SP4CE

Test Readiness Review (TRR)

Presenters:
Jesse Bartlett, Jasmin Chadha, Cesario Garcia, Vicki Hurd, Jack Lana

Additional Team Members:
Aneesh Balla, Gio Borrani, Ryan Charles, Zach Fields, Sarah Leary

Company Sponsor:
Blue Origin

Faculty Advisor:
Dr. Yu Takahashi

February 23, 2022
ASEN 4018-011 Team 1

Presentation Outline

- Project Overview
- Project Updates
- Schedule
- Test Readiness
- Budget

Project Overview

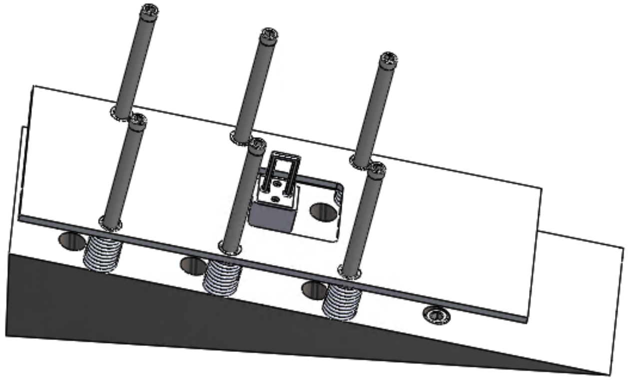
Cesario Garcia

SP4CE Motivation

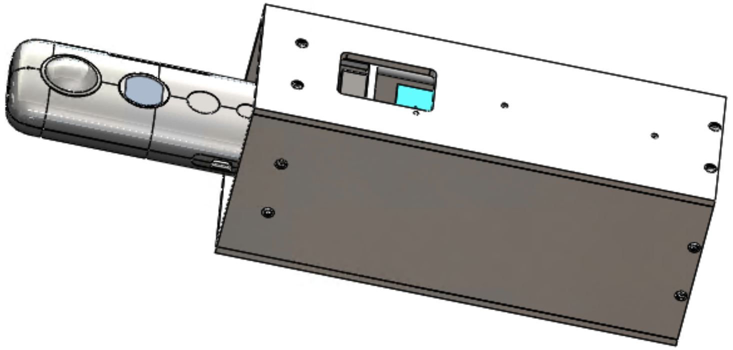
Background: Blue Origin needs a camera module that ejects from the New Shepard Booster at Booster/Crew Capsule separation, safely takes images/videos of astronauts in the Crew Capsule with Earth's horizon in the background, and survives reentry.

Mission Statement

*The **Suborbital Photography For Crew Experience (SP4CE)** module will provide Blue Origin with both a **Camera Ejection Device (CED)**, intended to be mounted inside of the Booster, and a **Crew Capsule Experience Camera (CCEC)** that will be ejected from the Booster, take pictures of the astronauts inside the Crew Capsule, and survive reentry.*



CED



CCEC

Blue Origin

Suborbital Photography for Crew Experience

Phase 1

SP4CE survives ascent within volume, temp, and load requirements

Phase 2

CED ejects CCEC on desired trajectory after Crew Capsule separates from Booster

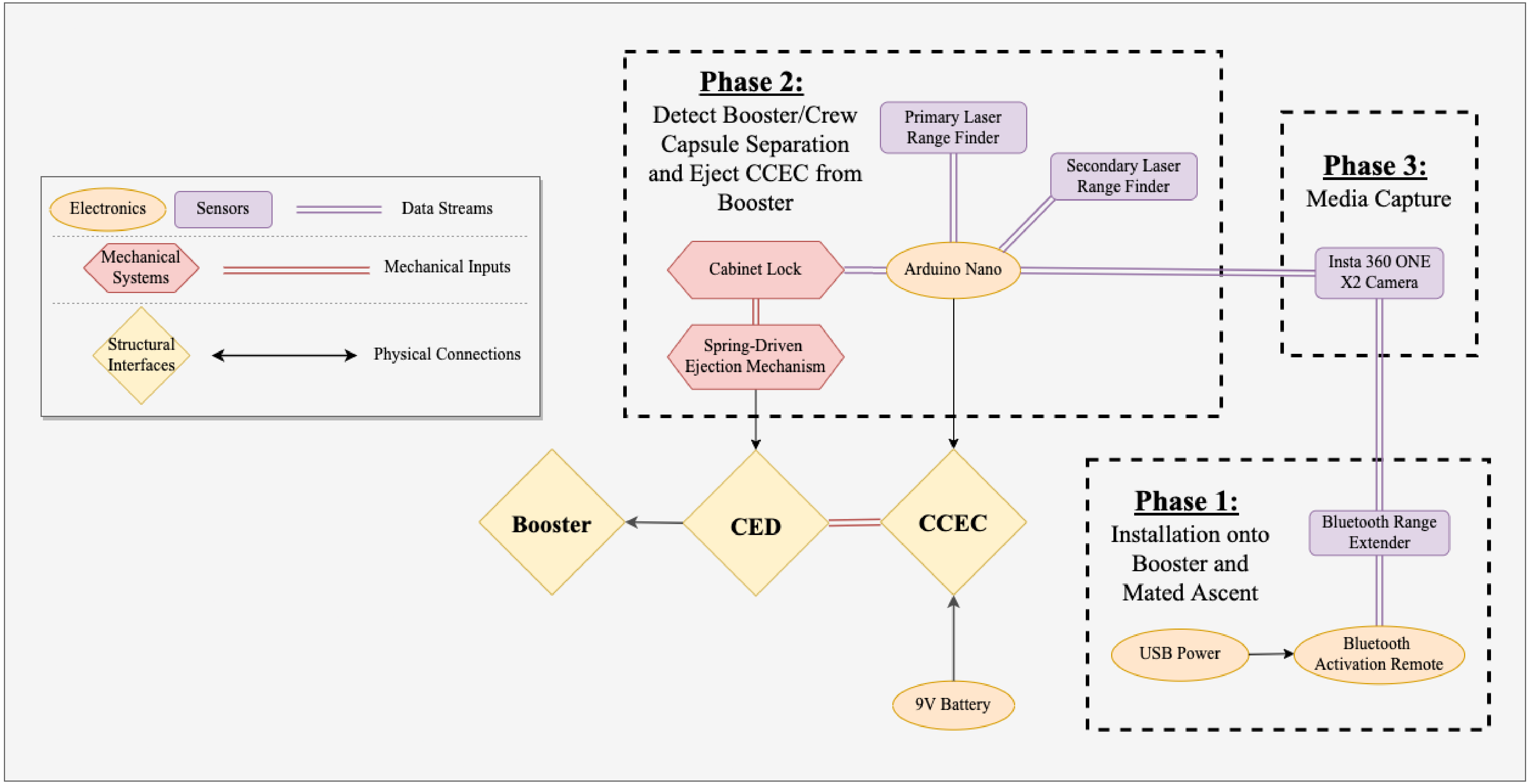
Phase 3

CCEC takes video of crew for 180 seconds and keeps separation from Crew Capsule

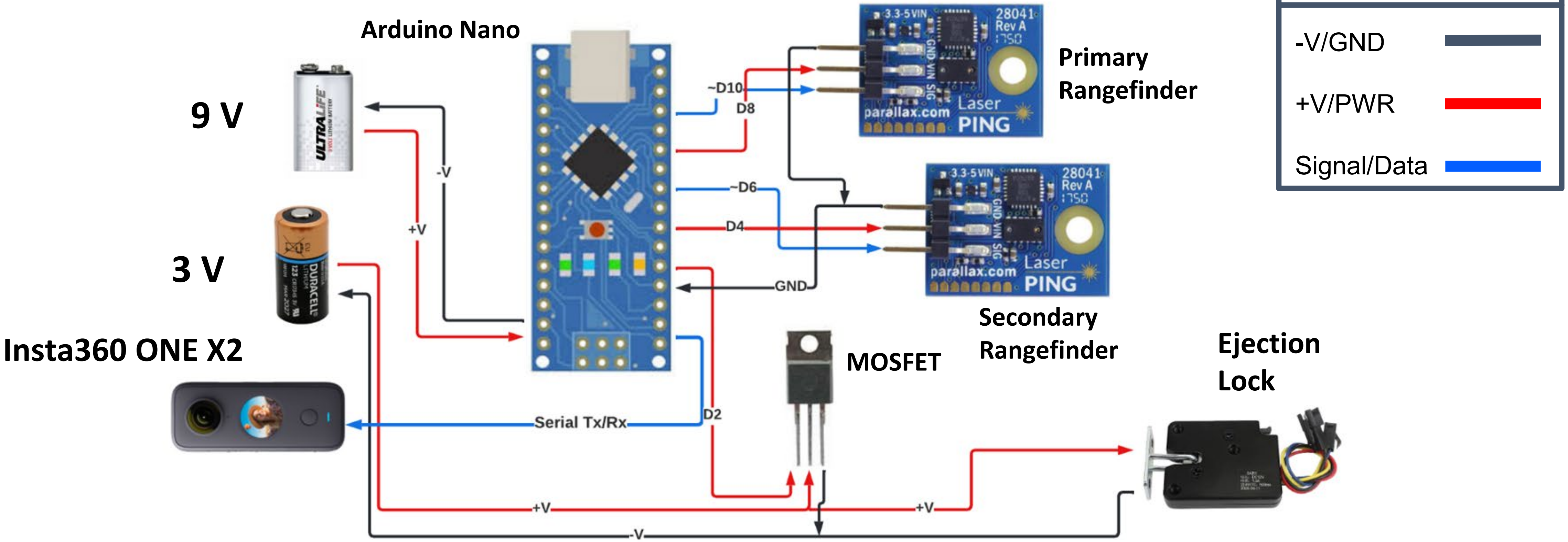
Phase 4

CCEC falls after Crew Capsule to ensure no in-flight contact and survives reentry

Functional Block Diagram



Electronics Diagram



Camera On → Laser On Until Separation → Trigger Ejection @ t ≈ 2s → Verify Ejection Via Laser → Video Capture Start

Primary Objectives

1. CED ejects CCEC **2 s** after Crew Capsule separation

1. CED imparts **9 ft/s** delta-v at **80°** angle on CCEC

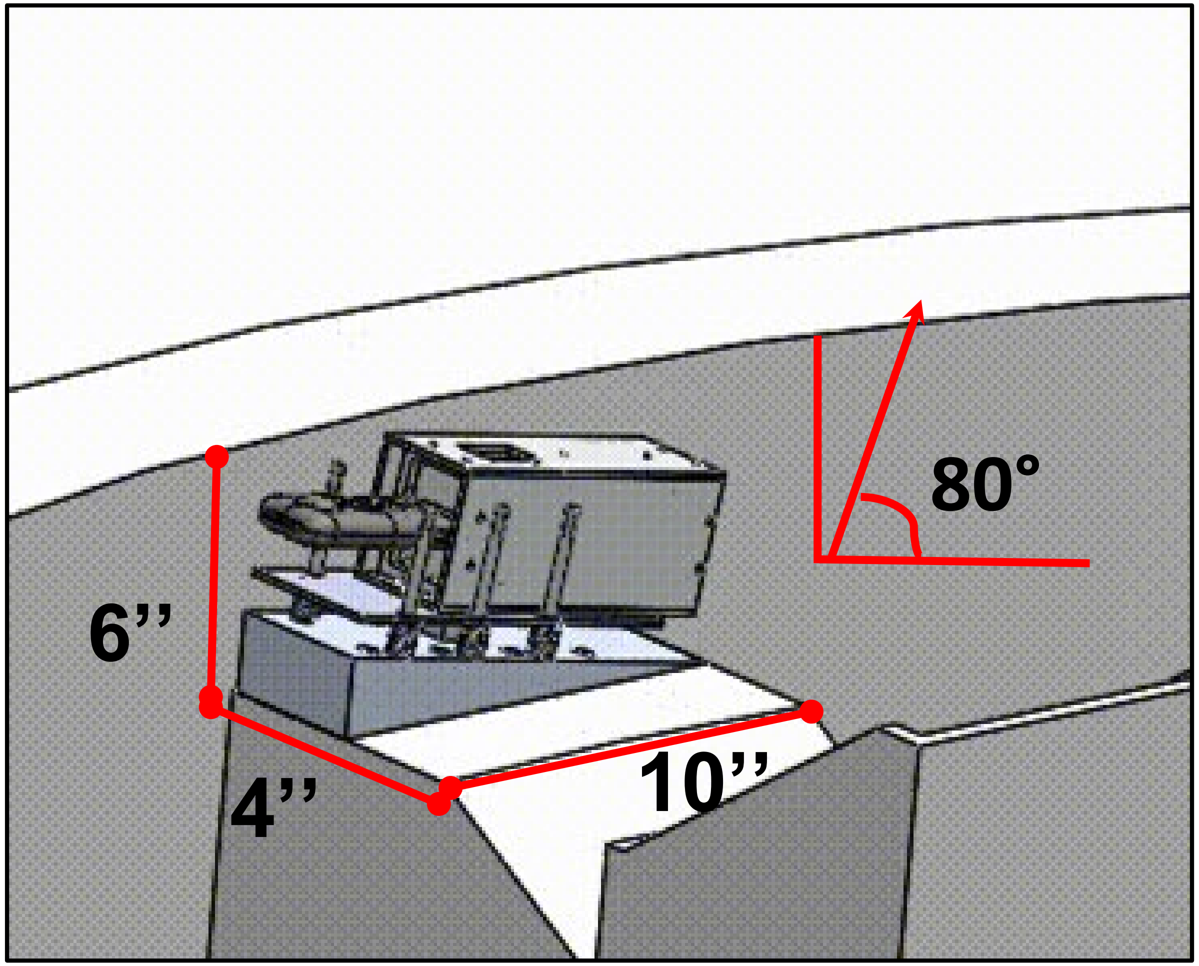
1. CCEC camera captures video for **180 s**

