

Shape Approximation in Camera Fields of View for Parachute Visibility Applications

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The ability to simulate camera line of sight and field of view is a powerful capability for flight mechanics simulations. This paper improves upon an existing camera visibility implementation that leverages geometry to estimate parachute visibility from a singular point by introducing a shape discretization method. The new method approximates a shape as a set of analytical points relative to a target marker within any number of camera fields of view. The method is developed in such a way to be generalized to a myriad of spacecraft applications. This effort focuses on an implementation to simulate parachute canopy visibility within the combined field of view of three cameras but additional applications are discussed. Monte Carlo analysis is used to assess the parachute canopy visibility example and demonstrate its improved performance over the previous method.

I. Introduction

OPTICAL cameras often play a critical role in spacecraft operations, supporting tasks such as navigation, performing scientific measurements, documenting crucial events, and more. As such, the ability to simulate visibility criteria during a trajectory is a useful aid when it comes to mission analysis and requirements verification. A primary consideration for camera pointing analysis in the past decade has revolved around parachute inflation. The Low Density Supersonic Decelerator (LDSD) program in particular invested in documenting and recording the inflation sequence to better understand the modeling and testing processes needed for parachute qualification [1, 2]. LDSD included two supersonic parachute tests in 2015 and 2016 [3, 4], both of which resulted in canopy failures. An example is shown in Figure 1, which depicts a frame capture from the camera installed on the first Supersonic Flight Dynamics Test (SFDT-1). A component of the SFDT program included camera pointing and sun exposure analysis to maximize parachute visibility during parachute deployment events in addition to mitigating the potential for sunlight to disrupt the camera's video feed [5]. In this analysis, the line of sight from each camera to the parachute apex was tracked, and an effective field of view estimate was developed using the parachute half angle to assess the full visibility of a parachute canopy.

A similar visibility analysis setup was employed for the Advanced Supersonic Parachute Inflation Research Experiment (ASPIRE) campaign, which involved a series of sounding rocket tests to qualify the Mars 2020 supersonic parachute for flight [6]. The desire to continue tracking parachute visibility has naturally extended to this campaign's successor, ASPIRE2, which was originally planned to launch out of Wallops Flight Facility (WFF) in 2026 prior to the NASA-led Mars Sample Return (MSR) campaign re-architecture studies. The ASPIRE2 campaign is seeking to qualify the supersonic parachute for the Sample Retrieval Lander (SRL) under the MSR program, which will be the largest supersonic parachute ever to be flown at Mars to date. The ASPIRE program qualified a 21.5 m diameter disk-gap band (DBG) parachute deployed at Mach 1.7, while, as of mid-2024, ASPIRE2 planned to qualify a 24 m diameter DBG parachute deployed at Mach 2.1. While the parachute visibility approximation developed by Ref [5] was sufficient for previous missions, the cameras on the ASPIRE2 test section were upgraded to higher resolution

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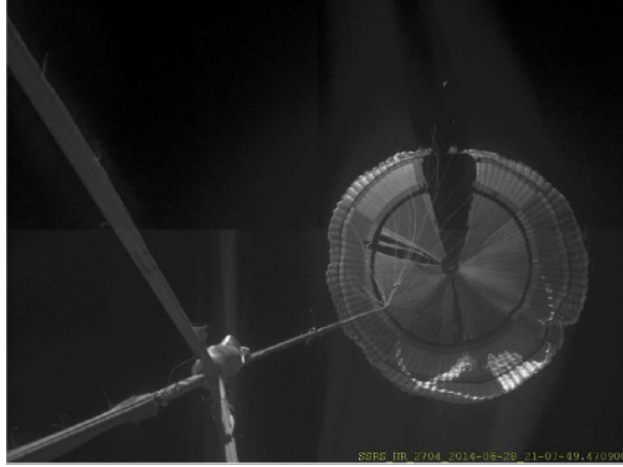


Fig. 1 GoPro screen captures during the LDSF SFD T flight test inflation event [5]

cameras with smaller fields of view. The combination of camera field of view (FOV) reduction and increased parachute canopy size corresponds to a much smaller area in which the parachute canopy could be captured. This paper introduces an improved methodology over that developed for the SFD T-1 camera pointing analysis in order to simulate a full parachute canopy within a combination of camera FOVs to assess the visibility of the entire parachute. The goal of this investigation is to develop a methodology that can approximate analytical shapes within the field of view of one or multiple cameras to support FOV analysis for various applications. One such example involves tracking the visibility of a descent vehicle landing ellipse, such as for the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) mission at Venus. This paper will focus on the application of a parachute canopy for the ASPIRE2 project, but additional applications will be discussed in further detail in later sections.

II. Methodology

This section will outline the methodology used to perform camera visibility analysis and the sub-systems that support it. The flight mechanics simulation tool used in this analysis is the Program to Optimize Simulated Trajectories II (POST2) [7]. POST2 is a C-based flight mechanics simulation tool with both three degree-of-freedom (DOF) and 6-DOF multi-body capabilities. It has been validated with numerous flights and contains many modules and sub-systems to support mission design and performance analysis.

While the methodologies outlined in this paper are developed in such a way to be generalizable, the focus of the paper will be on simulating parachute visibility using the ASPIRE2 concept of operations and mission requirements as a baseline for analysis with discussion on further applications outlined in Section IV.

A. POST2 Antenna Module

The POST2 antenna subsystem enables the tracking of secondary vehicles or targets and is depicted in Figure 2 [5]. The tracking occurs in an antenna-fixed frame such that the tracking is relative to the defined orientation of the antenna in terms of boresight and clock direction. The antenna origin and target are defined from user-defined markers that can be placed at any position relative to the vehicle body coordinate system.

