University of Colorado Boulder

ASEN 4018 Senior Projects, Spring 2019
Test Readiness Review (TRR)

CCAR

VANTAGE

Visual **A**pproximation of **N**anosat **T**rajectories to **A**ugment **G**round-based **E**stimation

Team: *Aaron Aboaf, Dylan Bossie, Sean Downs, Justin Fay, Marshall Herr, Josh Kirby, Lara Lufkin, Richard Moon, Nicholas Renninger, Zach Talpas, Jerry Wang*

Customer: *Prof. Penina Axelrad (CCAR), John Gaebler (CCAR)*

Advisor: *Prof. Marcus Holzinger*

Presenters

Overview	Lara Lufkin
Schedule	Nicholas Renninger
Test Readiness	Josh Kirby, Aaron Aboaf, Sean Downs, Zach Talpas, Marshall Herr
Safety Status	Richard Moon
Budget	Justin Fay

Project Overview

Project Purpose

Objectives:

The **long term vision** of this project is to augment existing, ground-based CubeSat Space Situational Awareness (SSA) by observing CubeSat deployments from the perspective of the NanoRacks (NR) ISS-based deployer.

This year's VANTAGE team will produce a **proof of concept** for this mission by developing a **ground based prototype** which will be tested using a simulated CubeSat deployment in a laboratory environment.

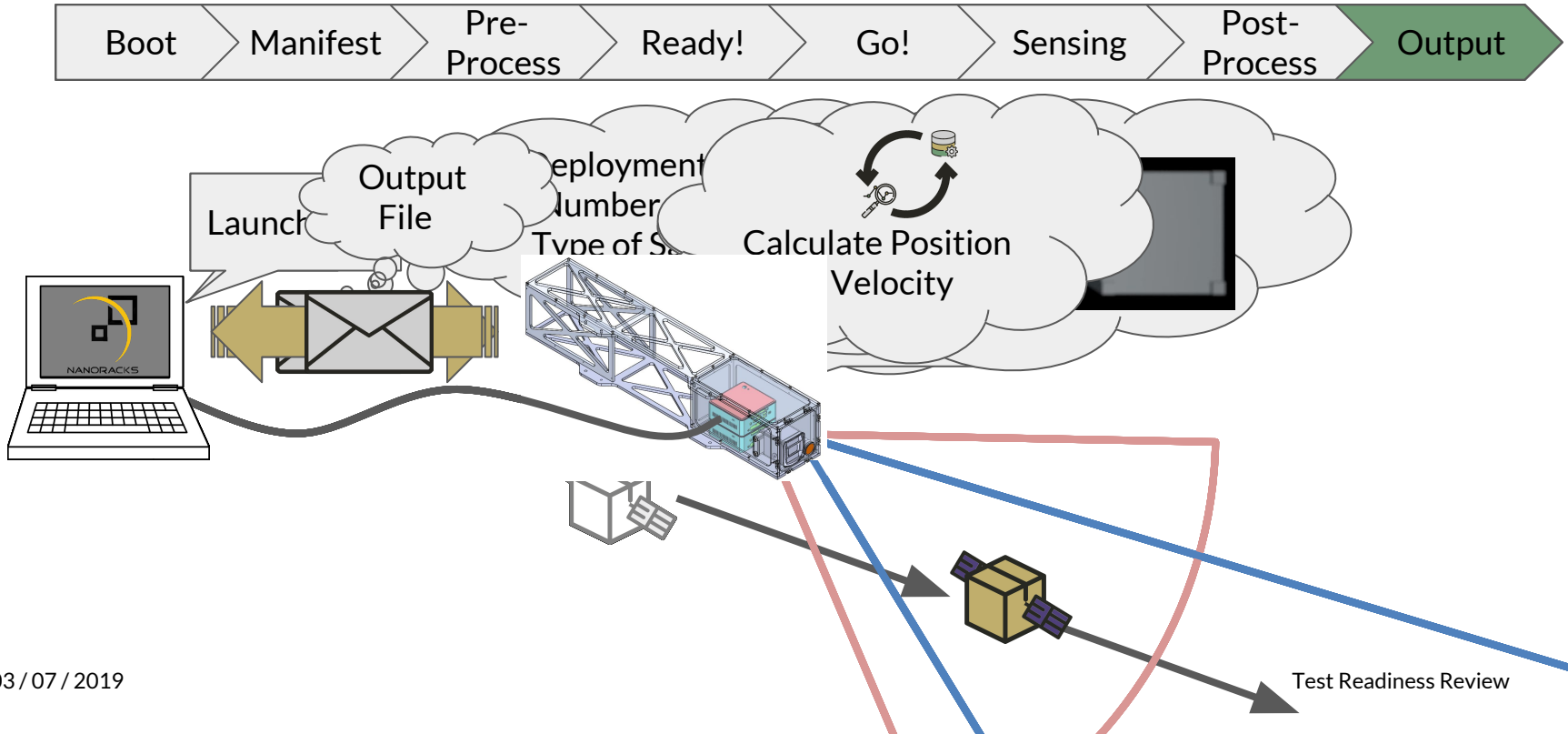
Project Stakeholders:

- Customer: Prof. Axelrad and John Gaebler
- Associated Company: NanoRacks

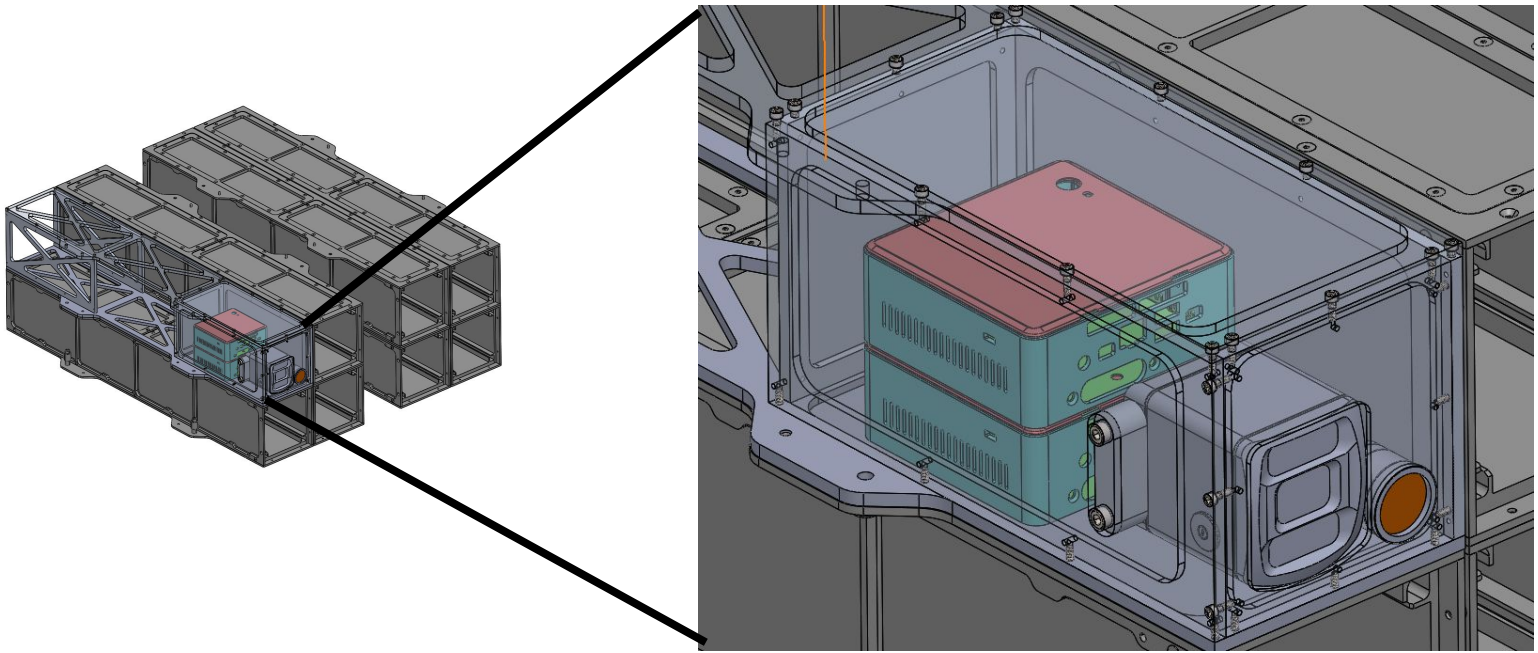
Specific Objectives

Structures - STR *(level 2)*	All key system components ***fit*** in the structure, but they only need to ***function*** as a “flat sat”
Tracking - TRK *(level 2)*	VANTAGE software will ***track the states*** of 1-6 mock CubeSats out to 100m and ***report off-nominal velocities*** of these CubeSats
Power - EPS *(level 3)*	VANTAGE’s EPS will distribute power corresponding to the available power from the NR deployer
Testing - TST *(level 2)*	Test rigs can ***simulate physical deployment*** of up to six (6) mock CubeSats ***out to 100m*** and record position ***truth data***

CONOPS

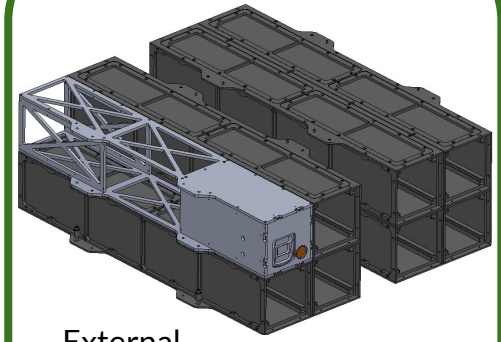

Boot
Manifest
Pre-Process
Ready!
Go!
Sensing
Post-Process
Output
Launch
Output File
Calculate Position
Velocity
NANORACKS

Baseline Design Overview



Baseline Design Overview

Interface With NanoRacks Ground-based Hardware

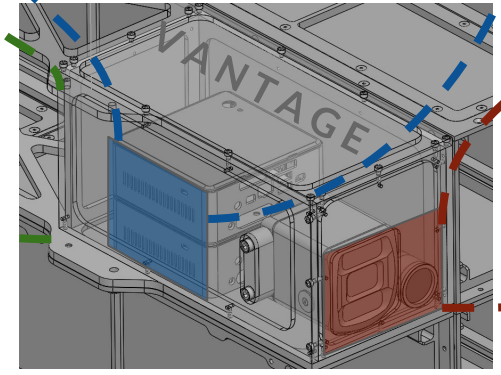


External Mounting

Avionics and Software

Next Unit of Computing (NUC)

