# Final Project Review

WINGS ‘N’ THINGS

# Wing Customer Requirements

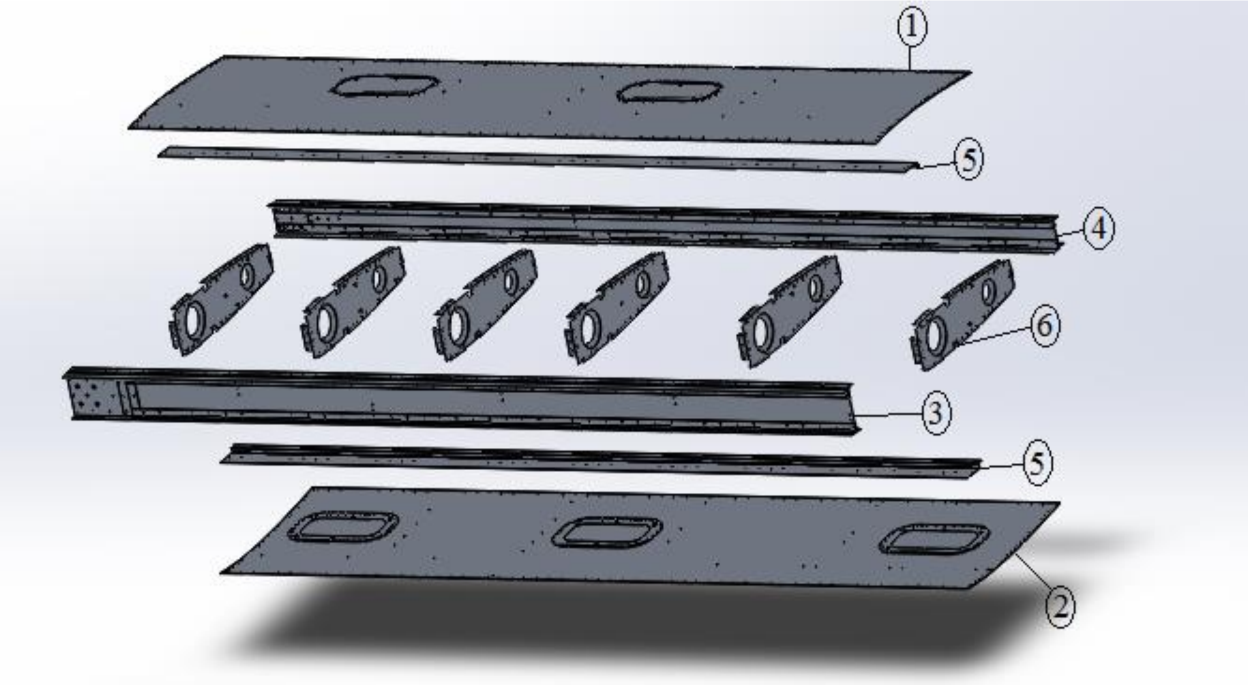
- 69 inch span with a 29 inch aerodynamic chord and rectangular planform
  - NACA 23015 airfoil
- 6g “limit” load with low margins of safety
  - Customer requests that the margins are low for assurance of failure during an ultimate load test
- Provisions for leading/trailing edges
  - Used T-sections to allow more structure to be added
- Complete set of CAD drawings and design package with enough detail to duplicate the wing
- Designed for structural efficiency

# Wing Requirements From Regulations

- Materials must conform to guidelines taking into account environmental effects
  - Verified by checking supplier information
- The methods of fabrication used must produce a consistently sound structure
  - Verified through a limit load test
- Fasteners must meet requirements and have redundant locking devices
  - Verify through supplier information
- Material strength properties must be chosen to minimize probability of structural failure
  - Verified through structural analysis/FEA
- Redundancies built into critical failure points
  - Verified through inspection of the design
- Fitting factor of 1.15 for untested fittings
  - Verified through analysis

# Detailed Design Description: Wing

- Top skin (.05”x16”x69” 6061-T4 aluminum)
- Bottom skin (.05”x16”x69” 6061-T4 aluminum)
- Aft spar (.05”x4.65”x72” 6061-T4 aluminum)
- Front spar (.05x2.65”x72” 6061-T4 aluminum)
- Stringers (.05”x3.2”x69” 6061-T4 aluminum)
- Rib assembly (NACA 23015 6061-T4 aluminum)



# Analysis: Wing Box Sizing

- Assumed skin was effective in carrying shear and direct stresses
  - Found highest and average shear in each skin panel
  - Checked margins against available .05” 6061-T6 aluminum
  - All margins +High for shear flow but skin thickness factored into buckling

- Used idealization to find initial boom size and optimized for direct stresses
  - T-section Front Spar (Boom 1 & 6): .15in^2
  - Z- section Stringers (Boom 2 & 5,): .15in^2
  - T-section Rear Spar (Boom 3 & 4): .15in^2
  - Sufficient to resist all direct stresses with a  minimum margin

# Analysis: Rib Spacing

- Utilized methods for curved thin sheets to find skin critical buckling stress
  - Worst case: Skin panel between front spar and stringer 1
  - Buckling due to combination of shear/compression
    - Compression almost negligible compared to shear
  - Ribs spaced every 12 inches for adequate margin
  - Spacing optimized to 16 inches outboard