Tracking the target position, XC , relative to the antenna's fixed coordinate system enables the relative position to be parametrized into a vertical angle, ν and horizontal angle, η defined as:

$$\eta = \tan^{-1} \left(\frac{xc}{zc} \right) \quad (1a)$$

$$\nu = \tan^{-1} \left(\frac{yc}{zc} \right) \quad (1b)$$

where xc , yc , and zc are the components of the vector from the camera origin to the target in the antenna-fixed frame.

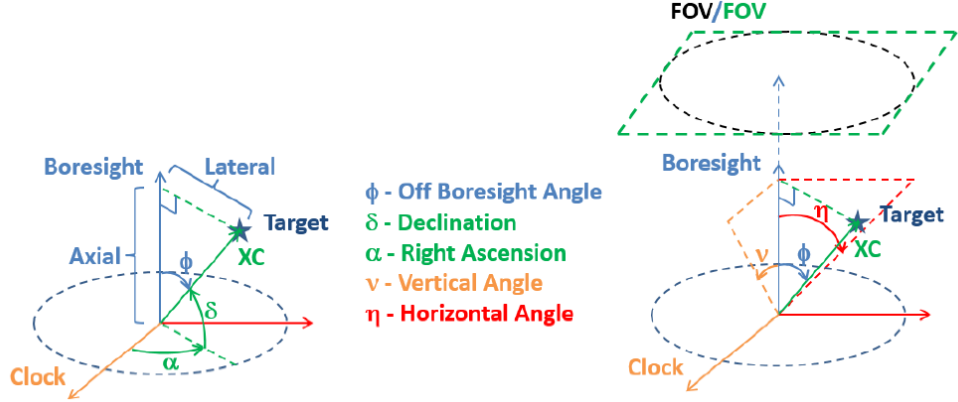


Fig. 2 Graphical depiction of the POST2 antenna module system [5]

This capability allows simulating a camera's ability to track individual targets (both user-defined markers and SPICE objects) and evaluate their position within the camera's field of view (FOV) size assuming the boresight vector is defined along the camera's line of sight, as shown in the image on the right of Figure 2. While this capability enables tracking targets within individual camera FOVs, it only considers the visibility of individual marker locations as opposed to entire shapes. This paper outlines a new approach to approximating entire shapes, discretized as individual points, within a camera field of view to enable more sophisticated visibility tracking in addition to enabling visibility computations across multiple camera FOVs. The paper focuses its application on parachute canopy visibility to meet requirements for ASPIRE2, but additional potential applications will be discussed in Section IV.

B. ASPIRE2 POST2 Simulation

This paper focuses on ASPIRE2 parachute visibility as its primary application. This section briefly covers the ASPIRE2 mission as well as the flight mechanics simulation setup as is relevant to the parachute visibility analysis. The ASPIRE2 flight, covered in more detail in Refs. [8] and [9], consists of a sub-orbital sounding rocket flight from Wallops Flight Facility (WFF) with the goal of testing the deployment of a 24m disk-gap-band (DGB) parachute at specific Mach and dynamic pressure conditions. This test campaign was originally developed with the goal of supporting the Sample Return Lander (SRL) phase of the Mars Sample Return (MSR) campaign.

The POST2 simulation is initiated at the payload separation event using vehicle states provided by WFF and uncertainties by the Jet Propulsion Laboratory (JPL). Active attitude control is employed using the NSROC Inertial Attitude Control System (NIACS) flight software provided by WFF. ASPIRE2 is required to test the parachute performance up to 1.4 times the load required for SRL (70-140 klpf), meaning parachute deployment must occur up to a maximum Mach number of 2.4 and dynamic pressure of 1500 Pa [8]. Three high-speed cameras and three wide-lens cameras are mounted to the aft end of the vehicle in order to record the parachute inflation process in detail, and therefore a major goal of the POST2 flight mechanics simulation is being able to track the parachute visibility.

The parachute itself is modeled as a rigid, secondary body that spawns aft of the nosecone at the line stretch event. The parachute aerodynamics and apparent mass are computed using a model derived from the Mars Science Laboratory and Mars 2020 flights [1]. More information on the ASPIRE2 parachute modeling can be found in Ref. [9]. Figure 3 depicts the parachute geometry and coordinate system with respect to the primary vehicle, where x^T and z^T define the nosecone's body coordinate system, otherwise referred to as the theoretical nose tip (TNT) system (marked by the black dot). The riser location is marked by the origin of the R coordinate system, whereas the theoretical suspension line confluence point (TSLCP) is marked by the red dot coinciding with the origin of the P coordinate systems.

