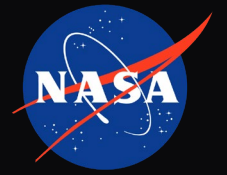


ASPIRE2



Shape Approximation in Camera Fields of View for Parachute Visibility Applications

Evan Roelke (AMA/NASA LaRC)

Justin Green, Soumyo Dutta, R. Anthony Williams (NASA LaRC), Matthew Andreini (AMA/NASA LaRC)

**AIAA SciTech Forum & Exposition 2025
January 10, 2025**



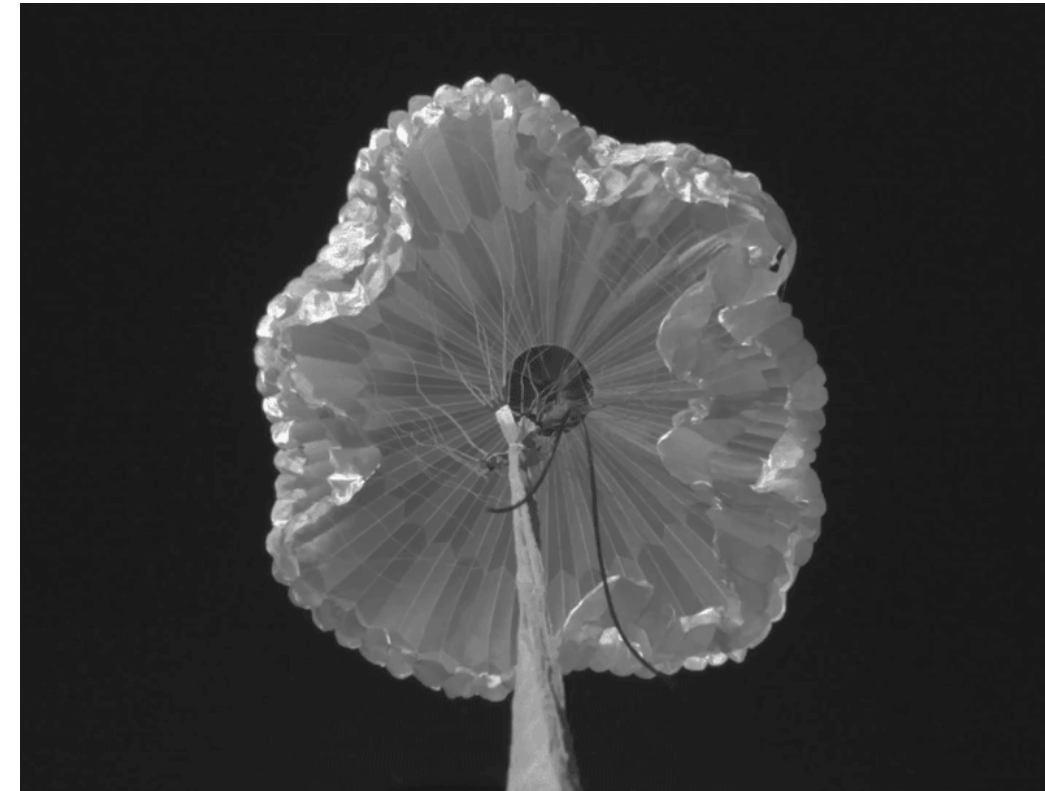
ASPIRE-SR03 Parachute. Credit: NASA

Overview



ASPIRE 2

- Low Density Supersonic Decelerator (LDSD) program included two supersonic parachute tests (SFDT-1 and 2) in 2015 and 2016
 - These flights led to more sophisticated parachute testing methodologies and highlighted the benefit of visualizing the parachute canopy during the inflation sequence
 - Track the parachute growth and dynamics during inflation
- SFDT flight test simulation included camera pointing/exposure analysis to maximize parachute visibility during flight
 - Similar analysis employed for the Advanced Supersonic Parachute Inflation Research Experiment (ASPIRE) flights in 2017 and 2018 to structurally qualify the Mars2020 parachute
- Plans for ASPIRE2 intend to qualify a larger parachute and the SFDT/ASPIRE camera analysis may be insufficient for the required analysis
- A new method of tracking the parachute canopy during a flight mechanics trajectory simulation is introduced to resolve this issue



Credit: NASA

Outline



ASPIRE 2

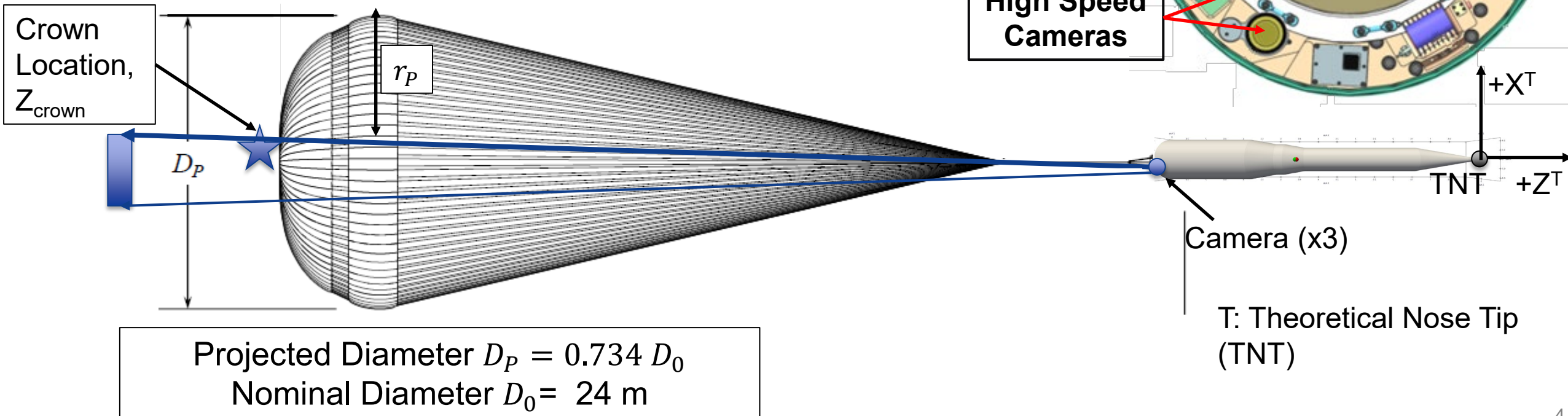
- ASPIRE2 Overview
- SFDT Visibility Methodology / Motivation
- Parachute Canopy Skirt Discretization
- Discretization Results
- Monte Carlo Results
- Additional Applications
- Summary & Future Work