# Analysis: Stiffener Spacing

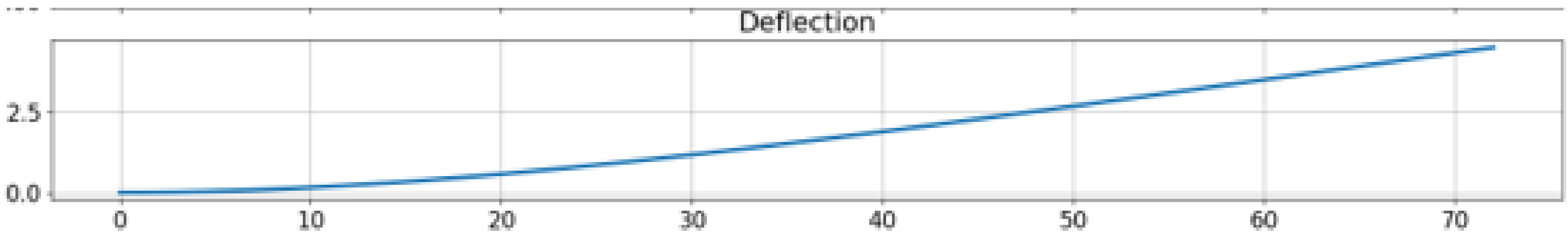
- Utilized thin flat sheet buckling to find critical buckling stress
  - Worst case: Front spar web – holds highest shear
  - Buckling due to combination of shear/in-plane bending
  - Method takes spar chords into account
  - For low margin design no stiffeners were needed

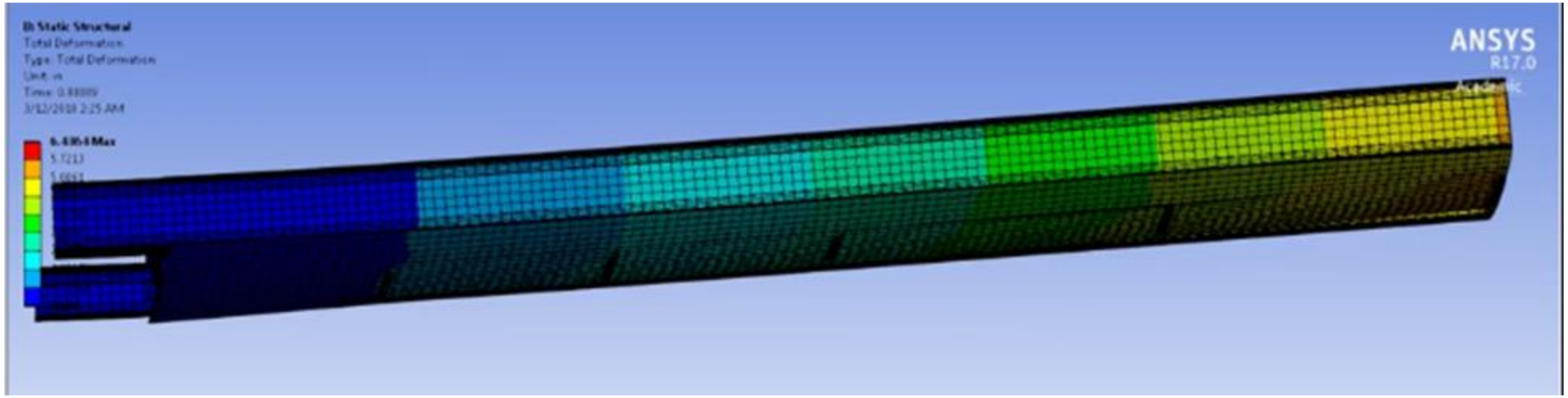
# Analysis: Rivet Spacing

- Rivet spacing calculation was done based on FAA requirements.
- Things to consider for rivet spacing:
  - Edge Distance: According to FAA the minimum edge distance should be 2 times the diameter of rivet.
  - Pitch Distance: Pitch distance can range from 3D to 12D.
  - Rivet length: 1.5D + the thickness of material
  - Row distance: 2.5 times pitch distance

