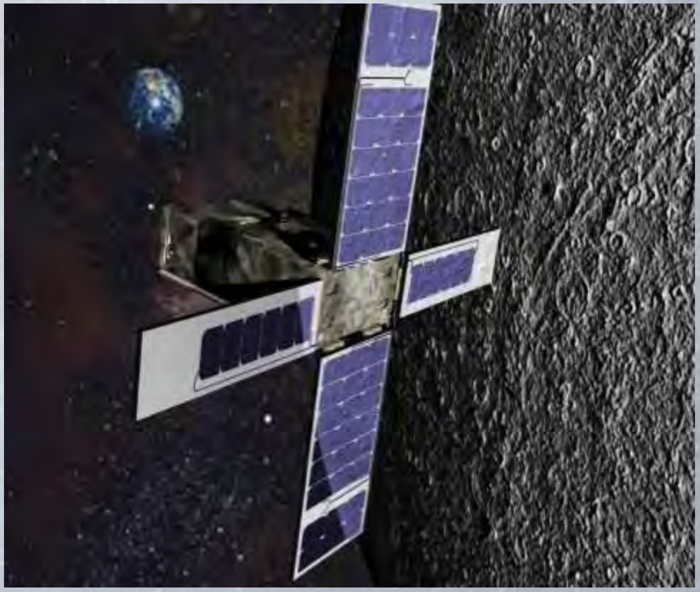
OSPRE
Test Readiness Review

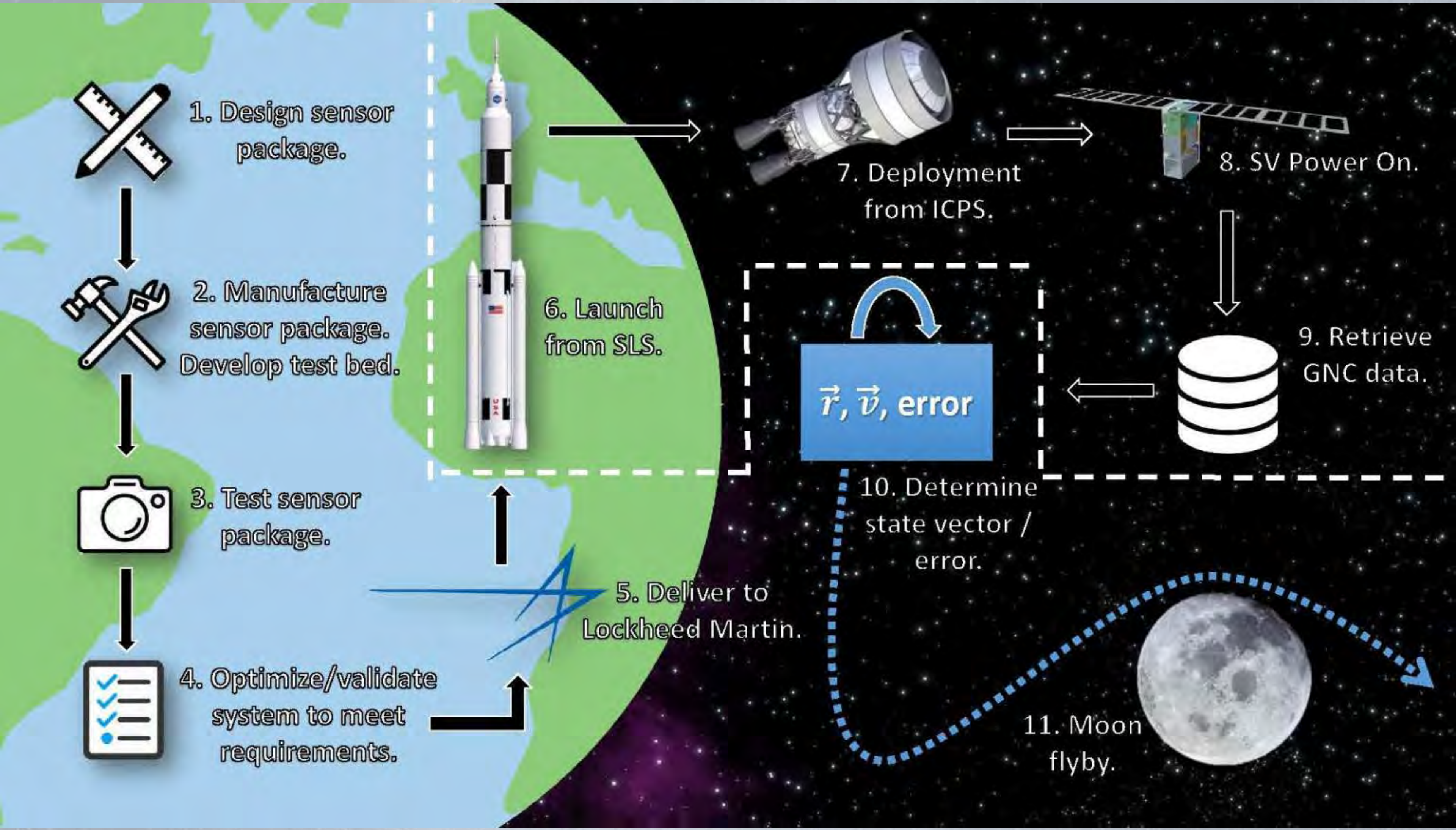
OVERVIEW

Project Purpose

- **Customer**: Lockheed Martin
- **Objective**: To use optical relative navigation to determine a spacecraft’s state vector and state vector error during a lunar transit
- CubeSat based on NASA CubeQuest Challenge
  - Lunar mission
  - Launch on SLS EM-1



Mission CON-OPS



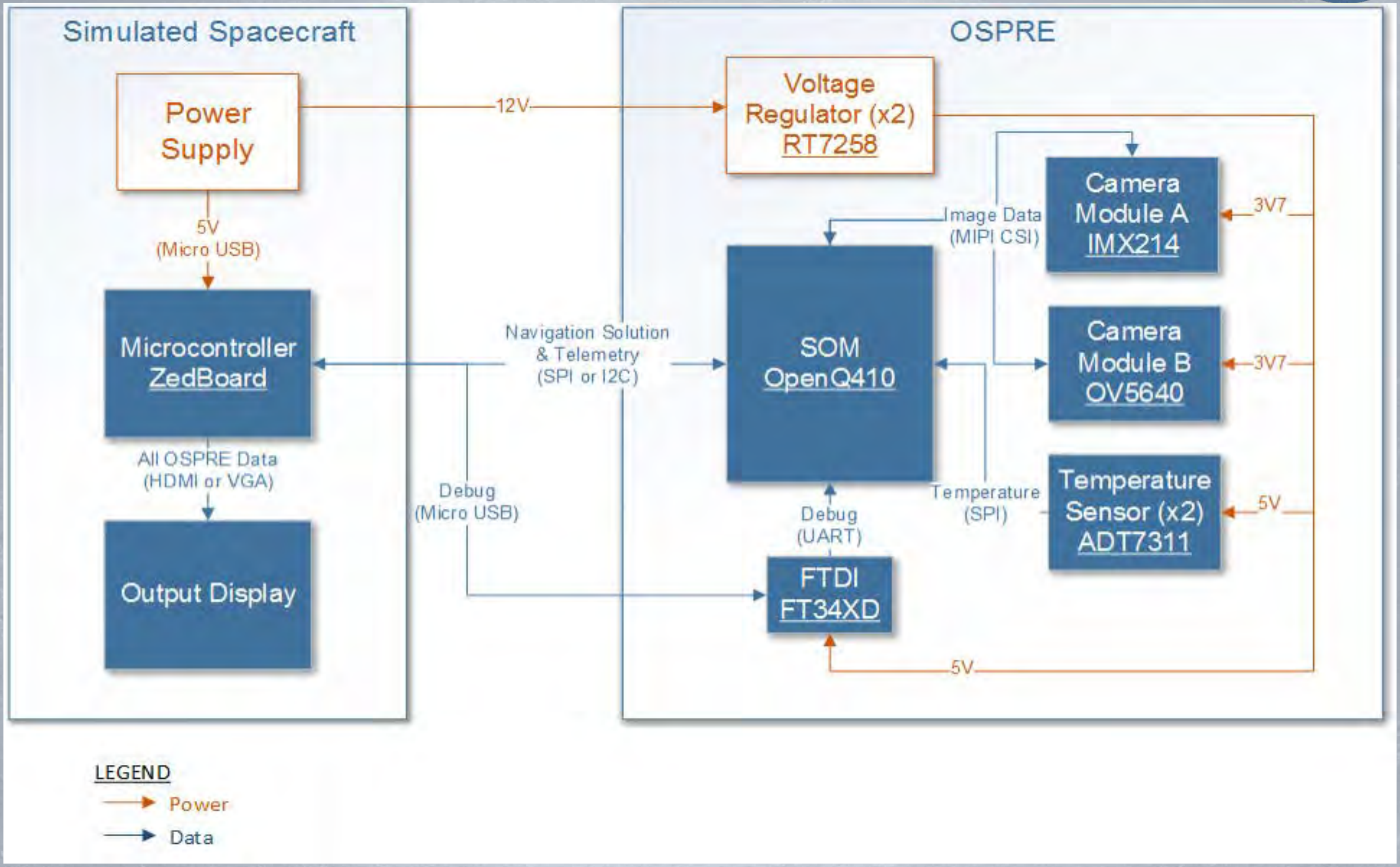
Specific Objectives

	Level 1	Level 2	Level 3
Data Processing	OSPRE shall output a state vector for full Moon and Earth disks and shall gather data for no longer than an hour at a time.	OSPRE shall estimate the error of the state vector.	OSPRE shall provide the state vector error within an accuracy of 1000km and 250m/s and shall function for all Moon and Earth phases.
Electrical	OSPRE shall operate nominally provided 3.3V, 5V, or 12V electrical power, and interface with the ZedBoard and image sensor(s) using SPI, I^2C, or Cameralink.	OSPRE shall have a peak current of no more than 500mA and maximum power draw of no greater than 3W.	The system shall provide voltage sense and current sense telemetry.
Structural	OSPRE's mass shall not exceed 0.8kg.	OSPRE's dimensions shall not exceed 5cm x 5cm x 1cm.	-
Testing	OSPRE's testing shall include testing the accuracy of the algorithm. OSPRE shall create a software test capable of quantifying the navigation software's error.	OSPRE's testing shall include a physical simulation. OSPRE shall create an Earth-Moon testbed that quantifies the error of the navigation hardware.	OSPRE's testing shall incorporate hardware and software testing simultaneously. The system shall compute the state vector autonomously in a test environment.

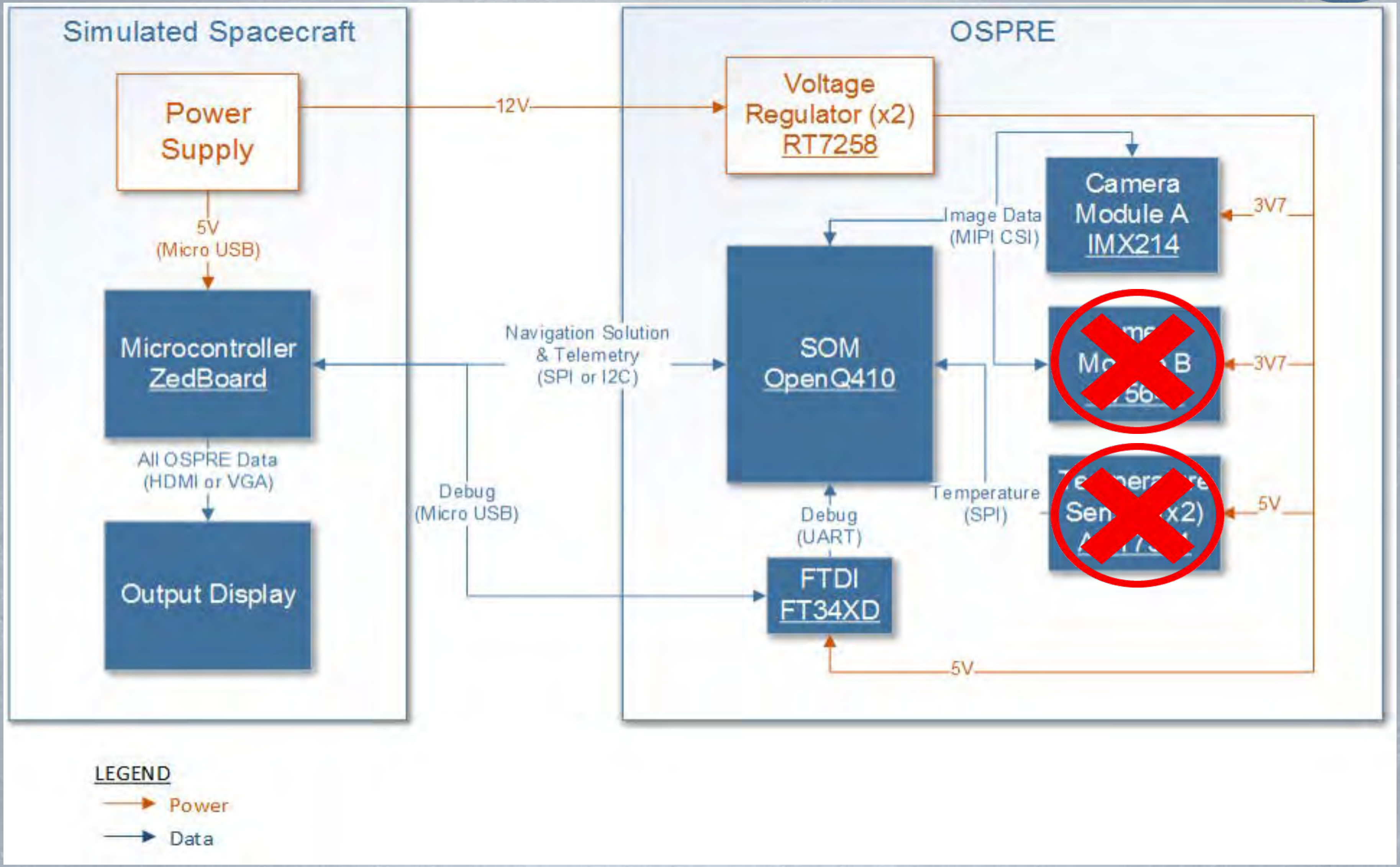
Specific Objectives

	Level 1	Level 2	Level 3
Data Processing	OSPRE shall output a state vector for full Moon and Earth disks and shall gather data for no longer than an hour at a time.	OSPRE shall estimate the error of the state vector.	OSPRE shall provide the state vector error within an accuracy of 1000km and 250m/s and shall function for all Moon and Earth phases.
Electrical	OSPRE shall operate nominally provided 3.3V, 5V, or 12V electrical power, and interface with the ZedBoard and image sensor(s) using SPI, I^2C, or Cameralink.	OSPRE shall have a peak current of no more than 500mA and maximum power draw of no greater than 3W.	The system shall provide voltage sense and current sense telemetry.
Structural	OSPRE's mass shall not exceed 0.8kg.	OSPRE's dimensions shall not exceed 5cm x 5cm x 1cm.	-
Testing	OSPRE's testing shall include testing the accuracy of the algorithm. OSPRE shall create a software test capable of quantifying the navigation software's error.	OSPRE's testing shall include a physical simulation. OSPRE shall create an Earth-Moon testbed that quantifies the error of the navigation hardware.	OSPRE's testing shall incorporate hardware and software testing simultaneously. The system shall compute the state vector **autonomously** in a test environment.

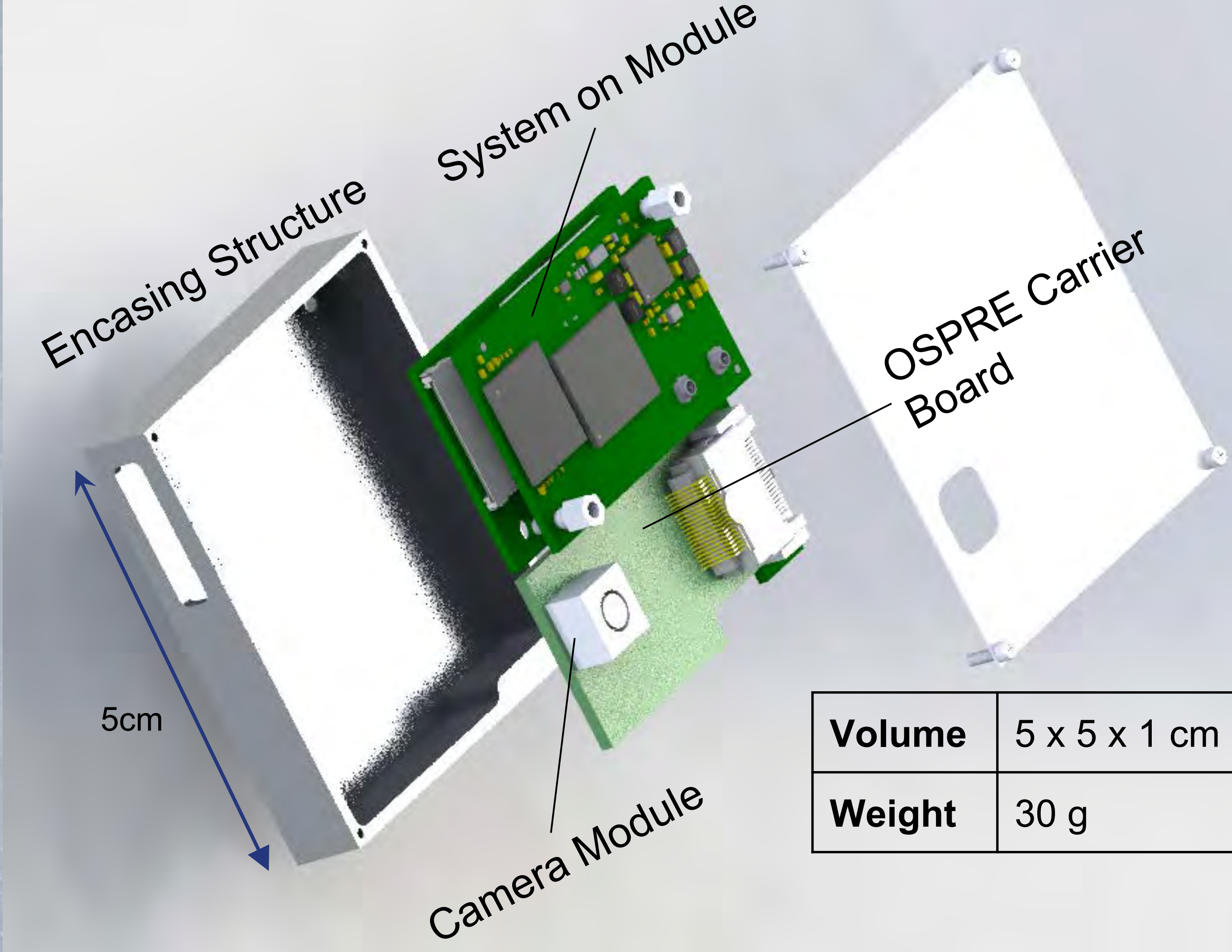
Functional Block Diagram



Functional Block Diagram



Baseline Design
OSPRE Sensor Package



Volume	5 x 5 x 1 cm
Weight	30 g

Baseline Design
Changes from MSR

- Camera "off-ramp" taken
  - Could not get 13MP camera working with SOM
    - Don't have the proper camera driver
  - Bought a cell phone (Motorola Moto G3) to use for Performance Testing and System-Level Testing
    - Uses same 13MP sensor and SOM that we have
  - Phone will be used in test setup to take pictures, in place of the OSPRE package
    - Images will then be fed to SOM and OSPRE software will run as if the camera controller had just taken a picture
    - Requires updated design for the camera mount

Critical Project Elements

Solution Accuracy:

- State vector must be determined to within required accuracy - 1,000km position, 250m/s velocity
    - Camera resolution, Image Processing, Navigation algorithms

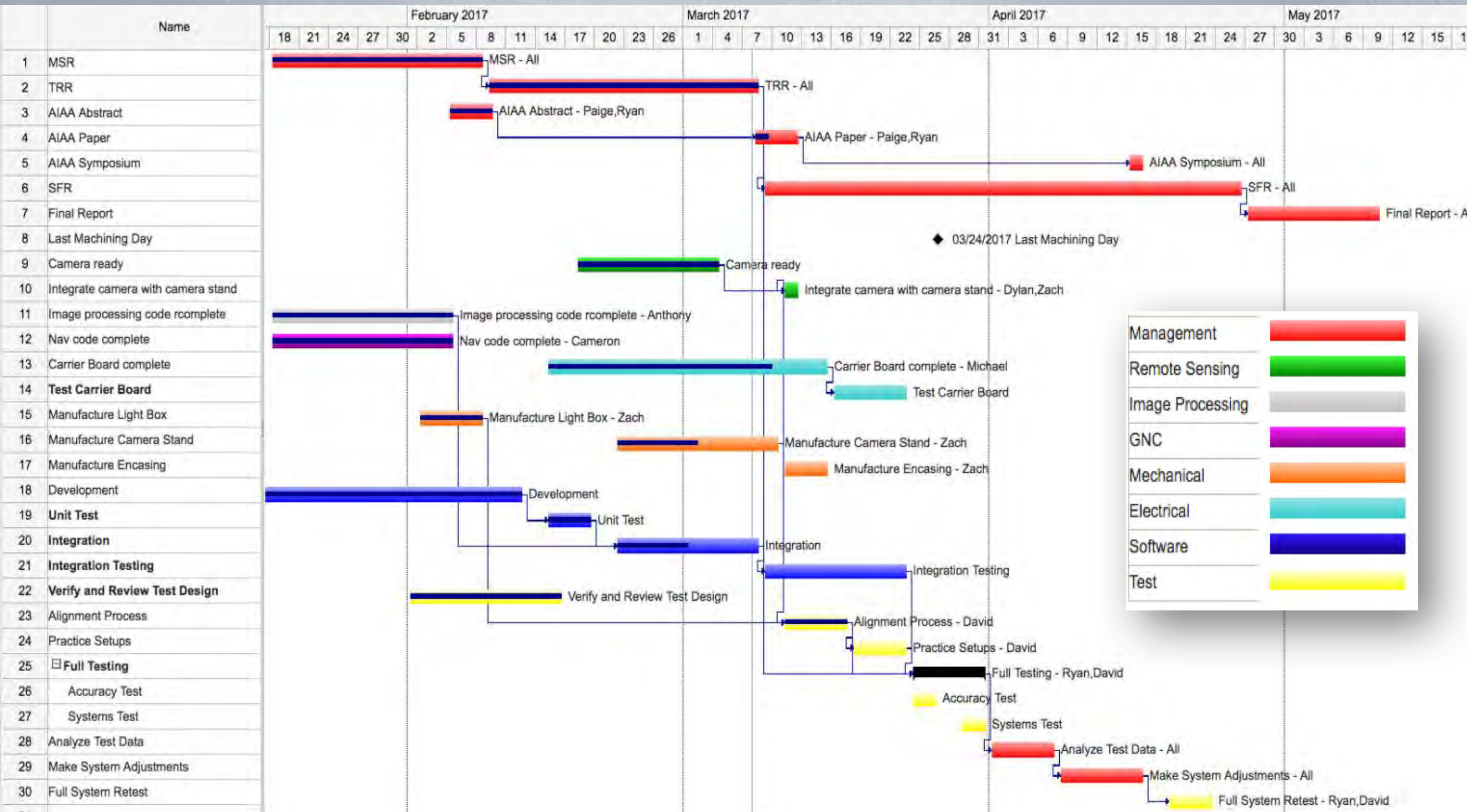
Testing Accuracy:

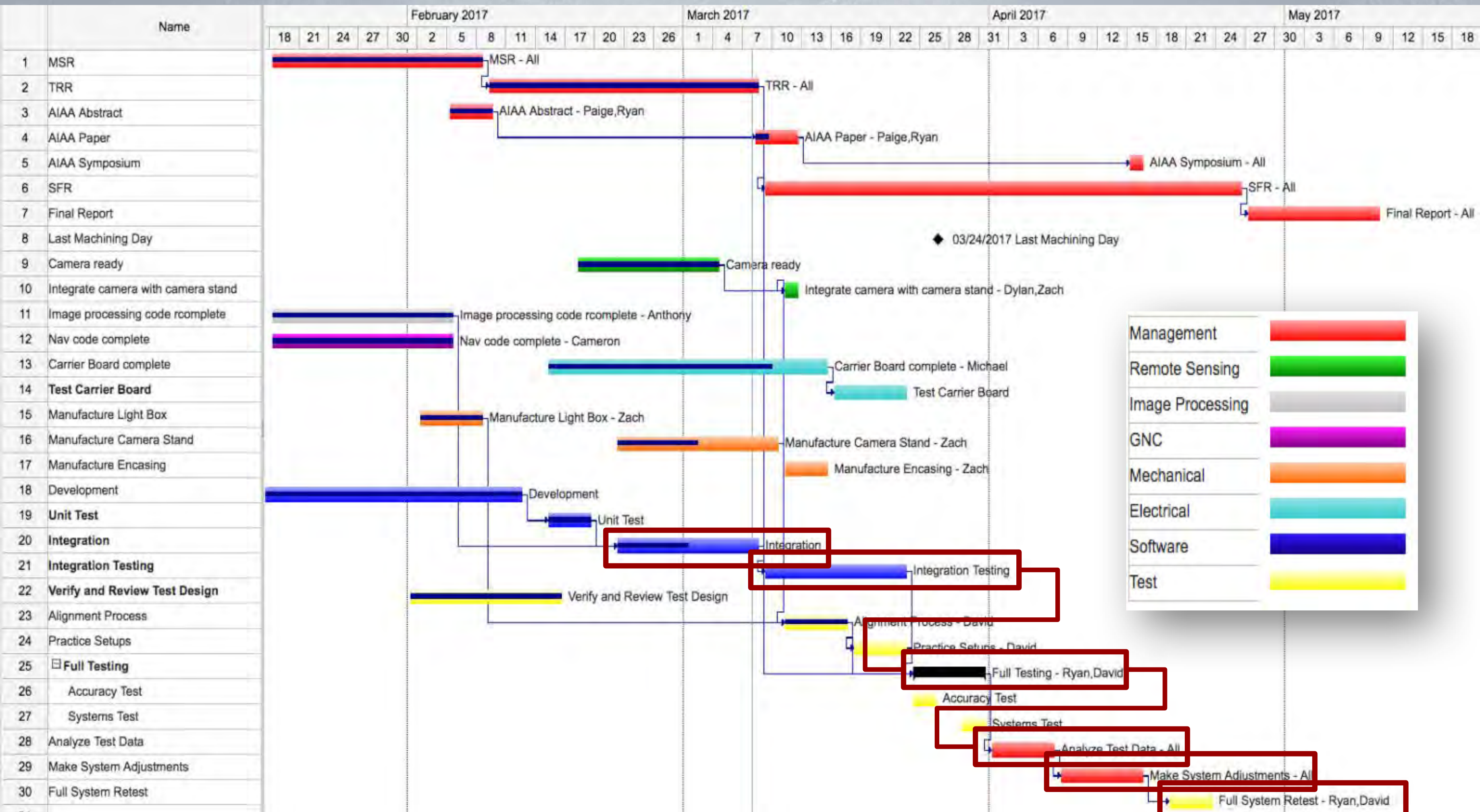
- Solution accuracy must be verified in testing
    - <100km position error
- Scaling of the Earth-Moon system
    - Measurement of distance between camera and target, measurement of the location of the center of the target