1. CCEC camera maintains temperature **<185°F**

Key	
CED = Camera Ejection Device	CCEC = Crew Capsule Experience Camera

Design Solution

- LaserPING Rangefinder (x2)
  - FOV: **50°**
  - fs: **25 ms**
- Insta360 ONE X2
  - AOV: **200°**
  - Resolution: **5.7K**
- Springs (x6)
  - Constant: **37.7 lbf/ft**
  - Compression distance: **2 in**
- Max force for lock: **110 lbf**
- Material: **Aluminum**

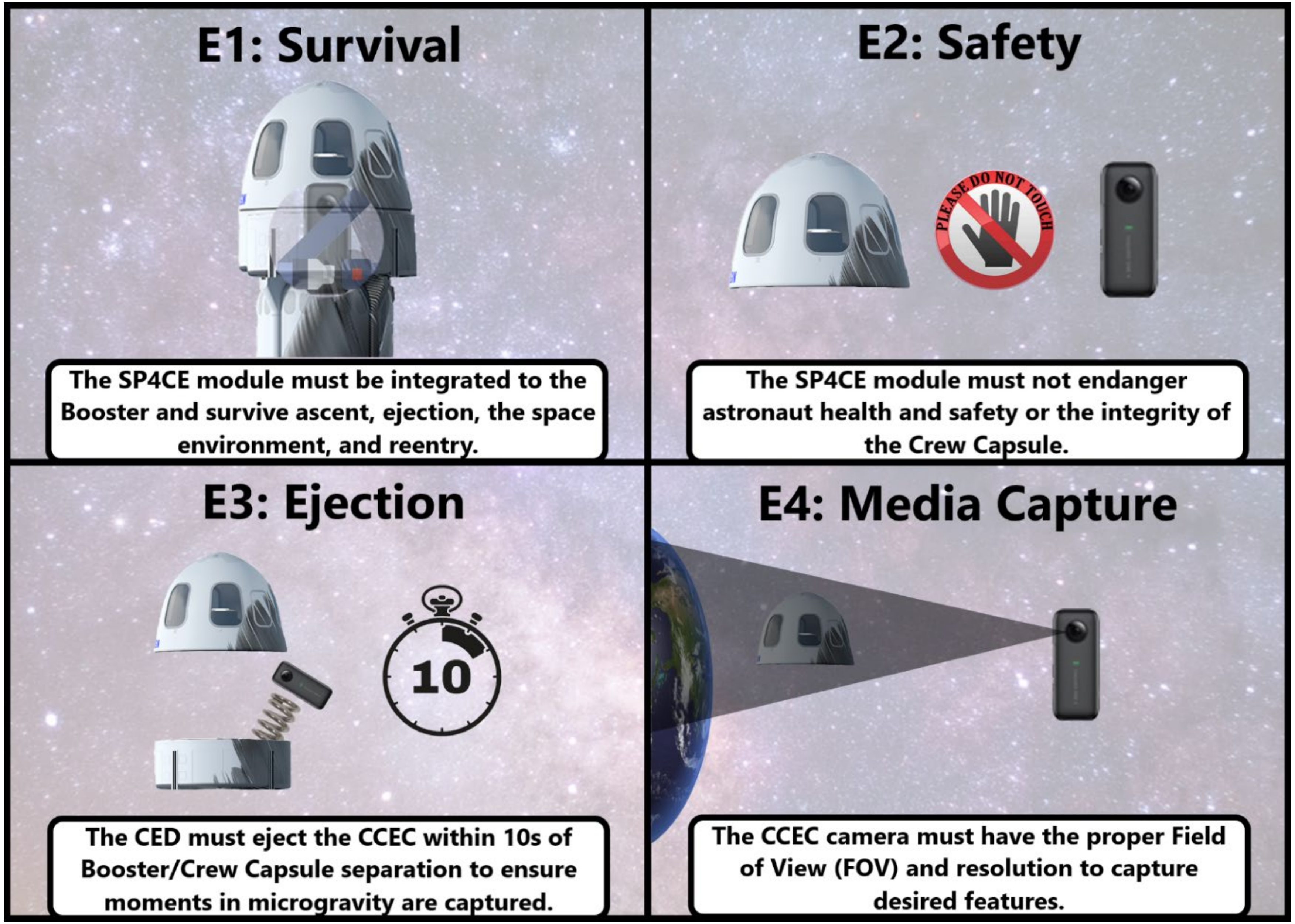


Changes to Design

1. Using Insta360 ONE X2
   - In lieu of ONE X

1. X2 will turn-on via Insta360 GPS remote before New Shepard Launch
   - Blue Origin approves of manual turn-on

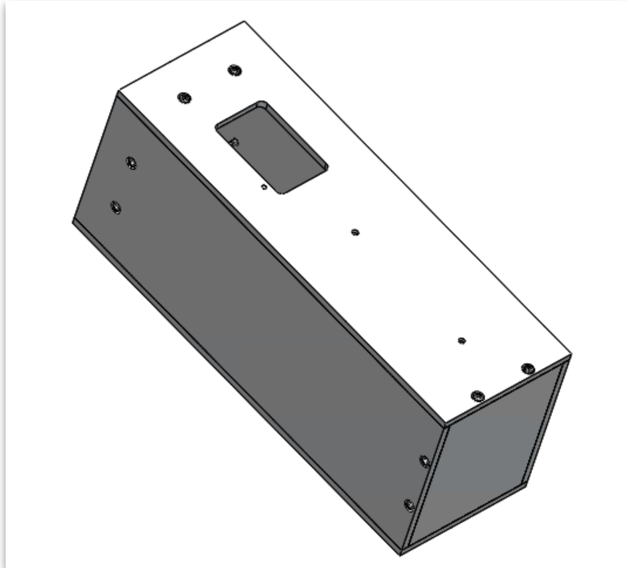
Critical Project Elements



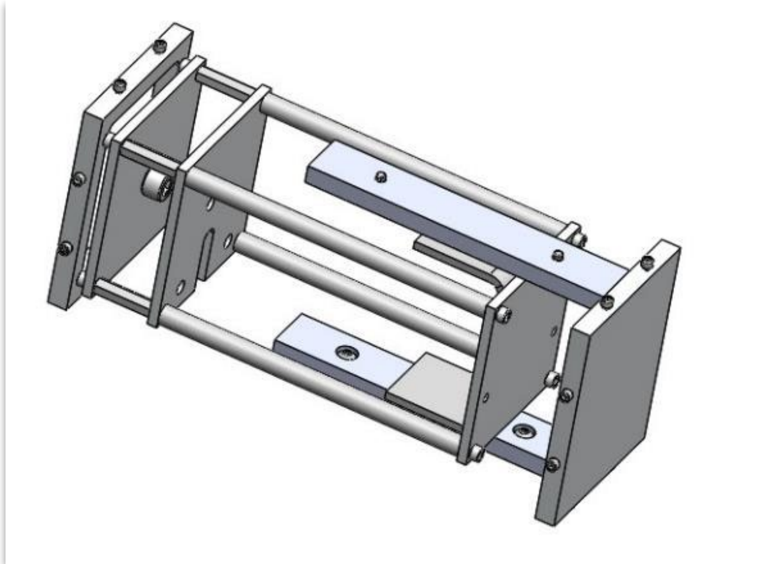
Project Updates

Jesse Bartlett

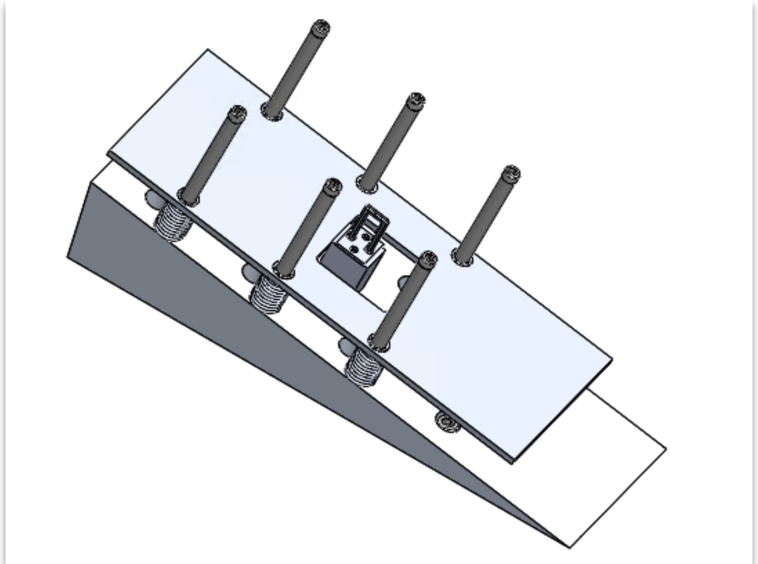
Manufacturing Updates



Stage 1: CCEC Exterior



Stage 2: CCEC Interior



Stage 3: CED

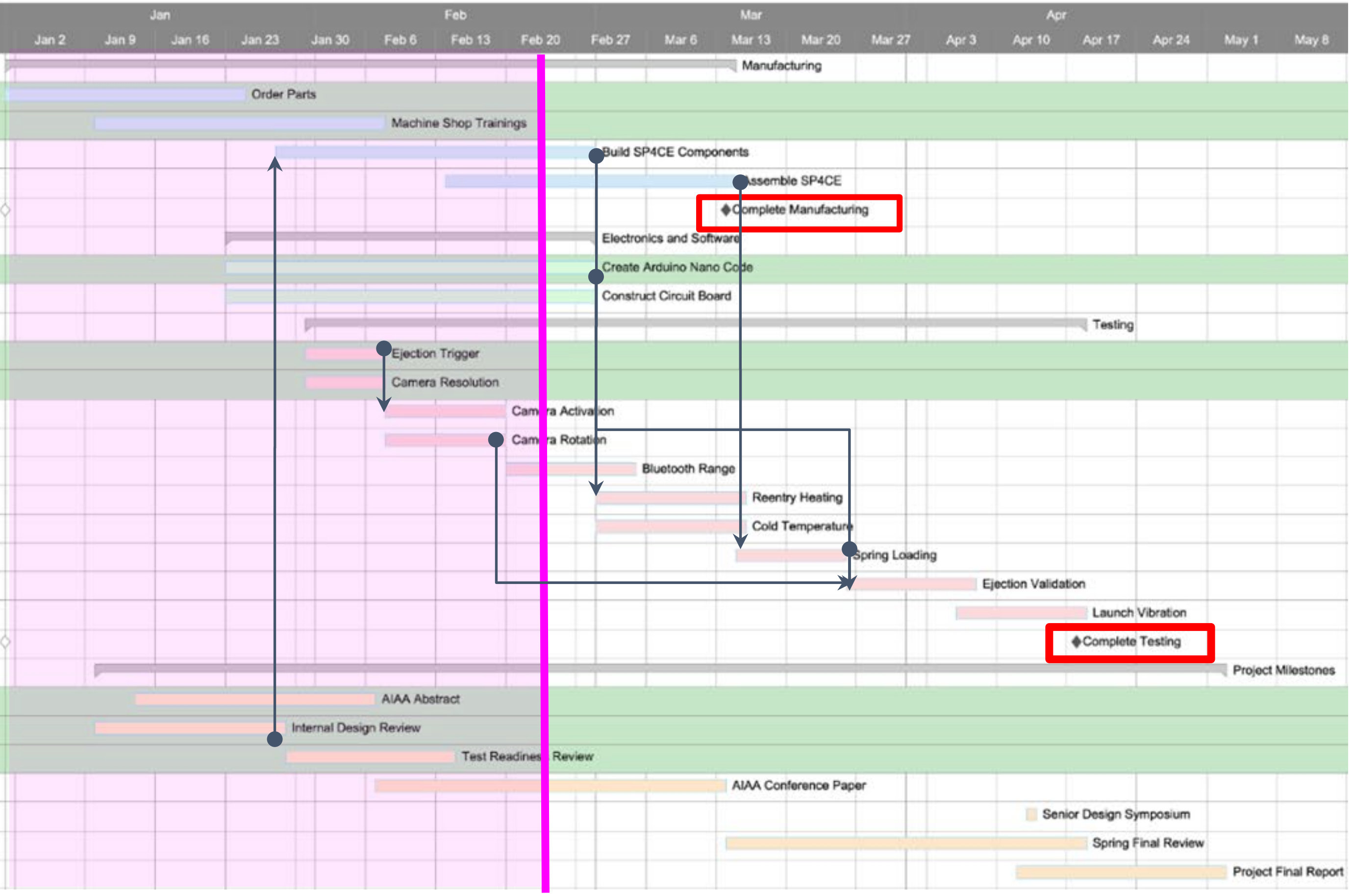
Schedule

Jasmin Chadha

Spring Schedule Overview

Legend
- Current Date
- Complete
- Milestone

Tasks	Start Date	Internal Due Date	Actual Due Date
Manufacturing	01/10/21		03/14/22
Order Parts	01/10/21	01/17/22	01/24/22
Machine Shop Trainings	01/10/22	01/24/22	02/07/22
Build SP4CE Components	01/28/22	02/14/22	02/28/22
Assemble SP4CE	02/14/22	03/07/22	03/14/22
Complete Manufacturing	03/14/22		03/14/22
Electronics and Software	01/23/22		02/28/22
Create Arduino Nano Code	01/23/22	02/21/22	02/28/22
Construct Circuit Board	01/23/22	02/21/22	02/28/22
Testing	01/31/22		04/18/22
Ejection Trigger	01/31/22	02/03/22	02/07/22
Camera Resolution	01/31/22	02/03/22	02/07/22
Camera Activation	02/08/22	02/14/22	02/19/22
Camera Rotation	02/08/22	02/14/22	02/19/22
Bluetooth Range	02/20/22	02/25/22	03/04/22
Reentry Heating	03/01/22	03/06/22	03/15/22
Cold Temperature	03/01/22	03/06/22	03/15/22
Spring Loading	03/15/22	03/20/22	03/25/22
Ejection Validation	03/26/22	04/02/22	04/07/22
Launch Vibration	04/06/22	04/13/22	04/18/22
Complete Testing	04/18/22		04/18/22
Project Milestones	01/10/22		05/02/22
AIAA Abstract	01/14/22	01/30/22	02/06/22
Internal Design Review	01/10/22	01/21/22	01/28/22
Test Readiness Review	01/29/22	02/07/22	02/14/22
AIAA Conference Paper	02/07/22	03/07/22	03/13/22
Senior Design Symposium	04/13/22		04/13/22