# Analysis: Deflection

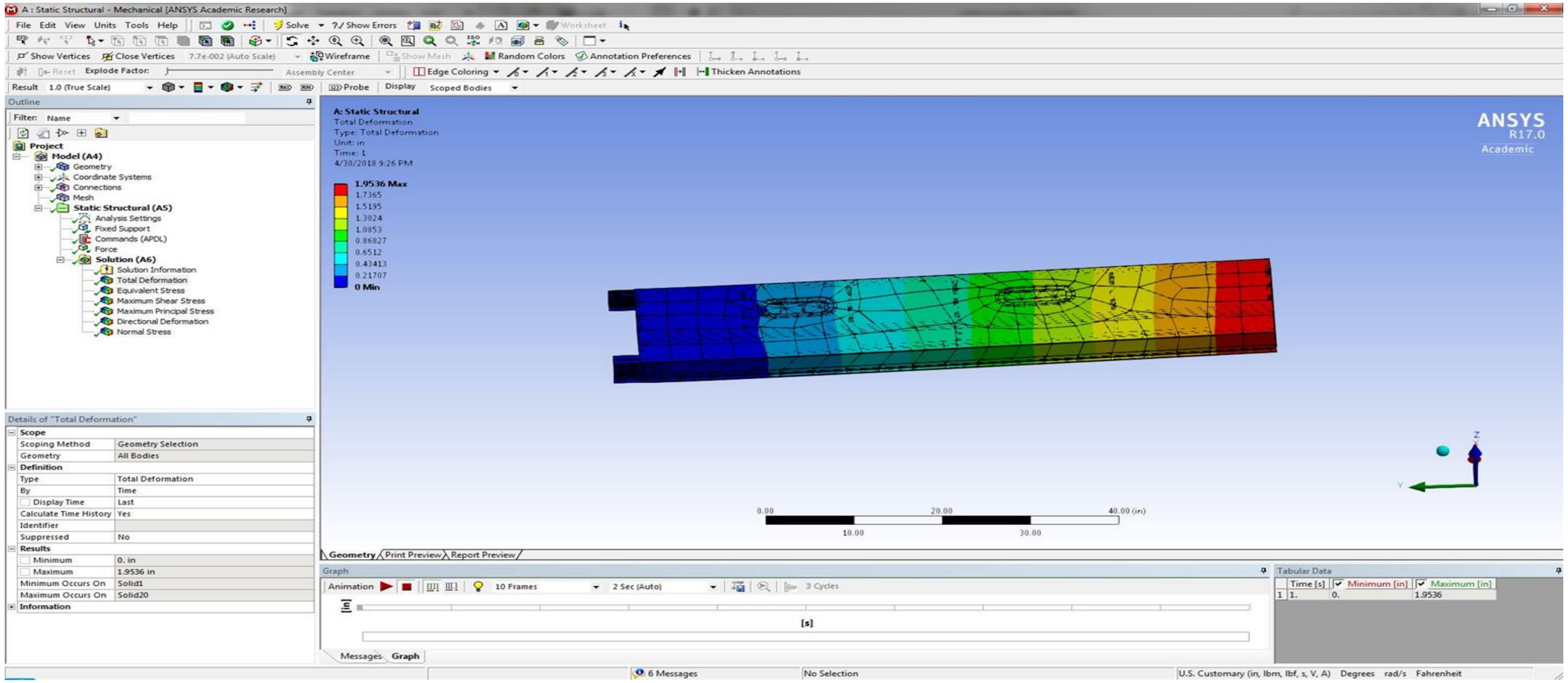
- Finite element analysis ran on the entire wing structure at 7.5g ultimate load
- Max deflection predicted at 4.6 inches, same preliminary calculations