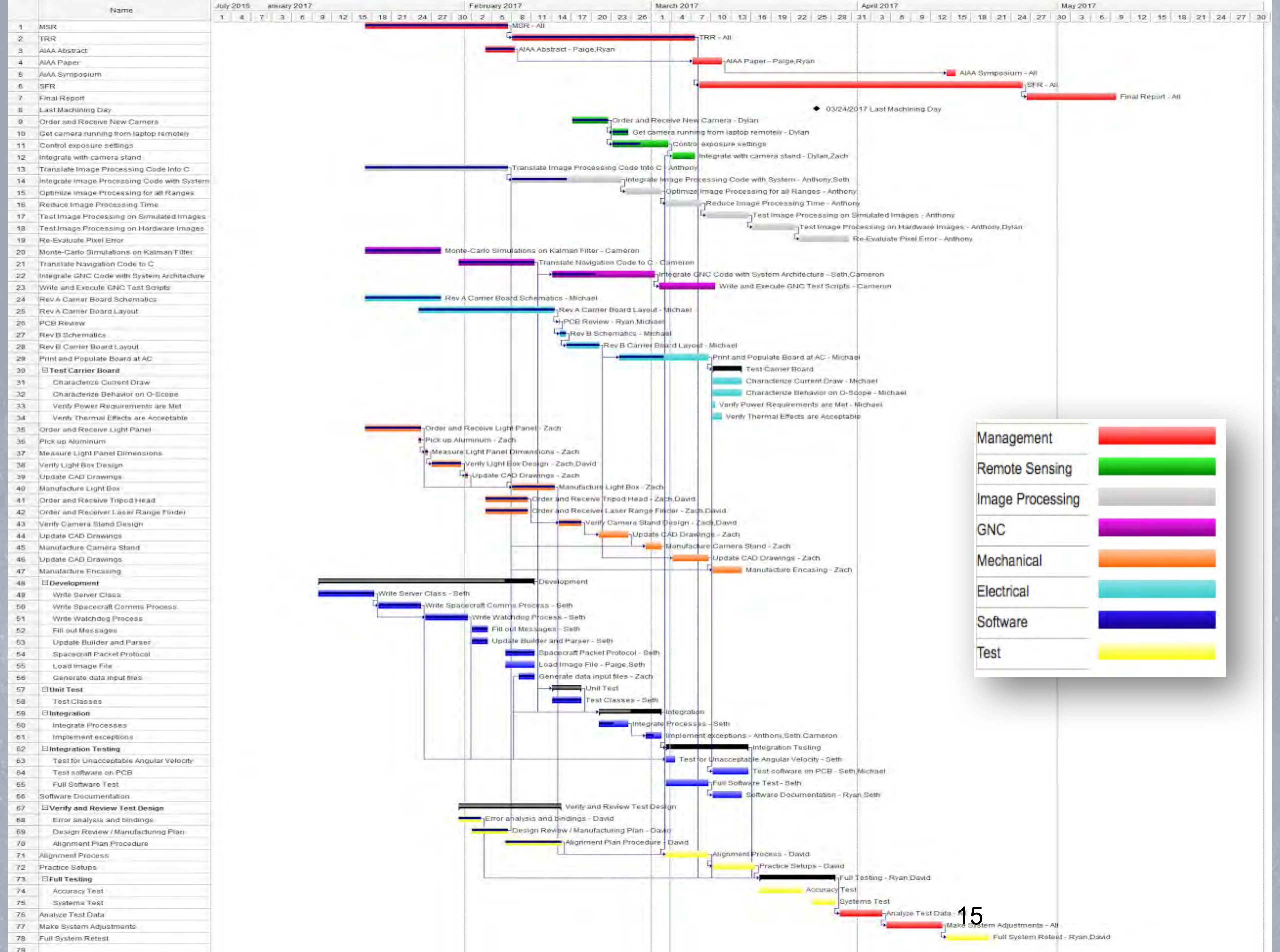
SWAP:

- Size, Weight, And Power requirements must be met
    - Component size, component power draw, component weight

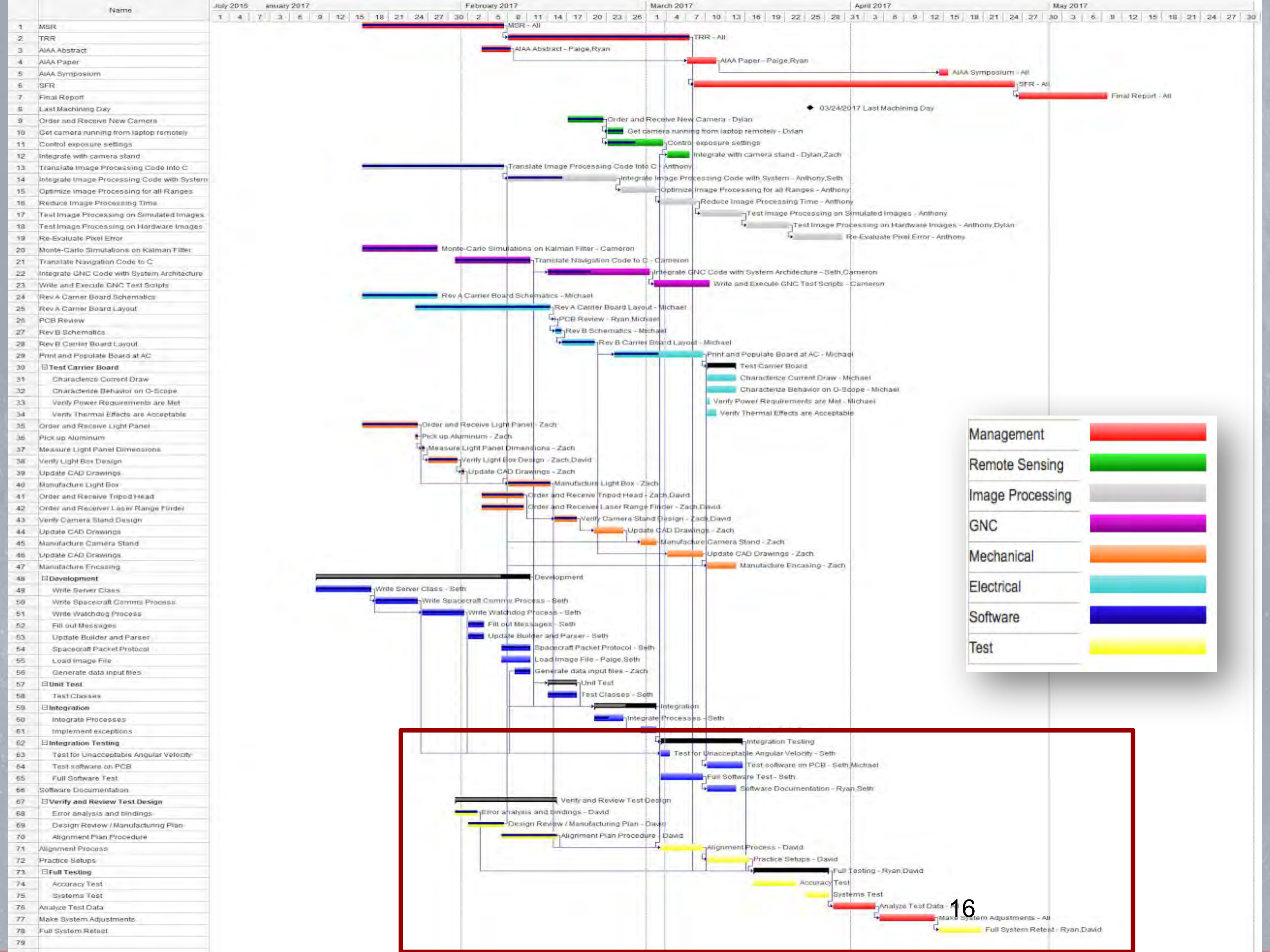
SCHEDULE

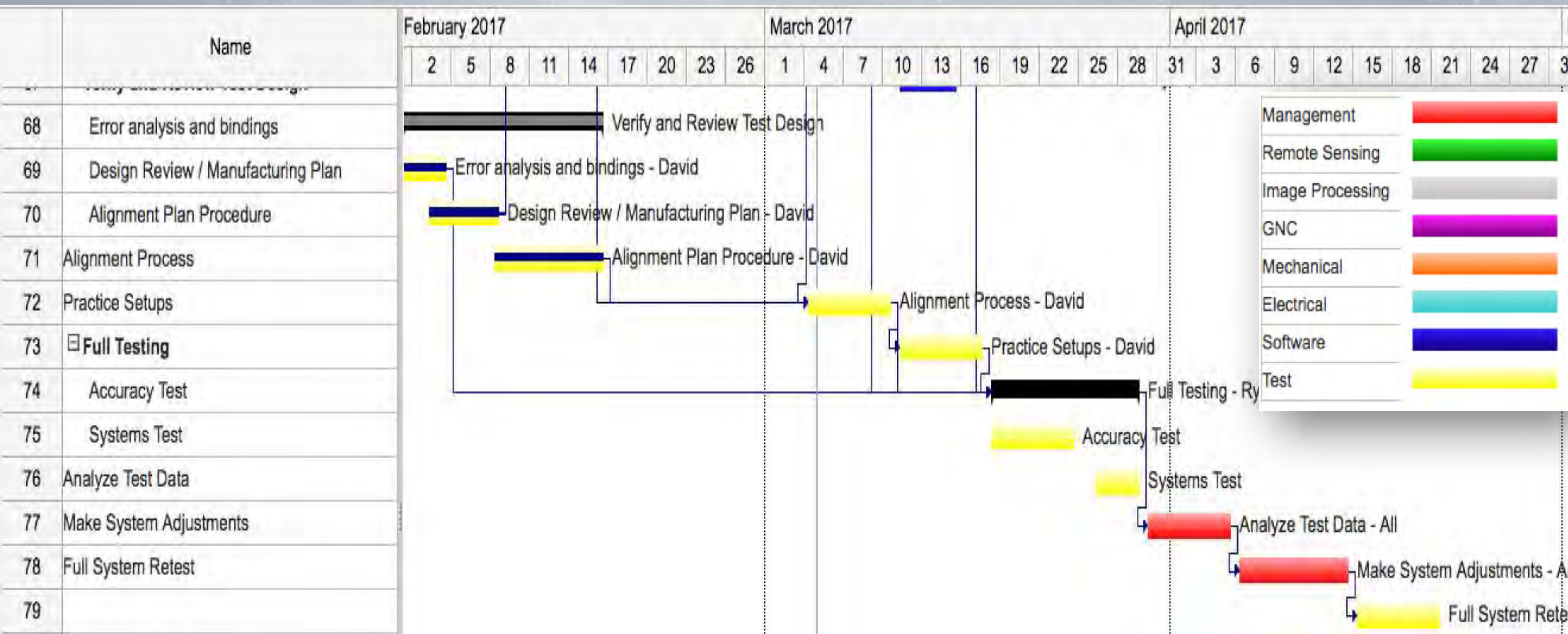

Name
February 2017
March 2017
April 2017
May 2017
18 21 24 27 30 2 5 8 11 14 17 20 23 26 1 4 7 10 13 16 19 22 25 28 31 3 6 9 12 15 18 21 24 27 30 3 6 9 12 15 18
1 MSR
2 TRR
3 AIAA Abstract
4 AIAA Paper
5 AIAA Symposium
6 SFR
7 Final Report
8 Last Machining Day
9 Camera ready
10 Integrate camera with camera stand
11 Image processing code rcomplete
12 Nav code complete
13 Carrier Board complete
14 Test Carrier Board
15 Manufacture Light Box
16 Manufacture Camera Stand
17 Manufacture Encasing
18 Development
19 Unit Test
20 Integration
21 Integration Testing
22 Verify and Review Test Design
23 Alignment Process
24 Practice Setups
25 Full Testing
26 Accuracy Test
27 Systems Test
28 Analyze Test Data
29 Make System Adjustments
30 Full System Retest
31
MSR - All
TRR - All
AIAA Abstract - Paige,Ryan
AIAA Paper - Paige,Ryan
AIAA Symposium - All
SFR - All
Final Report - All
03/24/2017 Last Machining Day
Camera ready
Integrate camera with camera stand - Dylan,Zach
Image processing code rcomplete - Anthony
Nav code complete - Cameron
Carrier Board complete - Michael
Test Carrier Board
Manufacture Light Box - Zach
Manufacture Camera Stand - Zach
Manufacture Encasing - Zach
Development
Unit Test
Integration
Integration Testing
Verify and Review Test Design
Alignment Process - David
Practice Setups - David
Full Testing - Ryan,David
Accuracy Test
Systems Test
Analyze Test Data - All
Make System Adjustments - All
Full System Retest - Ryan,David
Management
Remote Sensing
Image Processing
GNC
Mechanical
Electrical
Software
Test

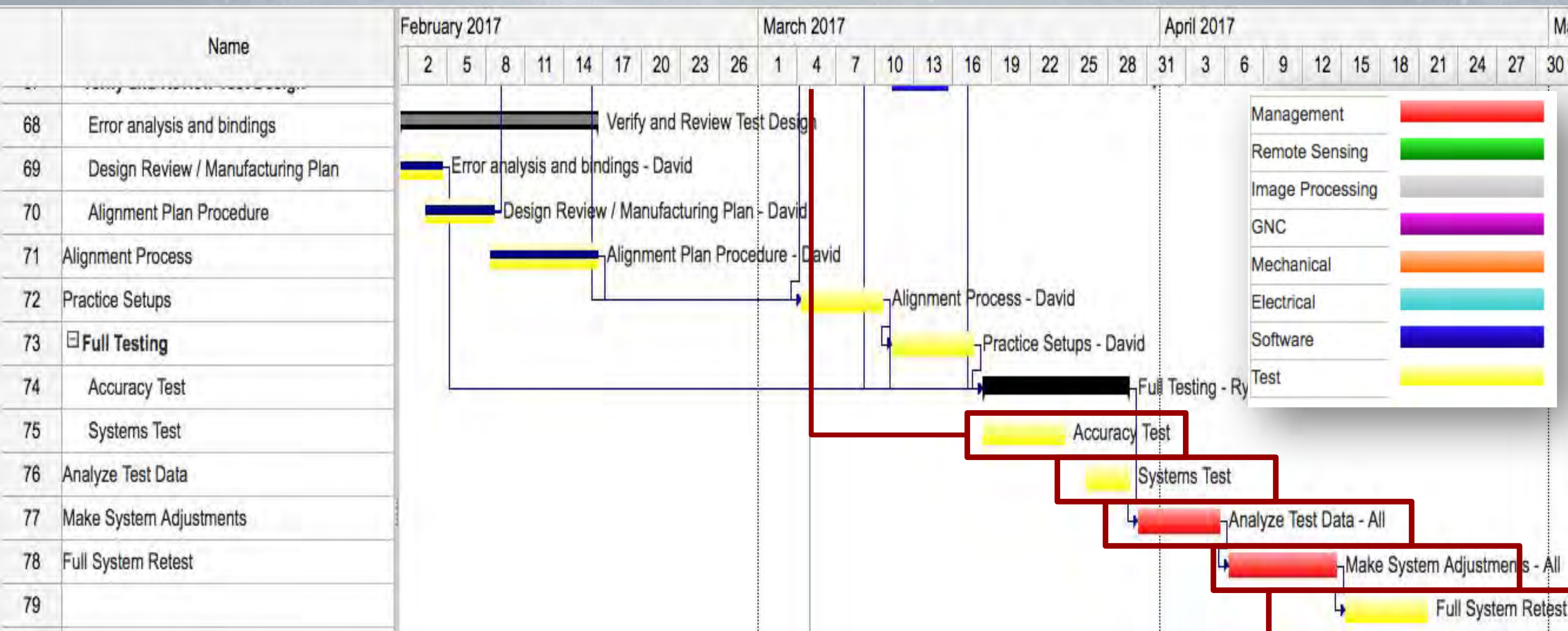

Name
February 2017
March 2017
April 2017
May 2017
18 21 24 27 30 2 5 8 11 14 17 20 23 26 1 4 7 10 13 16 19 22 25 28 31 3 6 9 12 15 18 21 24 27 30 3 6 9 12 15 18
1 MSR
2 TRR
3 AIAA Abstract
4 AIAA Paper
5 AIAA Symposium
6 SFR
7 Final Report
8 Last Machining Day
9 Camera ready
10 Integrate camera with camera stand
11 Image processing code rcomplete
12 Nav code complete
13 Carrier Board complete
14 Test Carrier Board
15 Manufacture Light Box
16 Manufacture Camera Stand
17 Manufacture Encasing
18 Development
19 Unit Test
20 Integration
21 Integration Testing
22 Verify and Review Test Design
23 Alignment Process
24 Practice Setups
25 Full Testing
26 Accuracy Test
27 Systems Test
28 Analyze Test Data
29 Make System Adjustments
30 Full System Retest
31
MSR - All
TRR - All
AIAA Abstract - Paige,Ryan
AIAA Paper - Paige,Ryan
AIAA Symposium - All
SFR - All
Final Report - All
03/24/2017 Last Machining Day
Camera ready
Integrate camera with camera stand - Dylan,Zach
Image processing code rcomplete - Anthony
Nav code complete - Cameron
Carrier Board complete - Michael
Test Carrier Board
Manufacture Light Box - Zach
Manufacture Camera Stand - Zach
Manufacture Encasing - Zach
Development
Unit Test
Integration
Integration Testing
Verify and Review Test Design
Full Testing - Ryan,David
Accuracy Test
Systems Test
Analyze Test Data - All
Make System Adjustments - All
Full System Retest - Ryan,David
Management
Remote Sensing
Image Processing
GNC
Mechanical
Electrical
Software
Test



Name
July 2016
January 2017
February 2017
March 2017
April 2017
May 2017
1 MSR
2 TRR
3 AIAA Abstract
4 AIAA Paper
5 AIAA Symposium
6 SFR
7 Final Report
8 Last Machining Day
9 Order and Receive New Camera
10 Get camera running from laptop remotely
11 Control exposure settings
12 Integrate with camera stand
13 Translate Image Processing Code into C
14 Integrate Image Processing Code with System
15 Optimize Image Processing for all Ranges
16 Reduce Image Processing Time
17 Test Image Processing on Simulated Images
18 Test Image Processing on Hardware Images
19 Re-Evaluate Pixel Error
20 Monte-Carlo Simulations on Kalman Filter
21 Translate Navigation Code to C
22 Integrate GNC Code with System Architecture
23 Write and Execute GNC Test Scripts
24 Rev A Carrier Board Schematics
25 Rev A Carrier Board Layout
26 PCB Review
27 Rev B Schematics
28 Rev B Carrier Board Layout
29 Print and Populate Board at AC
30 Test Carrier Board
31 Characterize Current Draw
32 Characterize Behavior on O-Scope
33 Verify Power Requirements are Met
34 Verify Thermal Effects are Acceptable
35 Order and Receive Light Panel
36 Pick up Aluminum
37 Measure Light Panel Dimensions
38 Verify Light Box Design
39 Update CAD Drawings
40 Manufacture Light Box
41 Order and Receive Tripod Head
42 Order and Receiver Laser Range Finder
43 Verify Camera Stand Design
44 Update CAD Drawings
45 Manufacture Camera Stand
46 Update CAD Drawings
47 Manufacture Encasing
48 Development
49 Write Server Class
50 Write Spacecraft Comms Process
51 Write Watchdog Process
52 Fill out Messages
53 Update Builder and Parser
54 Spacecraft Packet Protocol
55 Load Image File
56 Generate data input files
57 Unit Test
58 Test Classes
59 Integration
60 Integrate Processes
61 Implement exceptions
62 Integration Testing
63 Test for Unacceptable Angular Velocity
64 Test software on PCB
65 Full Software Test
66 Software Documentation
67 Verify and Review Test Design
68 Error analysis and bindings
69 Design Review / Manufacturing Plan
70 Alignment Plan Procedure
71 Alignment Process
72 Practice Setups
73 Full Testing
74 Accuracy Test
75 Systems Test
76 Analyze Test Data
77 Make System Adjustments
78 Full System Retest
79
MSR - All
TRR - All
AIAA Abstract - Paige,Ryan
AIAA Paper - Paige,Ryan
AIAA Symposium - All
SFR - All
Final Report - All
03/24/2017 Last Machining Day
Order and Receive New Camera - Dylan
Get camera running from laptop remotely - Dylan
Control exposure settings
Integrate with camera stand - Dylan,Zach
Translate Image Processing Code into C - Anthony
Integrate Image Processing Code with System - Anthony,Seth
Optimize Image Processing for all Ranges - Anthony
Reduce Image Processing Time - Anthony
Test Image Processing on Simulated Images - Anthony
Test Image Processing on Hardware Images - Anthony,Dylan
Re-Evaluate Pixel Error - Anthony
Monte-Carlo Simulations on Kalman Filter - Cameron
Translate Navigation Code to C - Cameron
Integrate GNC Code with System Architecture - Seth,Cameron
Write and Execute GNC Test Scripts - Cameron
Rev A Carrier Board Schematics - Michael
Rev A Carrier Board Layout - Michael
PCB Review - Ryan,Michael
Rev B Schematics - Michael
Rev B Carrier Board Layout - Michael
Print and Populate Board at AC - Michael
Test Carrier Board
Characterize Current Draw - Michael
Characterize Behavior on O-Scope - Michael
Verify Power Requirements are Met - Michael
Verify Thermal Effects are Acceptable
Order and Receive Light Panel - Zach
Pick up Aluminum - Zach
Measure Light Panel Dimensions - Zach
Verify Light Box Design - Zach,David
Update CAD Drawings - Zach
Manufacture Light Box - Zach
Order and Receive Tripod Head - Zach,David
Order and Receiver Laser Range Finder - Zach,David
Verify Camera Stand Design - Zach,David
Update CAD Drawings - Zach
Manufacture Camera Stand - Zach
Update CAD Drawings - Zach
Manufacture Encasing - Zach
Development
Write Server Class - Seth
Write Spacecraft Comms Process - Seth
Write Watchdog Process - Seth
Fill out Messages - Seth
Update Builder and Parser - Seth
Spacecraft Packet Protocol - Seth
Load Image File - Paige,Seth
Generate data input files - Zach
Unit Test
Test Classes - Seth
Integration
Integrate Processes - Seth
Implement exceptions - Anthony,Seth,Cameron
Integration Testing
Test for Unacceptable Angular Velocity - Seth
Test software on PCB - Seth,Michael
Full Software Test - Seth
Software Documentation - Ryan,Seth
Verify and Review Test Design
Error analysis and bindings - David
Design Review / Manufacturing Plan - David
Alignment Plan Procedure - David
Alignment Process - David
Practice Setups - David
Full Testing - Ryan,David
Accuracy Test
Systems Test
Analyze Test Data - All
Make System Adjustments - All
Full System Retest - Ryan,David
Management
Remote Sensing
Image Processing
GNC
Mechanical
Electrical
Software
Test


Name
July 2016
January 2017
February 2017
March 2017
April 2017
May 2017
1 MSR
2 TRR
3 AIAA Abstract
4 AIAA Paper
5 AIAA Symposium
6 SFR
7 Final Report
8 Last Machining Day
9 Order and Receive New Camera
10 Get camera running from laptop remotely
11 Control exposure settings
12 Integrate with camera stand
13 Translate Image Processing Code into C
14 Integrate Image Processing Code with System
15 Optimize Image Processing for all Ranges
16 Reduce Image Processing Time
17 Test Image Processing on Simulated Images
18 Test Image Processing on Hardware Images
19 Re-Evaluate Pixel Error
20 Monte-Carlo Simulations on Kalman Filter
21 Translate Navigation Code to C
22 Integrate GNC Code with System Architecture
23 Write and Execute GNC Test Scripts
24 Rev A Carrier Board Schematics
25 Rev A Carrier Board Layout
26 PCB Review
27 Rev B Schematics
28 Rev B Carrier Board Layout
29 Print and Populate Board at AC
30 Test Carrier Board
31 Characterize Current Draw
32 Characterize Behavior on O-Scope
33 Verify Power Requirements are Met
34 Verify Thermal Effects are Acceptable
35 Order and Receive Light Panel
36 Pick up Aluminum
37 Measure Light Panel Dimensions
38 Verify Light Box Design
39 Update CAD Drawings
40 Manufacture Light Box
41 Order and Receive Tripod Head
42 Order and Receive Laser Range Finder
43 Verify Camera Stand Design
44 Update CAD Drawings
45 Manufacture Camera Stand
46 Update CAD Drawings
47 Manufacture Encasing
48 Development
49 Write Server Class
50 Write Spacecraft Comms Process
51 Write Watchdog Process
52 Fill out Messages
53 Update Builder and Parser
54 Spacecraft Packet Protocol
55 Load Image File
56 Generate data input files
57 Unit Test
58 Test Classes
59 Integration
60 Integrate Processes
61 Implement exceptions
62 Integration Testing
63 Test for Unacceptable Angular Velocity
64 Test software on PCB
65 Full Software Test
66 Software Documentation
67 Verify and Review Test Design
68 Error analysis and bindings
69 Design Review / Manufacturing Plan
70 Alignment Plan Procedure
71 Alignment Process
72 Practice Setups
73 Full Testing
74 Accuracy Test
75 Systems Test
76 Analyze Test Data
77 Make System Adjustments
78 Full System Retest
79
Management
Remote Sensing
Image Processing
GNC
Mechanical
Electrical
Software
Test


