WASP Spring Final Review

April 27, 2021

ASEN 4028-011 Team 9

Company Customer:
Sierra Nevada Corporation (SNC)

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Presentation Outline

1. Project Purpose & Objectives
2. Design Description
3. Test Overview
4. Test Results
5. Systems Engineering
6. Project Management

Project Purpose & Objectives

Project Overview

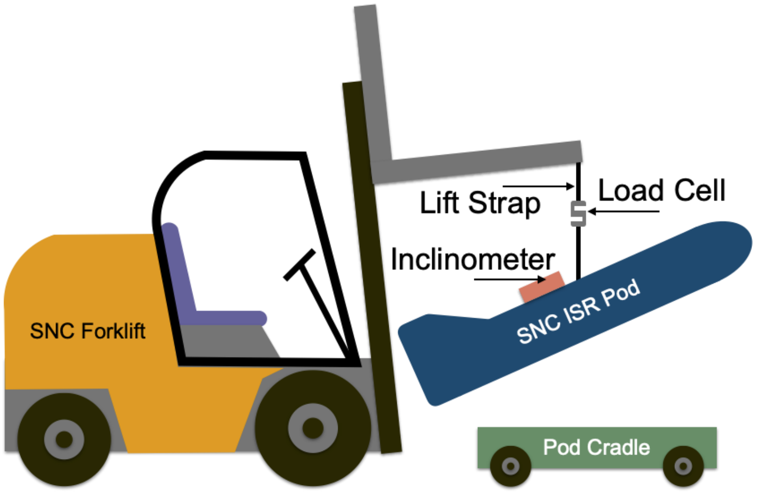
Background:

- **Sierra Nevada Corporation's ISR, Aviation, and Security (SNC IAS) division** needs a better way of **measuring the weight and CG** of their Intelligence, Surveillance, and Reconnaissance (ISR) pods.

Motivation:

- **Effective:** Current method of finding weight and CG is challenging.
- **Safety:** ISR Pods and Engineers are at risk with current method.

SNC's Current Method



Primary Project Objectives

1. Measure the **weight** and **CG location** of SNC ISR Pods to an accuracy of **±0.1%** and **±0.1 inch**, respectively.
2. Be able to use WASP for pods weighing up to **2000 lbs**.
3. Be able to accomodate pods with **14-inch** and **30-inch** lug spacing configurations.
4. Develop a measurement procedure for WASP that is feasible for SNC test engineers (**30-minute** test duration, **2 engineers**)

Level of Success

Project Elements	*Level 1*	*Level 2*	*Level 3*
Structural Integrity	Support 1000 lbs with FOS of 2.0	Support 2000 lbs with FOS of 2.0	
Mounting and Interfacing	Connect to 14” and 30” pod lug configurations		Modular Capabilities to connect future pod lug configurations
Measurement Accuracy	Measure weight within ±0.1% and X CG and Z CG locations within ±0.1"	Measure weight within ±0.1% and X CG, Y CG, and Z CG locations within ±0.1"	
User Interface	Measurement tool will output data to be manually entered into the software tool to perform calculations	Measurement tool will autonomously input data to the software tool to perform calculations.	The measurement tool will autonomously collect and analyze data and export results to an Excel-compatible file.
	The software tool will deliver the weight, X CG, and Z CG values averaged over at least 2 and up to 5 measurement sets	The software tool will deliver the weight, X CG, Y CG, and Z CG values averaged over at least 2 and up to 5 measurement sets	The software tool will deliver the weight, X CG, Y CG, and Z CG values averaged over more than 5 measurement sets
Test Operation	Test completed by 3 engineers	Test completed by 2 engineers	
	Test completed in 1 hour	Test completed in 0.5 hours	
	Test engineers will be able to successfully perform test with guide of engineer familiar to tool	Test engineers will be able to successfully perform test by following test procedure	
Transportation	Tool is maneuverable by 3 team members	Tool is maneuverable by 2 team members	

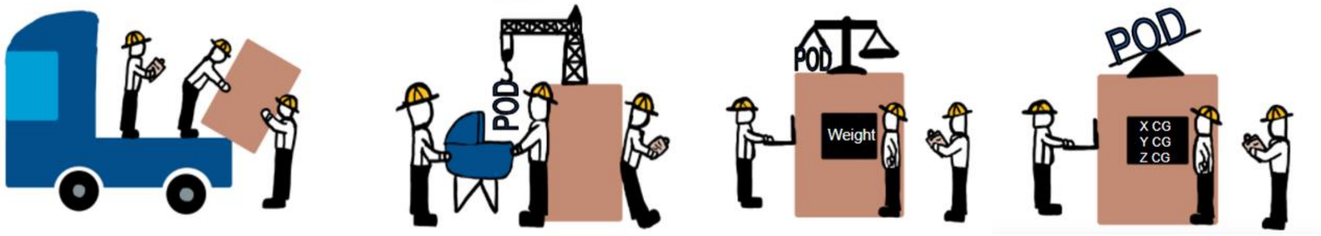
Concept of Operations

Transportation & Maneuverability

1) Pod mounted to WASP and lifted from cradle

2) WASP weighs pod, records measurements

3) WASP tilts pod, records measurements



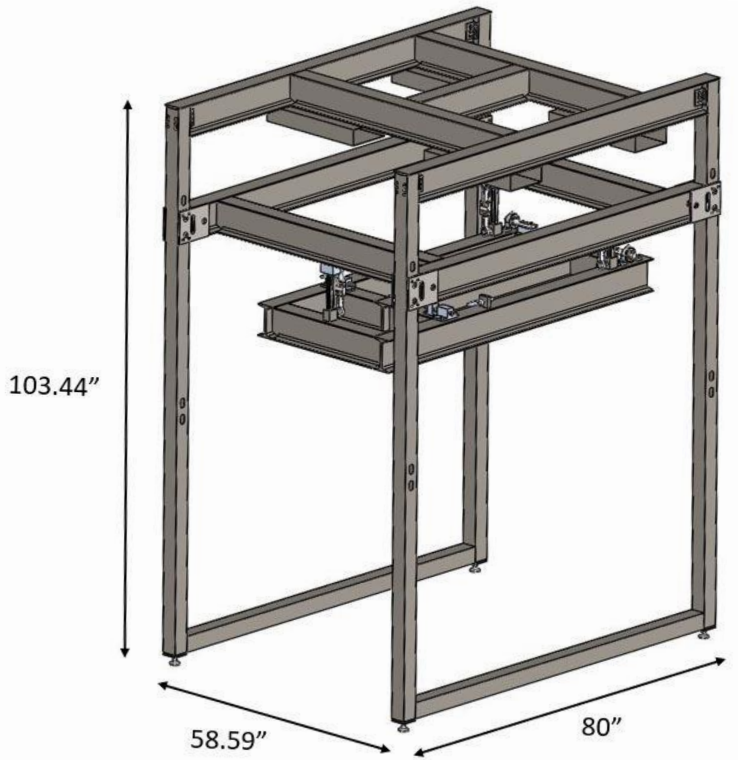
4) WASP returns pod to flat configuration

5) GUI computes total weight, CG

6) Pod lowered into cradle

Design Description

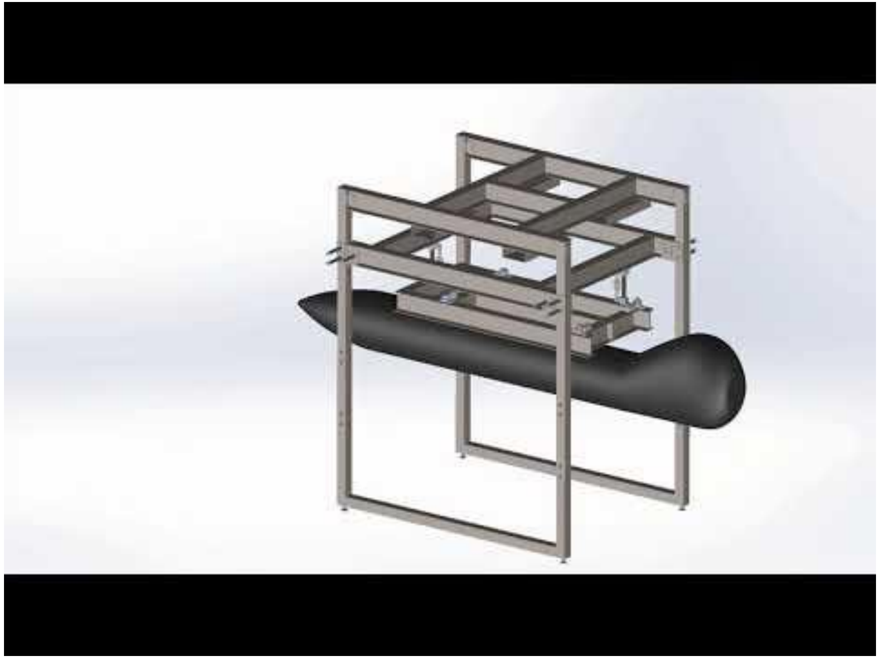
Baseline Design



- Estimated to weigh **1532 pounds**
- Primarily **A36 Carbon Steel** for desired strength

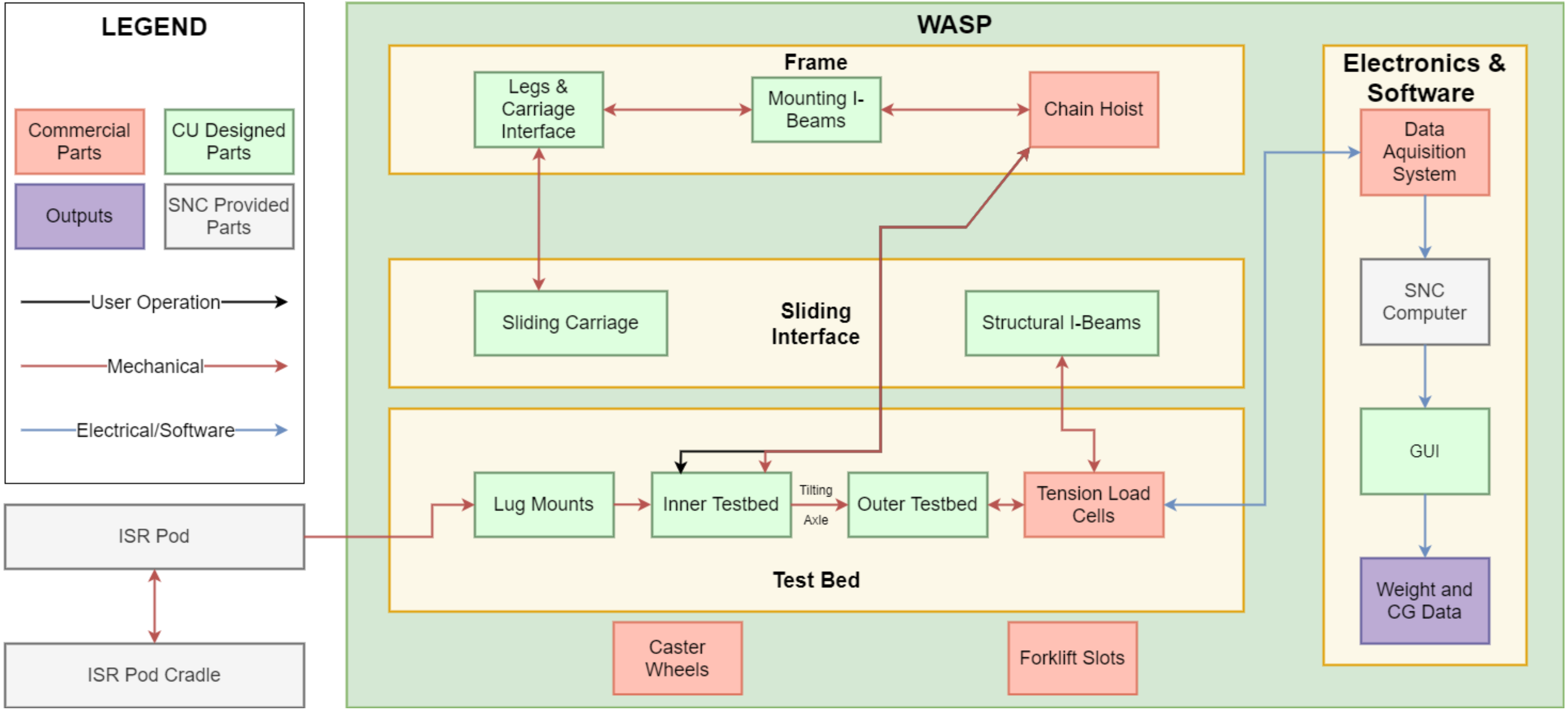
Test Procedure

Timelapse of Test Procedure

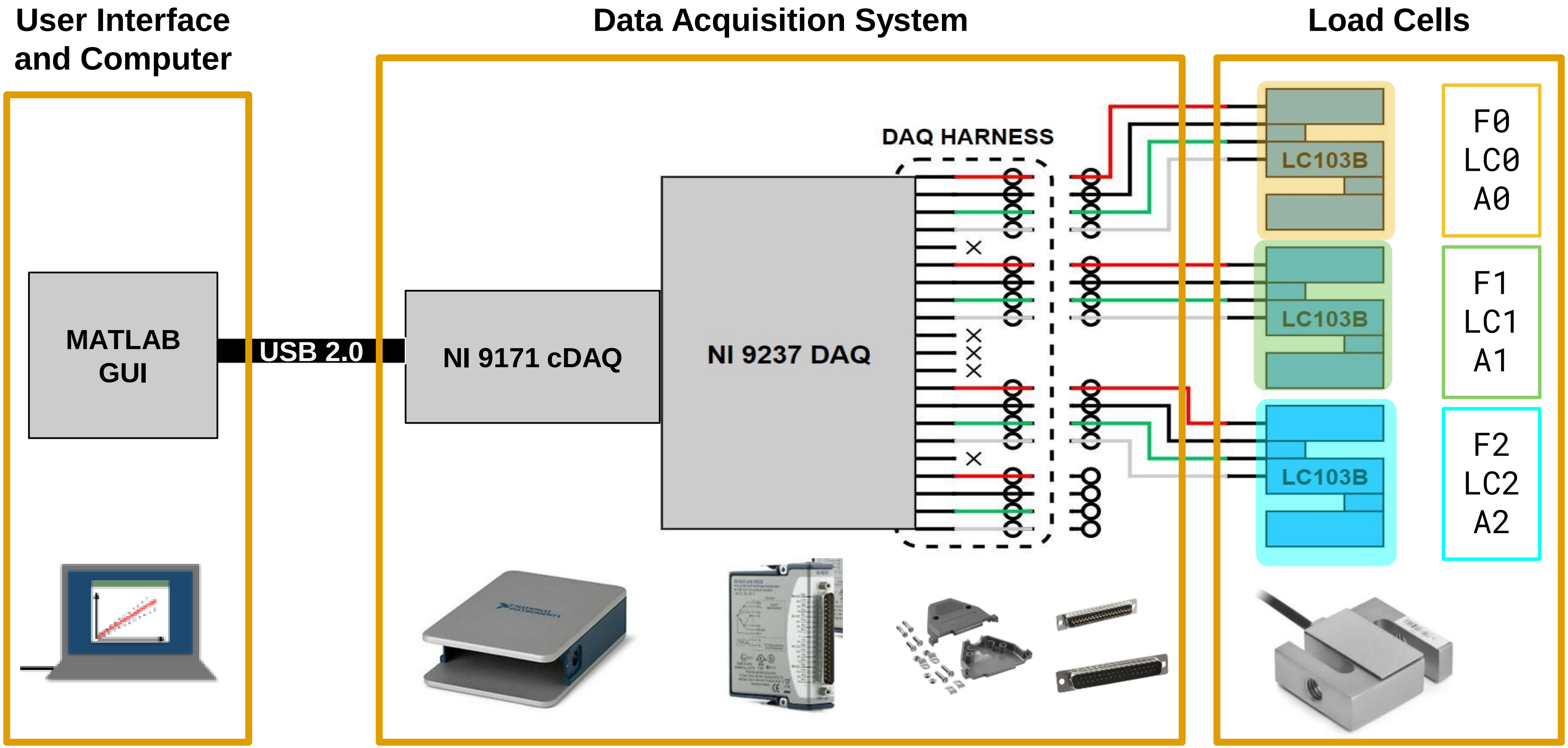


Animation of Measurement Procedure

Functional Block Diagram

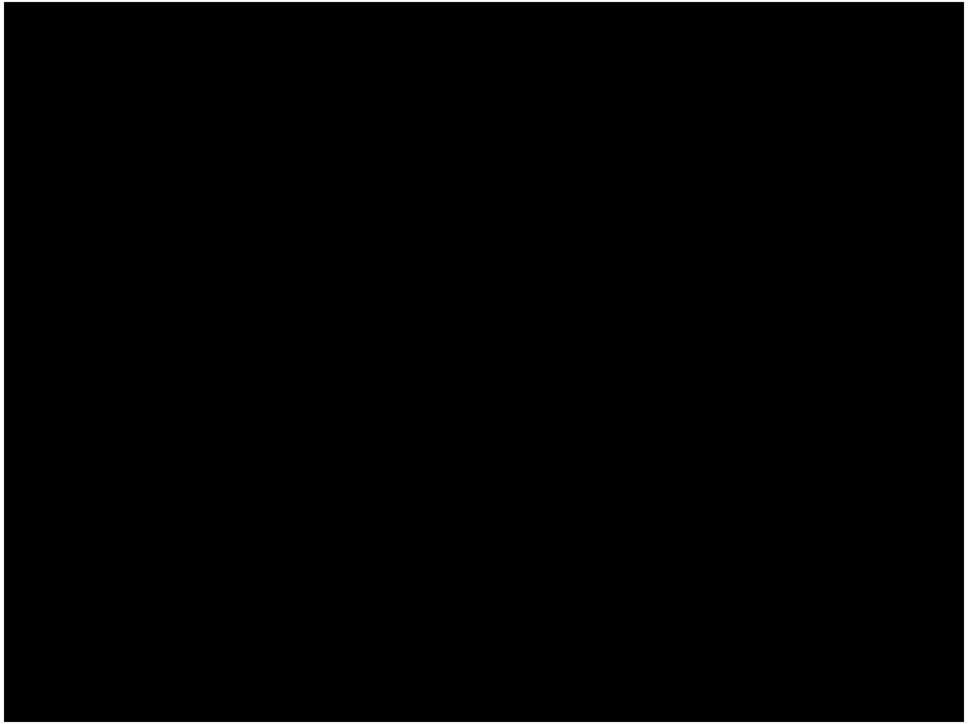


Electronics

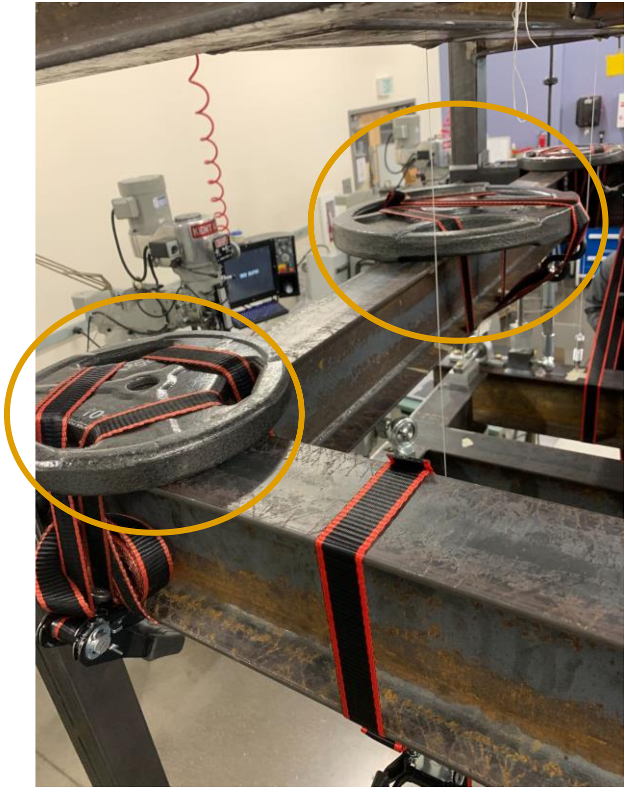


User Interface

1. **Test Details**
2. **Tare Load Cells**
3. **Take/Add Measurement**
4. **Enable/Disable Measurements**
5. **Export .csv files**



