty. Results are then post-processed in MATLAB to generate statistical figures of merit.

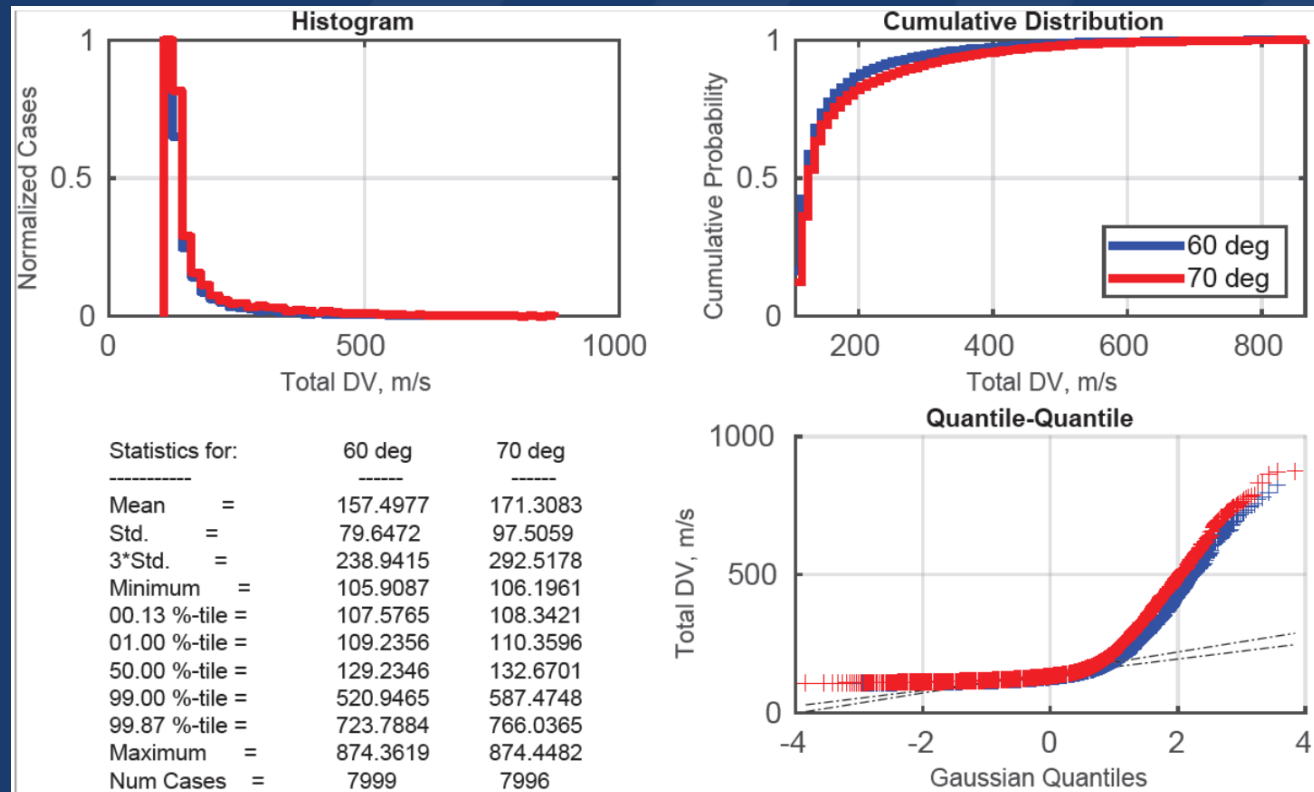
Parameter	Units	Dispersion	Distribution
Mass	Kg	0.5	3 σ Normal
Atmosphere	-	VenusGRAM 2005 [16]	GRAM Dispersion
Velocity	Km/s	0.05045	3 σ Normal
Flight Path Angle	Deg	0.117877	3 σ Normal
Latitude	Deg	0.223376	3 σ Normal
Longitude	Deg	0.038872	3 σ Normal
Simulation Runs	-	8000	3 σ Normal

463km Science Orbit

Bank Angle Modulation Results

Results showed few crash (“lander”) cases are incurred due to the low target orbit; however, these represent <1% of the dataset. The 60-degree sphere-cone required a slightly steeper EFPA than the 70-degree.