Spring Final Review	03/14/22	04/11/22	04/18/22
Project Final Report	04/12/22	04/30/22	05/02/22



Testing Schedule

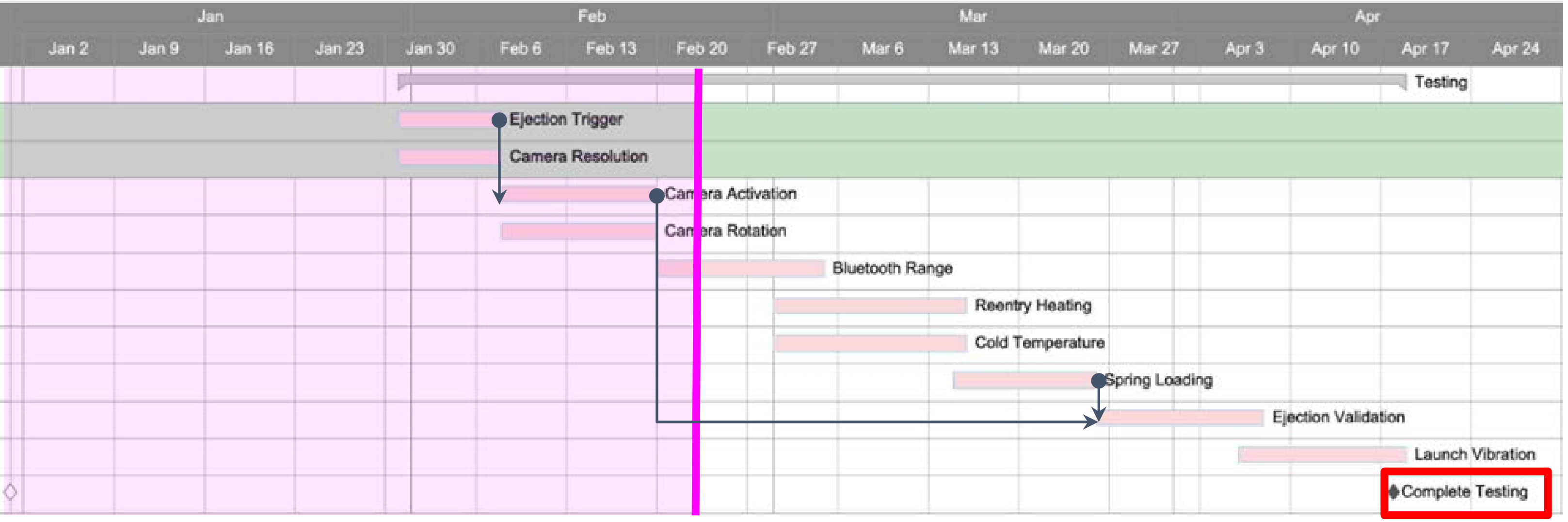
Legend

Current Date

Complete

Milestone

Tasks	Start Date	Internal Due Date	Actual Due Date
Testing	01/31/22		04/18/22
Ejection Trigger	01/31/22	02/03/22	02/07/22
Camera Resolution	01/31/22	02/03/22	02/07/22
Camera Activation	02/08/22	02/14/22	02/19/22
Camera Rotation	02/08/22	02/14/22	02/19/22
Bluetooth Range	02/20/22	02/25/22	03/04/22
Reentry Heating	03/01/22	03/06/22	03/15/22
Cold Temperature	03/01/22	03/06/22	03/15/22
Spring Loading	03/15/22	03/20/22	03/25/22
Ejection Validation	03/26/22	04/02/22	04/07/22
Launch Vibration	04/06/22	04/13/22	04/18/22
Complete Testing	04/18/22		04/18/22



Test Readiness

Jesse Bartlett, Jack Lana, Vicki Hurd

Test Readiness: Scope

Phase	Test	Model V&V	Equipment/Facilities
1: Ascent	Launch Vibration		Shaker table, accelerometers (x2), DAQ
2: Ejection	Ejection Trigger	Flowchart	
	Cold Temperature	Thermal shock, Insulation model	Thermocouples (type K, x3), LabView
	Spring Loading	Rotational Dynamics model	Load cells, DAQ
	Ejection Validation	Trajectory model	Logger Pro
3: Media Capture	Camera Resolution	Distance vs. Pixels model	
	Camera Rotation	Rotational Dynamics model	Spin module, LabView
	Camera Activation	Flowchart	
4: Reentry	Reentry Heating	Thermal model	Machine shop oven, thermocouples (type K, x4), LabView
	Drop Test	Ballistic coefficient	Logger Pro, altimeter

Ejection Validation (FR. 2, 4)

DR. 2.1-2.3: CCEC ejects **2 ± 1 seconds** after separation at **80 ± 3°** with a velocity of **9 ± 1 ft/s**
DR. 4.1: Camera turns on and records **1 second** after ejection

Deadline: 04/07

Status: Not Started

Rationale/Requirements for V&V:

- Demonstrate the SP4CE module's ability to satisfy **DR. 2.1-2.3** and **DR 4.1**

Equipment/Facilities:

- SP4CE module, 3"x3" opaque object, landing area padding, reference object for Logger Pro

Procedure:

- Move 3"x3" object away from CCEC, simulating the Crew Capsule
- Film ejection with reference object in view

Risk Reduction:

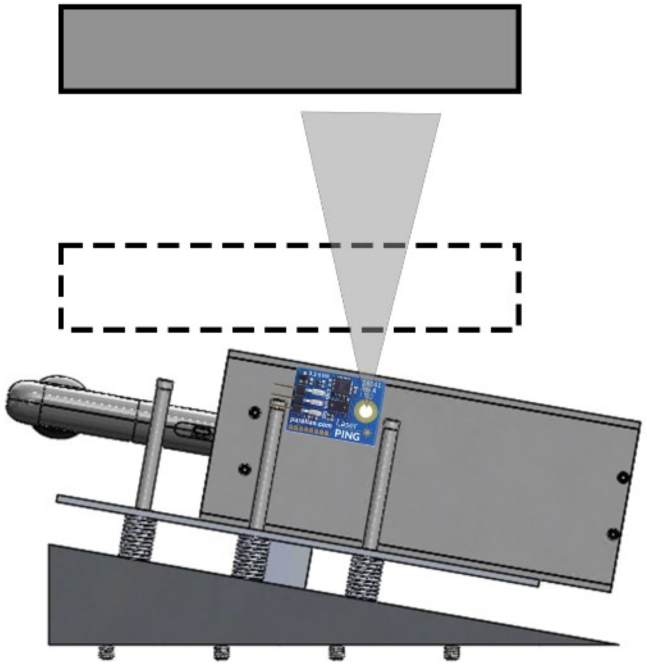
- Mitigates likelihood of CCEC hitting the Crew Capsule

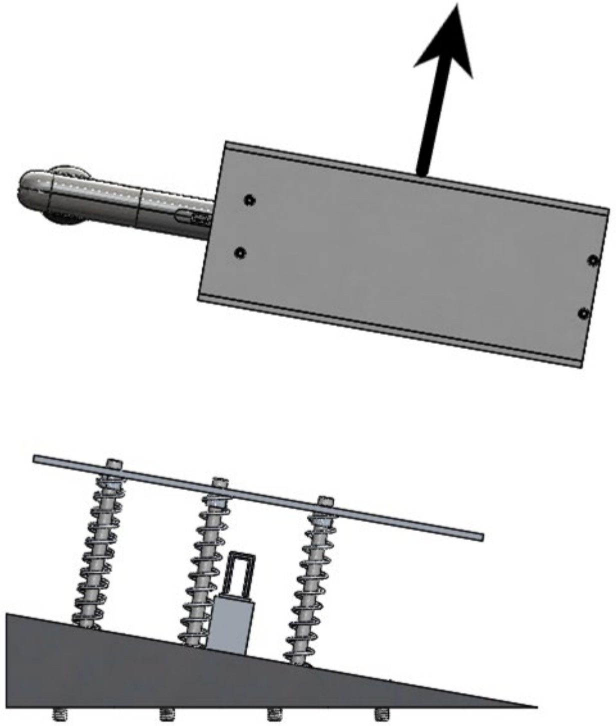
Ejection Validation (FR. 2, 4)