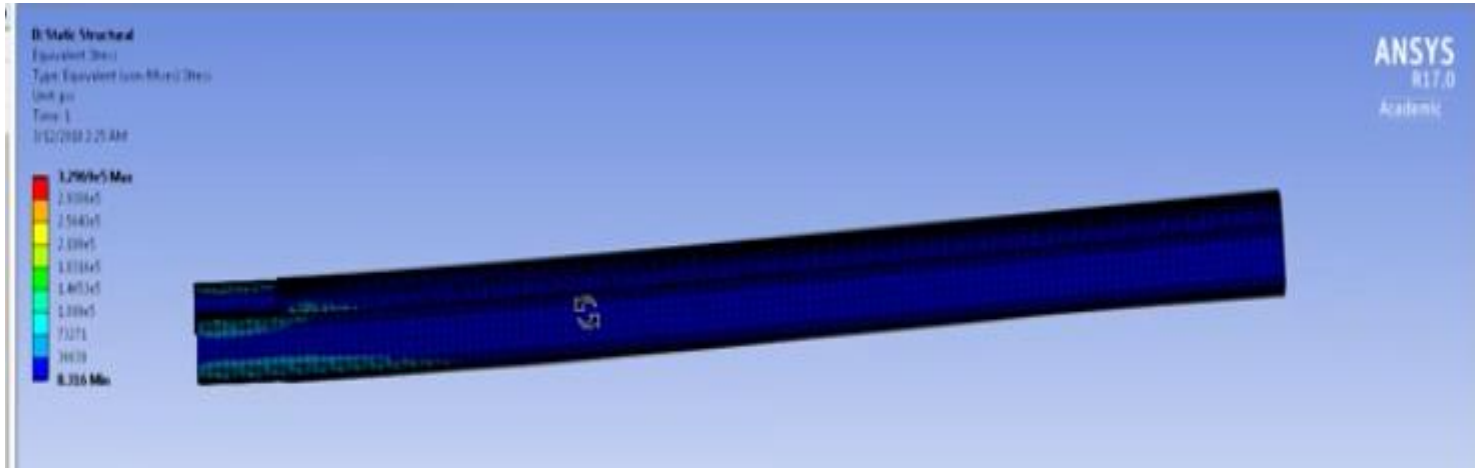
# Analysis: Deflection

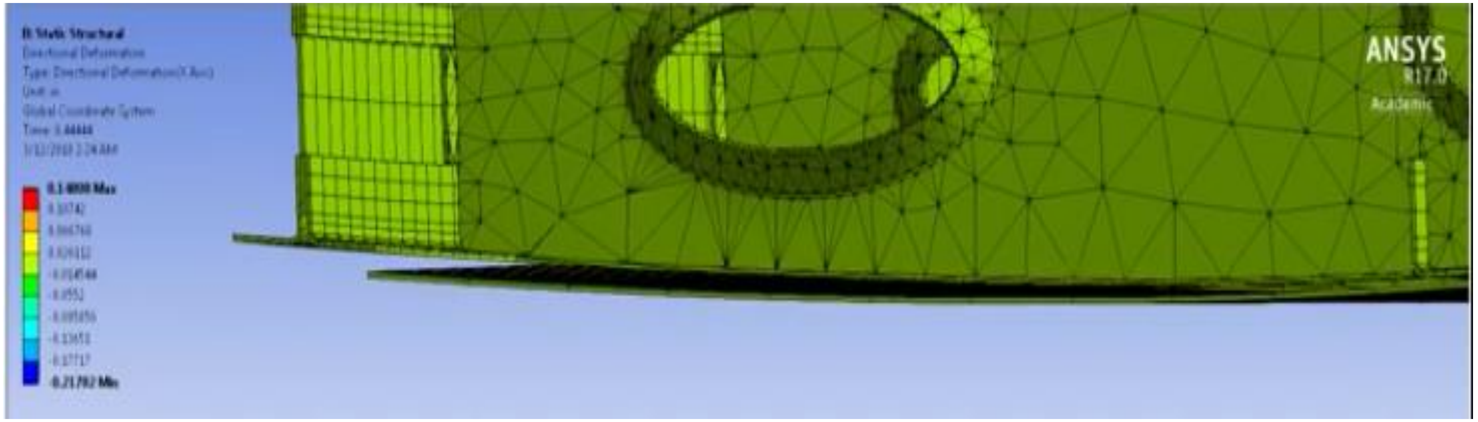
- At 6g load condition, deflection is predicted at 1.95 inches



# Analysis: FEA Stress and Failure

At 9g ultimate load, maximum stress is found at the root of the wing, with a failure mode of buckling in the forward skin panel. This matches predictions from hand calculations.



# Wing Requirements Compliance

- Load test will be performed to take the wing box to 6g limit load
  - Wing should experience no failure or plastic deformation during the test
  - Maximum deflection of 1.95 inches predicted from FEA

- All other requirements met through design calculations and inspection

# Wing Manufacturing

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# Significant Issues: Wing

- Some manufacturing defects in the wing box
  - The ribs were made utilizing a jigsaw
  - Edge distance on certain rivets
  - Poor manufacturing jigs/lack of resources
  - Spar caps production
- Finite element model not completely accurate
  - Issues with the mating elements in the assembly
  - Recommend rebuilding/troubleshooting the CAD model provided

# Wing Resource and Schedule Evaluation

- Used many already purchased supplies to reduce budget
- Final cost: ~$400.00 w/o shipping Predicted Cost: $72.00
- Predicted cost assumed no aluminum would have to be purchased
  - Purchased 8ft sheets to avoid splicing spars and skins
- Schedule delays during drawing review phase
  - Underestimated time taken to design small details

# Recommendations

- Use extrusions for spars and stringers
- Use proper tooling when manufacturing ribs
- Rebuild model in CATIA for more accurate Finite Element Analysis

# Rig- Customer Requirements

- Design to apply 1.5 ultimate wing load
- Application on at least 3 points along span
- Chordwise placement flexibility (for torsion and shear center testing)
- Structural substantiation for static load, fatigue life and deflections
- Portable and fits through standard classroom doors
- Cyclic load capability desired (fatigue testing!)
- Provisions for additional load axes (e.g., drag)

# Rig-Derived Requirements

- Ensure Rig is safe to operate, and absorb unexpected released energy
  - Fulfilled by utilizing linear actuators
- Enable actuators to tilt towards direction of wing during deflection
  - Fulfilled by using pivoted force distribution
- Rig must be able to withstand deflection of wing at interface, without intervention.
  - Over designed with a steel plate and stiffener
- Rig must be assembled while keeping in mind possible future application/ changes
  - Fulfilled by using 80/20 extrusions

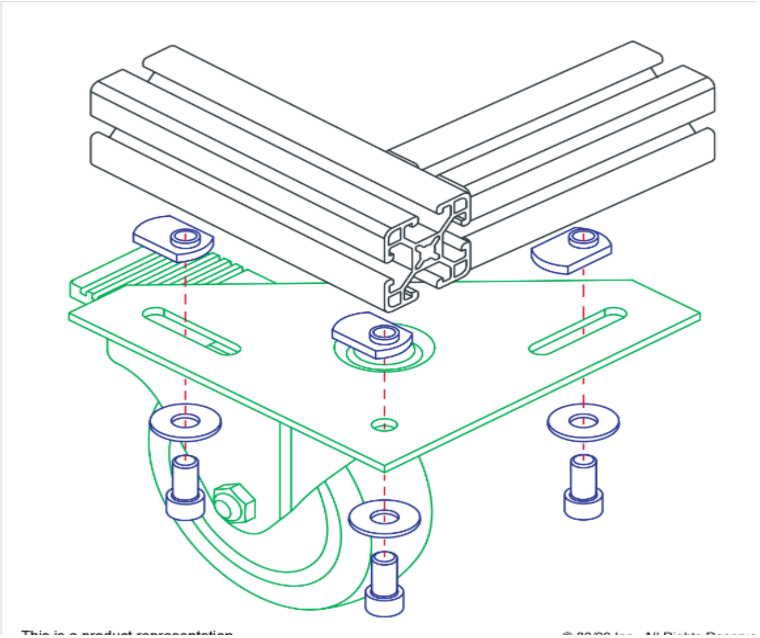
# Detailed Description of Rig Design

- 5 ft. tall, 6.7 ft. long, 2.5 ft. wide
- T-slotted aluminum frame
  - 15-series square profile family
  - Modularity for additions of amenities such as handles and test materials
  - High versatility and adaptability for future projects and testing
- Hex wrench adjusts x and y positions for actuator mounting. (both horizontal and vertical supports)
- Wing - Rig interface
  - ½” x 9” x 30” steel plate
  - 2 aluminum ½” thick, 6” square T6 aluminum brackets