Figure 3 indicates cameras mounted on the rear of the vehicle marked by a blue circle facing aft. The camera field of view is depicted as being projected past the parachute crown (not to scale). The parachute vent, which is the primary point of interest for this analysis, is marked with a blue star, and its distance from the nose of the vehicle (in TNT

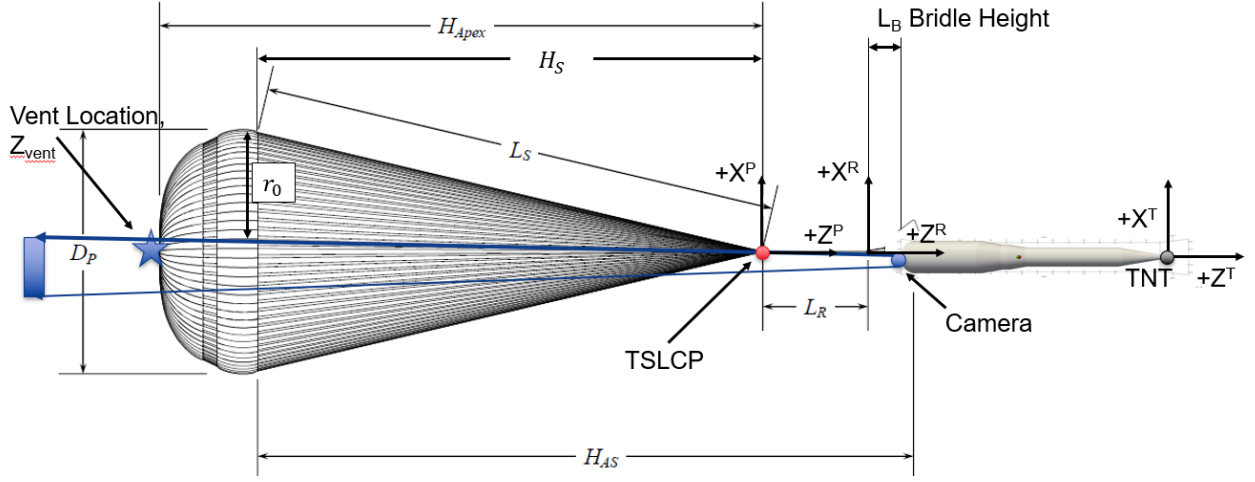


Fig. 3 ASPIRE2 parachute diagram

coordinates), Z_{vent}^T , can be computed as:

$$\begin{aligned} Z_{vent}^T &= Z_{TSLCP}^T + H_S + r_0 \\ &= Z_{bridle}^T + L_B + L_R + \sqrt{L_S^2 + \left(\frac{D_0}{2}\right)^2} + \frac{D_0}{2} \end{aligned} \quad (2)$$

where Z_{TSLCP}^T is the z-coordinate of the theoretical suspension line confluence point (TSLCP) in TNT coordinates, Z_{bridle}^T is the z coordinate of the bridle lines in TNT coordinates, L_B is the axial height of the bridle lines, L_R is the riser length, H_S and L_S are the suspension line height and length, respectively, and $r_0 = \frac{D_0}{2}$ is the inflated parachute radius assuming a spherically-inflated parachute. Note that assuming the inflated parachute has a diameter equal to the projected diameter, D_P , would be more conservative since $D_P < D_0$. The cameras are mounted approximately at the same axial location as the bridle line attachments, and therefore the distance from the camera to the parachute vent is simply $L_B + L_R + H_S + r_0$. The camera field of view is defined in terms of horizontal and vertical angles, so the total field of view length and width are determined from the projection of these angles from the distance from camera origin to parachute vent. Fortunately, the POST2 antenna subsystem enables the parametrization of parachute vent location into horizontal and vertical angles that can be directly compared with the camera FOV angle dimensions.

C. Parachute Visibility

This section will discuss the process outlined in Ref.[5] for estimating the visibility of an entire parachute using the antenna module covered in Section II.A. The visibility is depicted in Figure 4 in which a single dimension of the camera FOV is outlined in blue as a projection from the camera origin enveloped by the parachute.

Solely tracking the visibility of the parachute apex is insufficient when it comes to knowing the visibility of the entire canopy. This is because if the marker lies exactly along the projected blue line, the antenna sub-system would consider the parachute vent visible but half of the parachute canopy would actually be outside the FOV, as depicted in Figure 4b. Instead, the camera full FOV can be reduced by the parachute half angle (computed from the suspension line height and nominal parachute diameter) to describe the effective field of view, depicted in Figure 4c as a pair of projected red lines. Therefore, the full parachute canopy will only be fully visible if the parachute vent marker lies within the effective field of view limits, enabling a simple approximation for full parachute visibility in flight mechanics simulations. While this approach works well for individual cameras, it is only applicable to objects with circular projections into the camera field of view plane, assumes a rigid parachute canopy, and does not consider the possibility of overlapping camera FOVs.

The methodology using an effective FOV was suitable for the SFDT and ASPIRE programs. However, it falls short for the ASPIRE2 program due to a combination of increased parachute diameter and decreased camera FOV size in favor of higher resolution. This combination resulted in extremely narrow effective fields of view and a resultant failure to meet mission requirements stating that the full parachute canopy must be visible in any two cameras throughout the