Name
February 2017
March 2017
April 2017
2 5 8 11 14 17 20 23 26 1 4 7 10 13 16 19 22 25 28 31 3 6 9 12 15 18 21 24 27 30
68 Error analysis and bindings
69 Design Review / Manufacturing Plan
70 Alignment Plan Procedure
71 Alignment Process
72 Practice Setups
73 Full Testing
74 Accuracy Test
75 Systems Test
76 Analyze Test Data
77 Make System Adjustments
78 Full System Retest
79
Verify and Review Test Design
Error analysis and bindings - David
Design Review / Manufacturing Plan - David
Alignment Plan Procedure - David
Alignment Process - David
Practice Setups - David
Full Testing - Ry
Accuracy Test
Systems Test
Analyze Test Data - All
Make System Adjustments - All
Full System Retest
Management
Remote Sensing
Image Processing
GNC
Mechanical
Electrical
Software
Test

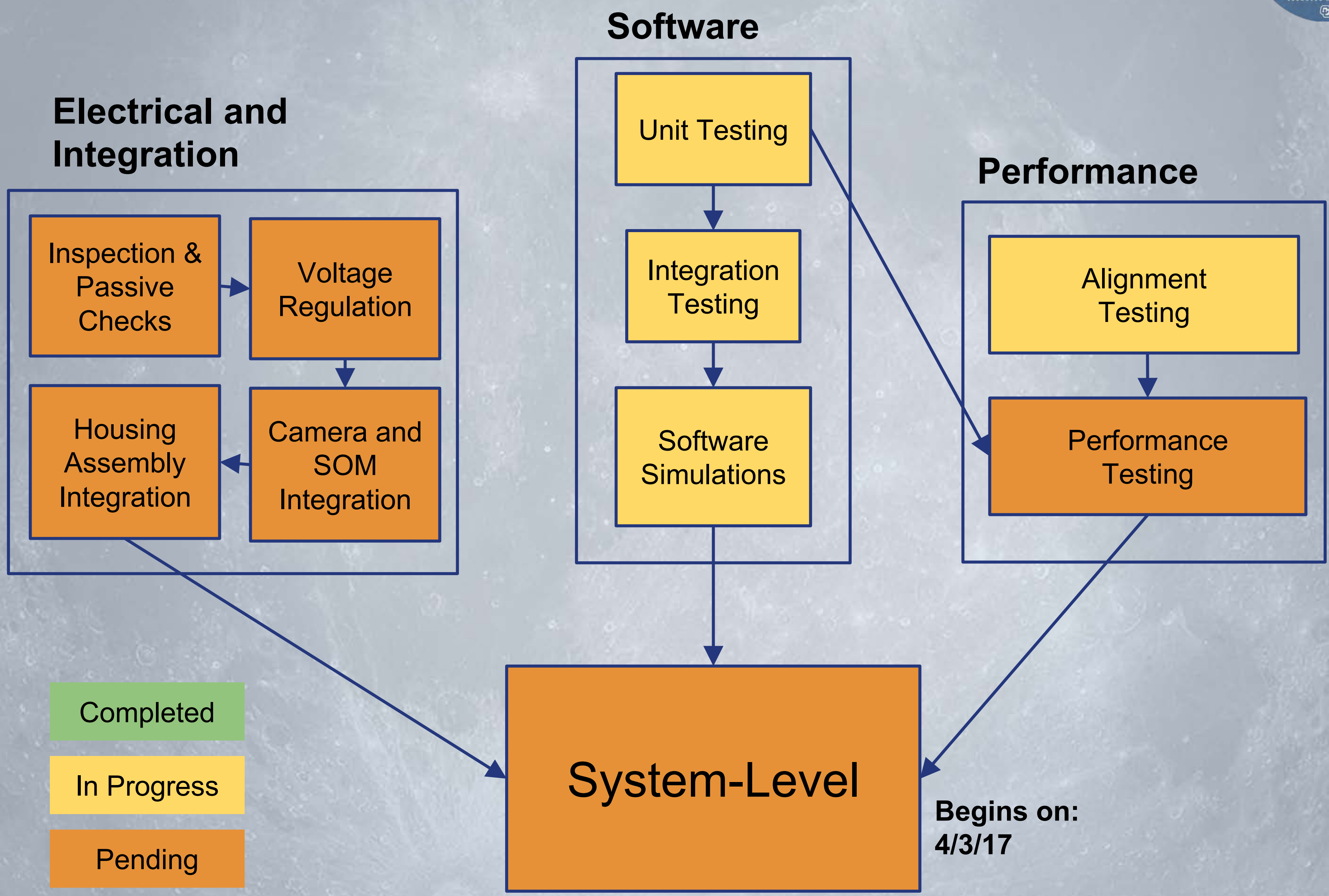

Name
February 2017
March 2017
April 2017
2 5 8 11 14 17 20 23 26 1 4 7 10 13 16 19 22 25 28 31 3 6 9 12 15 18 21 24 27 30
68 Error analysis and bindings
69 Design Review / Manufacturing Plan
70 Alignment Plan Procedure
71 Alignment Process
72 Practice Setups
73 Full Testing
74 Accuracy Test
75 Systems Test
76 Analyze Test Data
77 Make System Adjustments
78 Full System Retest
79
Verify and Review Test Design
Error analysis and bindings - David
Design Review / Manufacturing Plan - David
Alignment Plan Procedure - David
Alignment Process - David
Practice Setups - David
Full Testing - Ry
Accuracy Test
Systems Test
Analyze Test Data - All
Make System Adjustments - All
Full System Retest
Management
Remote Sensing
Image Processing
GNC
Mechanical
Electrical
Software
Test

Schedule Summary

Task	Due Date	Status
Camera setup	March 3rd	Complete
Software integration	March 6th ext. March 10th	In progress
Manufacturing	March 13th	In progress • Light box in assembly • Camera stand in progress • Encasing in progress
Carrier Board	March 13th ext. March 20th	In progress • Layout complete • Order pending
Performance Testing	March 23rd	Pending

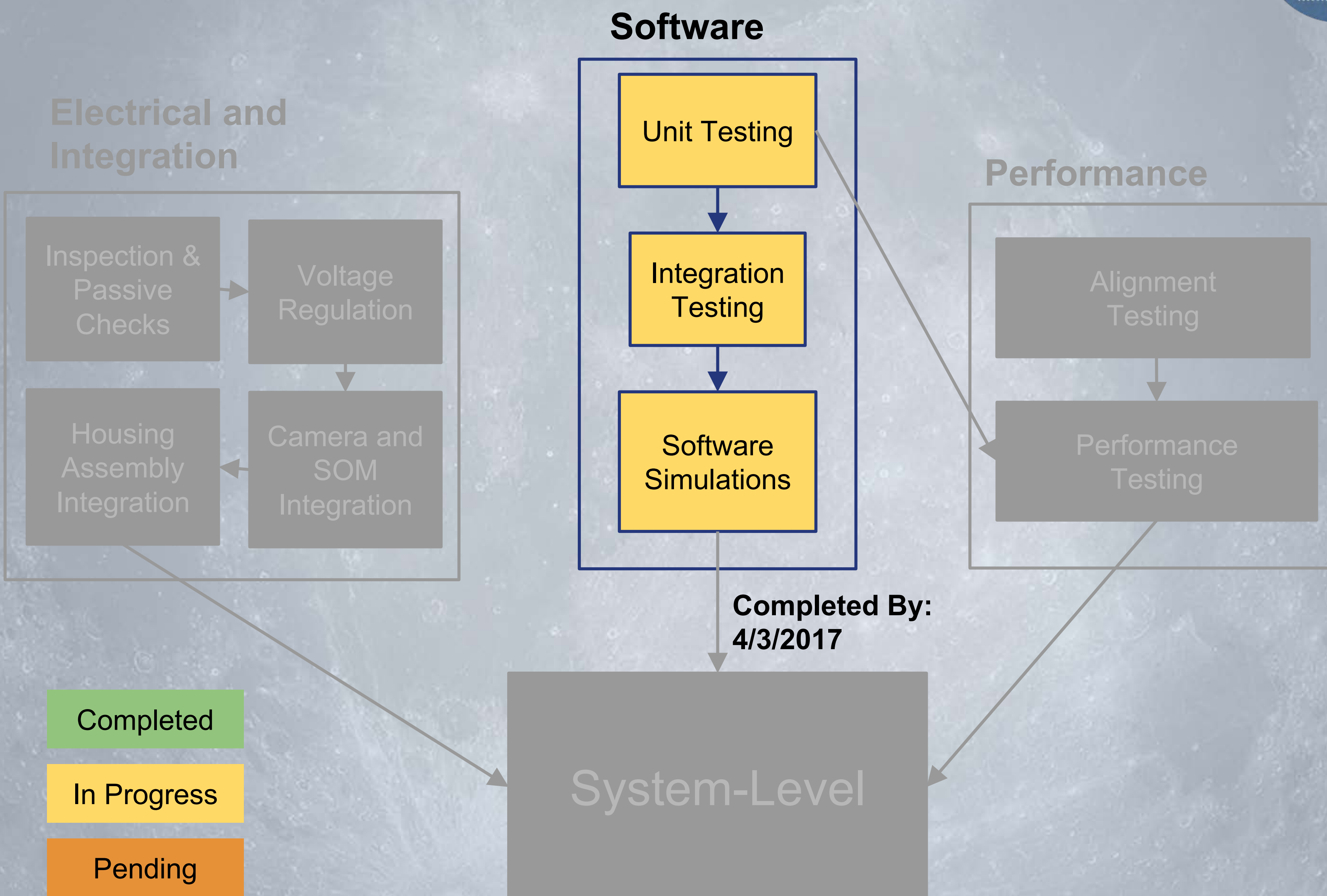
TEST READINESS

Test Breakdown

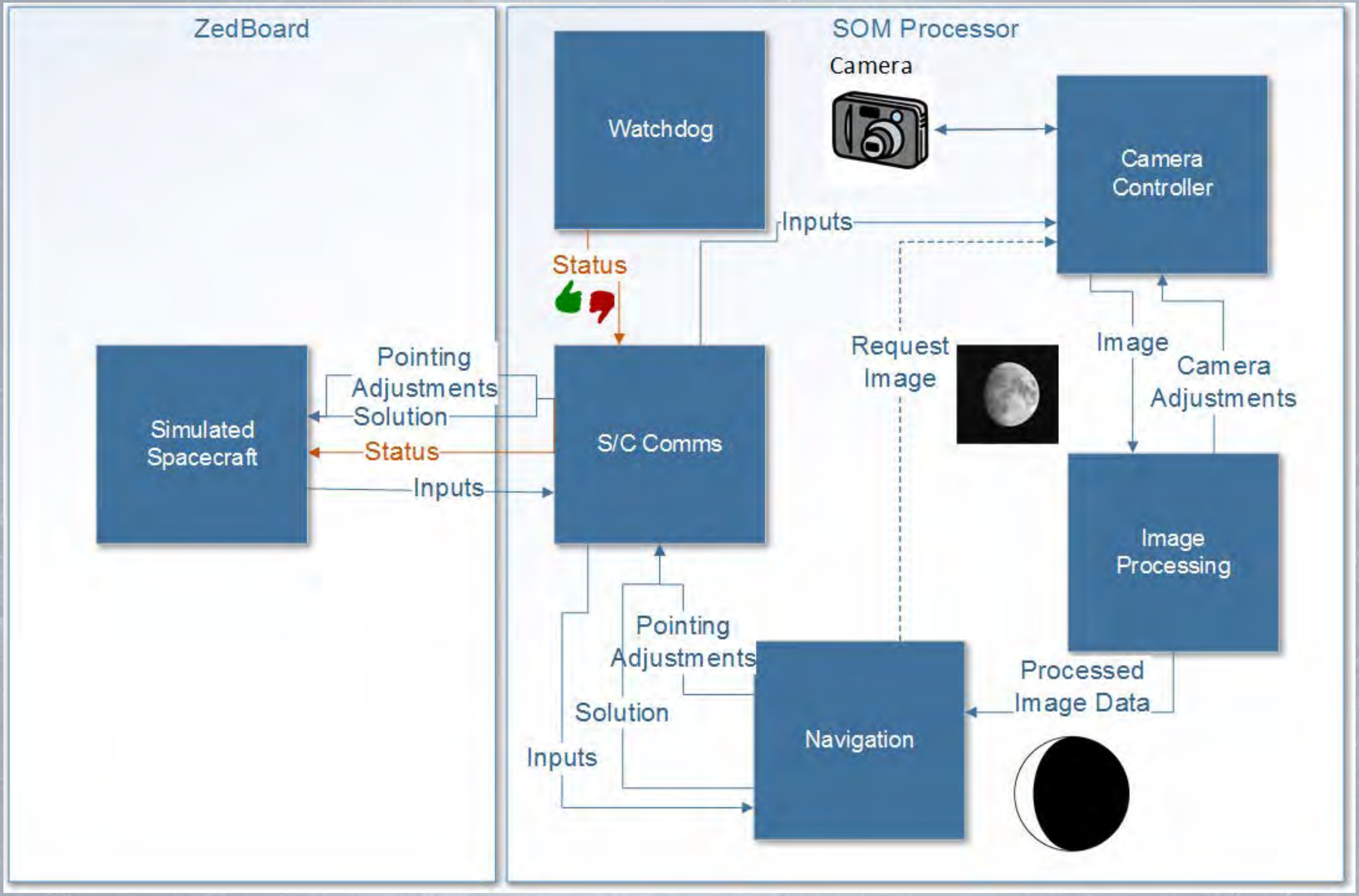


SOFTWARE TESTING

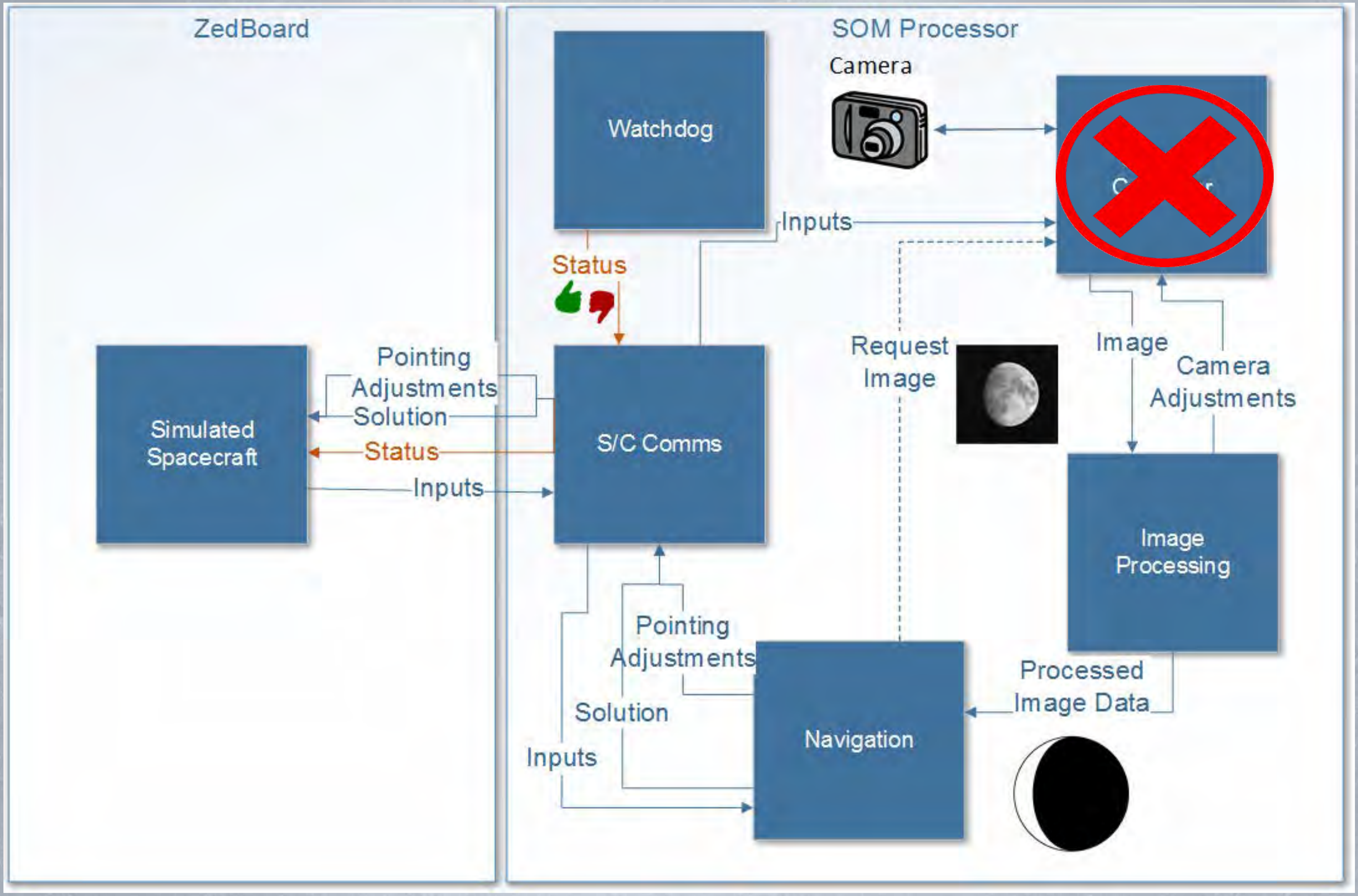
Test Breakdown



Software - Scope



Software - Scope



Software Testing Scope

Test Procedures

- **Unit Testing**:
  - Individually tested for expected outcomes and for edge cases (invalid inputs)
- **Integration Testing**:
  - Software works as a whole on personal PC
  - Software works as a whole on the SOM, and unit tests will be re-run
- **Software Simulations**:
  - System Soak
    - Run software for a long period of time to check for memory leaks
  - Software Mission Simulation
    - Simulated flight using STK and OSPRE software to evaluate performance

Software Testing
Software Mission Simulation

Software Error

Positions & Velocities over a nominal orbit

STK State Vector

$\vec{r}$

Position & Velocity computed by OSPRE will be compared to STK

Computed State Vector

Image Generation

Generate an expected image based on the STK position

OSPRE Software

$\vec{r}, \vec{v}$, error

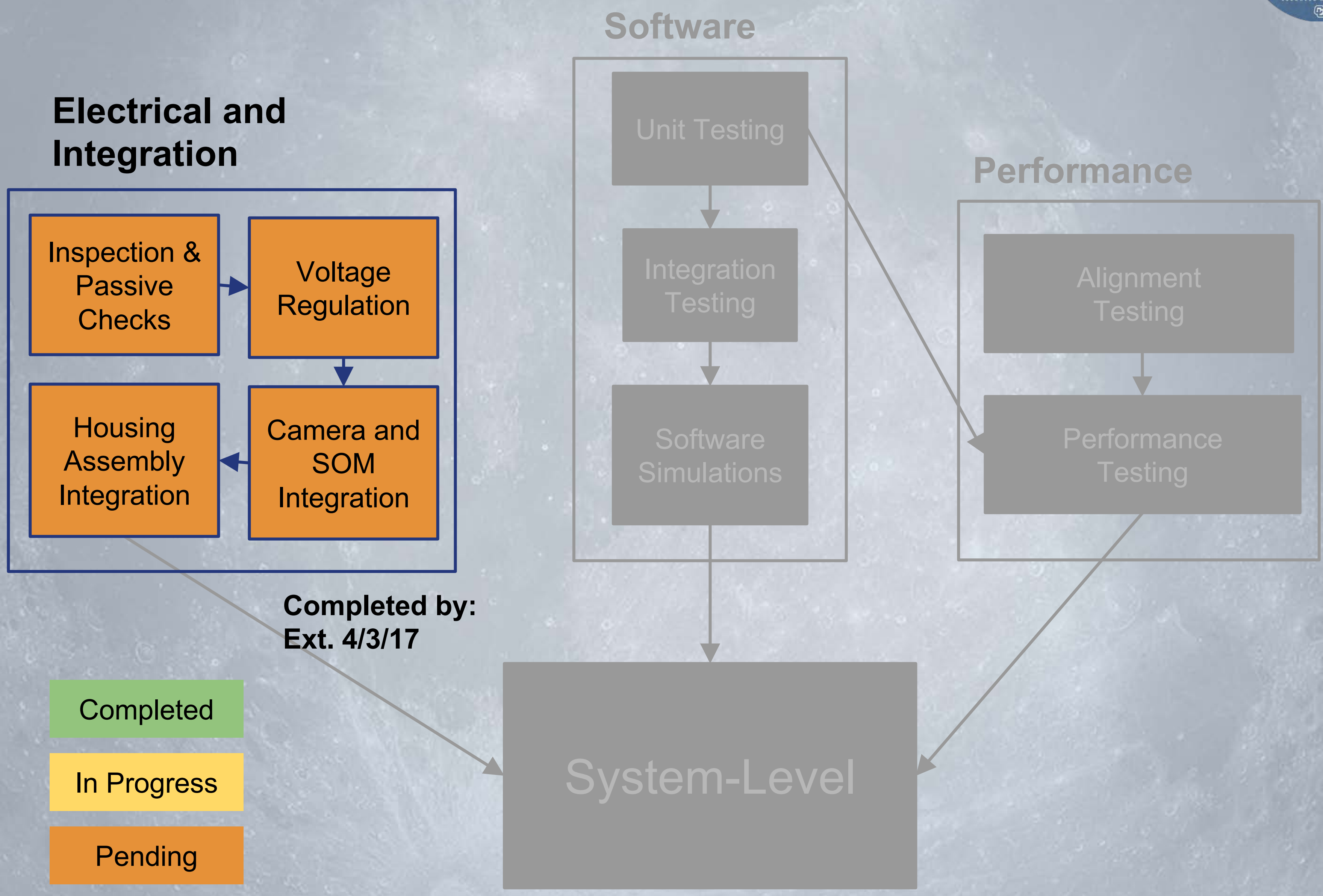
Digital image is passed to Image Processing, then to Navigation, & finally to S/C Comms

Software Testing
Risk Reduction

- Unit Testing reduces project risk because it makes it easier to isolate and fix bugs within the system early on
- Integration Testing reduces risk because it proves that the OSPRE software will work together on the SOM
- Software Simulations reduce risk because they test the software in a flight-like environment

ELECTRICAL & INTEGRATION TESTING

Test Breakdown



Carrier Electrical & Integration Test

Requirements Verification Matrix

REQ ID		REQ Summary	Verification Method
FR2.0	DR2.6	Total mass of less than or equal to 0.8 kg	Measurement of assembled module
	DR2.7	Overall dimensions of 5 x 5 x 1 cm	
FR2.1 DR2.1	DR2.1.1	Operate on 3.3, 5, and/or 12VDC supply	Demonstration of operation with DC supply
	DR2.1.2	Peak Current NGT 500mA	Measurement during operation
	DR2.1.3	Peak Power draw NGT 3W	Analysis using current and voltage measurement

Carrier Electrical & Integration Test
Facilities and Equipment Requirements

Facility	Status
Aerospace Electrical Shop	Access Received

Equipment	Status
*Carrier Board	To be ordered
DC Power Supply (5 & 12V output)	In Aerospace Electrical Shop
Digital Multimeter	In Aerospace Electrical Shop
Optical loupe (~4X)	Received
Thermal Meter or FLIR Camera	Renting from ITLL
Scale	In Aerospace Electrical Shop
OSPRE Test Cable	In Progress