Updates Since TRR



Ballast implemented to counteract jamming of sliding interface

Testbed **alignment method** leads to more repeatable CG measurements

Caster wheels added for maneuverability

Test Overview

Testing Scope - Overview

Level	Test	Model/Process Validated	Equipment/Facilities Used
Component	**Lug Mount Tensile**	FEM Model	Modified Lug Mount, EM MTS
	Load Cell Characterization	Monte Carlo Simulation	WASP Load Cells + DAQ System, EM MTS
	Component Checks	N/A	None
Sub-System	**E&S Functionality**	Software Flowchart	WASP DAQ System
	Structural Integrity	FEM Model	Weight, Strain Gauges, WASP DAQ System, AES Forklift
System	**Measurement Accuracy**	Monte Carlo Simulation	SNC Test Article
	System Accreditation	CONOPS	SNC Test Article, Volunteer Engineers

Testing Scope - Project Objectives

Project Objective	*Highest Success Level Criteria*	*Test*
Structural Integrity	Support 2000 lbs with FOS of 2.0	Lug Mount Tensile Test, Structural Integrity Test
Mounting and Interfacing	Modular Capabilities to connect future pod lug configurations	Lug Mount Tensile Test
Measurement Accuracy	Measure weight within ±0.1% and X CG, Y CG, and Z CG locations within ±0.1"	Load Cell Characterization, Measurement Accuracy Test
User Interface	The measurement tool will autonomously collect and analyze data and export results to an Excel-compatible file.	Electronics and Software Functionality Test
	The software tool will deliver the weight, X CG, Y CG, and Z CG values averaged over more than 5 measurement sets	
Test Operation	Test completed by 2 engineers	System Accreditation
	Test completed in 0.5 hours	
	Test engineers will be able to successfully perform test by following test procedure	
Transportation	Tool is maneuverable by 2 team members	

Test Results

Load Cell Characterization - Modeling

DR 1.1.3/2.1.3: Sensors shall be calibrated such that measured values are accurate within ±0.1% of the pod's true total weight, and within ±0.1" of the pod's true total CG

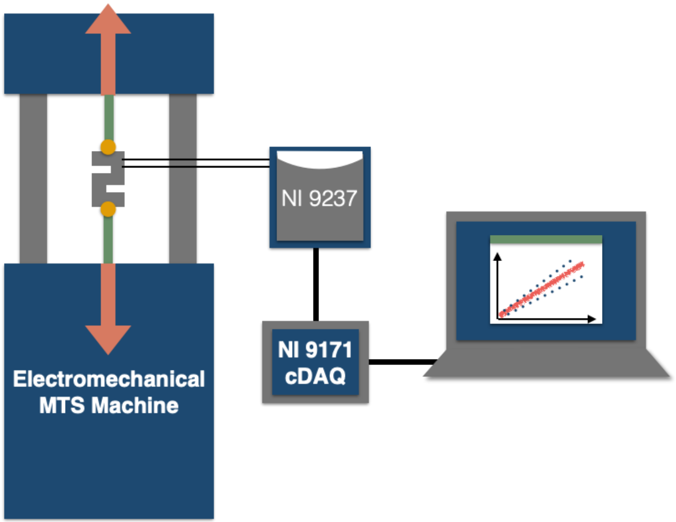
DR 1.1.3

DR 2.1.3

Rationale/Motivation:

- Verify load cell accuracy and data processing methods
- Rule out load cells as problem source for full-system errors

Load Cell	Combined Error (Non-Linearity + Hysteresis)	Sensitivity
Omega LC103B	0.020% FSO	3.0 ± 0.008 mV/V



3 Parts:

1. Linearity & Sensitivity
   - Apply load using tensile testing machine
2. Drift
   - Apply constant load for 60 minutes
3. **Measurement Accuracy Test**

Load Cell Characterization - Results

DR 1.1.3/2.1.3: Sensors shall be calibrated such that measured values are accurate within ±0.1% of the pod's true total weight, and within ±0.1" of the pod's true total CG	DR 1.1.3 / DR 2.1.3

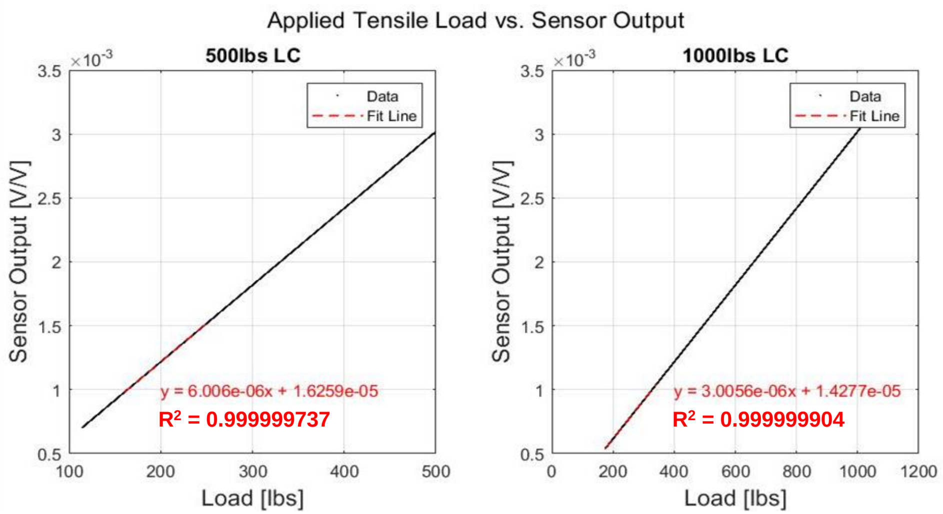
Linearity: CONFIRMED

Load Cell	Y-Intercept	Slope	R-squared value
500-lb	16.259 [µV/V]	6.006 [V/V]/lbs	0.999999737
1000-lb	14.277 [µV/V]	3.006 [V/V]/lbs	0.999999904

Sensitivity: CONFIRMED

Load Cell	Sensitivity (mV/V)	Expected Slope ([µV/V]/lbf)	Measured Slope ([µV/V]/lbf)	Difference (% load)
500-lb	2.9980	5.9960	6.006	0.056 < 0.07*
1000-lb	3.0024	3.0024	3.006	0.040 < 0.07*

*expected combined accuracy of MTS Machine (0.05%) and Omega load cell (0.02%)



Project Element	*Level 1*	*Level 2*	*Level 3*
Measurement Accuracy	Measure weight within ±0.1% and X CG and Z CG locations within ±0.1"	Measure weight within ±0.1% and X CG, Y CG, and Z CG locations within ±0.1"	

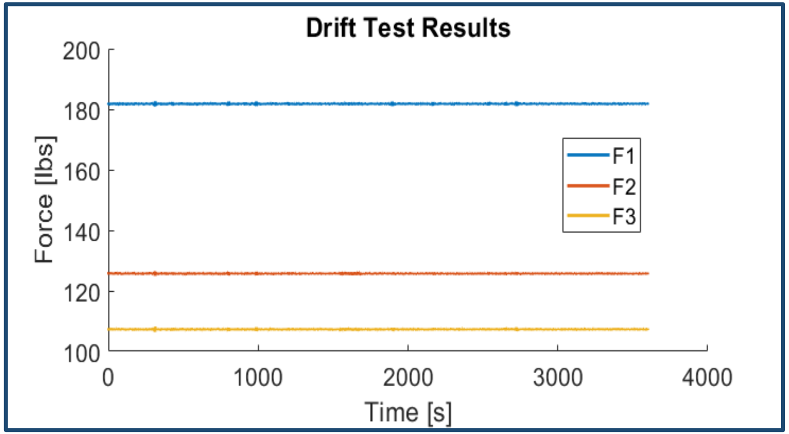
Load Cell Characterization - Results

DR 1.1.3/2.1.3: Sensors shall be calibrated such that measured values are accurate within ±0.1% of the pod’s true total weight, and within ±0.1” of the pod’s true total CG	DR 1.1.3 DR 2.1.3

Drift: CONFIRMED

Load Cell	Initial Load	Final Load	Mean Load	Measured Slope
LC0 [500lb]	181.783 lbs	181.802 lbs	181.794 lbs	0.0092 lbs/hr
LC1 [500lb]	125.730 lbs	125.699 lbs	125.706 lbs	-0.0237 lbs/hr
LC2 [500lb]	107.291 lbs	107.292 lbs	107.292 lbs	0.0062 lbs/hr

Drift is at most **0.005% FSO** in one hour of applied load.



Project Element	*Level 1*	*Level 2*
Measurement Accuracy	Measure weight within ±0.1% and X CG and Z CG locations within ±0.1"	Measure weight within ±0.1% and X CG, Y CG, and Z CG locations within ±0.1"
Test Operation	Test completed in 1 hour	Test completed in 0.5 hours

Electronics and Software Functionality - Results

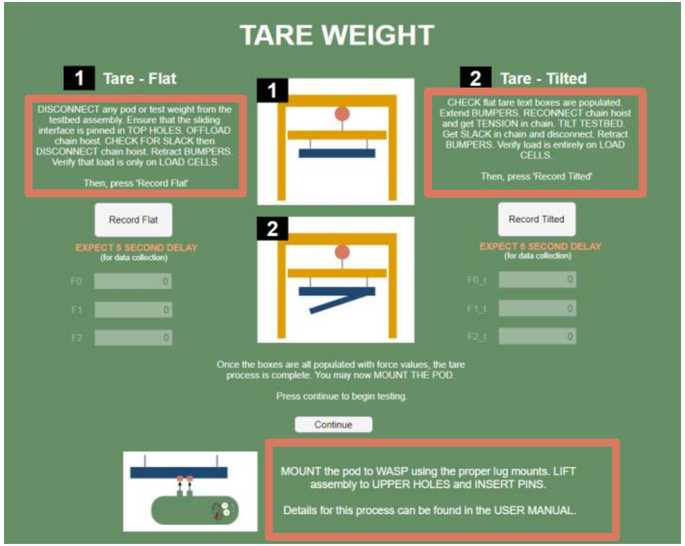
DR 8.1: WASP shall have a computer based tool that interfaces with the sensors	**DR 8.1**

Software: **Fully Functional**

- Easy to use UI walks through procedure

Hardware: **Successfully Integrated**

- Communication between load cells and UI for automated data processing



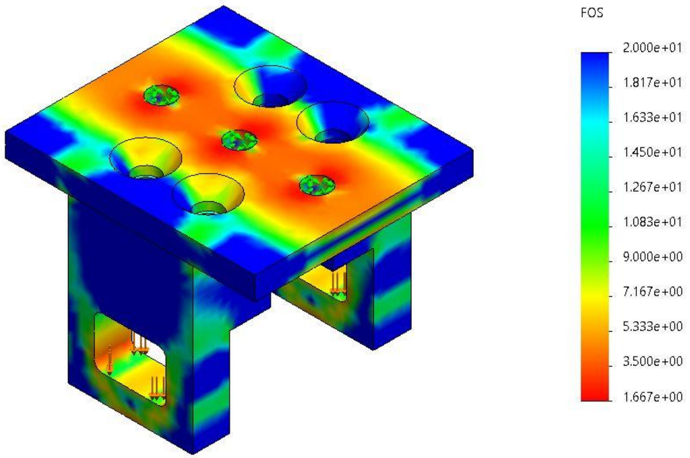
Tare menu from the User Interface

Project Element	*Level 1*	*Level 2*	*Level 3*
User Interface	Manual Data Entry	Autonomous data entry and calculations	Level 2, plus excel compatible results export
	Delivery of weight, X and Z CG from between 2 and 5 data sets	Delivery of weight, X, Y, and Z CG from between 2 and 5 data sets	Delivery of weight, X, Y, and Z CG from 5+ data sets

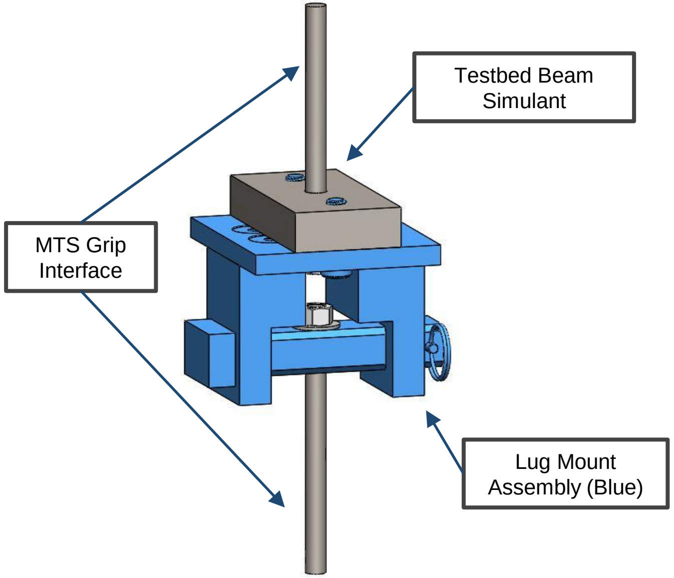
Lug Mount Tensile Test - Modeling

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0 | DR 3.1

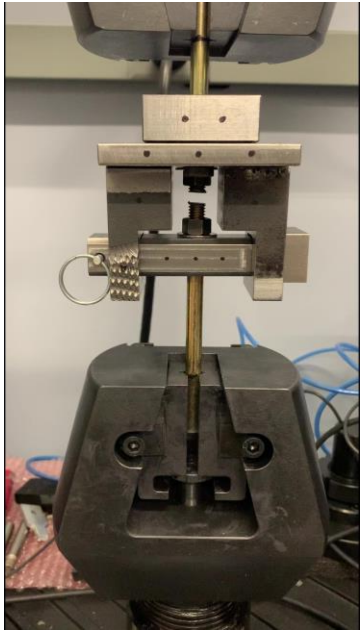
- Lowest (~3) predicted safety factor in 2000 lb lug mounts



Conservative Finite Element Analysis



Test Setup Design

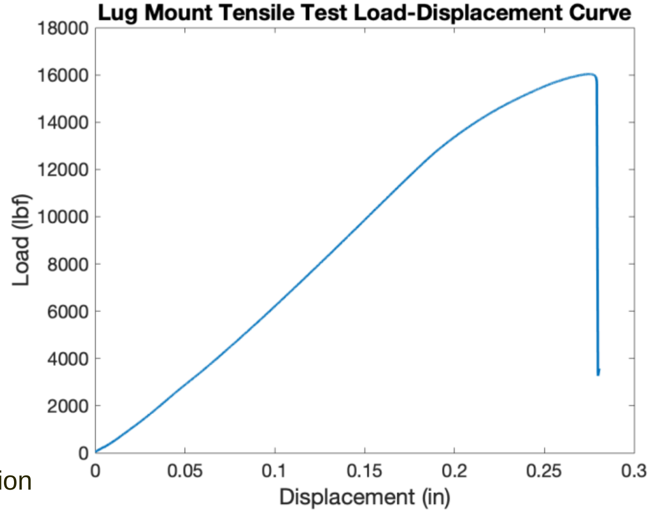


Physical Setup

Lug Mount Tensile Test - Results

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0 | **DR 3.1**

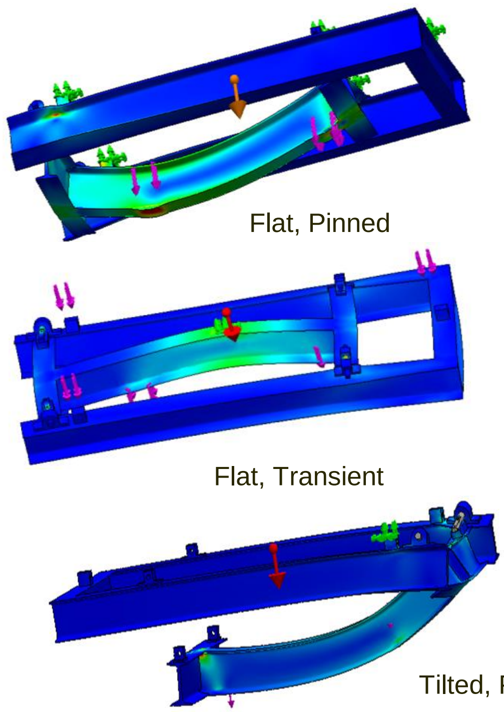
- Model Prediction:
  - Top plate yield near bolt holes ≥3,400 lbf
- Observed Results:
  - Yielding ~13,000 lbf in top plate and threads
  - 6.5 ≤ FOS ≤ 7.75 for mount itself
- Consequences:
  - Design: **DR 3.1 Satisfied** for **this** component
  - Model: Interpretation of the model is complicated
    - Fixed geometry increases stress in nearby material
    - Assembly treated as one part (fused) in model - internal reactions between components increase stiffness, push back plastic deformation



