Spring Final Review

Team CHAIR April 19, 2021

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Customer: Dr. Torin Clark

Purpose & Objectives

Purpose

Customer aimed to provide multiple sensory cues in conjunction in order to increase aircraft attitude awareness for remote pilots.

The team aimed to create a proof-of-concept research tool for the customer that can be further developed into a full system.

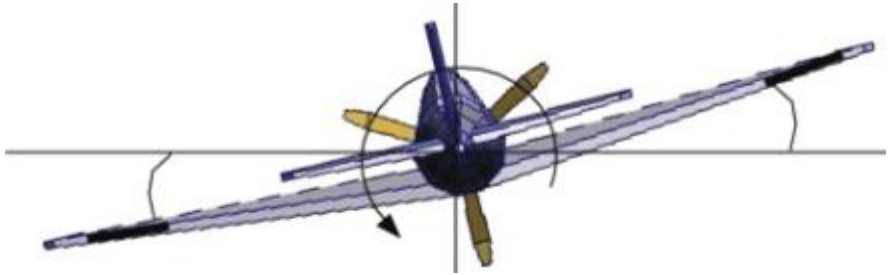


Fig: aircraft in a roll

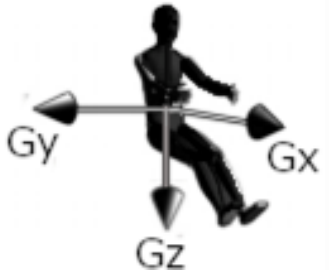
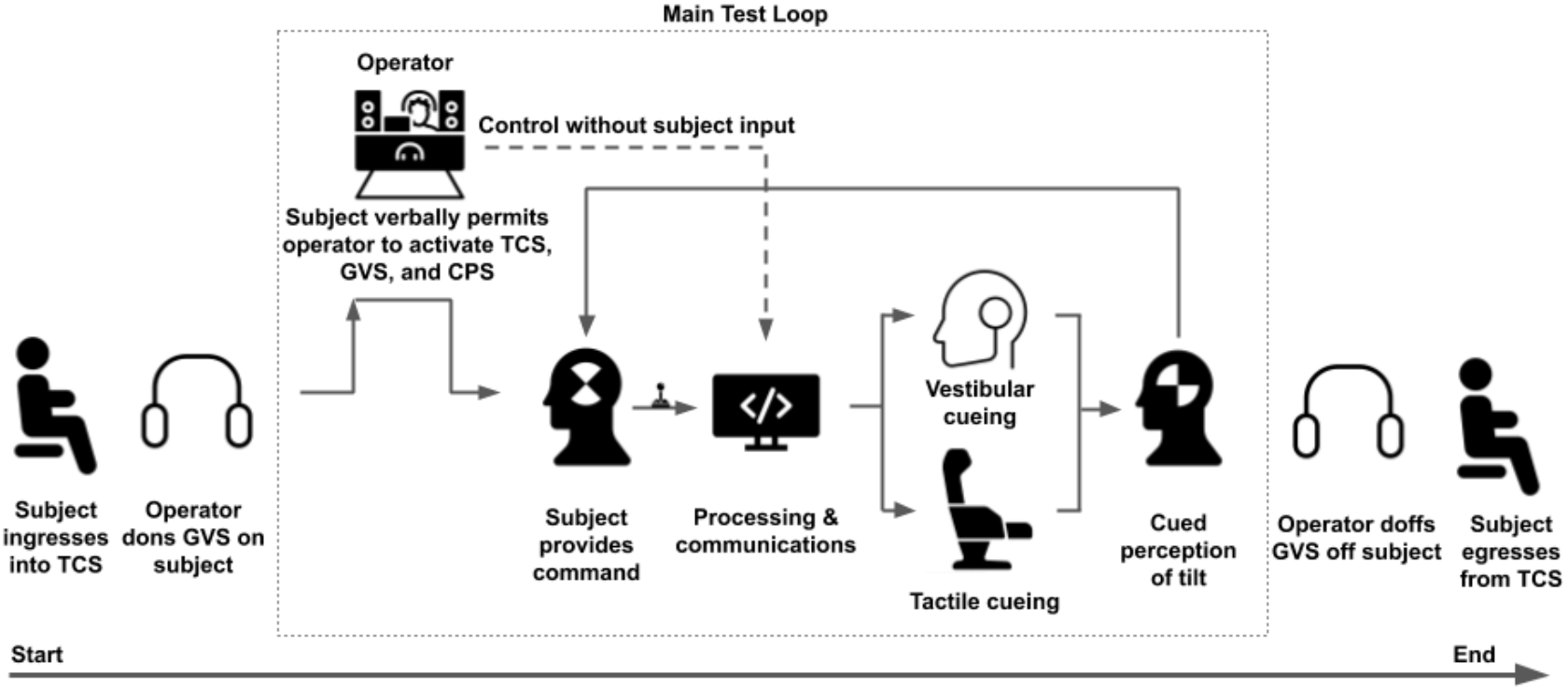


Fig: body-centric reference axes

Concept of Operations



Levels of Success

Level 1: Discrete, static tilt cueing about the body x axis

Level 2: Continuous, sinusoidal tilt cueing about the body x axis

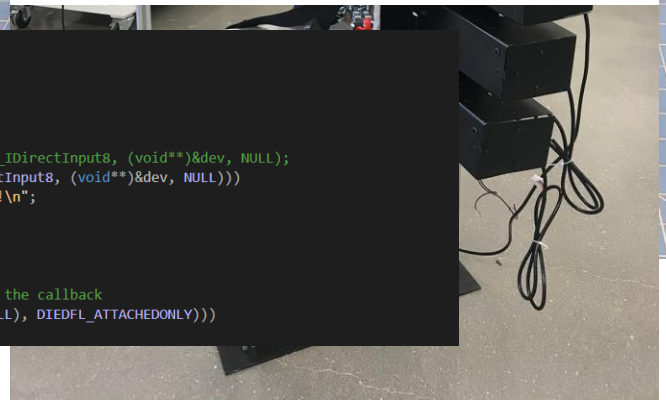
Level 3: Variable tilt profile developed in real time through joystick control

Design Description

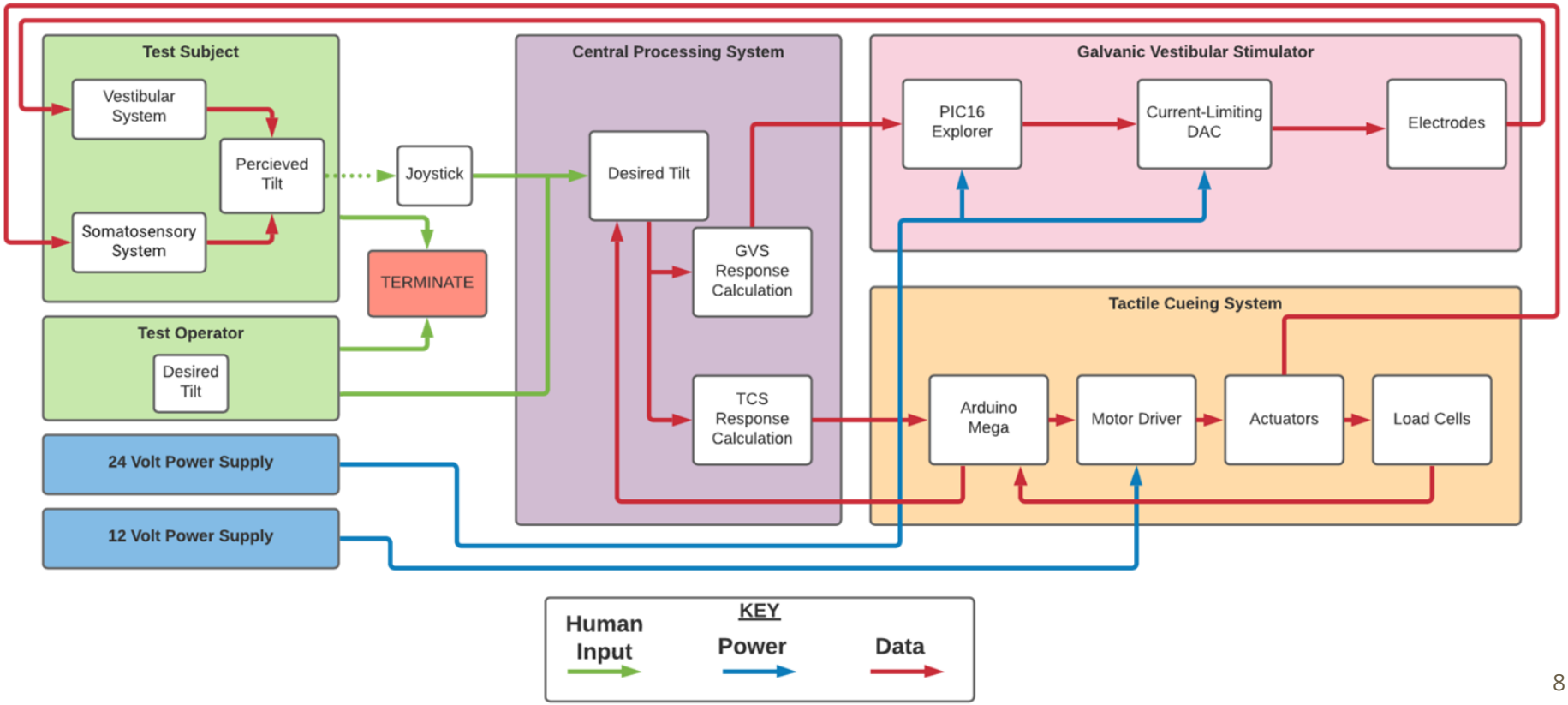
Critical Project Elements

- Tactile Cueing System (TCS)
  - Applies pressure to subject
- Galvanic Vestibular Stimulator (GVS)
  - Stimulates vestibular system
- Central Processing System (CPS)
  - Coordinates cueing

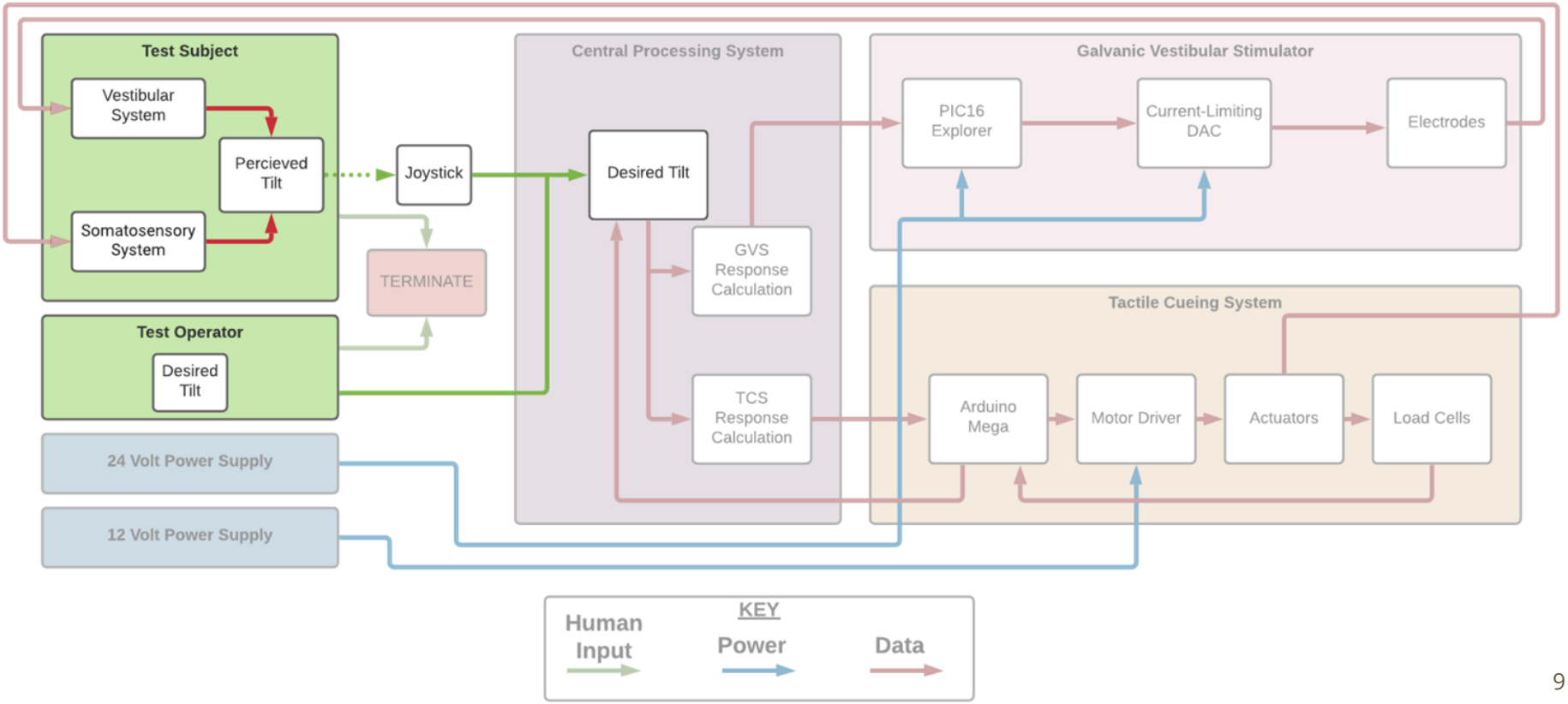

```
40  int main()
41  {
42
43      std::cout << "Hello World! Team CHAIR 2021!!!\n";
44      std::cout << "(1)-----First we created the DirectInput 8 COM object.\n";
45
46      //HRESULT myCOM = DirectInput8Create(GetModuleHandle(NULL), DIRECTINPUT_VERSION, IID_IDirectInput8, (void**)&dev, NULL);
47      if (FAILED(DirectInput8Create(GetModuleHandle(NULL), DIRECTINPUT_VERSION, IID_IDirectInput8, (void**)&dev, NULL)))
48          std::cout << "Critical error: Unable to create the main DirectInput 8 COM object!\n";
49      else {
50          std::cout << "          SUCCESS--> Created DirectInput8 interface\n";
51      };
52      std::cout << "(2)-----Next we enumerate all connected Joystick(s).\n";
53      // issue may be with 3 argument, should be a 32bit pointer thats passed each time to the callback
54      if (FAILED(dev->EnumDevices(DI8DEVCLASS_GAMECTRL, myEnumCallBack, GetModuleHandle(NULL), DIEDFL_ATTACHEDONLY)))
55          std::cout << "Critical error: Unable to enumerate Devices\n";
```