DR. 2.1-2.3: CCEC ejects **2 ± 1 seconds** after separation at **80 ± 3°** with a velocity of **9 ± 1 ft/s**
DR. 4.1: Camera turns on and records **1 second** after ejection

Deadline: 04/07

Status: Not Started





Spring Loading (FR. 2)

DR. 2.3.1: Spring force of **37.7 ± 7.5 lbf**

Deadline: 03/25

Status: Not Started

Rationale/Requirements for V&V:

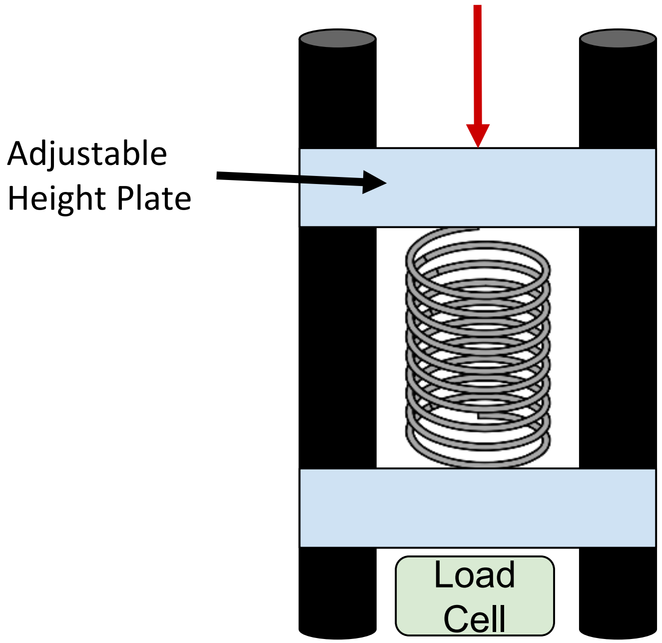
- Verify each spring force varies **≤ 20%**

Equipment/Facilities:

- CED springs, load cell, DAQ, spring compression structure

Procedure:

- Place a load cell on one of the six springs
- Compress springs 2 inches and release
- Measure force output of spring
- Repeat for all remaining springs



Camera Resolution (FR. 1)

DR. 1.2: Astronaut faces are visible up to **75 feet**

Deadline: 02/07

Status: Complete

Rationale/Requirements for V&V:

- Detect, Recognize, and Identify human faces at **80 feet**, **20 feet**, and **10 feet**, respectively

Equipment/Facilities:

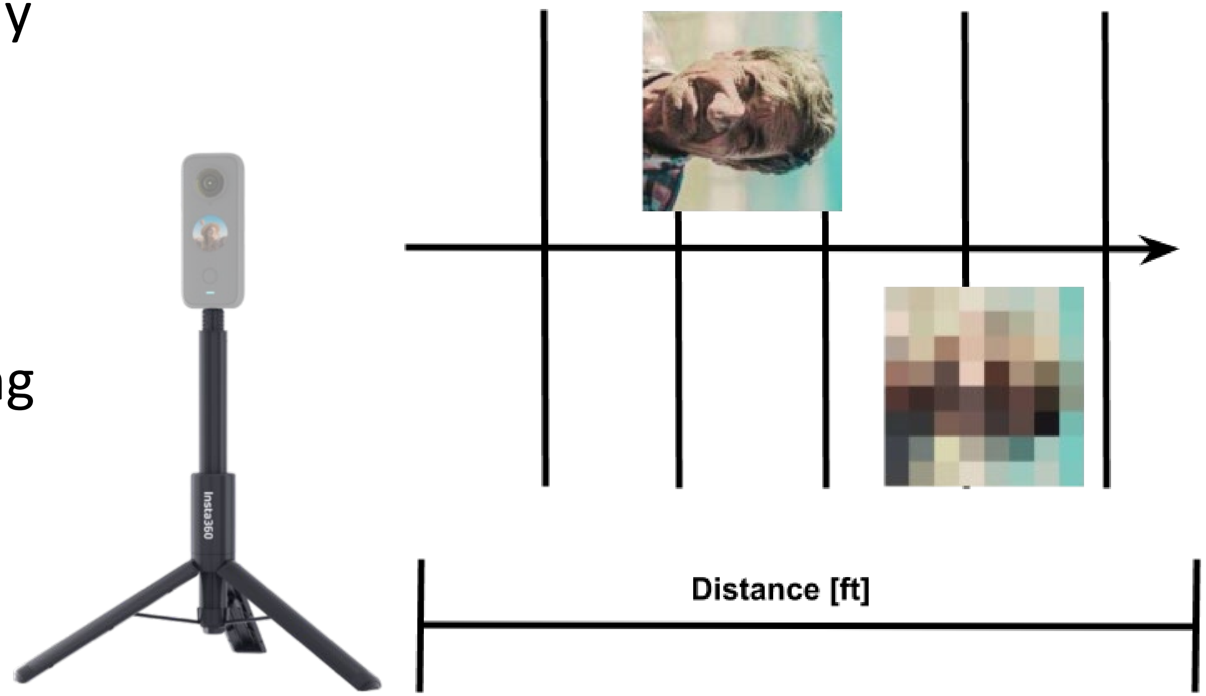
- Insta360 One X2, tripod, tape measure, distance markers

Procedure:

- Record video of subject at distances ranging from 10-100 ft

Risk Reduction:

- Increases likelihood of videos containing astronaut faces and desired features

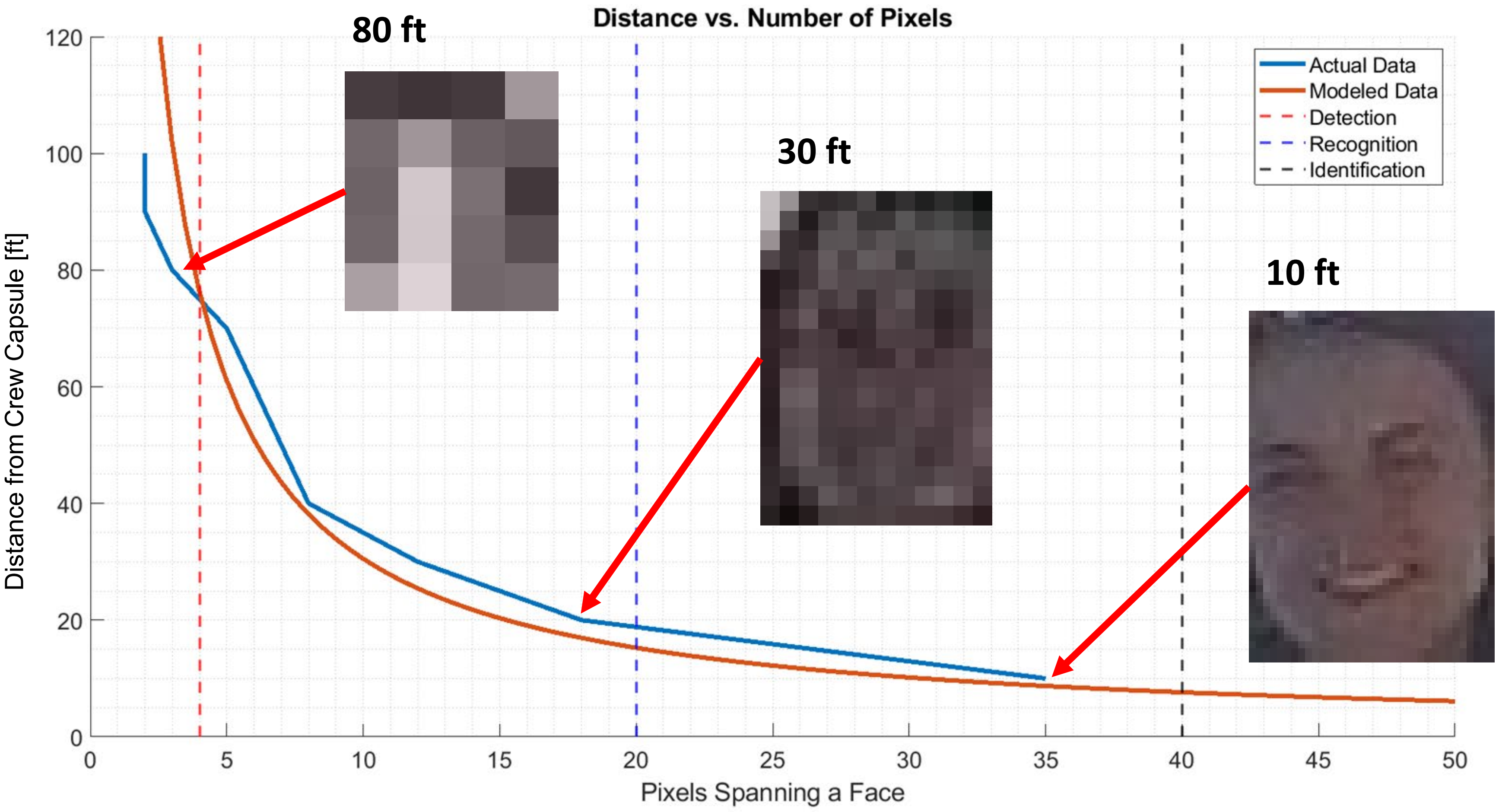


Camera Resolution (FR. 1)

DR. 1.2: Astronaut faces are "detectable" up to **75 feet**

Deadline: 02/07

Status: Complete



Camera Rotation (FR. 1)

DR. 1.3: Camera captures video up to **10 rad/s**

Deadline: 02/19

Status: In Review

Rationale/Requirements for V&V:

- Characterize spin compensation capabilities of the camera about different axes

Equipment/Facilities:

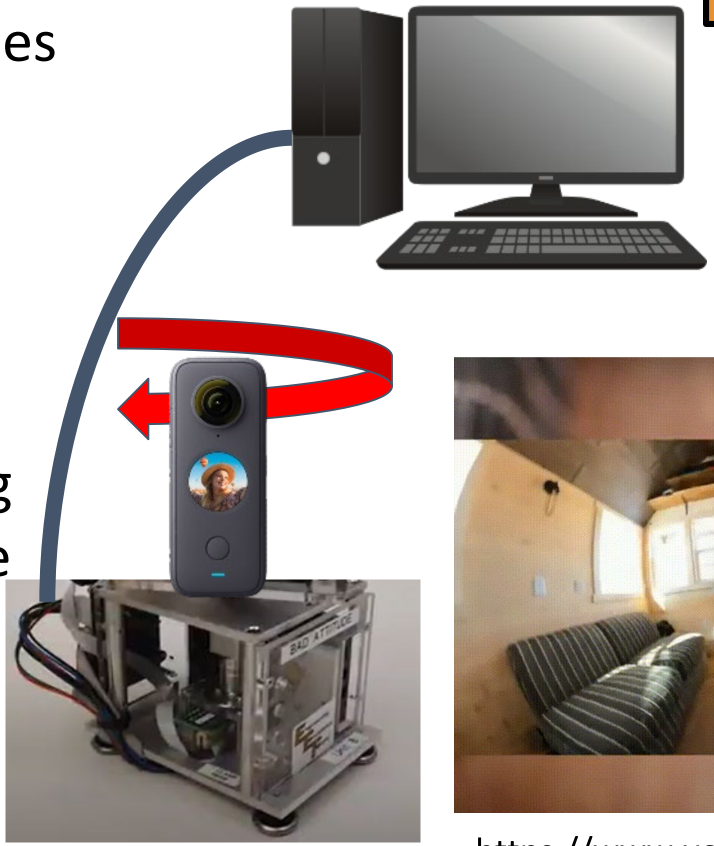
- Spin module, mounting apparatus, level, LabView, Insta360 One X2

Procedure:

- Rotate camera on spin module, increasing rate up to **12 rad/s** (~**115 rpm**) in multiple orientations

Risk Reduction:

- Increasing likelihood of quality media capture



https://www.youtube.com/watch?v=I37Cf1QT92A

Camera Rotation (FR. 1)

