WASP Test Readiness Review

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ASEN 4028-011 Team 9

Company Customer:
Sierra Nevada Corporation (SNC)

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Presentation Outline

1. Project Overview
2. Project Updates
3. Schedule Review
4. Test Readiness
5. Budget Review

Project Overview

Project Overview

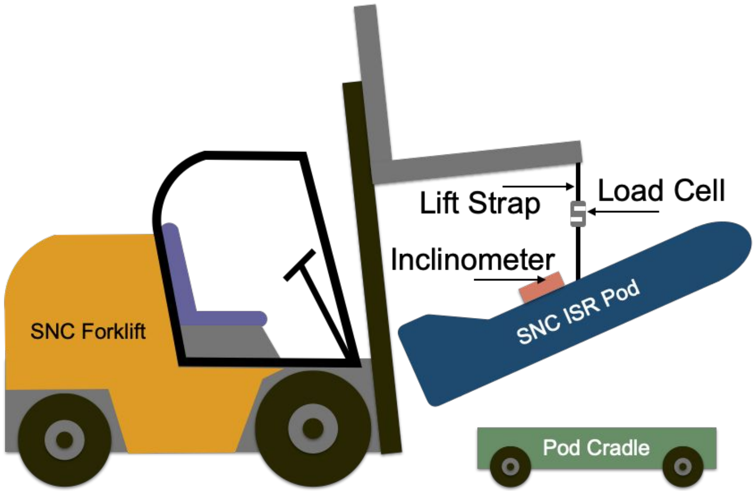
Background:

- **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**)

Concept of Operations

Transportation & Maneuverability

1) Pod mounted to WASP and lifted from cradle

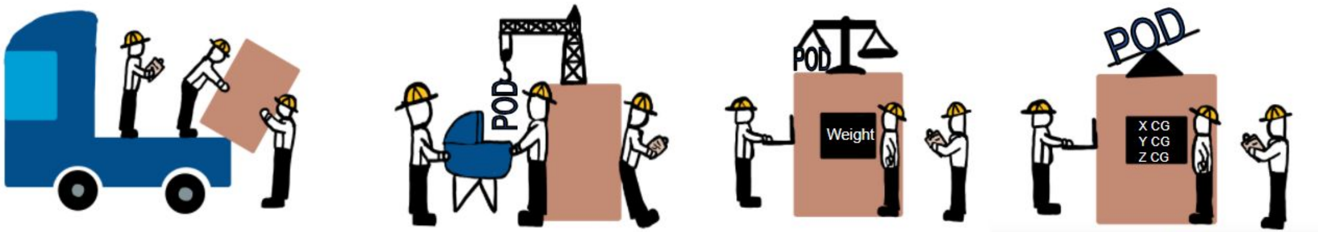
2) WASP weighs pod, records measurements

3) WASP tilts pod, records measurements

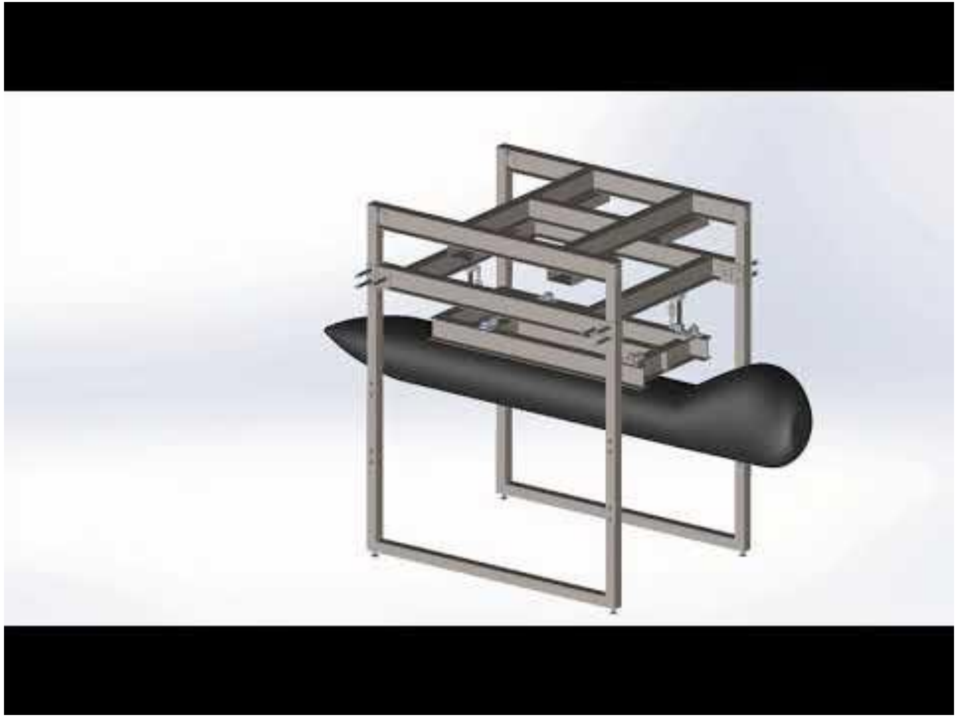
4) WASP returns pod to flat configuration