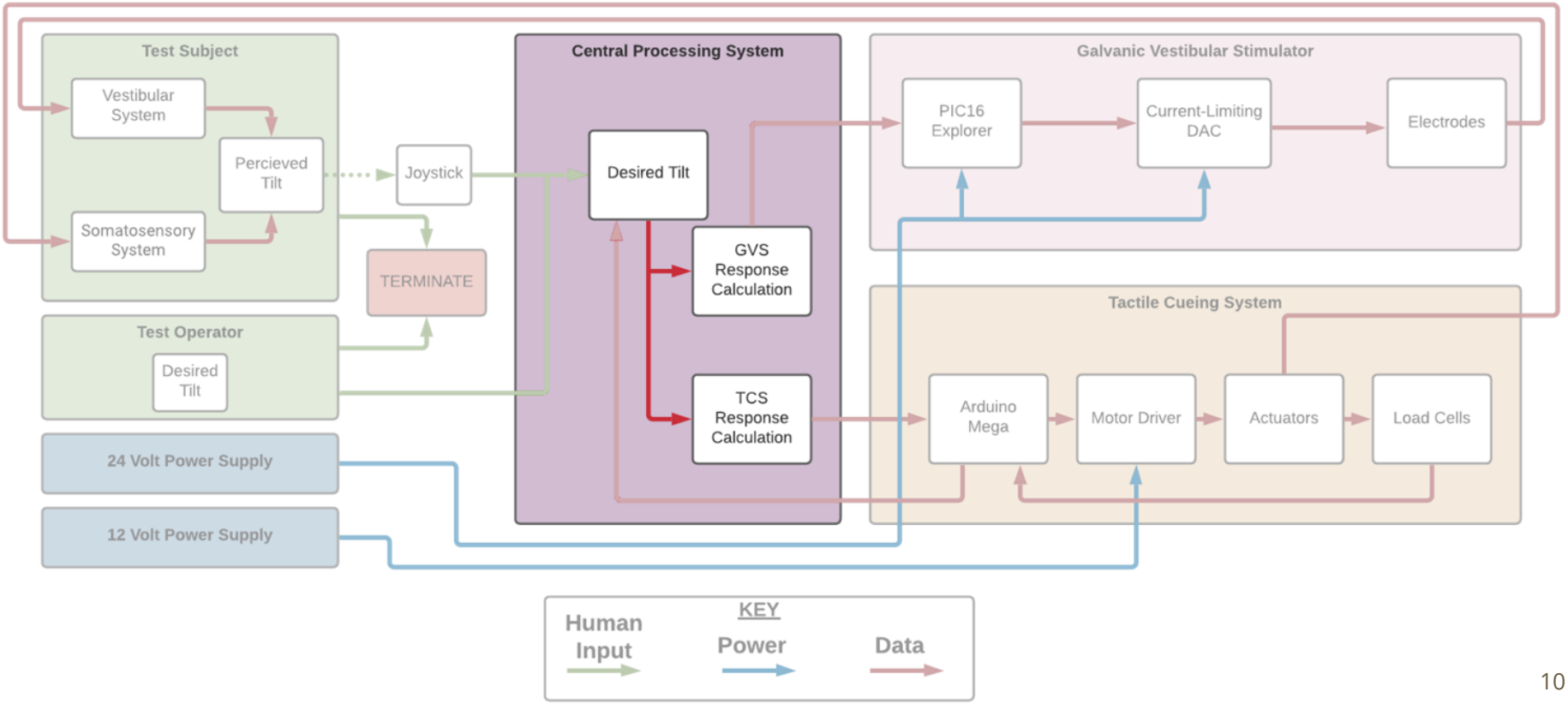
Functional Block Diagram



Functional Block Diagram



Functional Block Diagram



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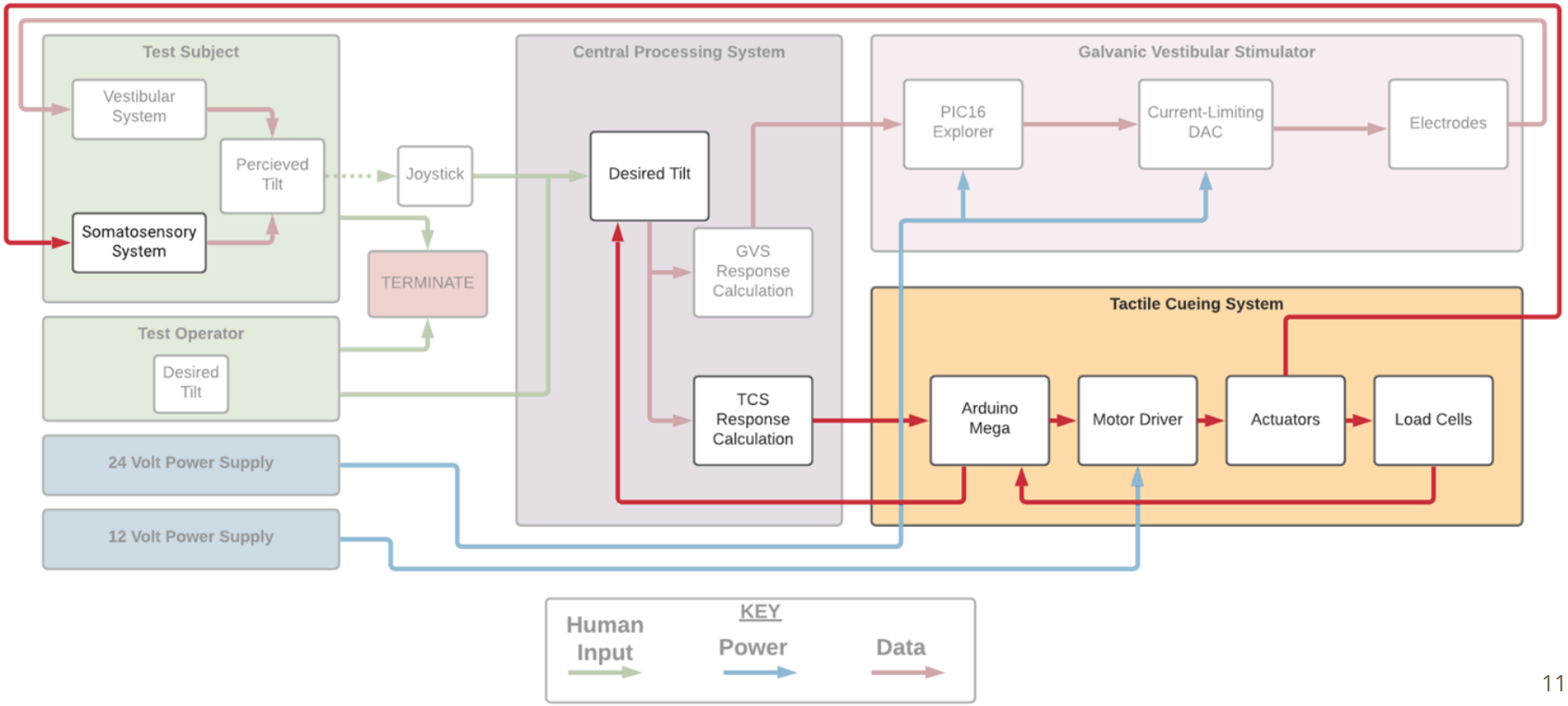

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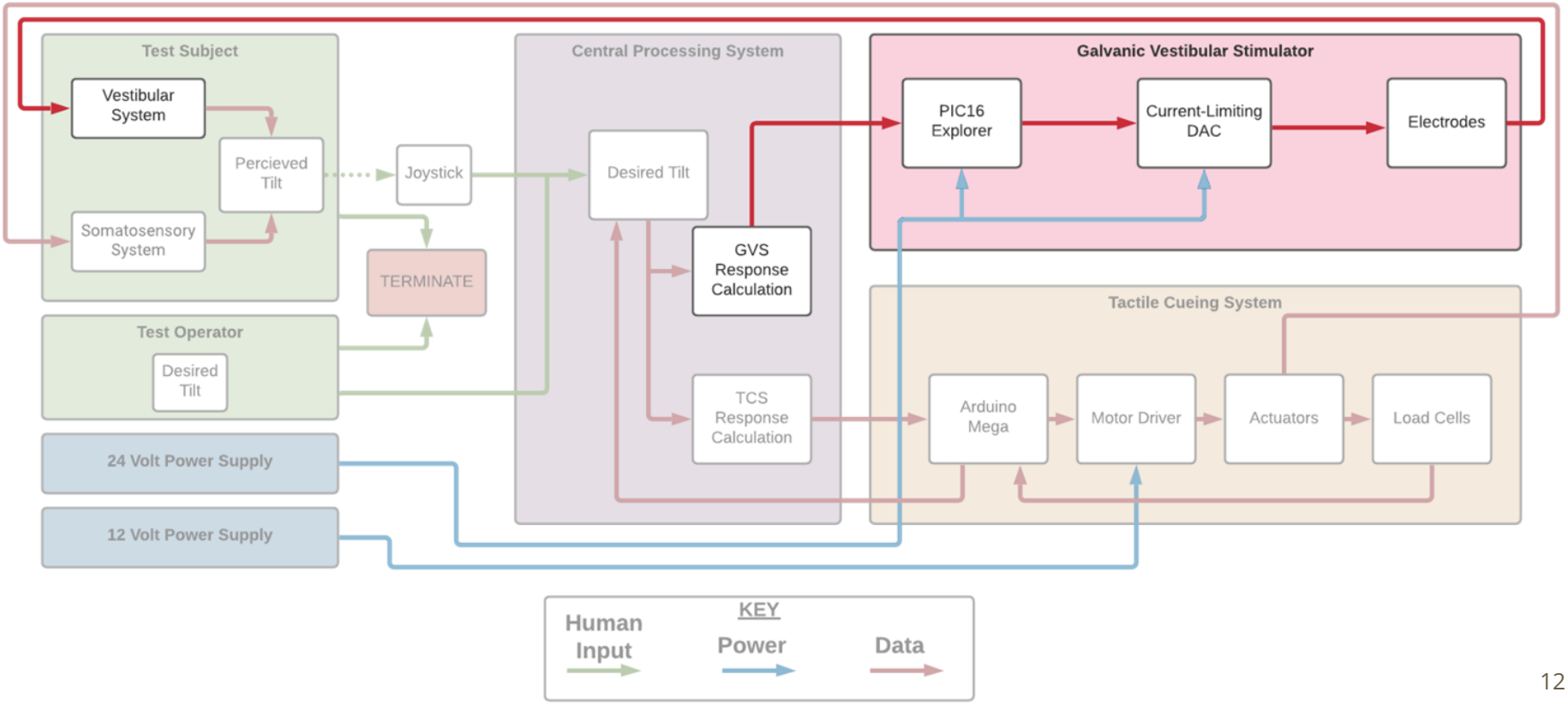

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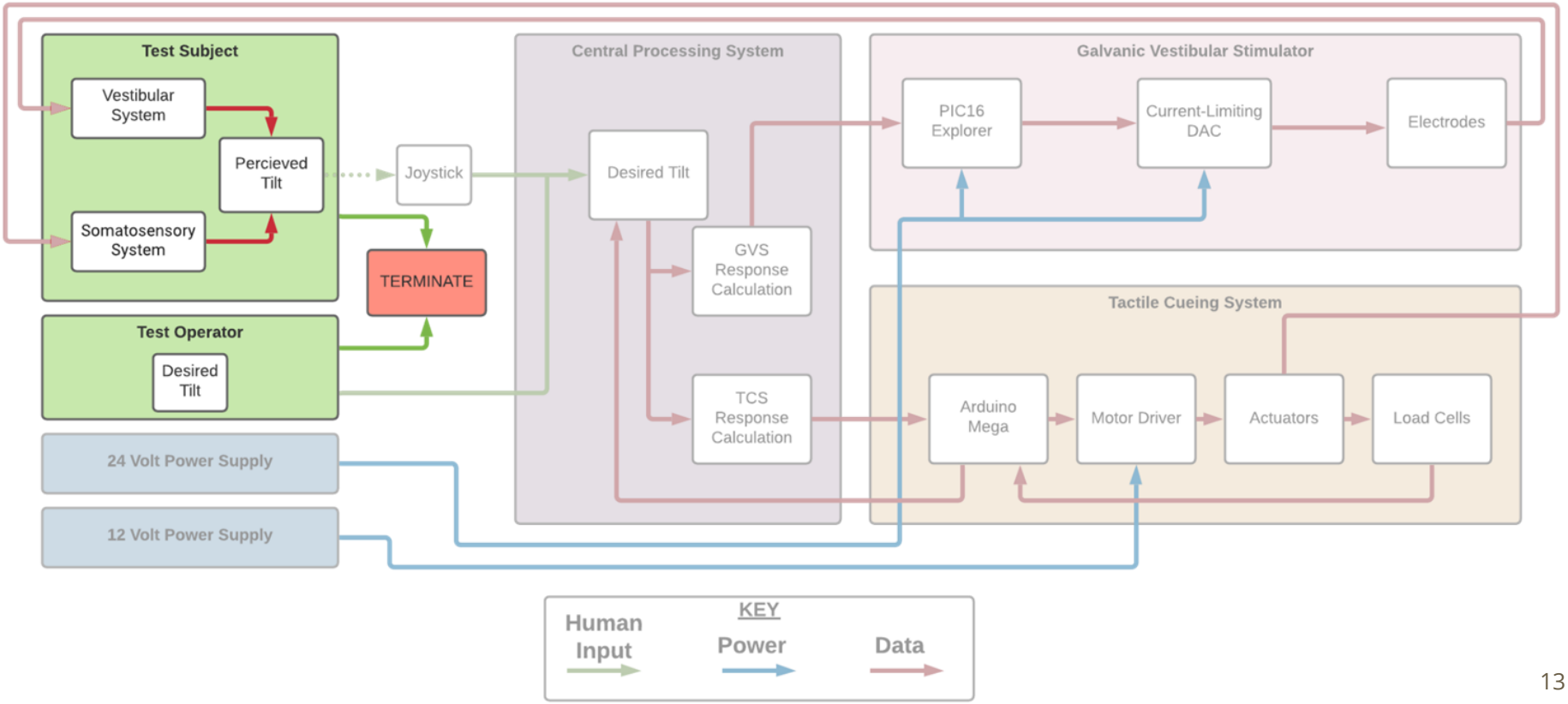
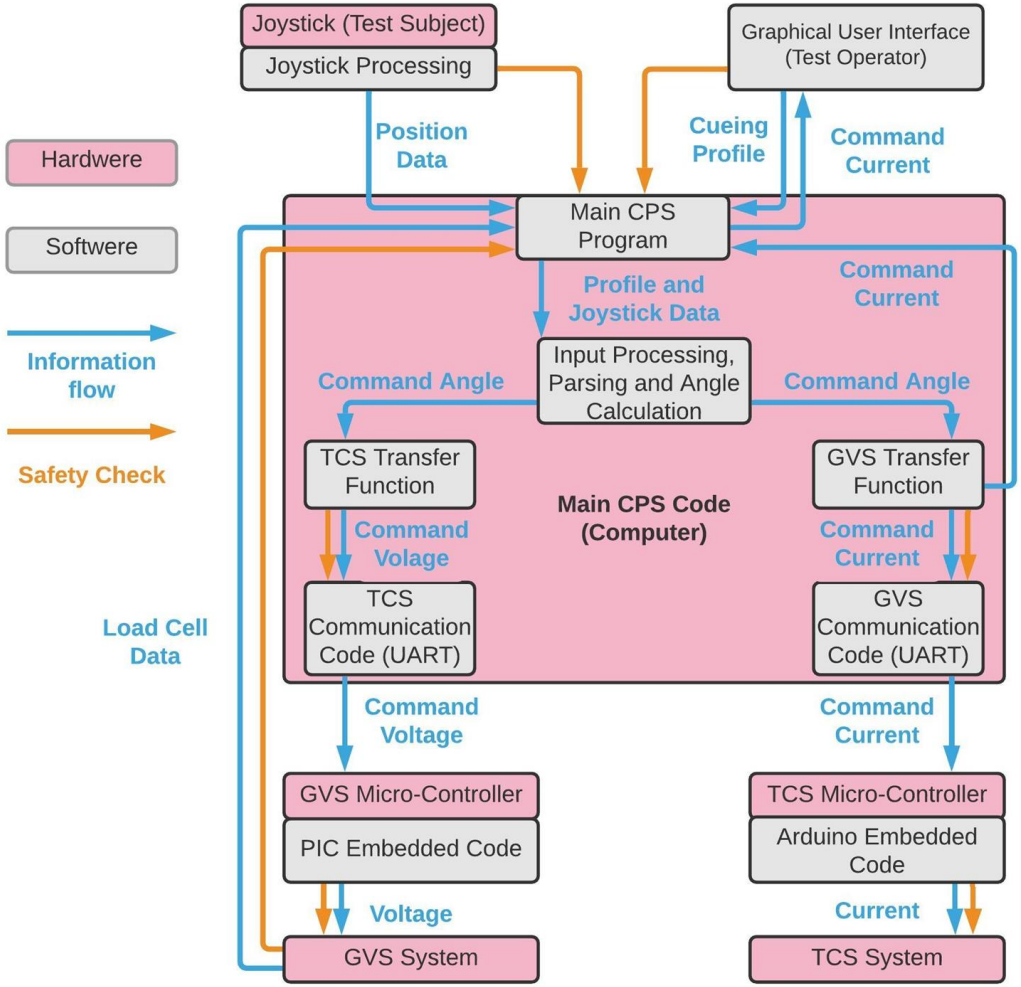


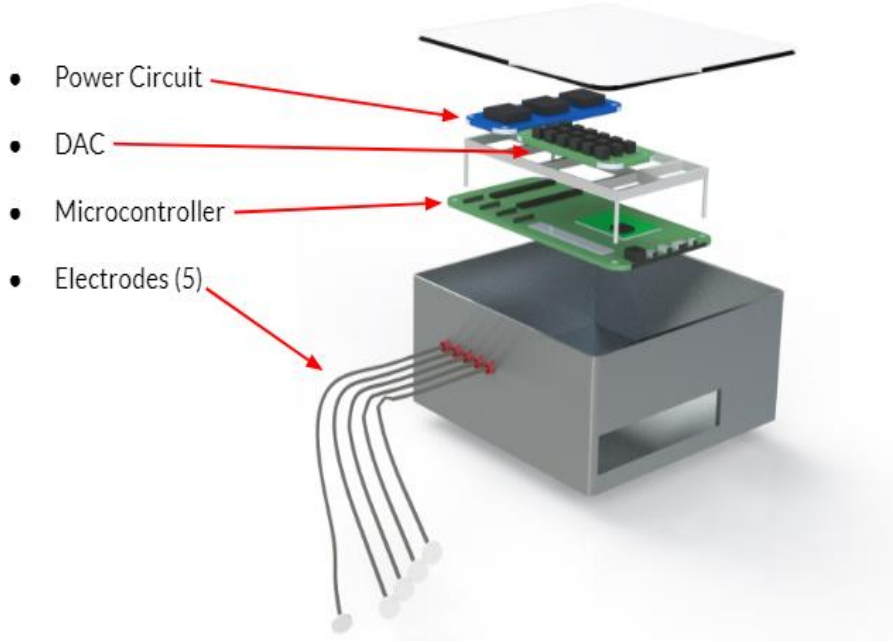
CPS Design

- GUI
  - Takes in test operator inputs, profiles and displays load-cell/system data
- Main Code
  - The main code coordinates the software flow and call subroutines
- Main Code Subroutines
  - Joystick processing, TCS/GVS communication code and other subroutines
- GVS Microcontroller Code
  - Embedded code to command a current via the DAC
- TCS Microcontroller Code
  - Embedded code to command a voltage and take in load-cell data