DR. 1.3: Camera captures video up to **10 rad/s**

Deadline: 02/19

Status: In Review

Preliminary Test Results

~1.6 rev/s = 10.4 rad/s ✓

Reentry Heating (FR. 6)

DR. 6.1: Camera maintains a temperature less than **185°F**

Deadline: 03/15

Status: Not Started

Primary Thermal Model

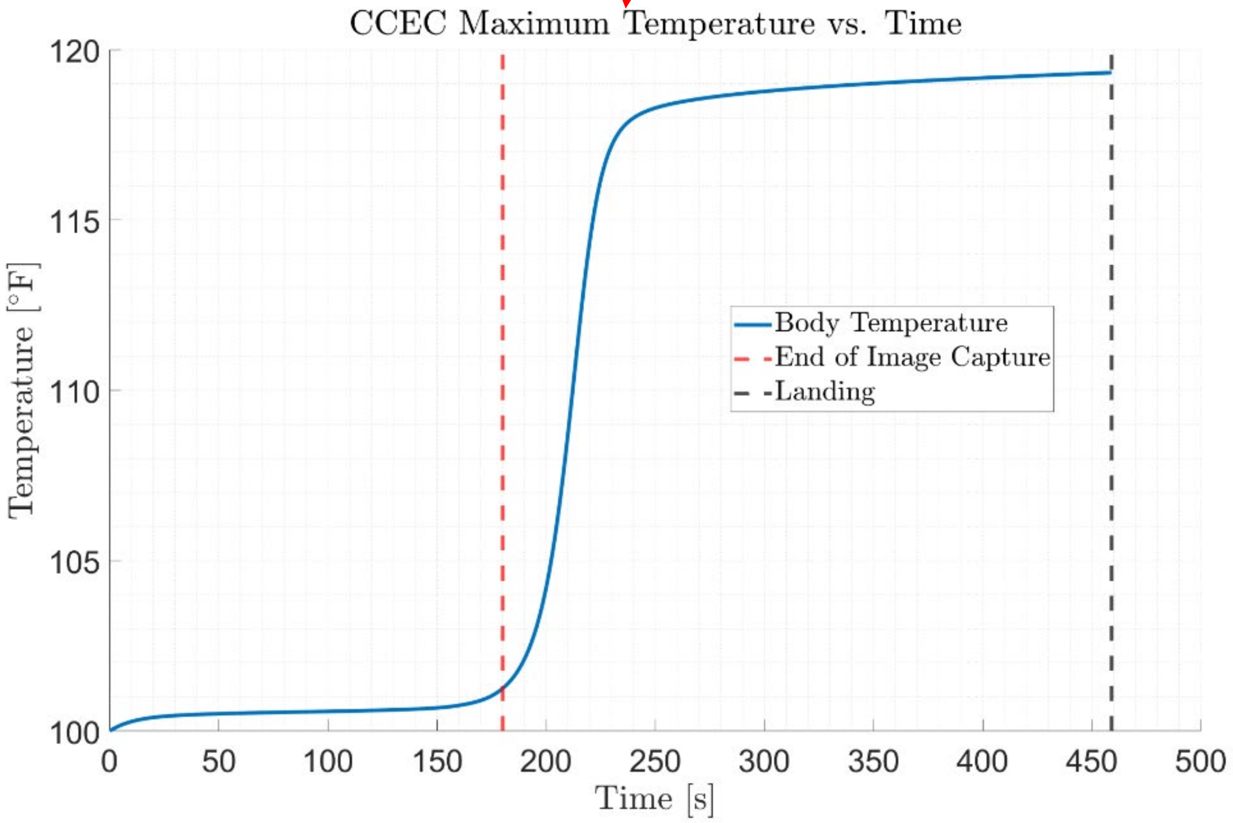
- Worst case T_0 = 100°F
- T_{max} = 120°F
- Difficult to simulate reentry conditions

Secondary Thermal Model

- Aluminum has a high thermal conductivity
- Assume: $T_{body} = T_{wall}$ [1]

Reentry Heating Test

- Validate Secondary Thermal Model
- Assume Primary Thermal Model is correct



Reentry Heating (FR. 6)

DR. 6.1: Camera maintains a temperature less than **185°F**

Deadline: 03/15

Status: Not Started

Rationale/Requirements for V&V:

- Validate the temperature of the body remains nearly constant, despite 1D heating

Equipment/Facilities:

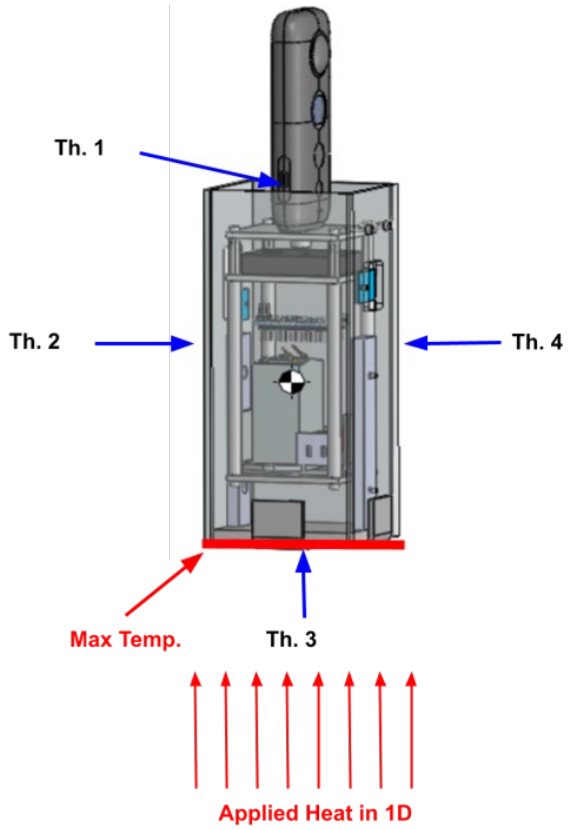
- Machine shop oven, thermocouples (type K, x4), CCEC, LabView

Procedure:

- Set machine shop oven to **120°F**
- Insert one side of CCEC into oven to simulate 1D heating and measure temperature in four locations

Risk Reduction:

- Increases the likelihood of SD card surviving reentry



Bluetooth Range

Pre-Launch Ops: Ensure power-on from Blue Origin launch tower

Deadline: 03/04

Status: Not Started

Rationale/Requirements for V&V:

- Ensure Bluetooth remote range reaches Blue launch tower through aluminum fin box

Equipment/Facilities:

- CCEC, Insta360 GPS Bluetooth remote, aluminum sheet, laser rangefinder

Risk Reduction:

- Ensure that camera turns on prior to launch so that media can be captured during flight

Insta360 GPS Remote

Bluetooth Range

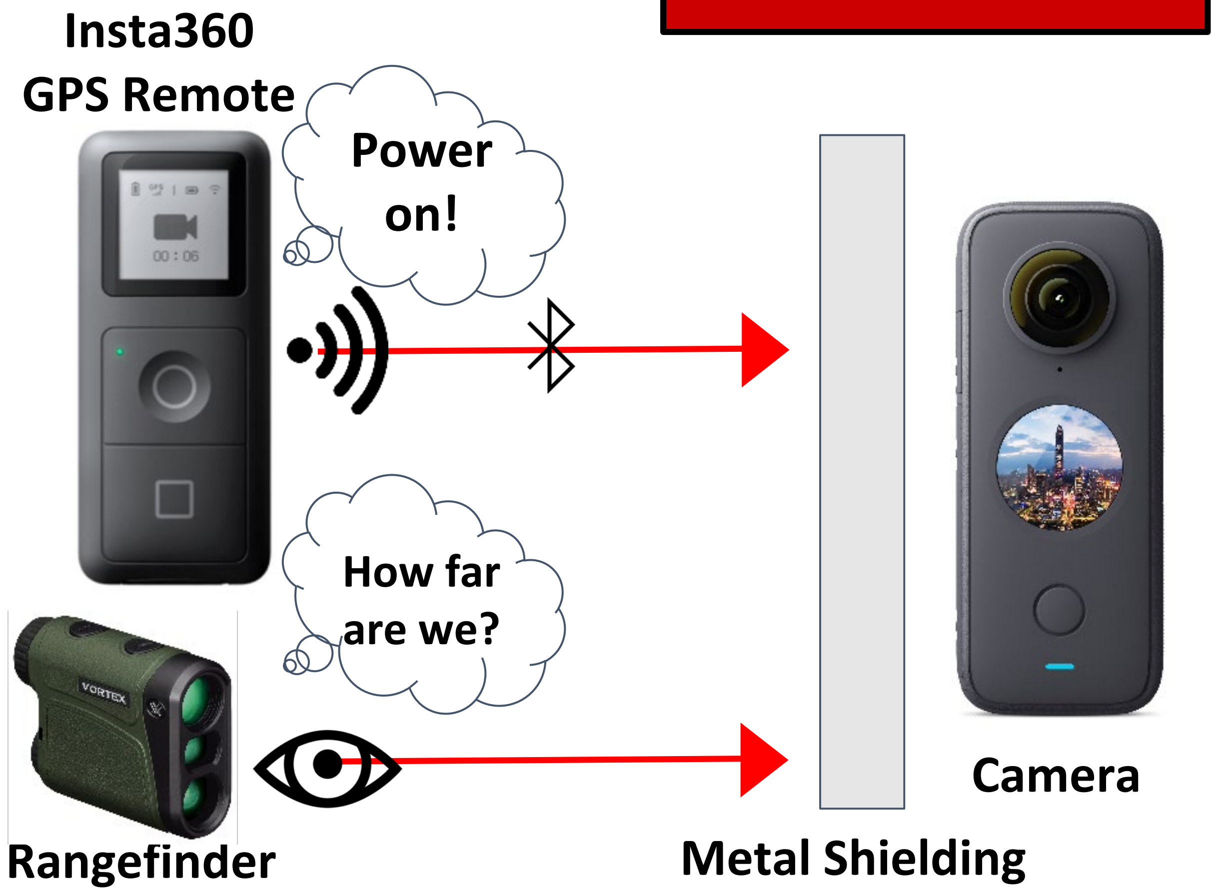
Pre-Launch Ops: Ensure power-on from Blue Origin launch tower

Deadline: 03/04

Status: Not Started

Procedure:

- Put CCEC behind aluminum sheet to simulate fin box installation
- Walk backwards in increments of 1 yd and attempt to power on
- Use rangefinder to note exact distance where power on fails



Test	Status
Spring Loading	Not Started
Ejection Validation	Not Started
Camera Resolution	Complete
Camera Rotation	In Review
Reentry Heating	Not Started
Bluetooth Range	Not Started