ASPIRE2 Overview



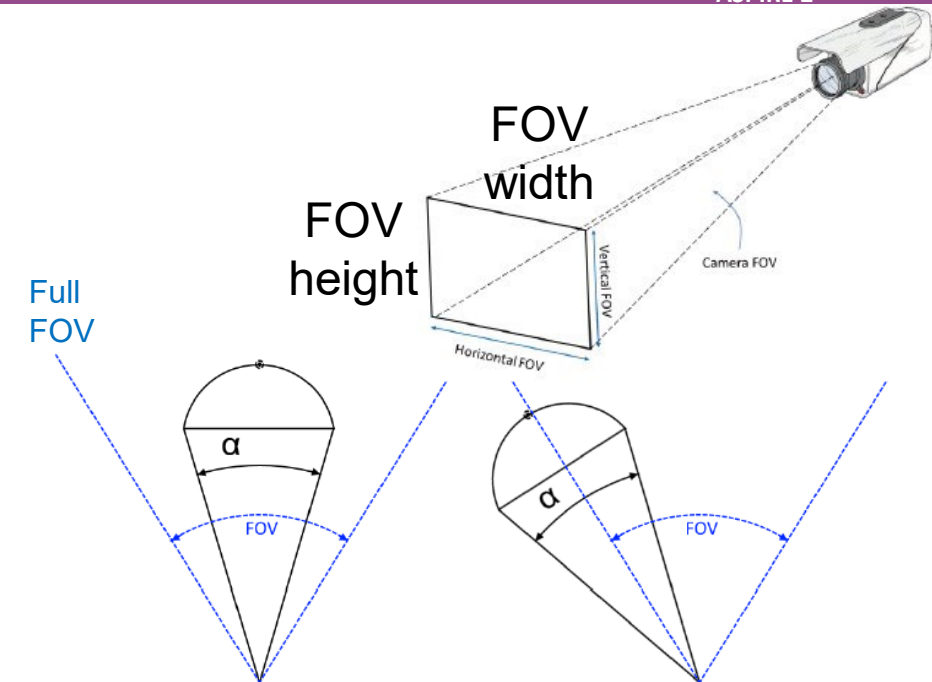
ASPIRE 2

- ASPIRE2 is a proposed sounding rocket flight test to launch from Wallops Flight Facility (WFF) that will deploy a 24m disk gap band (DGB) parachute at the conditions required to qualify the Sample Return Lander (SRL) parachute for the Mars Sample Return (MSR) campaign
- Three cameras are mounted on the aft end of the test article to track the parachute canopy during inflation
- The flight mechanics simulation is developed using the Program to Optimize Simulated Trajectories II (POST2), a flight-validated, 6DOF multi-body tool developed by NASA LaRC
- Theoretical Nose Tip (TNT) used as primary vehicle coordinate system

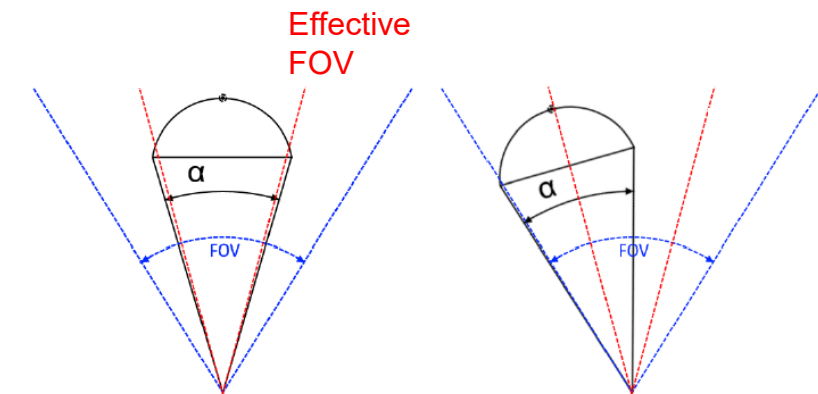


Motivation

- SFDT methodology tracks the parachute crown point to evaluate within the camera field of view (FOV)
- Introduced an “effective FOV” which is defined by the full FOV reduced by the parachute half angle
 - Ensures the parachute canopy is visible when the parachute crown remains inside the effective FOV
- ASPIRE high speed cameras had a rectangular FOV of size $47.2^\circ \times 30.6^\circ$ and a parachute half-angle of 9.97°
- ASPIRE2 cameras planned to have reduced FOV size of $43.1^\circ \times 25^\circ$ and a larger parachute half-angle of 12.47°
 - This reduces the effective FOV quadrant size from 5.33° to 0.03° !**
Meaning the parachute is assessed to almost never be fully visible in each individual camera

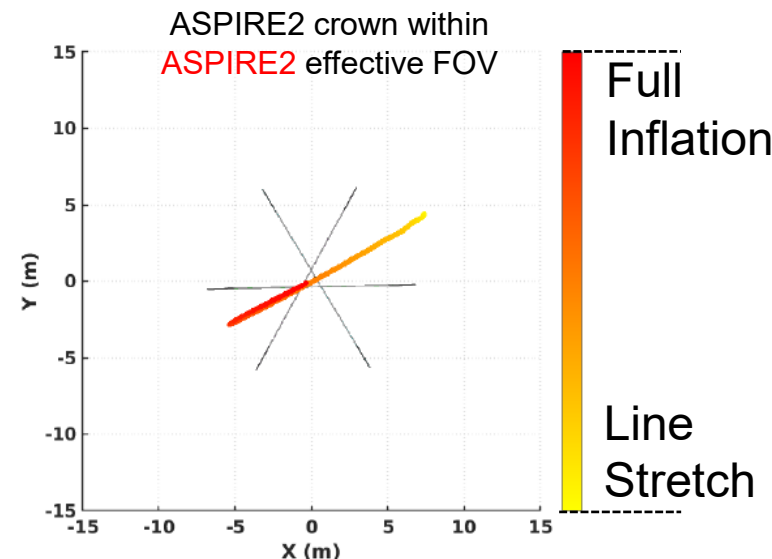
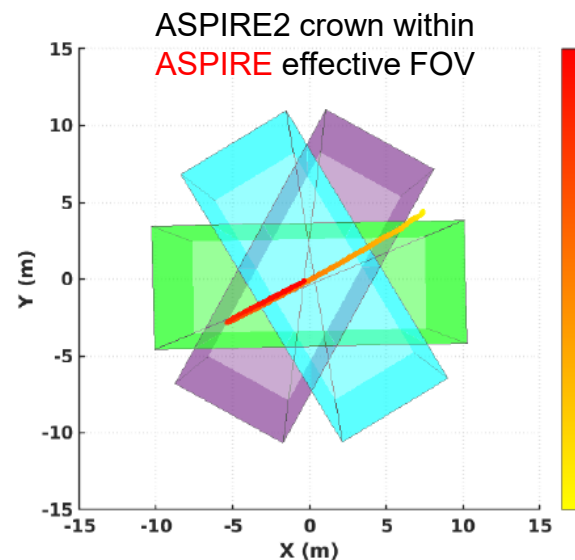