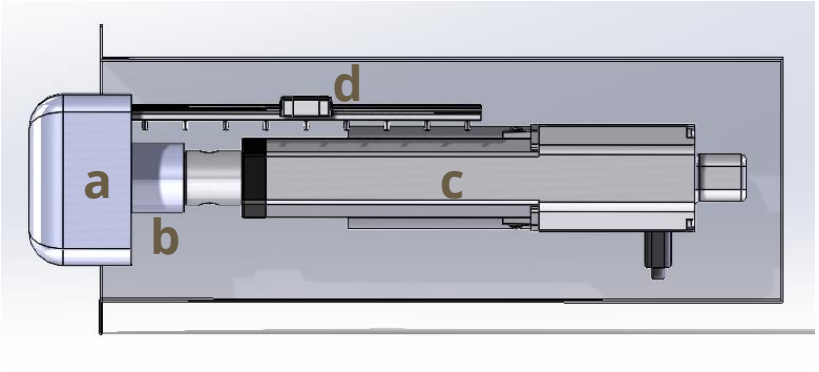


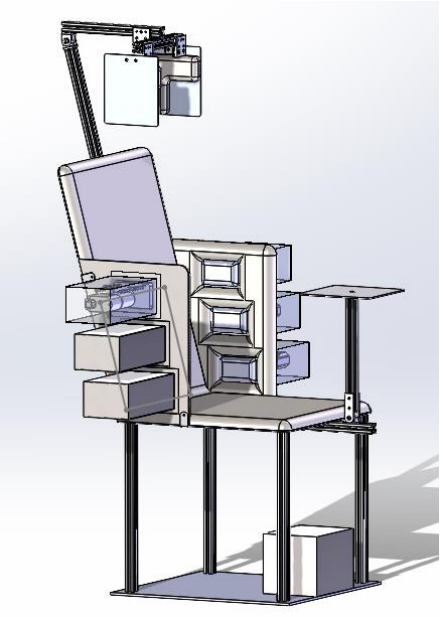
GVS Design

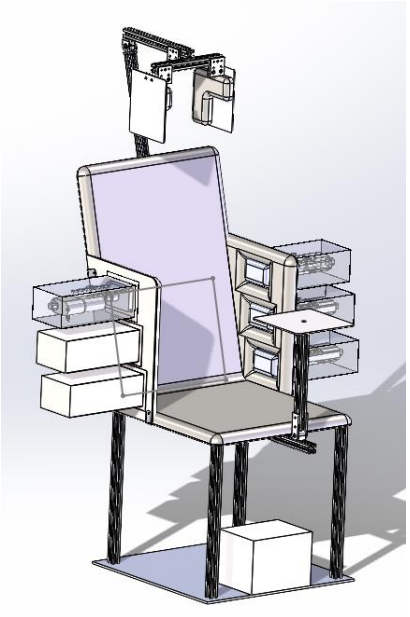
- Power Circuit:
  - Relays toggle each electrode as source/sink. Current mirrors control maximum sink
- DAC:
  - Drive currents across dynamic, non-Ohmic load or bias current mirrors open
- Microcontroller
  - Interfaces CPS with DAC and Power Circuit
  - Controls timing operations
- Electrodes
  - Self-adhesive electrodes allow for variable arrangement



TCS Design







a: pressure module (foam, pine, faux leather upholstering)

b: load cell

c: linear actuator

d: linear guides

CPS Safety

Test	Driving Requirements	Status
Test subject terminate button	DR 2.4	Passed
Operator terminate button	DR 2.5	Passed
Joystick/Operator data capture/curation	DR 2.4	Passed
Malicious data capture/curation	DR 2.4	Passed
Safe TCS/GVS Commands	DR 2.4,DR 2.5,DR 3.1	Passed
Terminate time	DR 2.5	Passed
Power cycle	DR 2.4	Passed

= Failed

Passed = Completed and Passed

Testing = Testing in progress

GVS Safety

Test	Driving Requirements	Status
1mA & 4mA endurance test	DR 4.4.2, DR 4.4	Passed
Safe/Accurate commands	DR 1.2, DR 2.3	Passed
Power cycle	DR 4.4, DR 4.4.2	Passed
Malicious commands	DR 2.3	Passed

F = Failed Passed = Completed and Passed Testing = Testing in progress

TCS Safety

Test	Driving Requirements	Status
Safe command	DR 1.1,DR 1.1.1,DR 1.1.3,DR 2.1	Passed
Malicious command	DR 1.1,DR 1.1.1 ,DR 1.1.3,DR 2.1	Passed
Seat back structure	DR 1.1.2,DR 4.2	Passed
Center of Gravity	DR 1.1.2,DR 4.2	Passed
Endurance Test	DR 4.3,DR 4.4,DR 4.4.2	Passed

F = Failed Passed = Completed and Passed Testing = Testing in progress

Fully Integrated System Safety

Test	Driving Requirements	Status
CPS Test suite	DR 2.4,DR 2.5,DR 3.1	Testing
GVS Test suite	DR 4.4, DR 4.4.2,DR 1.2, DR 2.3	Testing
TCS Test suite	DR 1.1,DR 1.1.1,DR 1.1.3,DR 2.1,DR 1.1.2,DR 4.2,DR 4.3,DR 4.4,DR 4.4.2	Testing

= Failed

Passed = Completed and Passed

Testing = Testing in progress

Test Overview

Test Overview

- Tests performed at the component, subsystem and full system levels
- CPS and components: test focusing on communication and synchronization of all the subsystems
- GVS and components: test focusing on commanding appropriate currents
- TCS and components: test focusing on commanding correct actuators force

Component Testing

- Central Processing System
  - Initializing MCU communications - DR 2.4 - Command values to MCU’s
- Galvanic Vestibular Stimulator
  - Breadboard current control - DR 1.2 - Command electrical current between -4mA & 4mA
- Tactile Cueing System
  - Single actuator testing - DR - 2.1 - Command a tactile force

Subsystem Testing

- Central Processing System
  - CPS Joystick Integration - DR 2.5 & DR 3.1 - Emergency shutdown switch & cueing profile input
- Galvanic Vestibular Stimulator
  - Resistor testing - DR 1.2 - Command electrical current between -4mA & 4mA in the GVS circuit configuration
- Tactile Cueing System
  - Stress testing & CG analysis - DR 4.2 & 1.1.2 - Accommodate the 50th percentile for male weight and height & the TCS must remain static

Full System Testing

- All subsystem testing repeated while within full integration.
- Subsystem Sync
  - GVS & TCS cues occur within 100ms of each other - DR 3.2
- Cue Response Time
  - From joystick input to GVS & TCS cues in less than 200ms - DR 3.3

Test Results

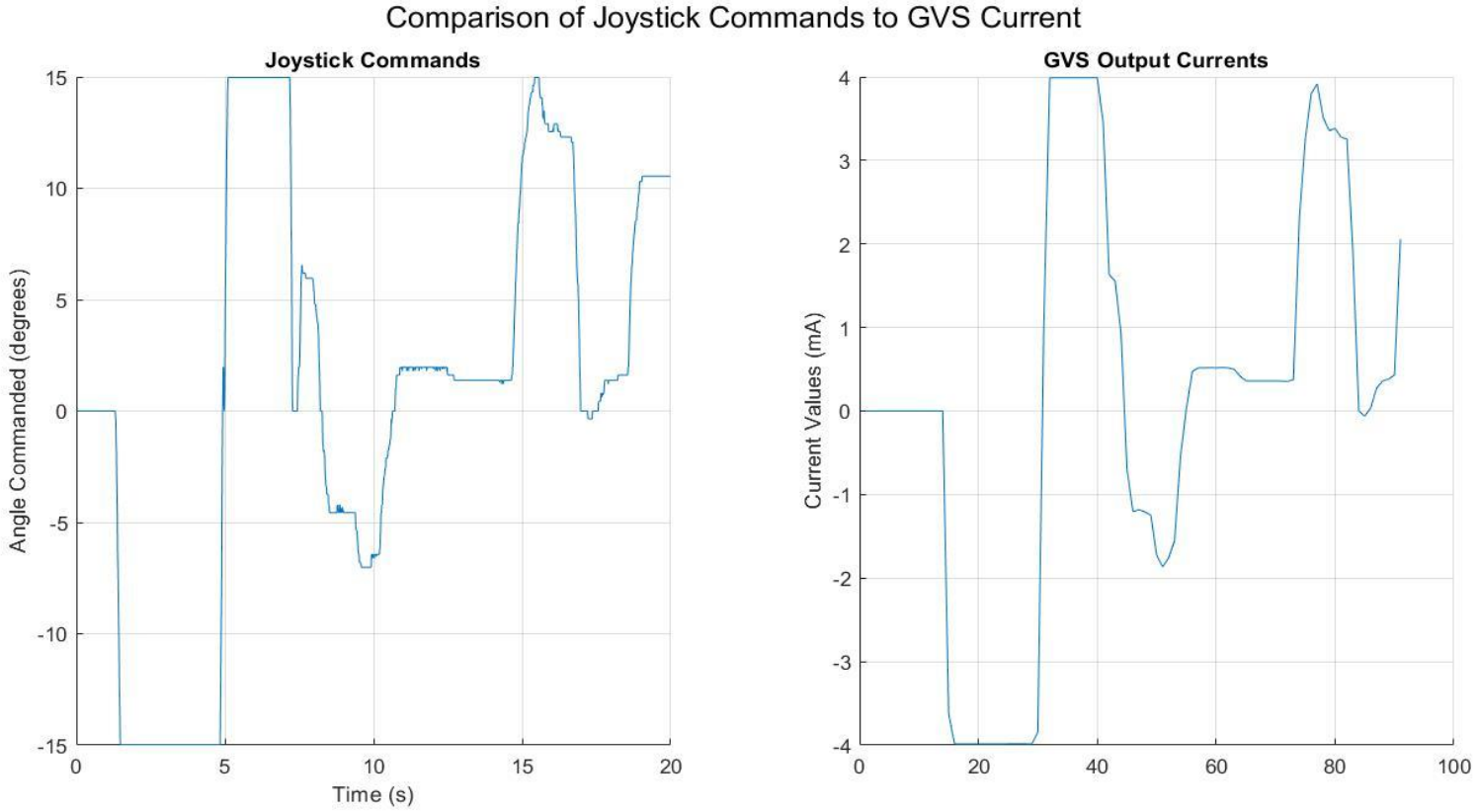
CPS Tests Results

CPS Modular Testing Results

Component	Requirements	Test(s)	Result
Main Code	DR 2.4, DR 2.5, & DR 3.4	Main code builds and runs on multiple machines without external devices	Passed
Joystick	DR 2.4, DR 2.5	Joystick setup is successful • C++ code is polling joystick position • trigger pull is registering	Passed
GVS	DR 3.2, DR 3.3 & DR 3.4	Commands are sent successfully to the PIC controller from C++ code, converted to currents as expected for full range of values	Passed
TCS	DR 3.1	Commands are sent successfully to the Arduino • TCS measured response corresponds to expected force outputs• TCS load cell outputs read successfully	Passed
UI	DR 3.4	CLI allows test operator to input relevant information such as joystick mode, cuing profile, and subject weight • CLI resists user errors such as incorrect inputs, improper file format • Prototype GUI has been created using QT	Passed

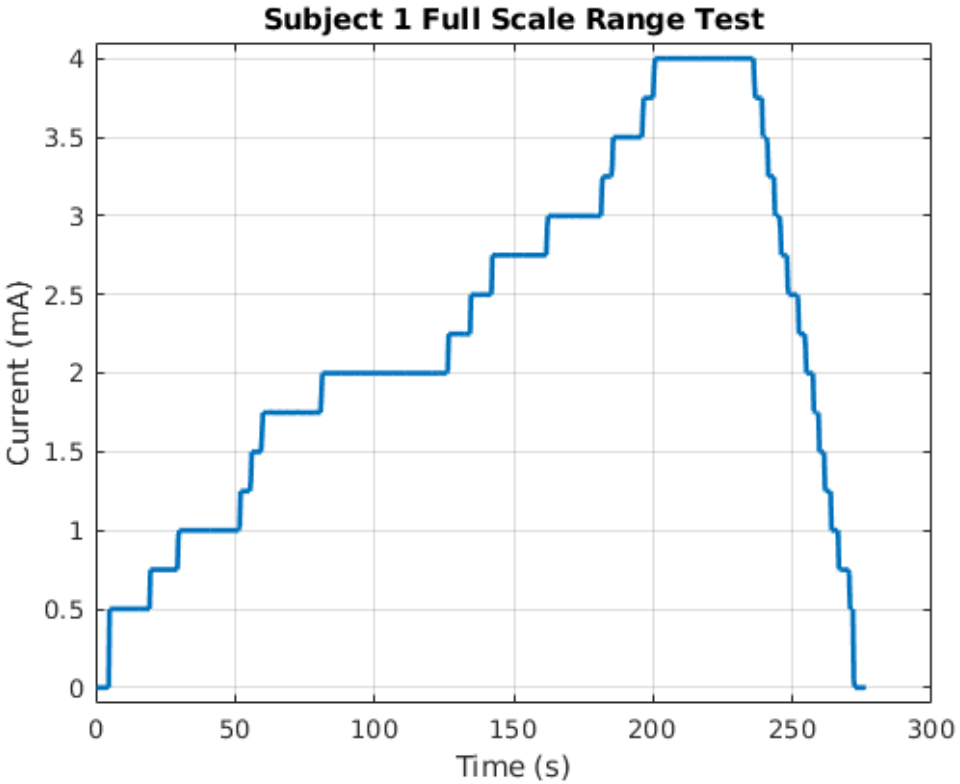
CPS-Hardware Integration Testing Results

Component	Requirements	Testing	Status
Joystick	DR 2.5, DR 3.1, & DR 3.3	Joystick code is integrated with CPS • Data is passed to the main code as expected in both mode 2 and mode 3 • Joystick commands are capped at +/- 15 degrees • A a trigger pull initiates termination	Passed
GVS	DR 3.2, DR 3.3 & DR 3.4	GVS communication code is integrated into the main CPS • GVS commanding from CPS is working (values have been calculated correctly, sent and are executed by the GVS) • Current measurements from multimeter have been verified against commanded values • Stop button successfully returns GVS to zero current before stopping the test	Passed
TCS	DR 3.1	TCS code has been integrated into main CPS • Confirmed serial handshake with TCS Incomplete: CPS command test, load cell read test	Testing
GVS-Joystick	DR 2.4, DR 2.5, DR 3.3 & DR 3.4	Joystick successfully commanding GVS in modes 2 & 3 • Termination zeros GVS current and ends test • Current readings track joystick motion with high fidelity	Passed
Full System	DR 3.2	Incomplete: CPS commands to both TCS and GVS • TCS-GVS lag test • Full system lag test • Full system terminate test	Testing


Comparison of Joystick Commands to GVS Current
Joystick Commands
Angle Commanded (degrees)
Time (s)
GVS Output Currents
Current Values (mA)