Project Element	*Level 1*	*Level 2*	*Level 3*
Structural Integrity	Support 1000 lbs with FOS of 2.0	Support 2000 lbs with FOS of 2.0	
Mounting and Interfacing	Connect to 14” and 30” pod lug configurations		Modular capabilities to connect future pod lug configurations

Structural Integrity Test - Modeling

DR 3.1: Structural components must have a safety factor against yield of > 2.0	DR 3.1
DR 3.3: WASP shall lift pods out of their cradles	DR 3.3

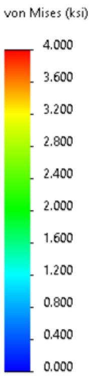


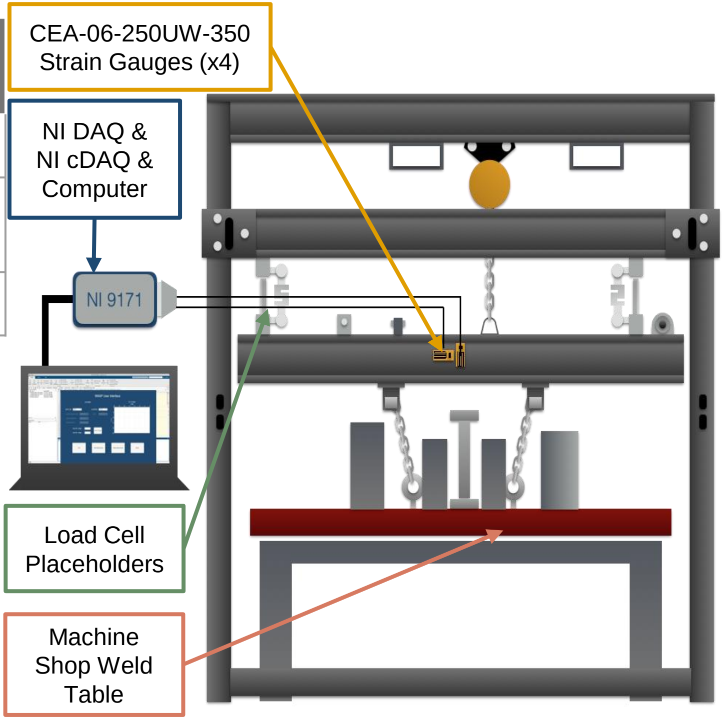
Flat, Pinned

Flat, Transient

Tilted, Pinned

Loading Case (at 2205 lbs)	Expected Max Stress (Von Mises) [psi]
Flat, Pinned	~385
Flat, Transient (Unpinned)	~971
Tilted, Pinned	~223





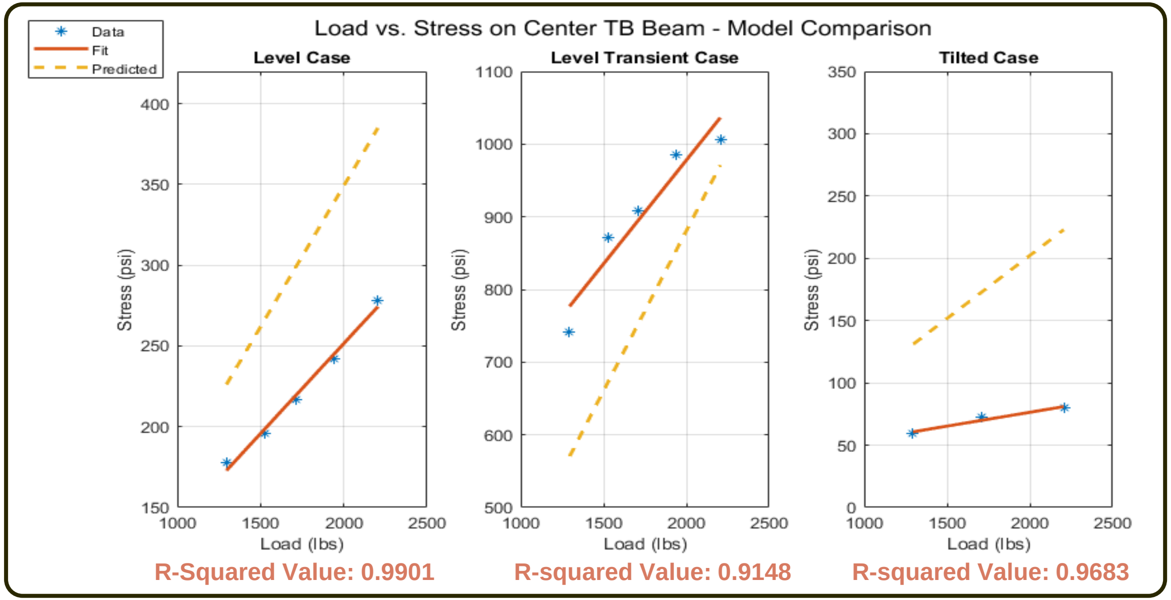
Structural Integrity Test - Results

DR 3.1: Structural components must have a safety factor against yield of > 2.0 **DR 3.3:** WASP shall lift pods out of their cradles	DR 3.1 DR 3.3

Cannot validate FOS > 2.0 for the ***whole structure*** without a second structure

- Lowest Predicted FOS tested (LMTT)
- Tested in all possible configurations

Loading Case (2205 lbs)	Expected Max Stress [psi]	Actual Max Stress [psi]
Flat, Pinned	~385	278
Flat, Transient	~971	1006
Tilted, Pinned	~223	80

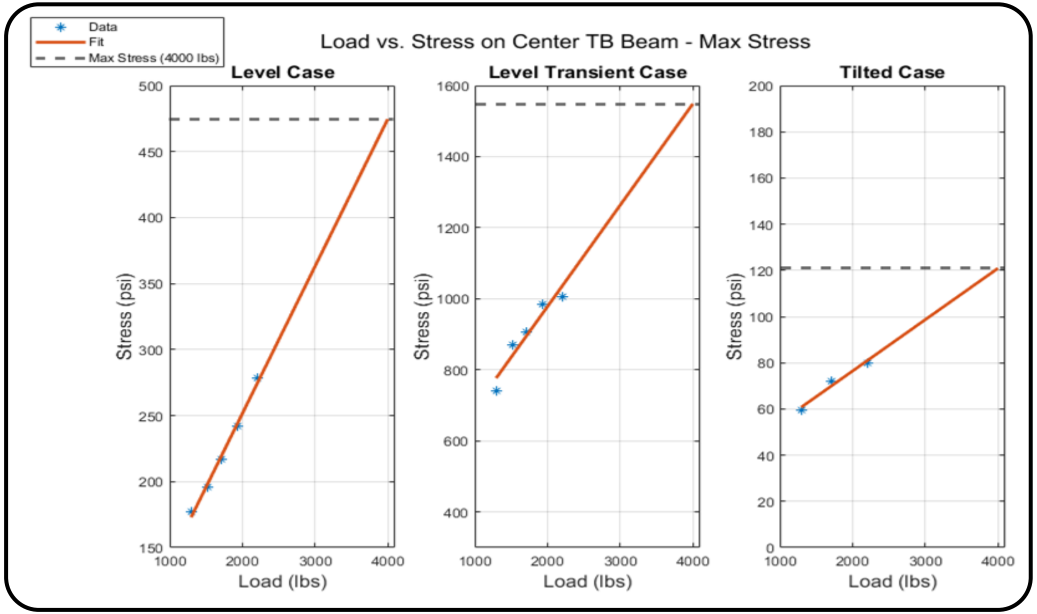


Project Element	Level 1	Level 2	Level 3
Structural Integrity	Support 1000 lbs with FOS of 2.0	Support 2000 lbs with FOS of 2.0	

Structural Integrity Test - Results

DR 3.1: Structural components must have a safety factor against yield of > 2.0
DR 3.3: WASP shall lift pods out of their cradles

DR 3.1
DR 3.3



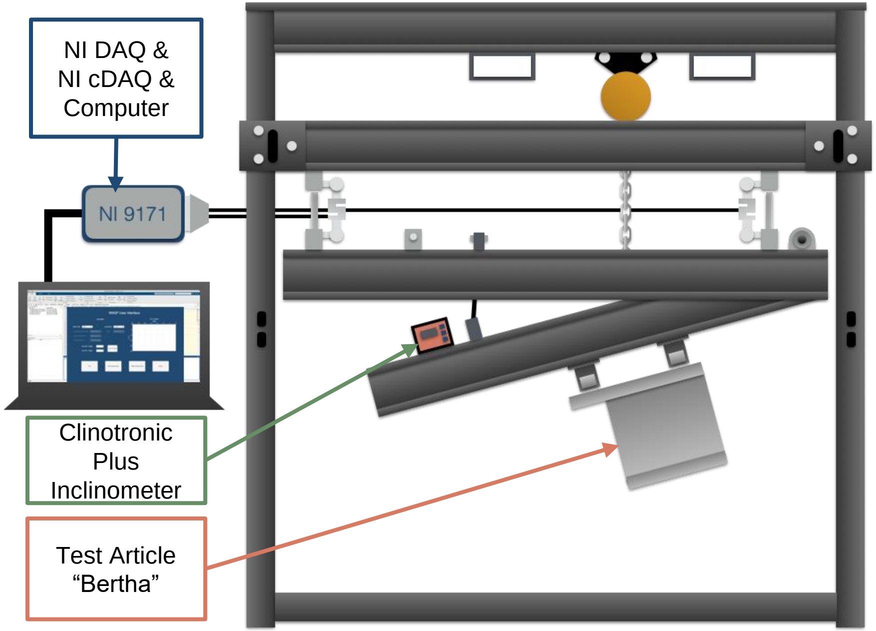
- **Extrapolated to 4000 lbs** since we do not have data
  - We can trust the data we have to extrapolate
- We can find the theoretical max stress based off data

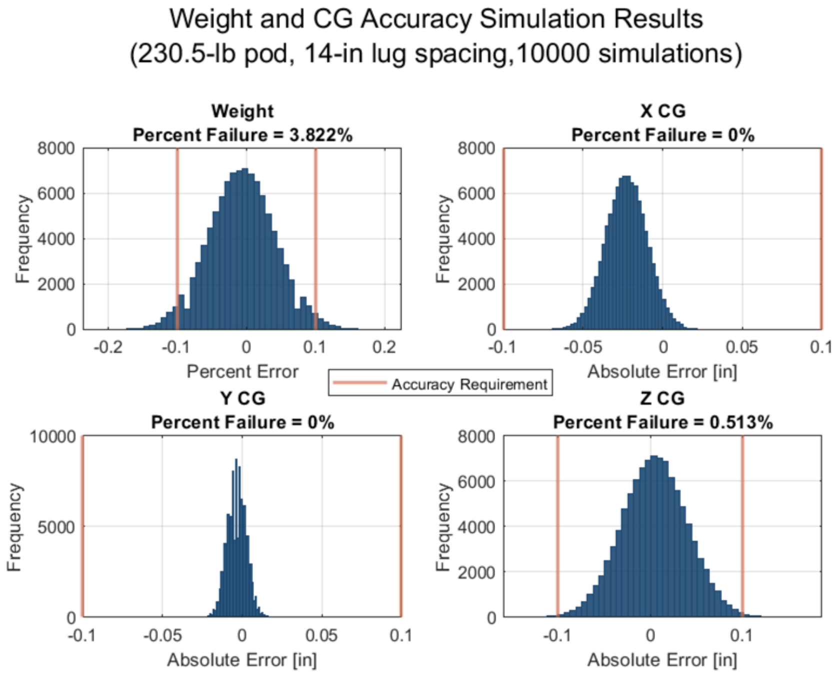
Max Loading Condition	Max Stress (4000 lbs) [psi]	FOS
Flat, Transient	1549	**23.4**

Project Element	Level 1	Level 2	Level 3
Structural Integrity	Support 1000 lbs with FOS of 2.0	Support 2000 lbs with FOS of 2.0	

Measurement Accuracy Test - Modeling

DR 1.1: WASP shall measure the weight of the pod within a tolerance of ± 0.1% of the pod weight	DR 1.1
DR 2.1: WASP shall measure the CG of the pod within a tolerance of ± 0.1” of the pod CG	DR 2.1

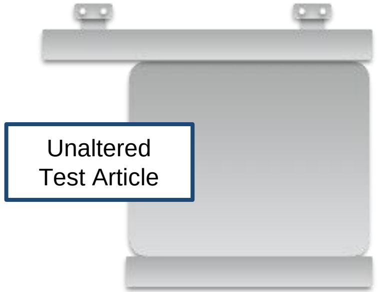




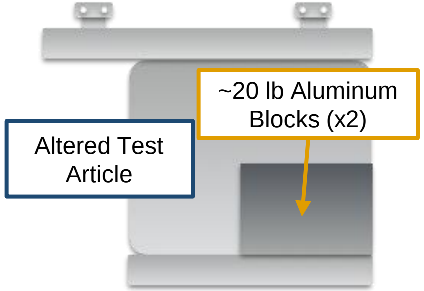
Measurement Accuracy Test - Results

DR 1.1: WASP shall measure the weight of the pod within a tolerance of ± 0.1% of the pod weight
DR 2.1: WASP shall measure the CG of the pod within a tolerance of ± 0.1” of the pod CG

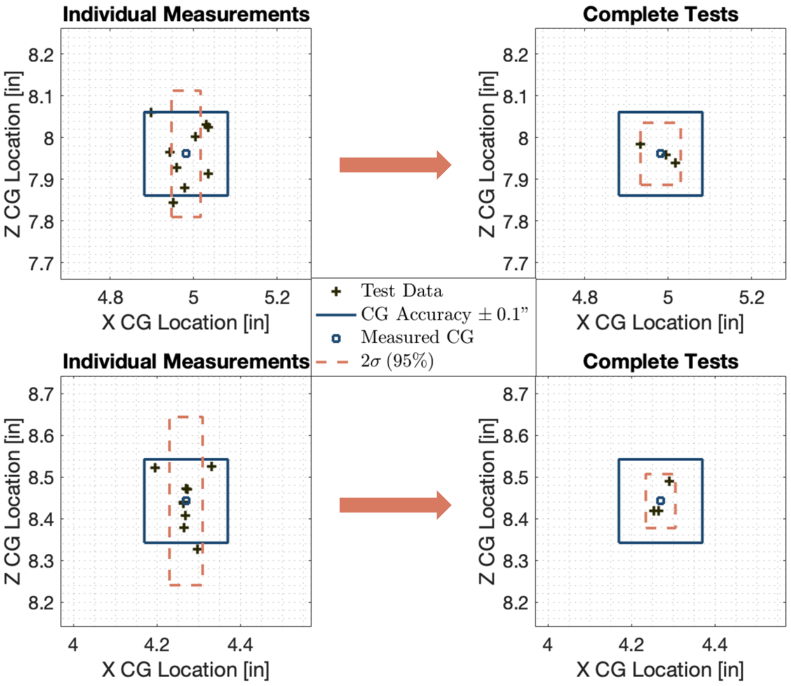
DR 1.1
DR 2.1



Individual Measurements:
9 Measurement Sets
88.9% Success Rate



Individual Measurements:
9 Measurement Sets
88.9% Success Rate



Full Tests (Avg of Measurements):
3 Tests
100.0% Success Rate

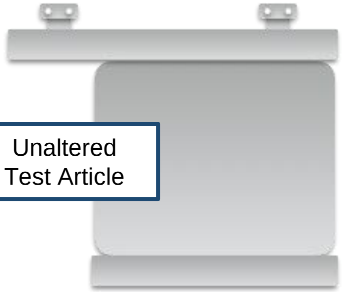
Full Tests (Avg of Measurements):
4 Tests
100.0% Success Rate

Measurement Accuracy Test - Results

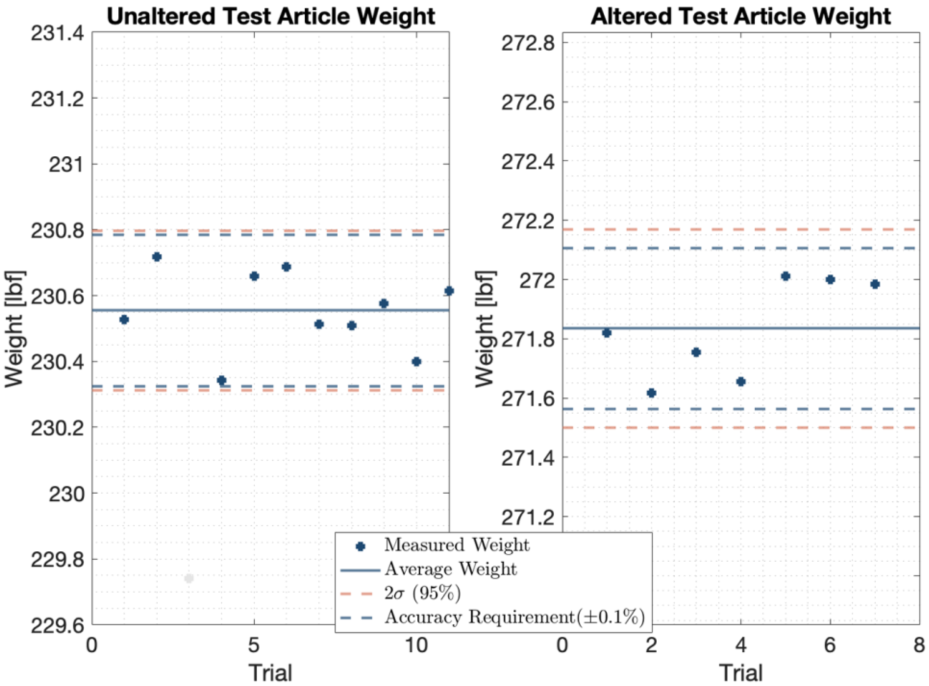
DR 1.1: WASP shall measure the weight of the pod within a tolerance of ± 0.1% of the pod weight
DR 2.1: WASP shall measure the CG of the pod within a tolerance of ± 0.1" of the pod CG