*Not to Scale



*Not to Scale

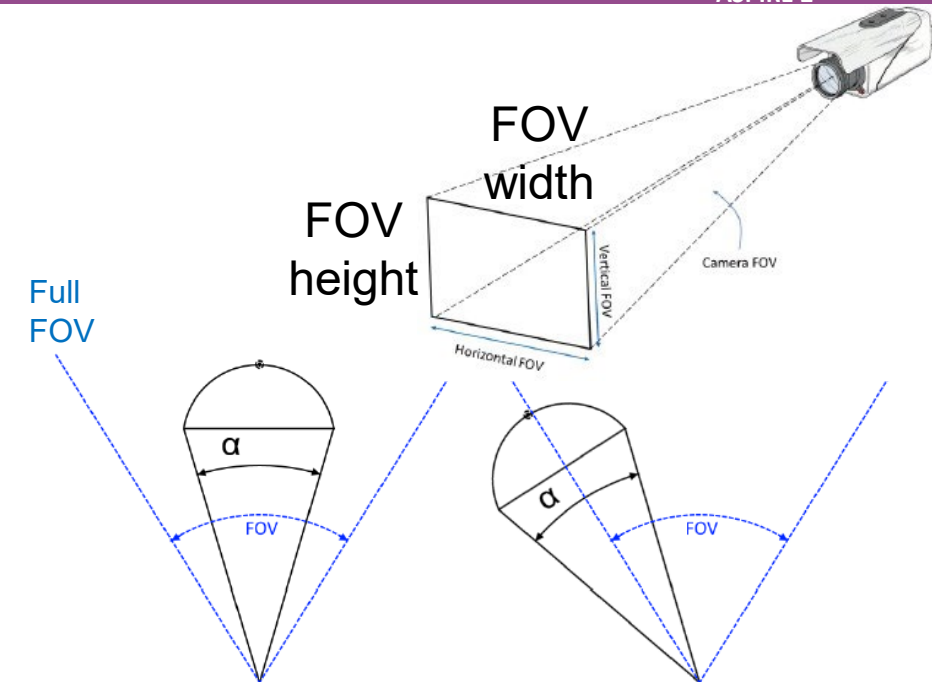
Source: “SFDT-1 Camera Pointing and Sun Exposure Analysis and Flight Performance”, Joseph White, Soumyo Dutta, and Scott Striepe. AAS/AIAA Space Flight Mechanics Meeting, AAS 15-218. 2015



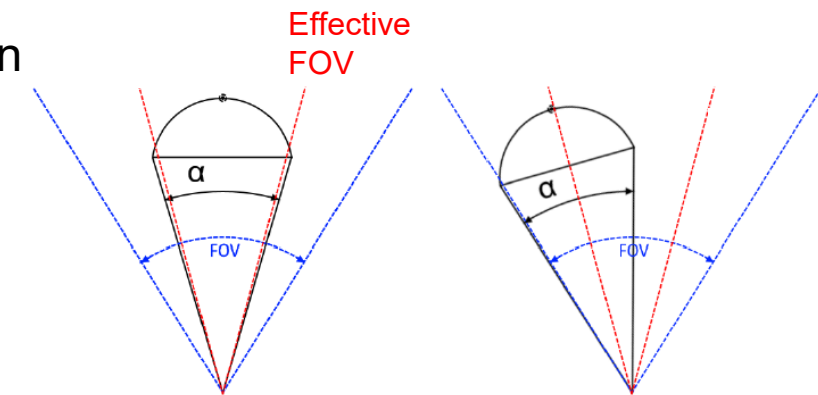
*Projections of parachute camera fields of view in TNT frame up to parachute canopy height

Motivation

- SFDT methodology tracks the parachute crown point to evaluate within the camera field of view (FOV)
- Introduced an “effective FOV” which is defined by the full FOV reduced by the parachute half angle
 - Ensures the parachute canopy is visible when the parachute crown remains inside the effective FOV
- ASPIRE high speed cameras had a rectangular FOV of size $47.2^\circ \times 30.6^\circ$ and a parachute half-angle of 9.97°
- ASPIRE2 cameras planned to have reduced FOV size of $43.1^\circ \times 25^\circ$ and a larger parachute half-angle of 12.47°
 - This reduces the effective FOV quadrant size from 5.33° to 0.03° !**
Meaning the parachute is assessed to almost never be fully visible in each individual camera