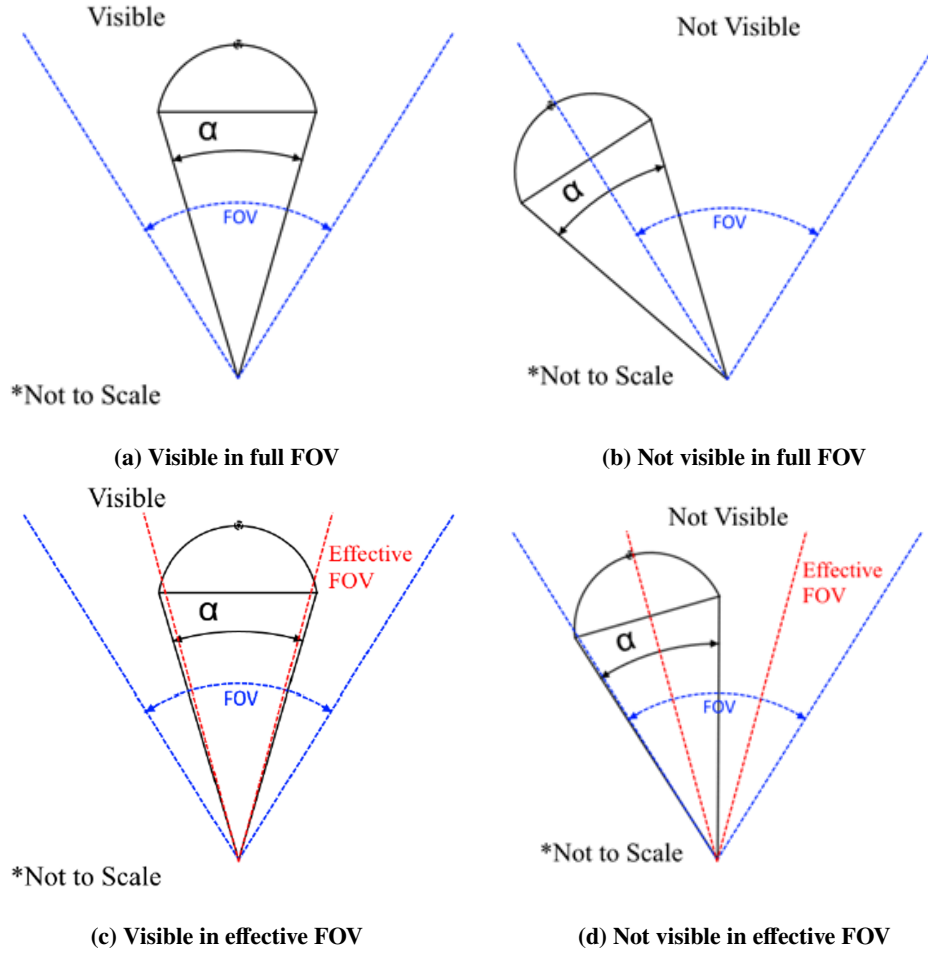


Fig. 4 Full camera FOV vs. effective FOV [5]

majority of the inflation sequence. This is visualized in Figure 5, which shows the parachute vent trace (magenta) inside the effective fields of view of the 3 high speed cameras allocated to the ASPIRE and ASPIRE2 flights. Note these fields of view are projections from the origin of the respective camera up to the parachute skirt canopy. While Figure 5a shows that the ASPIRE field of view size envelopes the vent trace under nominal conditions, it is immediately obvious from Figure 5b that the increase in parachute diameter and reduction in camera FOV size in ASPIRE2 leads to very small effective FOV when scaling down the FOV with the parachute half angle. This reduction is problematic in terms of meeting mission requirements.

However, when considering the full camera FOVs, as shown in Figure 6, a fictitious circle of diameter equal to the projected parachute diameter ($D_P = 0.734D_0$) drawn at either end of the parachute vent trace suggests that a combination of fields of view would envelope the entire parachute canopy at any given point throughout inflation. Note that the projected parachute diameter is considered for FOV visibility to account for area oscillations, which are large parachute force oscillations typically observed above Mach 1.4 as the parachute canopy undergoes cycles of collapsing and re-inflating. [10]. This further indicates that the effective field of view implementation may not be sufficient for properly capturing visibility when multiple camera FOVs can be leveraged. This paper seeks to develop a methodology to simulate the full parachute canopy within the combined FOVs of multiple cameras in such a way to be generalized to other applications in flight mechanics simulations.