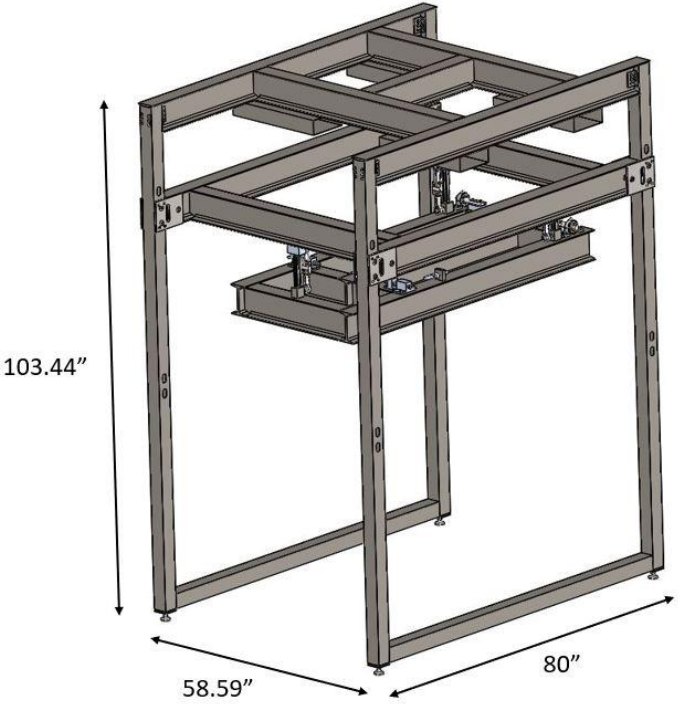
5) GUI computes total weight, CG

6) Pod lowered into cradle

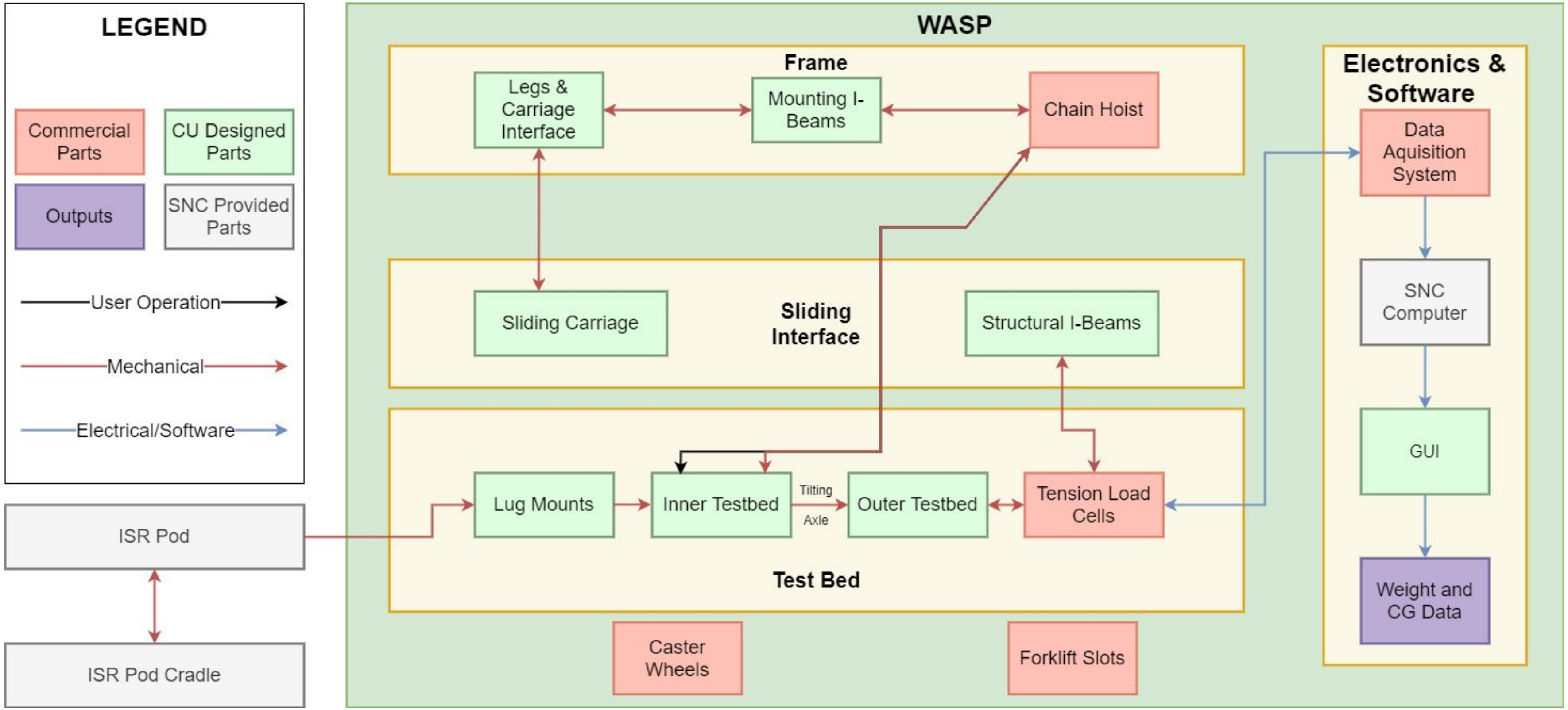


Baseline Design





Functional Block Diagram



Critical Project Elements

CPE	Description	FR
E1	All static possible loading must be handled by the frame. It must be portable and support at least 2000 lbs.	FR3, FR4
E2	WASP should rigidly interface with lugs for all pod types.	FR3
E3	WASP must be capable of weight measurements with ±0.1% of true value; CG measurements within ±0.1" of true value.	FR1, FR2
E4	Testing procedures for weight and CG calculations must be well-developed.	FR5
E5	Since heavy loads are involved, both the pods and WASP operators should be safe from harm.	FR5

Project Updates

Project Updates - Manufacturing Structure

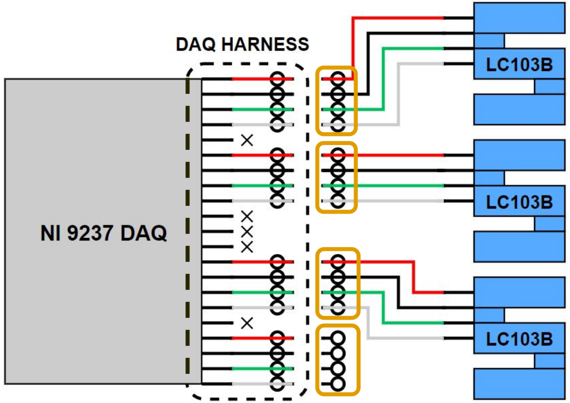
Forklift Slots

Outer Testbed

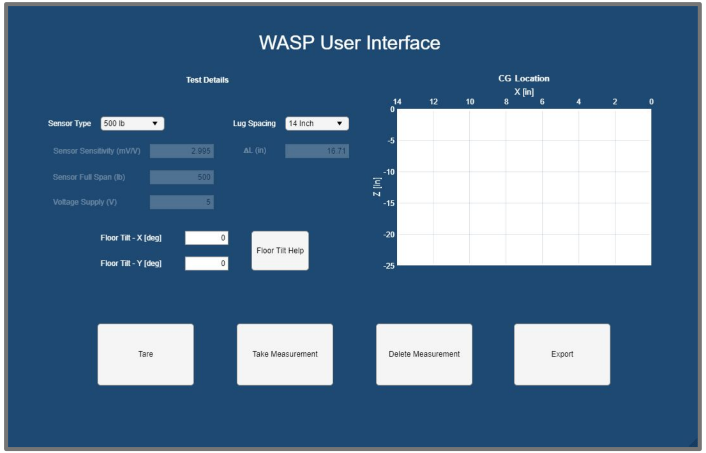
Outer Frame

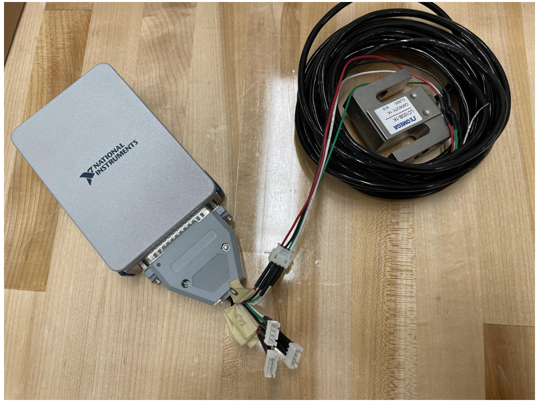
Sliding Interface

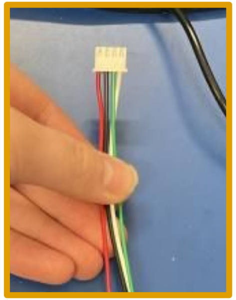
Project Updates - Electronics & Software