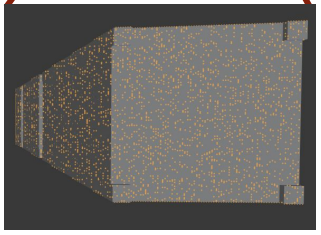
MATLAB SW

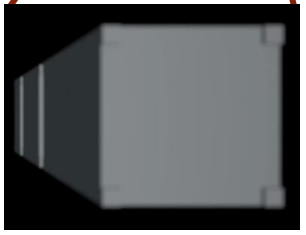


Acquire Data

Time of Flight (TOF) Camera

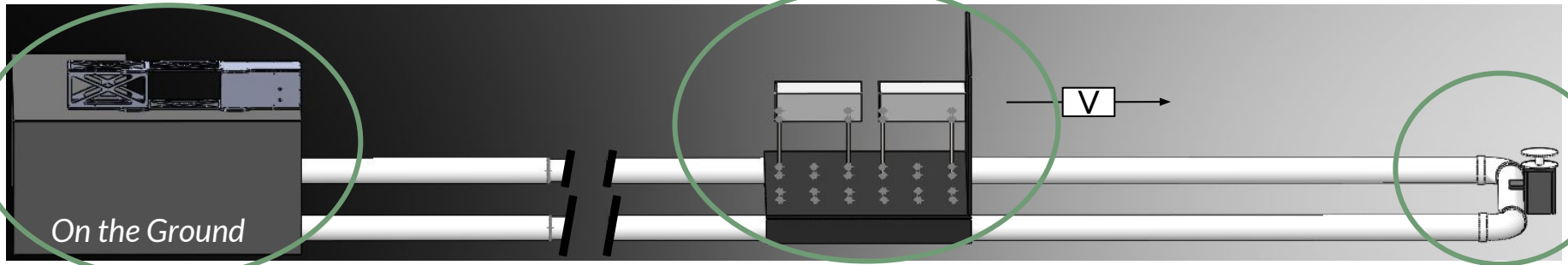
Monochrome Camera



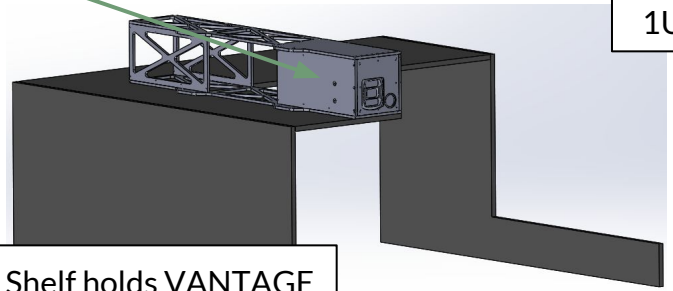


Modular Test Overview

Full Track Not Shown

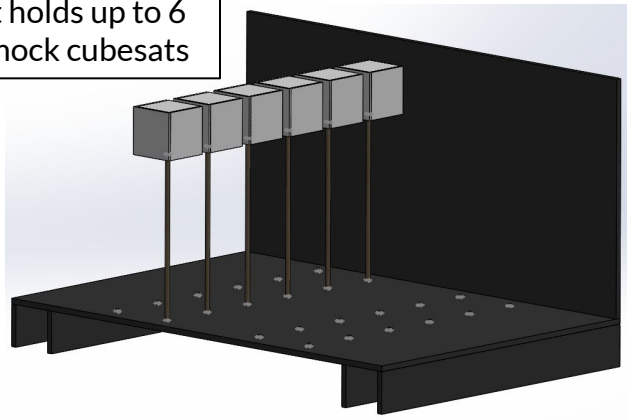


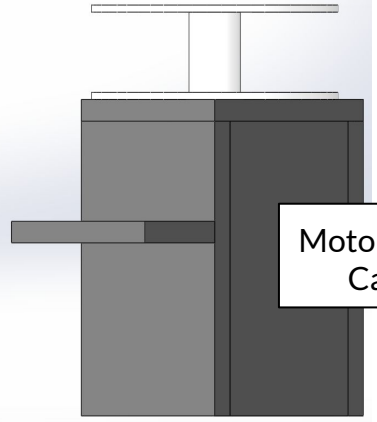
VANTAGE



Shelf holds VANTAGE structure

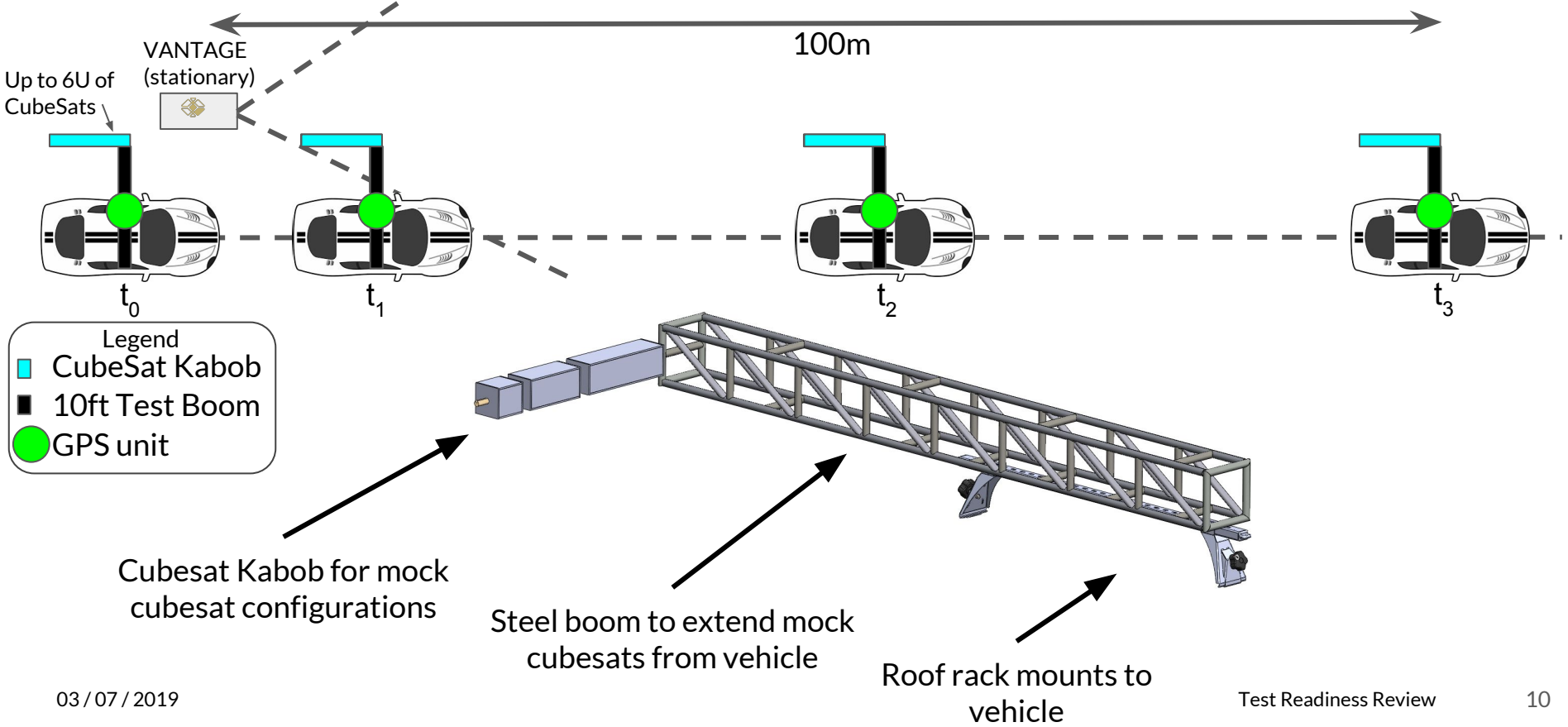
Cart holds up to 6 1U mock cubesats





Motor pulls Cart

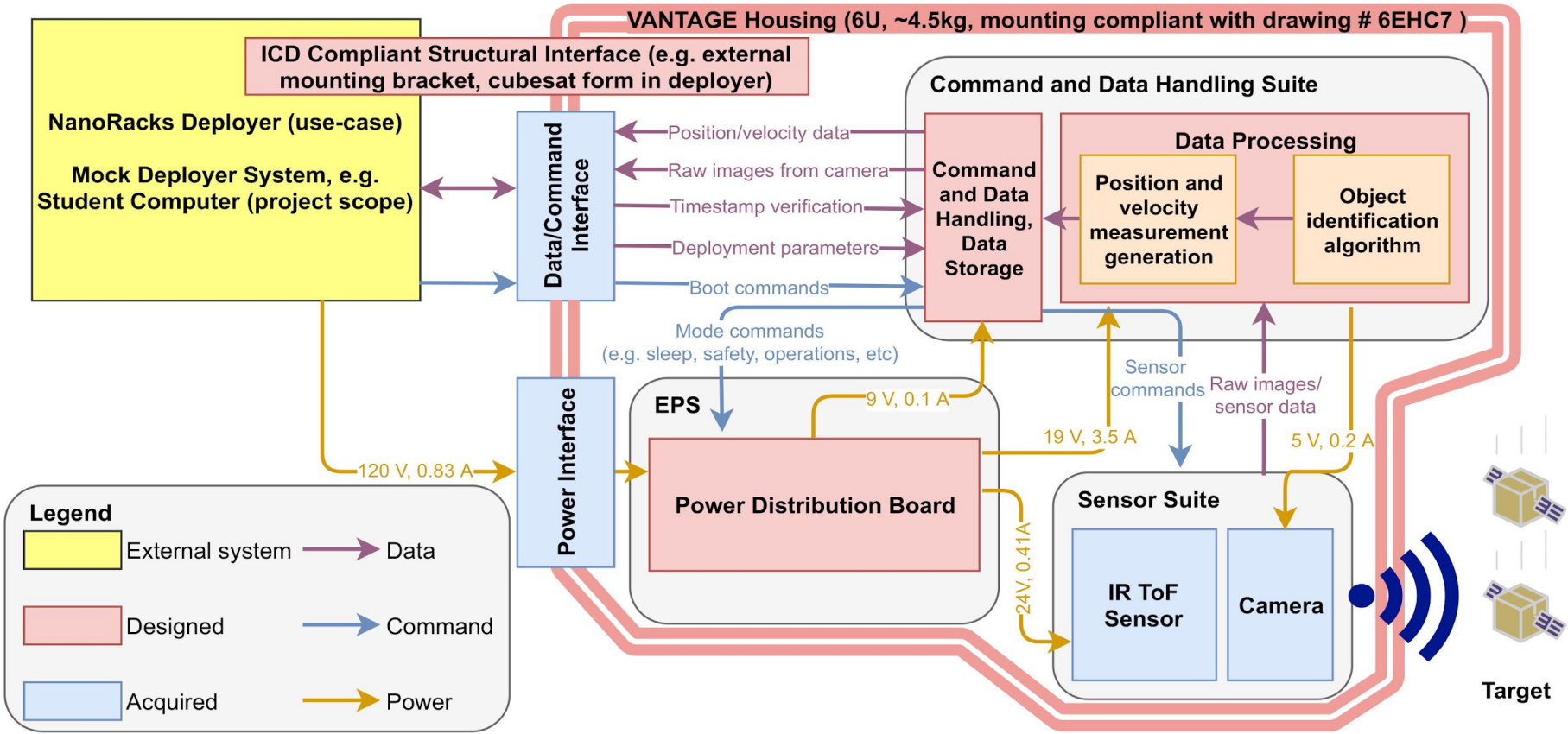
100m Test Overview



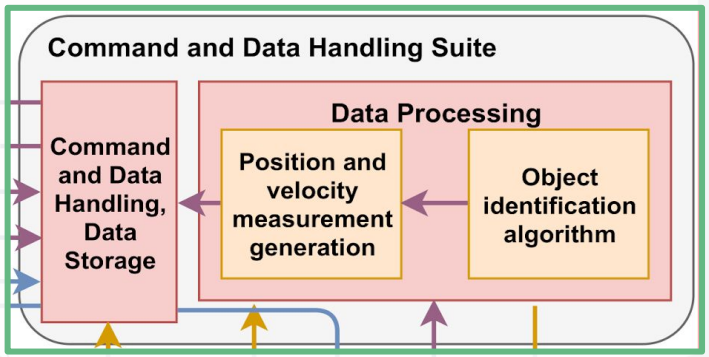
Design Updates Since MSR

- Modular test motor changed from a stepper motor to a DC brushless motor to increase velocity range and decrease complexity.

Critical Manufacturing Elements



Critical Testing Elements



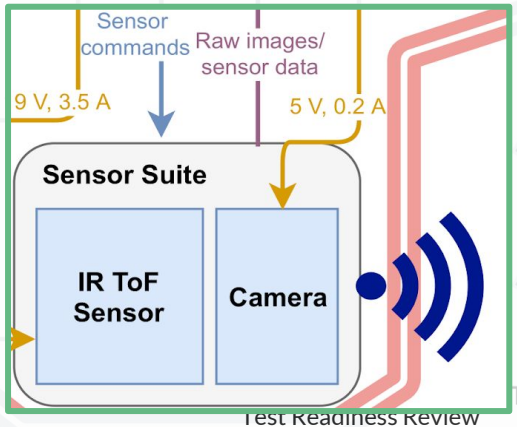
CPE Summary	Specific Objective	Testing Item