- Comparable performance
- 60-deg having a lower cleanup cost
- 60-deg also has fewer crashes



463km Science Orbit

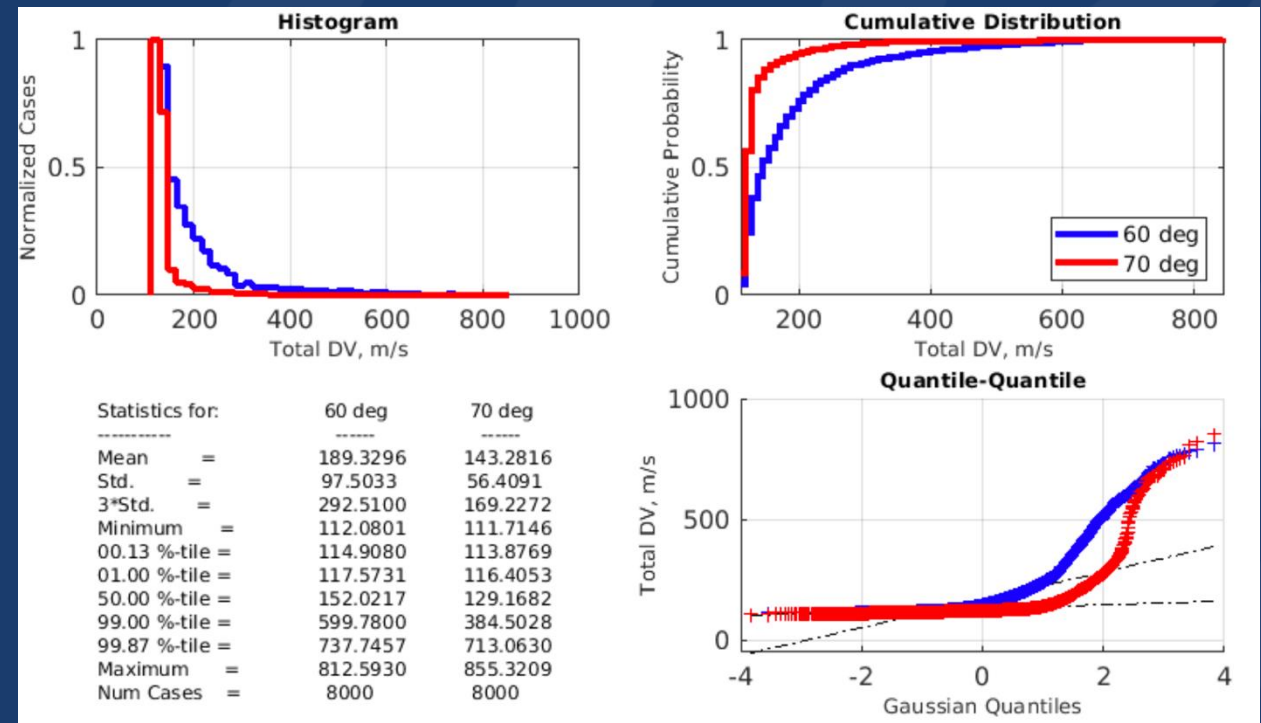
Direct Force Control Results

Guidance parameters and EFPA was slightly tuned but were on the scale of <0.001 degrees. Unlike BAM, no crash cases occurred, which can be attributed to increased control authority.

- Larger difference in performance
- Distributions are dissimilar
- 70-deg having a lower cleanup cost