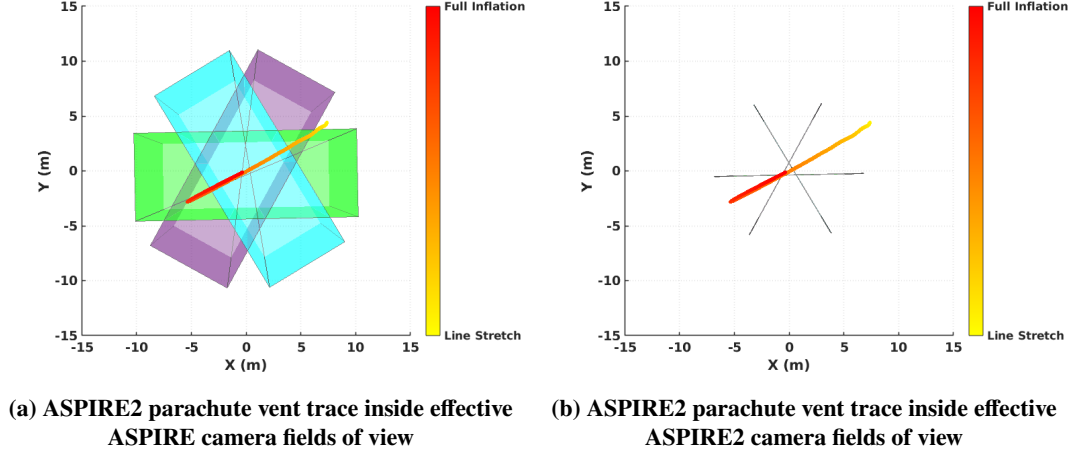


Fig. 5 ASPIRE2 parachute vent trace inside effective fields of view

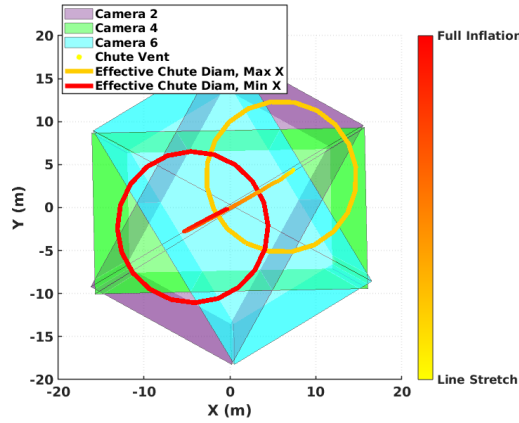


Fig. 6 Parachute canopy visualized within ASPIRE2 camera full field of view

D. Parachute Skirt Discretization Method

In order to improve visibility statistics of the parachute, a shape discretization method is proposed that approximates an object shape within the full camera FOV (or within multiple camera FOVs). It is developed with parachute canopy skirt visibility in mind but is implemented in such a way as to be generalized for any shape that can be parameterized as a set of points relative to a target marker. For a parachute canopy specifically, this method involves discretizing the parachute skirt into a set of points encircling the parachute apex. Each of these points is independently evaluated within each camera FOV after being rotated into the proper coordinate system. The parachute visibility is then computed based on the number of these skirt points that lie within any of the camera fields of view. This also enables the simulation to estimate the ratio of the number of canopy skirt points visible at any given moment. The initial results of this method are discussed in Section III.

Figure 7a depicts the vector diagram of the relevant vehicle markers and associated vectors. The vehicle coordinate system originates at the theoretical nose tip (TNT) marked by point N with the $+Z$ axis pointing out the nose. The parachute apex, marked as point V , is tracked using the POST2 marker module, which enables tracking position, velocity, and acceleration of user-defined points in the vehicle body coordinate system. Note that the vector length $|\mathbf{x}_{NV}^T|$ is simply equal to Z_{vent}^T from Equation 2. Each camera also contains its coordinate system defined by its "up" orientation and boresight vector. There are additional markers placed at each camera location, C_i . The motion of these markers are tracked during the simulation and an antenna module described by Ref [5] is used to track the position vectors $\mathbf{x}_{NV}$ (the vector from the nose to parachute vent), $\mathbf{x}_{NC}$ (the vector from the nose to camera), and $\mathbf{x}_{CV}$ (the vector from the camera to parachute vent) for each camera in their respective coordinate systems.

At each simulation time step, the parachute skirt is discretized as a set of points relative to the known vent location. Maintaining the spherically-inflated parachute assumption, the position vector from the parachute vent to each skirt point can be computed at $\mathbf{x}_{VS}^T = [r_P \cos \theta, r_P \sin \theta, r_0]$ for a clock angle $\theta = [0, 360^\circ]$ in the TNT coordinate system. Note that the parachute canopy standoff distance from the vent is equal to the nominal parachute radius, whereas the canopy itself is assumed to have a radius equal to that of the projected parachute, where $r_P = 0.734r_0$, as shown in Figure 7b. This is again to account for potential area oscillations in the parachute canopy. The rock and tilt angles of the parachute at the current time must also be accounted for. Therefore, a rotation matrix from the nominal to current vent location, $[M_{VS}]$, is computed as follows:

$$[M_{VS}] = [I_{3 \times 3}] + \text{skew}(\mathbf{v}) + \text{skew}(\mathbf{v})^2 \frac{1}{1 + \lambda} \quad (3)$$