Calculate Individual CubeSat Position and Velocity Within Error Bounds	Tracking Lvl. 2	Use Simulated Data to Verify **Software** and Data Handling Functionality

Critical Test Elements

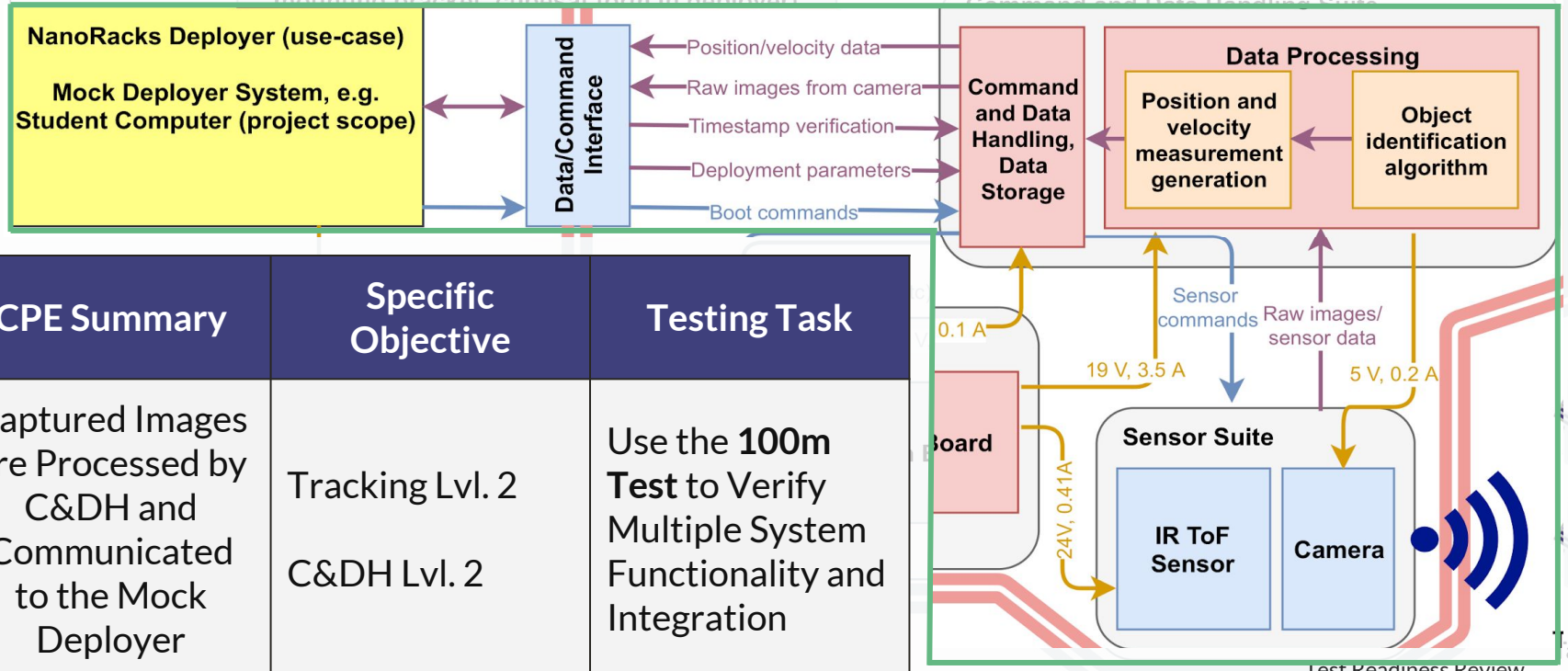
CPE Summary	Specific Objective	Testing Task
Individual Components Will Fit Inside the VANTAGE Structure and the Structure Will Interface With the NanoRacks System	Structures Lvl. 2	The VANTAGE **Structure** Will Be Integrated Onto the NanoRacks Deployer to Verify Compliance

Critical Testing Elements

CPE Summary	Specific Objective	Testing Task
VANTAGE Captures and Stores Sensor Data for Future Processing	Command & Data Handling Lvl. 2	Use **Modular Test** Data to Verify Sensor Functionality and Software Integration



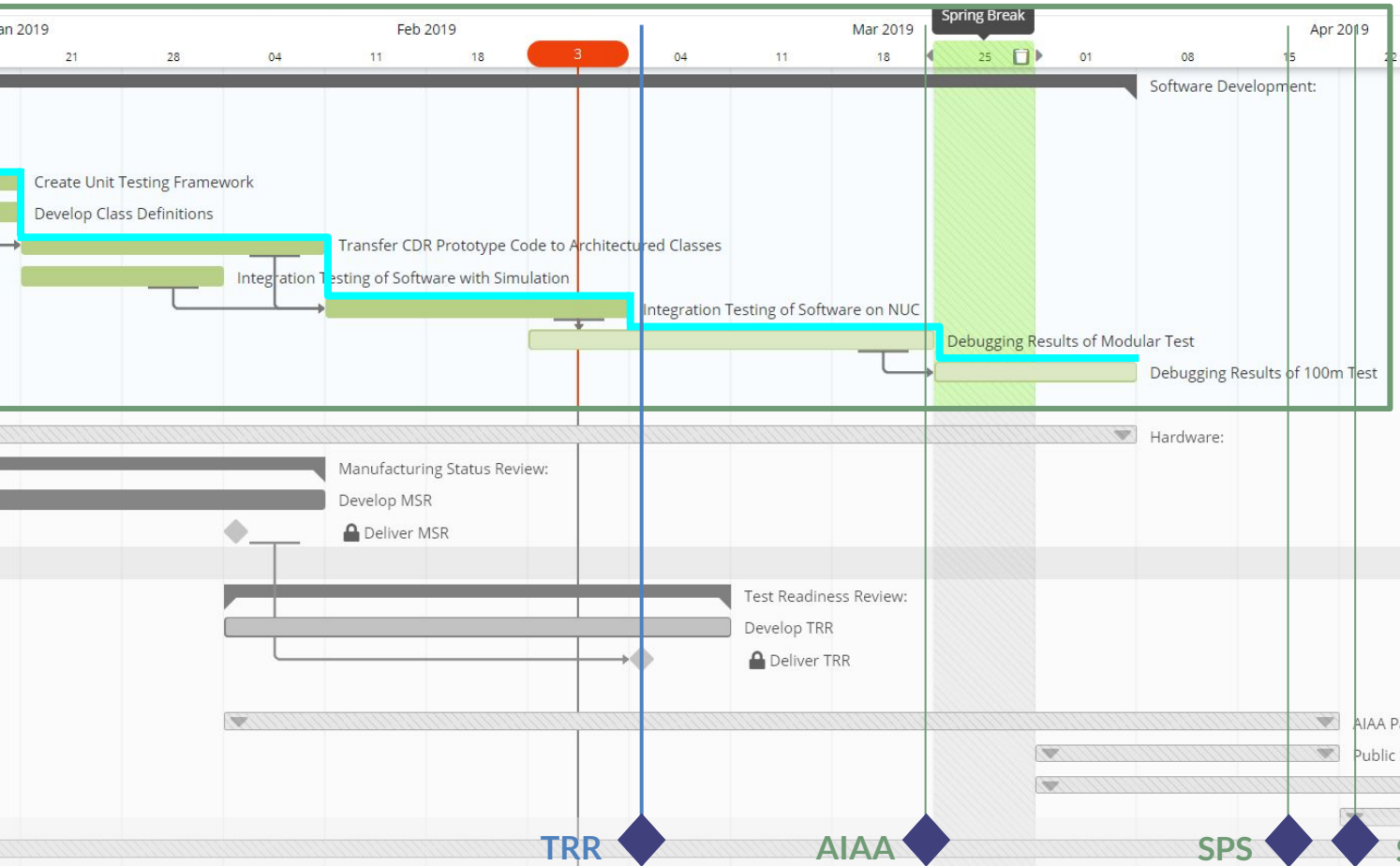
Critical Testing Elements



CPE Summary	Specific Objective	Testing Task
Captured Images are Processed by C&DH and Communicated to the Mock Deployer	Tracking Lvl. 2 C&DH Lvl. 2	Use the **100m Test** to Verify Multiple System Functionality and Integration