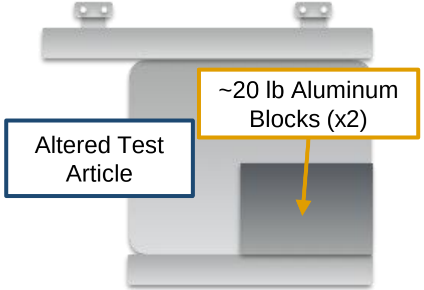
DR 1.1

DR 2.1



Complete Tests:
10 Tests
94.26% Success Rate





Complete Tests:
7 Tests
89.48% Success Rate

Measurement Accuracy Test - Results

DR 1.1: WASP shall measure the weight of the pod within a tolerance of ± 0.1% of the pod weight
DR 2.1: WASP shall measure the CG of the pod within a tolerance of ± 0.1” of the pod CG

DR 1.1
DR 2.1

Accuracy			
Test Article →	Unaltered (SNC)	Unaltered (WASP)	Altered (WASP)
X CG [in]	4.61	4.98	4.27
Y CG [in]	0.00	0.03	0.01
Z CG [in]	7.39	7.96	8.44
Weight [lbf]	231.7	230.55	271.87

Repeatability/Success Rate (Unaltered)		
	Monte Carlo Simulation	Measurement Accuracy Test
X CG	100.0%	100.0%
Y CG	100.0%	100.0%
Z CG	99.5%	100.0%
Weight	96.2%	94.26%

Project Element	*Level 1*	*Level 2*	*Level 3*
Measurement Accuracy	Measure weight within ±0.1% and X CG and Z CG locations within ±0.1"	Measure weight within ±0.1% and X CG, Y CG, and Z CG locations within ±0.1"	

System Accreditation - Modeling

DR 6.1: WASP shall complete a single weight and balance test in no more than 30 minutes	DR 6.1
DR 6.3: WASP shall require no more than two engineers to complete one test	DR 6.3

- **Rationale/Motivation:**
  - Verify procedural requirements
- **Procedure:**
  - Run multiple accuracy tests with non-WASP engineers
  - Record weight and CG measured by volunteers
- **Note:** Only Measurements and Dismounting are included in the 30 minute time constraint

Procedure	Time
Tare Procedure	12 mins
Mounting Procedure	7.5 mins
Measurements	25 mins
Dismounting Procedure	5 mins
Total	30 mins

Safety Assurances	Protective Equipment	Operational Guidelines	Visual Checks
Implementation	Hard Hats, Safety Glasses, Gloves	Specific Instructions in User Manual and GUI	Color Coding Critical Items (pins, lug mounts, load cells)

System Accreditation - Results

DR 6.1: WASP shall complete a single weight and balance test in no more than 30 minutes	DR 6.1
DR 6.3: WASP shall require no more than two engineers to complete one test	DR 6.3

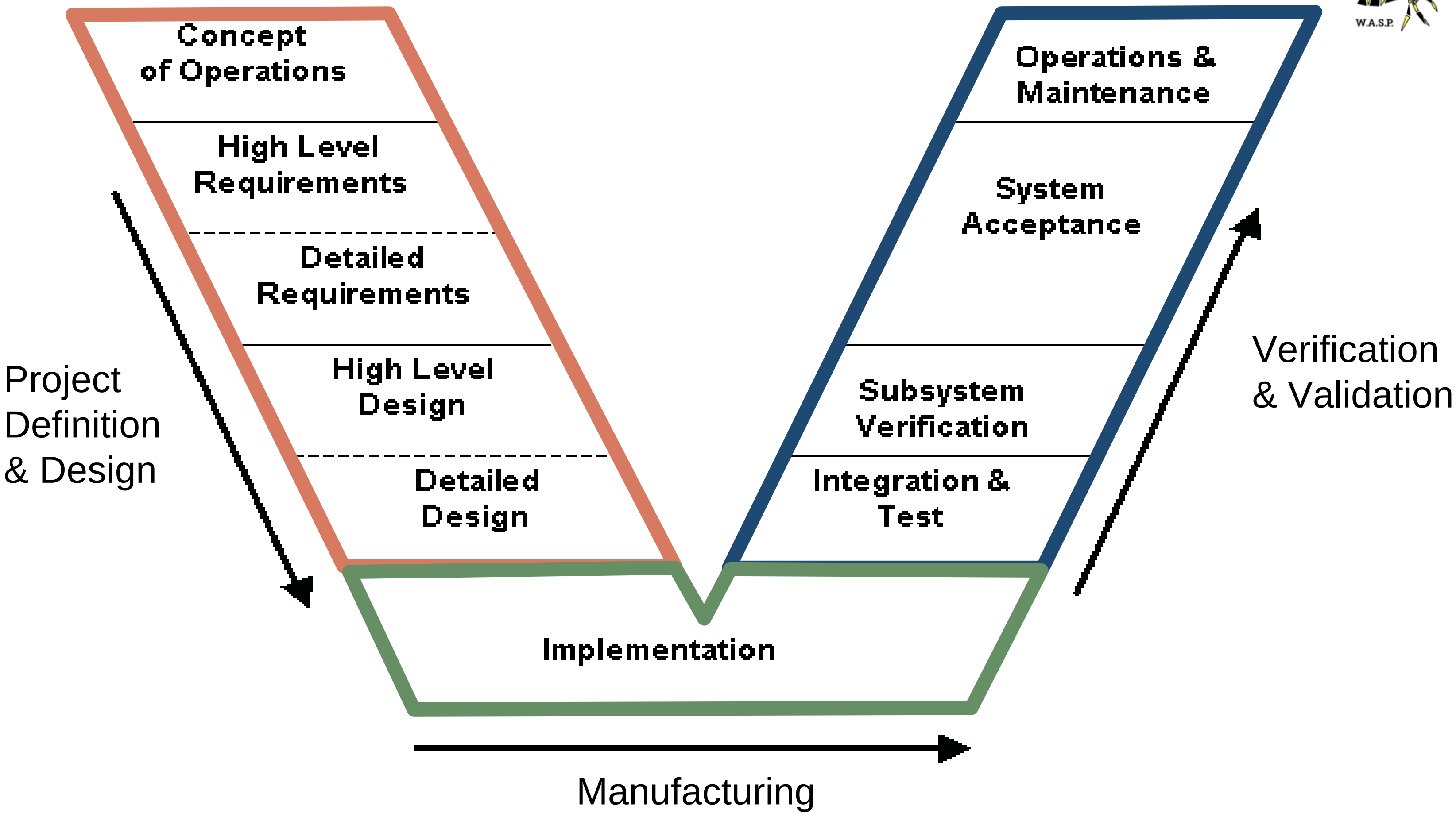
Procedure (2 Engineers)	Group 1 Time	Group 2 Time	Group 3 Time	Projected Time
Tare Procedure	11.66 mins	18.30 mins	12.50 mins	12 mins
Mounting Procedure	9.37 mins	14.03 mins	7.50 mins	7.5 mins
Measurements	21.82 min (3)	9.15 mins (1)	7.50 mins (1)	25 mins
Dismounting Procedure	3.00 mins	DNF	2.50mins	5 mins
Total (Measurement and Dismount)	**24.82 mins**	**~27.45 mins**	**~25 mins**	**30 mins**

Project Element	*Level 1*	*Level 2*	*Level 3*
Test Operation	Test completed by 3 engineers	Test completed by 2 engineers	
	Test completed in 1 hour	Test completed in 0.5 hours	

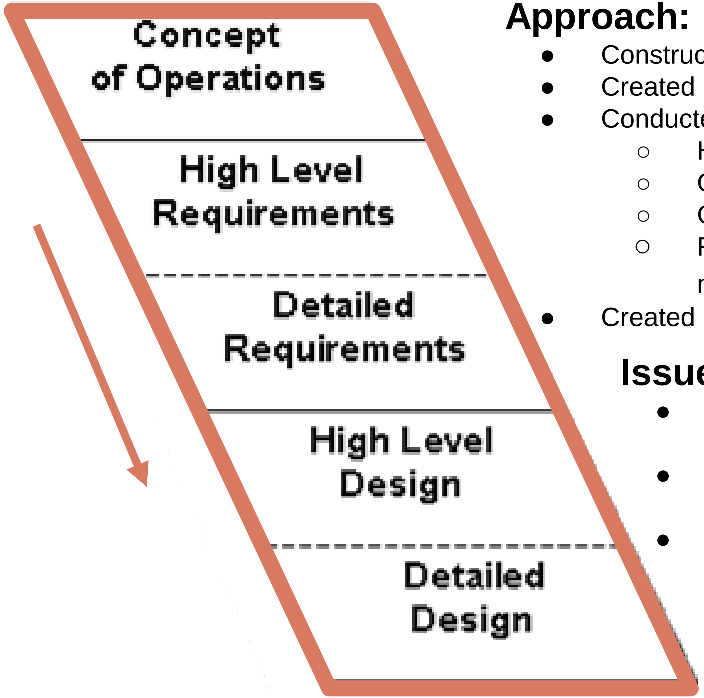
Testing Recap - Project Objectives

Project Objective	Success Criteria		Test
Structural Integrity	Support 1000 lbs with FOS of 2.0 (Level 1)	Support 2000 lbs with FOS of 2.0 (Level 2)	Lug Mount Tensile Test, Structural Integrity Test
Mounting and Interfacing	Modular Capabilities to connect future pod lug configurations (Highest Level)		Lug Mount Tensile Test
Measurement Accuracy	Measure weight within ±0.1% and X CG, Y CG, and Z CG locations within ±0.1" (Highest Level)		Load Cell Characterization, Measurement Accuracy Test
User Interface	The measurement tool will autonomously collect and analyze data and export results to an Excel-compatible file. (Highest Level)		Electronics and Software Functionality Test
	The software will deliver the weight, X, Y, and Z CG values averaged over more than 5 measurement sets (Highest Level)		
Test Operation	Test completed by 2 engineers (Highest Level)		System Accreditation
	Test completed in 0.5 hours (Highest Level)		
	Test engineers will be able to successfully perform test by following test procedure (Highest Level)		
Transportation	Tool is maneuverable by 2 team members		

Systems Engineering

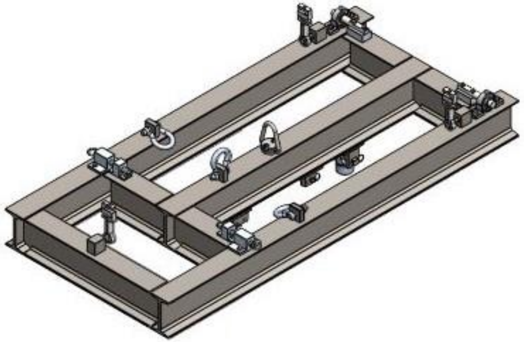

Concept of Operations
High Level Requirements
Detailed Requirements
High Level Design
Detailed Design
Implementation
Integration & Test
Subsystem Verification
System Acceptance
Operations & Maintenance
Project Definition & Design
Manufacturing
Verification & Validation

Project Definition, Concept & Design Phase



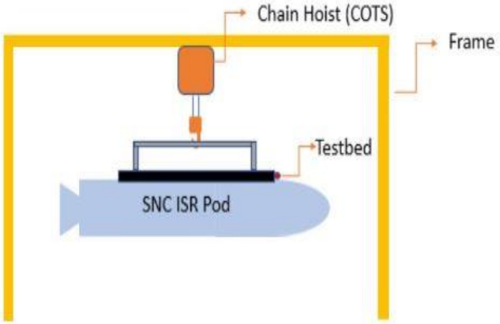
Approach:

- Constructed **CONOPS**
- Created Functional and Derived Requirements
- Conducted **Trade Studies**
  - Hybrid Test Bed
  - Omega Load Cells with Inclinometer
  - Chain Hoist Lifting Mechanism
  - Forklift Slots and Caster Wheels for maneuverability
- Created plan for manufacturing and testing



Issues:

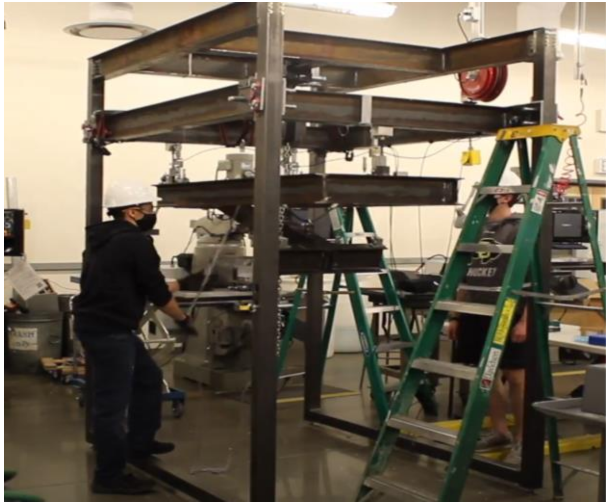
- Not having enough **money** to be able to create WASP with a significant margin
- Not having enough **time** to manufacture all of WASP along with possible COVID implications
- Making sure all parts would work together

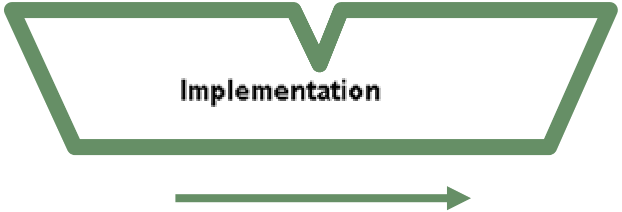


Lessons Learned:

- **Logistics** are just as important as engineering analysis
- Trade Studies are extremely helpful in determining the best solution

Manufacturing





Approach:

- Followed **manufacturing plan** made in Critical Design Phase

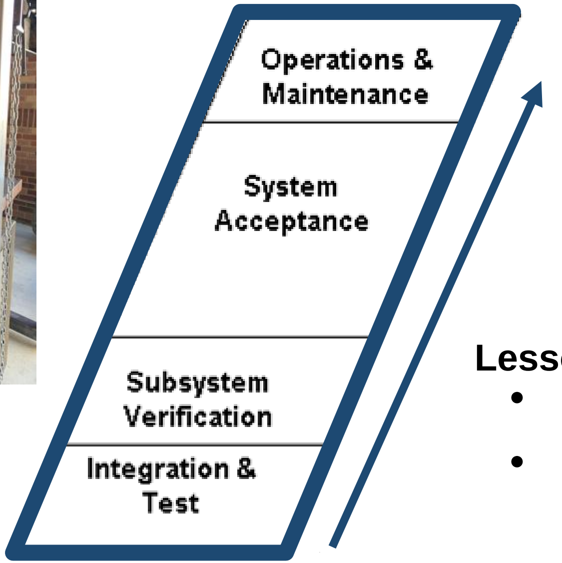
Issues:

- Designed Parts/Structure were very different than the manufactured part or structure
    - Dimension mismatches causing non-predicted behavior/loads
    - Problems with functionality of Sliding Interface
- COVID/Extraneous Events caused delays in manufacturing as we expected

Lessons Learned:

- Discrepancies between the designed and manufactured part(s) will occur and will cause issues
- **Unique and unpredicted problems** will arise such as the tilted sliding interface

Verification & Validation



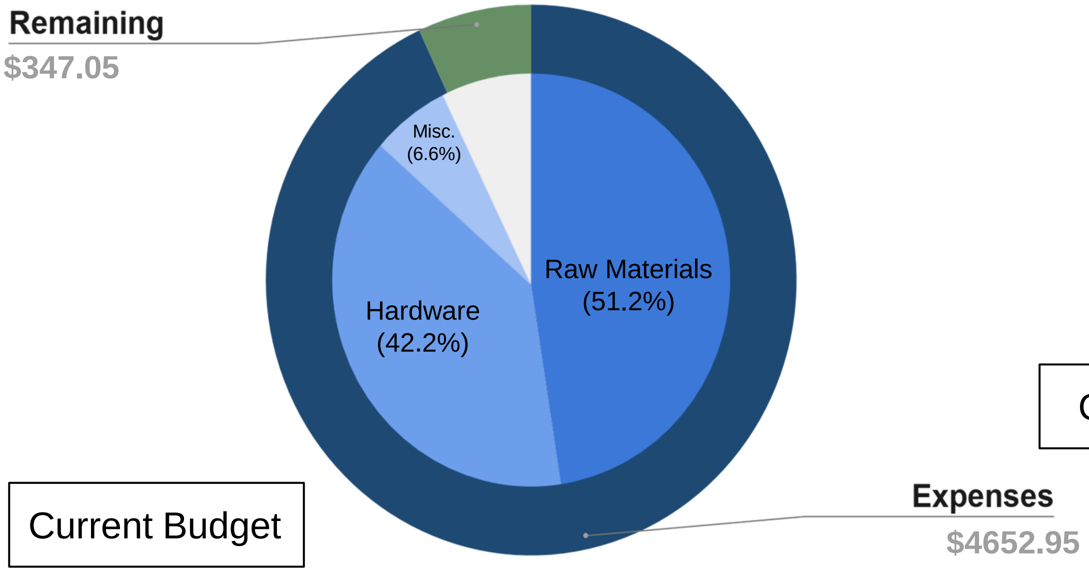
Approach:
- Followed **testing plan** created in Critical Design Phase
- Verify and Validate our requirements

Issues:
- Tests never worked as expected the first time
- Most tests took longer than the allotted time given
- Some scheduling issues
- Design dimensions of CG equations were not the same as physical dimensions