Budget

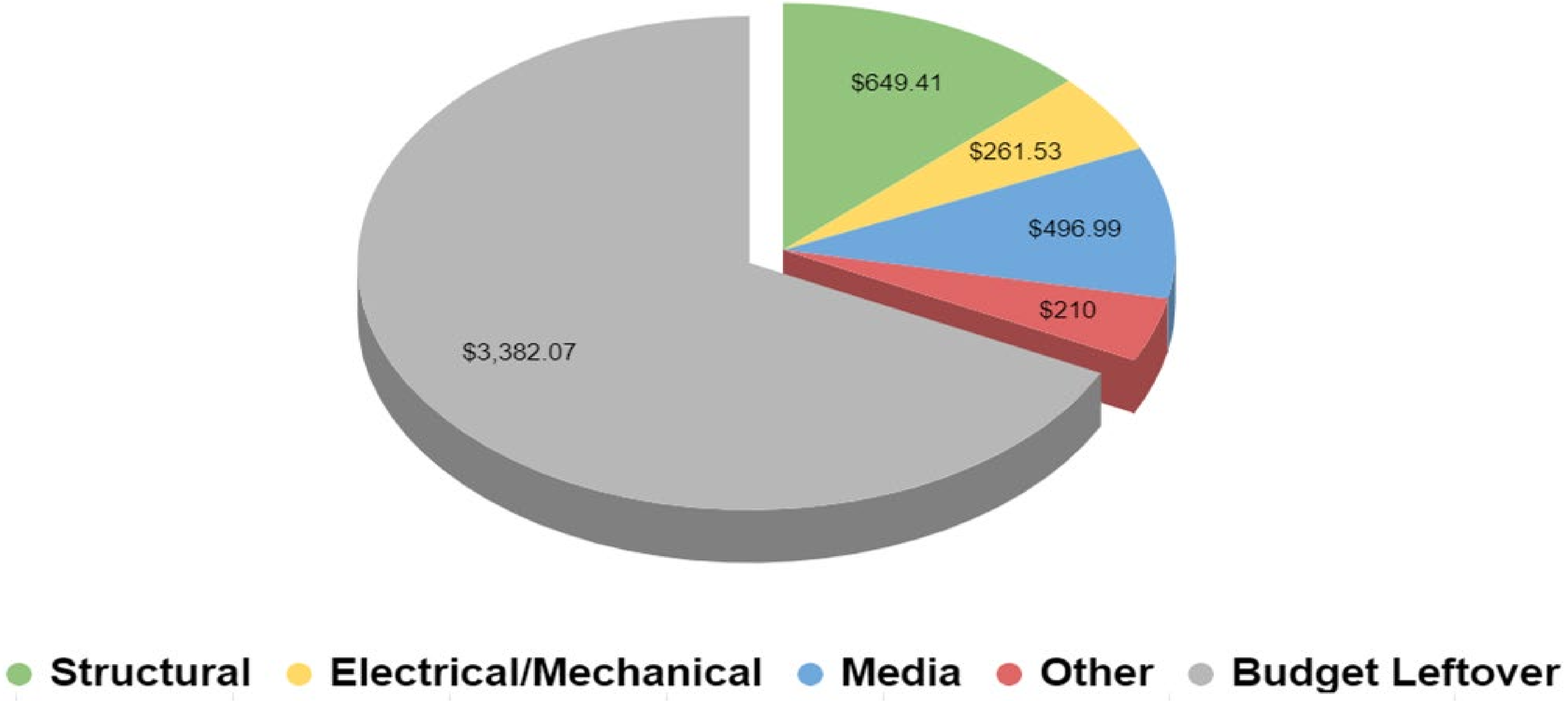
Jasmin Chadha

Expenses

Expected: $2,338.95

Current: $1,617.93

Upcoming: Testing fe



Parts Ordering

Waiting On			
Item	**Expected Arrival**	**Applicable Test**	**Test Date**
Bluetooth Remote	02/15	Bluetooth Range	02/20
Vibe Table Parts	unknown	Launch Vibration	04/06

Questions?

Backup Slides

Supporting Materials

1. Acknowledgement & References
2. Administrative
3. Additional Tests
4. Diagrams

Acknowledgements & References

Acknowledgements

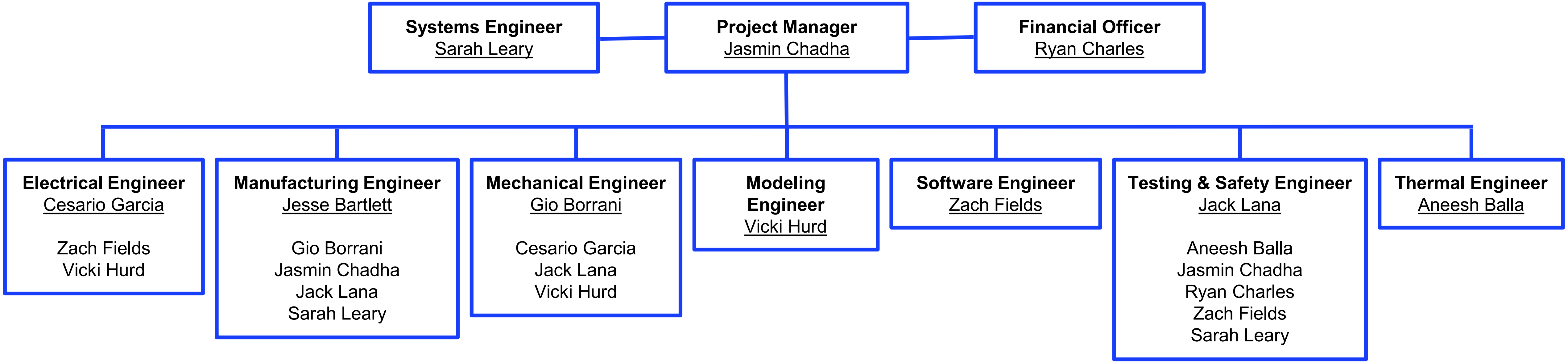
- **Blue Origin POCs:** Dean Misterek, Gary Lai
- **Faculty Advisor:** Dr. Yu Takahashi
- **Teaching Fellows:** Emma Markovich, Colin Claytor
- **ASEN 4018 Professors**: Dr. Kathryn Wingate, Dr. Jelliffe Jackson
- **Additional Professors:** Bobby Hodgkinson, Trudy Schwartz, Matt Rhode
- **TRR Reviewer**: GRASS

References

1. https://ocw.mit.edu/courses/mathematics/18-303-linear-partial-differential-equations-fall-2006/lecture-notes/heateqni.pdf

Administrative

Spring Organizational Chart



Functional Requirements

FR 1	The CCEC shall capture video of the entire Crew Capsule with the Earth's horizon in the background including features (e.g. clouds) and astronauts' faces in windows during the period of Crew Capsule microgravity.
FR 2	The CCEC shall be ejected from the Booster by the CED at or after Booster/Crew Capsule separation.
FR 3	The CCEC shall maintain a neutral or positive separation rate from the Crew Capsule following ejection through Crew Capsule apogee.
FR 4	The CCEC shall take videos of the CC starting no later than 10 seconds following Booster/CC separation with video taken for at least the next 180 seconds.
FR 5	The CCEC shall have a ballistic coefficient less than the Crew Capsule (0.5 lbm/in^2) to ensure no in-flight contact during reentry.
FR 6	The CCEC shall survive reentry.
FR 7	The SP4CE module should have a loaded weight of less than 50 lbm.

Acronyms

Acronym	Definition
AOV	Angle Of View
CC	Crew Capsule
CCEC	Crew Capsule Experience Camera
CED	Camera Ejection Device
CONOPS	Concept of Operations
COTS	Commercial, Off-The-Shelf
DR	Design Requirement
fps	frames per second
FR	Functional Requirement
FOV	Field Of View
ICD	Interface Control Drawing
IR	Infrared
LEO	Low Earth Orbit
SP4CE	Suborbital Photography For Crew Experience
TPS	Thermal Protection System
V&V	Verification and Validation

Notable Term Definitions

Term	Definition
CCEC	The module being ejected from the Booster. Houses the camera and recovery system.
CED	The physical mechanism that triggers ejection and ejects the CCEC. Remains in the Booster.
Fin Box	The location on the Booster inside which the SP4CE module is mounted.
ICD	Volumetric constraint for SP4CE provided by Blue Origin.
PM4	Synonymous with the Booster
SP4CE	The collective CCEC and CED assembly.
Wet mass	Total mass including propellant.

Additional Tests

Test	Status
Launch Vibration	Not Started
Ejection Trigger	Complete
Cold Temperature	In Review
Camera Activation	Not Started
Drop Test	Not Started

Launch Vibration

E1: The SP4CE module must be easily integrated to the Booster and survive ascent, ejection, the space environment, and reentry.

Deadline: 04/18

Status: Not Started

Rationale:

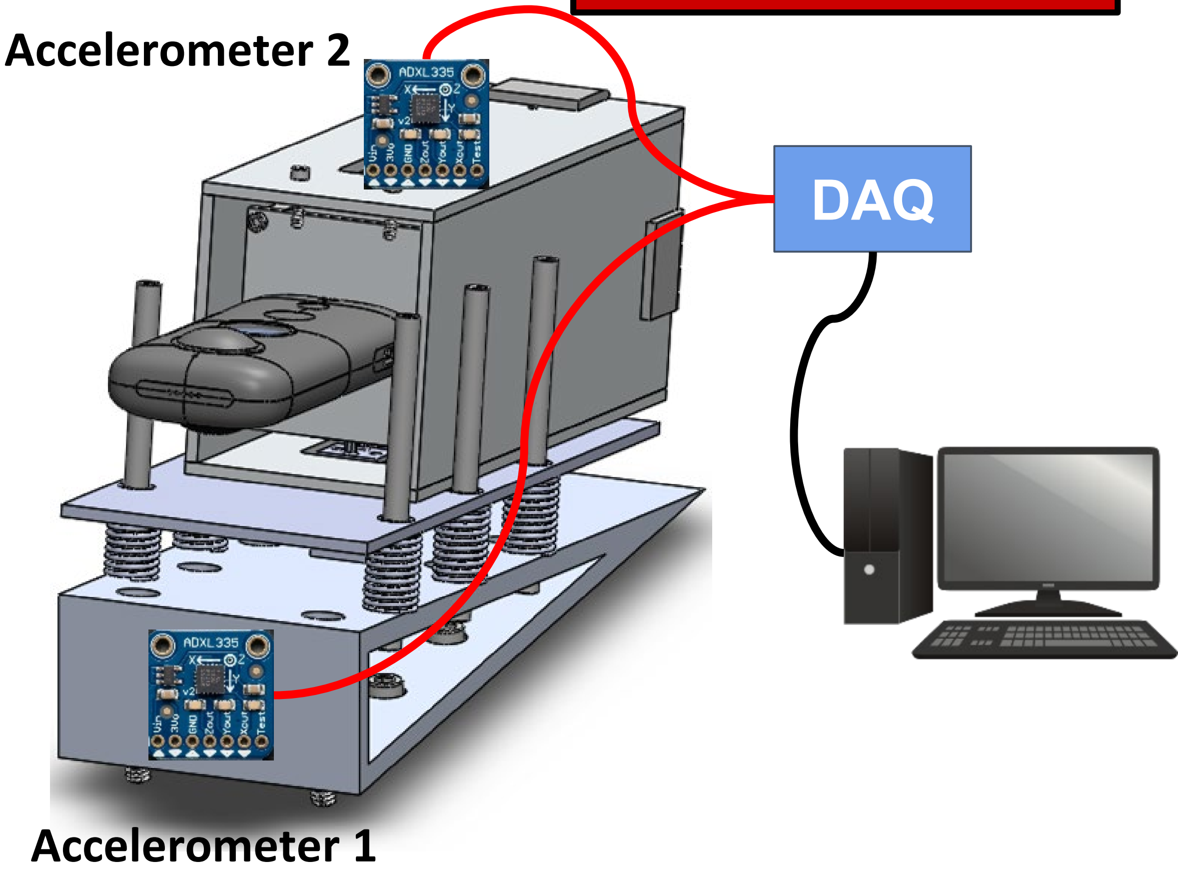
- Demonstrate the SP4CE module's ability to withstand single axis launch vibrations

Equipment/Facilities:

- SP4CE module, mounting plate adaptor, two-axis accelerometers (x2), Vibe Table, DAQ
- PILOT Lab testing room

Procedure:

- Mount adaptor plate and SP4CE on Vibe Table
- Secure accelerometers in specified locations
- Run system through launch vibration profile



Ejection Trigger (FR. 2)

DR. 2.1: Ejection occurs **2 ± 1 seconds** after separation

Deadline: 02/07

Status: Complete

Rationale:

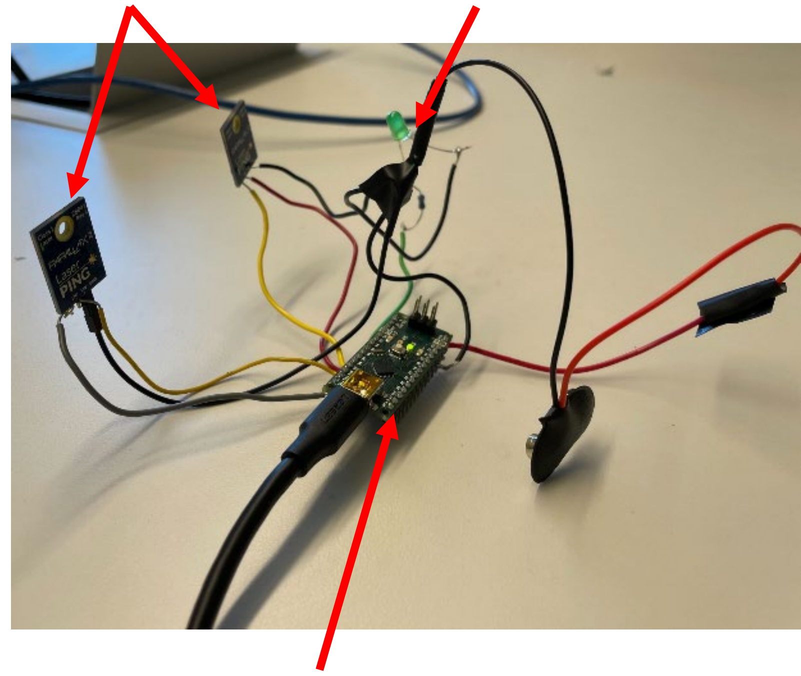
- Demonstrate capability of rangefinders and Arduino to trigger ejection with simulated CC separation

Equipment/Facilities:

- Arduino, rangefinders (x2), 3”x3” opaque object, LED

Procedure:

- Run Arduino with object in front of CC facing rangefinder
- Remove object and ensure Arduino sends eject signal (LED indicator)
- Repeat, checking functionality of ejection confirmation rangefinder



Ejection Trigger (FR. 2)

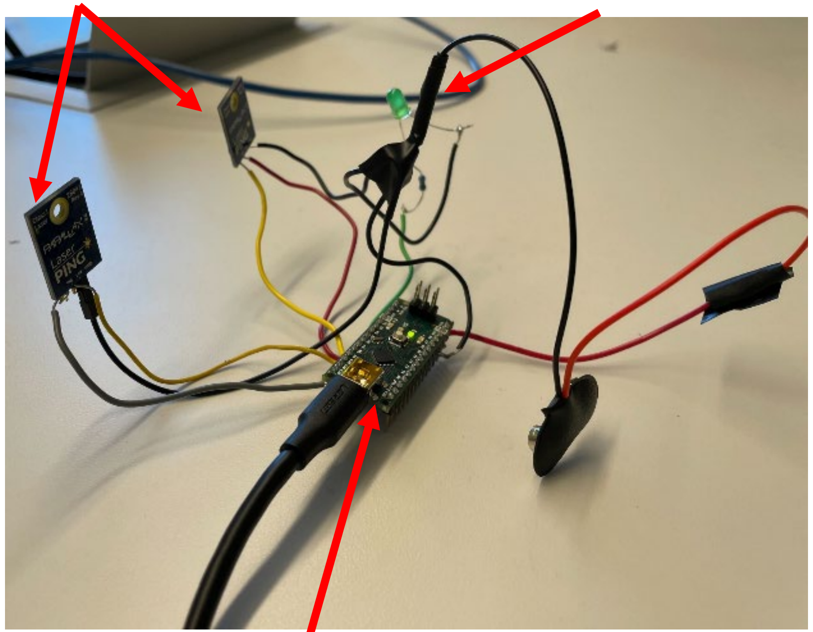
DR. 2.1: Ejection occurs **2 ± 1 seconds** after separation

Deadline: 02/07

Status: Complete

Rangefinders

LED Indicator



Arduino

Camera Activation (FR. 4)

DR. 4.1: The CCEC camera shall turn on no later than **1 second** after ejection

Deadline: 02/19

Status: Not Started

Rationale:

- Demonstrate the electronic capability to remotely turn on the camera and begin recording
- Simulate interference booster will create

Equipment/Facilities:

- Insta360 One X2, Arduino Nano, USB-C connector, Bluetooth remote

Procedure:

- Power on the camera with the bluetooth remote
- Begin media capture using the Arduino
- Introduce a barrier simulating the booster, and repeat

Cold Temperature (FR. 4)

DR. 4.2.1: Camera battery is between **-4 and 104°F** during media capture

Deadline: 03/15

Status: In Review

Rationale:

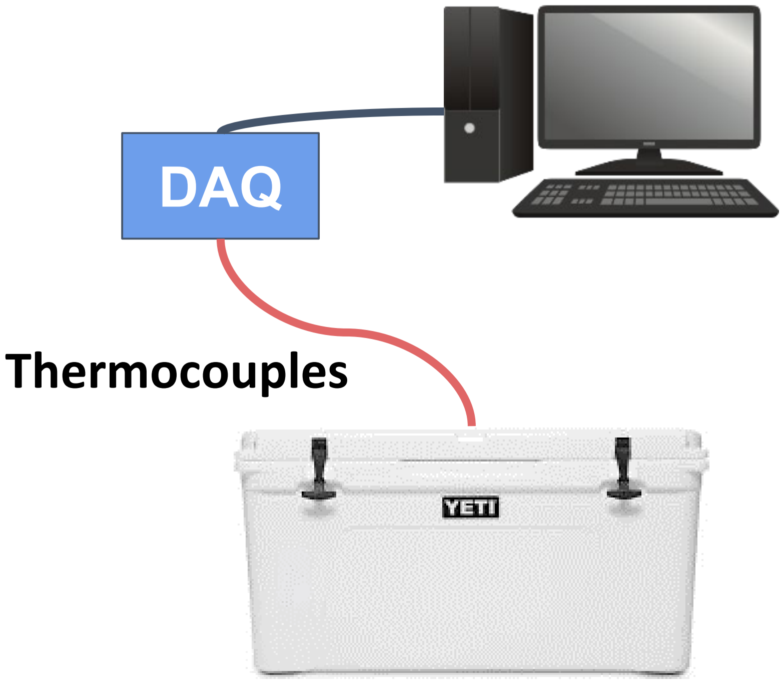
- Demonstrate that the camera battery stays within operating temperature while exposed to flight-like temperatures
- Investigate lens capability under extreme temperatures

Equipment/Facilities:

- Insta360 One X2, cooler, dry ice, stopwatch, thermocouples (type K, x3), DAQ

Procedure:

- Place camera in dry ice cooler
- Monitor temperature at different locations for **180 seconds**



Drop Test (FR. 5)

FR. 5: Ballistic coefficient is less than **0.5 lbm/in^2**

Deadline: 03/18

Status: Not Started

Note: Not critical path

Rationale:

- Verifying the drag coefficient of the CCEC
- Observing aerodynamic stability

Equipment/Facilities:

- Helicopter/Building, CCEC, altimeter, Logger Pro, phone camera

Procedure:

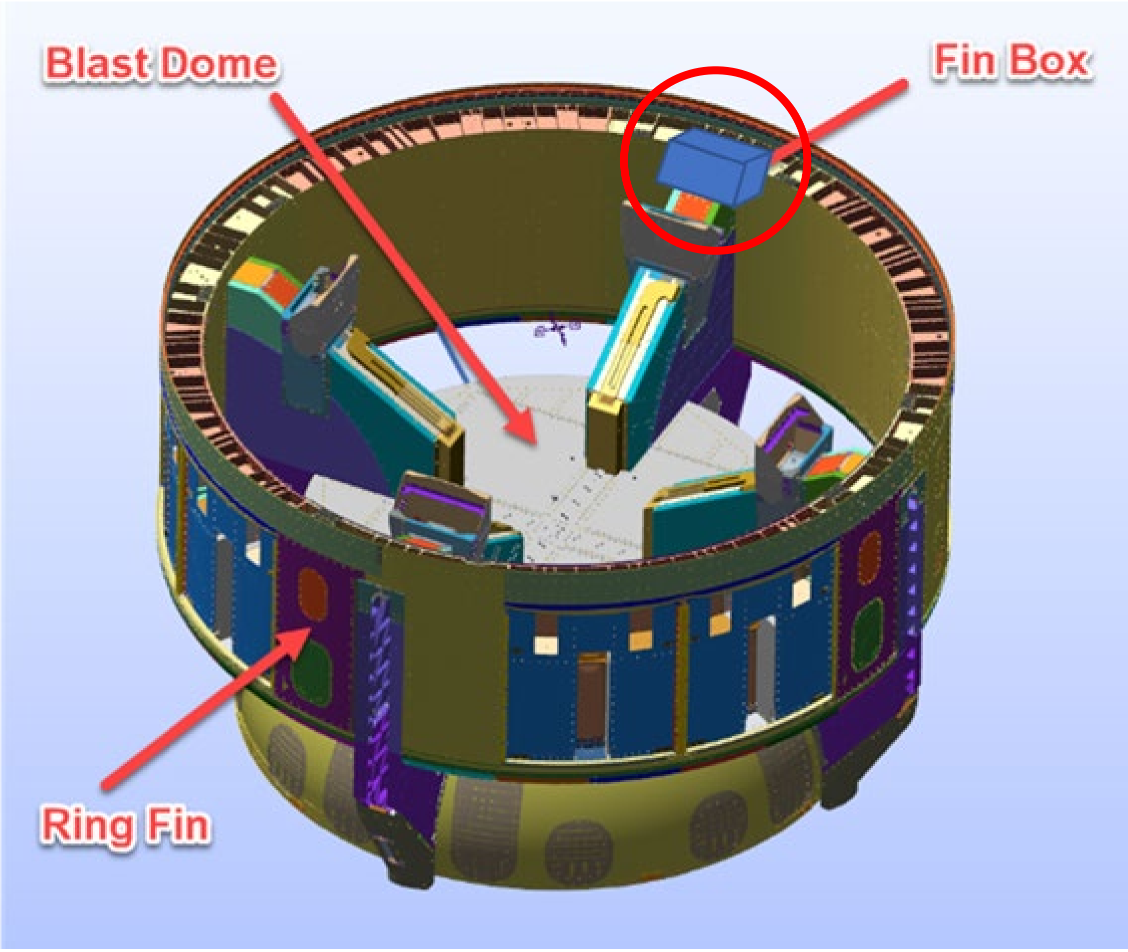
- Set up cell phone camera on a tripod with a reference object for Logger Pro
- Begin recording, drop the CCEC from at least 300 meters, and record time-to-fall

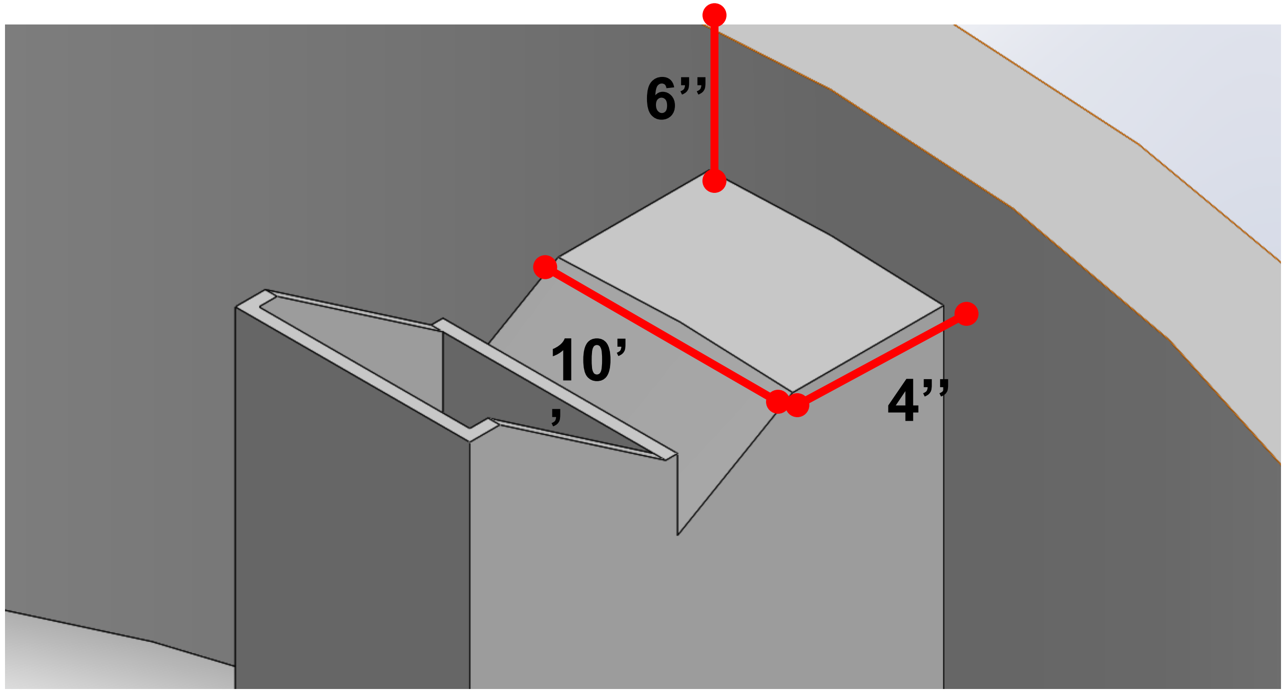
Post-Processing:

- Qualitatively determine aerodynamic stability
- Use height and time-to-fall as a means to calculate drag coefficient

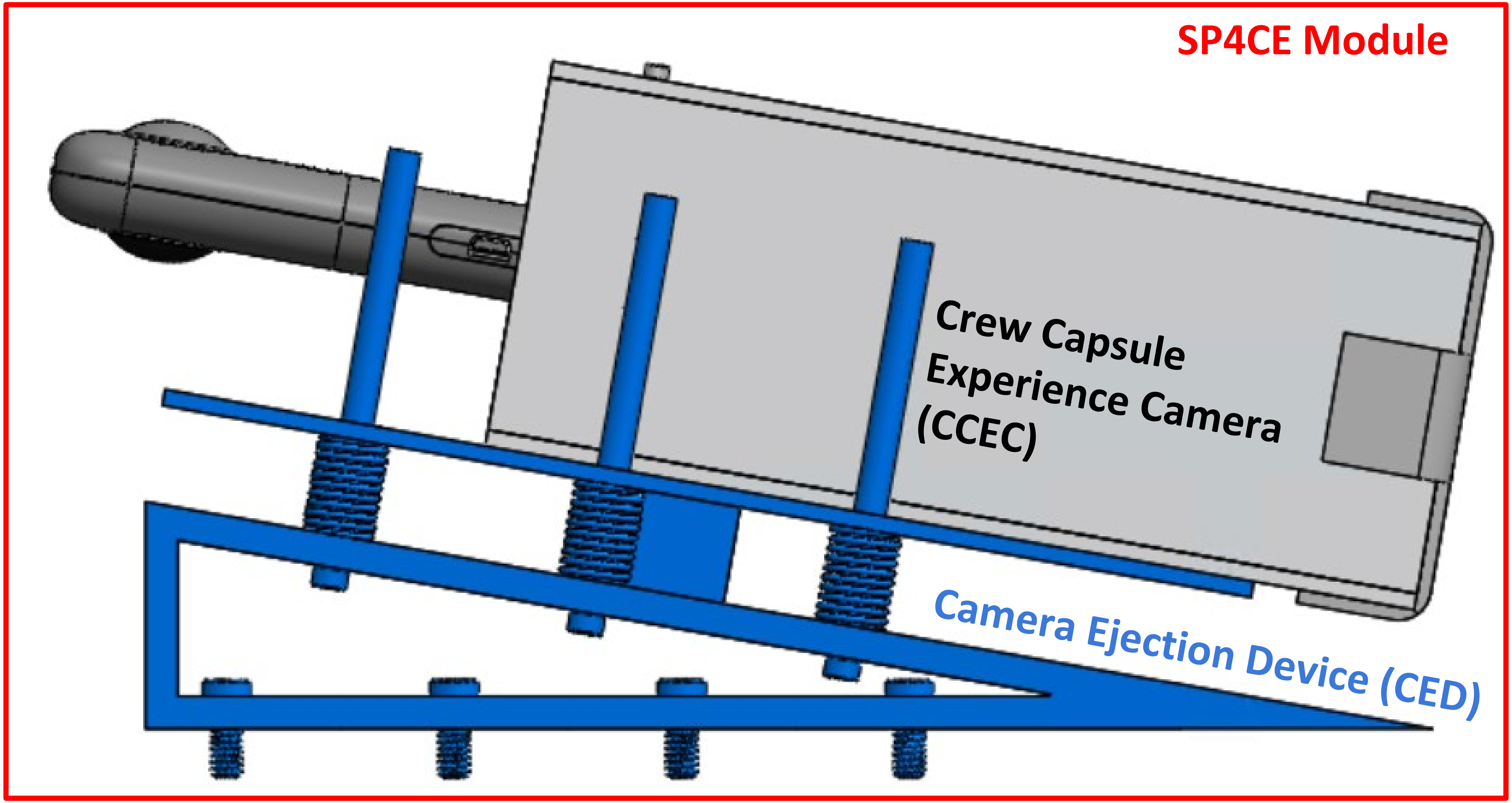
Diagrams

Location & Volumetric Reference

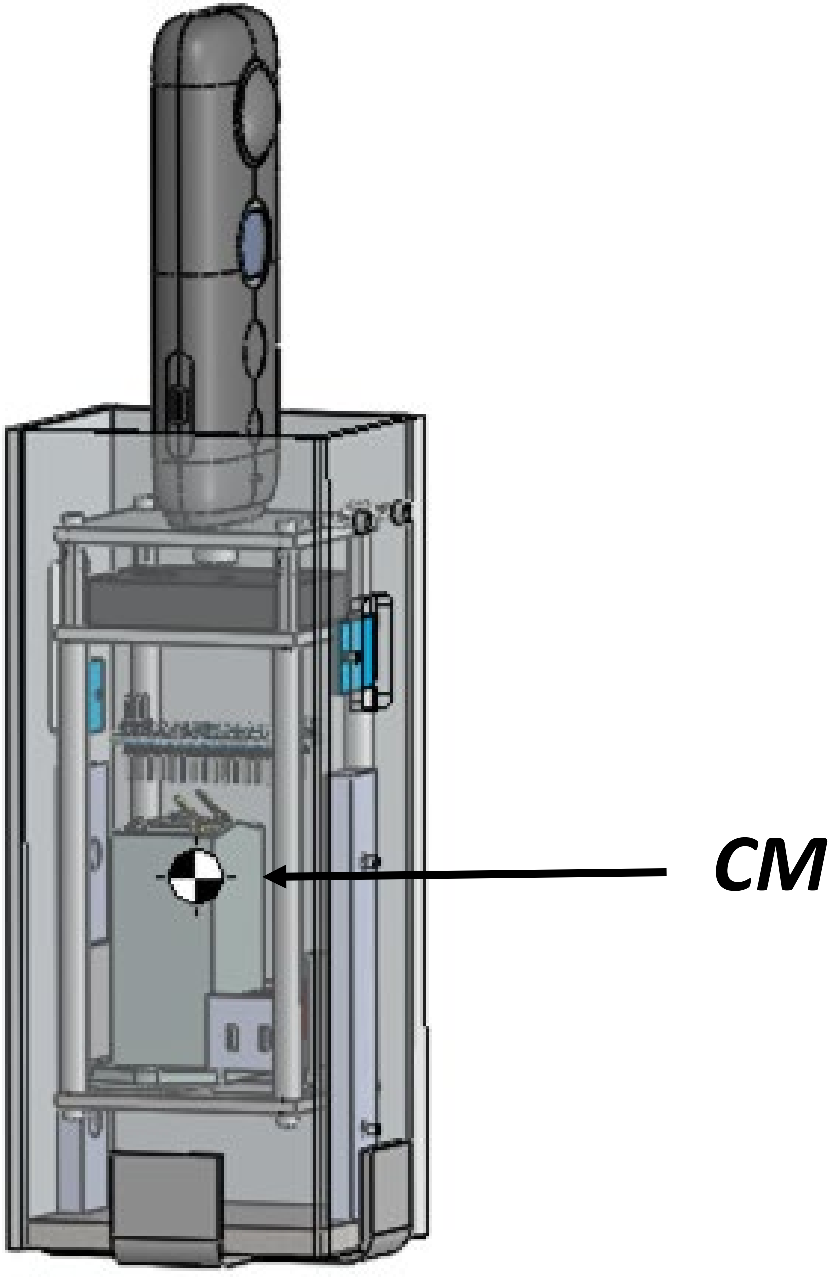


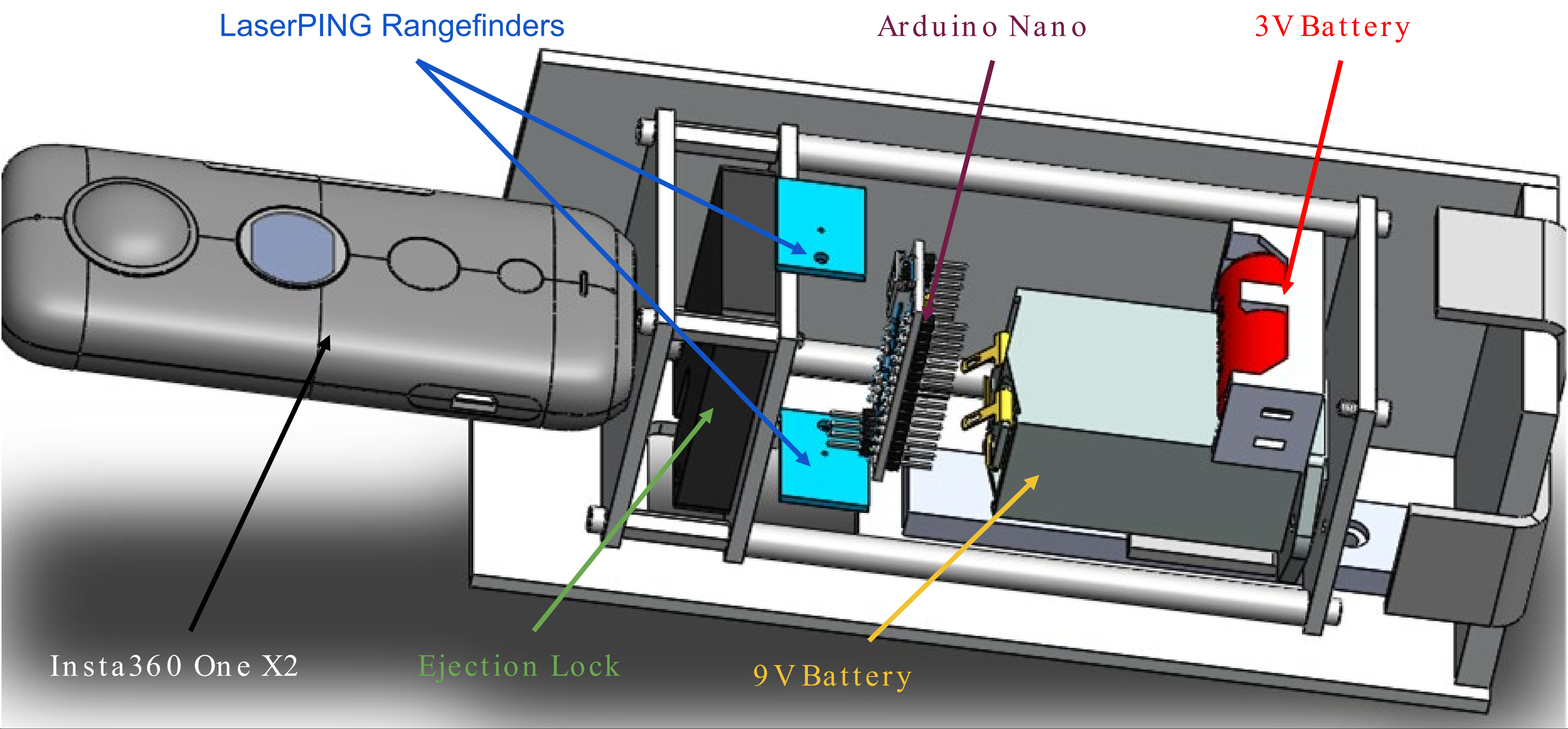


Magnified Fin Box


SP4CE Module
Crew Capsule Experience Camera (CCEC)
Camera Ejection Device (CED)

Center of Mass




LaserPING Rangefinders
Arduino Nano
3V Battery
Insta360 One X2
Ejection Lock
9V Battery