*Will be ordered ASAP

Carrier Electrical & Integration Test

Test Procedures

Visual Inspection

- BOM Crosscheck
- Workmanship

Passive (Resistance) Checks

- Hook-up Check against Schematics
- Short/Isolation Checks

Voltage Regulation Check

- 12 & 5VDC supplied
- Verify 3.7 & 5VDC at TP's
- Over/Under volt check

SOM Integration Check

- Install SOM
- Physical fit-check/board clearances

SOM Op Check

- SOM Start-up
- Current, Temp Monitoring
- Cam voltage checks
- UART comm check

Cam Integration Check

- Install camera module
- Current, Temp Monitoring

Housing Assembly Integration

- Physical fit-check
- Weight measurement
- Verify grounding

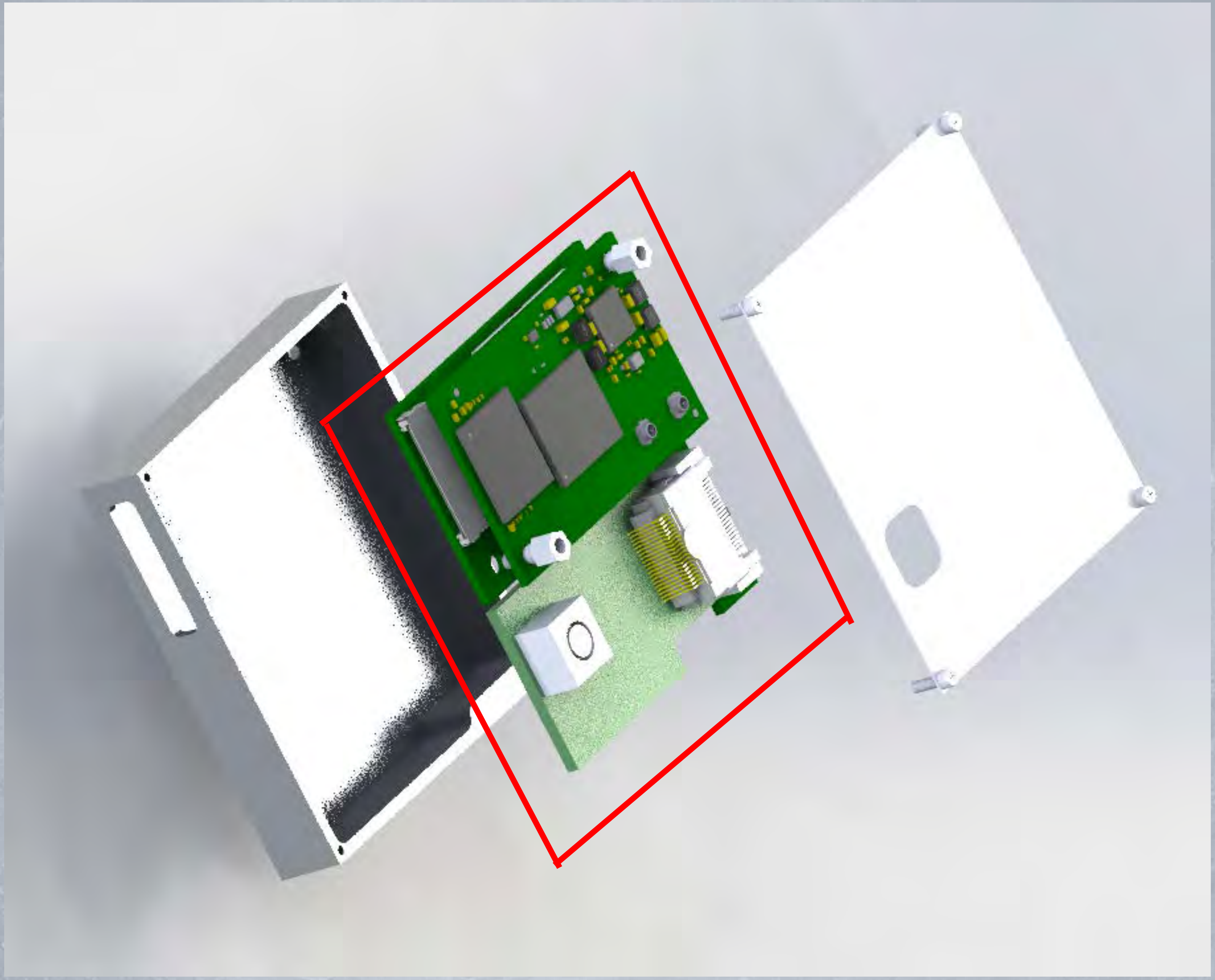
Thermal Check in Housing

- SOM Start-up
- Monitor temp over time

Disassembly for SW Install

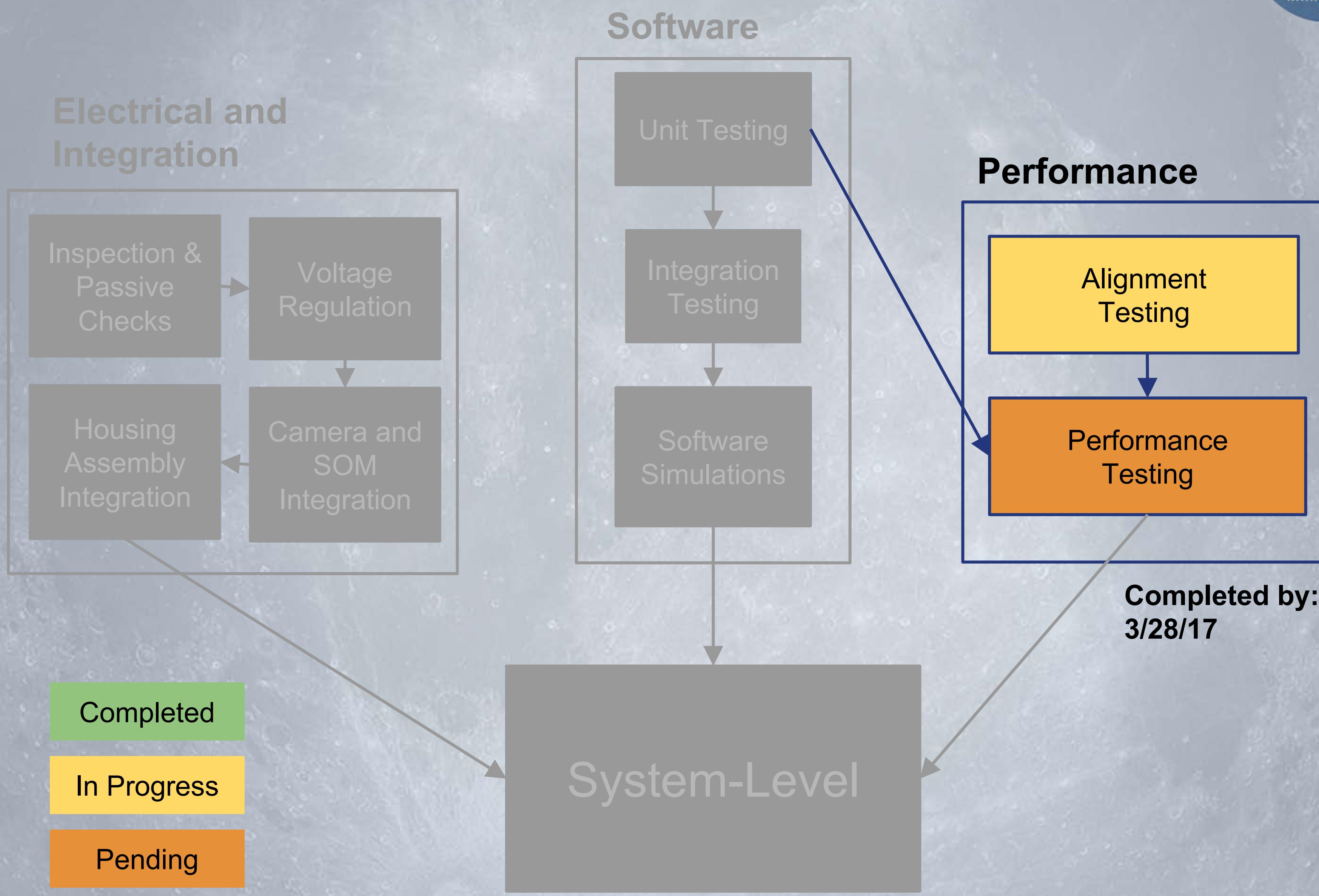
***Completed by: 4/3/2017**

Carrier and Electrical Integration Test
Scope



PERFORMANCE TESTING

Test Breakdown



Performance Testing
Requirements Verification Matrix

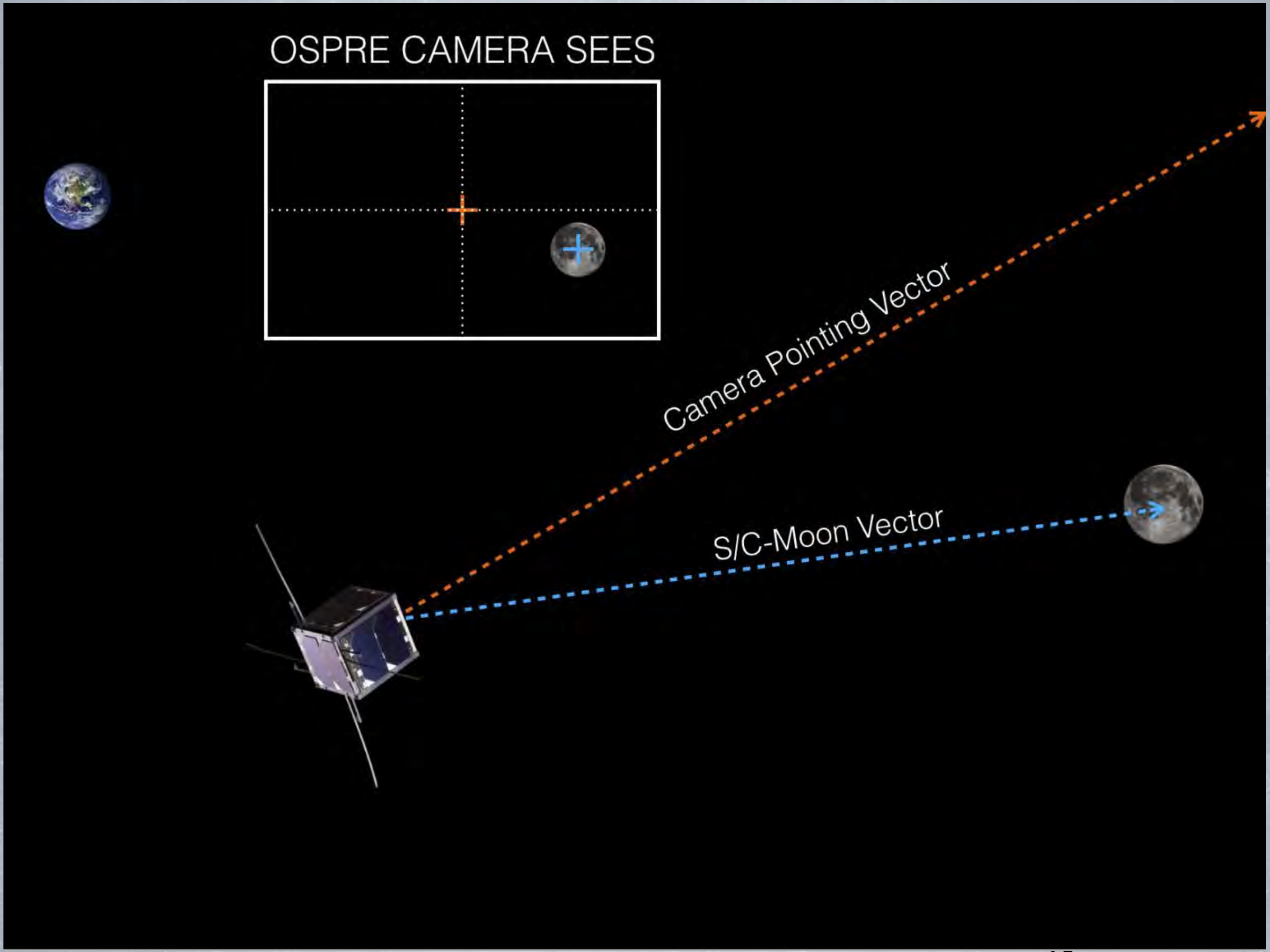
REQ ID		REQ Summary	Verification Method
FR1.1	DR1.5	OSPRE shall output the computed state vector update and error.	Test Data Analysis
FR1.2	DR1.2	OSPRE shall achieve less than 1000 km of positional accuracy.	
FR1.3	DR1.3	OSPRE shall achieve less than 250 m/s of velocity accuracy.	

Performance Testing
Risk Reduction: Project-Level

- Increase our understanding of system capabilities
  - Angles only navigation algorithm
  - Kalman filter
  - Image Processing
- Quantify worst-case positional error
- Quantify worst-case velocity error

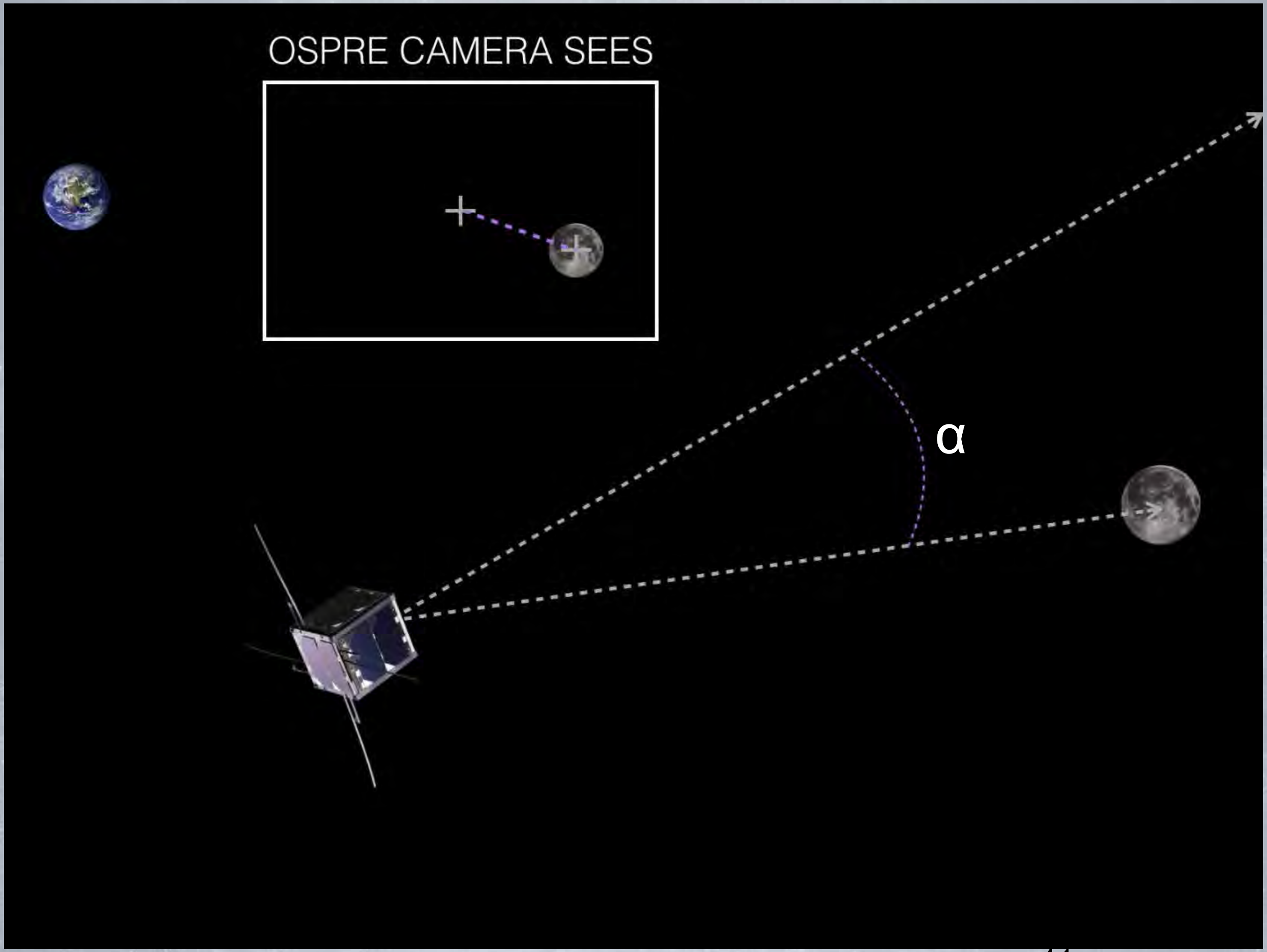
Performance Testing
Test Setup

Performance Testing
Test Setup



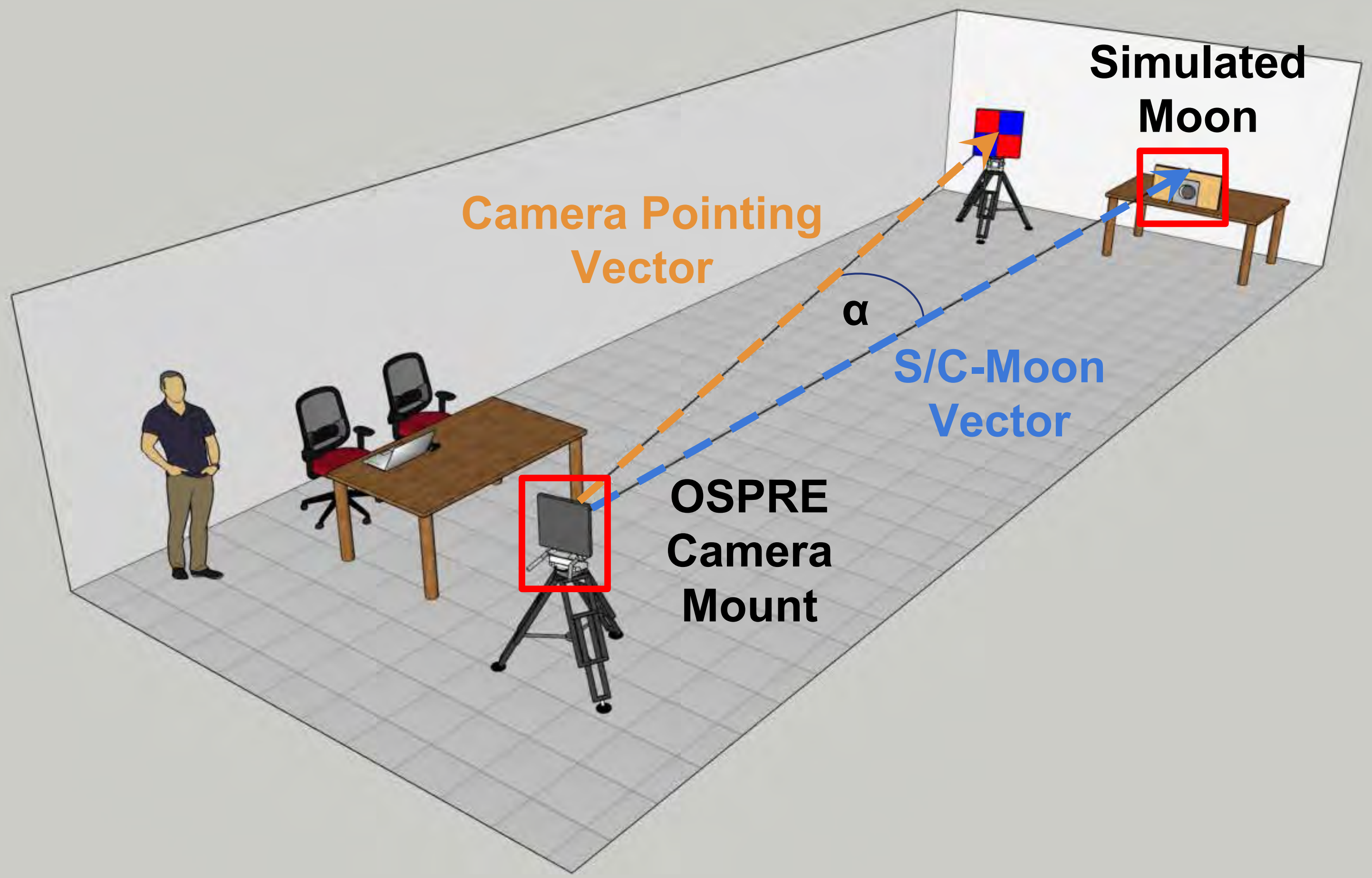
Performance Testing

Test Setup



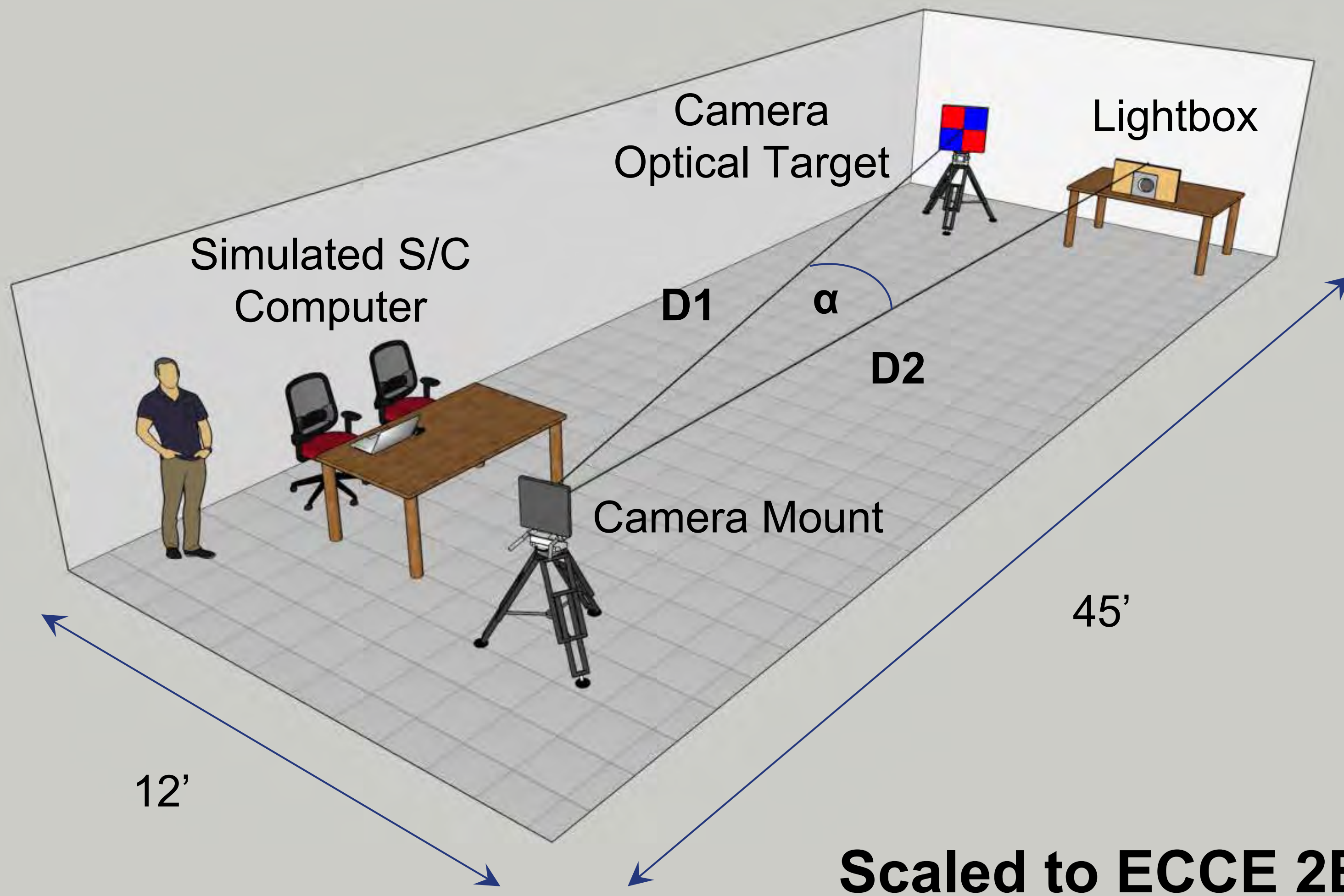
Performance Testing

Test Setup



Scaled to ECCE 2B49A

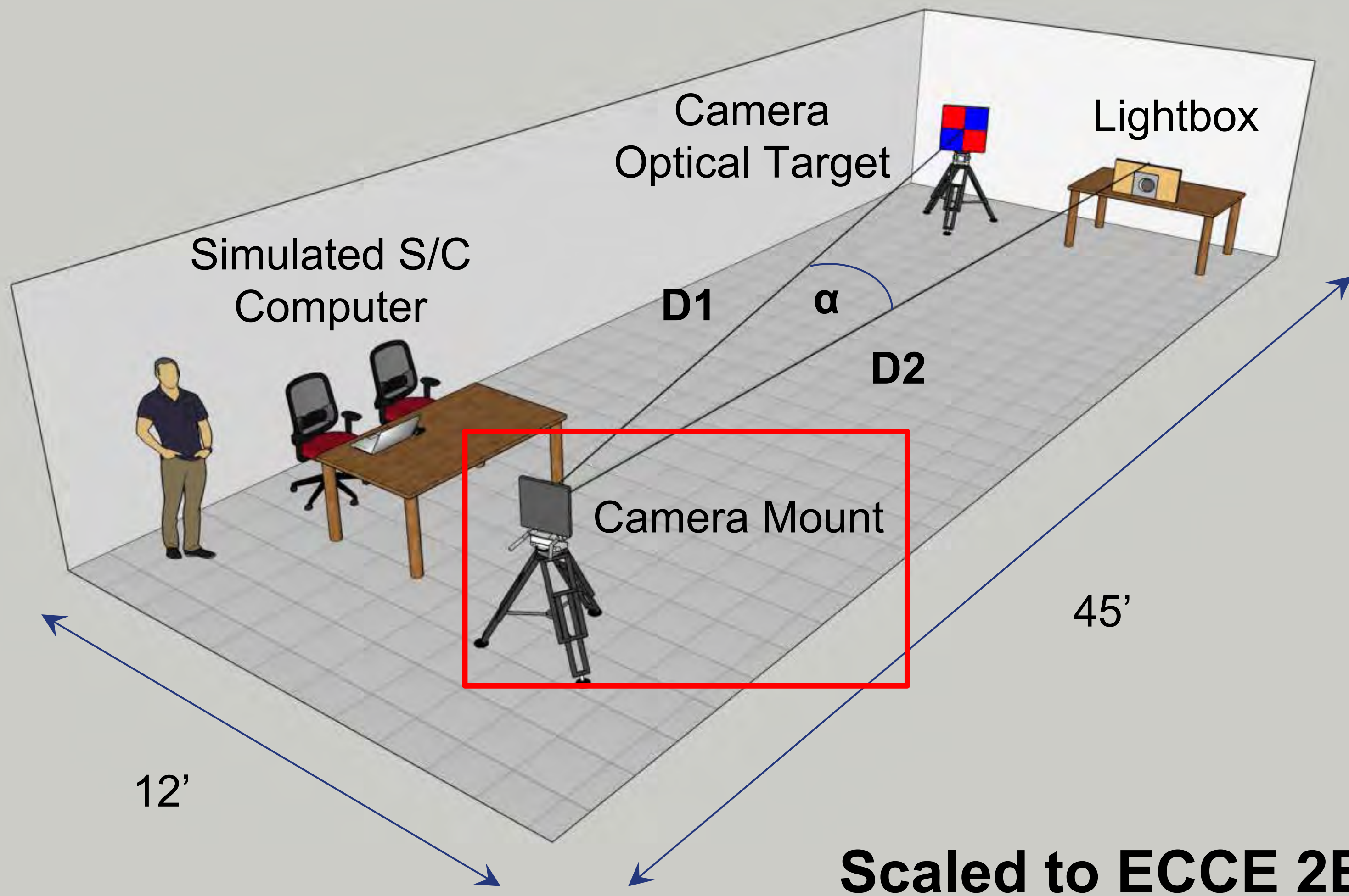
Performance Testing
Test Setup



Scaled to ECCE 2B49A

Performance Testing

Test Setup



Scaled to ECCE 2B49A

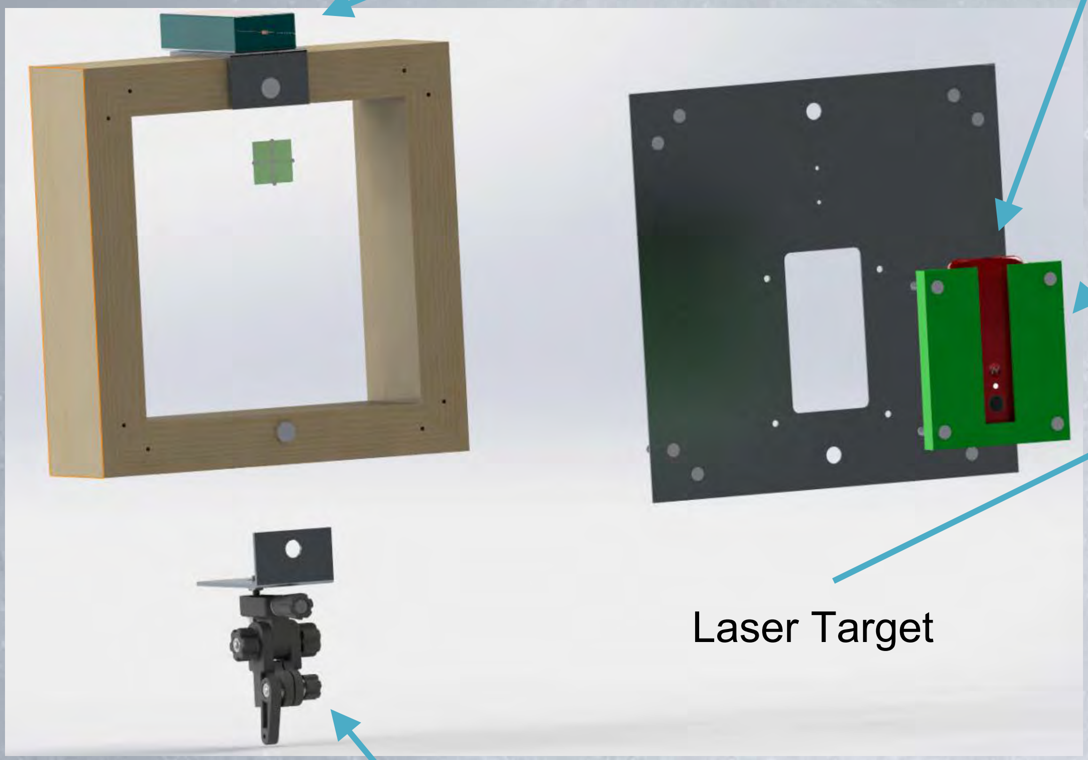
Performance Testing

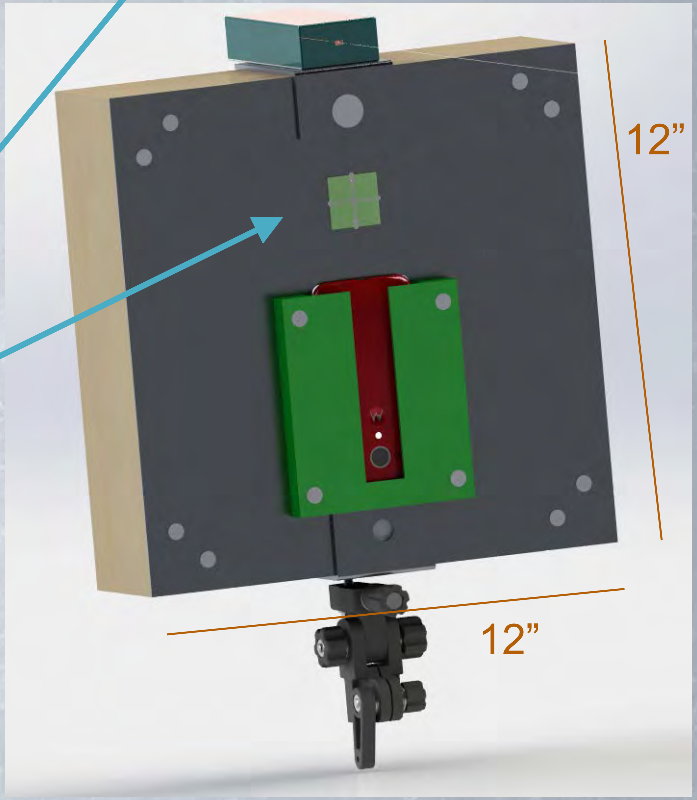
Constructed Test Equipment: Camera Mount