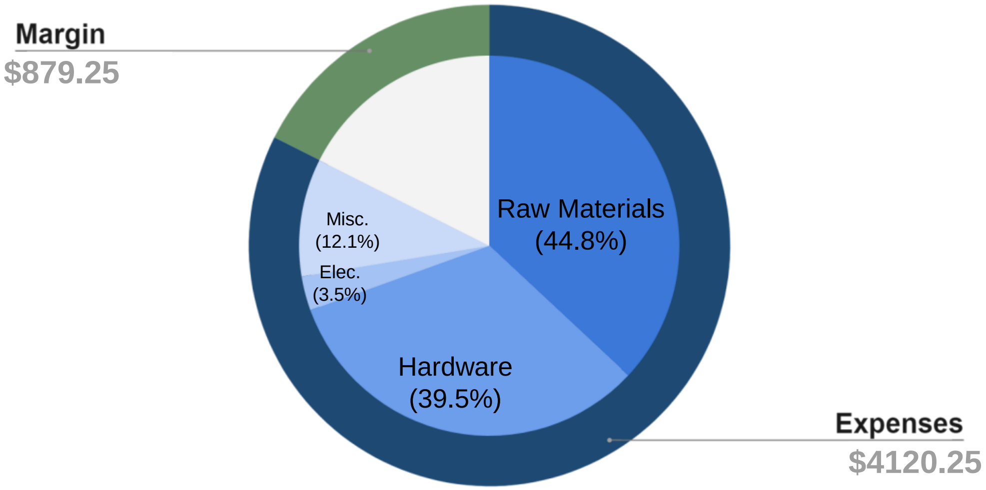
Lessons Learned:
- Never expect anything to work the first time around
- Prepare for a test as early as possible before the test start date

Project Management

Budget Review



Current Budget



CDR (Planned) Budget

Total Project Cost: $4652.95

WASP Team Efforts Summary

Total Hours:

5649 Hours (best estimate)

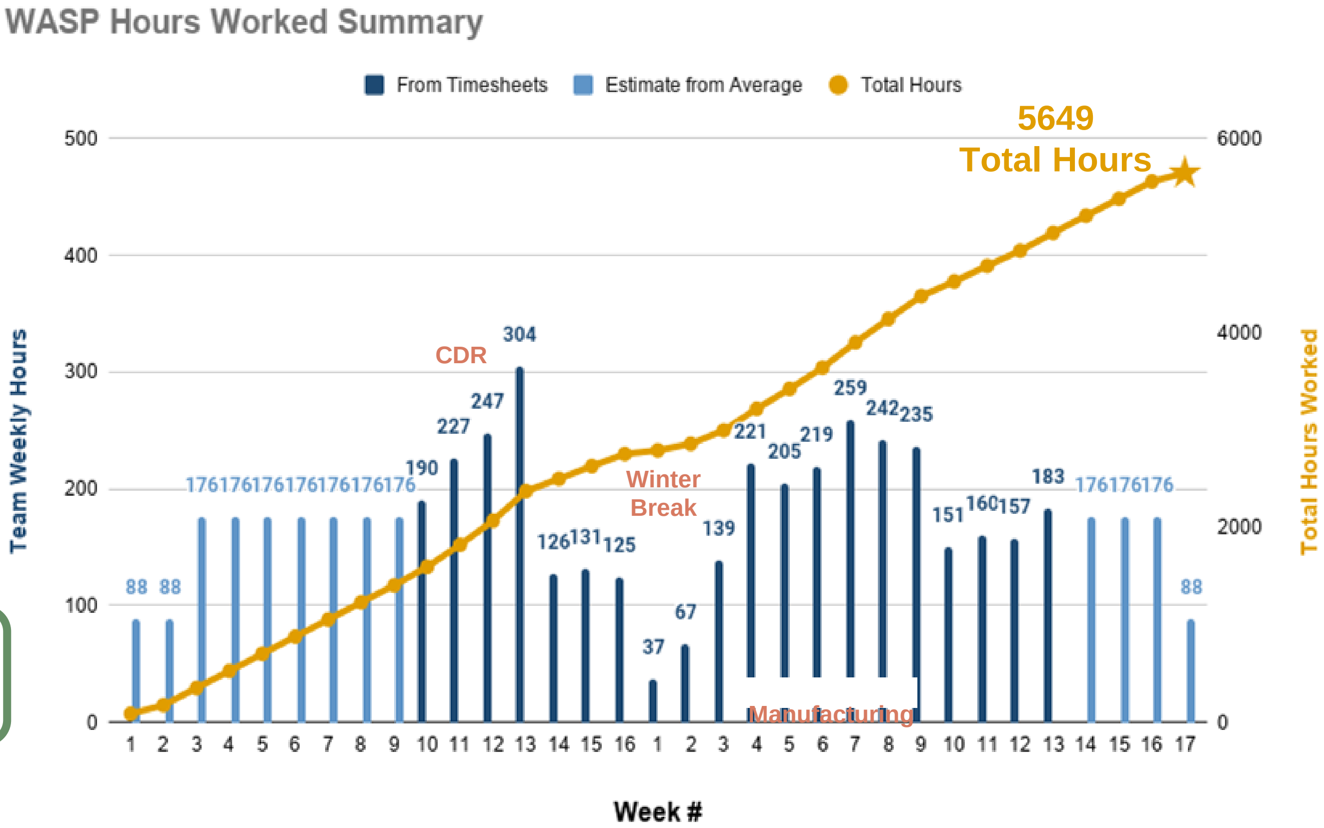
Cost Summary:

Materials ---------------- $4652.95

Equivalent Wages ---- $174,840
($65K salary)

Overhead -------------- $349,681
(200%)

TOTAL -------- $544,174



Project Management Analysis

Approach:

Team Structure
- All team members distinct leads
- Mid-project restructure
- Standards for mutual respect
- Checks & Balances
- Prioritizing team social activities

Work Management
- Team-developed, PM-enforced timeline
- Internal deadlines before course deadline
- Weekly team & subteam tag-ups

Customer Interfacing
- Bi-weekly or monthly status updates
- Tracked open action items

Successes:

Deliverables
- On-time and quality
- Opportunity for many external reviews

Functionality
- Efficient brainstorming
- All FRs satisfied!
- All objectives satisfied!

Team Morale
- We are all best friends!
- High ambition from start to finish

Challenges:

- Significant budget concerns during design
- Balancing remote and in-person work
- Sustained few personnel issues

Lessons Learned:

- Raw materials ≈ stocks
- **Be creative with funding**
  - Customer offsetting sensor costs

- **Delays are unavoidable**
- If margin is exhausted early on, have to build in more (R2R delay)
- Relying on **external services** can cause unexpected delays

- **Prioritize function** over classic organization for subteams
- **Revision control is critical** (CAD and UI)
- Setting expectations early for increases in weekly hours
- Benefits of frequent communication with customer
- Make your **team** your **family**

Acknowledgements

SNC Team:

Becky Vander Hoeven, Gary Hutton, Stephen McLaughlin, Jon Matula, AJ Olson

Advisory Board Members and AES Faculty:

Dr. Allison Anderson, Lara Buri, Dr. Donna Gerren, Camilla Hallin, Professor Bobby Hodgkinson, Dr. Jelliffe Jackson, Dr. Francisco Lopez Jimenez, Professor Matt Rhode + Machine Shop Staff, Professor Trudy Schwartz, Dr. Zachary Sunberg, KatieRae Williamson, Dr. Kathryn Wingate

Special Thanks to our Volunteer Operators:

Omar Ahram, Niko De Boucaud, Axel Haugland, Abby Hause, Sam Markovich, David Perkins

Thank you to everyone who helped WASP be a success!

Questions?

References

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Back-Up Material

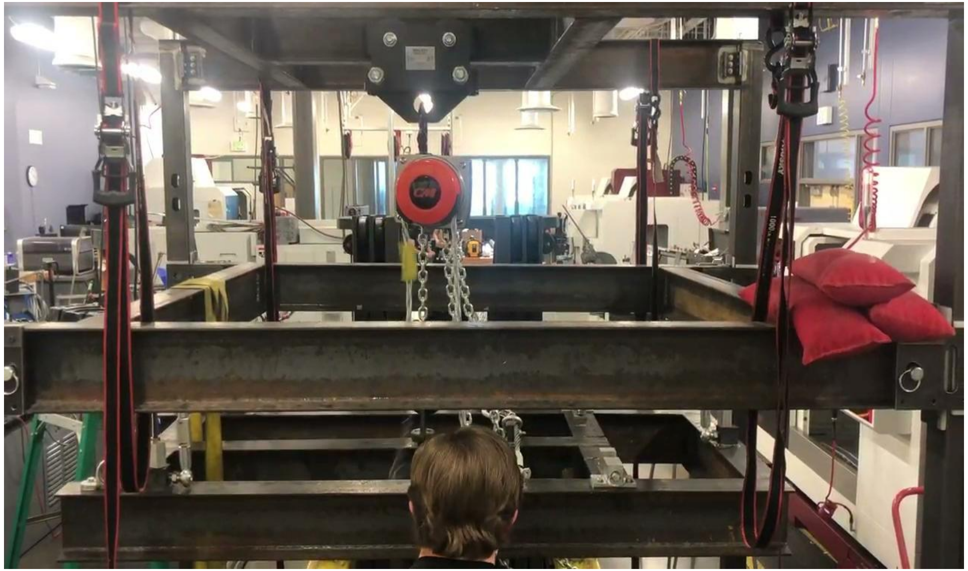
Manufacturing

Sliding Interface - Ballast to prevent tilting

The original design of the sliding plates was not sufficient in counterbalancing moments developed.

Main solution: use ballast on one side of sliding interface to counteract the moment developed.

Secondary solution: make the sliding plates larger to have 3x moment arm



Video shows the functionality of sliding with the ballast solution

Testbed - Multiple Equilibrium Positions

Noticed the testbed can hang in different static positions -- varying by ~0.75 inch at max

Using plumb bobs currently to note where the testbed should be positioned.

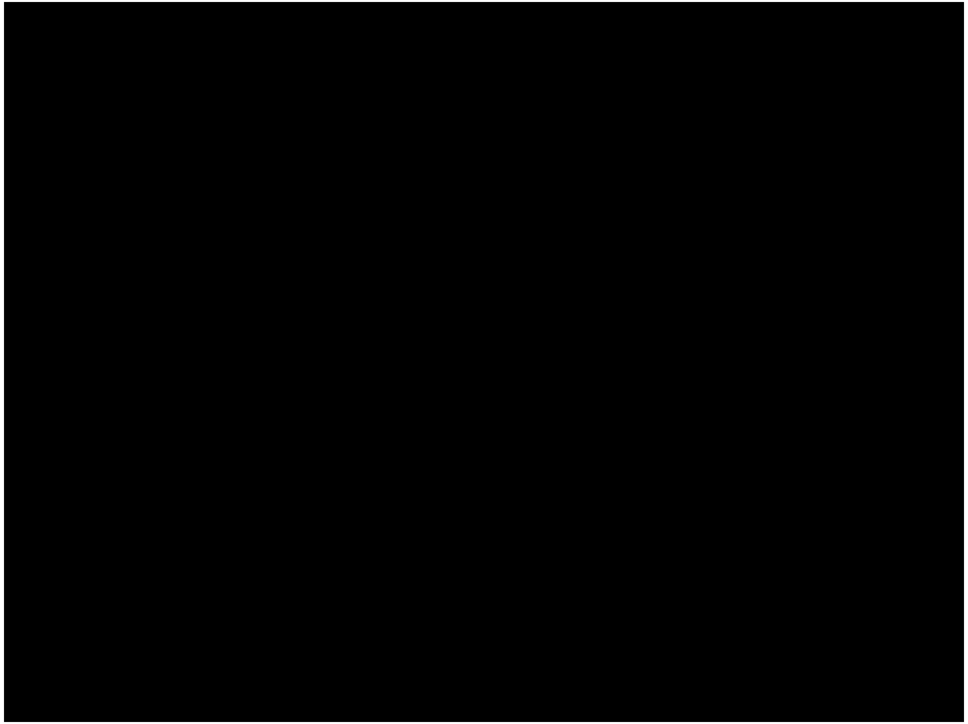
Will implement lasers for easier alignment procedure.

Caster Wheels - Improving Maneuverability

4 Caster Wheels used to allow for easy maneuverability on the floor of the hangar.

These were added later because they were a budget concern. (see slide 96)

Video shows 3 engineer maneuvering WASP with ease on the floor of machine shop. This was later tested with 2 engineers to ensure ability to meet project objective.



Testing

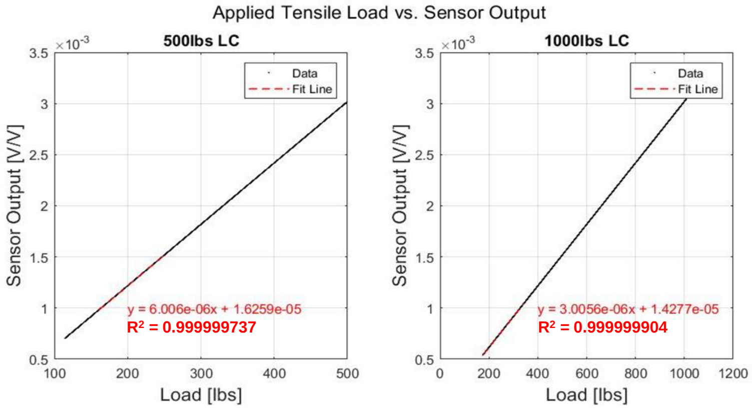
Load Cell Characterization

DR 1.1.3/2.1.3: Sensors shall be calibrated such that measured values are accurate within ±0.1% of the pod’s true total weight, and within ±0.1” of the pod’s true total CG
CPE 3: WASP must satisfy the strict accuracy tolerances given in the requirements

Deadline: 2/22

Completed 2/24

- **Rationale/Motivation:**
  - Improve fidelity of Monte Carlo Simulation of error in W & CG
  - Demonstrate correct data acquisition/processing by WASP software
- **Procedures:**
  - Tensile test - MTS
  - Drift test - MTS/WASP
  - Accuracy Test - Bertha/WASP



Normality of Error: LC - MTS

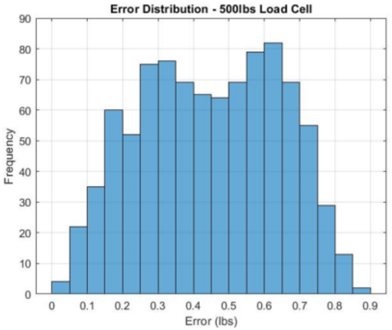
H_0: E~ N(μ_E , σ_E); H_a: E≁ N(μ_E , σ_E)

K-S Test for Normality, α = 5%

500 lbs LC: p = 6.54 x 10^{-4} < α

1000 lbs LC: p = 1.12 x 10^{-6} < α

REJECT THE NULL HYPOTHESIS



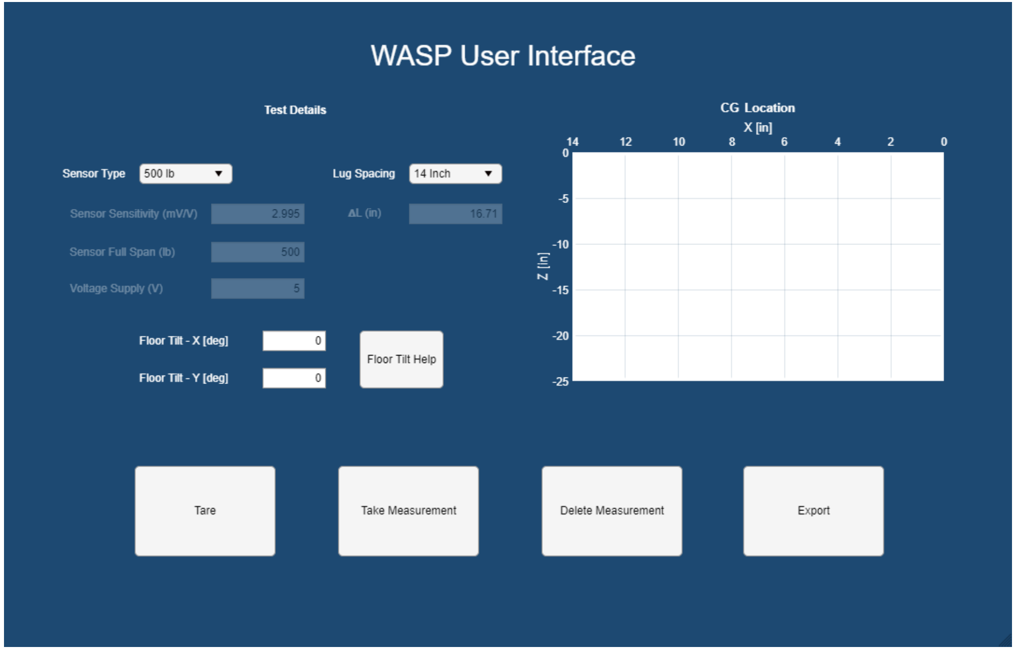
Electronics & Software Functionality Test

DR 8.1: WASP shall have a computer based tool that interfaces with the sensors

Deadline: 3/1

Completed 2/23

- **Rationale/Motivation:**
  - Connect completed code and hardware, ensure functionality
  - Test user interface for ease of use and bugs
- **Procedures:**
  - Hardware compatibility and functionality test
  - User interface functionality test
  - System accreditation test

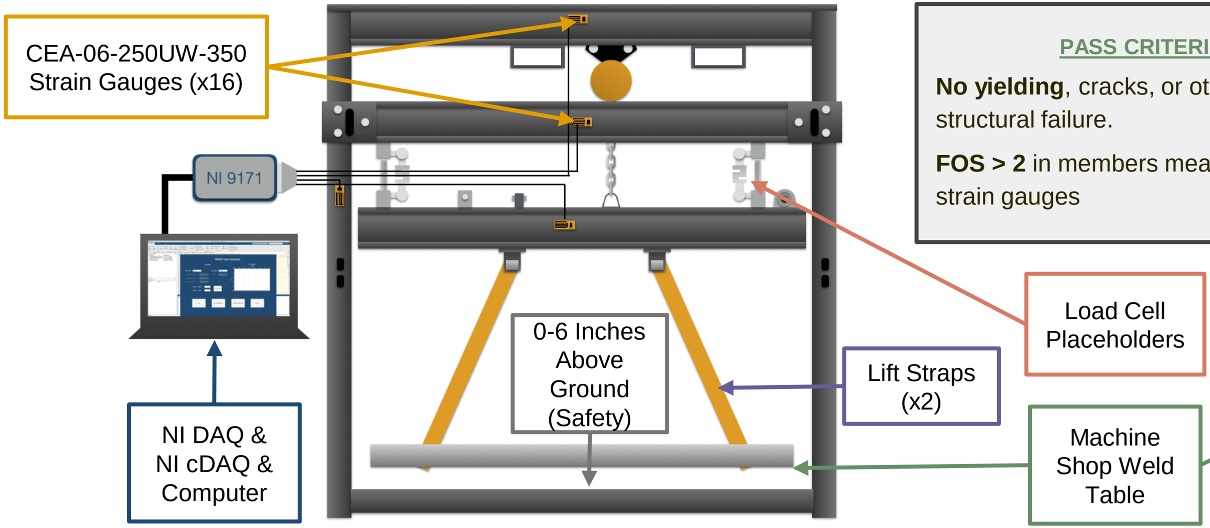


Structural Integrity Test

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0
DR 3.3: WASP shall lift pods out of their cradles
  CPE 1: Frame must statically support pods of up to 2000 lbs
  CPE 5: Pods and WASP operators must be safe from harm.