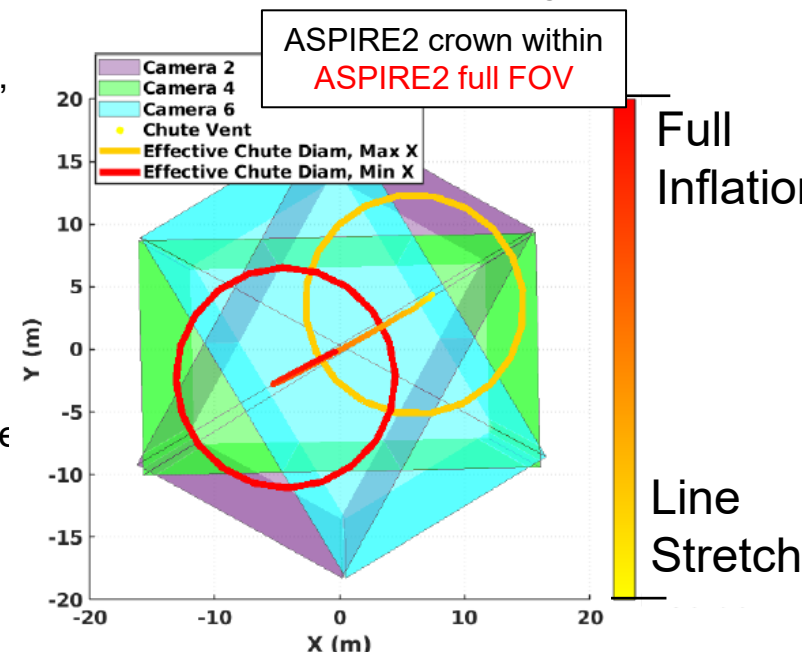


*Not to Scale



*Not to Scale

Source: “SFDT-1 Camera Pointing and Sun Exposure Analysis and Flight Performance”, Joseph White, Soumyo Dutta, and Scott Striepe. AAS/AIAA Space Flight Mechanics Meeting, AAS 15-218. 2015



Full Inflation

Line Stretch

- A circle with parachute projected diameter, D_P , inside the full camera FOVs suggests no singular camera can contain the entire parachute canopy
- But the *combination* of cameras can envelope the canopy and photogrammetry can be used to merge camera frames to visualize the full parachute canopy
- Rather than track just the parachute crown, the simulation must consider the entire canopy
- Thus, an analytical shape discretization method is developed**

Parachute Canopy Skirt Discretization

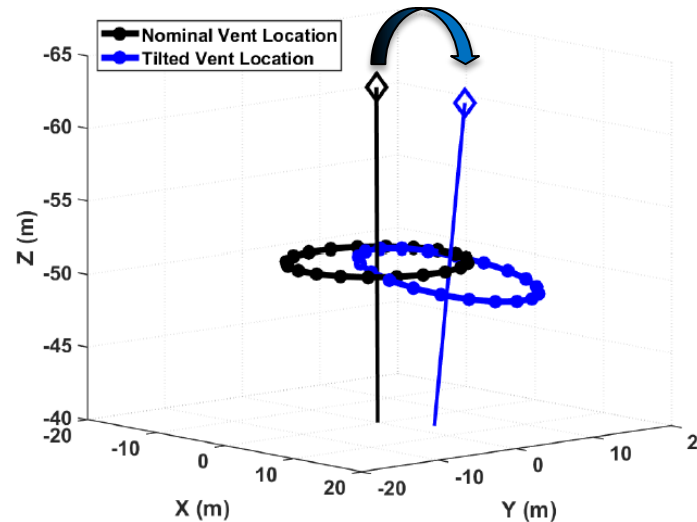


ASPIRE 2

- Discretize the parachute canopy into set of skirt points encircling the parachute vent/crown (Note: it is a conservative assumption that r_p is constant)

$$\mathbf{x}_{VS}^T = [r_p \cos \theta, r_p \sin \theta, r_0] \text{ for } \theta \in [0, 360^\circ], \quad r_p = D_p/2$$

- Each skirt point must be rotated by the current parachute tilt relative to the nominal location **in TNT coordinate**

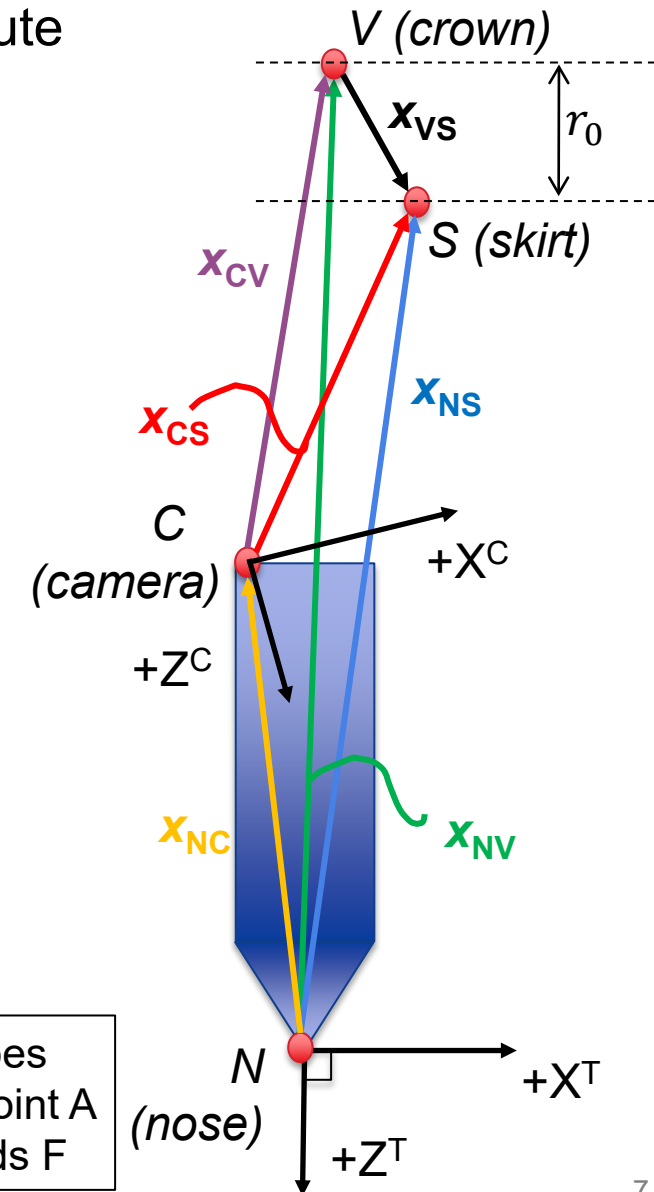


- For each skirt point we must compute the position vector relative to each camera, C_i , expressed relative to the **camera's coordinate system**

$$\mathbf{x}_{CS}^{c_i} = \mathbf{x}_{CV}^{c_i} + \mathbf{x}_{VS}^{c_i}$$

Note: Projected diameter used to account for area oscillations of the parachute canopy