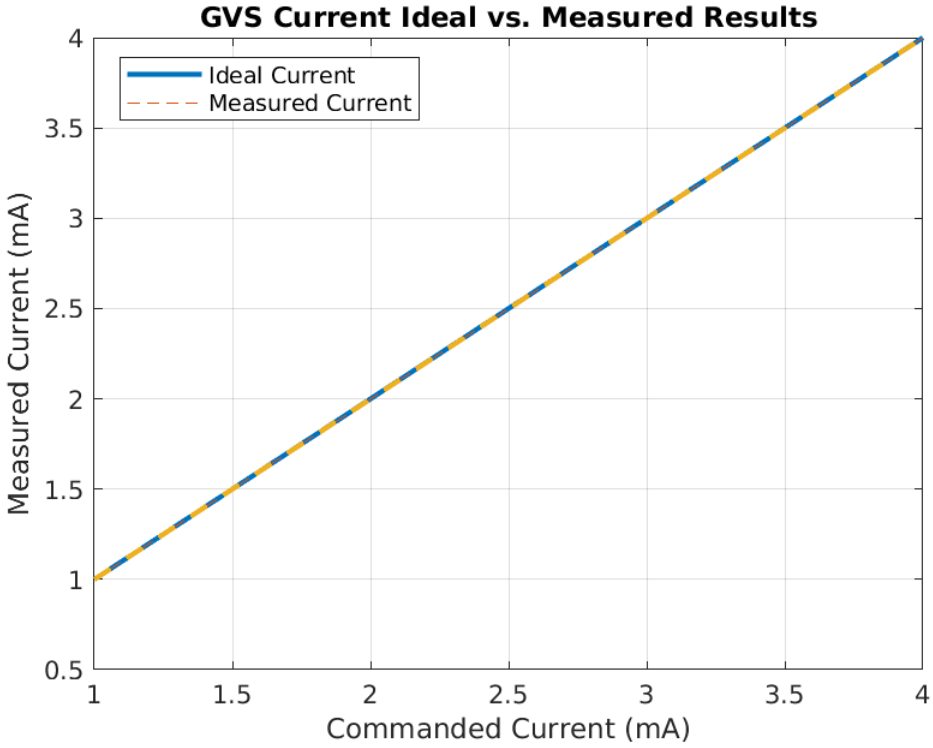
GVS Tests Results

GVS Subsystem V&V



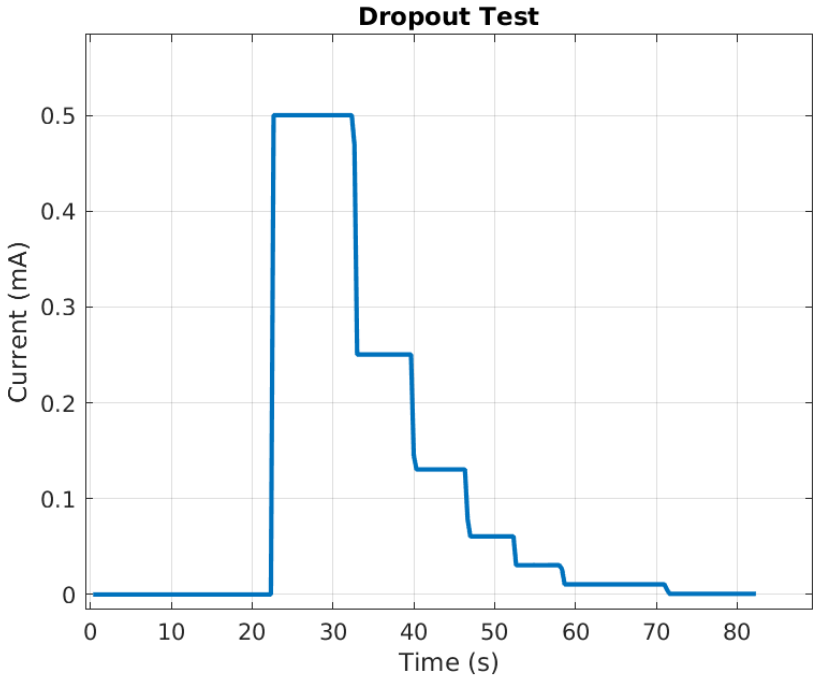
- All subsystem-level requirements have been validated with human-in-the-loop testing
- Verified ability to reach +/- 4mA
- Verified ability to reach +/- 4mA after 20 minutes of operation
- Meets or exceeds model predictions

GVS Model Validation



	Model Prediction	Measured Results	Validates Model?
Gain Error	93.8µA	1.30µA	**Valid**
Offset Error	6.25µA	1.48µA	**Valid**
Standard Deviation	50.0µA	29.5nA	**Valid**

GVS Model Validation



	Model Prediction	Measured Results	Validates Model?
Dropout	0.625mA	<0.010mA	**Valid**

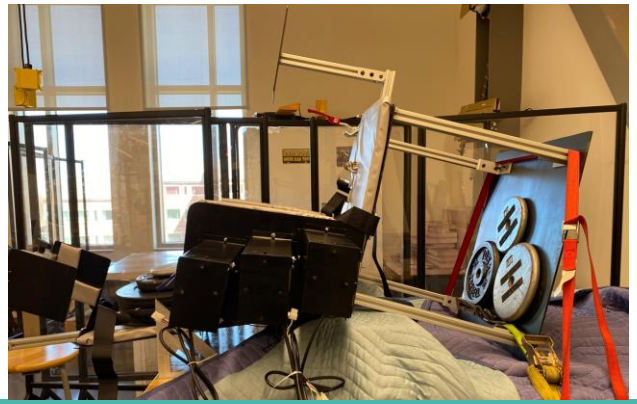
- 0.010mA is our lowest commandable value

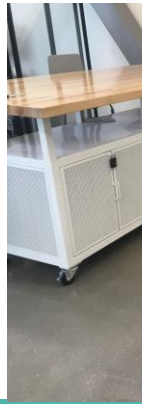
TCS Tests Results

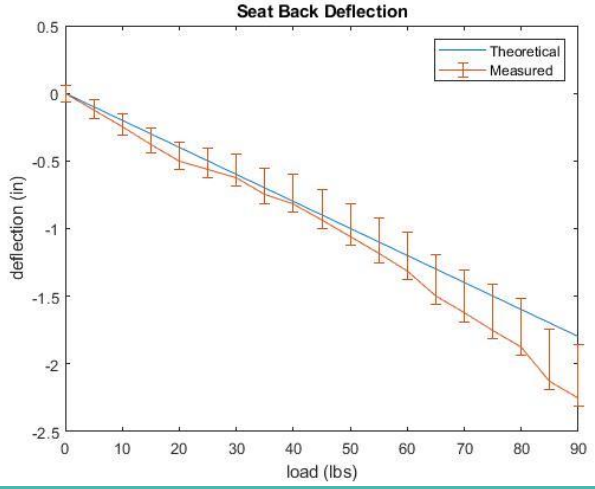
TCS Subsystem Structural Results

Dimension	Measurement
Pad to pad side width (hip width)	18.2”
Seat pan back to front (thigh length)	19”
Floor to top of seat pan cushion (heel to knee)	18.5”
Seat pan to top of seat back (butt to shoulder)	24.5”
Headrest height accommodation (butt to head)	22.5” - 44.2”
Headrest width accommodation (head width)	2.8” - 7.7”

	Model Prediction	Measured Results	Validates Model?
Weld Structural Test	30lbf	90lbf	**Valid**
CG Test	35lbf	45lbf	**Valid**





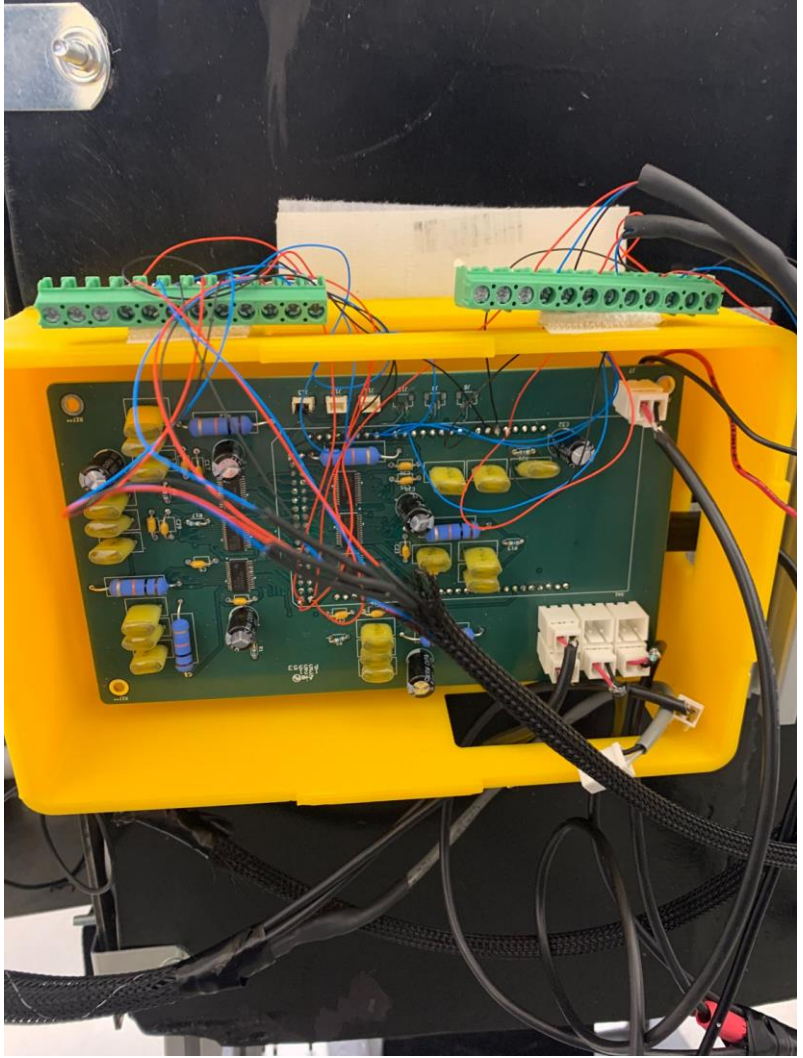


TCS Integrated Test 1 Results

- Conducted last week with a test dummy & was unsuccessful
  - Linear Guides were not secure enough for use & side panels flexed
  - Bonding the load cells to the actuator heads caused shear strain, unideal for theses sensors
  - Load cell connections were unreliable
  - Unstable controls when bad load cell readings occur
  - Power delivery to one actuator failed

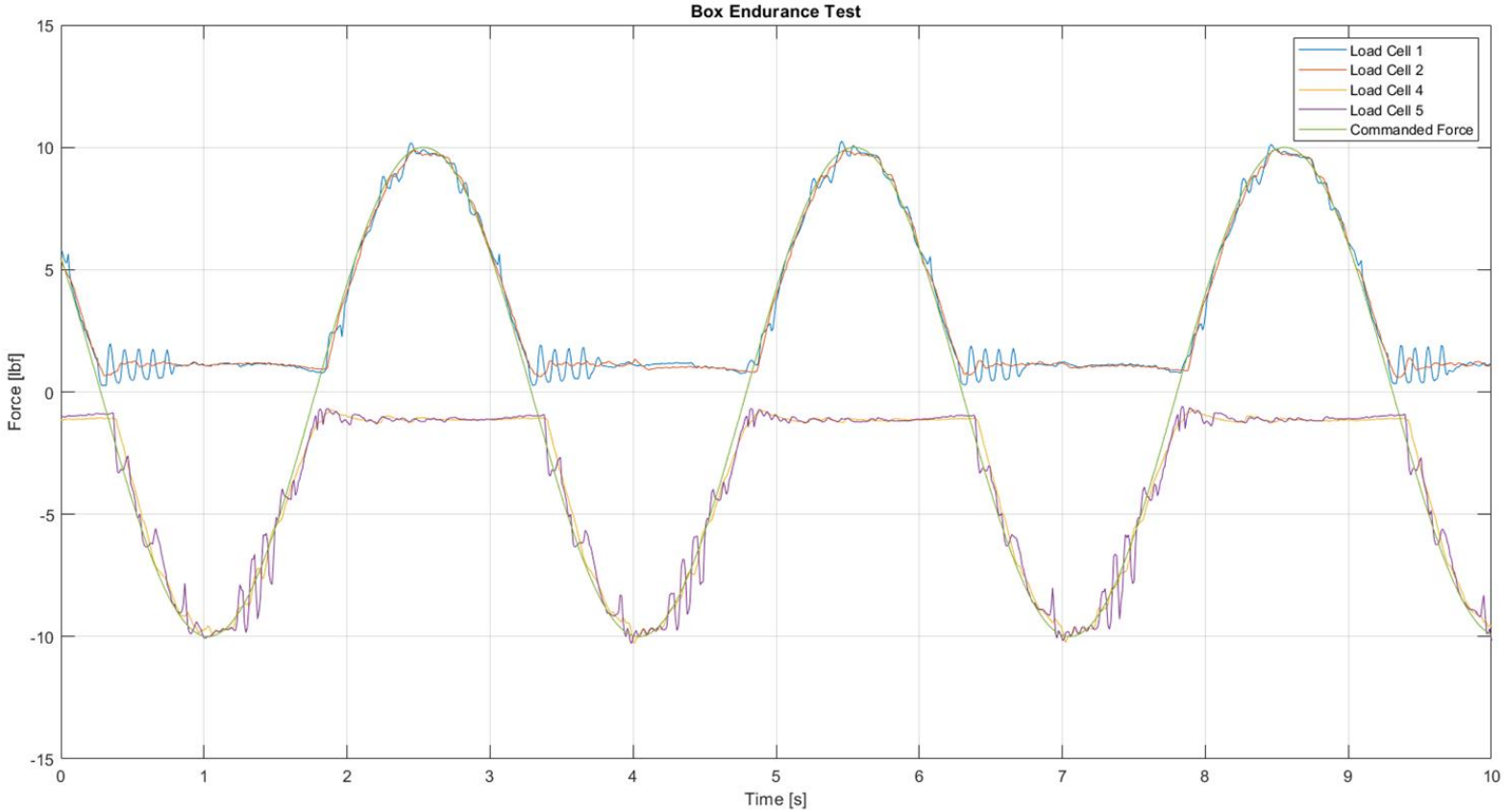
TCS Troubleshooting

- Solutions to Test 1 Issues
  - Created cross bar connections for the linear guides
  - Ordered two new load cells from SparkFun
  - Added a U-Joint bracket to increase rigidity
  - Load cell connections were rewired
  - Set TCS to run with four actuators while power delivery is debugged