Schedule

Software Test Schedule

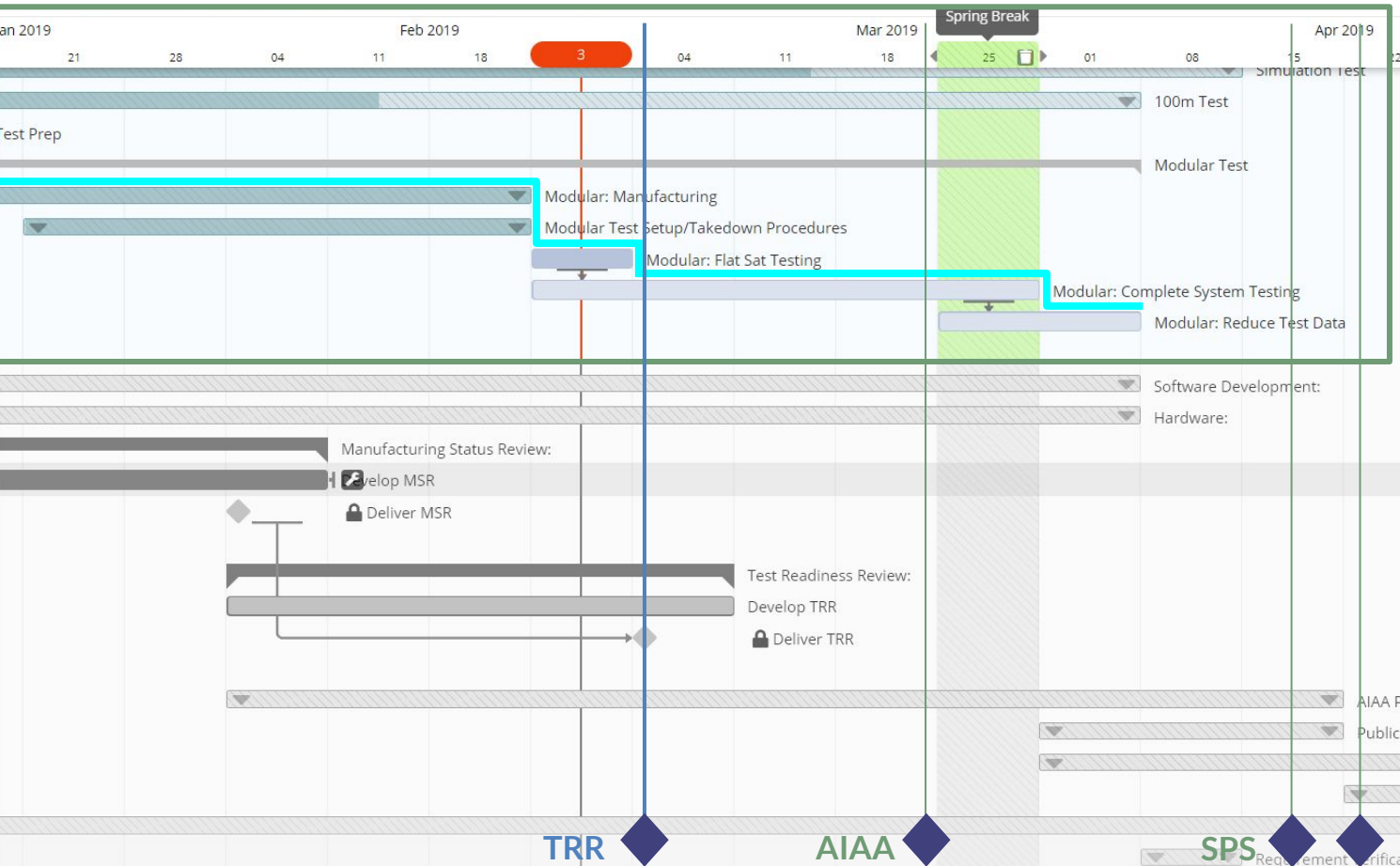


All Tasks have built in 10% approximate margin

LEGEND

- *Critical Path*
- Safety
- Electronics
- Software
- Sensors
- Structures
- Testing
- Finance

Modular Test Schedule

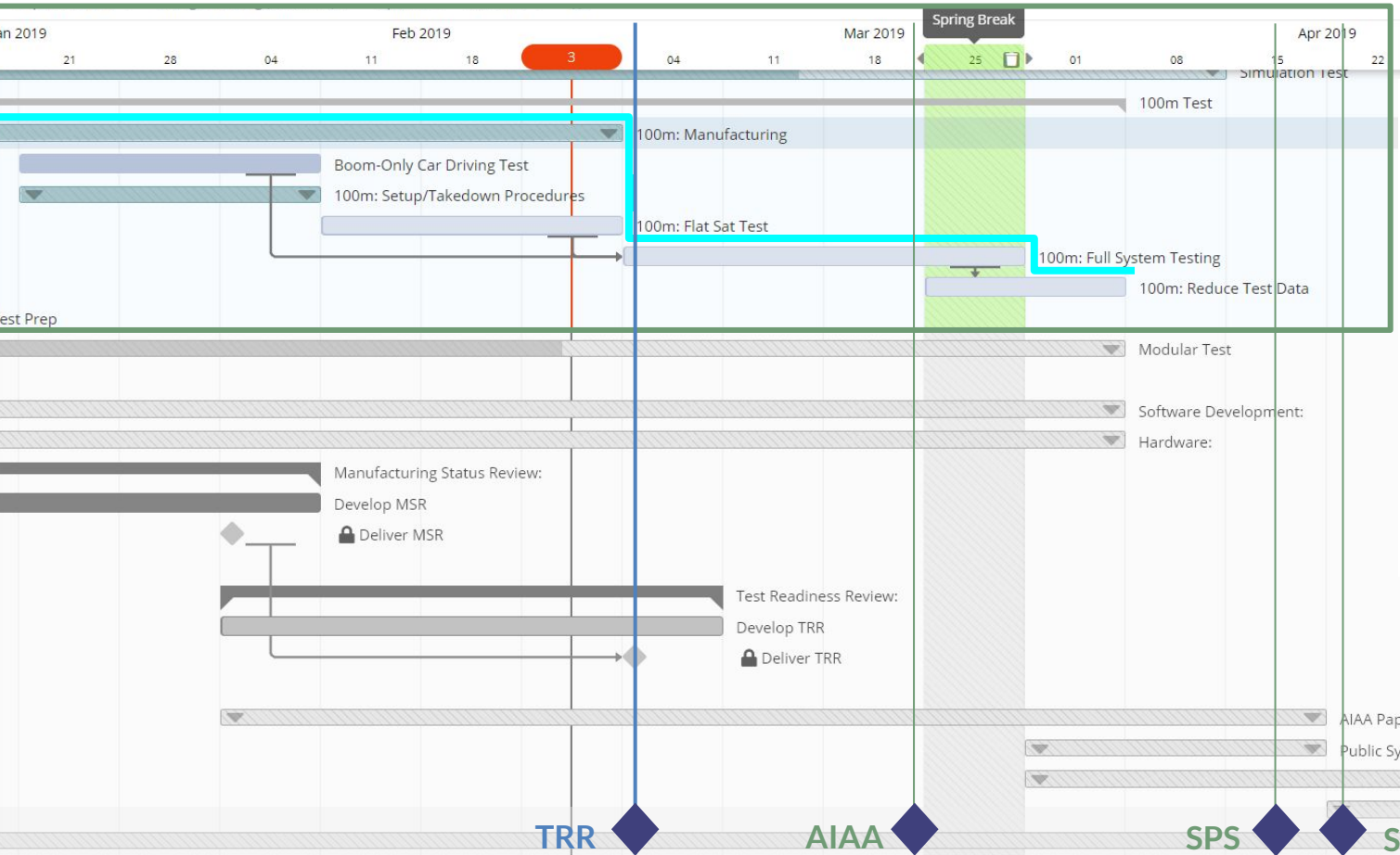


All Tasks have built in 10% approximate <u>margin</u>

LEGEND

- *Critical Path*
- Safety
- Electronics
- Software
- Sensors
- Structures
- Testing
- Finance

100m Test Schedule



All Tasks have built in 10% approximate margin

LEGEND

- *Critical Path*
- Safety
- Electronics
- Software
- Sensors
- Structures
- Testing
- Finance

Test Readiness

Testing Overview

Subsystem Testing

- Software Functions
- GPS Error Characterization
- VICON Error Characterization
- Modular Test Structural Fit
- EPS Load Test
- 100 m Test Structural Fit
- Modular Test Motor Test

Integration Testing

- Sensors-Structural Integration Test
- Sensors-Software Integration Test
- Sensors-NUC Integration Test
- Sensors-Modular Test Rig Integration Test
- Sensor Calibration
- VICON-VANTAGE Data Integration
- Raspberry Pi & NUC LAN Boot
- Electrical System
- Data Transfer Test
- Structures-NanoRacks Deployer Fit Test

System Testing

- Simulation Test
- Modular Test
- 100 m Test

Legend

- In Progress
- Not Started
- Completed

Software Integration Testing

Subsystem Testing

- Software Functions
- GPS Error Characterization
- VICON Error Characterization
- Modular Test Structural Fit
- EPS Load Test
- 100 m Test Structural Fit
- Modular Test Motor Test