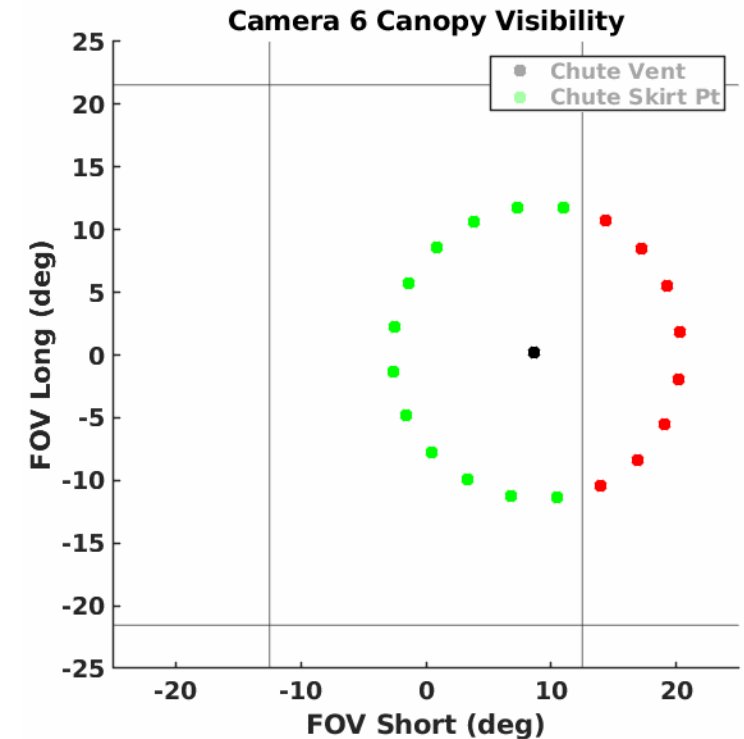
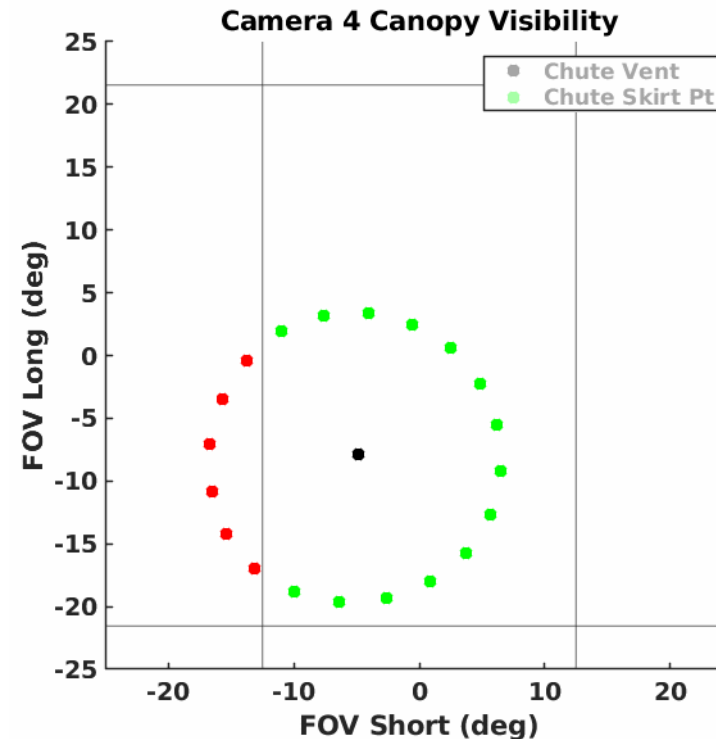
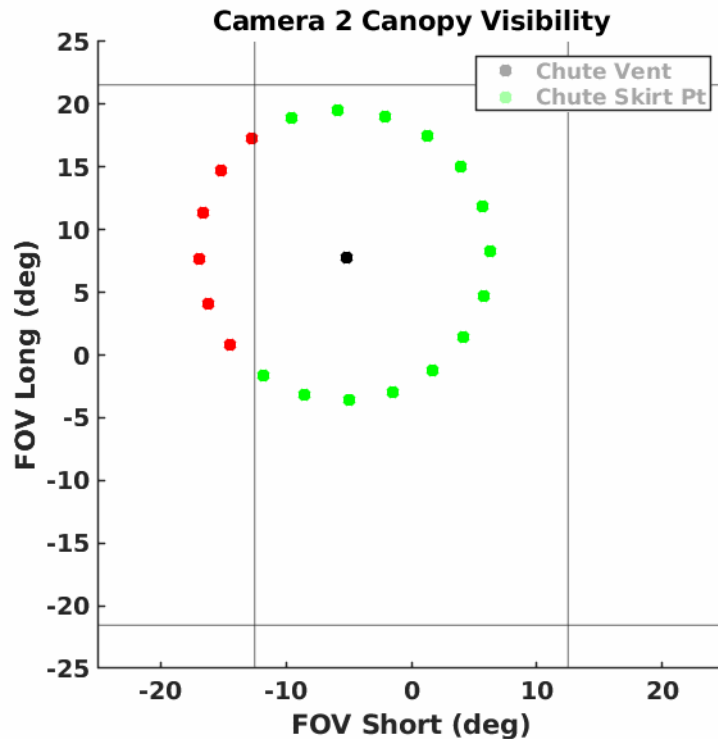
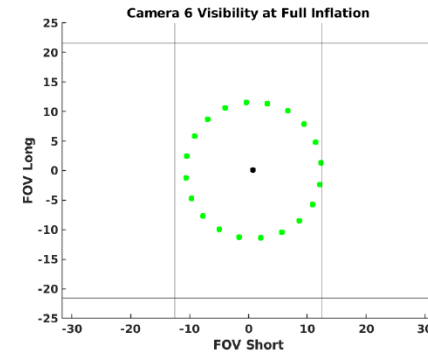
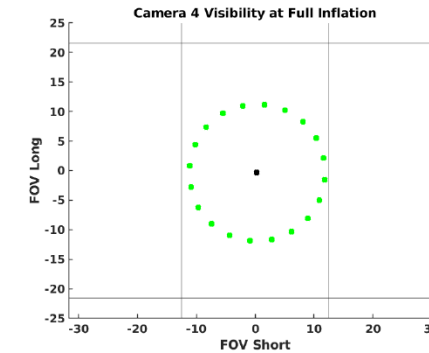
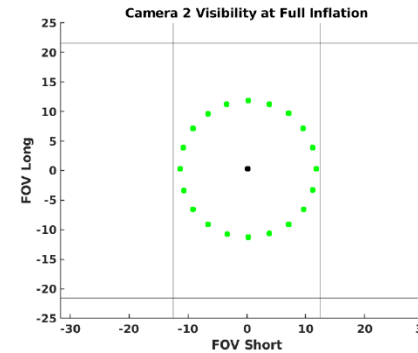
$\mathbf{x}_{AB}^F$ describes vector from point A to B in coords F