TCS Test 2 Results

- Conducted with ideal pressure pad loading



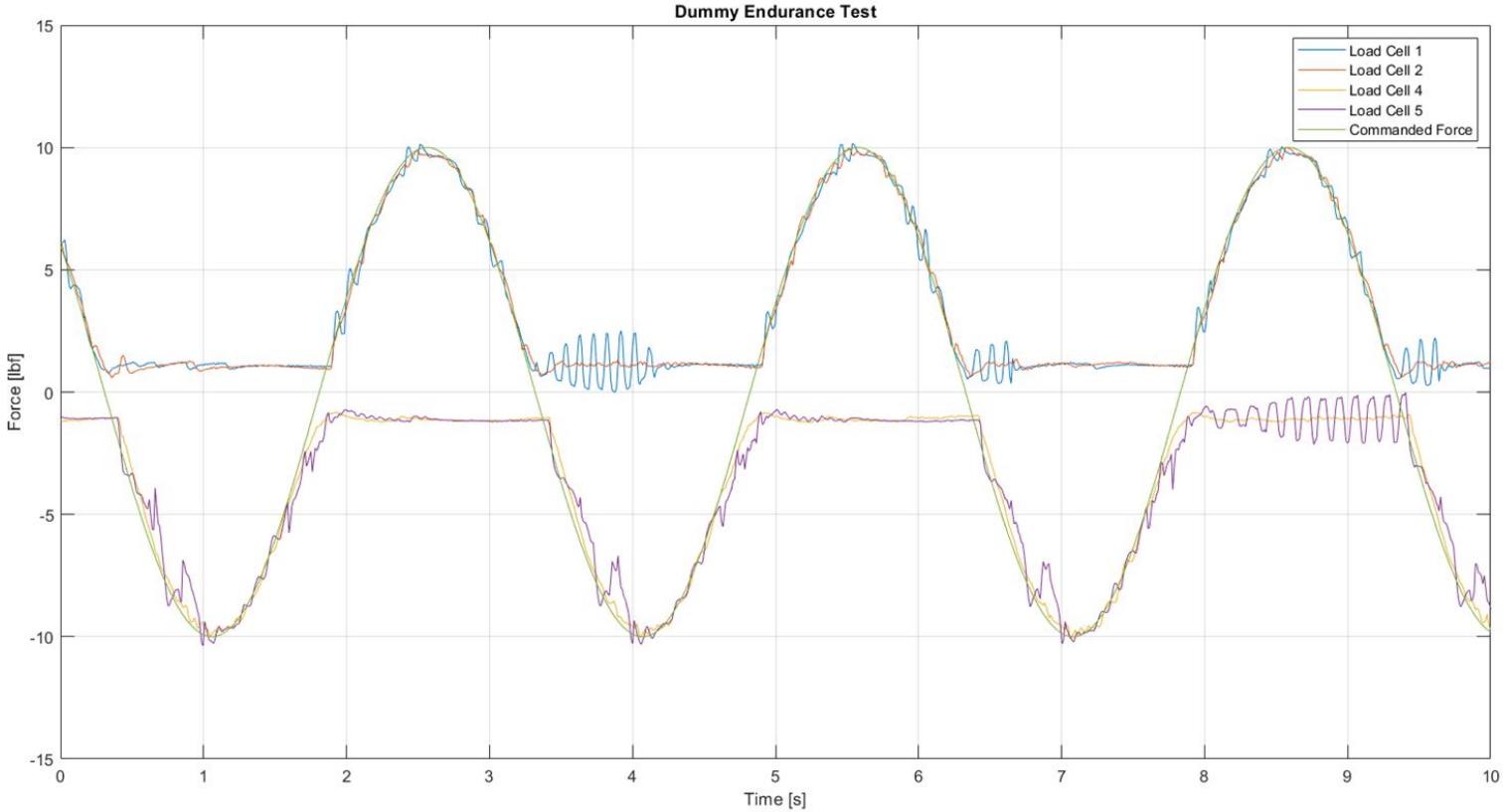
Ideal RMSE - 0.0084 lbf

Avg RMSE - 0.0120 lbf

1.4 times greater than ideal

TCS Test 2 Results

- Same endurance test conducted with a test dummy



Ideal RMSE - 0.0084 lbf

Avg RMSE - 0.0307 lbf

3.7 times greater than ideal

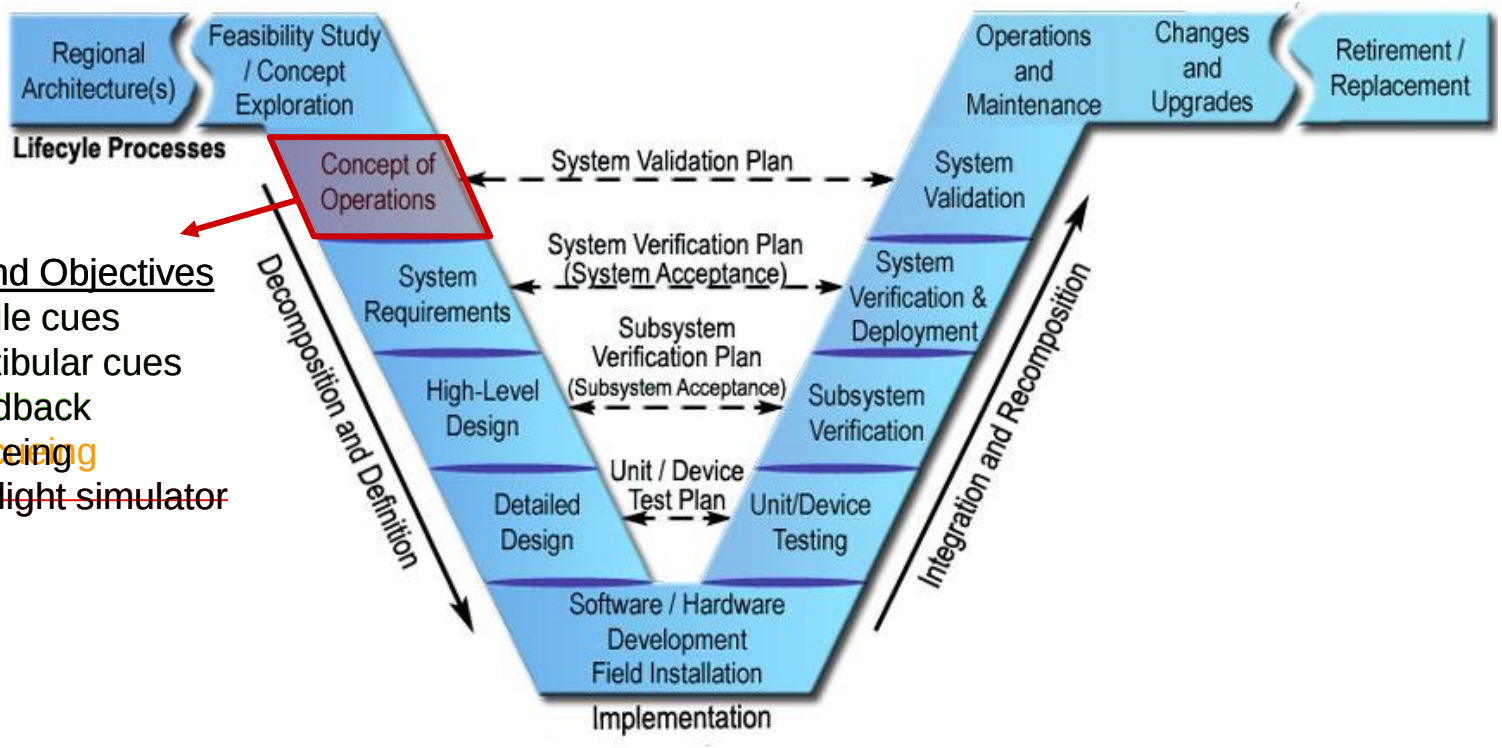
2.6 times bigger than box testing

TCS Subsystem V&V & Future Considerations

- Handshake with CPS successful; further integration testing still needed
    - Profile Test
    - Joystick Integration Test
    - Lag Time Testing
- 5 of 6 Actuators are functional & 4 are operational
- TCS Timeline
    - This week
        - Install new load cells
        - Fix power connection
        - Re-enable bottom two actuators
        - Research the source of load cell noise
        - Run integration tests between CPS & TCS
    - Next week
        - Run TCS in full system integration
        - Capture delay & response times

Systems Engineering

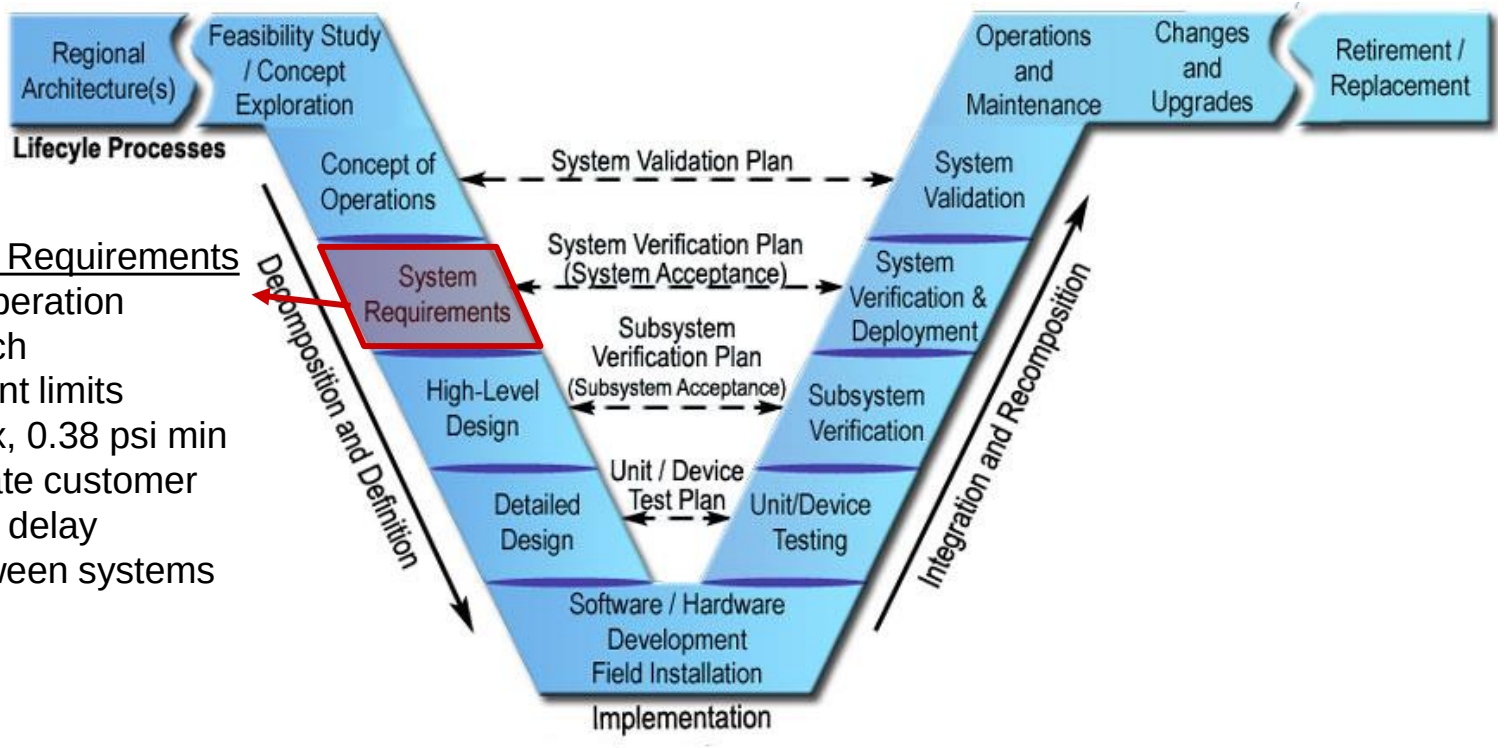
Systems Engineering “V”



ConOps and Objectives

- Provide tactile cues
- Provide vestibular cues
- Joystick feedback
- Multi axis cueing
- ~~Connect to flight simulator~~

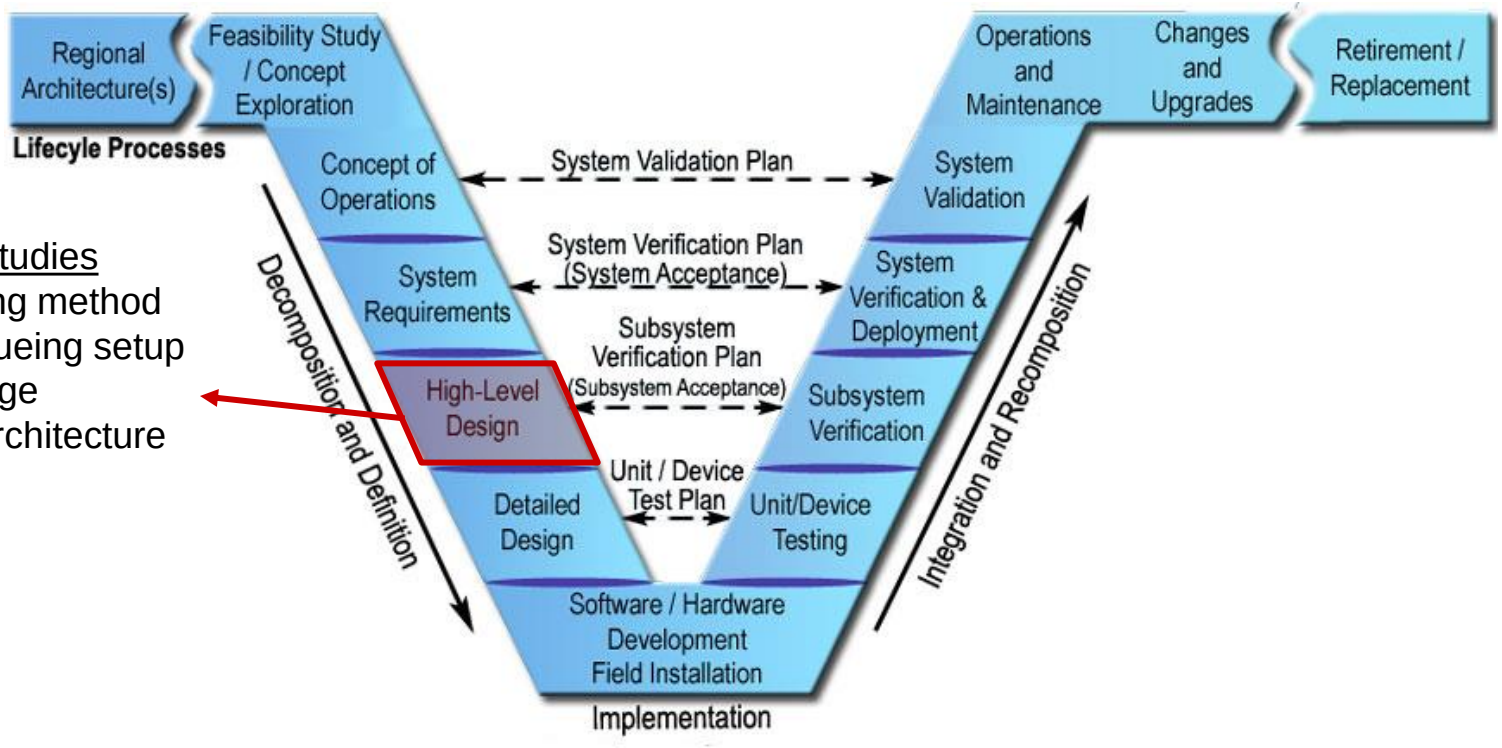
Systems Engineering “V”



Functional Requirements

- 30 minute operation
- Shutoff switch
- ±4 mA current limits
- 3.63 psi max, 0.38 psi min
- Accommodate customer
- 200 ms total delay
- 100 ms between systems

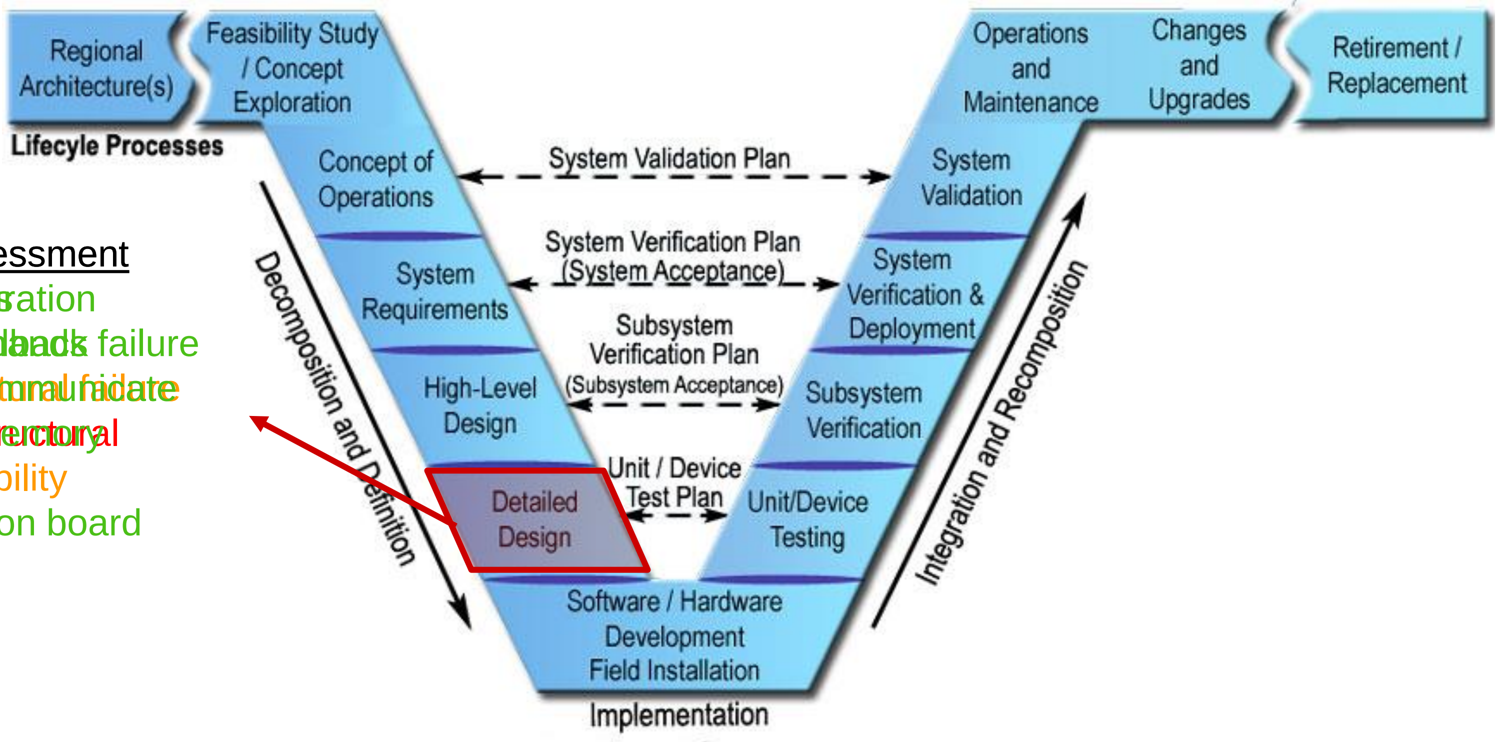
Systems Engineering “V”



Trade Studies

- Tactile cueing method
- Vestibular cueing setup
- CPS language
- Computer architecture

Systems Engineering "V"