Conclusion

- 70-deg DFC had lowest overall cleanup cost

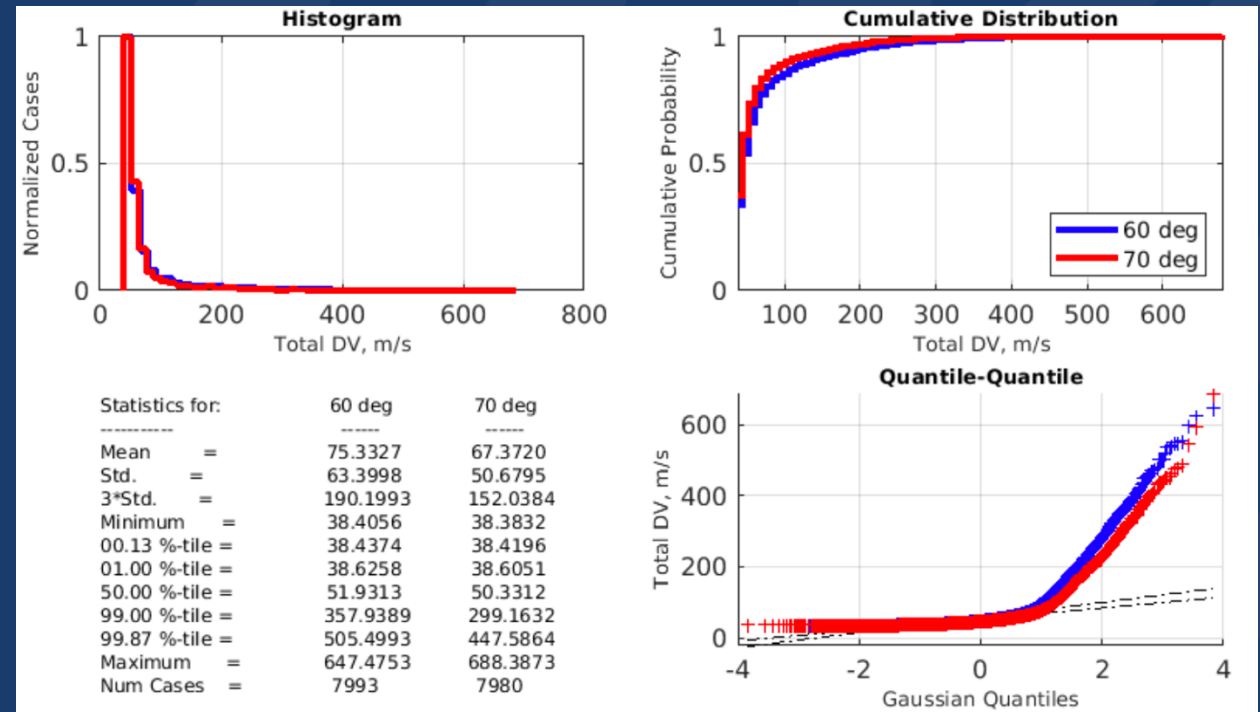


100,000km x 1,000km Science Orbit

Bank Angle Modulation Results

The 1,000km periapsis was selected as it reduced circularization costs and still met science requirements. FNPAG struggled to converge on a switching time as the EFPAs were so close to the escape boundary. To fix this, FNPAG is forced to only fly in phase2 (lifting-down) which decreased correction costs.

- A few cases fail to capture
- Distributions are similar, as with 463km
- 70-deg having a lower cleanup cost



100,000km x 1,000km Science Orbit

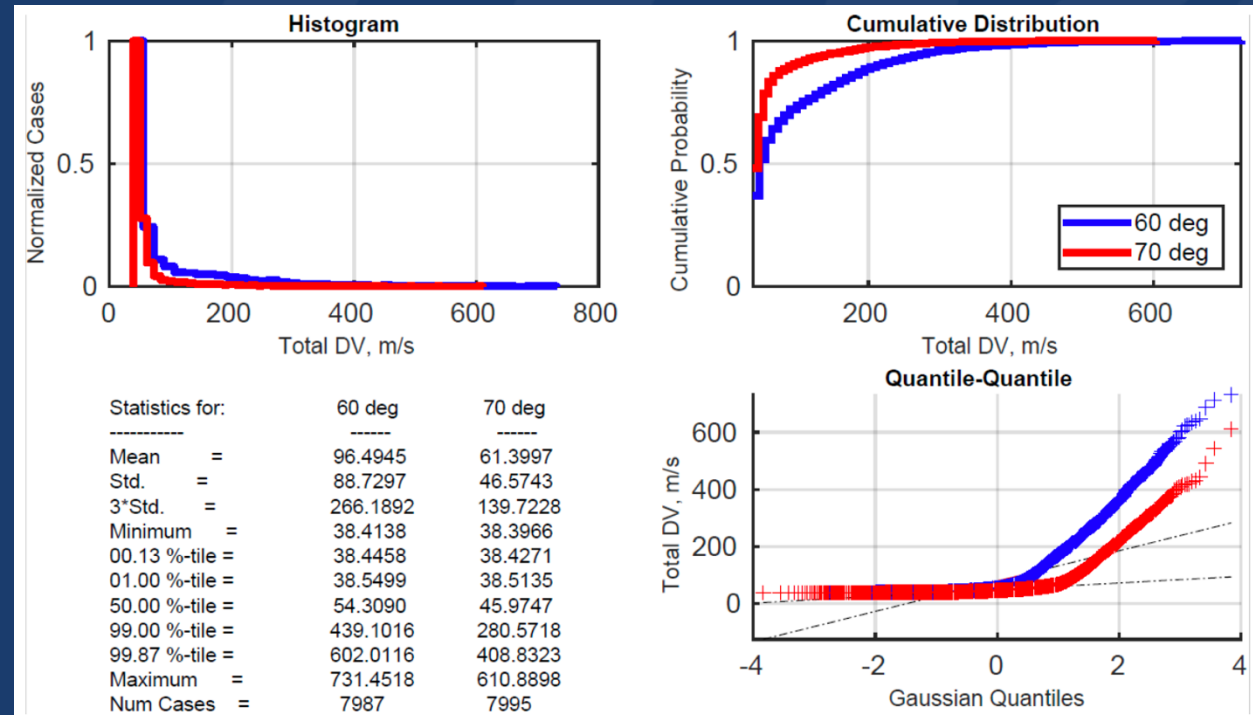
Direct Force Control Results

Again, a few flyby cases do occur due to the closeness to the flyby EFPA. The difference in distribution can further indicate increased aeroshell sensitivity in DFC.