where

$$\mathbf{v} = \hat{\mathbf{x}}_{NV} \times \hat{\mathbf{x}}_{CS}$$

$$\lambda = \hat{\mathbf{x}}_{NV} \cdot \hat{\mathbf{x}}_{CS}$$

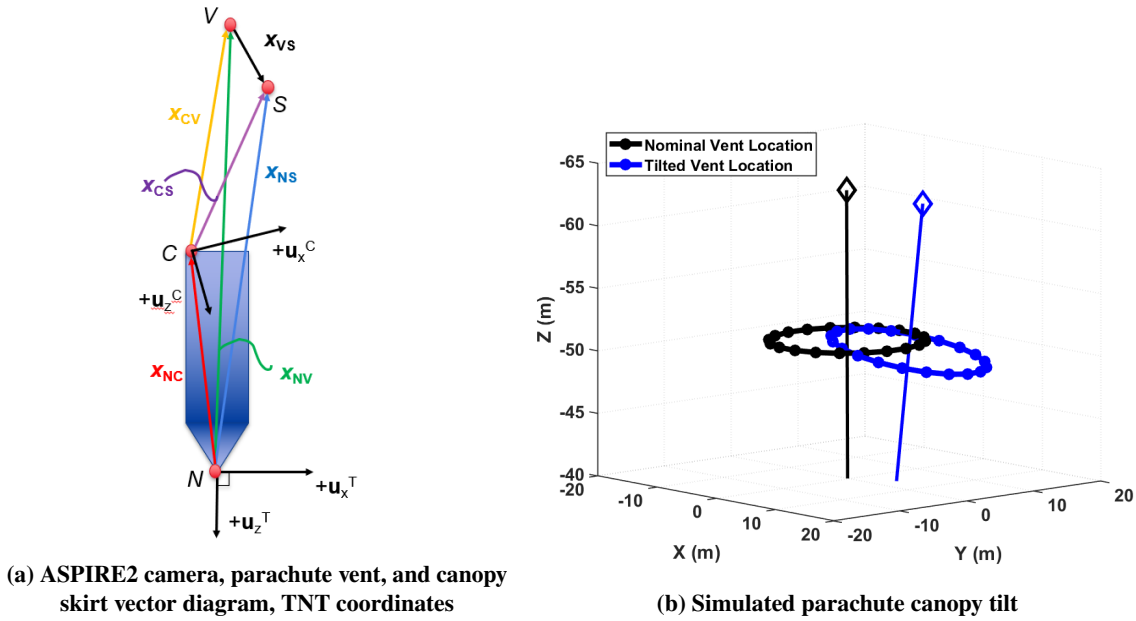


Fig. 7 ASPIRE2 parachute canopy skirt setup

An example of this tilt is shown in Figure 7b, which depicts the parachute apex, marked by diamonds, relative to the canopy. The circles along the canopy represent each discretized point (joined by a line here for ease of visualization), and the black asterisk represents the nominal vent location. Equation 3 computes the rotation matrix from the nominal vent location (black) to that of the current vent location (blue). This rotation matrix is applied to each discretized point, resulting in the blue parachute canopy points shown in Figure 7b.

During the simulation, position vectors are tracked in antenna-specific coordinate systems based on definition of each antenna's orientation in terms of clock direction and boresight vector. The coordinate system for the antenna tracking the parachute vent from the vehicle nose is denoted as R , while each individual camera antenna coordinate system is denoted as C_i . Therefore, $\mathbf{x}_{NV}^T$ must first be rotated from the TNT coordinate system into R coordinates before computing $[M_{VS}]$. Specifying all vectors relative to the antenna module's internal coordinate system helps generalize the implementation so that it can be agnostic to any individual vehicle structural frame definition. The rotation matrix $[M_{VS}]$ can then be used to compute each individual canopy skirt point relative to the parachute vent in

the antenna-relative coordinate system, $\mathbf{x}_{VS}^R$. Finally, each skirt point position can be evaluated relative to the individual camera as:

$$\mathbf{x}_{VS}^{C_i} = [M_{RC_i}] \mathbf{x}_{VS}^R \quad (4)$$

$$\mathbf{x}_{CS}^{C_i} = \mathbf{x}_{CV}^{C_i} + \mathbf{x}_{VS}^{C_i} \quad (5)$$

where $[M_{RC_i}]$ is the rotation matrix from antenna coordinates R to camera antenna coordinates C_i , which is known through each individual antenna rotation matrix to inertial coordinates, $[M_{RC_i}] = [M_{IR}][M_{IC_i}]^T$. Note that $\mathbf{x}_{CV}^{C_i}$, the position of the parachute vent relative to each camera, is known throughout the simulation through the antenna setup. Finally, with $\mathbf{x}_{CV}^{C_i}$ known, the horizontal and vertical angles can be computed using Equation 1 which can be evaluated directly against the prescribed field of view size of the camera to assess visibility of each point. When evaluated at each time step, the simulation can track the visibility of the canopy within any combination of camera fields of view as opposed to being limited to evaluating visibility per camera as with the approach taken in Ref. [5].

By disassociating from fixed markers as a means of simulating the parachute canopy, this method offers improved flexibility to field of view calculations, allowing users to define points as either mathematical expressions and/or functions of time. For example, the radius of the parachute skirt points will increase from line stretch until full inflation and can be modeled as such. The internal visibility computations being performed within the pre-defined antenna coordinate system also offers flexibility in application, allowing a user to define all marker positions relative to a prescribed body coordinate system and not being limited to specific antenna lines of sight or orientations. A fixed radius is considered for visualization purposes in this work; the consequences of choosing this conservative option are discussed in Section III.

III. Results

This section presents initial findings using the parachute skirt discretization method on the visibility of the parachute canopy using the ASPIRE2 application outlined in Section II.B. Section III.B covers baseline Monte Carlo performance, while Section III.C investigates performance for various camera failure scenarios.

The ASPIRE2 vehicle is equipped with three high speed cameras which are the primary sources for tracking parachute canopy under inflation. While each individual camera does not have a sufficiently wide field of view to track the parachute canopy, as shown in Figure 5b, post-flight photogrammetry could be feasible to stitch together each camera's frames in order to regenerate the full parachute canopy. Under this assumption, the analysis in the subsequent sections employ the discretization method outlined in Section II.D and evaluate each canopy skirt point within the fields of view of all three high speed cameras.

A. Parachute Canopy Discretization Results

The visibility of the canopy skirt points at parachute line stretch is shown in Figure 8, which plots each point's horizontal and vertical angles within the camera field of view angle size. The parachute vent is shown in black, points inside the camera FOV are shown in green, and points outside the FOV are in red. Figures 8a-8c depict the parachute canopy for each high speed camera at line stretch (i.e. parachute deployment), while Figures 8d-8f showcase the canopy position in each camera at full inflation.

Figure 8 shows the different orientation of the parachute vent relative to the respective camera position and alignment and demonstrates that each canopy skirt point is being properly evaluated within the respective camera FOV. At line stretch, no single camera is able to fully capture the parachute canopy; however, all 3 cameras contain the parachute canopy within their prescribed FOVs at full inflation. Regardless, it is apparent from studying these figures that every canopy point lies within at least one camera FOV at line stretch, and therefore the assumption that post-flight camera frame stitching would enable the full canopy to be visible is likely valid. This specific analysis also conservatively assumes that the parachute is fully inflated at line stretch when evaluating visibility. Realistically, at line stretch the discretized points would be clustered in a smaller radius. This choice will reduce overall Monte Carlo visibility metrics, but it is a conservative estimate and can always be adjusted.

To support the claim that post-flight photogrammetry might enable full canopy visibility, Figures 9a and 9b show the discretized parachute canopy within the full camera FOVs from a top-down and side view, respectively. It is clear that the parachute canopy lies within the combined FOVs of each camera.