DAQ to Male Connectors Harness







Load Cells to Female Connector

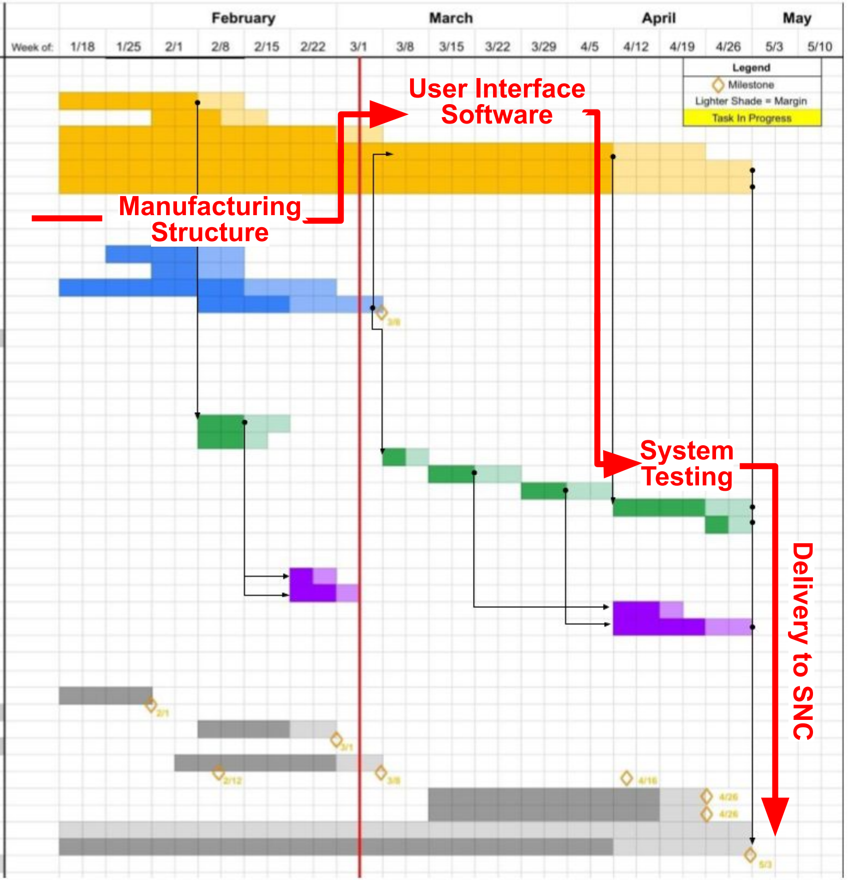
USER INTERFACE DEVELOPMENT

Phase	Description	Status
1	Main functionality	Complete
2	Improve Robustness	In Progress
3	System Accreditation	Not Started

Schedule

Spring Semester Overview - Critical Path

Status	WASP Task	Duration (weeks)	Margin (weeks)	Planned Start Date	Actual Start Date	Planned End Date	Deadline Date	Actual End Date
Ahead of Schedule	**Electronics & Software**							
	Build Connectors to DAQ for Test	1	1	11/25	12/1	12/2	12/9	12/1
	Build Cable Harnesses	5	1	11/25	12/1	1/29	2/5	2/8
	Build Connectors to Load Cells	1.5	1	2/1		2/11	2/18	2/8
	Test Specific Codes	6	1	10/28	10/28	3/1	3/29	3/1
	User Interface Code	10	2	10/28	10/28	4/12	4/26	
	Git Repository			11/23		4/12	5/3	
	E&S System Manual	12	3	1/18		4/12	5/3	
Using Margin	**Manufacturing**							
	Preliminary Materials Ordering/Shipping	4	1	12/14	12/14	1/11	1/18	1/19
	Secondary Materials Ordering/Shipping	2	1	1/25	1/26	2/8	2/15	
	Training	1	1	2/1		2/8	2/15	
	Manufacturing Parts	4	2	1/18		2/15	3/1	
	Assembly	2	2	2/8		2/22	3/8	
	Manufacturing Completed	7		1/18		3/8	3/8	
	Last Machining Day							3/22
On Time	**Integration & Testing**							
	Setup E&S Suite for Functionality Test	0.25	0.25	12/2	12/1	12/3	12/5	12/1
	E&S Functionality	1	0.5	12/5	12/1	12/12	12/16	12/1
	Load Cell Characterization Test	1	1	2/8		2/15	2/22	2/23
	Lug Mount Tensile Test	1	0.5	2/8		2/15	2/18	
	Setup WASP for Structural Test	0.5	0.5	3/8		3/11	3/15	
	Structural Integrity Test	1	1	3/15		3/22	3/29	
	Measurement Accuracy Test	1	1	3/29		4/5	4/12	
	System Accreditation Test	2	1	4/12		4/26	5/3	
	WASP Full Integration for Delivery	0.5	0.5	4/26		4/29	5/3	
On Time	**Analysis**							
	Update MCS with Load Cell Data	0.5	0.5	2/22		2/25	3/1	
	Load Cell Characterization	1	0.5	2/22		3/1	3/4	
	Stress Extrapolation	1	0.5	4/12		4/19	4/22	
	WASP Error Characterization	2	1	4/12		4/26	5/3	
On Time	**Deliverables**							
	Finalized Budget + Approval	5	0.5	11/4	11/4	12/9	12/12	12/14
	MSR Slides	2		1/18	1/18	2/1	2/1	2/1
	MSR Presentation						2/2	2/2
	TRR Slides	3	1	2/1		2/22	3/1	
	TRR Presentation						3/3	
	SAWE Conference Paper	4	1	2/1		3/1	3/8	
	Symposium Presentation + Poster	2	1	3/29		4/12	4/16	
	Spring Final Review	5	1	3/8		4/12	4/26	
	Project Final Report	5	2	3/8		4/12	4/26	
	Safety Guidelines Document	4	16	11/9	11/9	12/7	5/3	
	User Procedure Document	12	3	1/18		4/12	5/3	
	WASP Delivery to SNC						5/3	