# Rig Description (Continued)

A strong 3x6 inch profile (still within the 15 series) make up the bulk of the frame. This minimizes the contribution of deflection from the rig during testing.

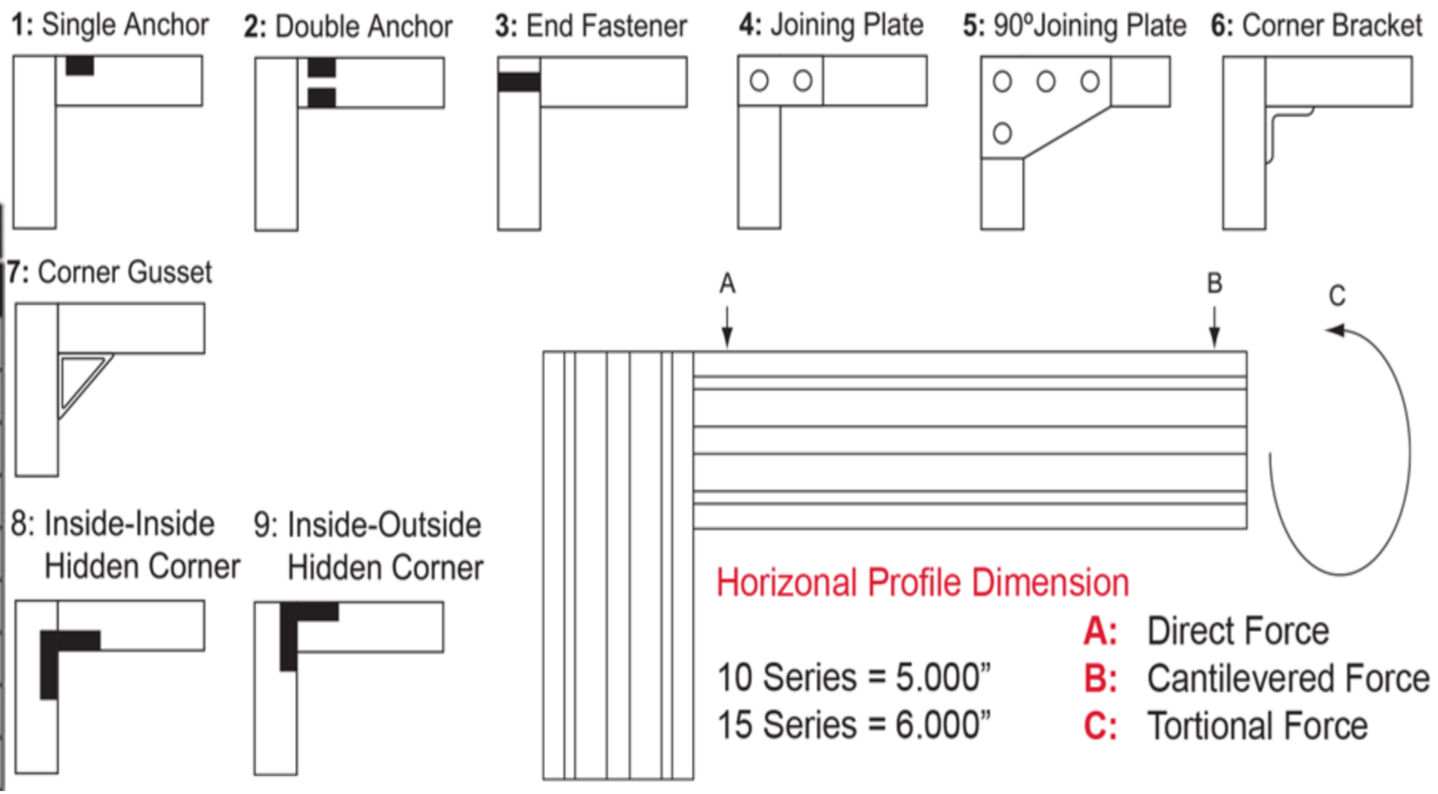
- Test rig sits on six 5 inch diameter lockable swivel wheels
- 300 lb.............. weight limit per wheel
- Securely fastened by 3 T-slot bolt/nut pairs



# Rig Design: Fastener Selection

- Selected Fastener: Double anchor for actuator base members, single anchor for other 80/20 interfaces. Counterbore cost $2.60 each hole.
- Anchors are entirely adjustable
- Highest strength capability
- Comparable cost to other fasteners

| Fastener | 1515 Profile | | |
|---|---|---|---|
| | A (lbs.) | B (lbs.) | C (Inch-lbs.) |
| 1 | 950 | 1,000 | 700 |
| 2 | 1,200 | 1,200 | 2,000 |
| 3 | 1,000 | 820 | 1,150 |
| 4 | 225 | 200 | 1,100 |
| 5 | 250 | 200 | 1,260 |
| 6 | 575 | 225 | 500 |
| 7 | 575 | 750 | 500 |
| 8 | N/A | N/A | N/A |
| 9 | N/A | N/A | N/A |