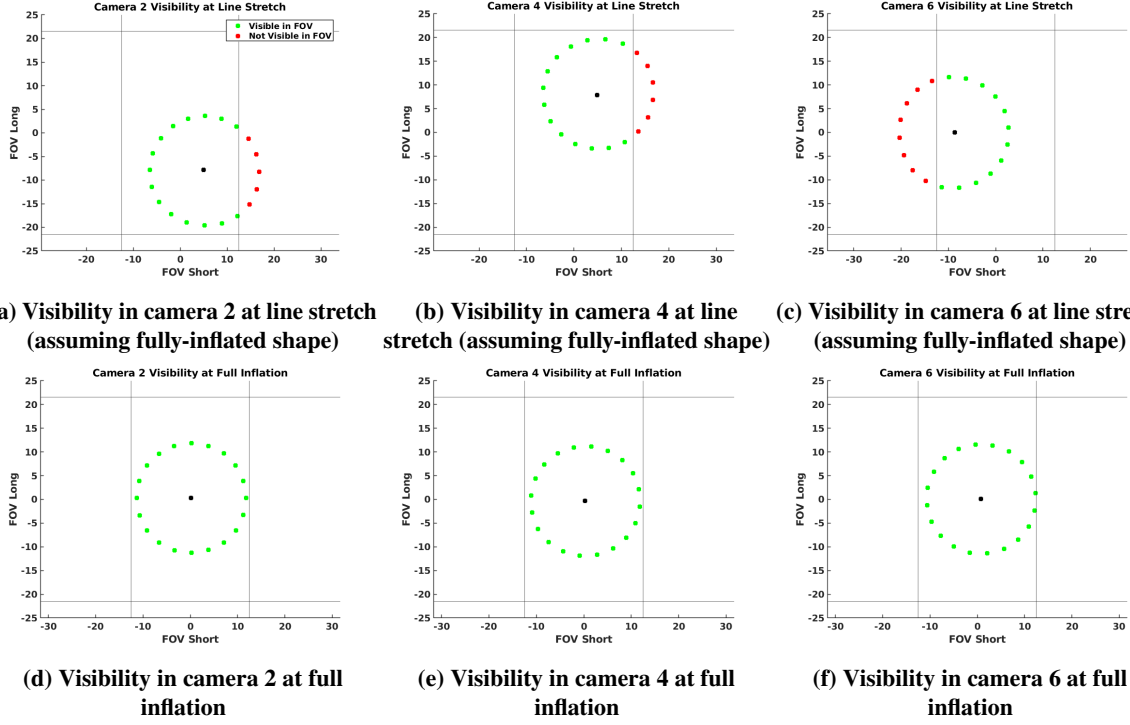


Fig. 8 Parachute canopy visibility in individual ASPIRE2 high speed cameras with chute discretization method

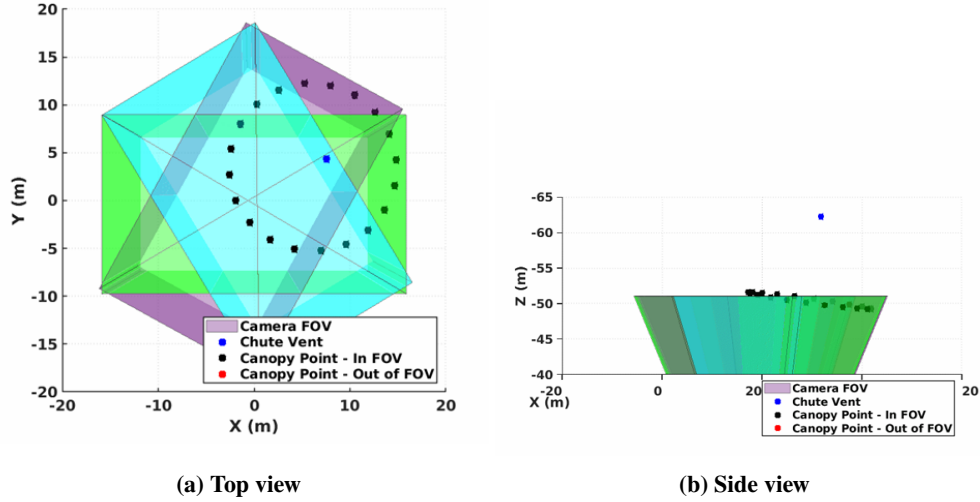
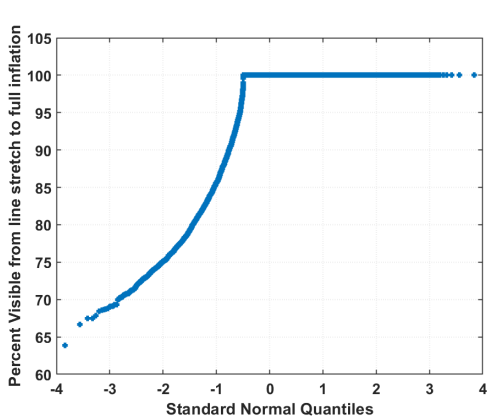


Fig. 9 Discretized canopy points within combined camera fields of view

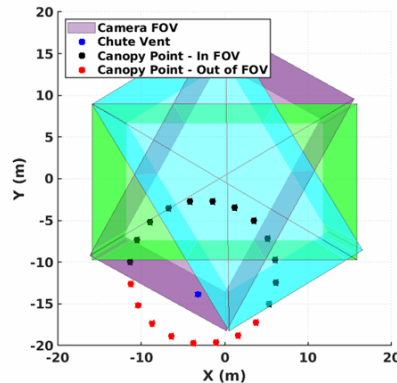
B. Baseline Monte Carlo Results

Knowing that the parachute canopy is fully visible for nominal performance is useful, but applying dispersions to the parachute inflation event and initial parachute orientation permits a broader investigation into the visibility statistics using the discretization method. As such, 8000 Monte Carlo cases are run using POST2. At each time step the discretized points are evaluated within the combined camera FOVs to determine a percentage of time the entire canopy is visible throughout inflation. Figure 10a shows the Guassian quantiles of the visibility percentages for each case.