x_{AB}^F describes
vector from point A
to B in coords F

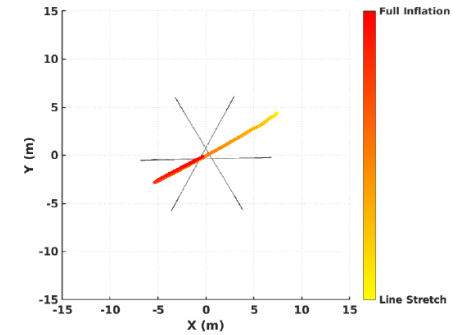
Individual Camera Visibility

- We can evaluate visibility of each canopy skirt point inside each individual camera throughout inflation
- This also highlights the infrequency in which a single camera FOV envelops the parachute canopy
 - Only around full inflation are all skirt points within the fields of view entirely

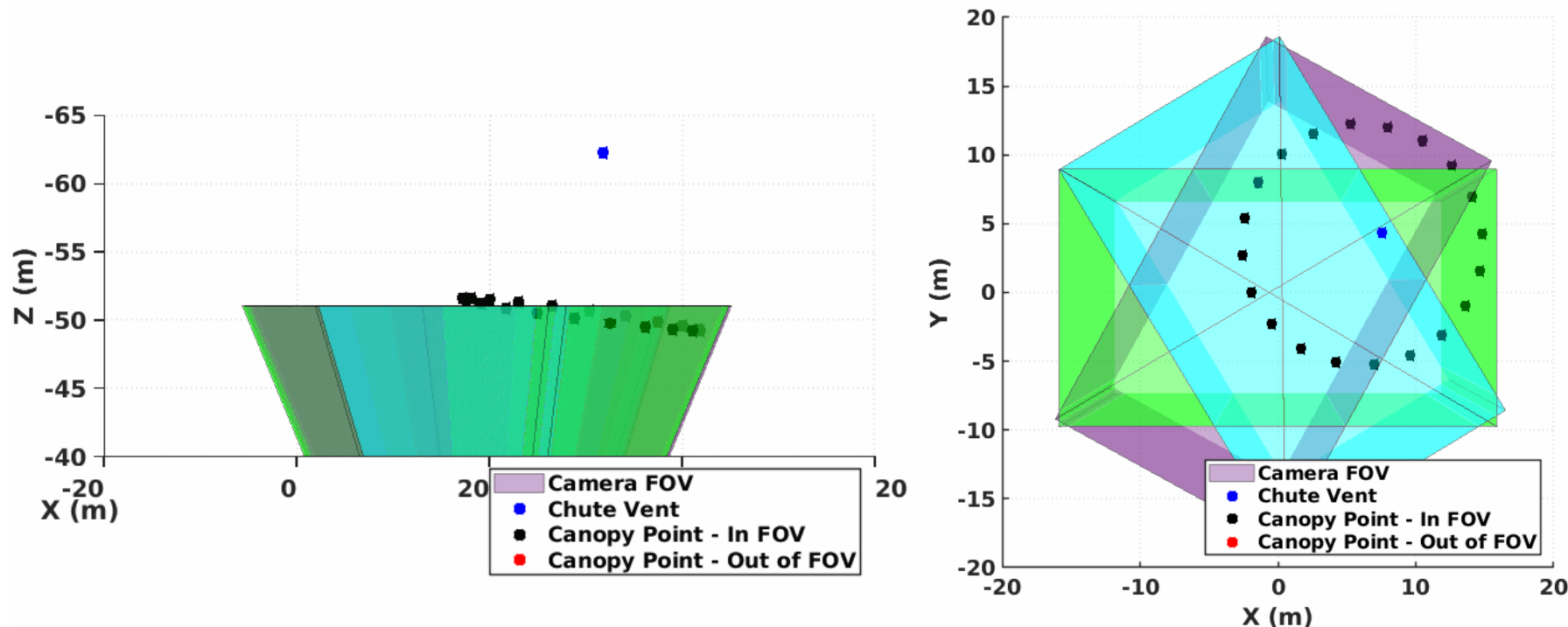


Combined Camera Visibility

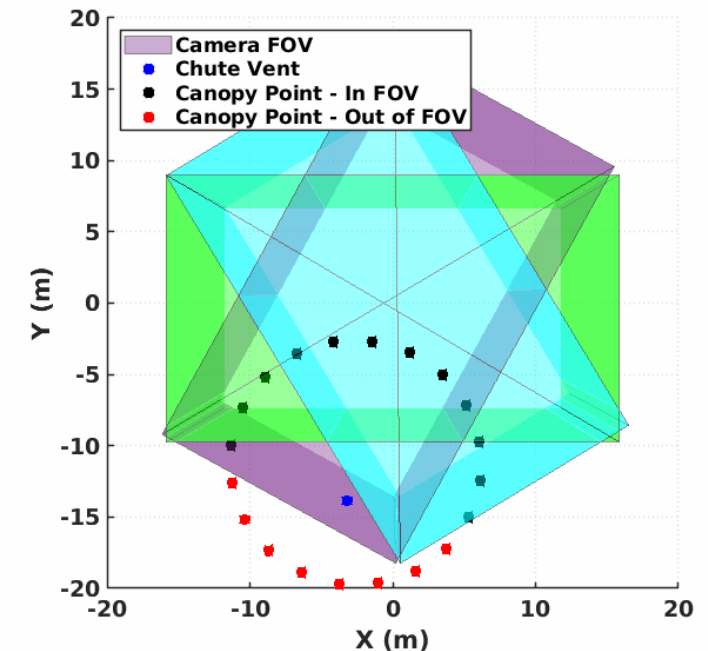
- Finally, we can combine the visibility criteria within each camera to determine if the parachute canopy is entirely visible in the combined FOV
- The nominal trajectory shows 100% visibility throughout inflation, whereas recall using the ASPIRE effective FOV (per camera) metric, the parachute would be considered rarely visible in its entirety