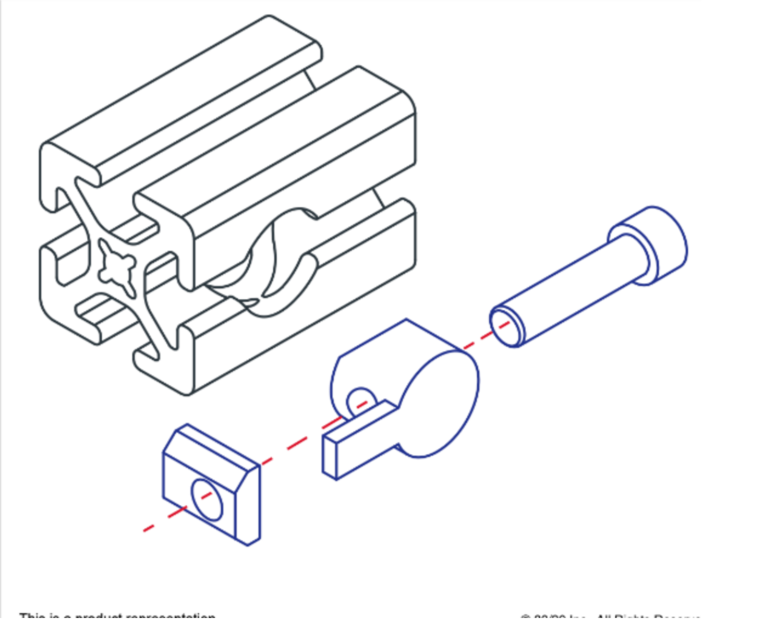
# Rig Design: Anchor Fasteners

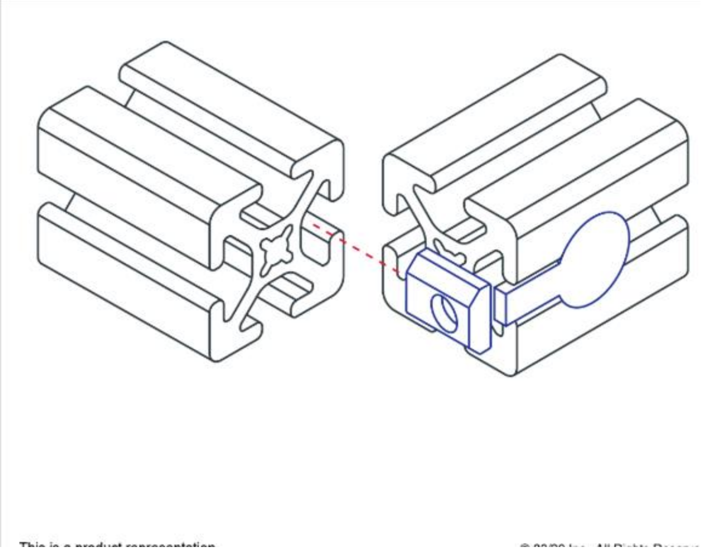
A ball end hex wrench allows for simple loosening from the side, allowing the frame to slide freely to a new location to be tightened back up.  No disassembly required

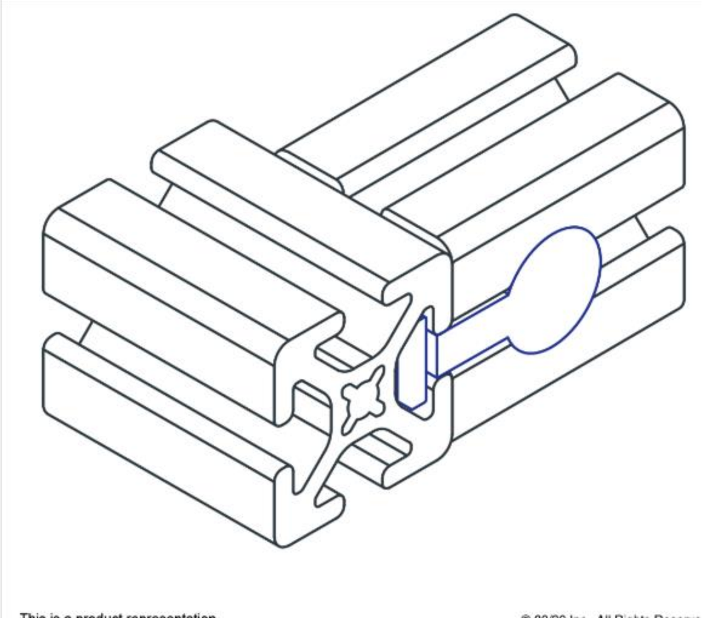
One-time Initial assembly
Adjustable State