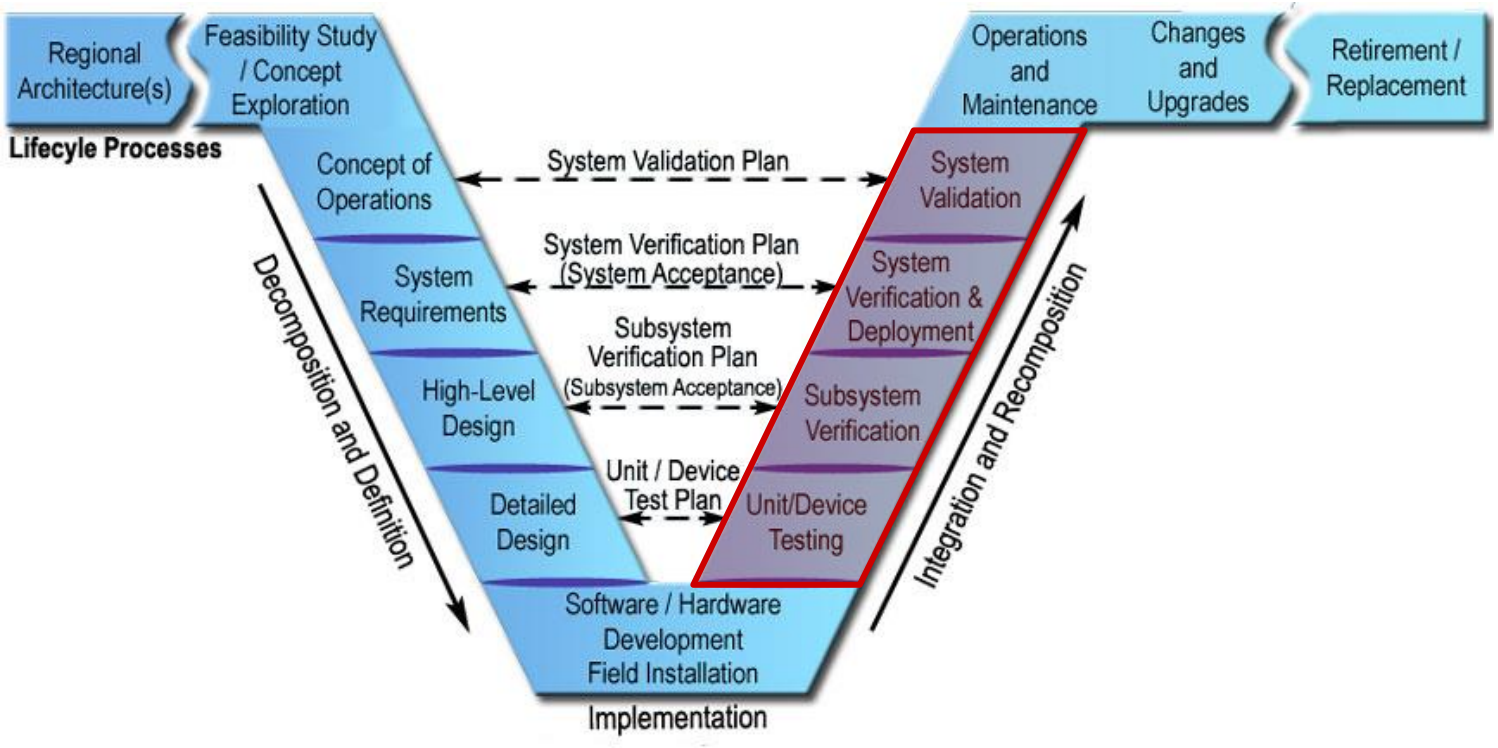


Risk Assessment

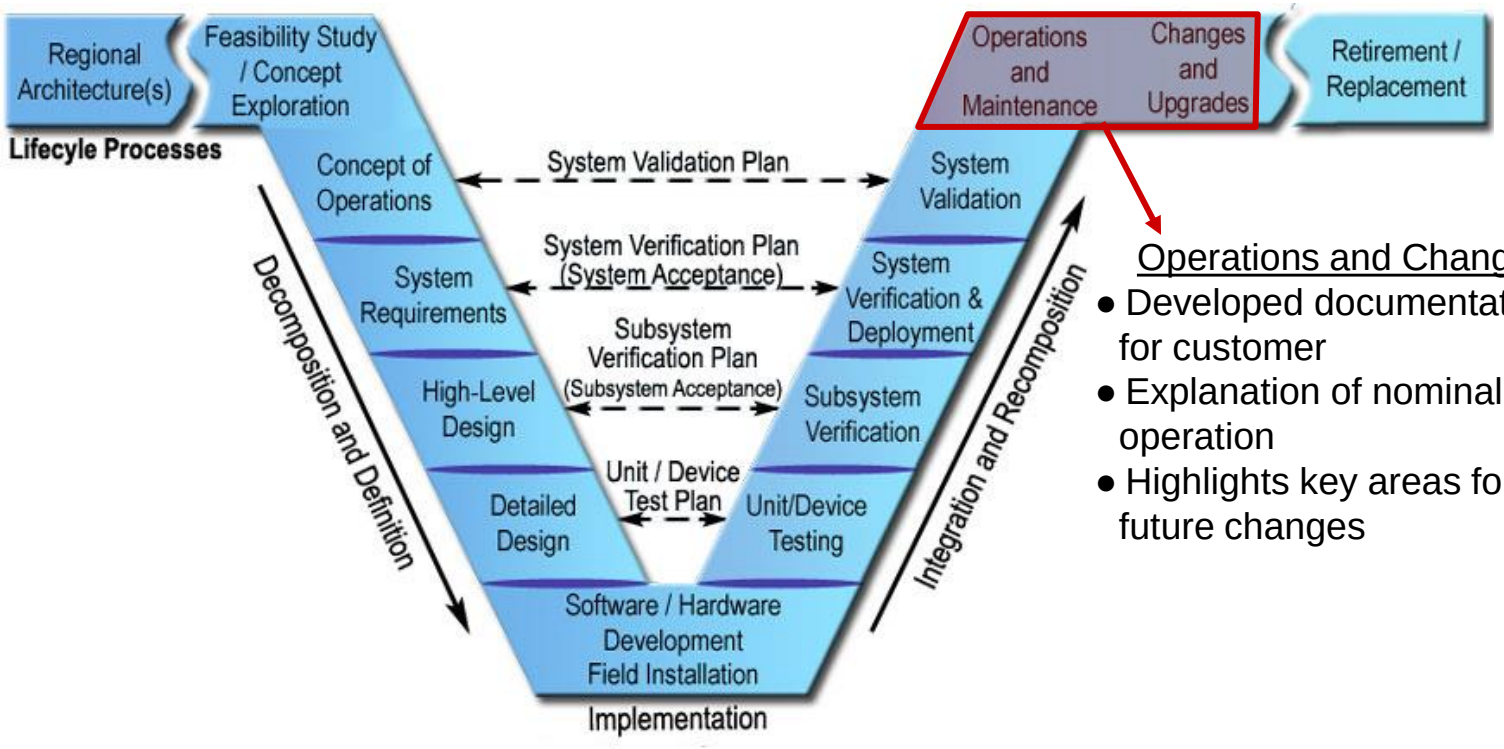
- Actuator Saturation
- Load cell failure
- Primary structural failure
- Secondary structural failure

- High tag rates
- Unsafe feedback
- Inability to communicate
- Overuse of memory
- Lack of portability
- DAC evaluation board

Systems Engineering "V"



Systems Engineering "V"



Operations and Changes

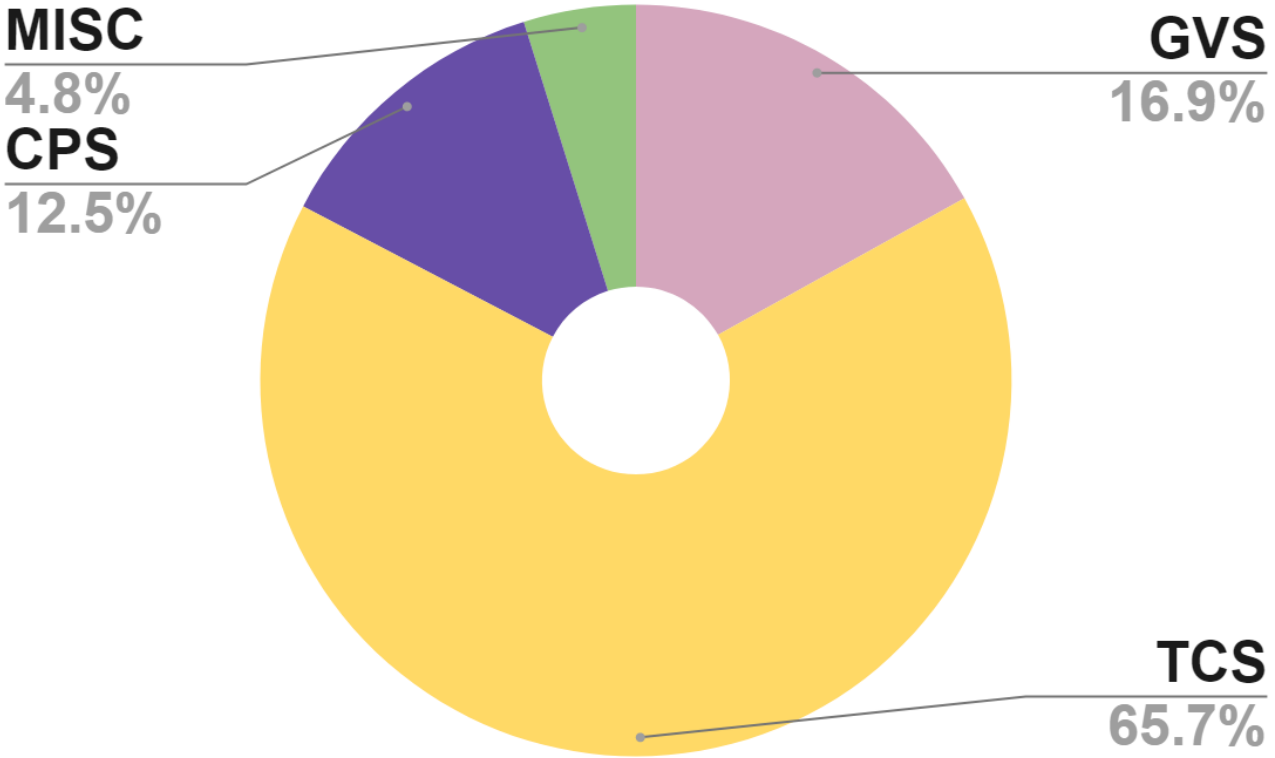
- Developed documentation for customer
- Explanation of nominal operation
- Highlights key areas for future changes

Project Management

Budget Breakdown

Subsystem Breakdown			
Subsystem	**Budget**	**Margin**	**Total Expenses**
Galvanic Vestibular Stimulator (GVS)	$ 775.00	$ 86.11	$ 772.97
Tactile Cueing System (TCS)	$ 2,850.00	$ 316.67	$ 3,000.63
Central Processing System (CPS)	$ 650.00	$ 72.22	$ 570.32
Misc	$ 225.00	$ 25.00	$ 220.50
Total	**$ 4,500.00**	**$ 500.00**	**$ 4,564.42**

Expenses Breakdown

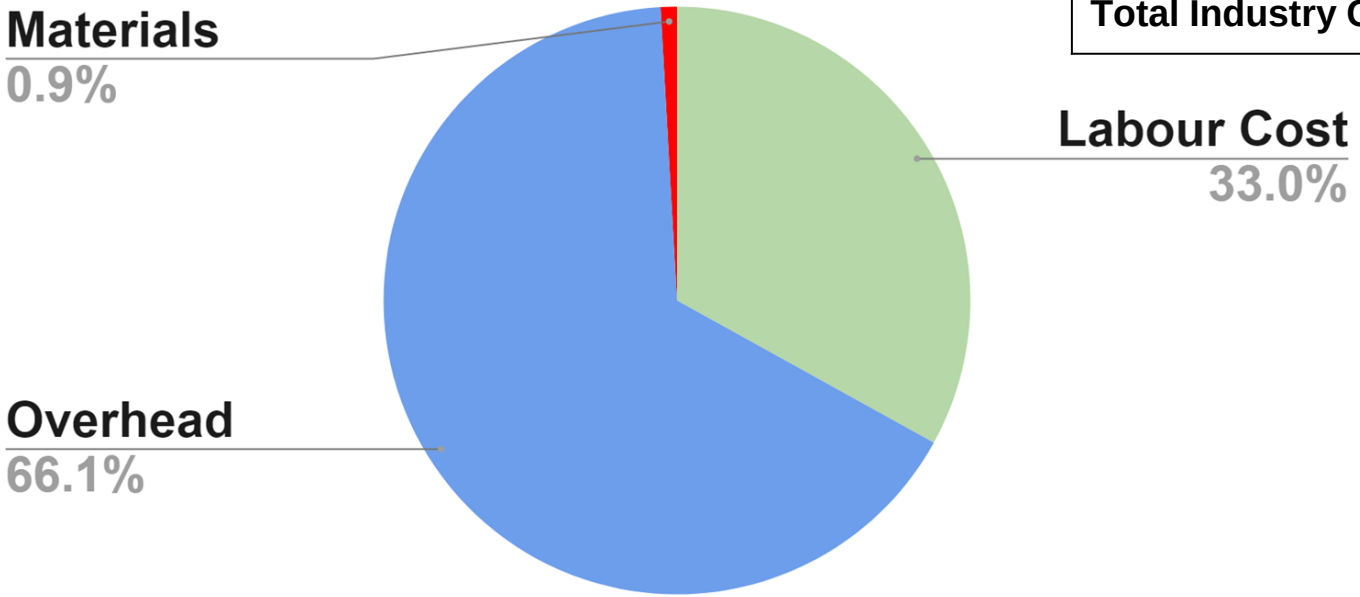


CDR Budget Comparison

CDR/SFR Budget Comparison			
Subsystem	**CDR**	**SFR**	**Difference**
Galvanic Vestibular Stimulator (GVS)	$600	$ 772.97	$ 172.97
Tactile Cueing System (TCS)	$2,500	$ 3,000.63	$ 500.63
Central Processing System (CPS)	$600	$ 570.32	$ (29.68)
Misc	$500	$ 220.50	$ (279.50)
Total	**$4,200**	**$ 4,564.42**	**$ 364.42**

Industry Cost

Direct Labour Cost:	$ 168,000.00
Overhead:	$ 336,000.00
Materials:	$ 4,564.42
Total Industry Cost:	**$ 508,564.42**



Approach & Challenges

- Approach
  - Flexibility was vital
  - Three weekly team meetings & weekly subsystem meetings
  - Weekly advisory meetings & updates to the customer

- Challenges
  - Working remotely & facility restrictions
  - Tracking progress of the three subsystems
  - Difficulty getting parts quickly due to pandemic

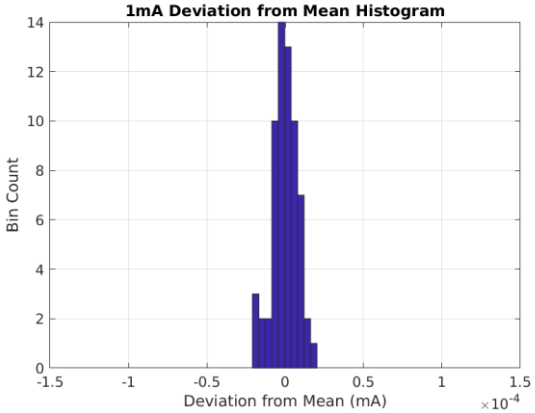
- Takeaways
  - Always plan contingencies
  - Give the team freedom

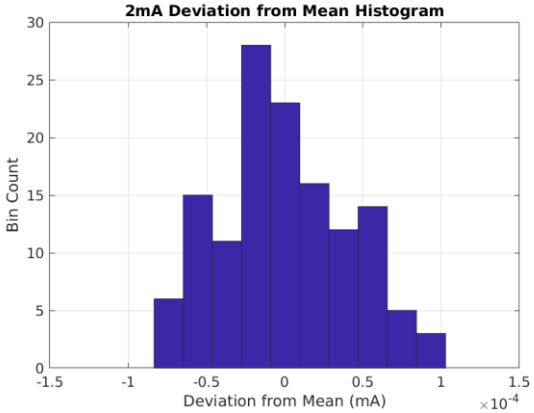
Acknowledgements

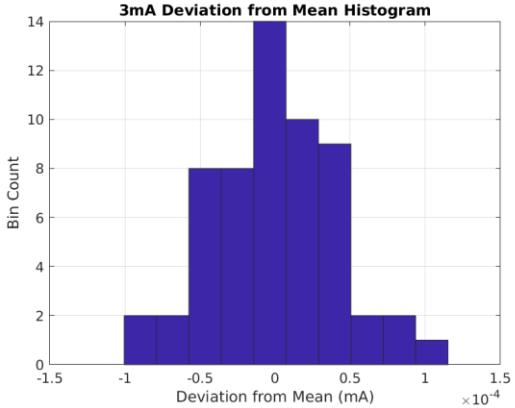
- Customer: Dr. Torin Clark
- Advisor: Dr. Allison Anderson
- Aerospace Professional Advisory Board
- The Machine & Electronics Shop
- PILOT & their staff