Laser Ranger

Moto G Cell Phone

Cell Phone Mount



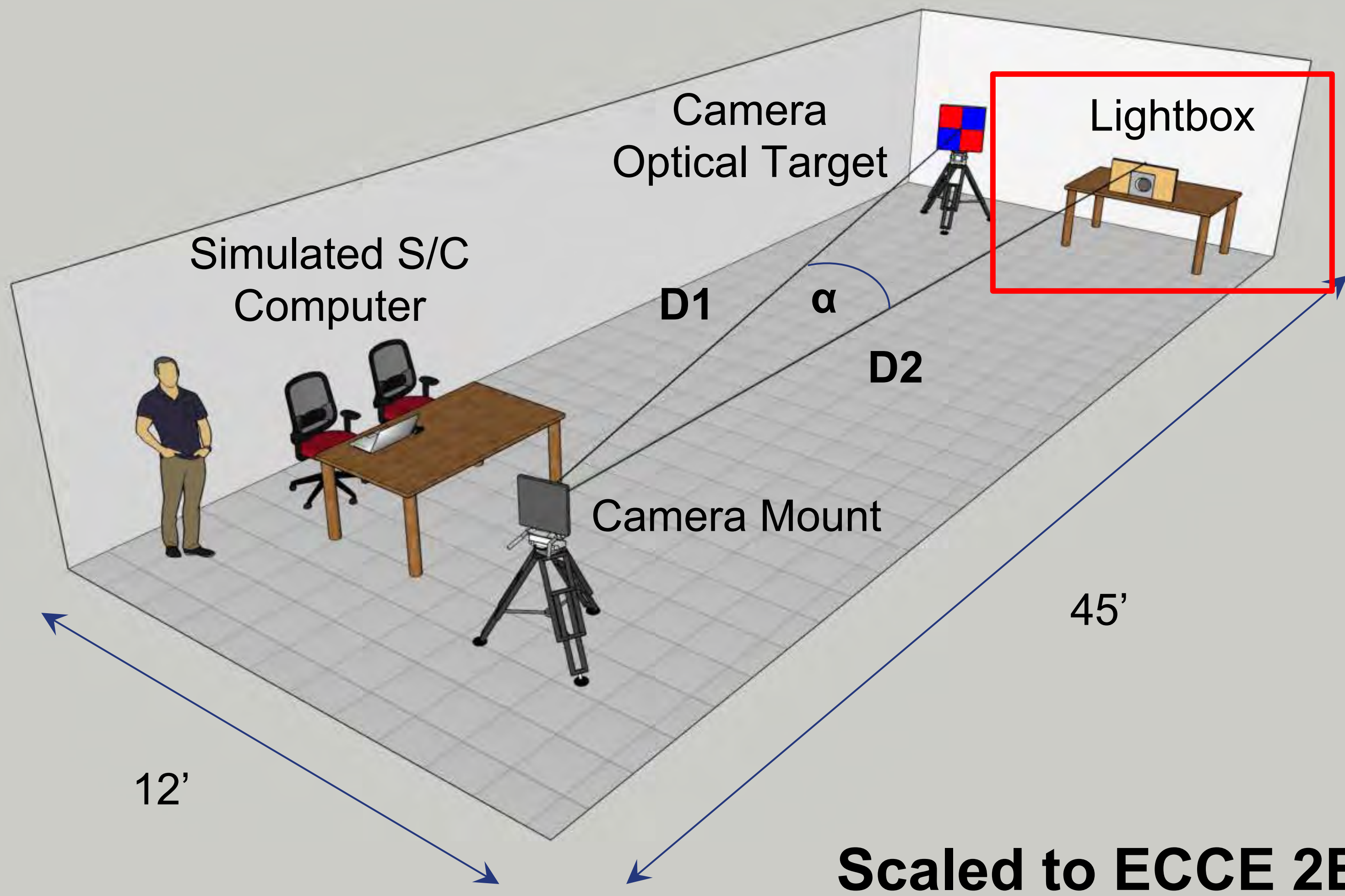


Laser Target

Geared Tripod Mount

Performance Testing

Test Setup



Scaled to ECCE 2B49A

Performance Testing
Constructed Test Equipment: Lightbox

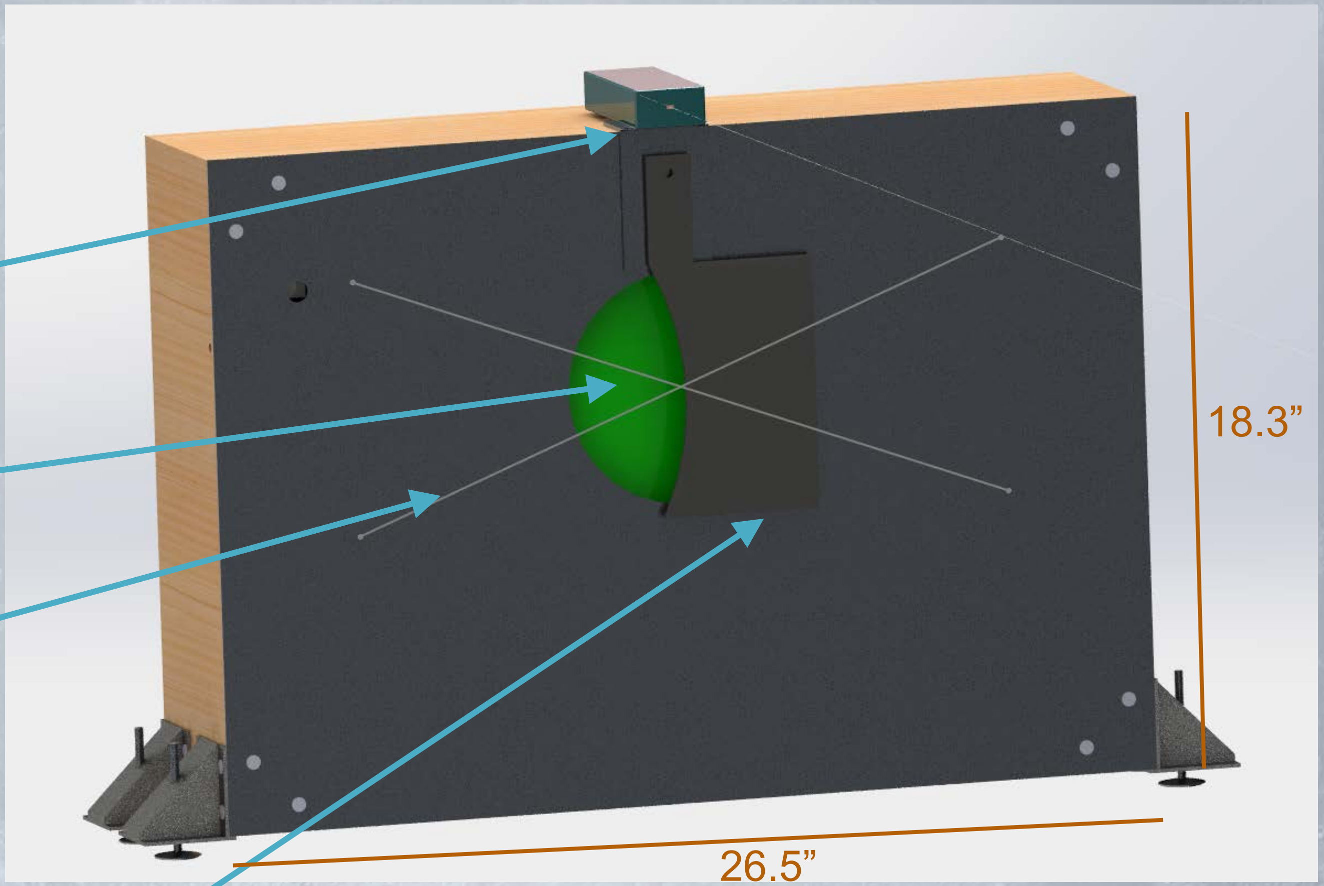
COMPONENTS:

Laser Range Finder

Light Panel

Alignment Wires

Phased Moon Cutout

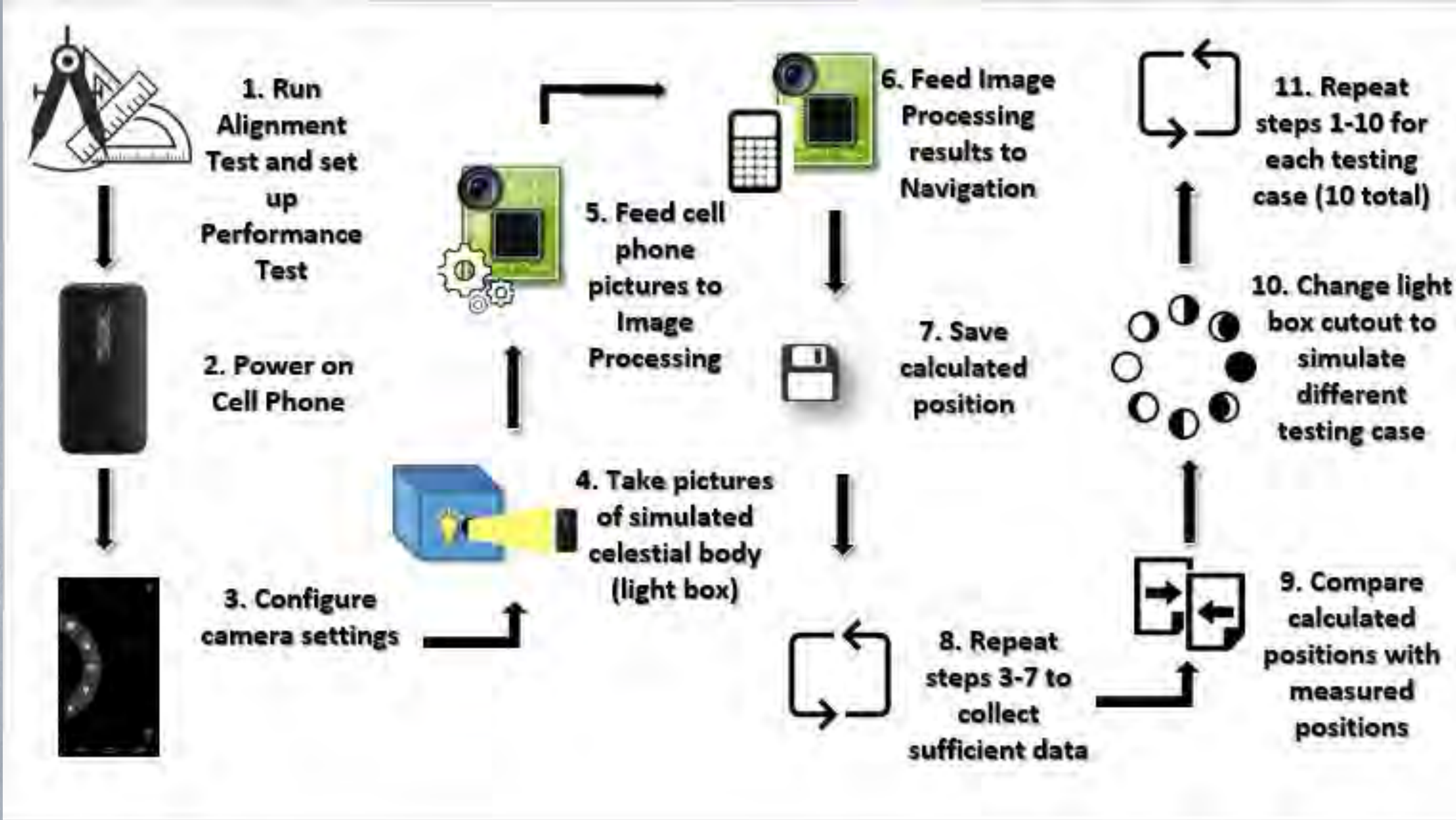


Performance Testing
Facilities and Equipment Requirements

Facility	Status
ECEE 2B49A	Permission Received

Equipment	Status
Lightbox	In Assembly
Camera mount	Construction in Progress
Camera target	In Progress
Laser ranger (x2)	Received
Measuring Tape	Received
Level (x2)	Received
Support equipment	Permission Received
Simulated S/C Computer	Received

Performance Testing
Test Procedure



Performance Testing
Changes Since CDR

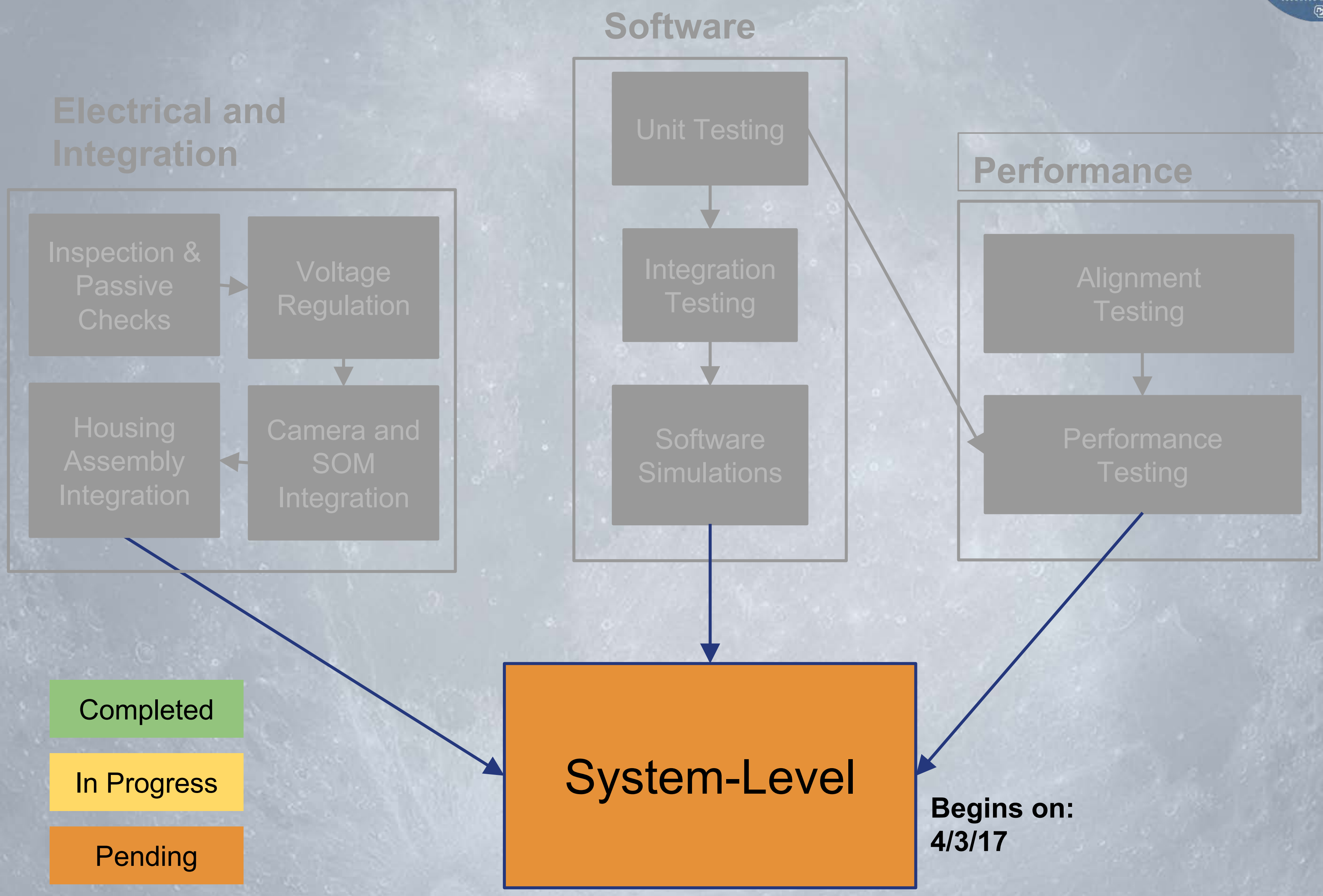
- Re-evaluated measurement tools to reduce reliance on advertised accuracy/precision
  - Accuracy certification standards (Ex. - ISO 16331-1)
- Improved error simulations to reflect new measurement accuracy as well as the most up-to-date test configurations
  - The test-attributed error remains below 100 km of scaled position uncertainty 98.31% of the time
- Detailed test procedures to help mitigate risk

Performance Testing
Expected Results

- **PRIMARY OBJECTIVE**: Acquire quality test images for calculating position and velocity errors
  - HYPOTHESIS: OSPRE meets position and velocity error requirements
- **SECONDARY**: Improve software simulation fidelity
  - The hardware introduces a component of error that can be incorporated into the software simulation to improve realism

SYSTEM-LEVEL TESTING

Test Breakdown



System-Level Testing
Requirements Verification Matrix

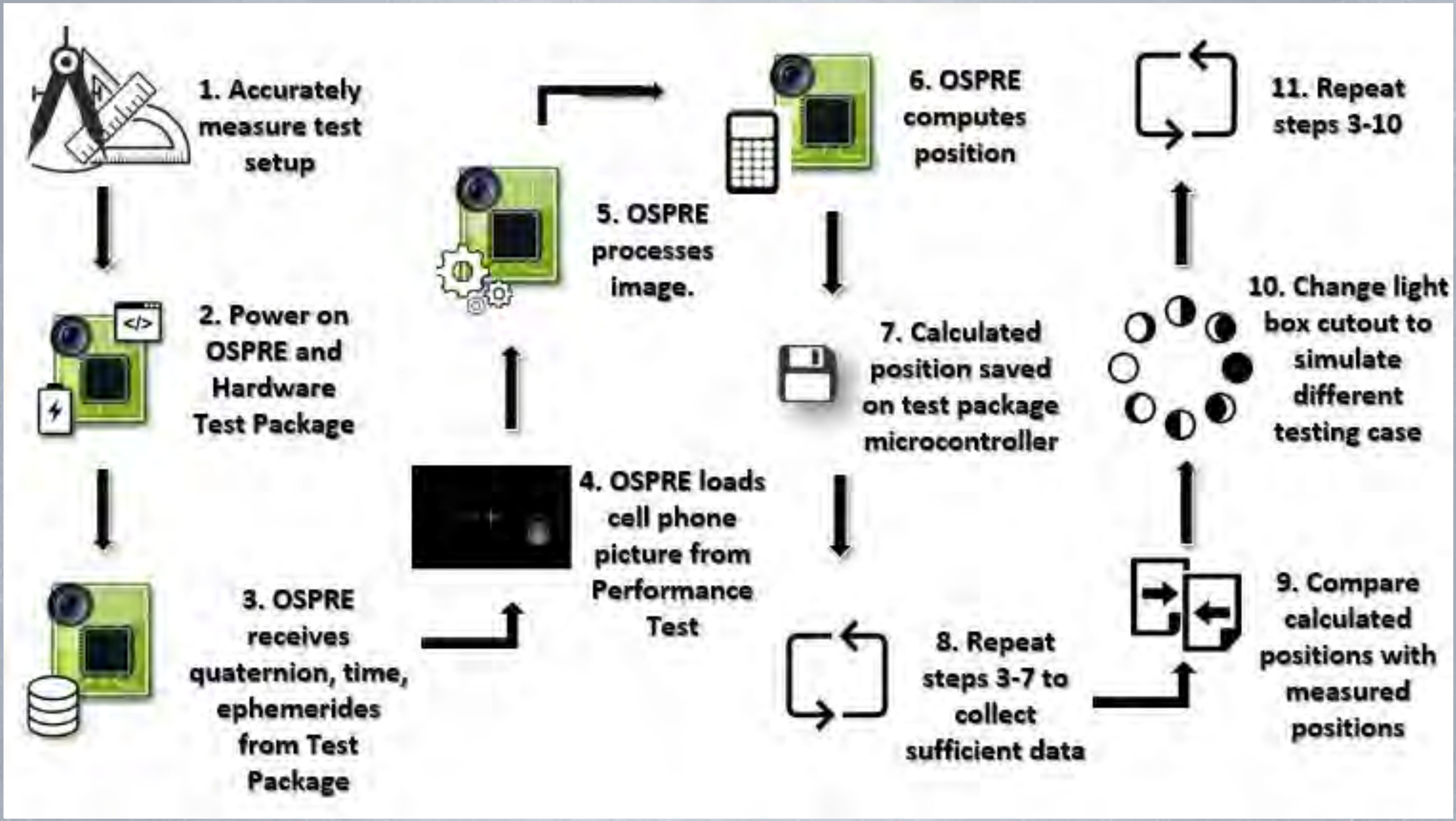
REQ ID		REQ Summary	Verification Method
FR1.1	DR1.1 - DR 1.5	OSPRE shall use angles-only navigation to determine a state vector.	System-Level Testing
FR1.2 & FR 1.3	DR1.2 & DR1.3	OSPRE shall determine the position and velocity to within 1000 km and 250 m/s of the true value.	
FR1.4	DR1.4	OSPRE shall calculate the Earth, spacecraft, Moon angle	
FR1.5	DR1.5	OSPRE software shall include solution validation.	
FR2.0	Various	OSPRE shall meet integration requirements.	