Integration Testing

- Sensors-Structural
- Sensors-Software Integration Test
- Integration Test
- Sensors-Modular Test Rig Integration Test
- Sensor Calibration
- VICON-VANTAGE Data Integration
- Raspberry Pi & NUC LAN Boot
- Electrical System
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System Testing

- Simulation Test
- Modular Test
- 100 m Test

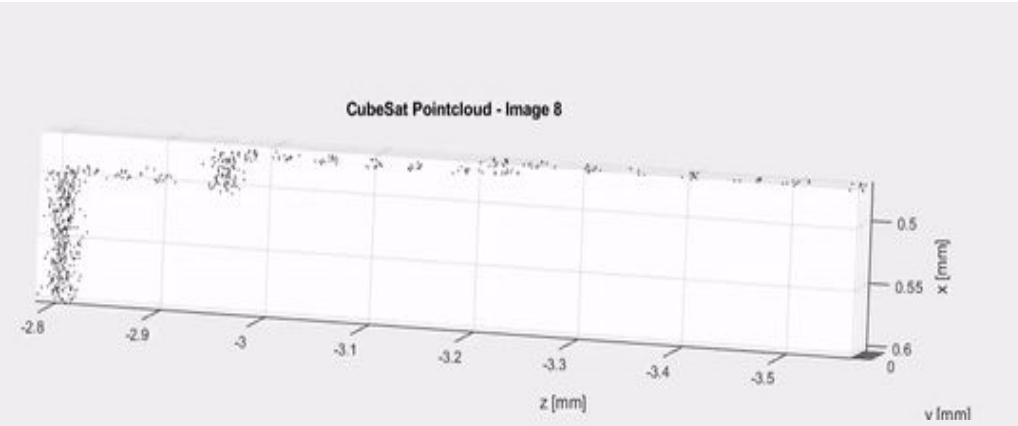
Legend

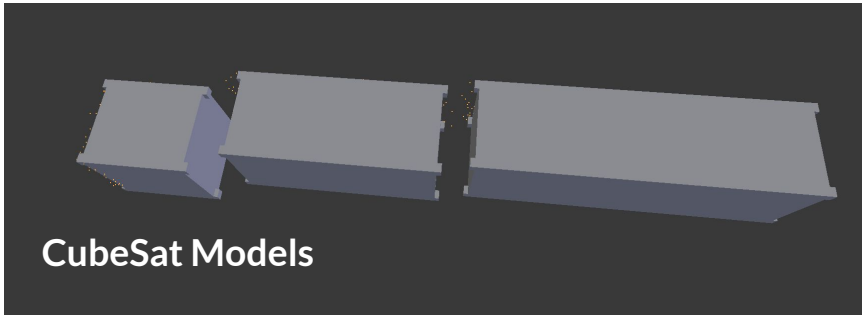
- In Progress
- Not Started
- Completed

Sensor-Hardware Integration

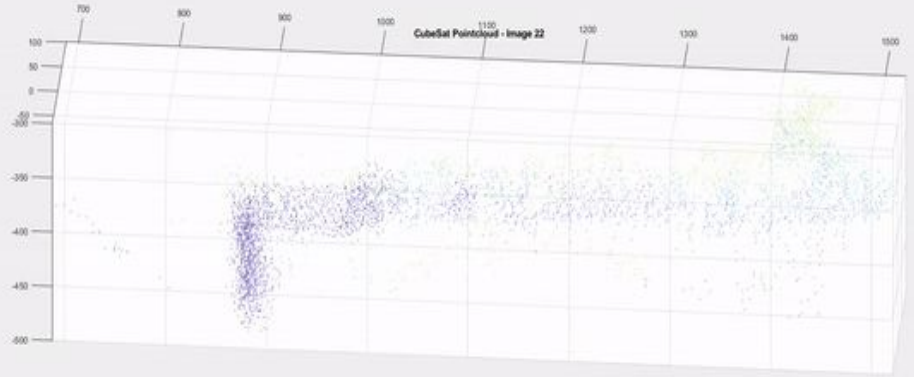
Model Validated	Risk Buy-Down	Expected Results	Status	Obstacles/Mitigation
Validate sensor integration with VANTAGE software for automated data capture	VANTAGE can perform integrated tests	Automated point cloud and grayscale image outputs from sensors	Initial setup complete	Ensuring consistent data capture/Extensive modular testing, reallocating resources

TOF Camera Integration



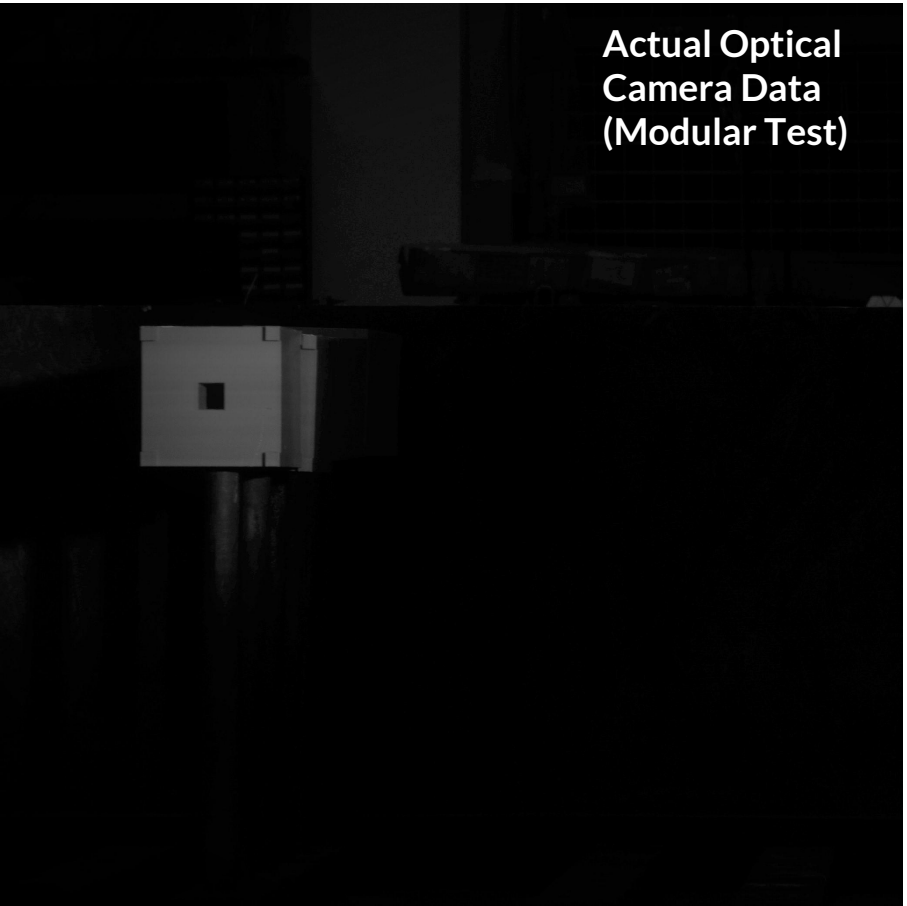


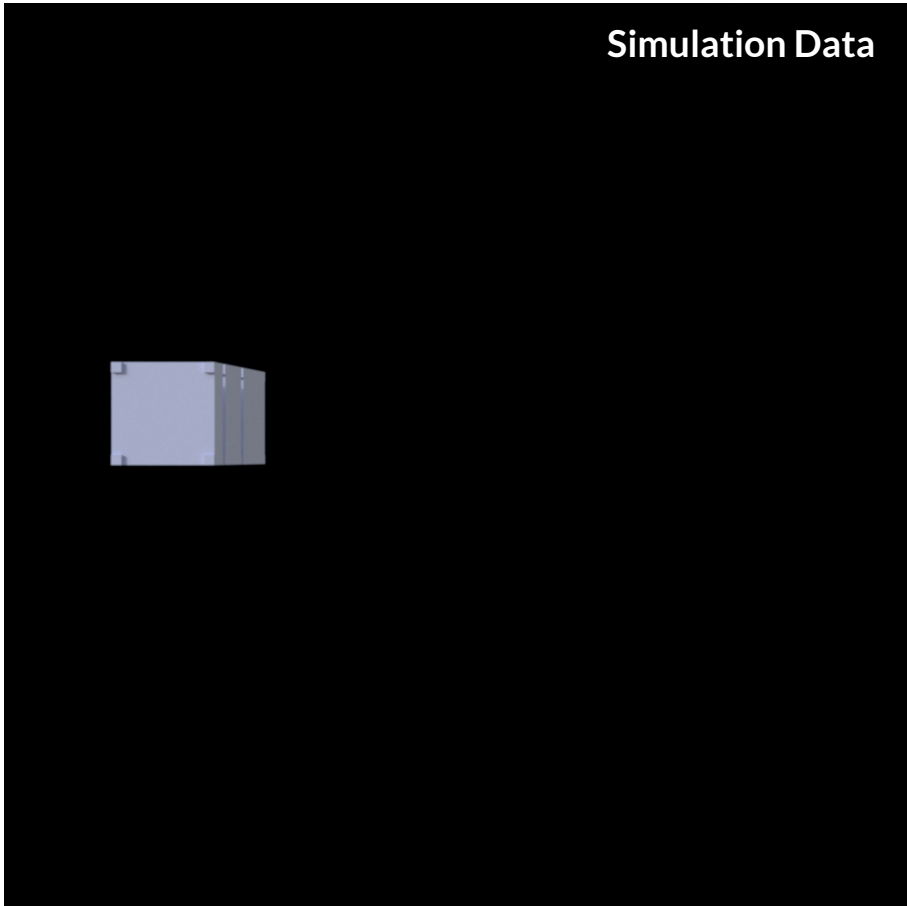
Simulation Data
(from Modular Test Simulation)



Actual ToF Sensor Data
(from Modular Test)