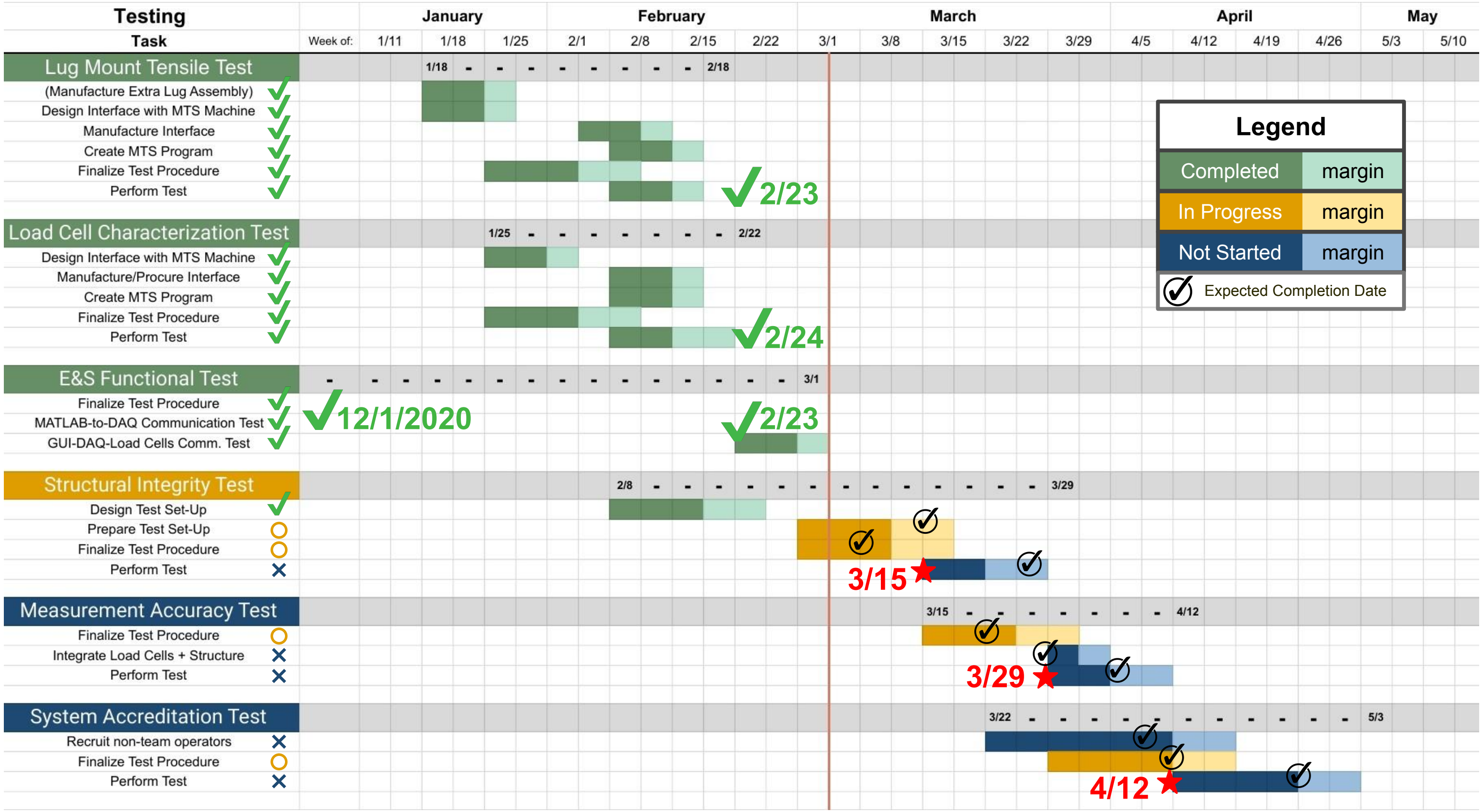
Legend

Milestone

Lighter Shade = Margin

Task In Progress

Testing Schedule Review



Test Readiness

Testing Scope - Overview

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

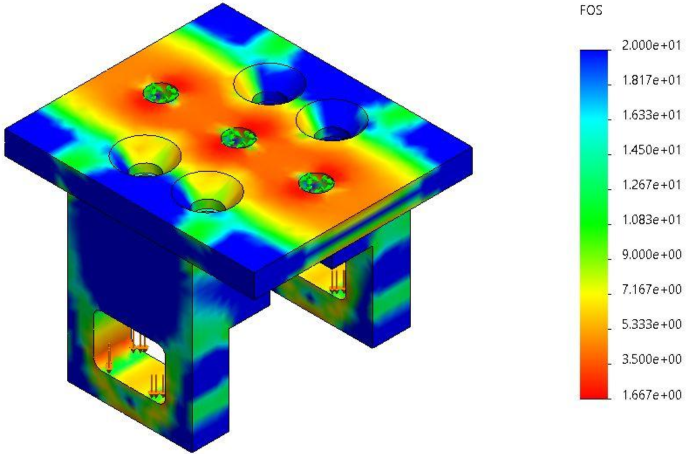
Lug Mount Tensile Test

Deadline: 2/18
Completed 2/23

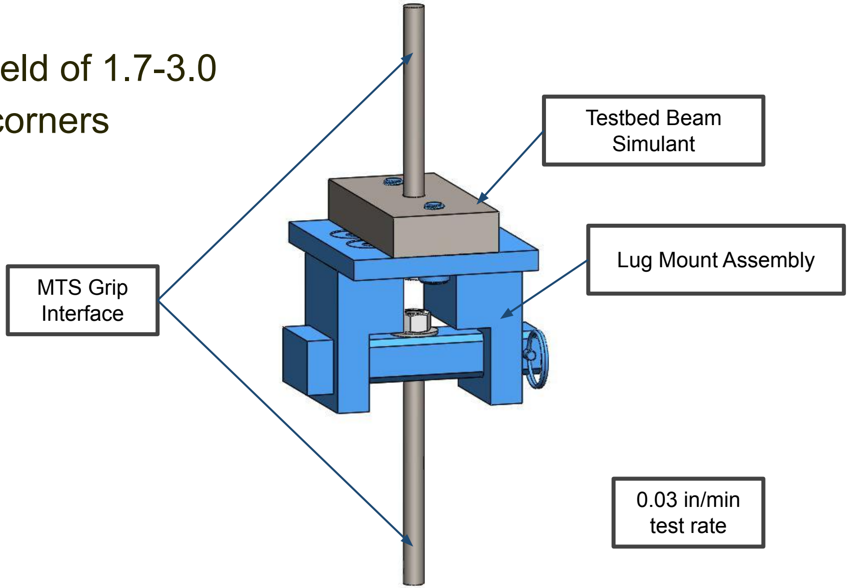
DR 3.1: Structural components must have a safety factor against yield of greater than 2.0

- **CPE 1:** Frame must statically support pods of up to 2000 lbs
- **CPE 5:** Pods and WASP operators should be safe from harm.

- **Rationale/Motivation:**
  - FEA model predicts minimum FOS against yield of 1.7-3.0 in concentrated regions near fixtures and in corners