SAME FACILITY, TOOLS, AND TEST SETUP AS PERFORMANCE

System-Level Testing
Risk Reduction: Project-Level

- Verify that the OSPRE system, operating as a whole, meets all customer requirements
- Characterize the OSPRE system
  - Power draw, thermal characteristics, timing, process bottlenecks, communication, etc.
- Identify potential system-level improvements
- Improve OSPRE's reliability and pedigree prior to delivery to customer

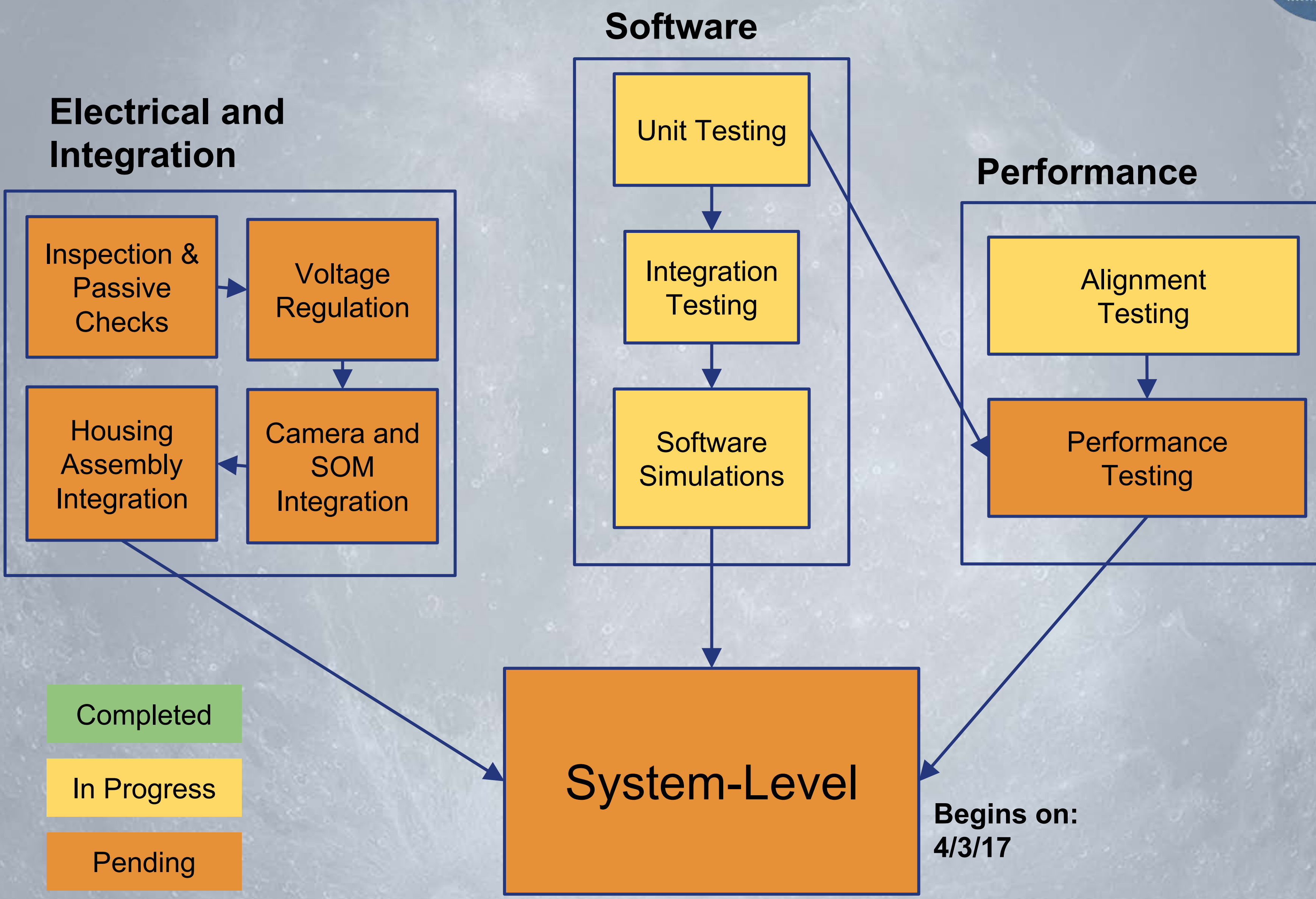
System-Level Testing
Test Procedure



System-Level Testing
Expected Results

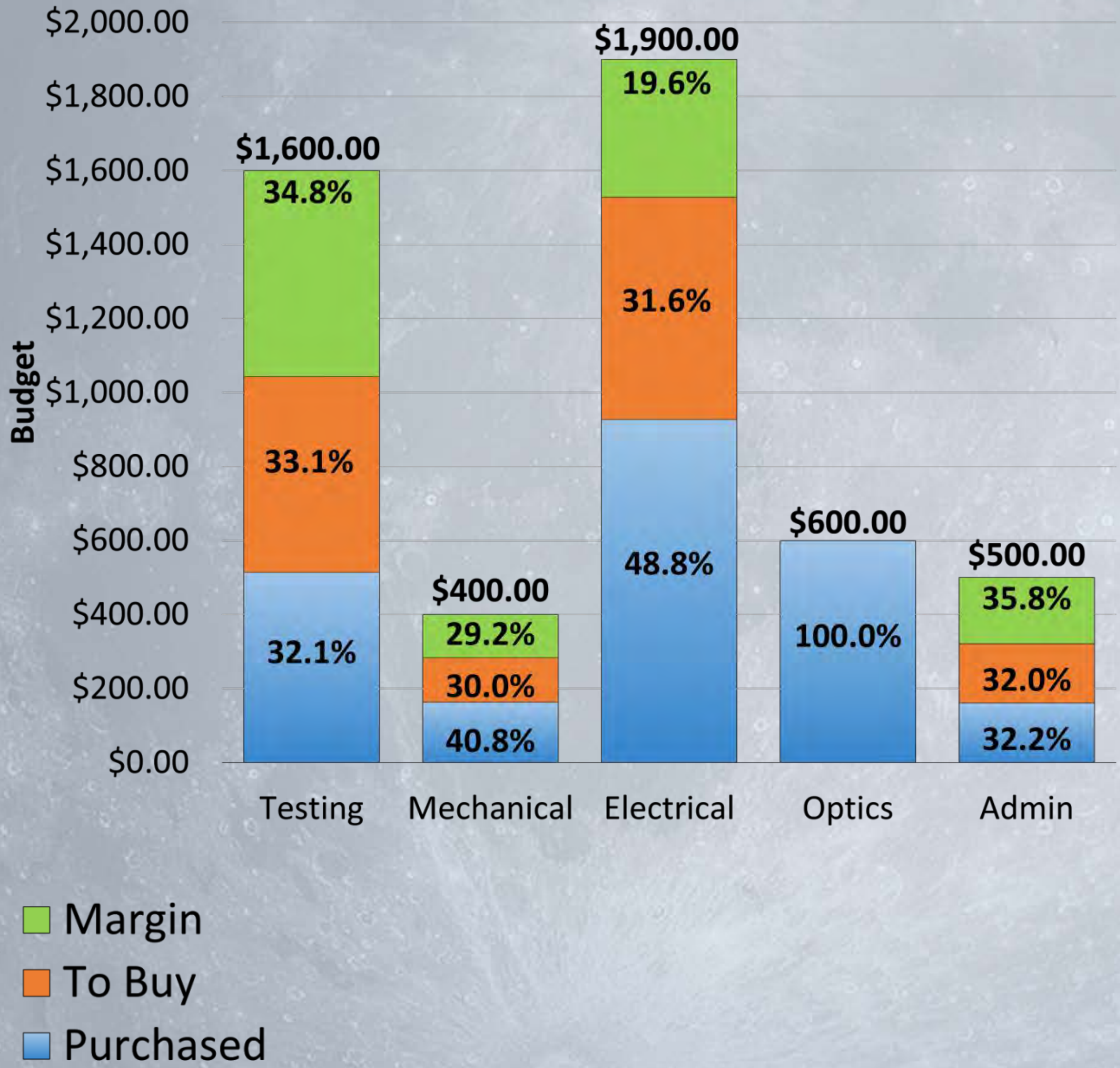
- **PRIMARY OBJECTIVE**: Validate that OSPRE meets all applicable functional and design requirements through demonstration
  - HYPOTHESIS: Test demonstrates that OSPRE, as a complete system, meets all functional and design requirements
- **SECONDARY OBJECTIVES**
  - The system's computational timing is quantified
  - Thermal characteristics are recorded
  - Camera limitations are better understood

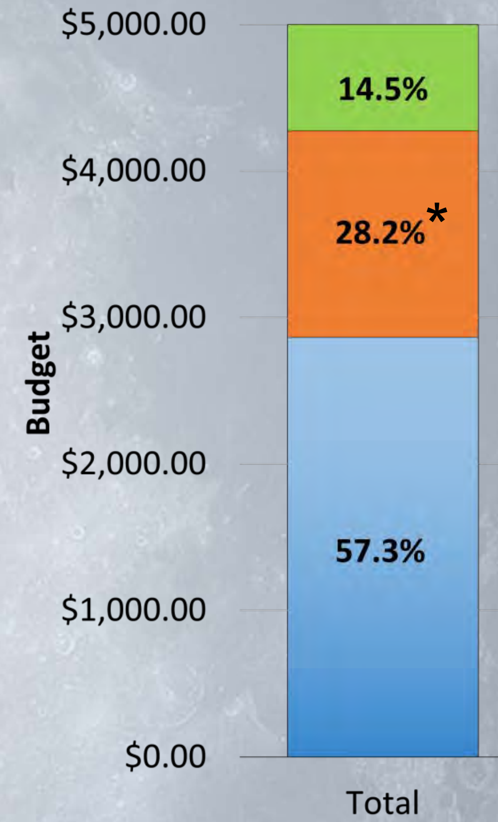
Test Status


Software
Unit Testing
Integration Testing
Software Simulations
Electrical and Integration
Inspection & Passive Checks
Voltage Regulation
Camera and SOM Integration
Housing Assembly Integration
Performance
Alignment Testing
Performance Testing
System-Level
Begins on: 4/3/17
Completed
In Progress
Pending

BUDGET

Budget





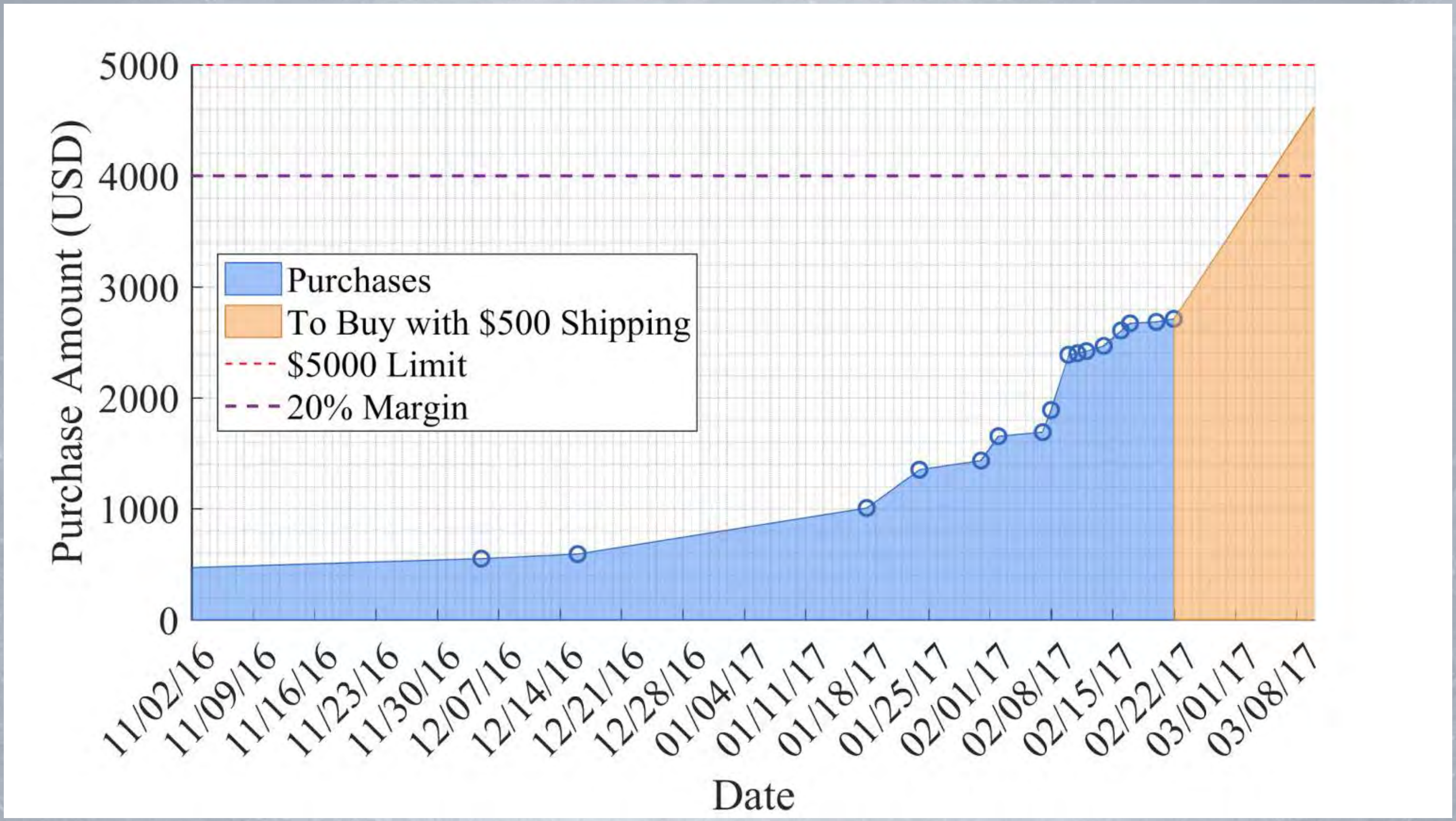
*** Includes $500 shipping margin**

Budget

Subsystem	Item	Procurement Status
Testing	Laser Range Finder	Received
	Light Panel	Received
	Geared Tripod Head	Received
	Lightbox Materials	Received
	Mount Materials	Shipped and building
Mechanical	Enclosure Materials	Received
	Enclosure Fasteners	Received
	Phase Materials	Not ordered, same day pickup
Electrical	Snapdragon 410 Dev Kit	Received
	ZedBoard	Received
	PCB Components	Received
	PCB	Not ordered

Subsystem	Item	Procurement Status
Optics	13 MP Camera	Received
	Moto G Phone	Received
	Snapdragon 410 Dev Kit	Received
Admin	CDR, FFR, MSR Printing	Received
	SFR, FDR Printing	Not ordered, next day pickup

Budget



Purchase Amount (USD)
5000
4000
3000
2000
1000
0
Purchases
To Buy with $500 Shipping
$5000 Limit
20% Margin
11/02/16
11/09/16
11/16/16
11/23/16
11/30/16
12/07/16
12/14/16
12/21/16
12/28/16
01/04/17
01/11/17
01/18/17
01/25/17
02/01/17
02/08/17
02/15/17
02/22/17
03/01/17
03/08/17
Date

Thank You

Paige Arthur	PM
Ryan Cutter	Systems
Seth Zegelstein	Software
Michael Ricciardi	Electrical
Anthony Torres	Image Processing
Cameron Maywood	Navigation
Dylan Richards	Remote Sensing
Zach Folger	Mechanical
David Walden	Testing

Backup Slides

Testing Scope, Overview
Test Plan Flowdown

Electrical Integration Testing
(2 Weeks)
- Inspection
- Continuity and Isolation
- Voltage Regulation Check
- SOM and Camera Integration
- Housing Fit-Check
- Thermal Characterization

Software Testing
(2 Weeks)
- Unit Testing
- Integrated Testing
- Angular Velocity Testing
- System Soak
- Software Performance

Error Performance Testing
(2 Weeks)
- STE Alignment Error Characterization
- Navigational Error Performance Testing

Integrated Systems Testing

COMPLETED | IN-PROGRESS | TO-DO

Requirement Verification

Functional Requirement	Verification & Validation Method
FR 0.0 - Provide relative navigation from an image sensor package on a lunar trajectory	System-Level Lightbox Test
FR 1.0 - Provide state vector within desired error bounds: Position: ± 1000 km Velocity: ± 250 m/s	System-Level Lightbox Test
FR 2.0 - Meet dimensional requirements: 5 x 5 x 1 cm	Dimensional Measurements
FR 2.1 - Meet electrical requirements: 0.3, 5, or 12VDC, 0.5A (max), 3W (max)	Carrier Electrical and Integration Testing
FR 2.2 - Meet interfacing requirements: SPI or I^2C	Software Capability

SOFTWARE TESTS

Software Testing
Requirements Verification Matrix

REQ ID		REQ Summary	Verification Method
FR1.1	DR1.1 - DR 1.5	OSPRE shall use angles-only navigation to determine a state vector.	Software Demonstration
FR1.2 & FR 1.3	DR1.2 & DR1.3	OSPRE shall determine the position and velocity to within 1000 km and 250 m/s of the true value.	
FR1.4	DR1.4	OSPRE shall calculate the Earth, spacecraft, Moon angle	
FR1.5	DR1.5	OSPRE software shall include solution validation.	
FR2.4	Various	OSPRE shall meet integration requirements.	

Software Testing
Facilities and Equipment

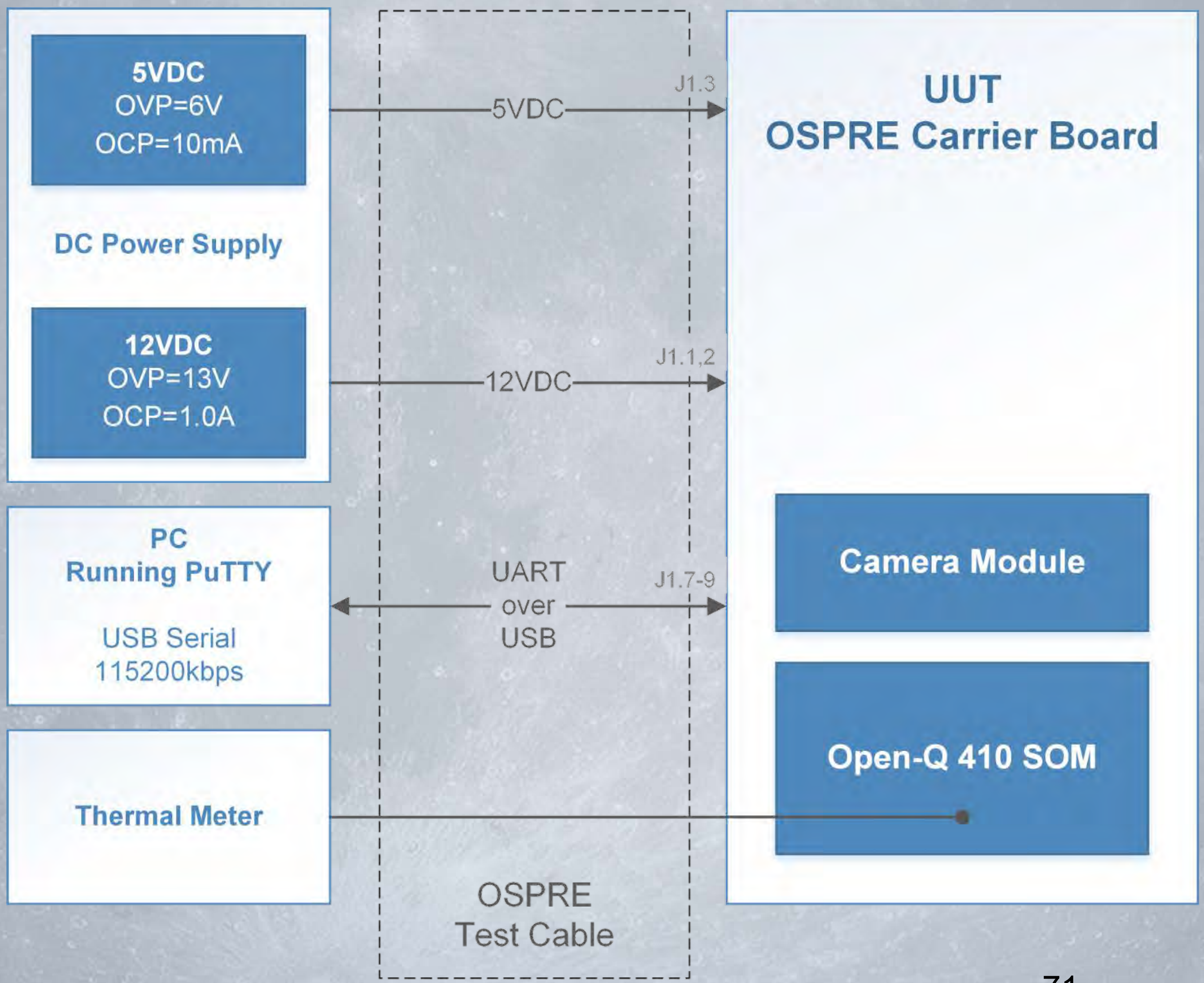
Facility	Status
Aerospace Electrical Shop	Access Received

Equipment	Status
Zedboard	Received
OpenQ410 SOM	Received

ELECTRICAL & INTEGRATION TESTS

Carrier Electrical & Integration Test

Test Setup



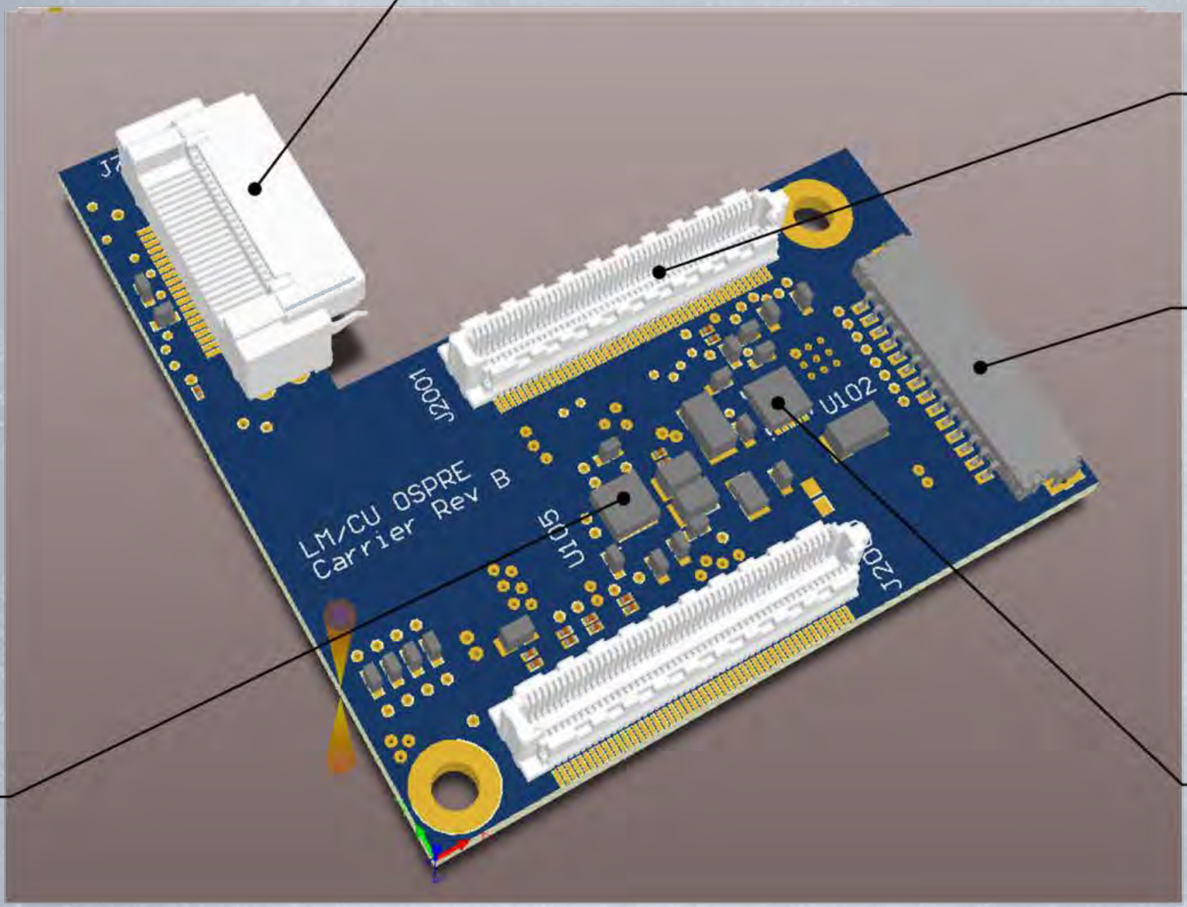
Carrier Electrical & Integration Test

Risk Reduction

- Inspection and Resistance checks
  - Identifies many discrepancies prior to application of power
  - Correction prevents cascading discrepancies
- Voltage Regulation Check
  - Verifies proper voltage levels before integration of SOM and camera module
  - Verifies electrical isolation of power traces, pads
  - Prevents over/under volt damage to SOM and camera module
- PCB Assembly Fit Check
  - Verifies isolation between PCB features and housing
  - Identifies areas of housing requiring polyimide insulation
- In-and-Out of Housing Thermal Characterization
  - Verifies SOM and camera will remain within acceptable temperature range
  - Identifies potential thermal dissipation needs prior to longer testing

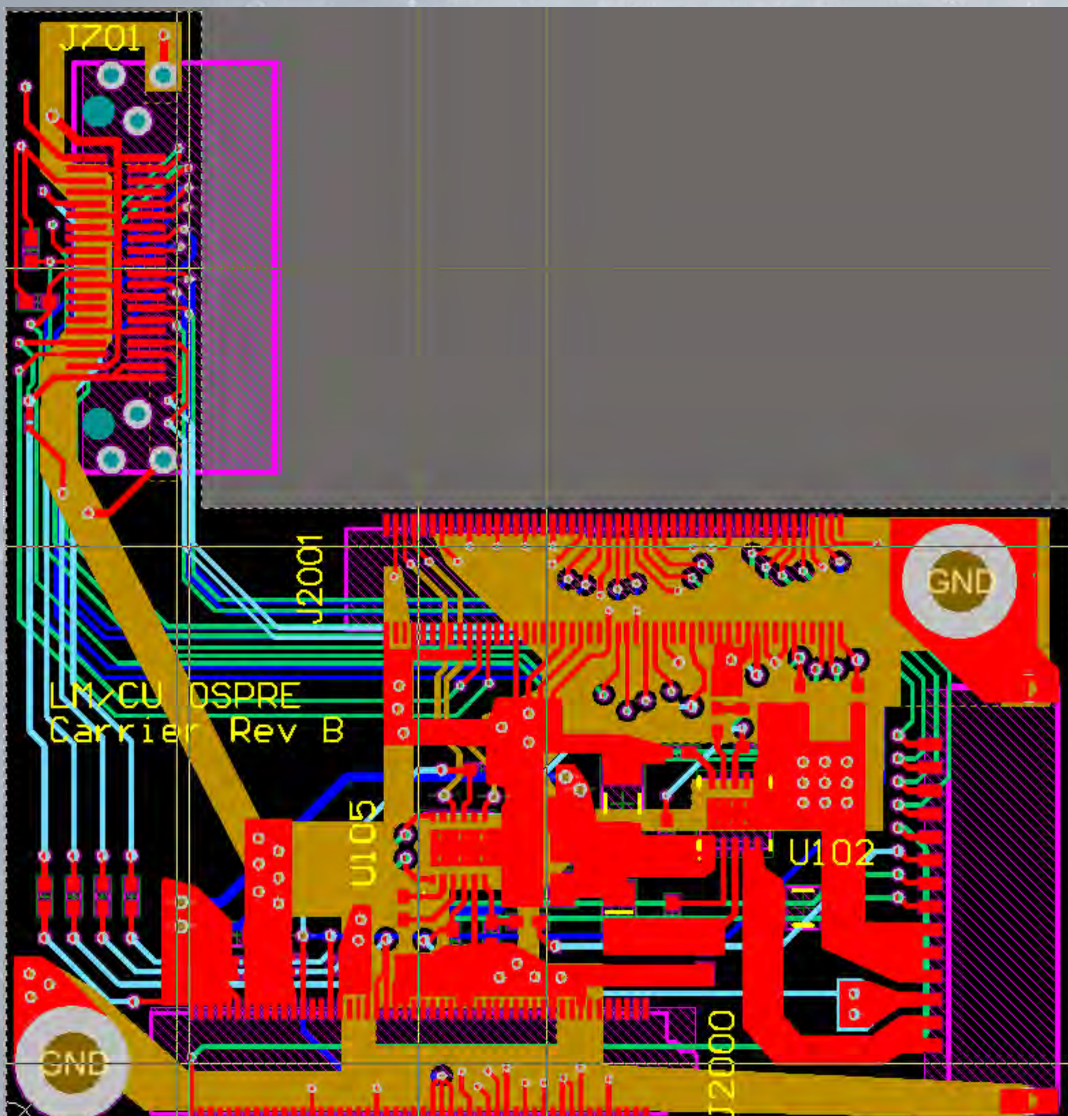
Carrier Electrical Test

CAD Model, Carrier Board



Carrier Electrical Test

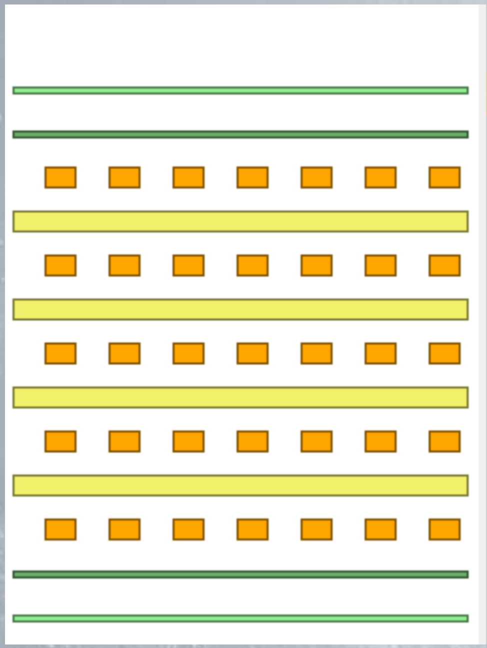
Layout, Carrier Board



- Dimensions:
  - 46 x 48mm overall
  - 1.216mm thick
- 5-Layer (FR4)
- Trace width:
  - Power: 10-16 mil
  - Signal: 8 mil
  - Min. 8 mil air gap
- Drill holes:
  - Count: 182
  - Size: 8 to 106 mil
- SMD Pads:
  - Count: 358
  - No vias under
- No hidden/buried/blind vias
- Cost:
  - PCB: $1234
  - Tooling: $450