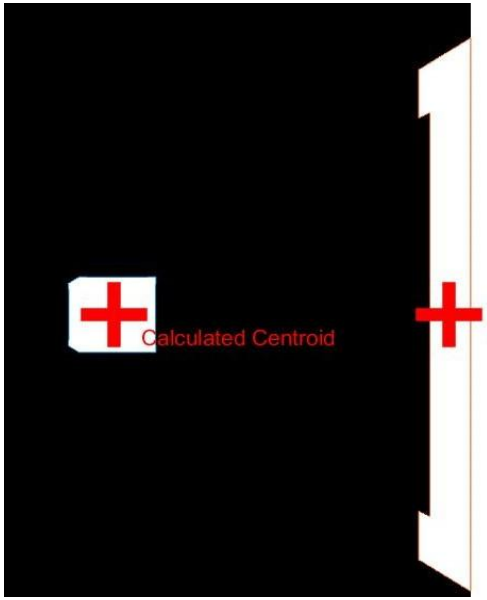
Optical Camera Integration

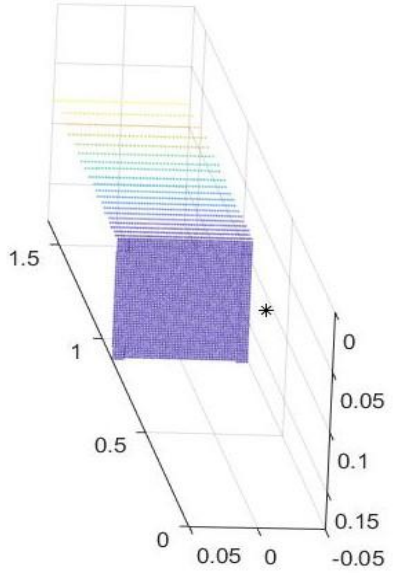




Integrated System Object Detection

Optical Object Detections





ToF Object Detection

Model Validated	Risk Buy-Down	Expected Results	Status	Obstacles/Mitigation
Validate processing of test data to meet software requirements	Using simulated data to increase real-world testing efficiency	Object detection in both grayscale and point cloud data sets	Unit tests for major functionality written	Pipelining unit tests into full system/Collaborative coding sessions

Structural Interface Testing

Subsystem Testing

- Software Functions
- GPS Error Characterization
- VICON Error Characterization
- Modular Test Structural Fit
- EPS Load Test
- 100 m Test Structural Fit
- Modular Test Motor Test

Integration Testing

- Sensors-Structural Integration Test
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- Data Transfer Test
- Structures-NanoRacks Deployer Fit Test

System Testing

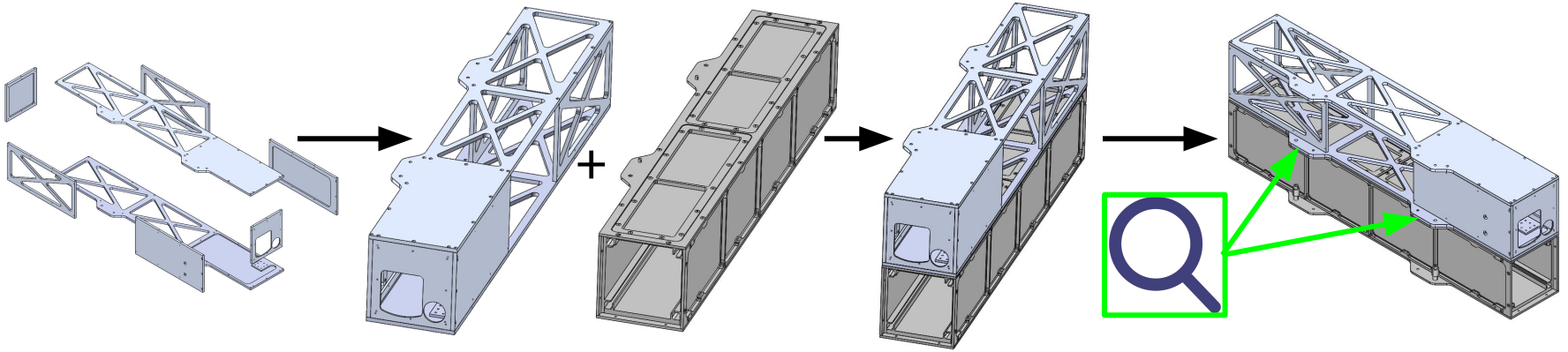
- Simulation Test
- Modular Test
- 100 m Test

Legend

- In Progress
- Not Started
- Completed

Structural Interface Test

OBJECTIVE: Be Mechanical ICD Compliant with NanoRacks Hardware



Model Validated	Risk Buy-Down	Expected Results	Status	Obstacles/Mitigation
Validate CAD and CAM for building the VANTAGE structure to support future iterations	VANTAGE provides a future platform for flight payloads	Structure integrates with the NanoRacks Deployer	In Manufacturing	Machining Time/ Early Completion and Plenty of Extra Time

Sensor Calibration Testing

Subsystem Testing

- Software Functions
- GPS Error Characterization
- VICON Error Characterization
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- EPS Load Test
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Integration Testing

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System Testing

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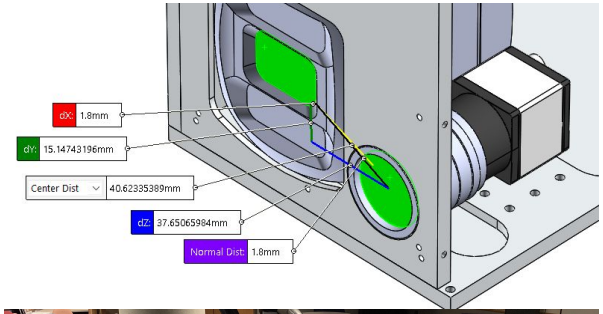
Legend

- In Progress
- Not Started
- Completed

Sensor Calibration Test

Objective: To calculate each camera's intrinsic parameters and relative position and orientation between the two cameras.

Procedure: Take images of a checkerboard in various orientations with both cameras at the same time. Use **stereo camera calibration** techniques to determine positional and angular orientation and uncertainties



Preliminary Stereo Calibration Results:

Measurements + uncertainty within expectations from mechanical model:

- Angular Uncertainty: [**2.67 4.82 0.34**] **degrees** **[x,y,z]**
- Camera Relative Positional Uncertainty: **12 mm**

Models Validated	Risk Buy-Down	Expected Results	Status	Obstacles/ Mitigation
Pinhole Camera Model, Mechanical Mounting Model	Tracing sources of error, systematic biases in data	Knowledge of pointing of sensors should be well within total error requirements	Iterating to improve uncertainty	Large calibration uncertainties -> More, smarter samples

Modular Test Overview

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- Not Started
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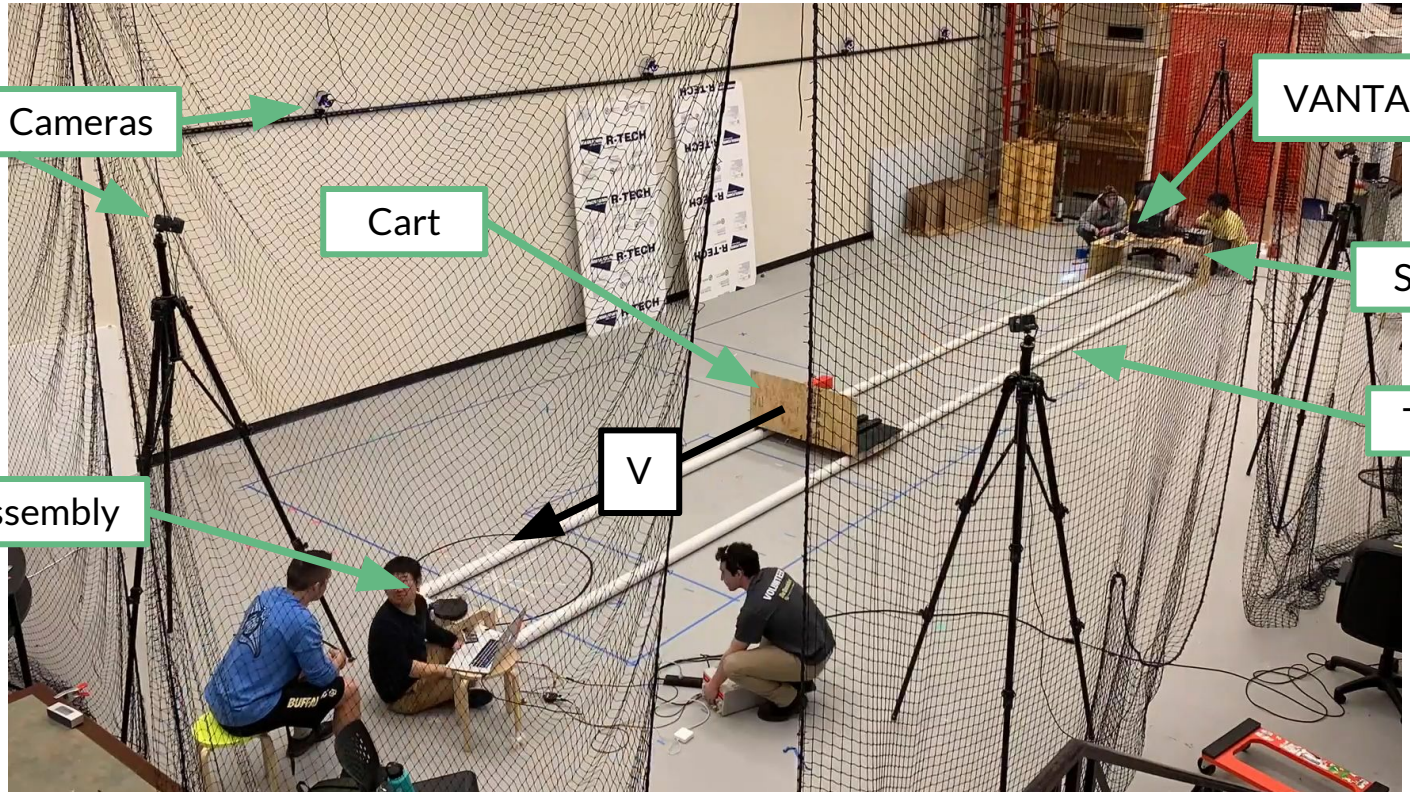
Modular Test Objectives

Test Objectives	Relevant DR's
Camera system functionality and single infocus image return	DR.1.1 DR.1.3 DR.1.4
Mock cubesat detection at 10 m range	DR.5.2
Position vector and velocity vector measurements are within error bounds for 10 m range	DR.6.1 DR.6.2
Off-nominal ejection times and velocities	DR.7.2 DR.7.3

Most Critical for Project Success

Modular Test Overview/Procedure



Modular Test Overview

Status

- Initial data collection has been done
- Error inherent in VICON has been characterized
- *Motor re-design in progress*
  - Motor Controller underperforming: max velocity ~0.625 m/s
  - Switching to a new motor with triple the torque that doesn't require a controller