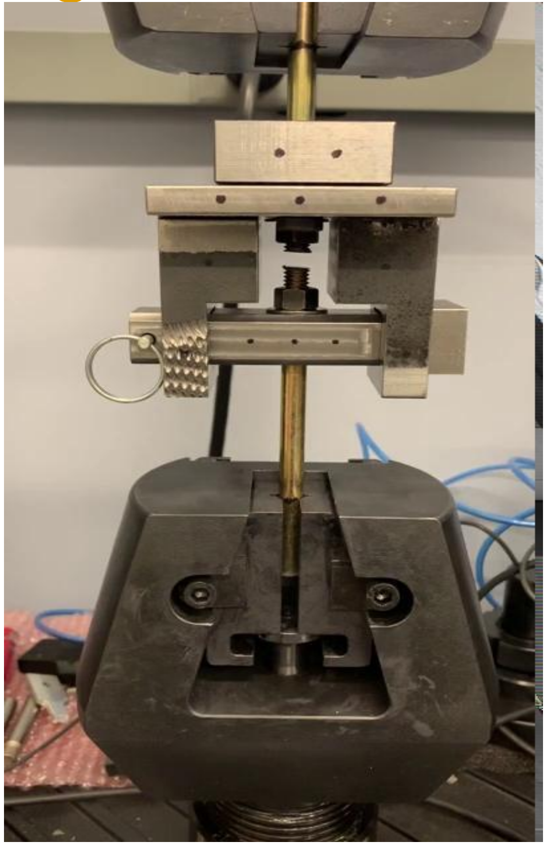


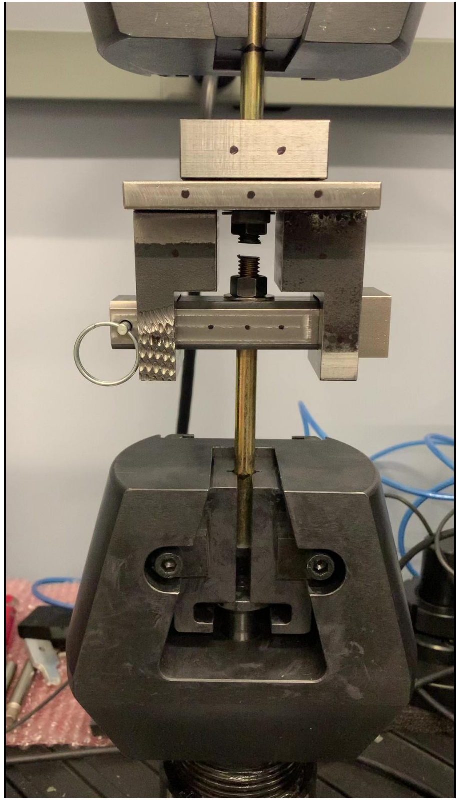
Convservative Finite Element Analysis - 2000 lb Loading



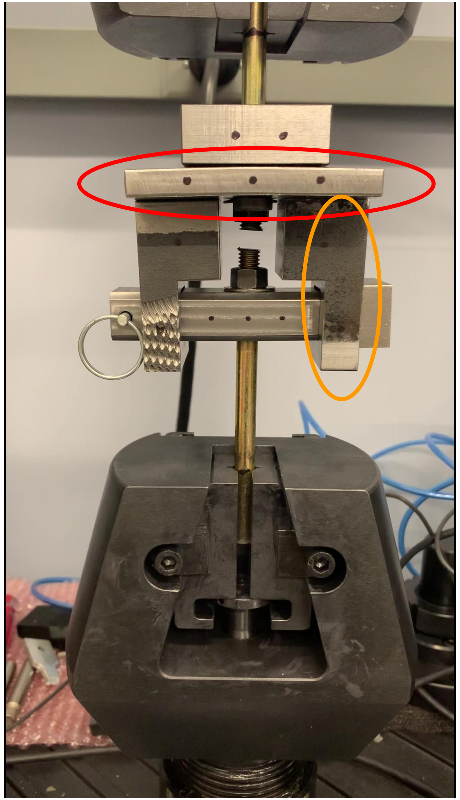
Lug Mount (Blue) and Interface

Lug Mount Tensile Test - Failure Video





Start of Test



End of Test (15500 lbs)

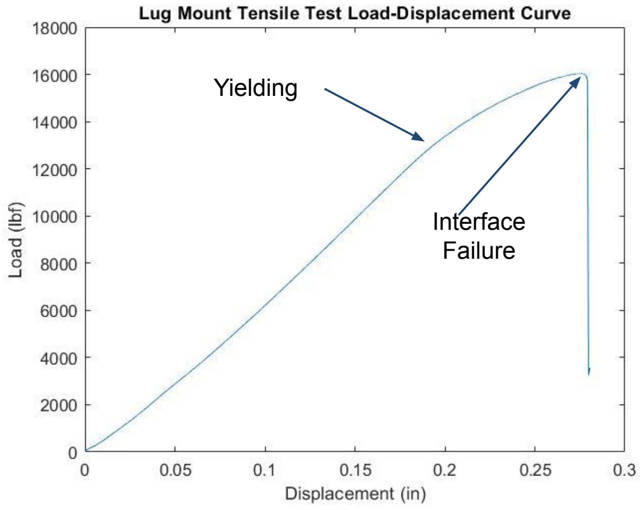
Lug Mount Tensile Test

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.

Deadline: 2/18

Completed 2/23

- **FEA Predicted Results:**
  - 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 plate and bolts, plate and flanges, flange and pin, and so on increase stiffness, push back plastic deformation
  - Risk: Reduction in likelihood of component failure



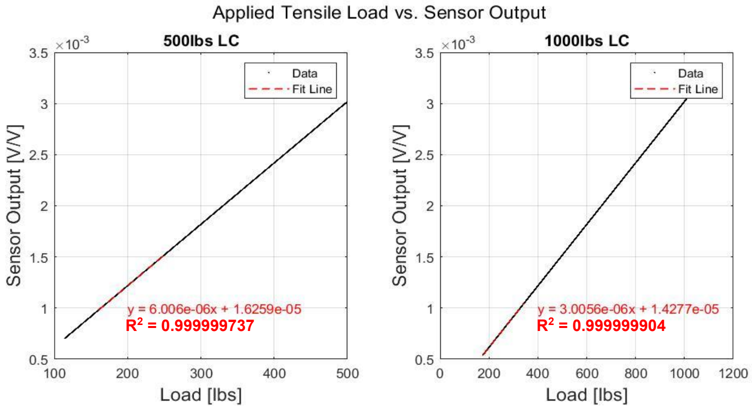
Lug Mount Force-Displacement Curve

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

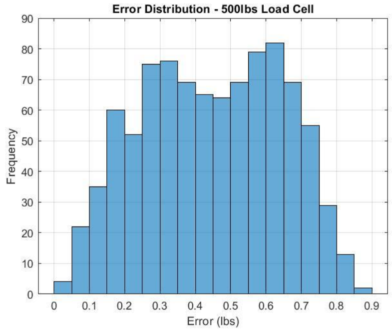
H_0: E~ N(μ_E , σ_E); H_a: E≁ N(μ_E , σ_E)

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



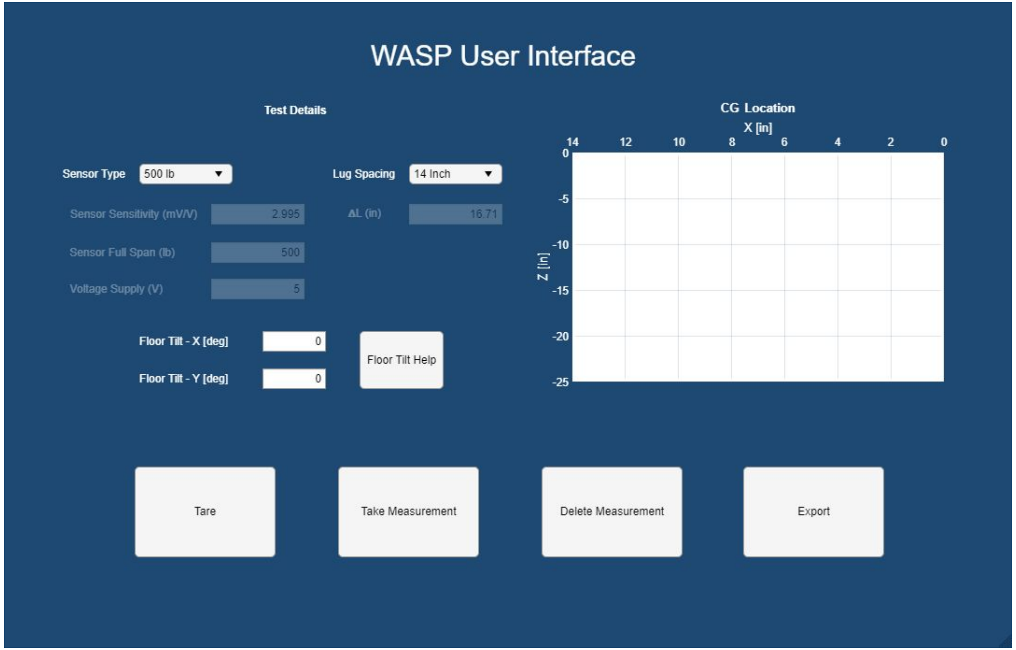
Electronics & Software Functionality Test