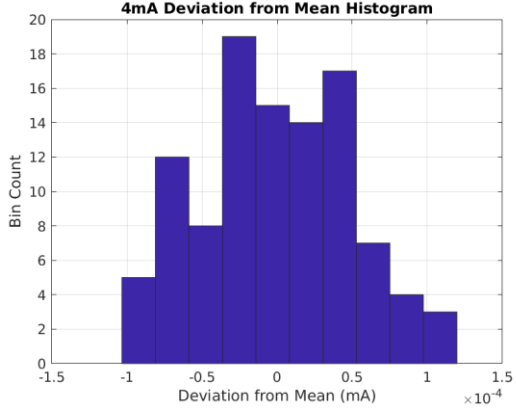
Backup Slides

GVS Accuracy Results

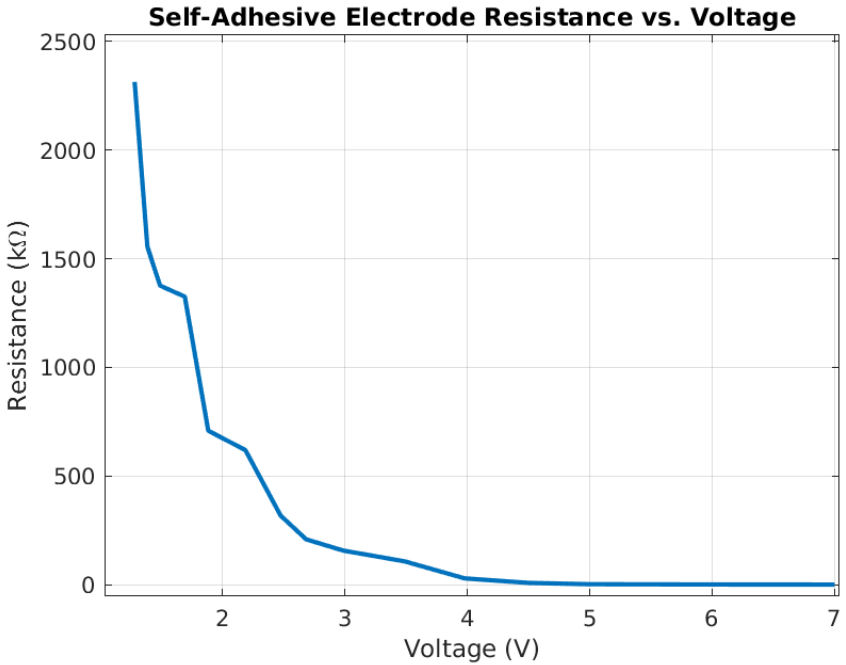








GVS Resistance Challenge

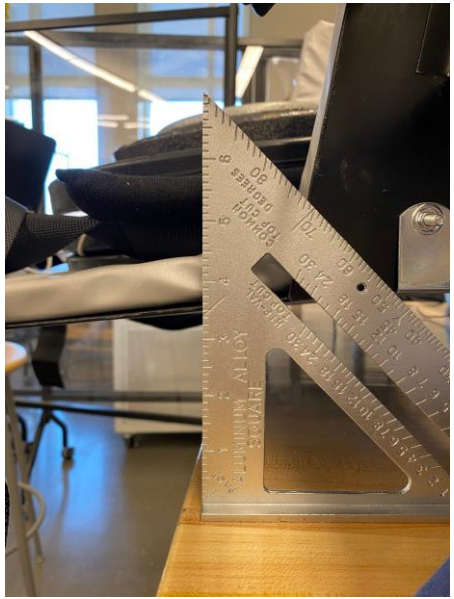


Electrode-Skin interface and Electrode-Metal interface have similar resistance behavior

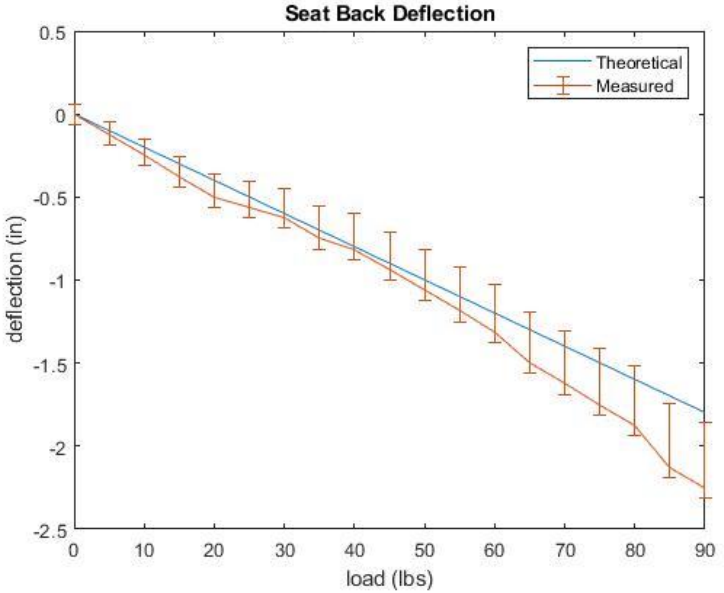
Nonlinearly increases at low voltage

Seat Back Structural Test

Initial Height

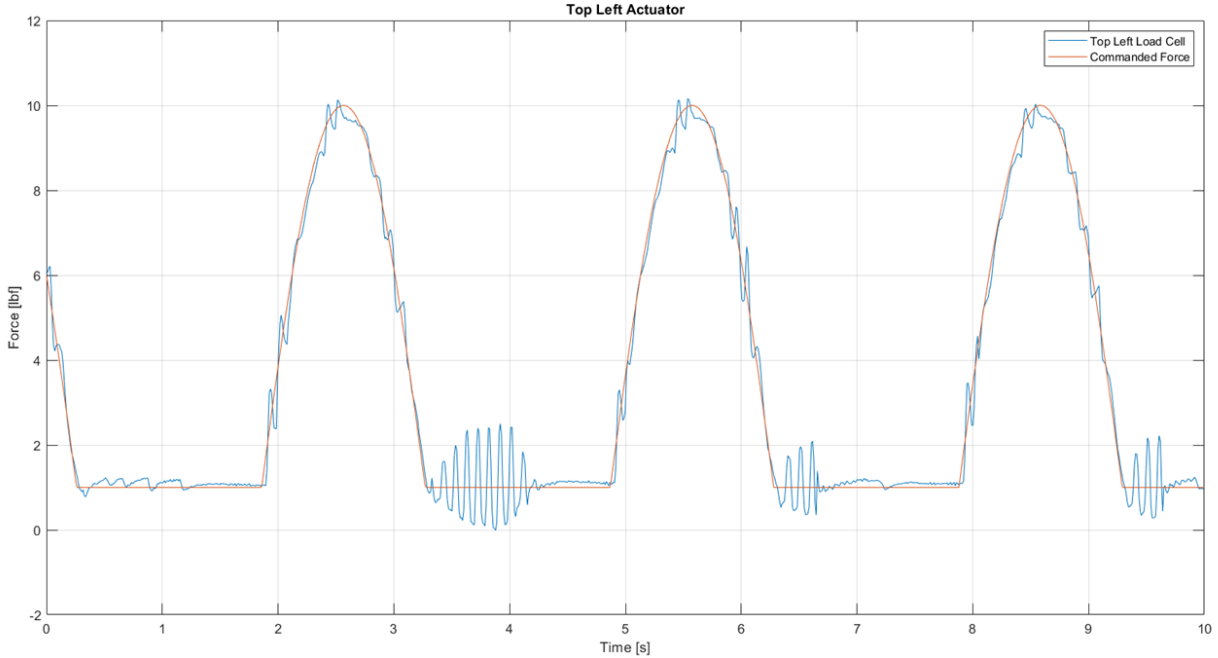


Final Height



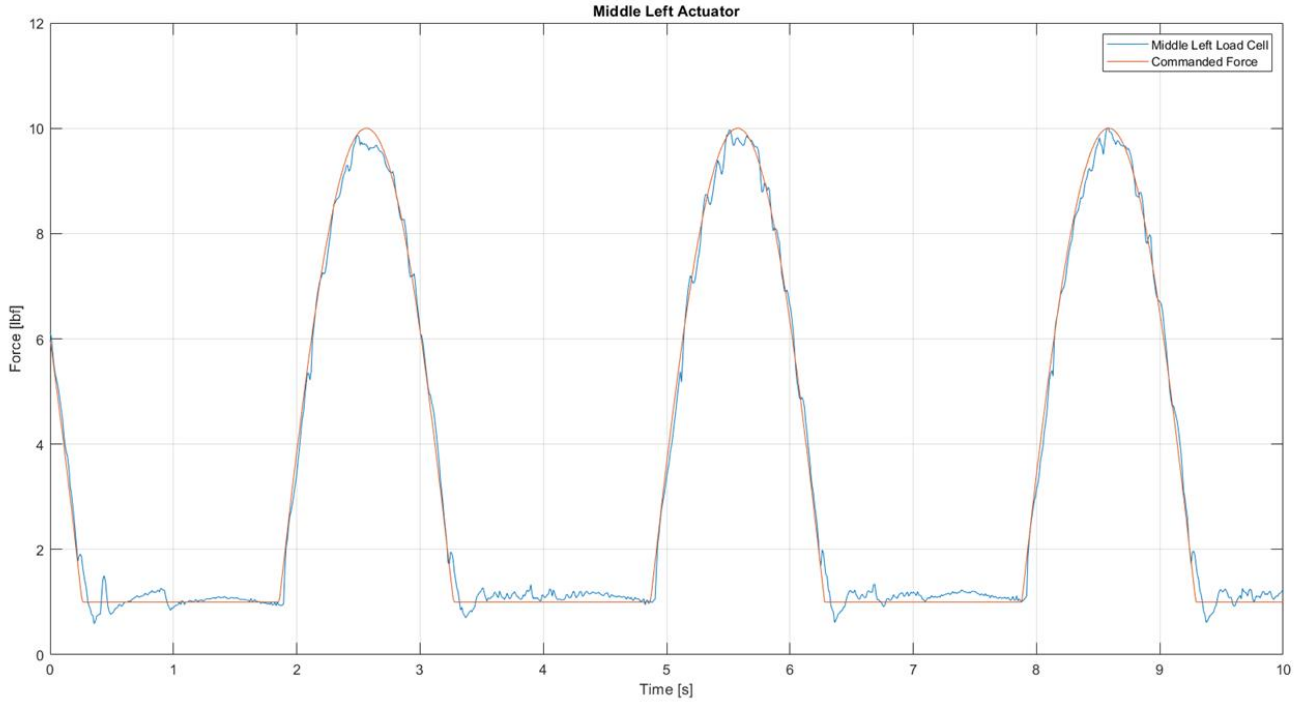
TCS Dummy Test RMSE Top Left Actuator

- RMSE 0.0218 lbf



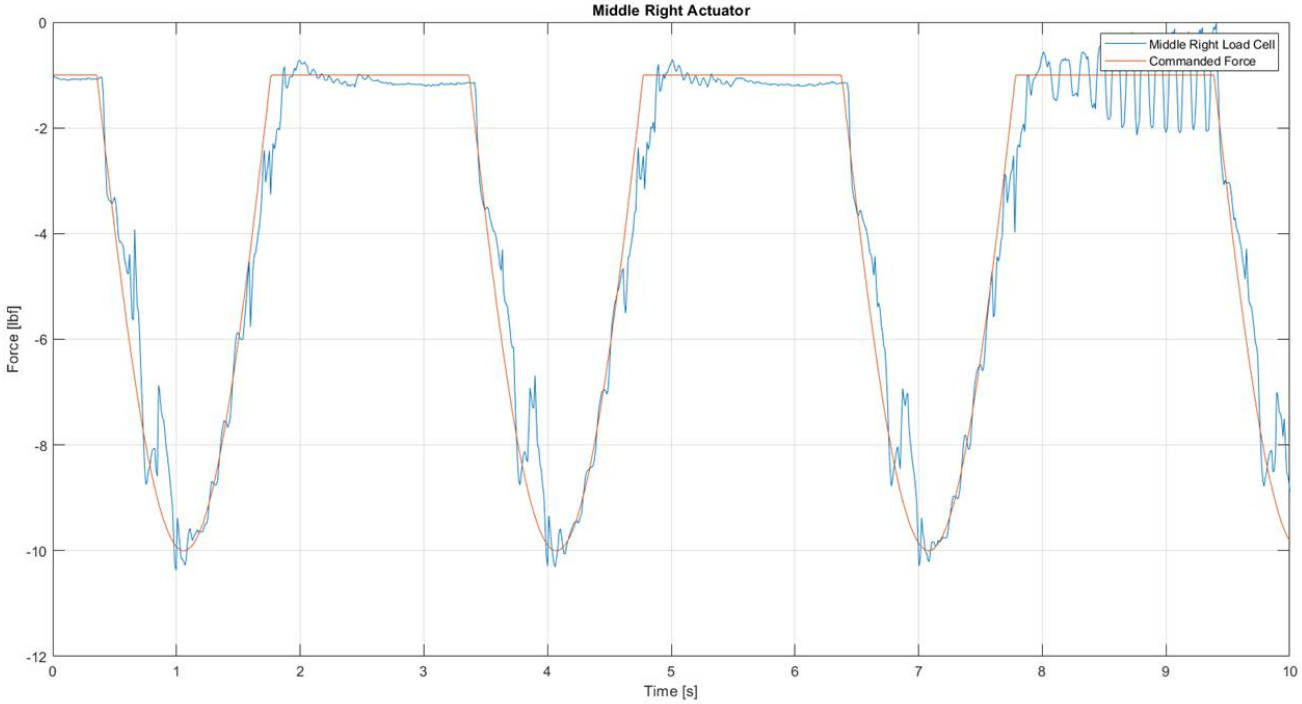
TCS Dummy Test RMSE Middle Left Actuator

- RMSE 0.006 lbf



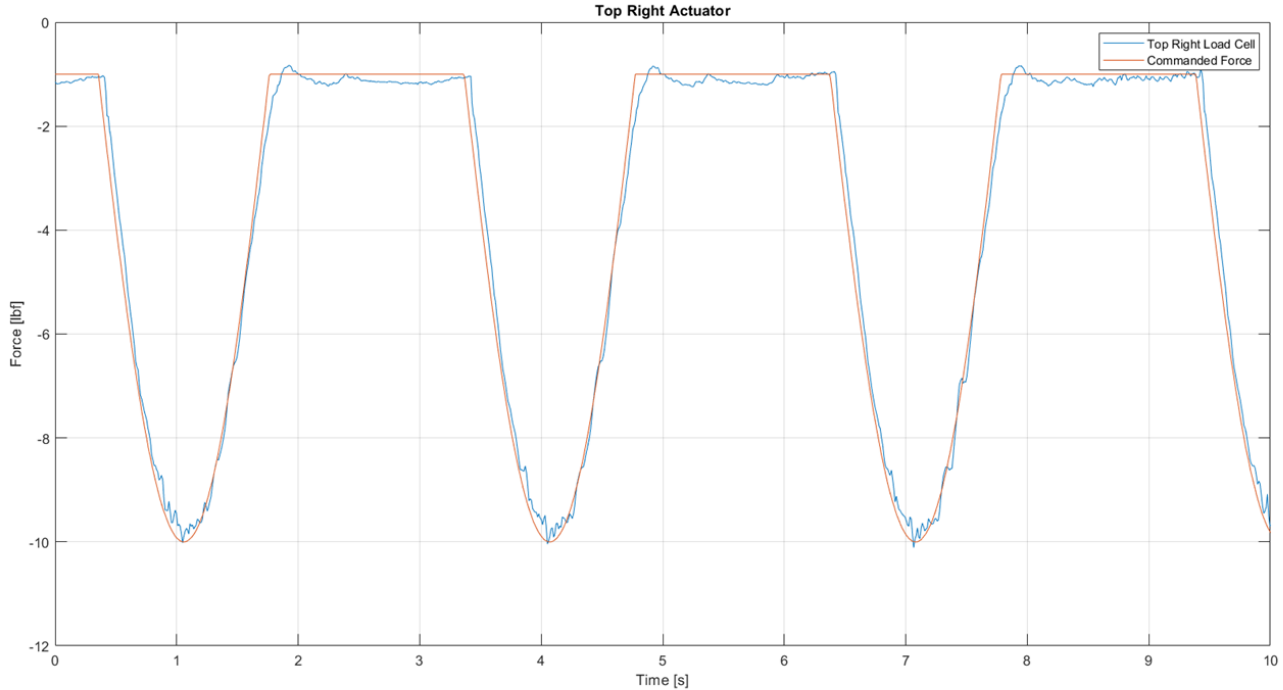
TCS Dummy Test RMSE Middle Right Actuator