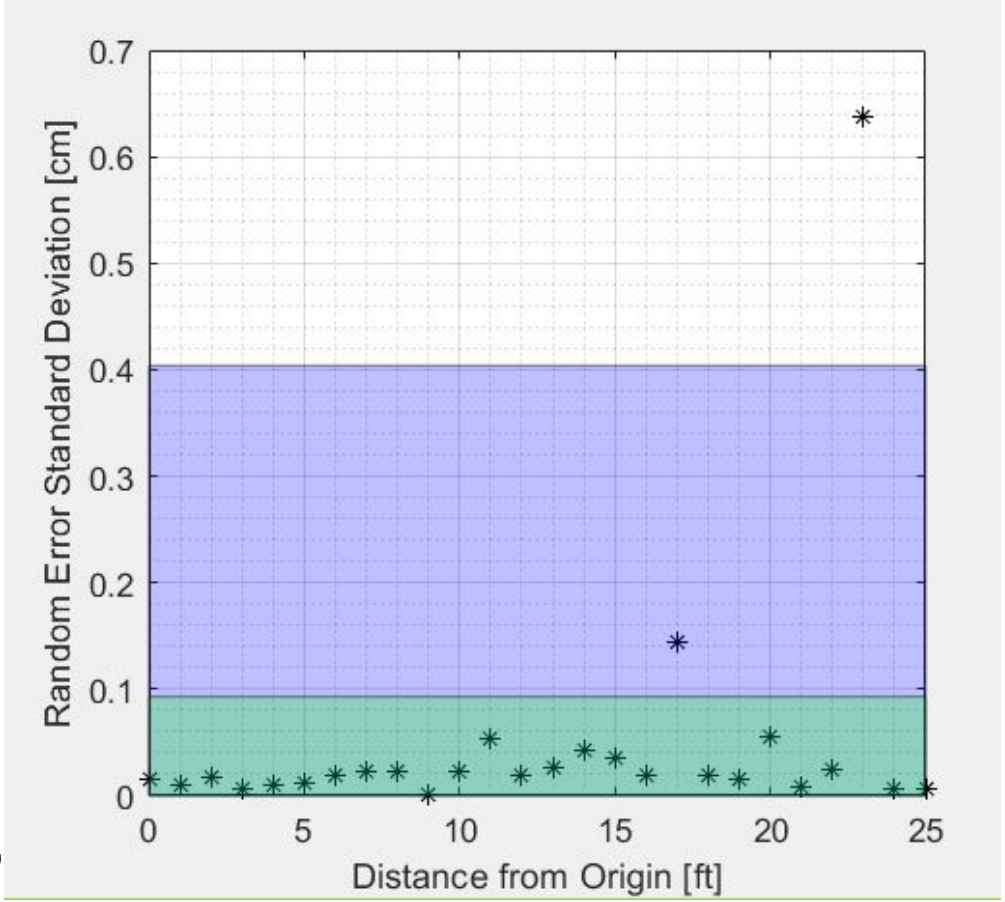
Equipment/Facilities

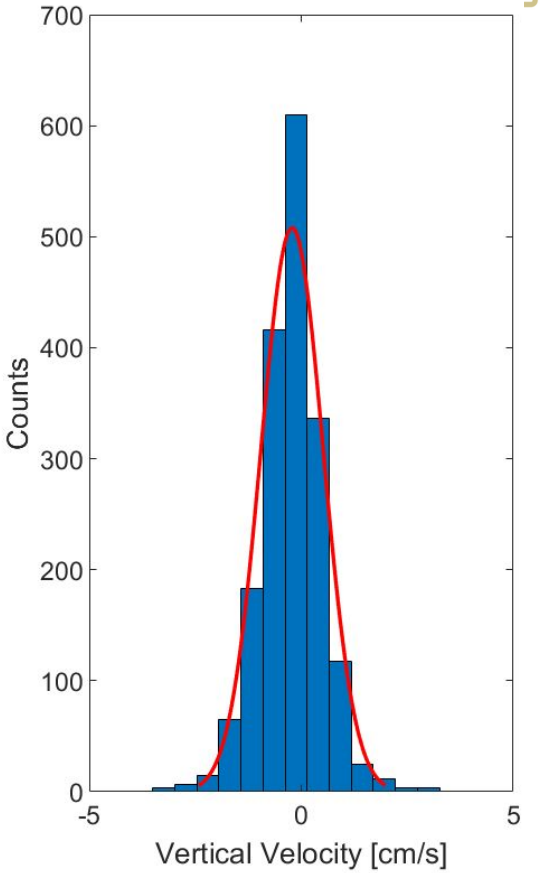
- Two Power Supplies (TOF Camera & Motor)
- Modular Test Rig
- VICON Tracker Balls
- VANTAGE Sensor Package
- Test done at RECUV VICON Lab

Modular Test Results

Expected Results	Test Objectives
Images of mock cubesats being deployed	Camera system functionality and single infocus image return
VANTAGE frame x,y,z cubesat centroid positions	Mock cubesat detection at 10 m range
VICON x,y,z positions & a fixed position offset vector from VICON object center to each cubesat centroid	Position vector and velocity vector measurements are within error bounds for 10 m range
Data from off-nominal deployments	Off-nominal ejection times and velocities

VICON Error Characterization





100 m Test Overview

Subsystem Testing

- Software Functions
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- VICON Error Characterization
- Modular Test Structural Fit
- EPS Load Test
- 100 m Test Structural Fit
- Modular Test Motor Test

Integration Testing

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System Testing

- Simulation Test
- Modular Test
- 100 m Test

Legend

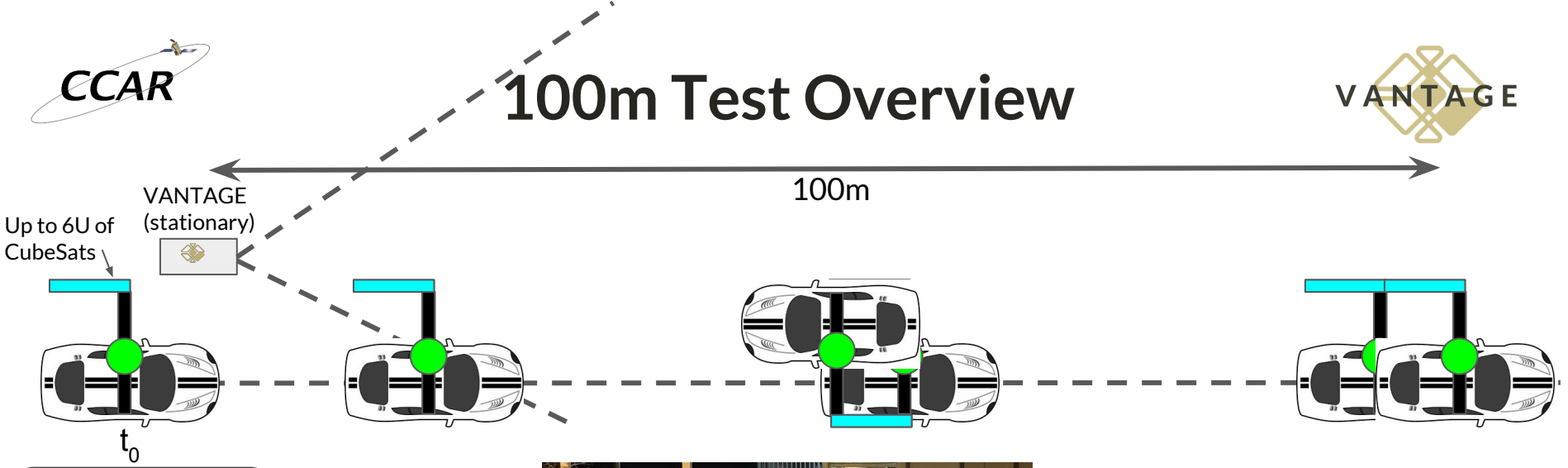
- In Progress
- Not Started
- Completed

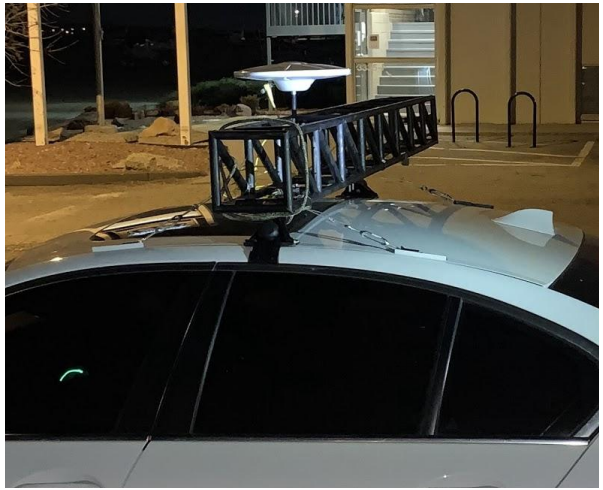
100m Test Objectives

Test Objectives	Relevant DR's
Mock cubesat detection at 100 m range	DR.5.2
Position vector and velocity vector measurements are within error bounds for 100 m range	DR.6.1 DR.6.2
Report data larger data file back to the user within allotted time	DR.8.1

Most Critical for Project Success

100m Test Overview





100m Test Overview

Status

- All fit checks have been completed
- Done a dry run of on site setup
- GPS uncertainty characterized
- Waiting for software to work with modular test data to characterize VANTAGE uncertainty
  - Ready to test when software is ready for full system automated testing