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



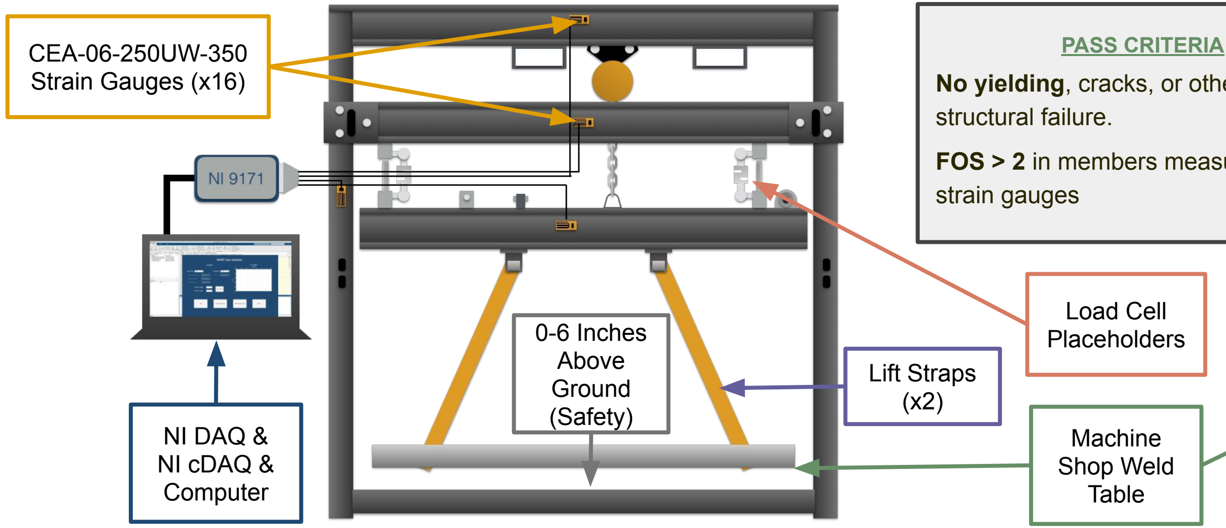
Structural Integrity Test

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

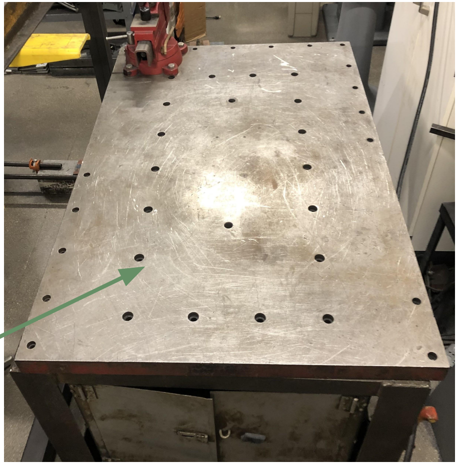
- **Rationale/Motivation:**
  - Demonstrate that the structure can support 2000 lb pods for SNC future growth



PASS CRITERIA

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

FOS > 2 in members measured by strain gauges



Structural Integrity Test

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Deadline: 3/29

Planning/Setup

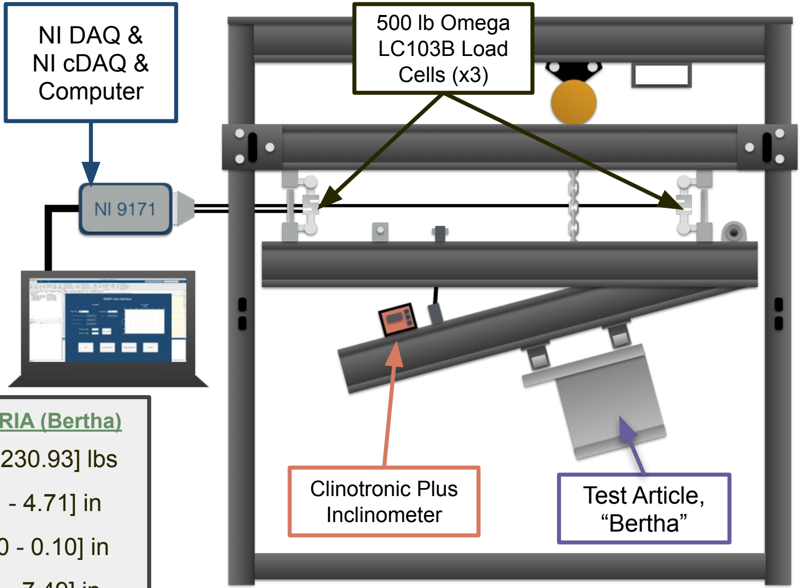
- **Pass Criteria:**
  - No yielding, cracks, or other forms of structural failure.
  - FOS > 2.0 in members measured by strain gauges (strain → stress → FOS)
- **Test Date:**
  - 3/15 - 3/22
- **Expected Results/Off-Ramps:**
  - **Pass:** Expected - move forward with MAT
  - **Fail:** Analyze failure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

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.