Initial Connection

Final

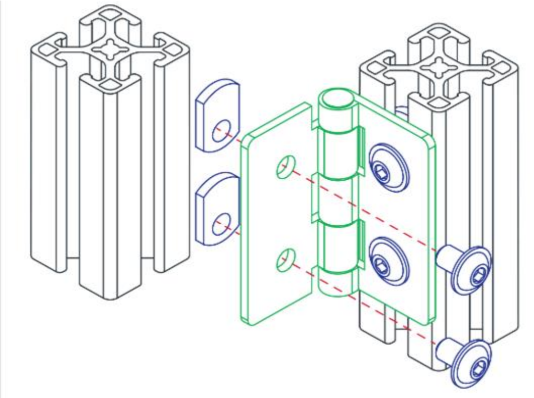


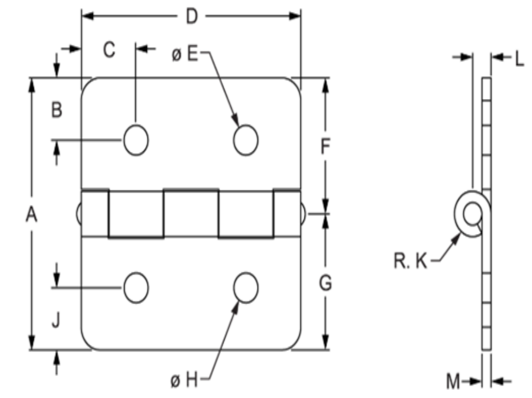


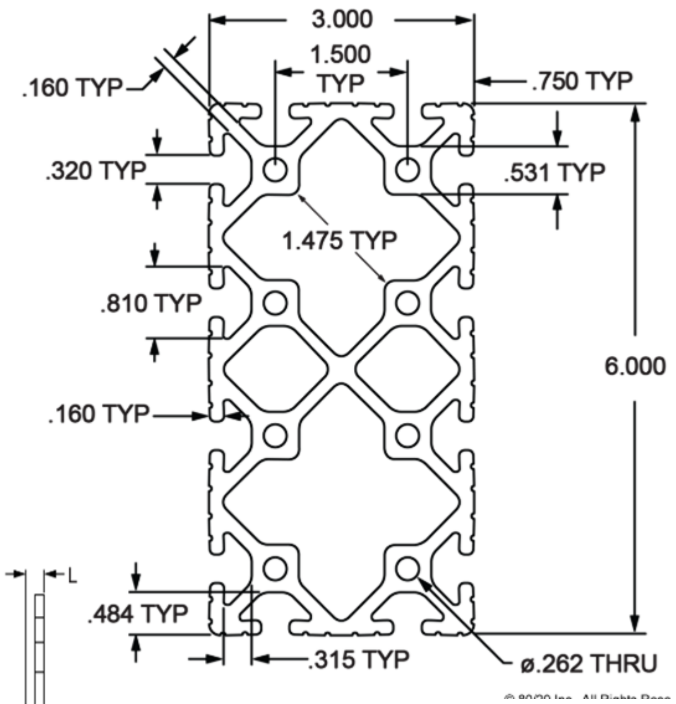


# Design Description: Value of 80/20

80/20 provides a plethora of technical information for their thousands of products.  With a sophisticated website, literature, software tools, CAD libraries, and videos, our product selection provides a worthy investment capable of significant adaptation and safe, reliable use. manipulation.






| | |
|---|---|
| **Length** | per inch |
| **Material** | Aluminum |
| **Grade** | 6105-T5 |
| **Finish** | Anodize |
| **Color** | Clear |
| **Drop Lock** | 2° |
| **Moment of Inertia - IX** | 22.0300"^4 |
| **Moment of Inertia - IY** | 6.5164"^4 |
| **Surface Area** | 5.963 Sq In. |
| **Yield Strength** | 35,000 psi. |
| **Modulus of Elasticity** | 10,200,000 Lbs / Sq. In. |
| **Weight lbs** | 0.5815 per inch |