Nominal ASPIRE2 Trajectory



Dispersed ASPIRE2 Trajectory

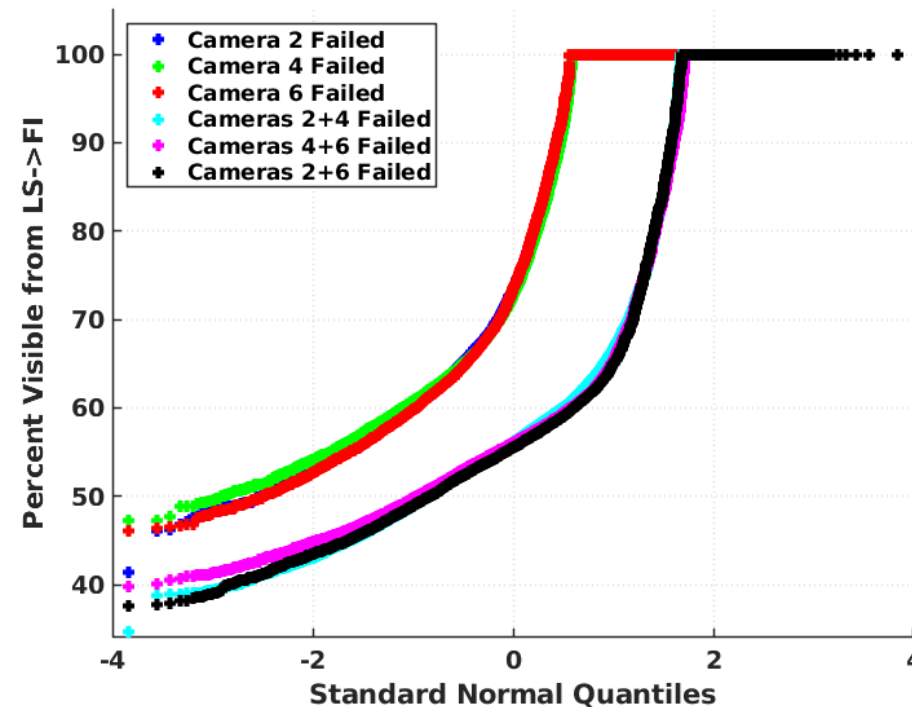
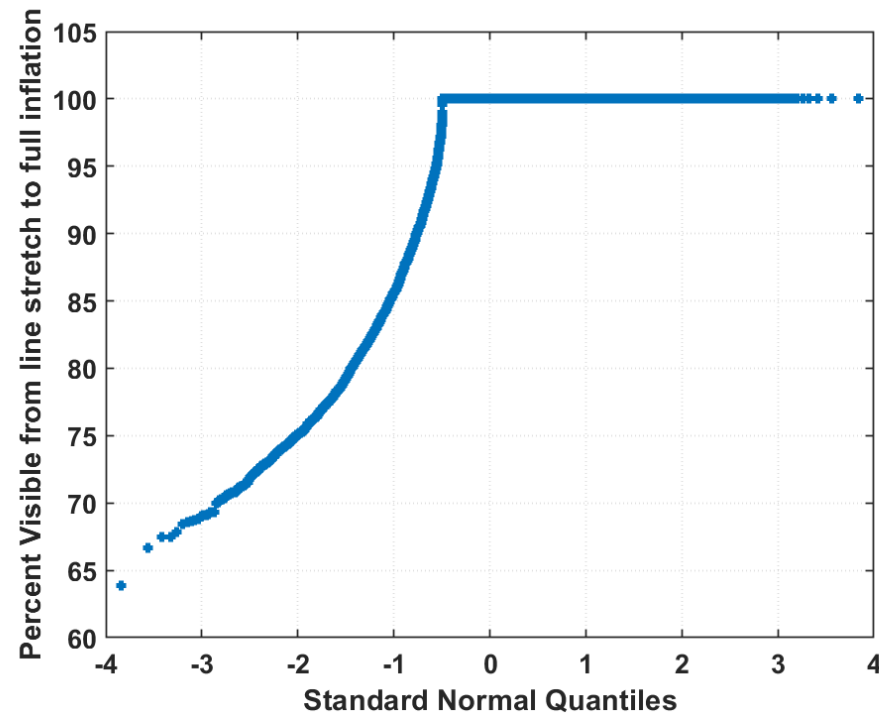


Monte Carlo Analysis



ASPIRE 2

- ASPIRE2 Monte Carlo trajectory simulations were run to determine the percentage of time the parachute canopy was fully visible within combined camera FOV during inflation
 - Results show that over 50% of cases have 100% visibility during inflation
 - Current methodology is conservative in assumption that canopy radius is held constant
- Camera fault (loss of camera) analysis was performed to assess changes in visibility for any combination of camera failures
 - Results indicate that the current camera orientation is effectively agnostic to individual camera failures



Additional Applications



ASPIRE 2

- This methodology is designed so that visibility analysis is performed in antenna-specific coordinate systems
- This makes the discretization method agnostic to specific vehicle setups
- In addition, any shape can be assessed within camera fields of view if an analytical expression or tabulated data set exists
- As such, this visibility method can be applied to a myriad of other applications including, but not limited to:
 - Tracking fixed landscape/landing ellipse points relative to descent vehicle for surface imaging
 - Heat shield tracking post-jettison
 - Ray tracing
 - Communications/line of sight
 - And more!



Image credit: NASA/JPL

Summary & Future Work



ASPIRE 2

- SFDT/ASPIRE-era parachute visibility methodologies used in flight mechanics simulations are insufficient for ASPIRE2 due to smaller camera field of view sizes and a larger parachute canopy.
- A shape discretization method is introduced to simulate the parachute skirt canopy as discrete points to evaluate within each ASPIRE2 high speed camera FOV
- By discretizing the parachute canopy skirt into distinct points, the full canopy visibility can be assessed in each individual camera as well as the combined FOVs of all three cameras
- Monte Carlo analysis was performed to assess the percent time the canopy is fully visible during the parachute inflation period
 - Over 50% of cases were fully visible during the entire inflation sequence
- Camera fault analysis was also performed to determine how visibility changes because of combinations of camera failures
 - Current ASPIRE2 setup shown to agnostic to specific camera failures
- Future Work:
 - Time-dependent parachute canopy radius during inflation event
 - Expand methodology to other applications



Questions?