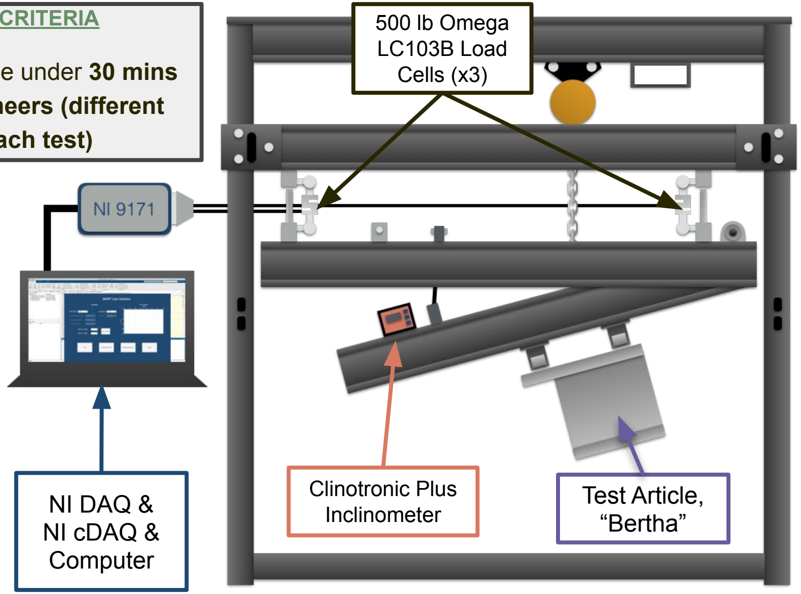
Deadline: 5/3

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

Budget

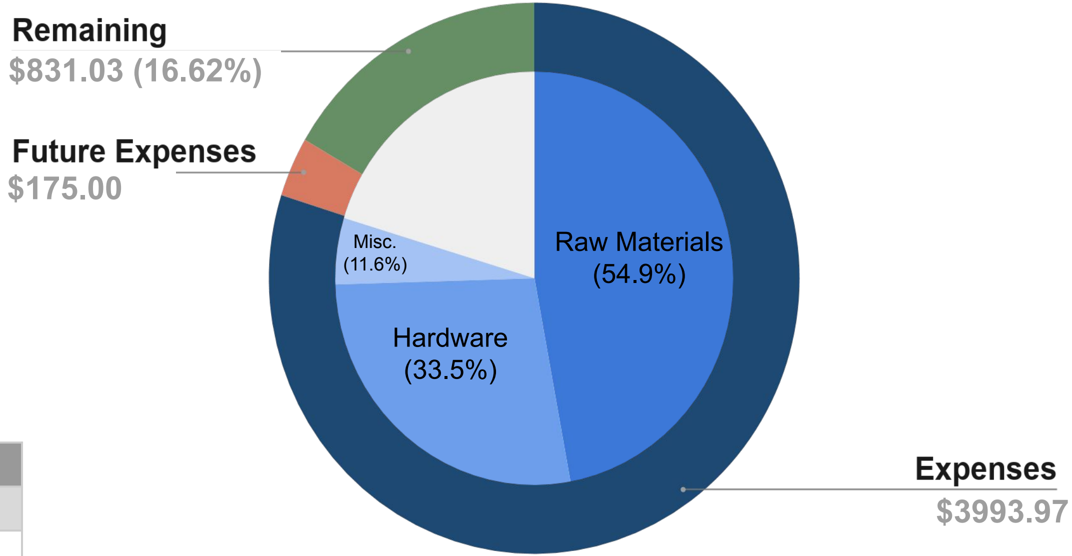
Budget Review

Future Expenses

Item	Cost
Welding gas	$75
Safety Placards	$100

Anticipated (If Possible) Expenses

Item	Cost
Improvements (Caster wheels)	$350
Spray Paint (Rust Prevention)	$50
	Total: $400



Acknowledgements

SNC Team:

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Questions?

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Back-Up Material

Testing

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)*

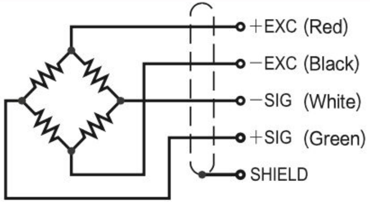
MTS Exceed Series 40 E45.105 Specifications

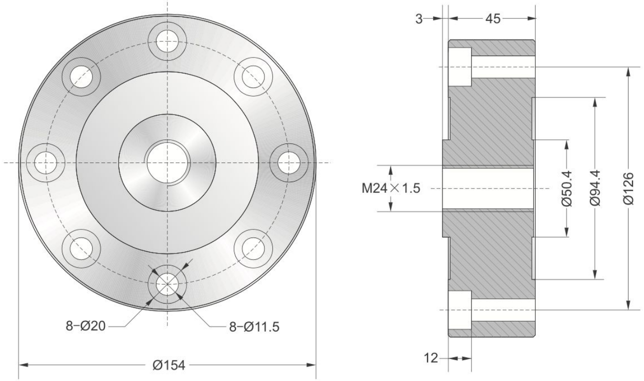
Model	E44.304	E45.105	E45.305
Maximum Rated Force Capacity	30 kN	100 kN	300 kN
Force Capacity Options	100 N, 250 N, 500 N, 1 kN, 2 kN, 5 kN, 10 kN, 20 kN, 30 kN	5 kN, 100 kN	200 kN, 300 kN
Frame Type	Floor-standing	Floor-standing	Floor-standing
Test Zones (single/dual)	Single/Dual	Single/Dual	Single/Dual
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

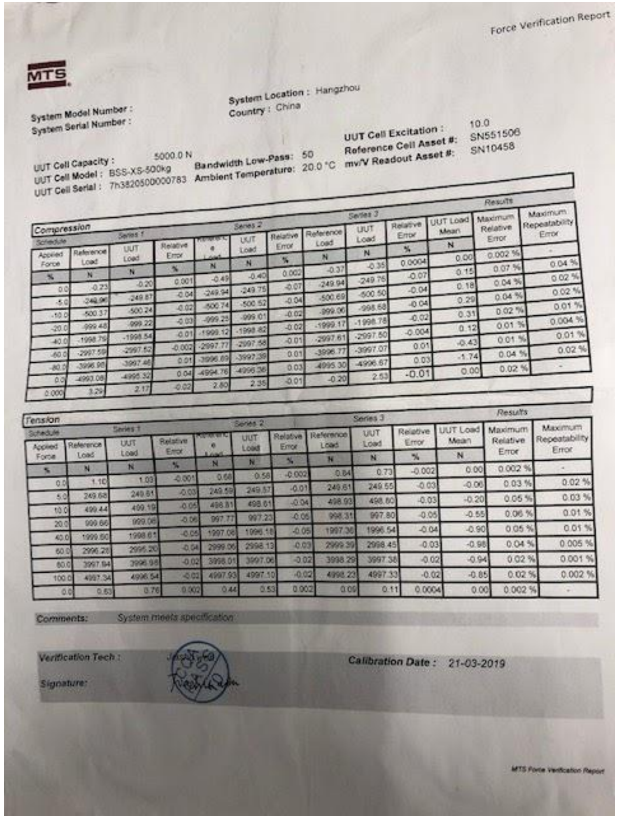




Specifications

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: Applied Force	Series 1: Reference Load	Series 1: UUT Load	Series 1: Relative Error	Series 2: Referenc e Load	Series 2: UUT Load	Series 2: Relative Error	Series 3: Reference Load	Series 3: UUT Load	Series 3: Relative Error	Results: UUT Load Mean	Results: Maximum Relative Error	Results: 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	-4996.36	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: Applied Force	Series 1: Reference Load	Series 1: UUT Load	Series 1: Relative Error	Series 2: Referenc e Load	Series 2: UUT Load	Series 2: Relative Error	Series 3: Reference Load	Series 3: UUT Load	Series 3: Relative Error	Results: UUT Load Mean	Results: Maximum Relative Error	Results: 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	498.80	-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	1997.06	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	-0.03	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 :

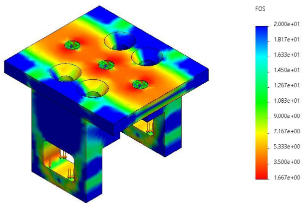
Signature:

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.