- RMSE 0.0314 lbf

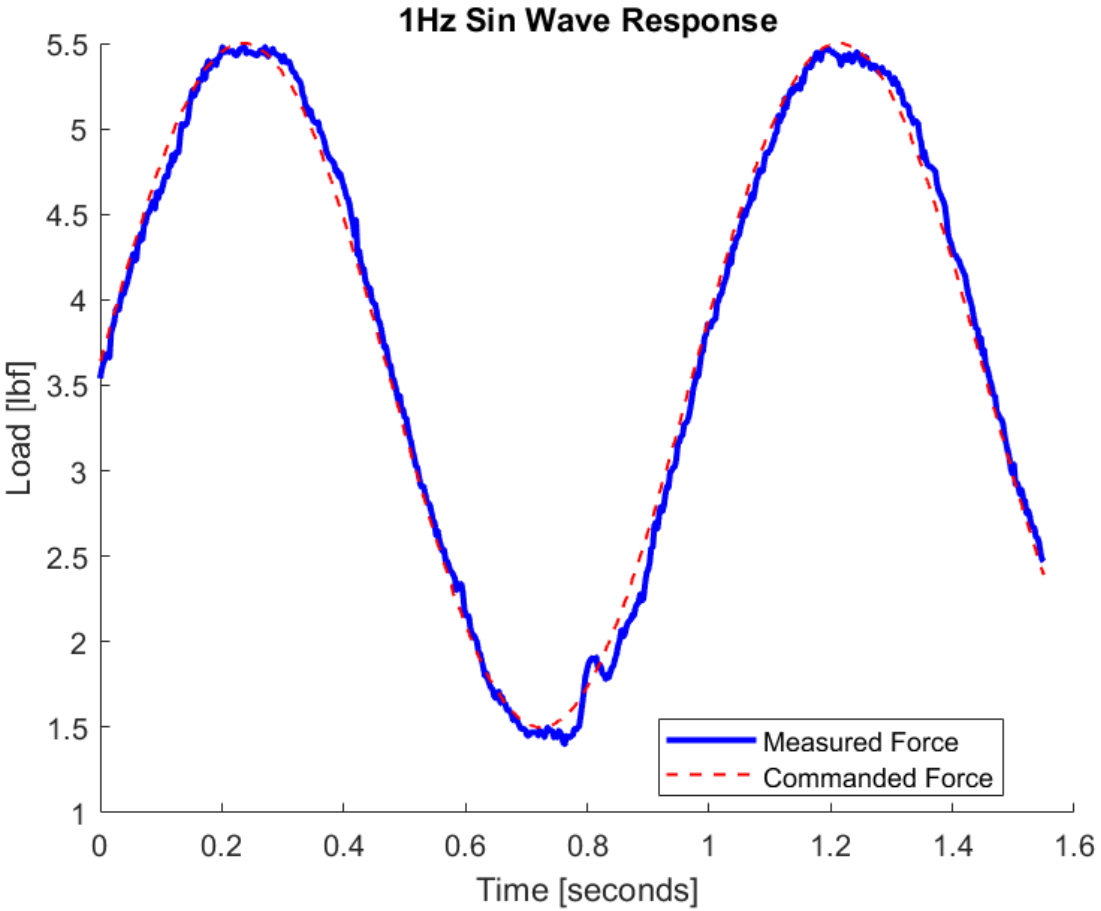


TCS Dummy Test RMSE Top Right Actuator

- RMSE 0.0637 lbf

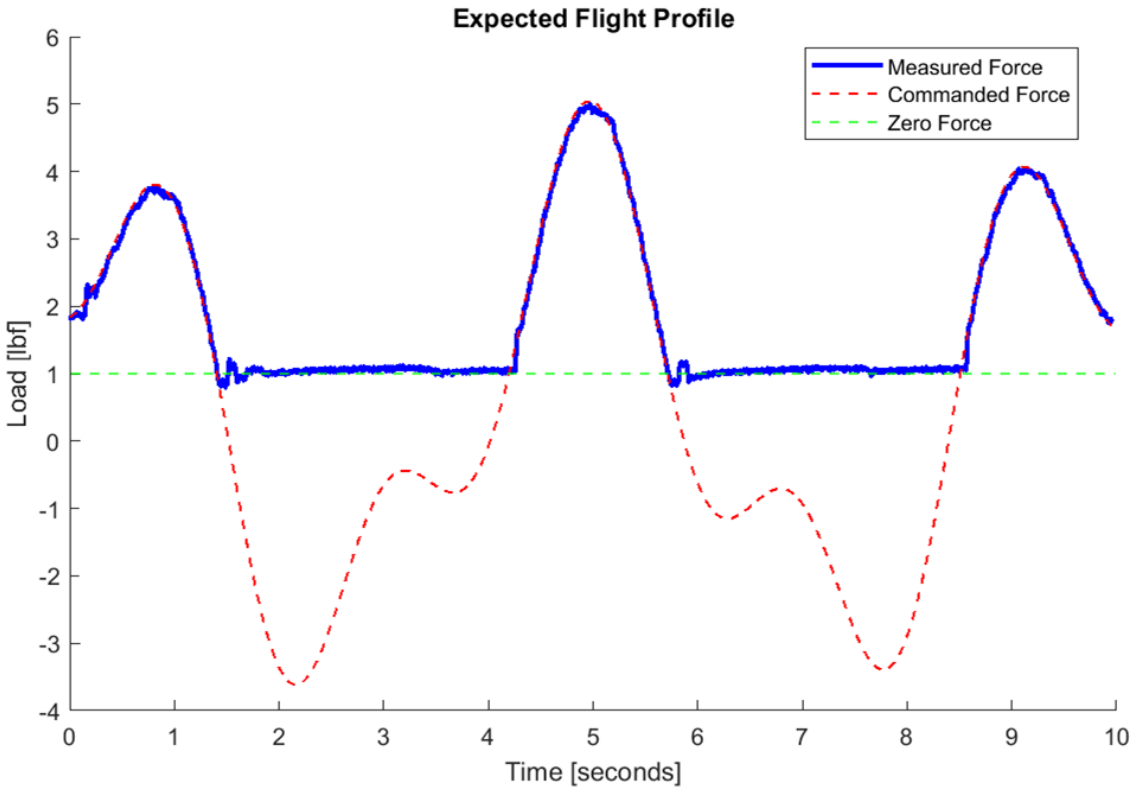


Single Actuator Response - 1HZ Sinusoid



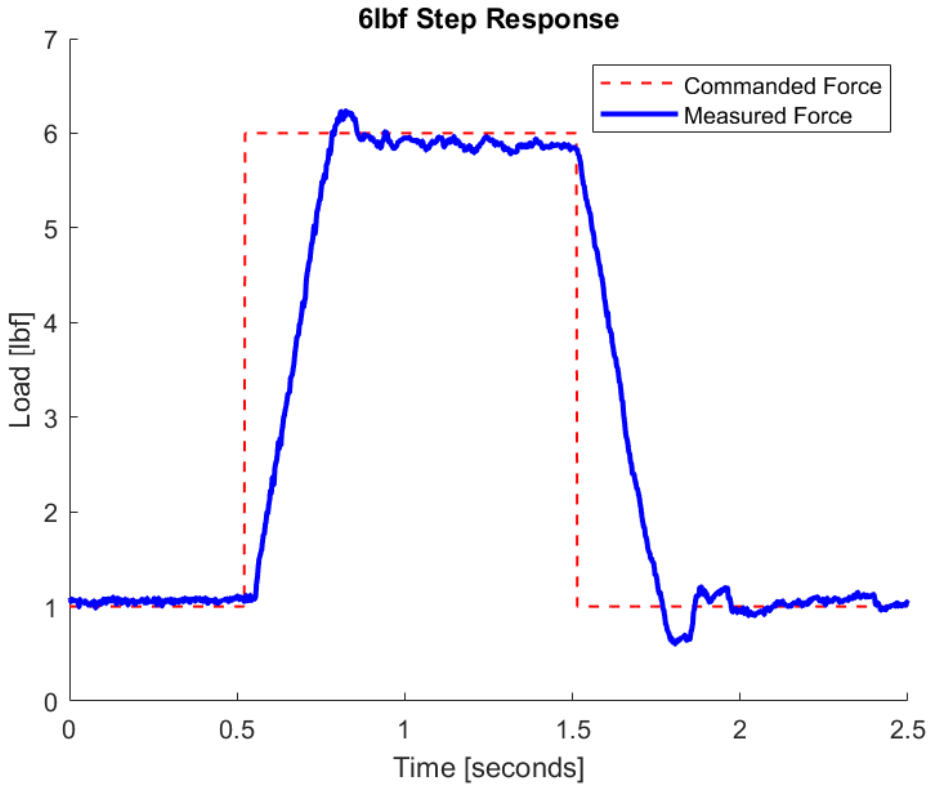
RMS Error: 0.0084 lbf

Single Actuator Response - Expected Profile



RMS Error: 0.0782 lbf

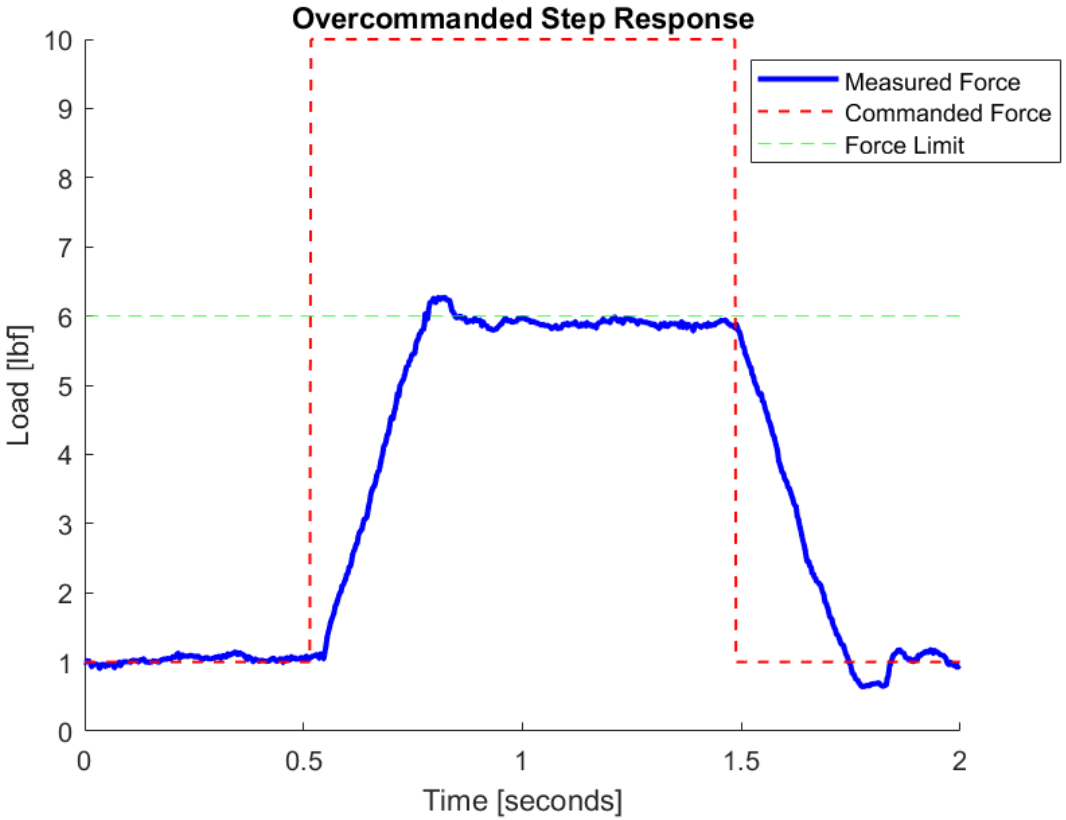
Single Actuator Response - 6 lbf Step



Steady State RMS Error: 0.0531 lbf

Overshoot: 0.24 lbf (4.00%)

Single Actuator Response - Over-commanded Step



Steady State RMS Error: 0.1134 lbf

Overshoot: 0.28 lbf (4.67 %)

Central Processing System Testing

CPS	
CPS Command	Complete
CPS to GVS Comms	Planned
CPS to GVS Command	Planned
Sync Delay	**Planned**
Test Subject Button	In progress

Rationale: Ensure synergy between GVS cue, and TCS cue. Motivated by DR 3.3. (<100ms))

Procedure: Quantify time from signal command to actuation for both GVS and TCS.

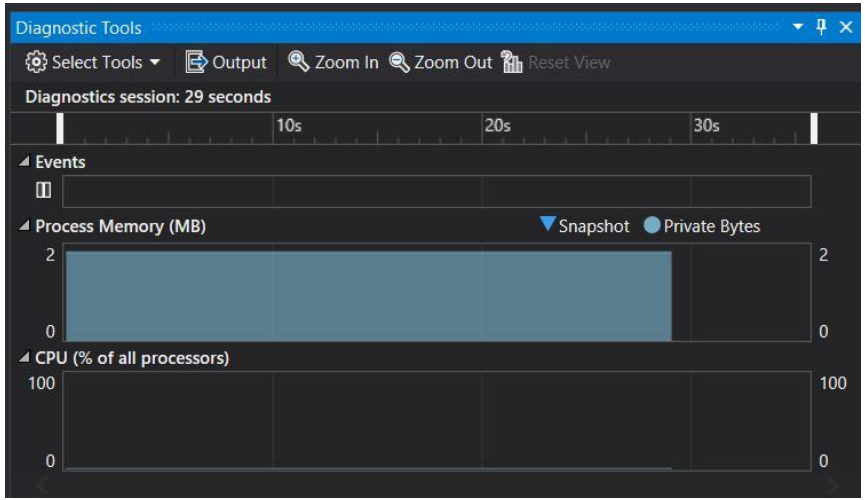
1. Commands at a determined period will be sent to GVS/TCS via the CPS.
2. The output waveform is phase shifted at the GVS/TCS and will be measured with an oscilloscope.
3. The delta between these two phases will be the ‘delay’ time.

Risk Reduction: Prevents possible disorientation Test subject.

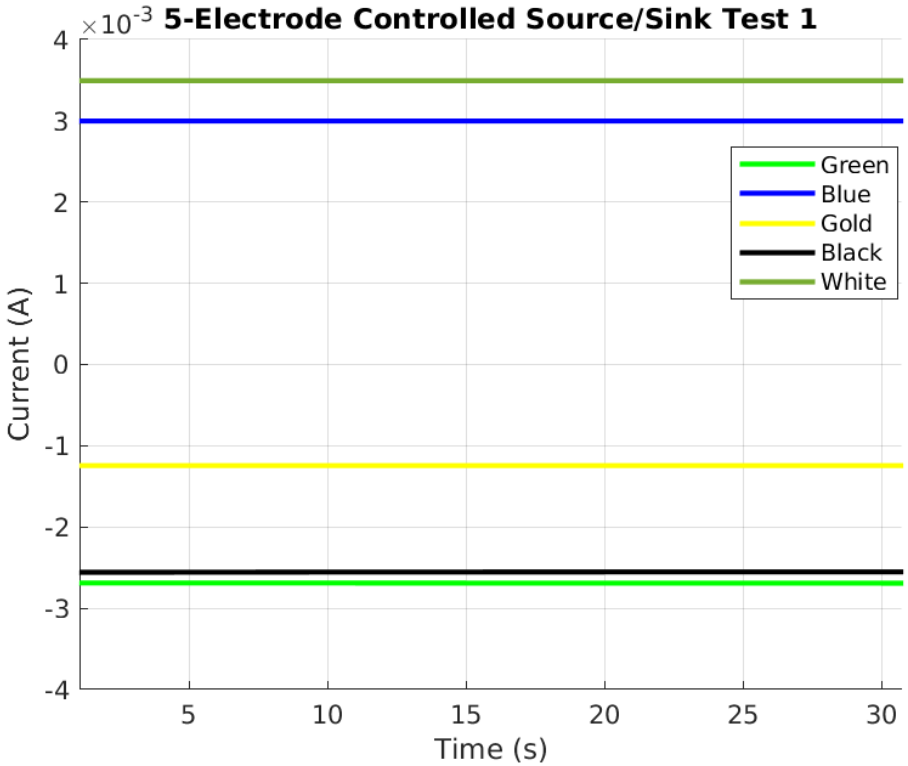
Equipment: Laptop, TCS Arduino, GVS PIC, associated cables. .
Expected Results: Delay between GVS and TCS is <100ms.

CPS Performance Metrics

- Maximum memory usage of ~3MB (Joystick and GVS combined)
- Maximum % CPU use of <1%
- 1ms response to stop commands from either operator or joystick (less if we define a smaller timestep)
- Windows compatible only (DirectInput), but confirmed to work on multiple laptop devices



GVS 5-Electrode Results



- Initial results confirm the ability of our circuit to control sinking for each electrode for a conducting pipe model
- More error involved, tuning will be required to validate model