It is apparent that slightly over 50% of Monte Carlo cases are fully visible throughout the entire inflation event, and the worst case trajectory tracks the full parachute about 64% of the time. The discretized points at line stretch for



(a) Parachute skirt visibility Monte Carlo results



(b) Worst performing Monte Carlo case canopy position within fields of view at line stretch

Fig. 10 Baseline discretization method Monte Carlo results

this case are depicted in Figure 10b, again with red points lying outside the combined FOV and black points lying inside. This case performs as such due to the excessive initial parachute cone angle. This result would be mitigated by a less conservative parachute canopy radius model; assuming a fixed parachute diameter for the entire inflation process reduces overall simulated visibility statistics but provides a conservative baseline from which to further iterate on. Regardless, these results show significant promise compared to the effective field of view implementation that would evaluate parachute visibility within each individual camera, as shown in Figure 5.

C. Camera Failure Analysis

The baseline Monte Carlo analysis from Section III.B can be expanded upon by assessing various camera fault scenarios. The shape discretization method enables analytical shapes to be evaluated with respect to any combination of camera FOVs. Therefore, it is trivial to assess parachute canopy visibility for any combination of camera failures as well. The results of six sets of 8000 Monte Carlo samples are shown in Figure 11, which plots the Gaussian quantiles for each combination of single and dual camera faults.

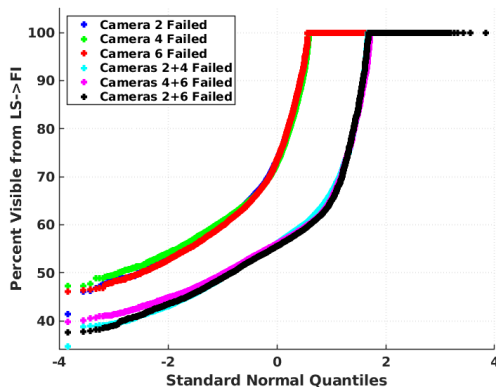


Fig. 11 Parachute skirt visibility camera fault Monte Carlo results

Most notable is the fact that the results are effectively agnostic to the specific failed camera; except for a few outlier cases, the distribution for each single-camera failure as well as each combination of two-camera failure scenario are similar. This suggests that the camera orientation for ASPIRE2 is robust to individual camera faults. Specifically, the reliability of parachute canopy tracking is not significantly dependent on any one camera. This type of analysis can be useful for mission designers to optimize the probability of successful visibility criteria with one or more camera failures.

IV. Additional Field of View Applications

Although the main focus of this paper has been parachute canopy visibility for the ASPIRE2 mission, it is developed in a way such that it can be applied to a wide variety of problems. As previously mentioned, evaluating marker visibility inside the antenna-specific frame makes the discretization method agnostic to any specific vehicle setup. In addition, the method is developed such that a shape can be evaluated within any combination of camera FOVs as long as it is in the form of an analytical expression or tabulated set of data.

One application similar to that investigated in this paper involves tracking an aeroshell heatshield following its separation from the primary vehicle. This analysis could be useful to simulate sensor imaging capabilities during descent. The setup for this application would be fairly similar to the parachute canopy tracking application; the simulation could track the heatshield nose and evaluate a set of radially-dispersed points, taking the heatshield attitude into account in a manner similar to that of Equation 3.

In addition, the discretization method enables tracking fixed surface points, which could be useful for simulating descent imaging capabilities of a spacecraft. For example, the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) mission has a science objective to take images of the Venusian surface during its descent sequence. Specifically, one of the science requirements is to have the field of view of the different images both taken in sequence and be overlapping so that a Digital Elevation Model (DEM) can be created in reconstruction [11]. The shape discretization method would be used to break the landing ellipse up into a discrete set of points to evaluate within the camera FOV. This analysis could provide metrics if the overlapping image sequence requirement is being met in Monte Carlo simulations, and could be used to target the vehicle trajectory to cover science areas of interest within the target landing ellipse.

V. Conclusions

Incorporating camera field of view capability into flight mechanics simulations is useful in mission planning and requirements verification. This paper introduces a shape discretization method to resolve analytical shape visibility within the field of view of a camera or combination of cameras. While relevant to numerous applications, this paper focused on the parachute canopy visibility within several camera fields of view for the Advanced Supersonic Parachute Inflation Research Experiment 2 (ASPIRE2) mission, building off of previous methodologies developed for the ASPIRE campaign. The application to parachute visibility was outlined, and results demonstrating its implementation were shared. Monte Carlo analysis was performed to present baseline statistical analysis indicating that this method showed promise in regards to parachute canopy visibility analysis. Additional fault scenarios were assessed to show that this method enables assessment of scenarios with varying combinations of camera failures. Additional applications were also shared, with primary focus being on a descent imaging scenario for the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) mission.

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