Deadline: 3/29

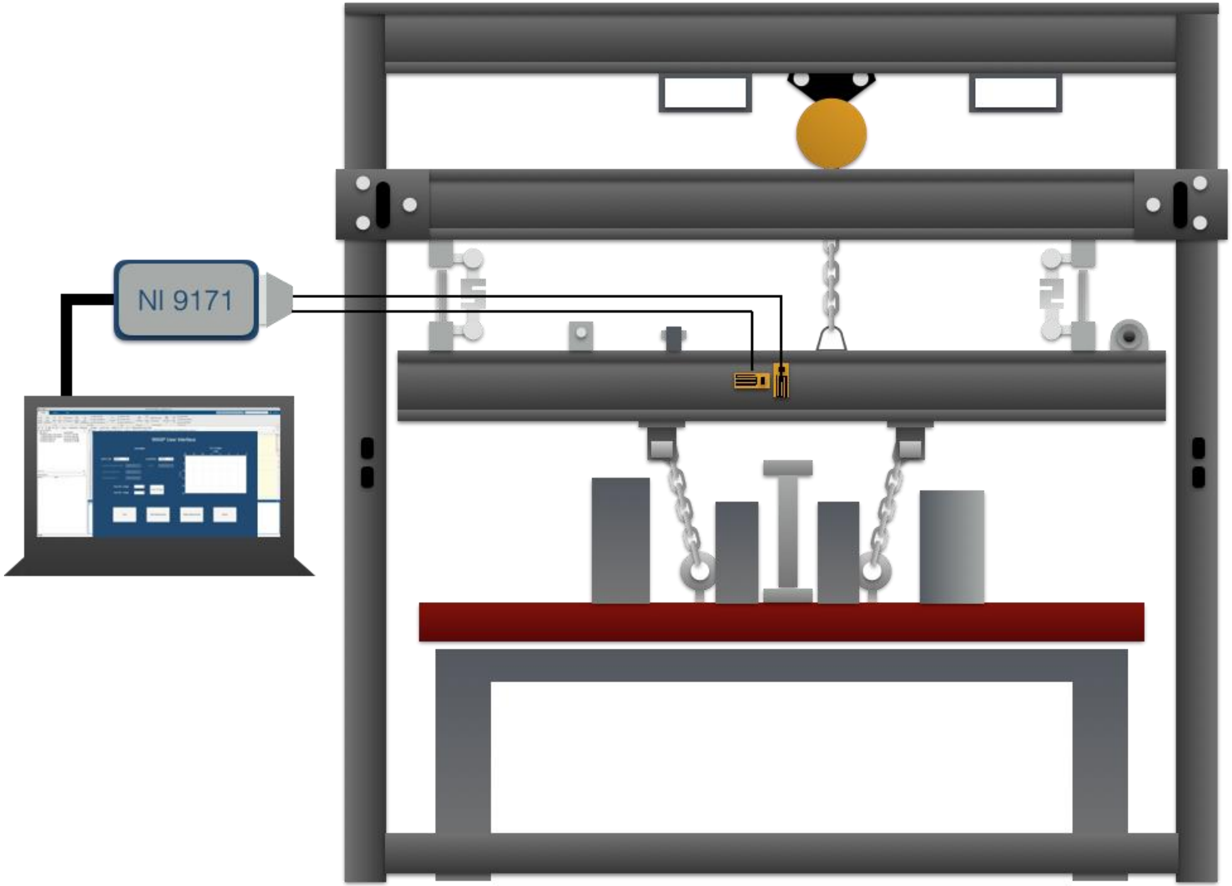
Planning/Setup



PASS CRITERIA

No yielding, cracks, or other forms of structural failure.

FOS > 2 in members measured by strain gauges


NI 9171

Structural Integrity Test

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0
DR 3.3: WASP shall lift pods out of their cradles
CPE 1: Frame must statically support pods of up to 2000 lbs
CPE 5: Pods and WASP operators must be safe from harm.

Deadline: 3/29

Planning/Setup

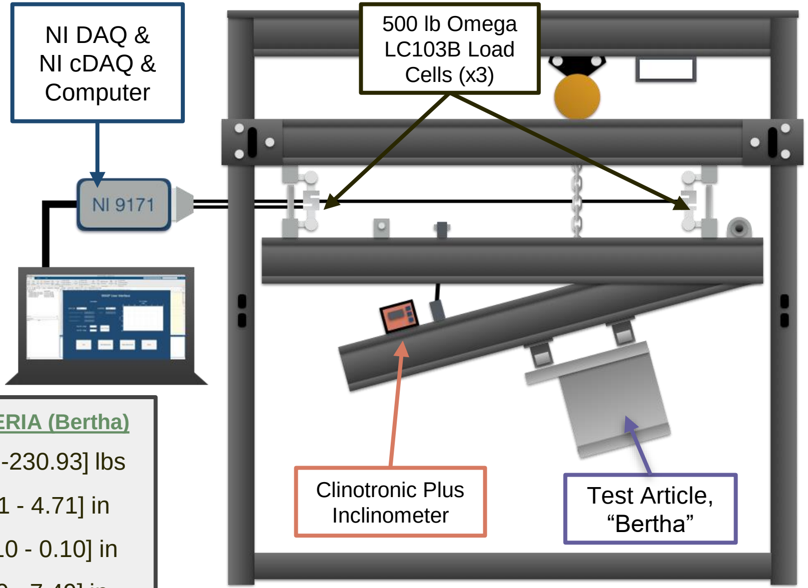
- **Pass Criteria:**
  - No yielding, cracks, or other forms of structural failure.
  - FOS > 2.0 in members measured by strain gauges (strain → stress → FOS)
- **Test Date:**
  - 3/15 - 3/22
- **Expected Results/Off-Ramps:**
  - **Pass:** Expected - move forward with MAT
  - **Fail:** Analyze failure mode, revisit analysis and design, redesign and attempt to rebuild

Measurement Accuracy Test

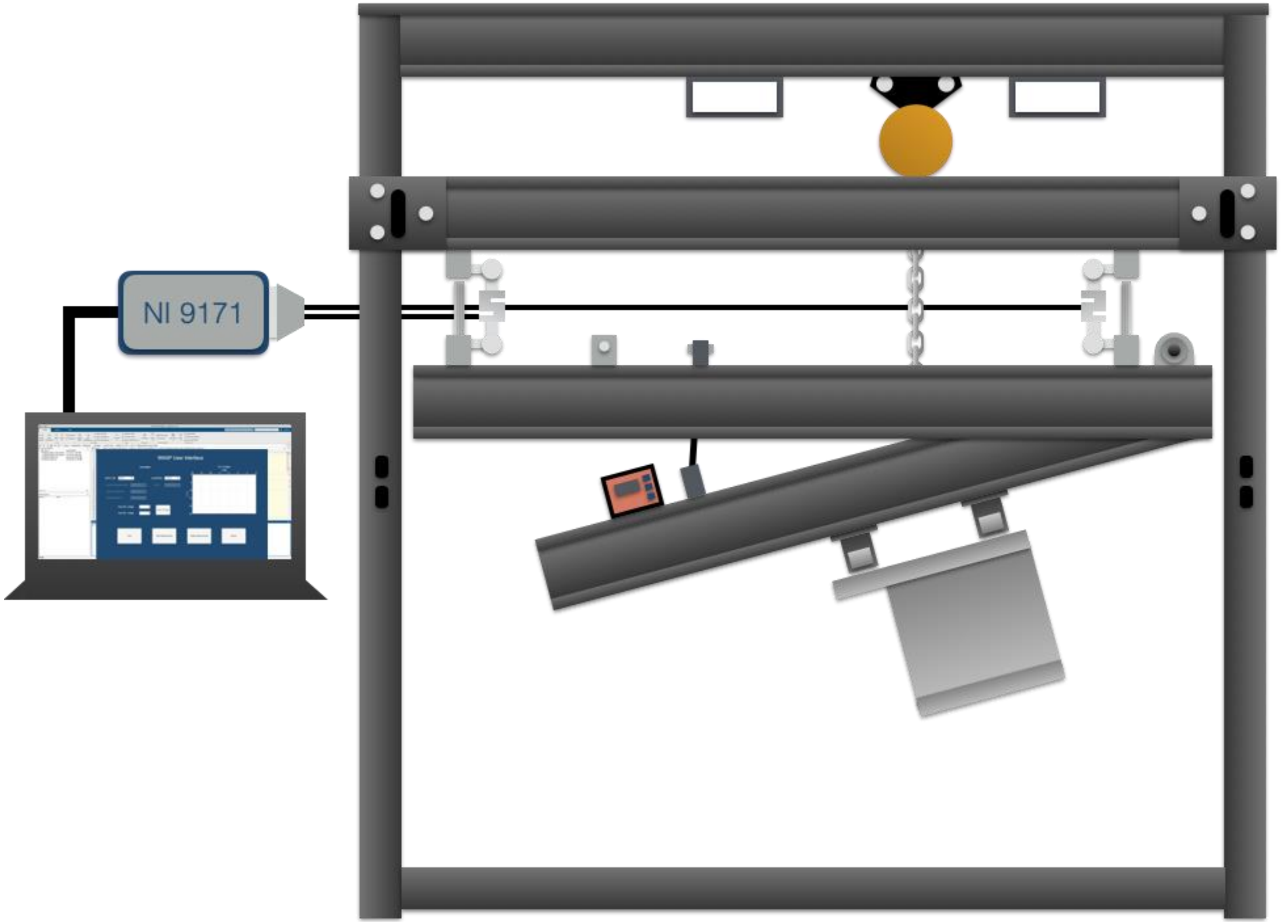
DR 1.1: WASP shall measure the weight of the pod within a tolerance of ± 0.1% of the pod weight
DR 2.1: WASP shall measure the CG of the pod within a tolerance of ± 0.1” of the pod CG
CPE 2: WASP shall rigidly interface with lugs for all pods types
CPE 3: WASP must satisfy the strict accuracy tolerances given in the requirements

Deadline: 4/12
Not Started

- **Rationale/Motivation:**
  - Validate accuracy predictions of Monte Carlo Simulation (>95% success)
- **Procedure:**
  - Complete 5 standard measurement sets with the test article
  - Record measured weight and CG
- **Expected Results/Off-Ramps:**
  - **Pass:** All reported values within accuracy tolerances
  - **Fail:** Recalibrate the software and remeasure dimensions



PASS CRITERIA (Bertha)
W = [230.47-230.93] lbs
X CG = [4.51 - 4.71] in
Y CG = [-0.10 - 0.10] in
Z CG = [7.29 - 7.49] in


NI 9171

System Accreditation

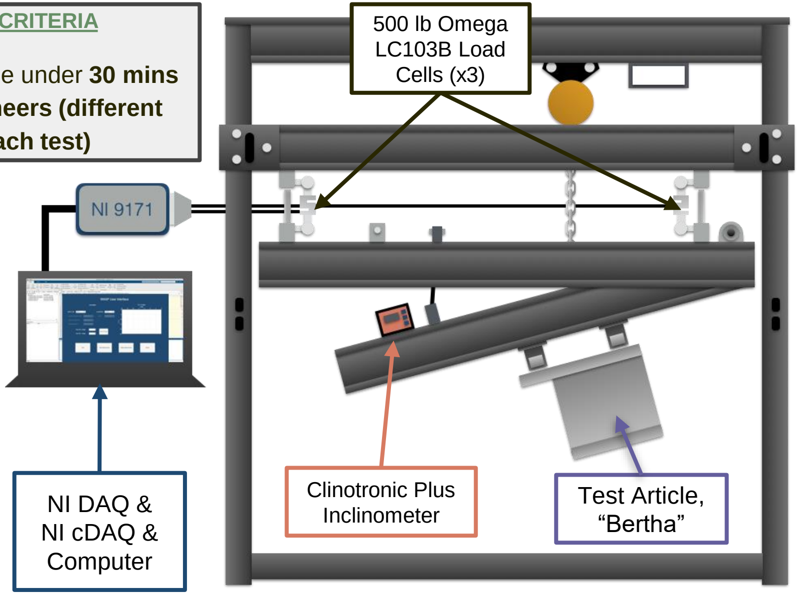
DR 6.1: WASP shall complete a single weight and balance test in no more than 30 minutes
DR 6.3: WASP shall require no more than two engineers to complete one test
CPE 4: Test procedures must be well developed
CPE 5: Pods and WASP operators should be safe from harm.

Deadline: 5/3
Not Started

- **Rationale/Motivation:**
  - Verify procedural requirements
- **Procedure:**
  - Run multiple accuracy tests with non-WASP engineers
  - Record weight and CG measured by volunteers
- **Expected Results/Off-Ramps:**
  - **Pass:** Prepare for delivery to customer
  - **Fail:** Modify the procedure and/or downgrade to level 2 objectives

PASS CRITERIA

Avg. Test Time under **30 mins** with **2 engineers (different for each test)**



Additional Checks Completed

Check	*Motivation*
Quality Checks on components (manufactured and COTS)	Match specifications to model
Conductivity on wire harnesses	Ensure pins are connected ONLY to correct input/outputs
Communication with Load Cells using fabricated harnesses	Demonstrate ability to pull data from load cells using final harnessing
Test/debug Measurement Accuracy Test script with electronics	Demonstrate functionality of the script to obtain necessary data for MAT
Test/debug User Interface with electronics	Demonstrate UI’s ability to correctly control data acquisition functions for WASP operation
Sliding Interface Fit Check	Ensure manufacturing imperfections allow smooth operation

Risk Assessment

Risk - Test Key

1. **LC-Misalignment -** Measurement Accuracy Test
2. **Misalignment -** Structural Integrity Test
3. **Structural Failure -** Structural Integrity Test
4. **Lug Interface -** Lug Mount Tensile Test
5. **Human Error -** System Accreditation
6. **COVID -** All
7. **Budget -** All

Risk Matrix	Impact Level				
Likelihood Level		*Low*	*Mild*	*Medium*	*High*
	High			**Misalignment**	**LC-Misalignment**
	Medium		**Misalignment**	**Budget COVID**	**Structural Failure Lug Interface Human Error Budget COVID**
	Low		**LC-Misalignment**		**Structural Failure Lug Interface Human Error**

Testing Status

Level	Test	Procedure Finalized?	Test Conducted?	Analysis Complete?
Component	Lug Mount Tensile	Yes	Yes	Yes
	Load Cell Characterization	Yes	Yes	Finish by 3/8
Sub-System	E&S Functionality	Yes	Yes	Yes
	Structural Integrity	Finish by 3/8	Scheduled 3/15	Scheduled 3/22
System	Measurement Accuracy	Finish by 3/22	Scheduled 3/29	Scheduled 4/12
	System Accreditation	Finish by 3/22	Scheduled 4/12	Scheduled 4/12

MTS Exceed Series 40 General Specifications

Accuracy Class	ISO 7500 Class 0.5 / Class 1 or ASTM E4
Force Range	0.4% - 100% of rated force capacity / 0.2-100% of rated force capacity
Rated Maximum Force at Max. Test Speed	100%
Rated Maximum Test Speed at Maximum Force	100%
Force Capacity	± 0.5% of the displaying / ± 1% of the displaying
Speed Accuracy	Set speed < 0.01mm/min: speed accuracy is within ± 1.0% of set speed Set speed ≥ 0.01mm/min: speed accuracy is within ± 0.2% of set speed
Position Accuracy	Within ± 0.5%
Strain Measuring Range	0.2% - 100% FS
Strain Accuracy	Class 0.5 and Class 1
Security Protection	Over-force, travel limits, over-voltage and others
Over Force Protection	10%
Data Acquisition Rate	1000 Hz
Control Loop Rate	1000 Hz
Environmental Requirements (For indoor use only)	
Operating Temperature	*5° C to 40° C (41° F to 104° F)*
Operating Humidity	*5% - 85% non-condensing*
Storage Temperature	*-18° C to 49° C (0° to 120° F)*
Maximum Storage Humidity	*90% non-condensing*
Maximum Attitude	*2000 meters*
Motor & Drive System	AC Servo Motor
Ballscrews	Pre-Forced
Position Measurement	Encoder
Additional DC Conditioning Channels	2 channels *(Examples: resistive extensometers and force cells)*
Additional Digital Conditioning Channels	1 channel *(Examples: long travel extensometer and quadrature encoders)*

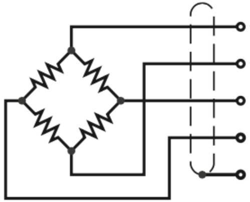
MTS Exceed Series 40 E45.105 Specifications