- Larger differences between the sphere-cones
- Distributions are much different
- 70-deg having a lower cleanup cost

Conclusion

- 70-deg had the lowest overall cleanup
- 70-deg had best performance using BAM
- Results are still preliminary



Feasibility and Recommendations

Vehicle Considerations

A key recommendation with the analysis performed is to utilize DFC with a 60-deg aeroshell for lower orbits and 70-deg BAM for higher orbits. The dry mass fraction of the vehicles are calculated assuming a similar Isp from the MarCO probes.

- 60-deg DFC had best performance for 463km orbit, but 70-deg DFC also performs similarly
- 70-deg DFC had the best performance amongst all other configurations for the elliptical orbit

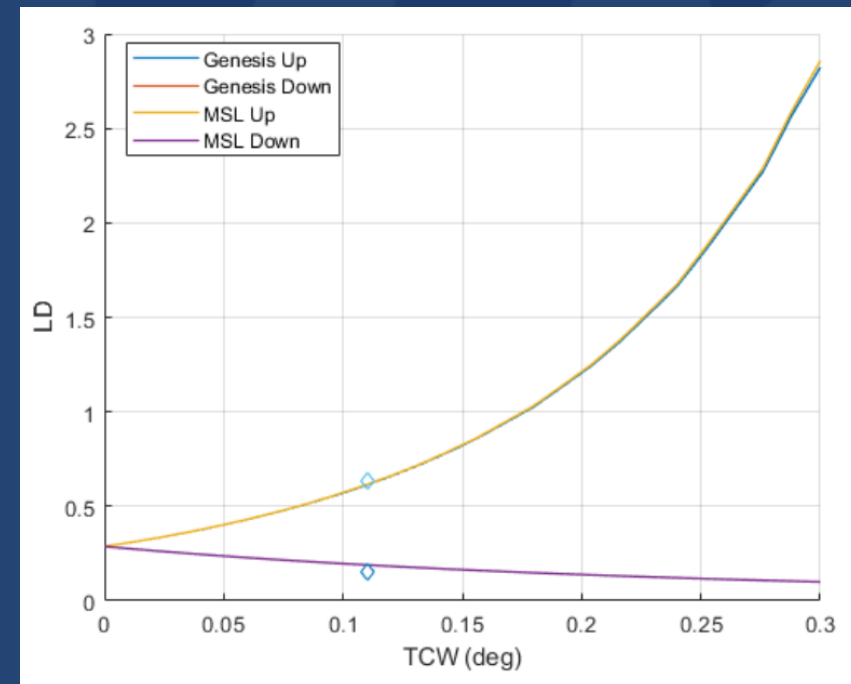
Orbit and Configuration	60-degree (delta-V, dry/wet mass %)	70-degree (delta-V, dry/wet mass %)
Circular 463km, BAM	129.23 m/s, 71.9%	132.67 m/s, 71.3%
Circular 463km, DFC	152.02 m/s, 67.9%	129.17 m/s, 71.9%
Elliptical 100,000km, BAM	51.93 m/s, 87.6%	50.33 m/s, 88.0%
Elliptical 100,000km, DFC	54.31 m/s, 87.1%	45.97 m/s, 89.0%

Feasibility and Recommendations

Theoretical Corridor Width

The vehicle analyzed was flown at an LD of 0.11, which largely dominates the TCW. Future analysis should determine the possibility of flying at a higher LD to increase capture rates and robustness.

- Higher angles of attack could cause instability or plasma on backshell
- Could be “better” LD for each aeroshell



Conclusion

Summary

The goal of this study was to determine the feasibility of a SmallSat aerocapture rideshare mission to Venus.

- Little difference between sphere-cones using BAM than DFC
- Crash and flyby cases incurred could be mitigated with better guidance, yet don't represent the majority of cases
- BAM had lower accuracy for higher orbits compared to DFC
- Recommending 60-deg BAM at 463km and 70-deg DFC at 100,000km
- Future work should determine if there is a better LD to increase TCW



Thank You