Carrier Electrical Test

Layout Stack-up, Carrier Board



Layer Name	Type	Material	Thickness (mm)	Dielectric Material	Dielectric Constant
Top Overlay	Overlay				
Top Solder	Solder Mask/Co...	Surface Material	0.01016	Solder Resist	3.5
Top Layer	Signal	Copper	0.036		
Dielectric 1	Dielectric	Core	0.254	FR-4	4.2
Signal Layer 2	Signal	Copper	0.036		
Dielectric 2	Dielectric	Core	0.254		4.2
Signal Layer 3	Signal	Copper	0.036		
Dielectric 3	Dielectric	Core	0.254		4.2
Signal Layer 4	Signal	Copper	0.036		
Dielectric 4	Dielectric	Core	0.254		4.2
Bottom Layer	Signal	Copper	0.036		
Bottom Solder	Solder Mask/Co...	Surface Material	0.01016	Solder Resist	3.5
Bottom Overlay	Overlay				

Carrier Electrical Test

Carrier ICD, External Connector

CONNECTOR PARNO		Hirose DF19G-14P-1H(54)	J1		
REFDES	**CONTACT**	**SIGNAL NAME**	**SOM ITFC**	**DESTINATION**	**NOTE**
J1	1	12VDC		To Bench PS	
J1	2	12VDC			
J1	3	5VDC			
J1	4	GND			
J1	5	GND			
J1	6	GND			
J1	7	UART_USB_DATA_P		To Test PC (NONFLT)	Serial over USB 115200BPS
J1	8	UART_USB_DATA_N			
J1	9	UART_USB_VBUS			
J1	10	OSPRE_ENABLE	KPD_PWR_N	To ZedBoard	Hold LOW 4-5 sec to boot
J1	11	SPI_CLK	BLSP30		
J1	12	SPI_SS	BLSP31		
J1	13	SPI_DATA_MOSI	BLSP32		
J1	14	SPI_DATA_MISO	BLSP33		

Carrier Electrical Test

Carrier ICD, Camera Module Connector

CONNECTOR PARNO		LSHM-120-01-L-RH-A-S-K		B2B CAM CONNECTOR	
REFDES	CONTACT	SIGNAL NAME	SOM ITFC	DESTINATION	NOTE
J701	36	BLSP_61			
J701	34	BLSP60			
J701	3	CSI0_CLK_N			DP
J701	5	CSI0_CLK_P			DP
J701	20	CSI0_I2C_SCL			
J701	22	CSI0_I2C_SDA			
J701	9	CSI0_LANE0_N			DP
J701	11	CSI0_LANE0_P			DP
J701	15	CSI0_LANE1_N			
J701	17	CSI0_LANE1_P			
J701	21	CSI0_LANE2_N			
J701	23	CSI0_LANE2_P			
J701	27	CSI0_LANE3_N			
J701	29	CSI0_LANE3_P			
J701	33	CSI0_MCLK			
J701	18	CSI0_PWDN			
J701	35	CSI0_RST			
J701	37	VPH_PWR_3P7			3.7VDC from LT1913
J701	39	VPH_PWR_3P7			3.7VDC from LT1913
J701	40	VPH_PWR_3P7			3.7VDC from LT1913
J701	2	VREG_L10_2P8			2.80VDC from SOM
J701	10	VREG_L17_2P85			2.85VDC from SOM
J701	6	VREG_L6_1P8			1.80VDC from SOM

Carrier Electrical Test

Carrier ICD, SOM Connector (J2000)

CONNECTOR PARNO		SS4-50-3.00-L-D-K		B2B SOM CONNECTOR	
REFDES	**CONTACT**	**SIGNAL NAME**	**SOM ITFC**	**DESTINATION**	**NOTE**
J2000	44	BOOT_CONFIG_BIT2		VREG_L5_1P8 (J2000.75)	
J2000	46	BOOT_CONFIG_BIT3		VREG_L5_1P8 (J2000.75)	
J2000	48	BOOT_CONFIG_BIT5		VREG_L5_1P8 (J2000.75)	
J2000	100	KPD_PWR_N		J1.10	OSPRE_ENABLE
J2000	89	VPH_PWR_3P7			
J2000	91	VPH_PWR_3P7			
J2000	93	VPH_PWR_3P7			
J2000	95	VPH_PWR_3P7			
J2000	97	VPH_PWR_3P7			
J2000	99	VPH_PWR_3P7		U102.BD	Main Power
J2000	69	VREG_L10_2P8			2V8DC to carrier
J2000	57	VREG_L17_2P85			2V85DC to carrier
J2000	59	VREG_L17_2P85			2V85DC to carrier
J2000	75	VREG_L5_1P8			1V8DC to carrier

Note: Unused and GND contacts not shown

Carrier Electrical Test

Carrier ICD, SOM Connector (J2001)

CONNECTOR PARNO		SS4-50-3.00-L-D-K		B2B SOM CONNECTOR	
REFDES	**CONTACT**	**SIGNAL NAME**	**SOM ITFC**	**DESTINATION**	**NOTE**
J2001	93	BLSP22_UART_RX	U105.RXD		UART to USB Receive
J2001	95	BLSP23_UART_TX	U105.TXD		UART to USB Transmit
J2001	9	BLSP30_SPI_CLK		J1.11	
J2001	11	BLSP31_SPI_SS		J1.12	
J2001	13	BLSP32_SPI_MOSI		J1.13	
J2001	15	BLSP33_SPI_MISO		J1.14	
J2001	80	BLSP60		J701.34	Camera
J2001	78	BLSP61		J701.36	Camera
J2001	5	BOOT_CONFIG_BIT0		VREG_L5_1P8	
J2001	50	CSI0_CLK_N		J701.3	MIPI CSI DATA Clock NEG
J2001	48	CSI0_CLK_P		J701.5	MIPI CSI DATA Clock POS
J2001	6	CSI0_I2C_SCL	APQ8016_GPIO30	J701.20	Camera Control
J2001	4	CSI0_I2C_SDA	APQ8016_GPIO29	J701.22	Camera Control
J2001	44	CSI0_LANE0_N		J701.9	MIPI CSI DATA Lane 0 NEG
J2001	42	CSI0_LANE0_P		J701.11	MIPI CSI DATA Lane 0 POS
J2001	49	CSI0_LANE1_N		J701.15	MIPI CSI DATA Lane 1 NEG
J2001	47	CSI0_LANE1_P		J701.17	MIPI CSI DATA Lane 1 POS
J2001	55	CSI0_LANE2_N		J701.21	MIPI CSI DATA Lane 2 NEG
J2001	53	CSI0_LANE2_P		J701.23	MIPI CSI DATA Lane 2 POS
J2001	43	CSI0_LANE3_N		J701.27	MIPI CSI DATA Lane 3 NEG
J2001	41	CSI0_LANE3_P		J701.29	MIPI CSI DATA Lane 3 POS
J2001	20	CSI0_MCLK	APQ8016_GPIO26	J701.33	Camera Clock
J2001	12	CSI0_PWDN	APQ8016_GPIO34	J701.18	Camera Power Down
J2001	2	CSI0_RST	APQ8016_GPIO35	J701.35	Camera Reset
J2001	34	VREG_L6_1P8			1V8DC to carrier

PERFORMANCE TEST

Performance Testing
Test Procedures: Content

- Test article descriptions
- References to applicable documentation
- Safety information and standard procedures
- Equipment inspection/preparation checklist
- Test setup procedures and diagrams with space for note taking
- Test procedures
- Test teardown and closeout
- Data analysis (simulation tools)

Operational Systems Testing Error

Source	Associated Error	Source	Human Error Margin
Lightbox Pointing	± 0.2°	Alignment error due to equipment	x 1.5 margin
Camera Pointing	± 0.007°	0.5 pixel error	x 1.1 margin
Calipers	± 0.025 mm	Advertised equipment error	x 1.5 margin
Steel Tape Measure	± 1.1 mm	Advertised equipment error	x 1.5 margin
Laser Ranger	± 1.5 mm	Advertised equipment error	x 1.2 margin
Center Finding	± 0.05 mm	Machining accuracy	x 1.2 margin

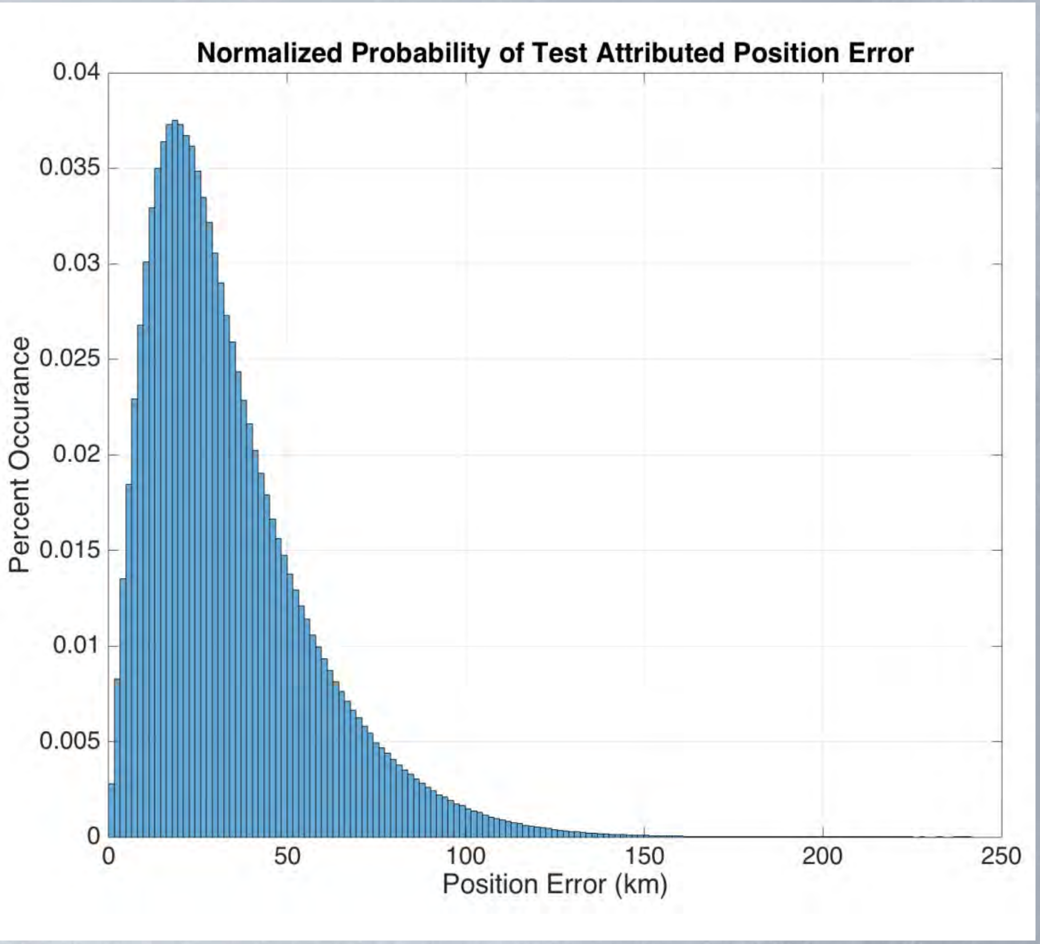
Operational Systems Testing Error

Worst Case Error Scenario

5,000,000 trials
Gaussian randomized error

<u>< 50 km Error Goal</u>
79.9% of the time

<u>< 100 km Error</u>
98.31% of the time

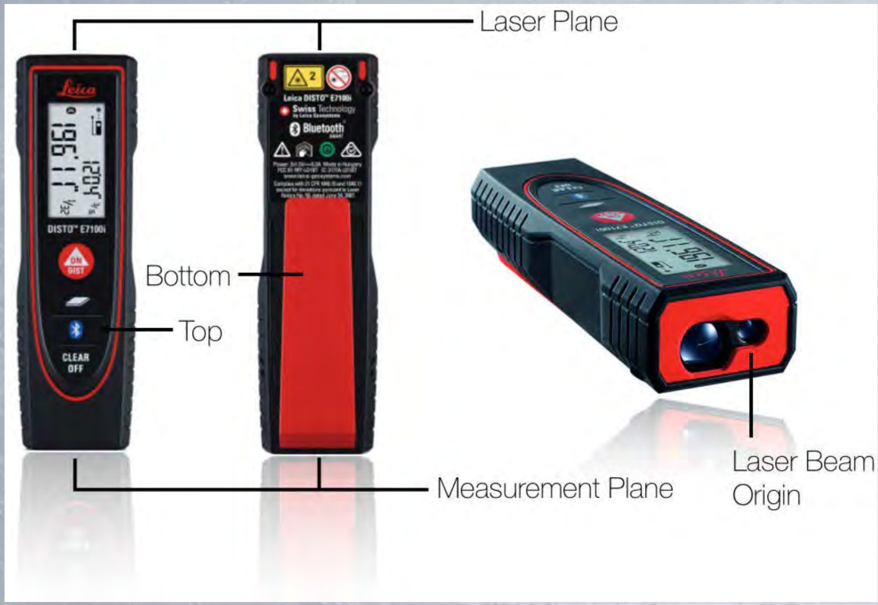


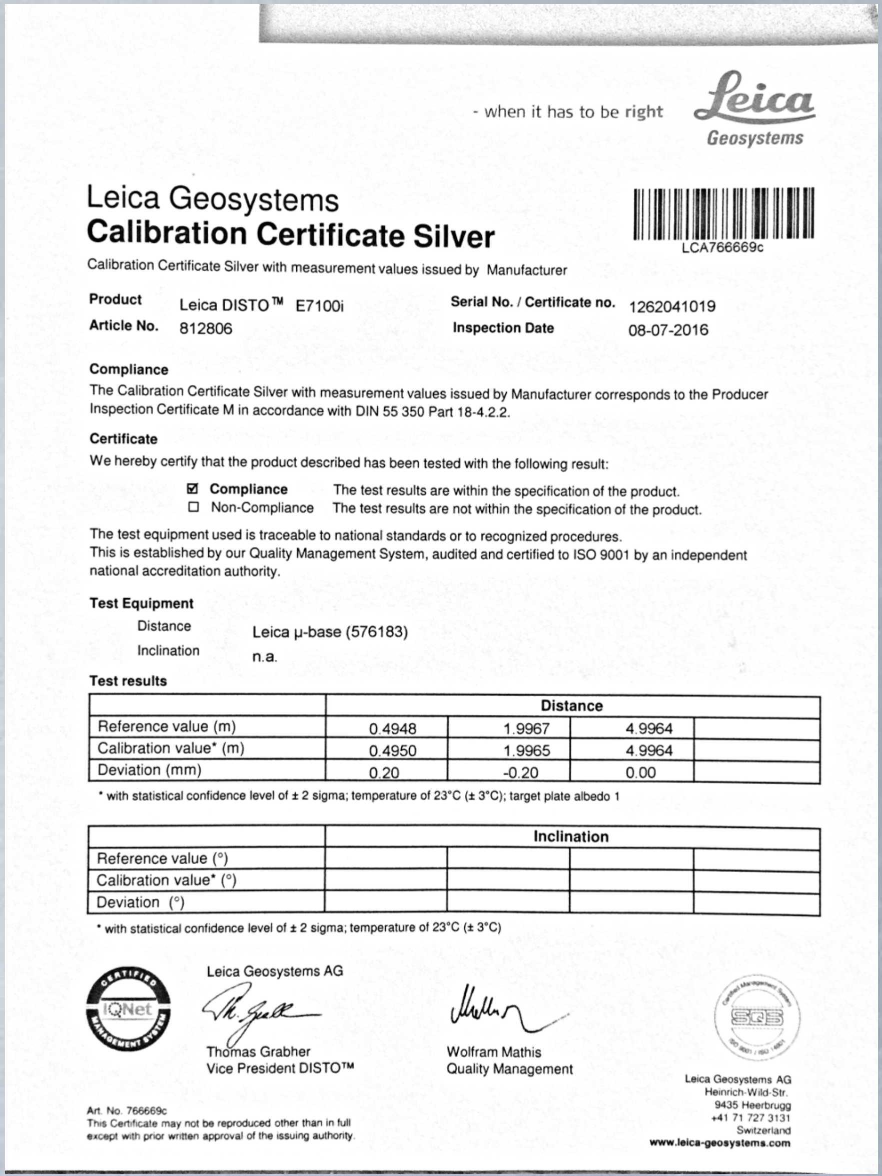
Performance Testing

Measurement Tools

Model: Leica DISTO E7100i

Accuracy: ± 1.5 mm with ISO 16331-1 Certification





- when it has to be right Leica Geosystems

Leica Geosystems
Calibration Certificate Silver

LCA766669c

Calibration Certificate Silver with measurement values issued by Manufacturer

Product	Leica DISTO ™ E7100i	**Serial No. / Certificate no.**	1262041019
Article No.	812806	**Inspection Date**	08-07-2016

Compliance
The Calibration Certificate Silver with measurement values issued by Manufacturer corresponds to the Producer Inspection Certificate M in accordance with DIN 55 350 Part 18-4.2.2.

Certificate
We hereby certify that the product described has been tested with the following result:

☒ **Compliance** The test results are within the specification of the product.
☐ Non-Compliance The test results are not within the specification of the product.

The test equipment used is traceable to national standards or to recognized procedures.
This is established by our Quality Management System, audited and certified to ISO 9001 by an independent national accreditation authority.

Test Equipment
Distance Leica μ-base (576183)
Inclination n.a.

Test results

	Distance			
Reference value (m)	0.4948	1.9967	4.9964	
Calibration value* (m)	0.4950	1.9965	4.9964	
Deviation (mm)	0.20	-0.20	0.00	

* with statistical confidence level of ± 2 sigma; temperature of 23°C (± 3°C); target plate albedo 1

	Inclination			
Reference value (°)				
Calibration value* (°)				
Deviation (°)				

* with statistical confidence level of ± 2 sigma; temperature of 23°C (± 3°C)

Leica Geosystems AG

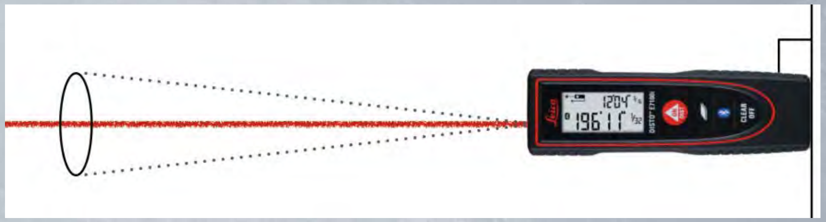
Thomas Grabher
Vice President DISTO™

Wolfram Mathis
Quality Management

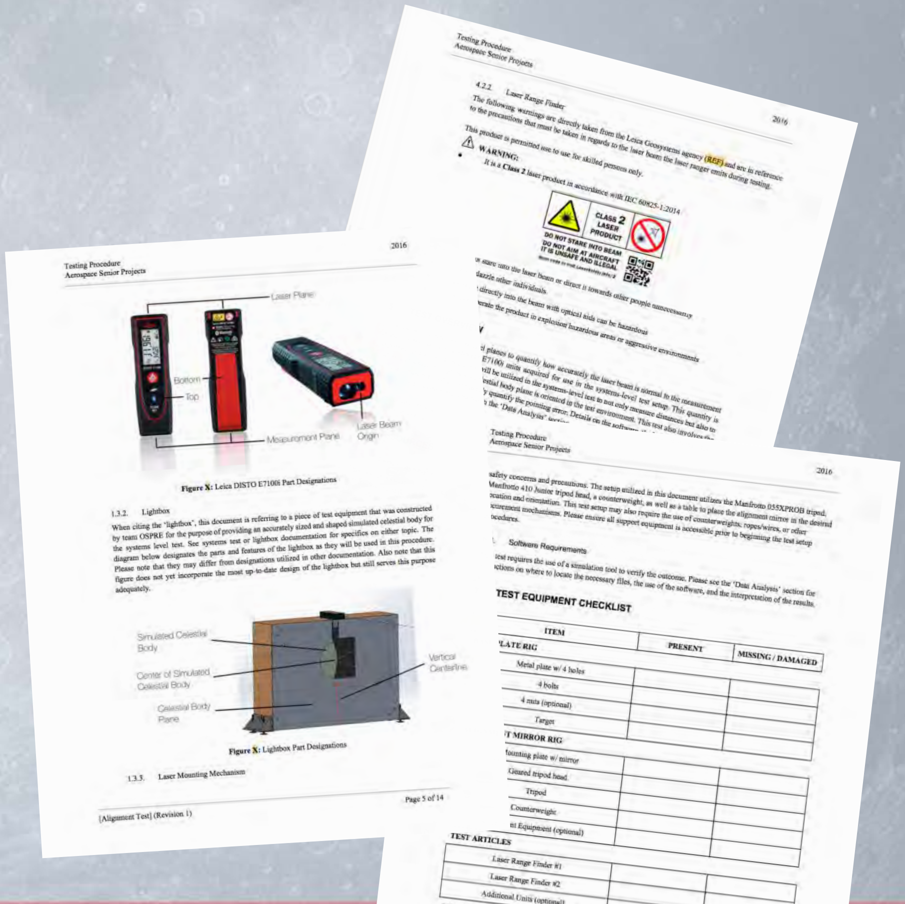
Leica Geosystems AG
Heinrich-Wild-Str.
9435 Heerbrugg
+41 71 727 3131
Switzerland
www.leica-geosystems.com

Art. No. 766669c
This Certificate may not be reproduced other than in full except with prior written approval of the issuing authority.

Performance Testing
Test Procedures: Alignment Testing



- **PURPOSE**
  - Quantify laser beam pointing uncertainty
  - Improve error model fidelity
- **ADDED VALUE**
  - Test procedure authorship practice
  - Lessons learned
  - Establish safety and



Testing Procedure
Aerospace Senior Projects

2016

4.2.2. Laser Range Finder

The following warnings are directly taken from the Leica Geosystems agency (REF) and are in reference to the precautions that must be taken in regards to the laser beam the laser ranger emits during testing.

This product is permitted use to use for skilled persons only.

WARNING:

- It is a **Class 2** laser product in accordance with IEC 60825-1:2014

…stare into the laser beam or direct it towards other people unnecessary
…dazzle other individuals.
…directly into the beam with optical aids can be hazardous
…erate the product in explosion hazardous areas or aggressive environments

…al planes to quantify how accurately the laser beam is normal to the measurement …E7100i units acquired for use in the systems-level test setup. This quantity is …will be utilized in the systems-level test to not only measure distances but also to …estial body plane is oriented in the test environment. This test also involves the …y quantify the pointing error. Details on the software … …the 'Data Analysis' section…

Testing Procedure
Aerospace Senior Projects

2016

Figure X: Leica DISTO E7100i Part Designations

1.3.2. Lightbox

When citing the "lightbox", this document is referring to a piece of test equipment that was constructed by team OSPRE for the purpose of providing an accurately sized and shaped simulated celestial body for the systems level test. See systems test or lightbox documentation for specifics on either topic. The diagram below designates the parts and features of the lightbox as they will be used in this procedure. Please note that they may differ from designations utilized in other documentation. Also note that this figure does not yet incorporate the most up-to-date design of the lightbox but still serves this purpose adequately.

Figure X: Lightbox Part Designations

1.3.3. Laser Mounting Mechanism

[Alignment Test] (Revision 1)

Page 5 of 14

Testing Procedure
Aerospace Senior Projects

2016

…safety concerns and precautions. The setup utilized in this document utilizes the Manfrotto 055XPROB tripod, …Manfrotto 410 Junior tripod head, a counterweight, as well as a table to place the alignment mirror in the desired …ocation and orientation. This test setup may also require the use of counterweights, ropes/wires, or other …asurement mechanisms. Please ensure all support equipment is accessible prior to beginning the test setup …ocedures.

… Software Requirements

…test requires the use of a simulation tool to verify the outcome. Please see the 'Data Analysis' section for …ctions on where to locate the necessary files, the use of the software, and the interpretation of the results.