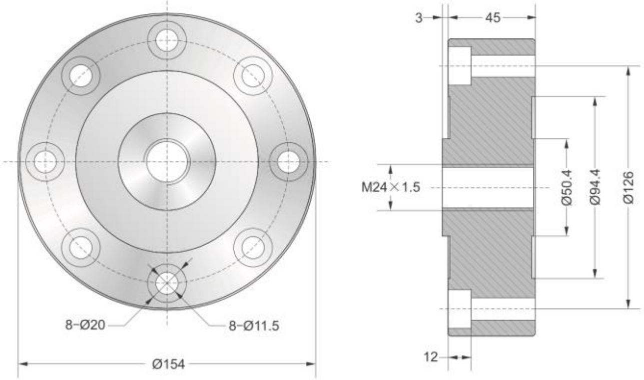
Model	E44.304	E45.105	E45.305
Maximum Rated Force Capacity	30 kN	100 kN	300 kN
Force Capacity Options	100 N, 250 N, 500 N, 1 kN, 2 kN, 5 kN, 10 kN, 20 kN, 30 kN	5 kN, 100 kN	200 kN, 300 kN
Frame Type	Floor-standing	Floor-standing	Floor-standing
Test Zones (single/dual)	Single/Dual	Single/Dual	Single/Dual
Maximum Test Speed	500 mm/min	500 mm/min	250 mm/min
Minimum Test Speed	0.001 mm/min	0.001 mm/min	0.001 mm/min
Position Resolution	0.000041 mm	0.000041 mm	0.000041 mm
Middle Crosshead Travel (without grips)	1150 mm	1050 mm	1100 mm
Middle Crosshead Travel (with grips)	850 mm (with XSD204B grips)	500 mm (with XSA105A grips)	540 mm (with XSA305A grips)
Test Width	340 mm	600 mm	580 mm
Frame Dimension (height x width x depth)	1862 x 845 x 716 mm	2133 x 1230 x 870 mm	2360 x 1215 x 960 mm
Weight	435 kg	1400 kg	1700 kg
Power Requirement	Single-phase 200-230V AC, 6 Amp 50/60 Hz, 1200W	Single-phase 200-230V AC, 10 Amp 50/60 Hz, 2000W	Three-phase 380-415V AC, or 440-480V AC, 6.8 Amp 50/60 Hz, 5000W

MTS Machine - DBSL-XS-10T Load Cell (100 kN)

Schematic

Red : + input
Black : − input
White : − output
Green : + output

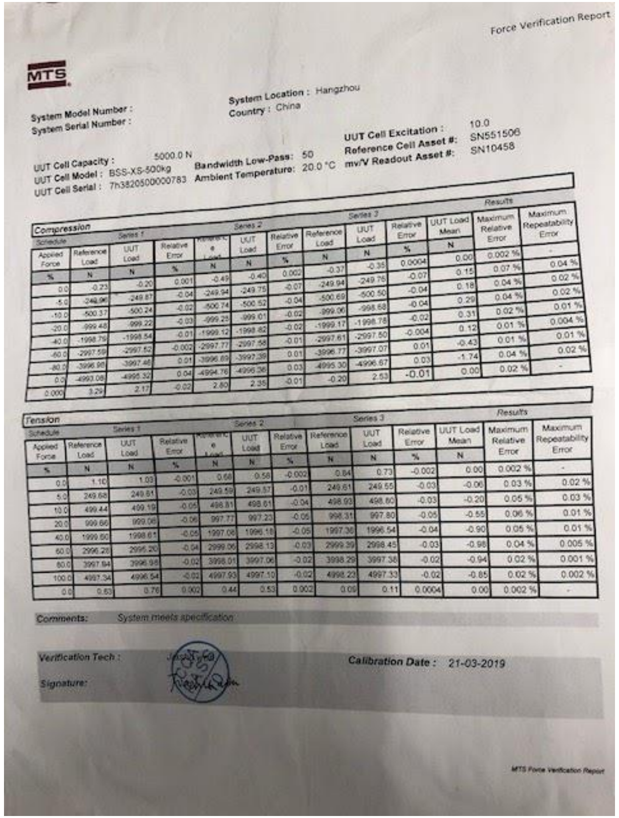




Specifications

Rated Output	3.0mV/V ±0.25%	Safe Temp. Range	-10ºC to + 70ºC
Zero Balance	±1% of rated output	Temp. Compensated	-10ºC to + 40ºC
Creep after 30 minutes	±0.03% of rated output	Safe Overload	150%
Nonlinearity	±0.03% of rated output	Input Impedance	387 ohm ± 20 ohm
Hysteresis	±0.03% of rated output	Output Impedance	350 ohm ± 5 ohm
Repeatability	±0.03% of rated output	Insulation Resistance	≥5000 M ohm (50V DC)
Temp. effect on output	≤0.002% of applied output/ºC	Rated Excitation	10V DC/AC
Temp. effect on zero	≤0.002% of rated output/ºC	Maximum Excitation	15V DC/AC
Wire Length	6m	Wire Material	Red(+E) Black(-E) White(-S) Green(+S)

MTS Machine - BSS--XS-500kg Load Cell (5 kN)



Force Verification Report

MTS

System Model Number :
System Serial Number :

System Location : Hangzhou
Country : China

UUT Cell Capacity : 5000.0 N
UUT Cell Model : BSS-XS-500kg
UUT Cell Serial : 7h3820500000783

Bandwidth Low-Pass: 50
Ambient Temperature: 20.0 °C

UUT Cell Excitation : 10.0
Reference Cell Asset #: SN551506
mv/V Readout Asset #: SN10458

Compression

Schedule	Series 1			Series 2			Series 3			Results		
Applied Force	Reference Load	UUT Load	Relative Error	Reference Load	UUT Load	Relative Error	Reference Load	UUT Load	Relative Error	UUT Load Mean	Maximum Relative Error	Maximum Repeatability Error
%	N	N	%	N	N	%	N	N	%	N		
0.0	-0.23	-0.20	0.001	-0.49	-0.40	0.002	-0.37	-0.35	0.0004	0.00	0.002 %	-
-5.0	-248.96	-249.87	-0.04	-249.94	-249.75	-0.07	-249.94	-249.76	-0.07	0.15	0.07 %	0.04 %
-10.0	-500.37	-500.24	-0.02	-500.74	-500.52	-0.04	-500.69	-500.50	-0.04	0.18	0.04 %	0.02 %
-20.0	-999.48	-999.22	-0.03	-999.25	-999.01	-0.02	-999.06	-998.68	-0.04	0.29	0.04 %	0.02 %
-40.0	-1998.79	-1998.54	-0.01	-1999.12	-1998.82	-0.02	-1999.17	-1998.78	-0.02	0.31	0.02 %	0.01 %
-60.0	-2997.59	-2997.52	-0.002	-2997.77	-2997.58	-0.01	-2997.61	-2997.50	-0.004	0.12	0.01 %	0.004 %
-80.0	-3996.98	-3997.46	0.01	-3996.89	-3997.39	0.01	-3996.77	-3997.07	0.01	-0.43	0.01 %	0.01 %
0.0	-4993.08	-4995.32	0.04	-4994.76	-4996.38	0.03	-4995.30	-4996.67	0.03	-1.74	0.04 %	0.02 %
0.000	3.29	2.17	-0.02	2.80	2.35	-0.01	-0.20	2.53	-0.01	0.00	0.02 %	-

Tension

Schedule	Series 1			Series 2			Series 3			Results		
Applied Force	Reference Load	UUT Load	Relative Error	Reference Load	UUT Load	Relative Error	Reference Load	UUT Load	Relative Error	UUT Load Mean	Maximum Relative Error	Maximum Repeatability Error
%	N	N	%	N	N	%	N	N	%	N		
0.0	1.10	1.03	-0.001	0.68	0.58	-0.002	0.84	0.73	-0.002	0.00	0.002 %	-
5.0	249.68	249.61	-0.03	249.59	249.57	-0.01	249.61	249.55	-0.03	-0.06	0.03 %	0.02 %
10.0	499.44	499.19	-0.05	498.81	498.61	-0.04	498.93	498.60	-0.03	-0.20	0.05 %	0.03 %
20.0	999.66	999.06	-0.06	997.77	997.23	-0.05	998.31	997.80	-0.05	-0.55	0.06 %	0.01 %
40.0	1999.60	1998.61	-0.05	1997.08	1996.18	-0.05	1997.36	1996.54	-0.04	-0.90	0.05 %	0.01 %
60.0	2996.28	2995.20	-0.04	2999.06	2998.13	-0.03	2999.39	2998.45	-0.03	-0.98	0.04 %	0.005 %
80.0	3997.94	3996.98	-0.02	3998.01	3997.06	-0.02	3998.29	3997.38	-0.02	-0.94	0.02 %	0.001 %
100.0	4997.34	4996.54	-0.02	4997.93	4997.10	-0.02	4998.23	4997.33	-0.02	-0.85	0.02 %	0.002 %
0.0	0.63	0.76	0.002	0.44	0.53	0.002	0.09	0.11	0.0004	0.00	0.002 %	-

Comments: System meets specification

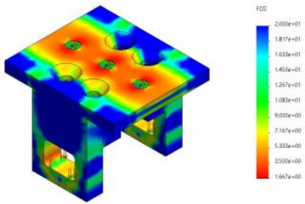
Verification Tech :
Signature:

Calibration Date : 21-03-2019

MTS Force Verification Report

Lug Mount Tensile Test - FEA

- **Reasons for Model Inaccuracy:**
  - Fixed geometry: Not physical for this situation as they are clearance holes. Fixing a face requires the material around it to provide reaction loading that can be orders of magnitude higher than if they are allowed to move slightly
    - e.g. when preparing for PDR we were originally fixing the ends of our beams. This would require other beams to not twist at all, leading to safety factors of 0.6 or less. In reality, those beams could twist (sometimes only by 0.064 degrees), increasing the safety factor by 100x or more.
  - Rigidity of assembly: FEA was not taking increased rigidity due to interactions between individual members into account - this decreased deflection in more vulnerable members and pushed yielding back. For example, lug pin and bolts (not modeled here) would contribute reactions to prevent top plate from bending. The interface between the plate and flanges is treated like fused material (i.e. it's all one part) which would provide some internal reactions, but not as much as when the lug pin and bolts are factored in.



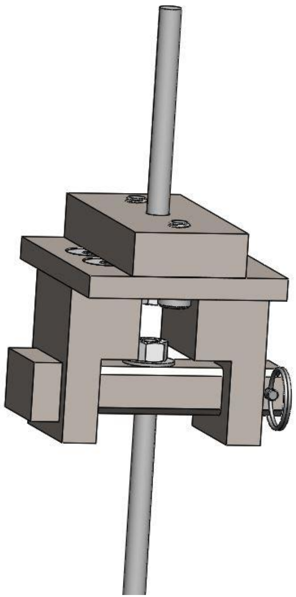
Lug Mount Tensile Test - FEA

- **Reasons for Model Inaccuracy:**
  - Type of yielding: Upon inspection, there was some an indentation on the top plate left behind by the washer. This is technically yielding, but does not affect the assembly or lead to catastrophic failure. This type of yielding is predicted by the model, but is not noticeable in MTS data. This could account for the lower-than-seen safety factors in our model.

Lug Mount Tensile Test - Additional Information

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0
CPE 1: Frame must statically support pods of up to 2000 lbs
CPE 5: Pods and WASP operators should be safe from harm.

- **Equipment/Facilities:**
  - Pilot Lab Electromechanical MTS machine
  - Modified 2000 lb lug mount assembly
    - 2 x ⅜-16 hex bolt connectors
    - 3/8” clearance hole in pin
    - 2” x 4” x 3/4” block to simulate testbed centerbeam
- **Procedure:**
  - Modified Tension (simplified) code in MTS TestSuite
  - Pull lug mount at 0.03 in./min until failure,
  - Record force [lbf], time [s], and extension [in.]



Model of Assembly with Interface

Lug Mount Tensile Test - Yielding Point Characterization

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0

CPE 1: Frame must statically support pods of up to 2000 lbs

CPE 5: Pods and WASP operators should be safe from harm.

- **Yielding at 13000 lbs could have been due to threads in interface or top plate**
  - In order to determine whether plate yielding began at that point:
    - Found the time at which yielding began in MTS data (607.858 seconds)
    - Found the video time associated with interface failure (555 seconds) and compared it to interface failure time in MTS data (778.858 seconds). Difference of 223.858 seconds
    - Used this to calculate time where yielding began in the video (607.858-223.858 = 384 seconds)
  - After careful inspection of the video, the plate began to visibly yield within 20 seconds of the 384s mark. So too, however, did the bolt threads.
  - Since the threads are small and moved little, they did not contribute to the majority of the yielding. It is safe to say that the safety factor of the mount is closer to 6.5 than 7.75, and that plastic deformation began closer to 13000 lbs than 15500 lbs when the interface failed.

Structural Integrity Test - Weld Table Weight

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0
DR 3.3: WASP shall lift pods out of their cradles
CPE 1: Frame must statically support pods of up to 2000 lbs
CPE 5: Pods and WASP operators must be safe from harm.

- **Weld Table Weighing:**
  - Currently do not know the weight of the table precisely
  - Options for weighing:
    - Weigh station - Drive truck to a weigh station with and without the table, take weight difference
    - 500 lb compression load cells and moment balance calculations - Assume CG is in the center of the table, measure force on load cells as a fulcrum is moved further from the center. Use these to determine the load on the fulcrum and sum with load cells to find weight
    - Custom load cell - Block of steel/aluminum with strain gauge attached. Characterize strain in MTS machine, then hang the table from the forklift with lift straps, measure strain, and correlate to a load
    - Heavy-duty hanging scale - Hang from forklift with lift straps ($90) https://www.vevor.com/products/hanging-scale-crane-scale-1000-kg-2000-lb-digital-industrial-heavy-duty-auto-off?gclid=CjwKCAiAm-2BBhANEiwAe7eyFEBeR4h483yczqLsTEoCgPsjyWkDRFTrqD-77TCHRVdJXwsf2x8z9hoCBGAQAvD_BwE

  - Factors in deciding:
    - Time - SIT must be conducted in mid-March
    - Budget - Avoid cutting into management reserves as much as possible given other constraints
    - Complexity - Increased complexity increases both error and time

Structural Integrity Test - Weld Table Weight

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0
DR 3.3: WASP shall lift pods out of their cradles
- **CPE 1:** Frame must statically support pods of up to 2000 lbs
- **CPE 5:** Pods and WASP operators must be safe from harm.

- **Update:**
  - After significant discussion, the team decided to weigh the plate using WASP
  - Will connect the weld table with the dummy load cells in place (after testing with smaller known weights)
  - Once structural integrity is guaranteed with the table, replace load cell replacement blocks with 1000 lb FSO load cells
  - Tare weight of testbed and measure the table
  - Once characterized, can replace the load cells with the dummy blocks and perform the actual structural integrity test with 2000 lbs.

Structural Integrity Test - Additional Information

DR 3.1: Structural components must have a safety factor against yield of greater than 2.0
DR 3.3: WASP shall lift pods out of their cradles
CPE 1: Frame must statically support pods of up to 2000 lbs
CPE 5: Pods and WASP operators must be safe from harm.

- **Equipment/Facilities:**
  - Machine shop welding table and scrap metal, lift straps, strain gauges, WASP DAQ system
- **Procedure:**
  - Utilize ~1300 lb welding table, ~700 lbs of metal, and interfacing. Thread lifting straps through welding table holes and attach to WASP via lug mounts.
  - Check for yielding or other signs of failure throughout the structure (especially in regions of complex geometry). Measure strain in critical (based on FEA) locations using strain gauges

Load Cell Characterization - Statistical Analysis (1)

Linear Model: 500lbs LC

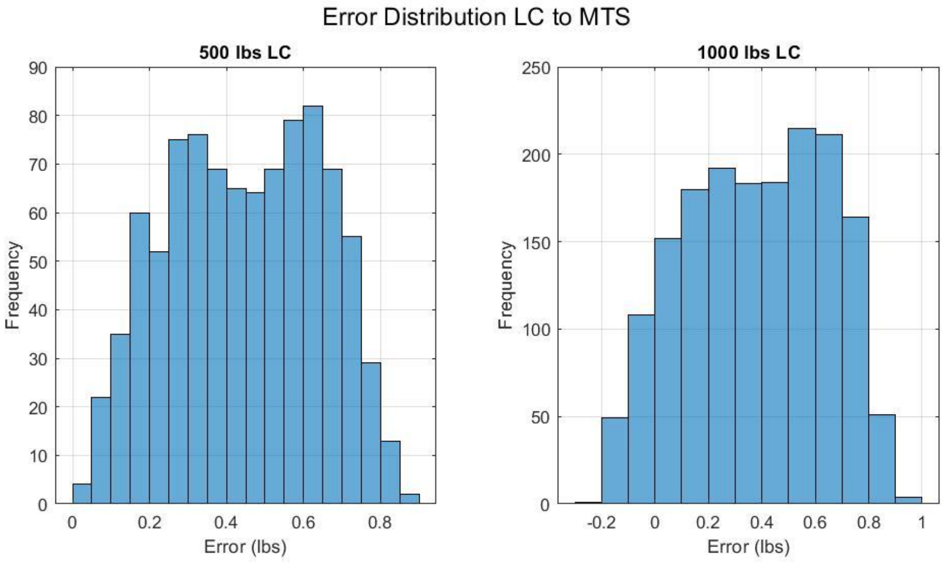
```
Linear regression model:
    y ~ 1 + x1

Estimated Coefficients:
                   Estimate        SE         tStat     pValue
                  __________    __________    ______    ______

    (Intercept)   1.6259e-05      3.29e-08    494.19      0
    x1             6.006e-06    1.0172e-10     59047      0


Number of observations: 920, Error degrees of freedom: 918
Root Mean Squared Error: 3.46e-07
R-squared: 1,  Adjusted R-Squared: 1
F-statistic vs. constant model: 3.49e+09, p-value = 0
```

Linear Model: 1000lbs LC

```
Linear regression model:
    y ~ 1 + x1

Estimated Coefficients:
                   Estimate         SE           tStat       pValue
                  __________    __________    __________    ______

    (Intercept)   1.4277e-05    1.4385e-08        992.47      0
    x1            3.0056e-06    2.2693e-11    1.3245e+05      0


Number of observations: 1694, Error degrees of freedom: 1692
Root Mean Squared Error: 2.27e-07
R-squared: 1,  Adjusted R-Squared: 1
F-statistic vs. constant model: 1.75e+10, p-value = 0
```

Load Cell Characterization - Statistical Analysis (2)

Normality of Error - 500lbs and 1000lbs Load Cells



Normality of Error: LC - MTS

$\mathbf{H_0}$: $E \sim N(\mu_E, \sigma_E)$; $\mathbf{H_a}$: $E \nsim N(\mu_E, \sigma_E)$

K-S Test for Normality, $\alpha = 5\%$

500 lbs LC: $p = 6.54 \times 10^{-4} < \alpha$

1000 lbs LC: $p = 1.12 \times 10^{-6} < \alpha$

REJECT THE NULL HYPOTHESIS

Performed K-S test on both the unadjusted and standard normalized data sets - both were non-normal

Monte Carlo Simulation

DR 1.1: WASP shall measure the pod weight within a tolerance of ±0.1% of the total pod weight

DR 2.1: WASP shall measure the pod X, Y, & Z CG of each pod with an accuracy of ±0.1 in.