evan.roelke@nasa.gov



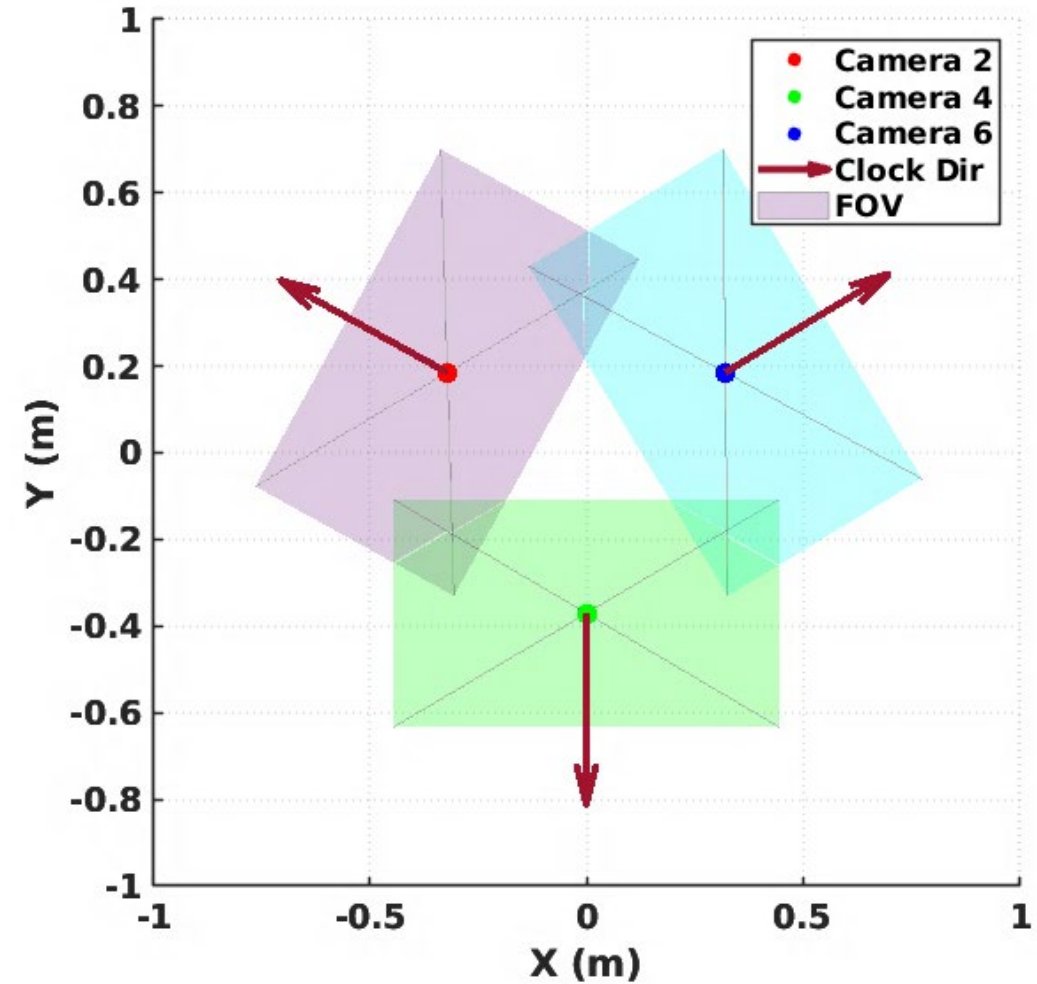
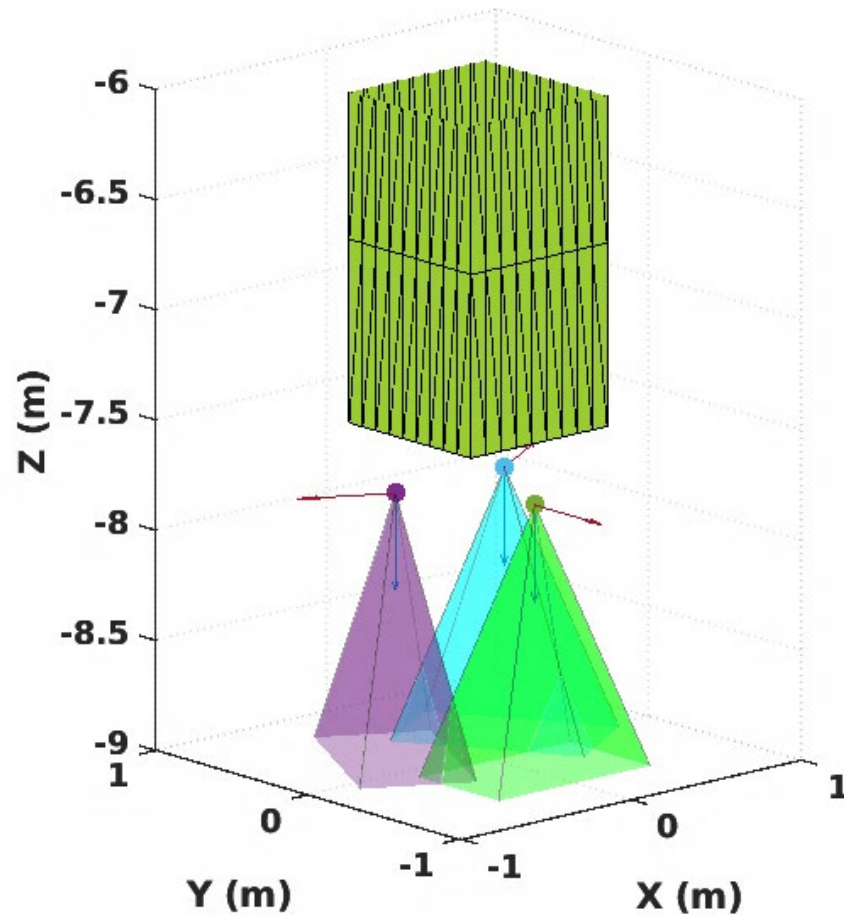
BACKUP

Camera Orientation



ASPIRE 2

- Camera short axis vector defines the clock direction (X axis) which orients field of view relative to the short/long axes



Current Setup - % Time chute in Effective FOV



ASPIRE 2

- First look at %time in each FOV (8000 cases only) between Line Stretch and Full Inflation
- Shows definitively not meeting the requirement of 90% for the effective field of view