TEST EQUIPMENT CHECKLIST

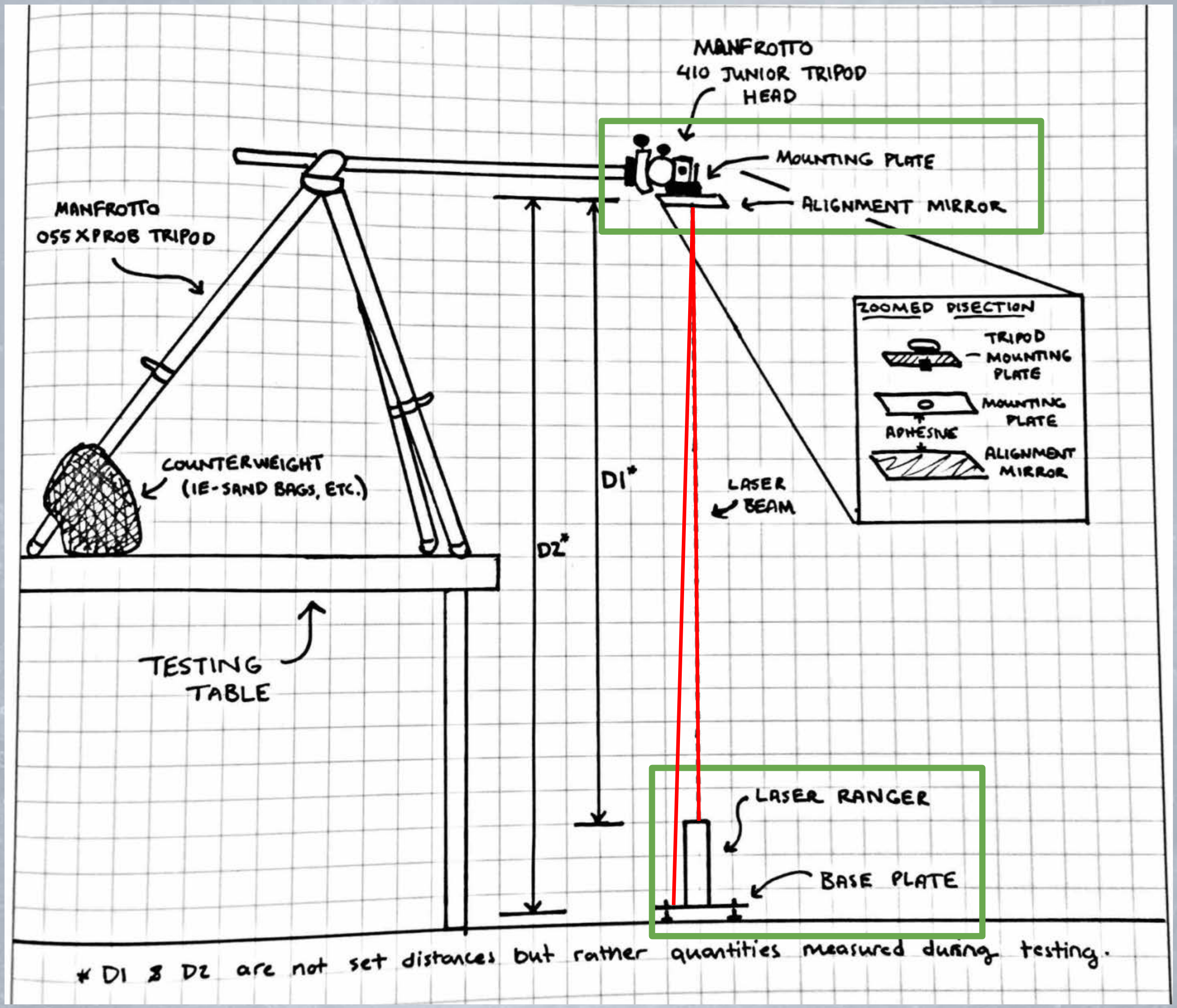
ITEM	PRESENT	MISSING / DAMAGED
…LATE RIG		
Metal plate w/ 4 holes		
4 bolts		
4 nuts (optional)		
Target		
…T MIRROR RIG		
…ounting plate w/ mirror		
Geared tripod head		
Tripod		
Counterweight		
…nt Equipment (optional)		

TEST ARTICLES

Laser Range Finder #1		
Laser Range Finder #2		
Additional Units (optional)		

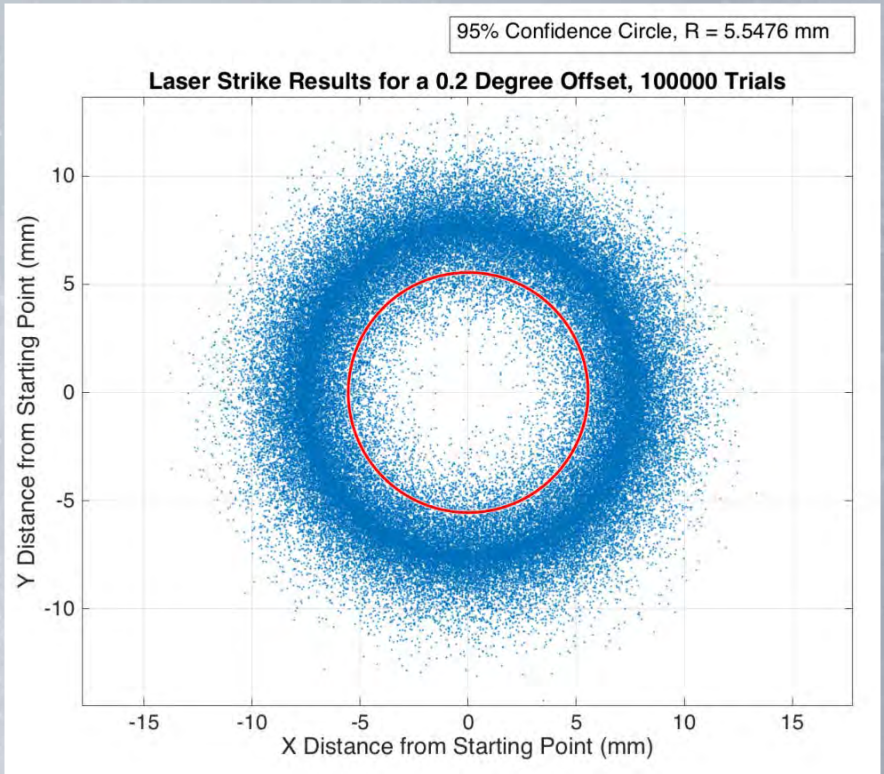
Performance Testing

Alignment Test: Basic Setup



Performance Testing
Alignment Test Results

- **SIMULATION TOOL**:
  - Using this tool, we can validate with 95% confidence that the laser ranger has between X and Y degrees of pointing error
  - Example simulation shown on the right



Mission Testing Manipulation

Camera Pointing

Manfrotto 410 Junior
Geared Tripod
Head

Manfrotto ProX
Tripod

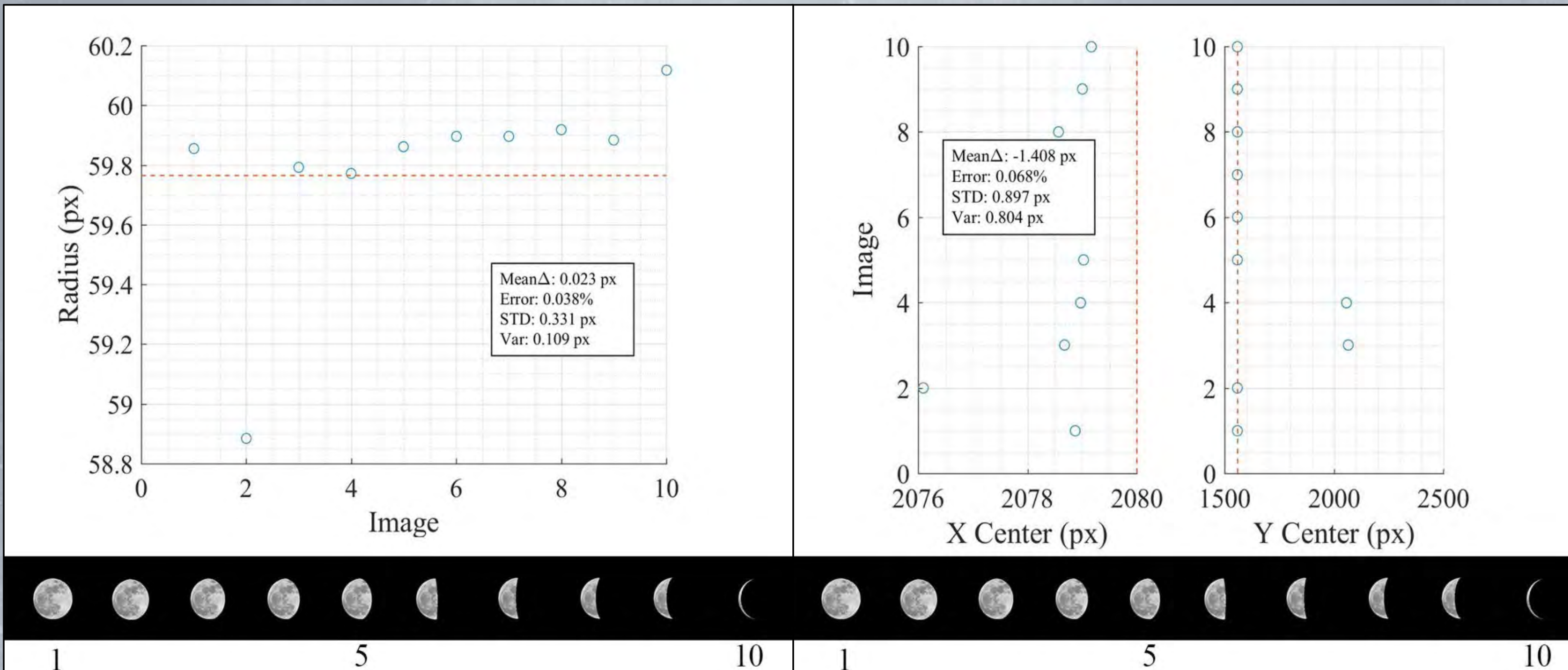
Performance Testing
Risk Reduction: Test-Level

- Validate critical tools are meeting accuracy tolerances
- Detailed and thorough test procedures
- Closely adhering to test & safety procedures
- Allot ample time in test facility
- Continuing improving error simulation
- Create and uphold safety procedures

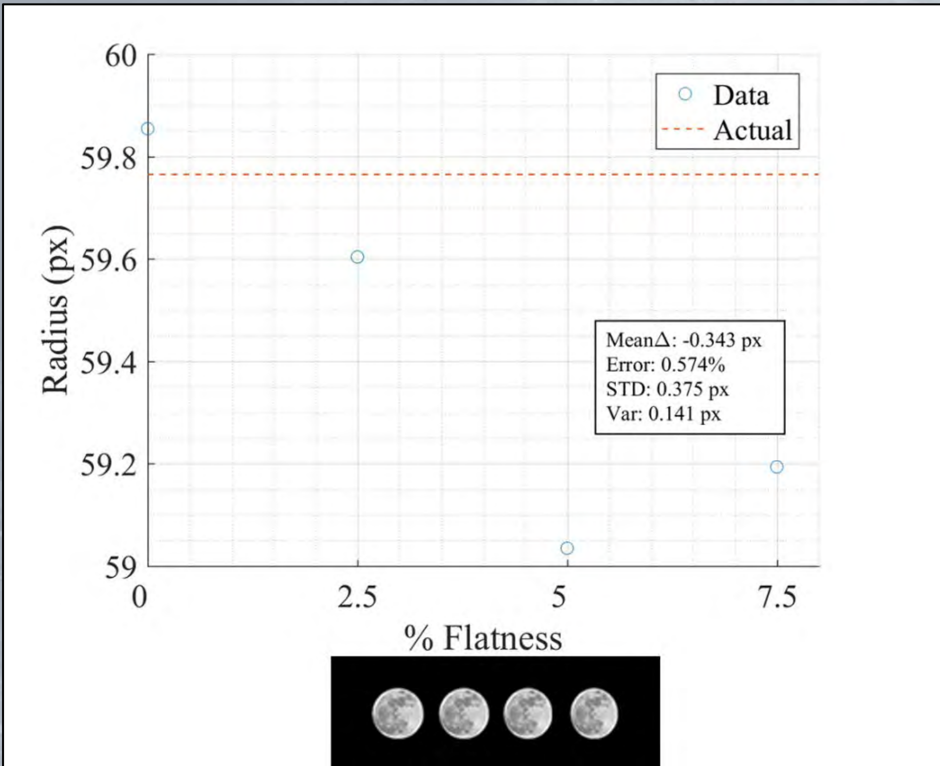
Validation

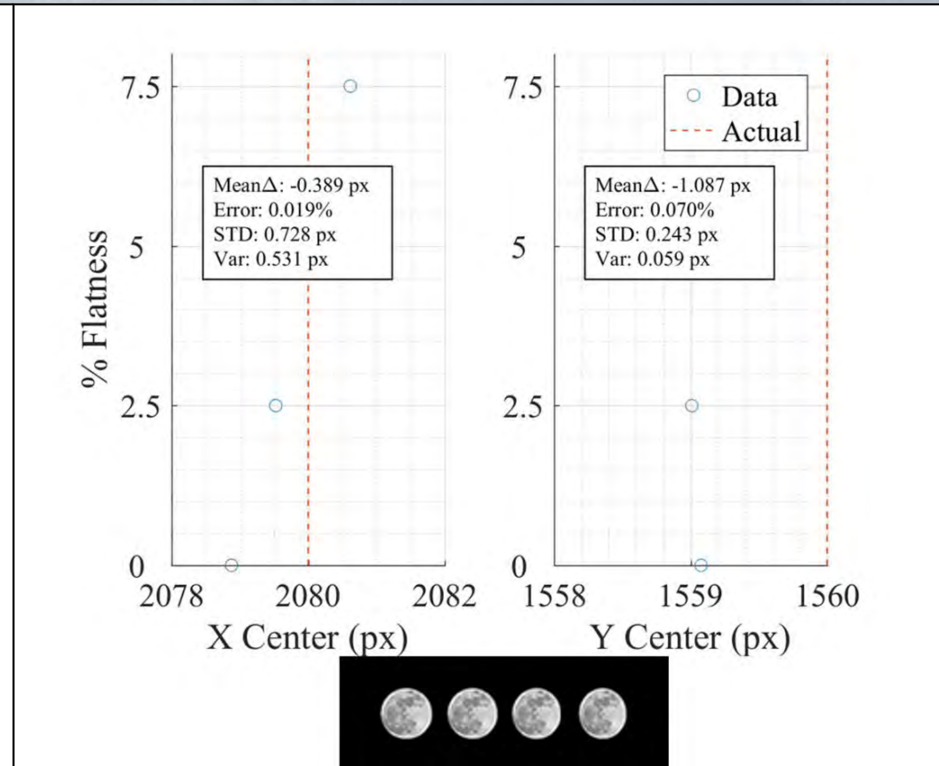
- Characterize camera performance
  - Compare image processing accuracy between test and digitally generated images
    - Make recommendations for sensor, exposure, or pre-processing improvements
- Validate mission simulation
  - Compare position and velocity errors
  - Confirm data collection timing

IMAGE PROCESSING

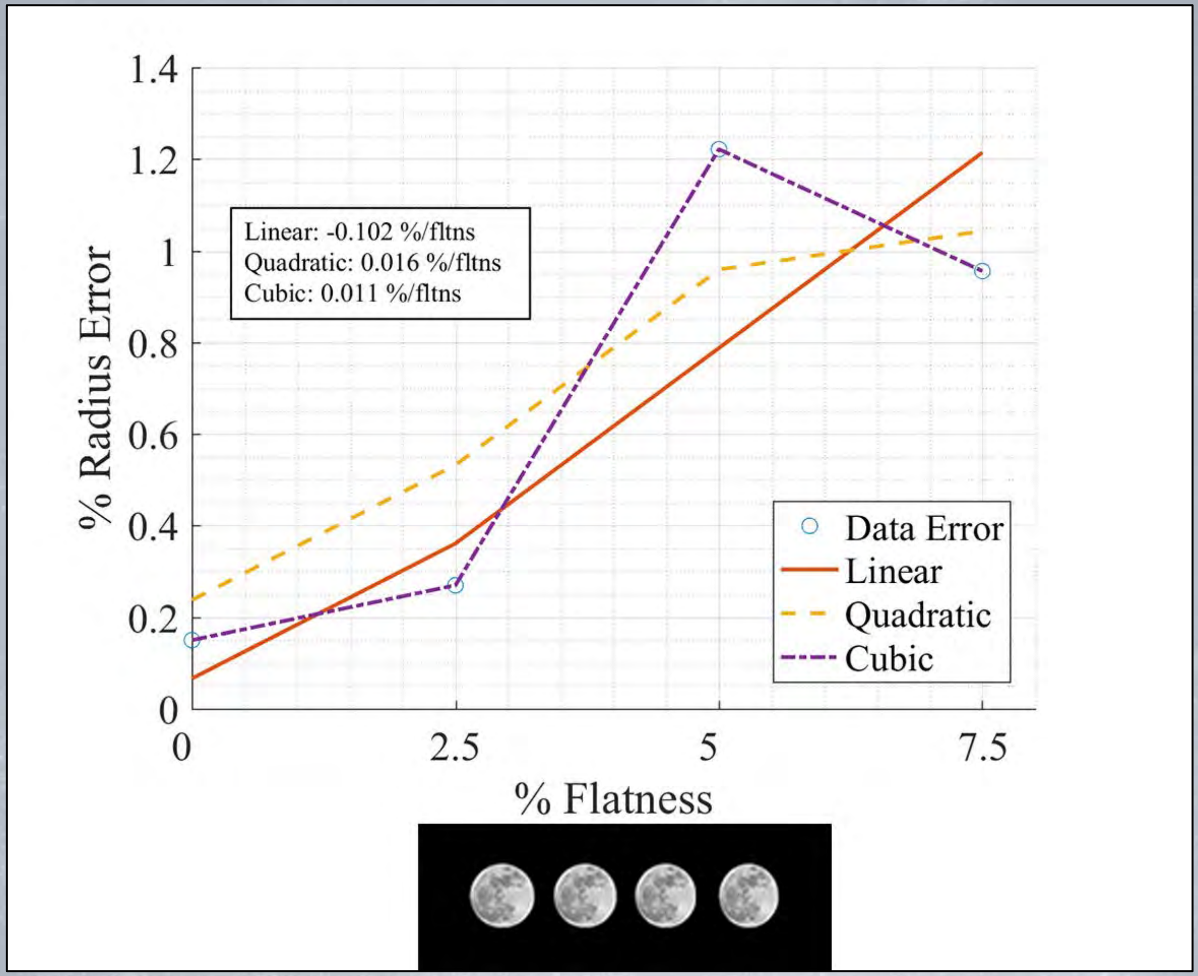


- Sensitivity with artificially created phases, using real moon image scaled to worst anticipated scenario of 67 pixel diameter





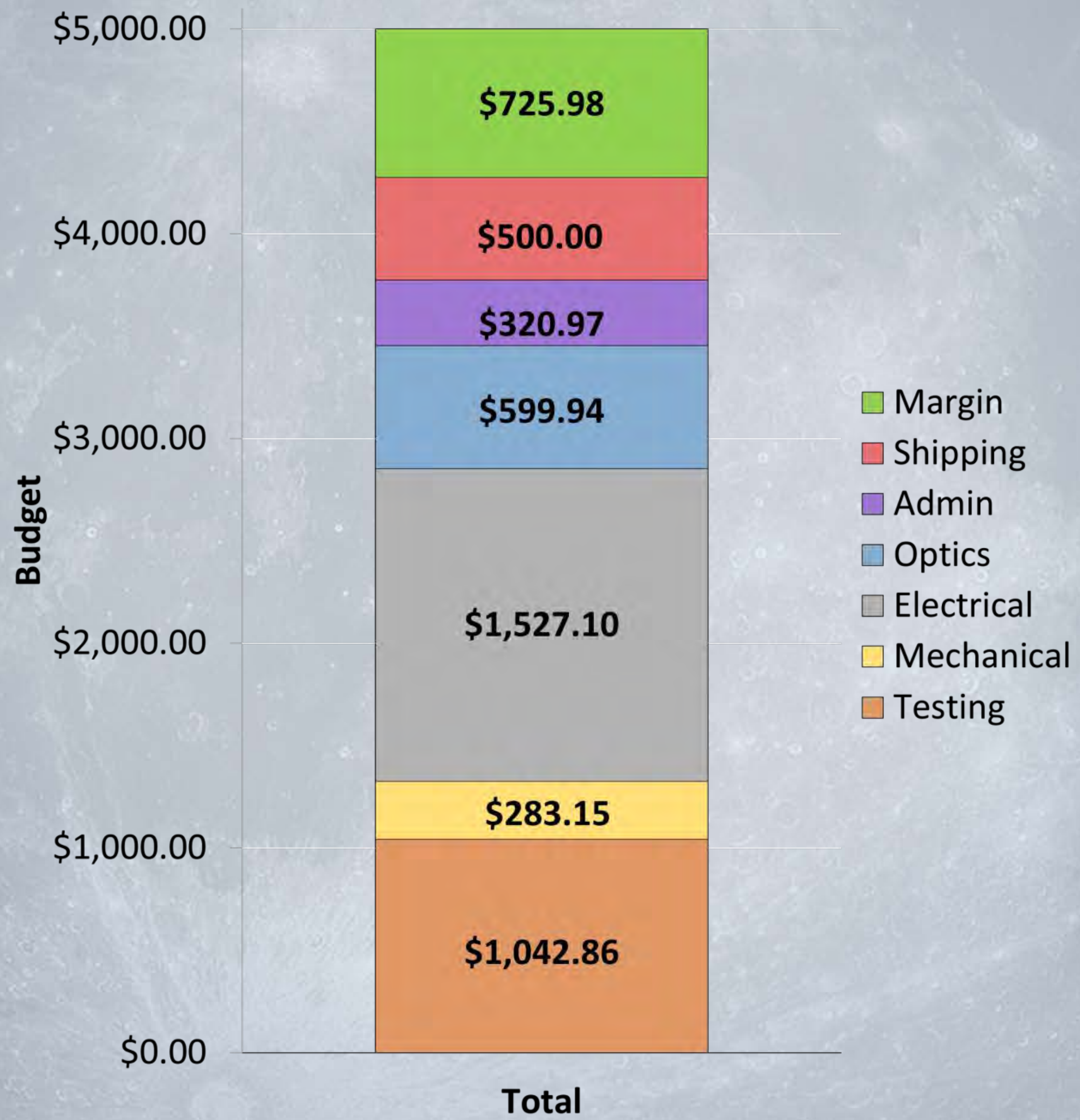
- Flatness is defined as the reduction in moon pixel width with constant height
- Used to evaluate how precise the test instruments need to be pointed at the lightbox



- Various regressions applied to evaluate flatness effect on radius error

BUDGET

Budget


$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$0.00
Budget
$725.98
$500.00
$320.97
$599.94
$1,527.10
$283.15
$1,042.86
Total
Margin
Shipping
Admin
Optics
Electrical
Mechanical
Testing

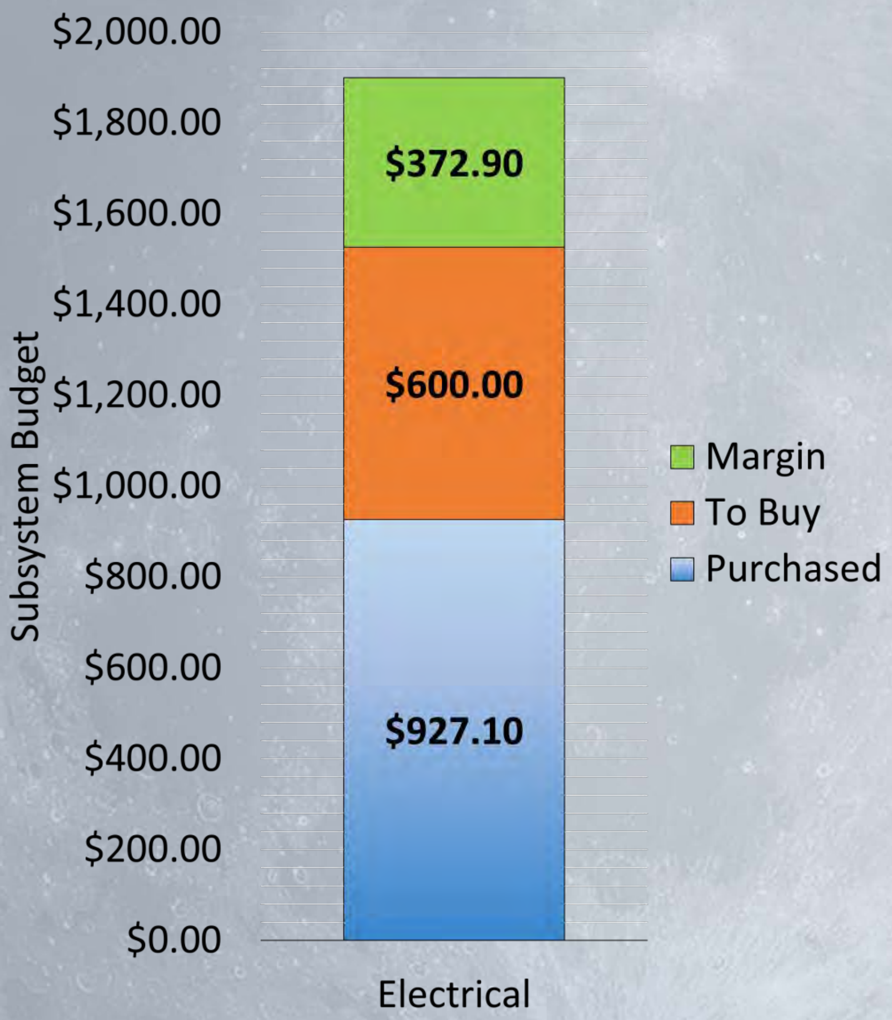
Budget

Component	% Subsystem Budget	Status
LED Lightpanel	5.1	Purchased
Precise geared tripod mount	13.7	Purchased
Laser Range Finder	18.6	Purchased
Calibration Materials	4.0	Purchased
Measurement Materials	9.1	To Buy
Structure	7.3	To Buy

Budget

Component	% Subsystem Budget	Status
Aluminum Encasing	9.4	Purchased
Moon Cutout Sheet Metal	11.2	Purchased
Enclosure Fasteners	8.3	Purchased
Black Acrylic Phase Detail	25.0	To Buy

Budget



Component	% Subsystem Budget	Status
Snapdragon 410 Development Kit	18.2	Purchased
ZedBoard	17.6	Purchased
PCB Components	13.0	
PCB	31.6	To Buy

Budget

Component	% Subsystem Budget	Status
13MP Camera	20.8	Purchased
Snapdragon 410 Dev Kit	57.5	Purchased
Moto G Phone	21.7	Purchased

Budget

Component	% Subsystem Budget	Status
CDR, FFR, PDR, MSR, and TRR Printing	32.2	Purchased
SFR and FDR Printing	32.0	To Buy