Equipment / Facilities

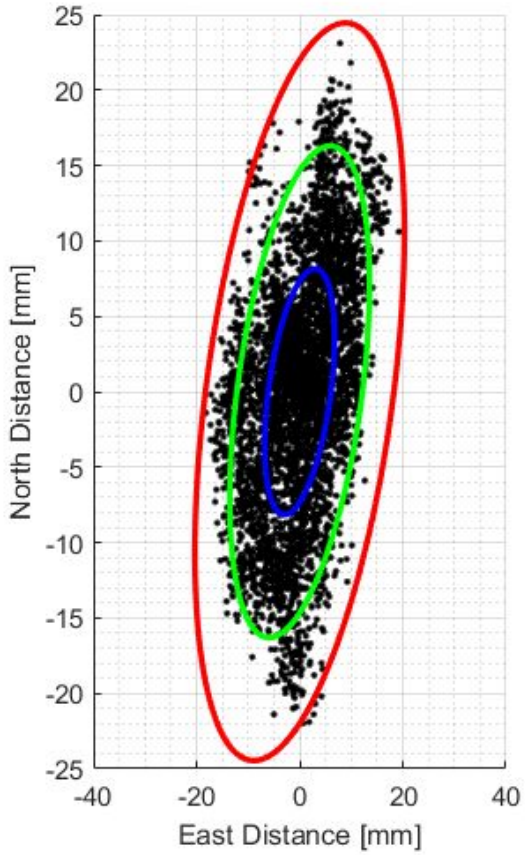
- Boulder Airport location works great
- Power generator available from Trudy
- All test rig stuff is ready
- VANTAGE sensor package ready with student computer ground station

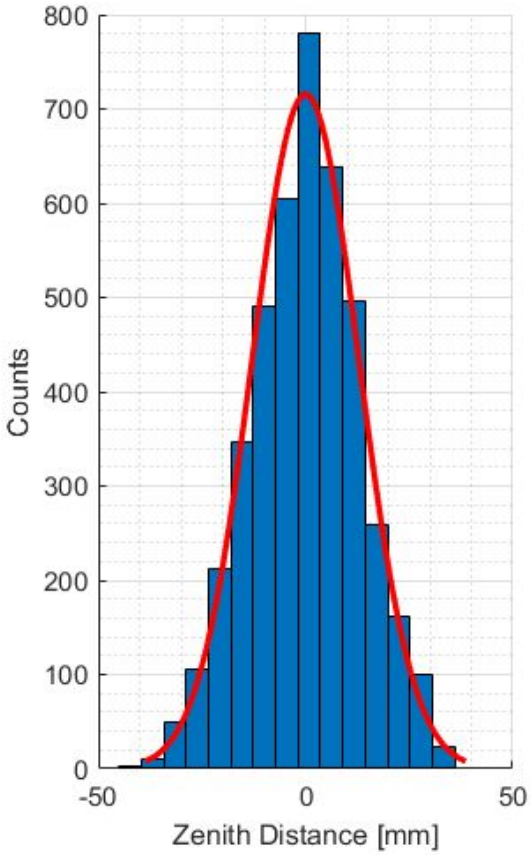
100 m Test Results

Expected Results	Test Objectives
Images of mock cubesats being deployed	Mock cubesat detection at 100 m range
VANTAGE frame x,y,z cubesat centroid positions & GPS truth x,y,z positions*	Position vector and velocity vector measurements are within error bounds for 100 m range
VANTAGE output file	Report data larger data file back to the user within allotted time

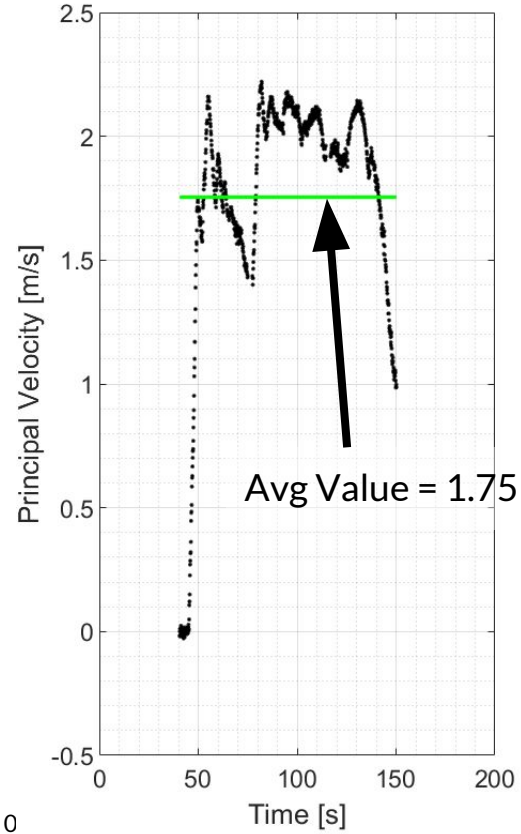
*Includes a fixed position offset vector from GPS antenna to each cubesat centroid

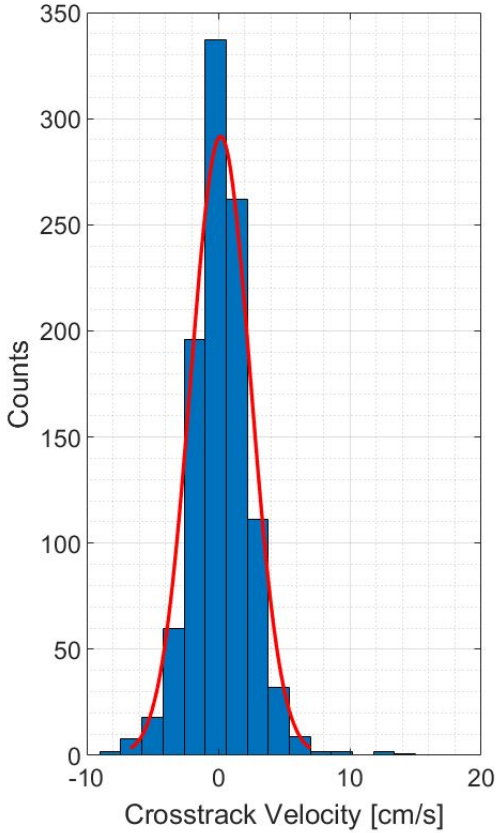
GPS Noise Characterization

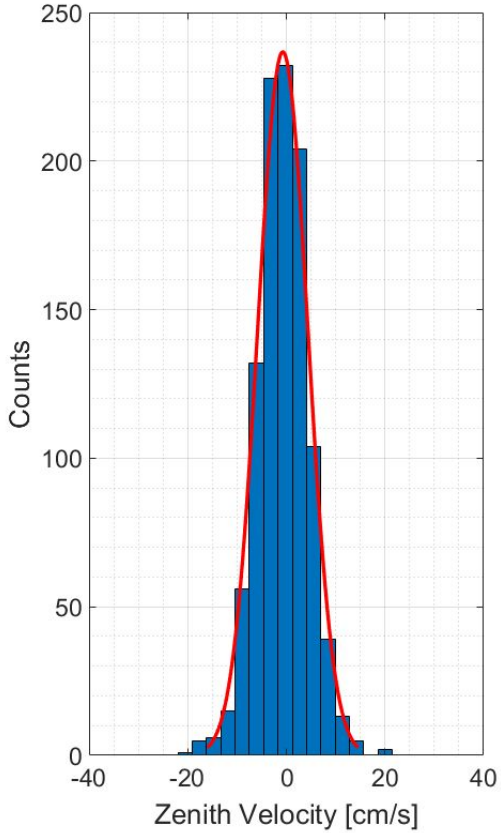




100m Test Velocity Characterization







Safety Status

Safety Procedures For Testing

Testing Procedures and Safety Regulations have been created for each of VANTAGE's main tests.

Modular Test

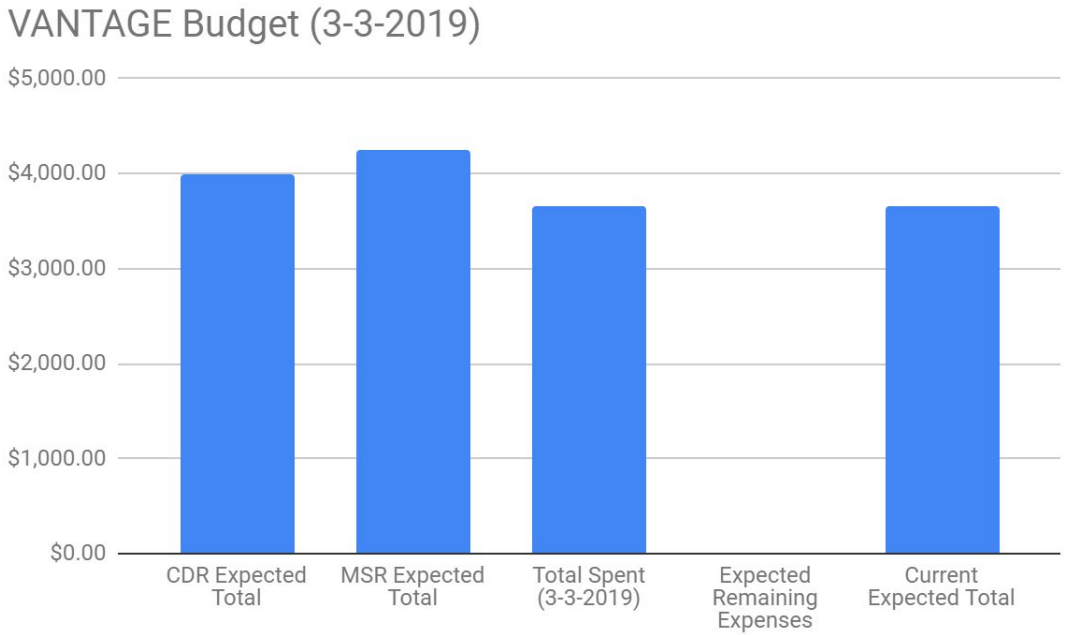
- When entering and exiting the VICON space, individuals should take precautions not to trip over or knock into *VICON netting or cameras*.
- No person should handle the cart, spool, or motor while the *motor is on*.
- *Sensors* should be handled with two hands and stored carefully.
- Each individual should *stand at least two feet away* from the testing system while it is running.

100m Test

- To ensure equipment safety, all equipment shall be *transported* and set up according to testing procedures. All testing will be rescheduled to avoid inclement weather.
- All members present during testing should be familiar with the testing procedures. While running a test, all members will *stand at least 10m away from the vehicle*.
- To avoid obstacles while in motion, *clear communication protocols* will be used and motion paths will be planned out before moving the vehicle.

Budget

Budget



Subsystem:	Structures	Sensors	Software	Electronics	Testing	Total
CDR Expected Total:	$365.86	$2,430.00	$0.00	$916.22	$645.85	$3,992.07
Remaining Purchases:	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Spent:	$286.33	$2,589.13	$0.00	$207.44	$582.34	$3,665.24
Current Expected Total:	$286.33	$2,589.13	$0.00	$207.44	$582.34	$3,665.24

Questions?