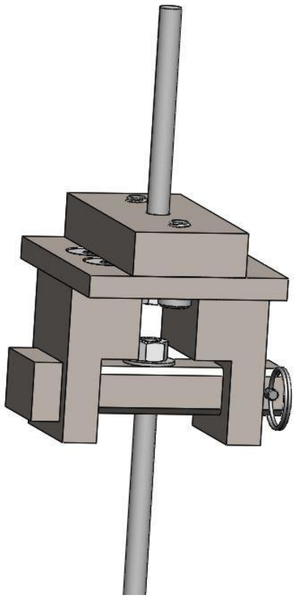
Lug Mount Tensile Test - FEA

- **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-2BBhANEiwAe7eyFEBeR4h483yczgLsTEoCgPsjyWkDRFTrqD-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

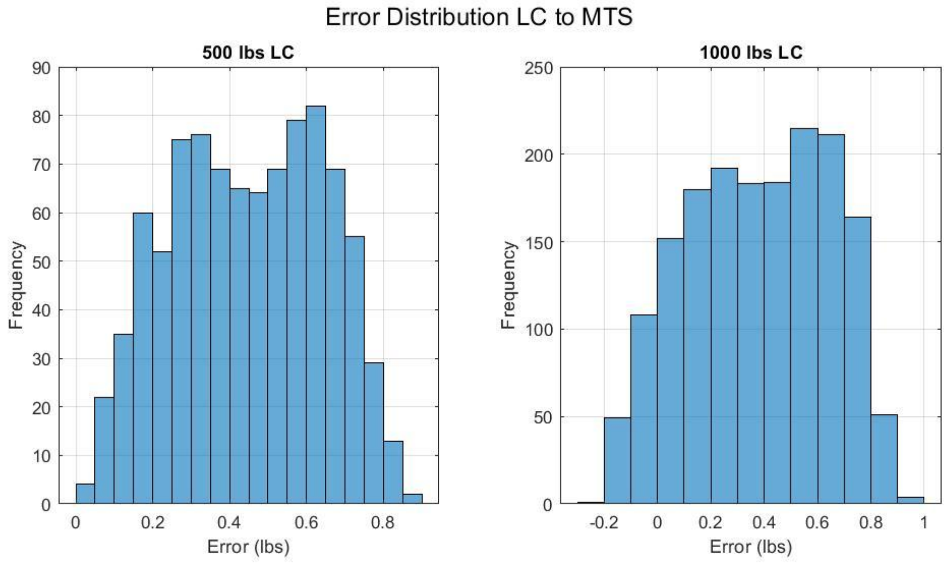
```
Linear regression model:
    y ~ 1 + x1

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

H_0: $E \sim N(\mu_E, \sigma_E)$; **$H_a$**: $E \nsim N(\mu_E, \sigma_E)$

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

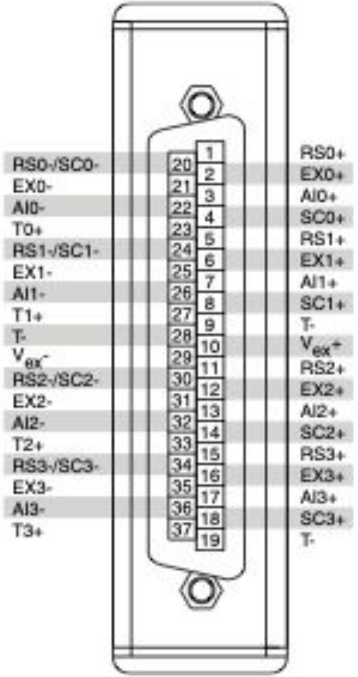
NI 9237

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

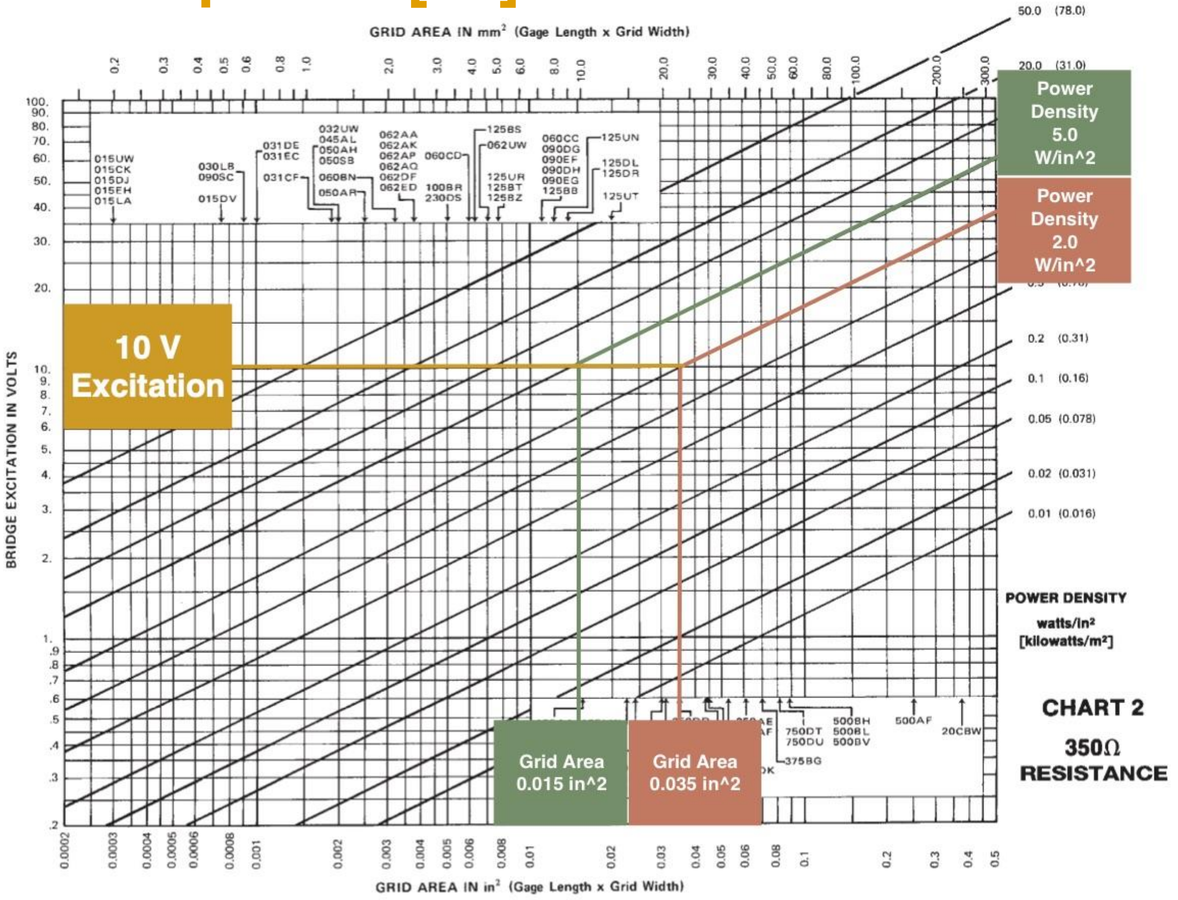
Dimensions:

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

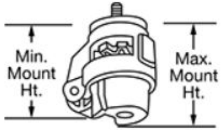
Female, 04JQ-BT [20]

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

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/