Updates to model:

- **Inclinometer accuracy = ±0.025°**, Wyler Clinotronic Plus [10]
- Load Cells Error distribution model
  - Mean = 0.0 % FSO
  - **Std. Dev. = (1/2.4)*(0.02% FSO)** [1]
- Worst-case scenario - model evaluated at **maximum** expected error:

W: 0.18% → 6.7σ
XCG: 0.05 in → 3.0σ
YCG: 0.07 in → 10.4σ
ZCG: 0.14 in → 3.3σ

	Load Cell Sensor Full-Span	
Pod Weight [lbs]	500 lbs	1000 lbs
200	> 95%	> 95%
300	> 95%	> 95%
350	> 95%	> 95%
400	X	> 95%
500	X	> 95%
600	X	> 95%
700	X	> 95%
800	X	> 95%
850	X	>95%
900	X	> 95%
1000	X	> 95%

Expected Success Rate for Satisfying Accuracy Requirements for Weight and CG vs. Pod Weight

(From Monte Carlo Simulations with N = 10000)

Electronics Hardware

Omega LC103B Load Cells [8]

Specifications:

Accuracy (>25lb): class C3
Approvals(>25lb): OIML R60
Output sensitivity (mV/V): 3.0±0.008 *(≤25lb 2.0±0.006)*
Maximum number of load cell intervals (nLC): 3000
Ratio of minimum LC verification interval (Y=Emax/vmin): 10000
Combined error (%FS): ±0.020
Minimum dead load: 0
Safe overload (%FS): 150%
Ultimate overload (%FS): 300%
Zero balance (%FS): ±1.0%
Excitation, recommended voltage (V): 5 to 12(DC)
Excitation maximum (V): 18(DC)
Input resistance (Ω): 430 ± 50
Output resistance (Ω): 351 ± 2
Insulation resistance (MΩ): ≥ 5000 (50VDC)
Compensated temperature (°C): -10 to 40
Operating temperature (°C): -35 to 65
Storage temperature (°C): -40 to 70
Element material: Stainless steel
Ingress protection (according to EN 60529): IP67
Recommended torque on fixation (Thread:lbf.ft):1/4"UNF:18 1/2"UNF:55 3/4"UNF:330 1"UNF:550 1 1/8"UNF:1070
Recommended torque on fixation (Thread:Nm):M8:25 M12:75 M20:450 M24:750 M30:1450

Wyler AG Clinotronic Plus [10]

Measuring range Messbereich		± 10 Arcdeg	± 30 Arcdeg	± 45 Arcdeg ± 60 Arcdeg
Calibration / Kalibrierung	Last values at: / letzte Werte bei:	± 10 Arcdeg	± 30 Arcdeg	± 50 Arcdeg resp. ± 60 Arcdeg
Limits of Error / Fehlergrenze		< 1 Arcmin + 1 Digit	< 1.5 Arcmin + 1 Digit	< 2 Arcmin + 1 Digit
Settle time / Messzeit	Value available after / Anzeige nach:	< 2 Secs.		
Resolution / Auflösung	Dep. on units set / abhängig von Einstellung	> 5 Arcsec (0.025 mm/m)		
Temp. Coeff. / Temperatur-Koeff.	Zero and scale / Null und Skala	< 0.01 Arcdeg./°C		
Data connection / Anschluss		RS485 / asynchron / 7 Bit / 2 Stop Bit / no parity / 9600 Baud		
Battery / Batterie		1 x Size AA 1.5V Alkaline		

NI 9237 Bridge Module [14]

DATASHEET

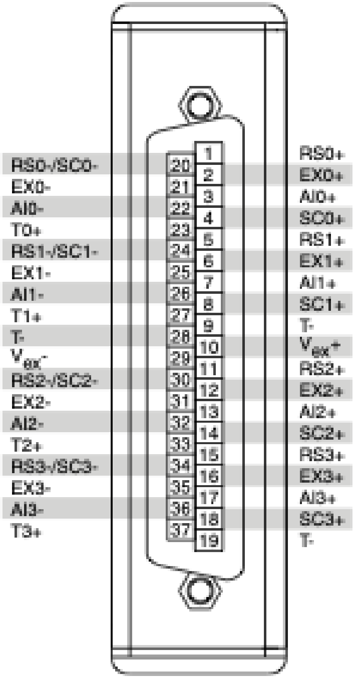
NI 9237

4 AI, ±25 mV/V, 24 Bit, 50 kS/s/ch Simultaneous, Bridge Completion

- 4 channels, 50 kS/s per channel simultaneous AI
- ±25 mV/V input range, 24-bit resolution
- Programmable half- and full-bridge completion with up to 10 V internal excitation
- 60 VDC, Category I bank isolation
- RJ50 or D-SUB connectivity options
- -40 °C to 70 °C operating range, 5 g vibration, 50 g shock

http://www.ni.com/pdf/manuals/374186a_02.pdf

NI 9237 Pinout/ Signal Descriptions [14]



Signal Descriptions

Table 1. NI 9237 Signal Descriptions

Signal Name	Description
AI+	Positive analog input signal connection
AI-	Negative analog input signal connection
RS+	Positive remote sensing connection
RS-	Negative remote sensing connection
EX+	Positive sensor excitation connection
EX-	Negative sensor excitation connection
T+	TEDS data connection
T-	TEDS return connection
SC	Shunt calibration connection

NI cDAQ-9171 Compact DAQ [15]

DEVICE SPECIFICATIONS

NI cDAQ™-9171

NI CompactDAQ One-Slot Bus-Powered USB Chassis

These specifications are for the NI cDAQ-9171 chassis only. These specifications are typical at 25 °C unless otherwise noted. For the C Series module specifications, refer to the documentation for the C Series module you are using.

Analog Input

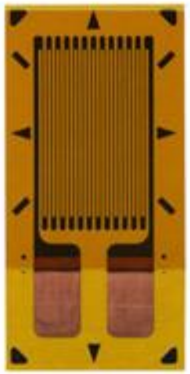
Input FIFO size	127 samples
Maximum sample rate[1]	Determined by the C Series module
Timing accuracy[2]	50 ppm of sample rate
Timing resolution[2]	12.5 ns
Number of channels supported	Determined by the C Series module

https://www.ni.com/pdf/manuals/374037b.pdf

Analog Output

Number of channels supported	
Hardware-timed task	
Onboard regeneration	16
Non-regeneration	Determined by the C Series module
Non-hardware-timed task	Determined by the C Series module
Maximum update rate	
Onboard regeneration	1.6 MS/s (multi-channel, aggregate)
Non-regeneration	Determined by the C Series module
Timing accuracy	50 ppm of sample rate
Timing resolution	12.5 ns
Output FIFO size	
Onboard regeneration	8,191 samples shared among channels used
Non-regeneration	127 samples
AO waveform modes	Non-periodic waveform, periodic waveform regeneration mode from onboard memory, periodic waveform regeneration from host buffer including dynamic update

MicroMeasurements CEA-06-250UW-350 Strain Gauge [16]



CHARACTERISTICS

Gage Length: 250
Resistance (Ω): 120,175,350,1000,120,175,350
Series: CEA,W2A
STC: 00,06,13,05,15,03,09
Options: P2,SP11

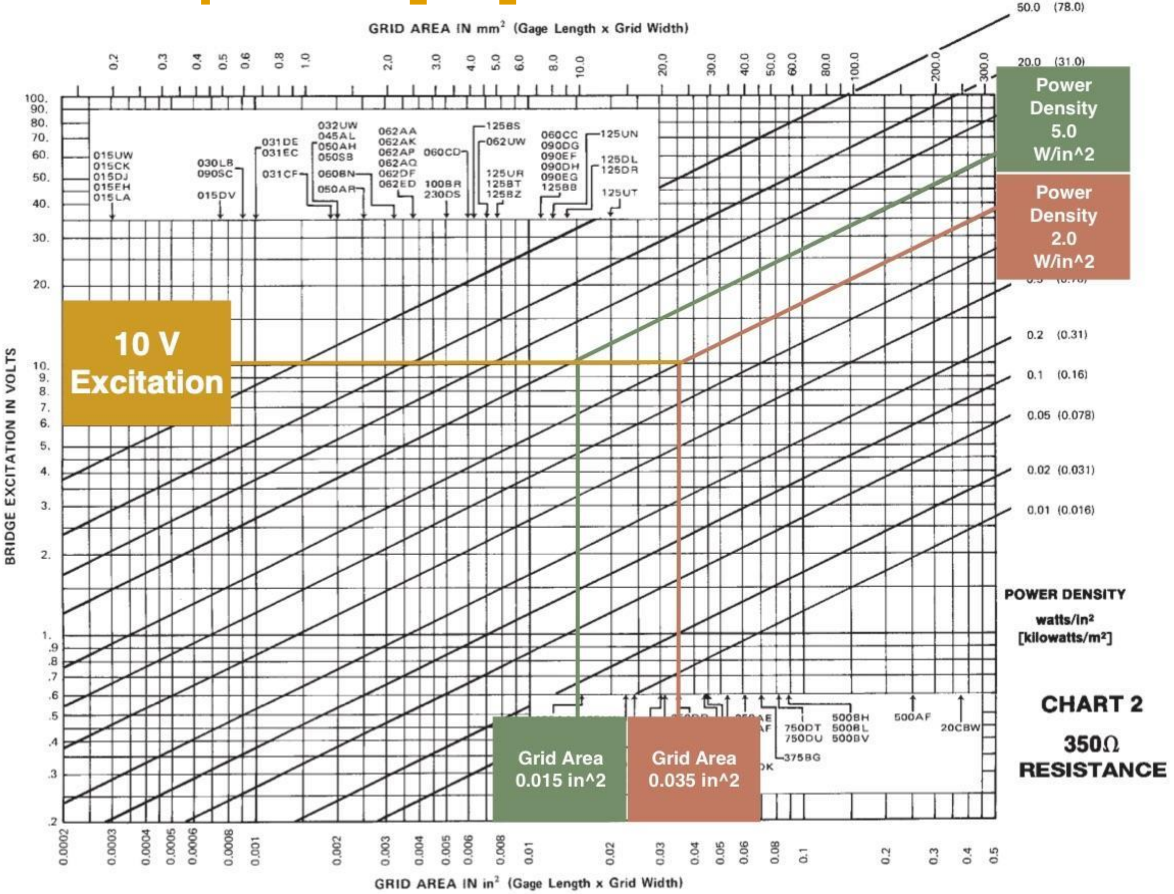
Dimensions:

Gage Length	Overall Length	Grid Width	Overall Width	Matrix Length	Matrix Width
0.25 in.	0.45 in.	0.18 in.	0.18 in.	0.55 in.	0.27 in.
6.35 mm	11.43 mm	4.57 mm	4.57 mm	14 mm	6.9 mm

https://micro-measurements.com/pca/detail/250uw

Strain Gauge Power Dissipation [12]

- **350Ω Resistance**
  - Same as LC103B
- **10V Excitation**
- **Moderate Accuracy**
  - Static conditions
  - 2 - 5 W/in^2
- **Grid Area Range**
  - 0.015 - 0.035 in^2
- **5 x EA-06-250UW-350-L**
  - 2 half-bridges
  - 1 quarter-bridge



DSUB-37 Connectors and Backshell [17] [18]

Connector [17]

https://www.digikey.com/en/products/detail/norcomp-inc/171-037-103L001/858153

Backshell [18]

https://www.digikey.com/en/products/detail/cinch-connectivity-solutions-aim-cambridge/40-9737H/3830312

4-Pin Connectors [19] [20]

Male, B4B-XH-A(LF)(SN) [19]

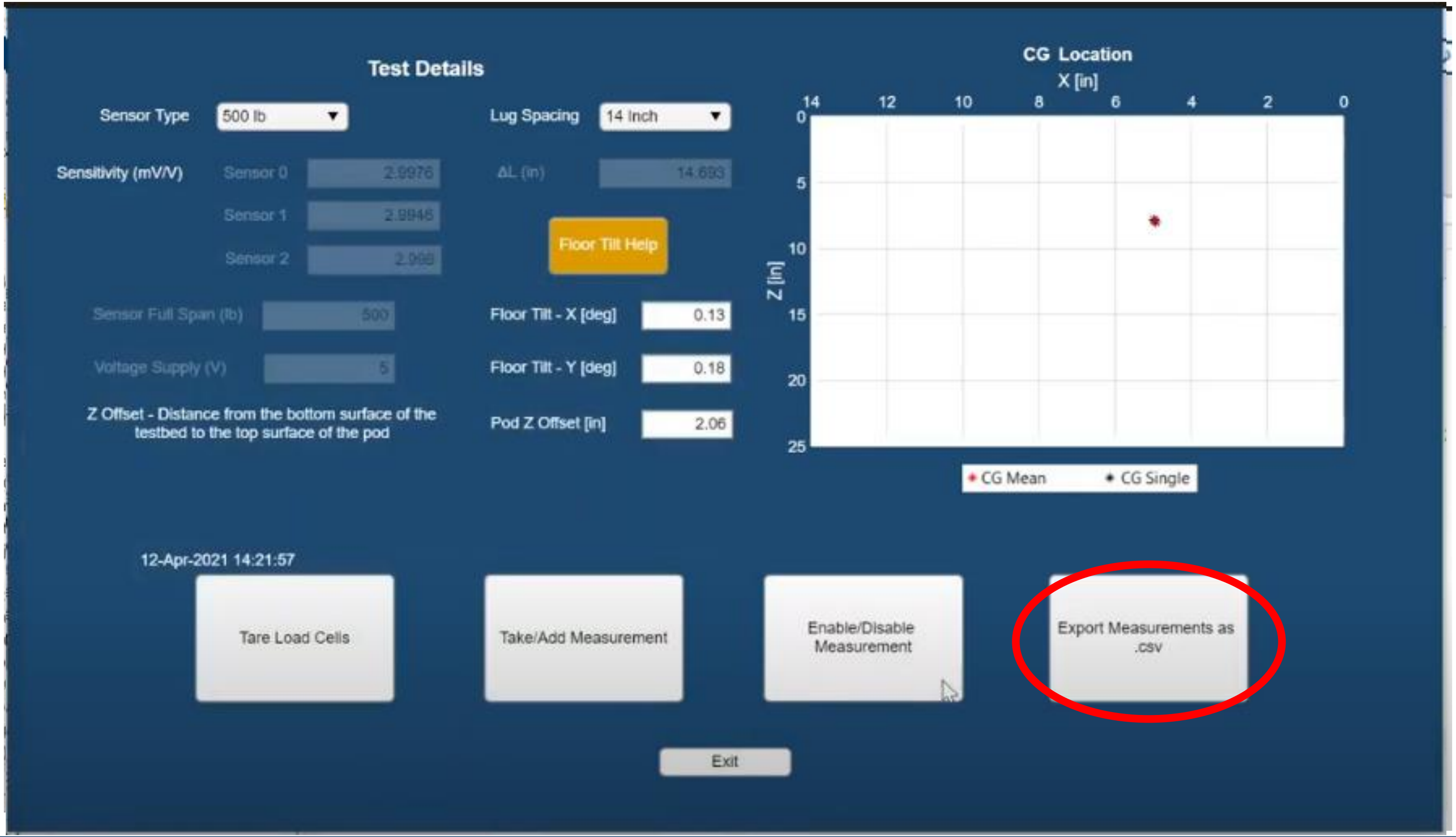
https://www.digikey.com/en/products/detail/jst-sales-america-inc/B4B-XH-A(LF)(SN)/1651047?utm_adgroup=Rectangular%20Connectors%20-%20Headers%2C%20Male%20Pins&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Product_Connectors%2C%20Interconnects_NEW&utm_term=&utm_content=Rectangular%20Connectors%20-%20Headers%2C%20Male%20Pins&gclid=CjwKCAiAo5qABhBdEiwAOtGmbhvw5bEfvam07AKWoDuHVHM6lvxH-ya19nDYdGUTEexmRweBrGN6khoCbqoQAvD_BwE

Female, 04JQ-BT [20]

https://www.digikey.com/en/products/detail/jst-sales-america-inc/04JQ-BT/4918835

GUI Operation

User Interface

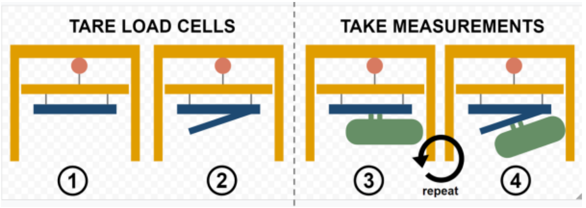


Safety

Safety Visual Checks

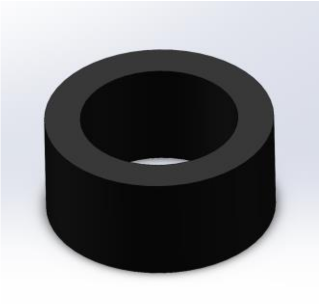
Pin Hooks

Test Bed Procedure Graphic

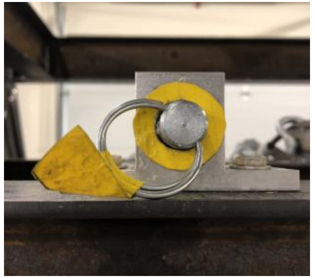


Do Not Push Decal

3D Printed Pin Caps



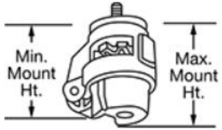
Color Coding (Pins/Load Cells/Lug Mounts)



Chain Hoist Slack Decal

Budget

Caster Wheels [21]



Mount Type	Stem
Wheel	
Diameter	2 1/2"
Width	1 1/8"
Number of	1
Mount Height	4 1/16"-4 5/8"
Capacity per Caster	1,100 lbs.
Hardness Rating	Hard
Hardness	Durometer 70D
Stem Type	Threaded
Stem Shape	Round
Stem Thread Size	1/2"-13
Stem Length	1 1/4"
Adjustment Style	Ratchet
Wheel/Tread Material	Nylon Plastic
Tread Shape	Flat
Nonmarking Wheels	Yes
Wheel Color	Black
Wheel Type	Solid
Wheel Bearing Type	Without Bearing

https://www.mcmaster.com/2445T24/