# Deflection Analysis: Rig Structure

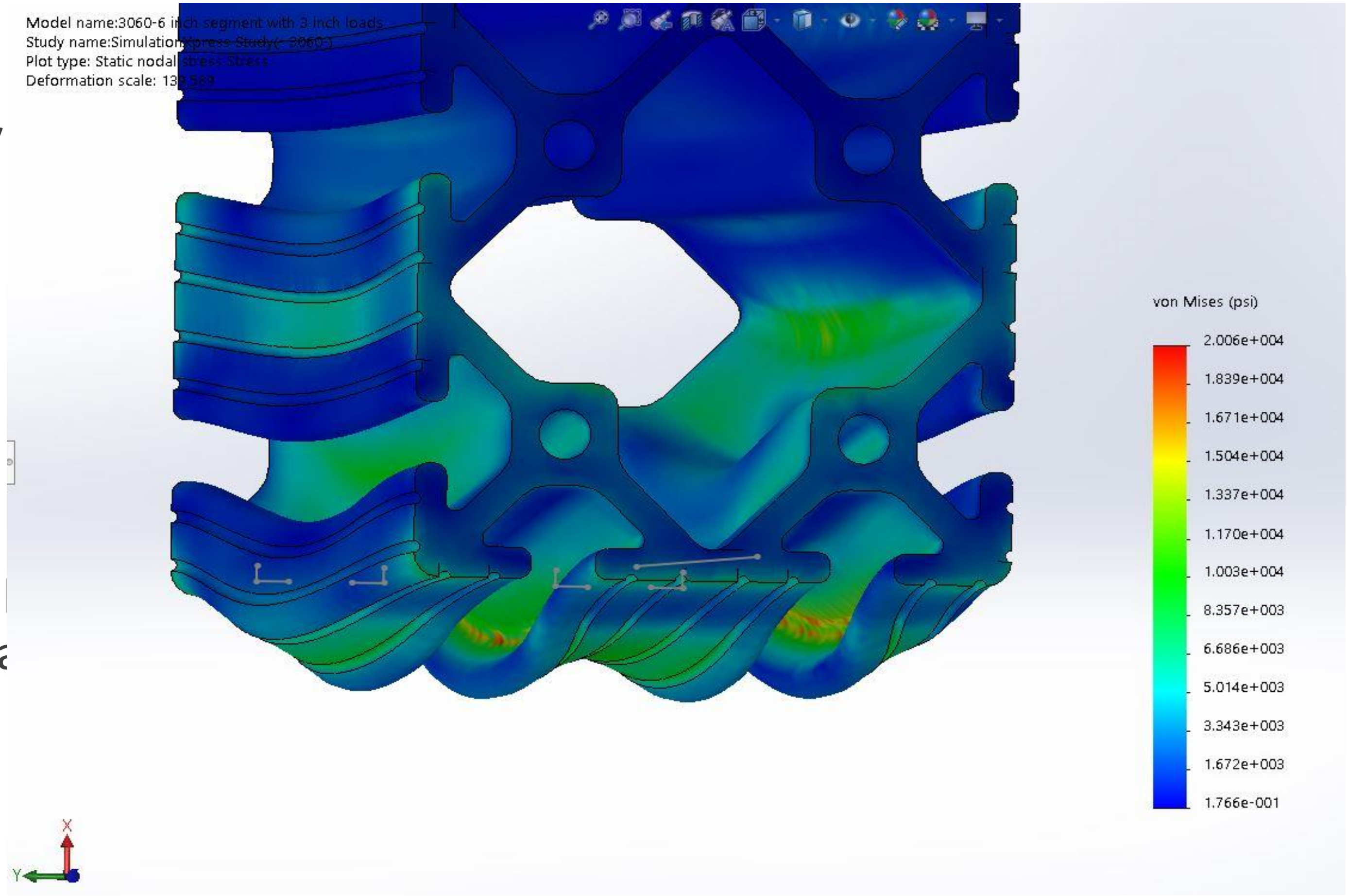
- Deflection calculations determined from the manufacturer’s deflection calculator
- Actuator base beam
  - 24” x 3” square beams deflect 0.002” under actuator’s max capability of 1,010 lbf
  - One double anchor fastener holds 1,200 lbf.  We have 4 on each beam.
- Actuator top beam
  - 24” long 1.5” x 3” profile beam deflects 0.0578” under actuator’s max capability of 1,010 lbf
  - 28” long 1.5” x 3” profile beam deflects 0.0919” under actuator’s max capability of 1,010 lbf
- deflection of the 3” x 6” profiles are less than 0.005”

# Analysis: T-slot Capability

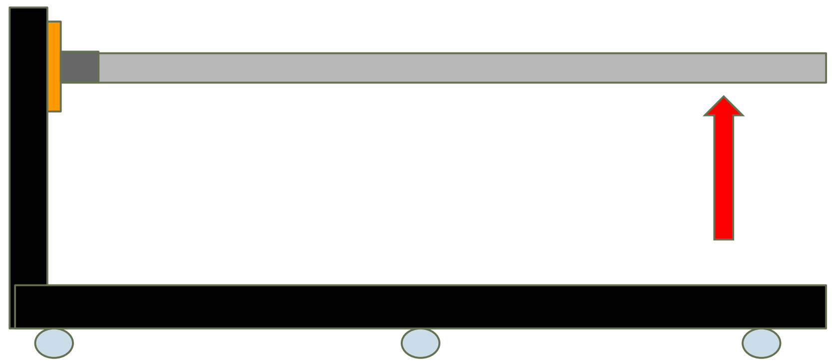
- Maximum risk for t-slot tear out is at the interface of the vertical members and the 45 degree supports, and at the wing/ rig interface.

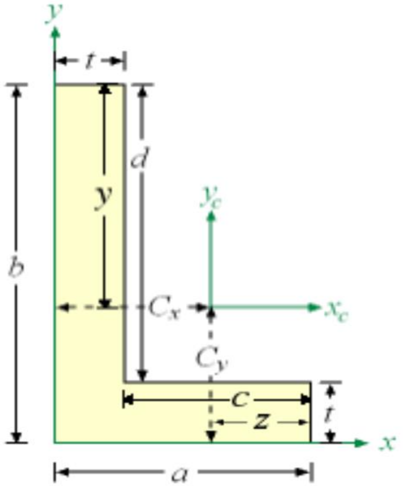
  Maximum load per 3 inch t-nut: 2400 lbf
  Maximum deflection: 0.004 in
  Minimum factor of safety: 1.4

- T-slot tear out will not occur under the loading conditions. To ensure capabi of all future applications, a second pa of 45 degree members was added.



# Analysis: Wing/Rig Interface






- Calculated max Moment at 90% of an original 72 plus additional interface to be 157,500 lb*in
- Max moment given at desired Factor of safety of 1.5
- Max moment was used to find max torsional stress for L brackets connecting to spars
- Max torsional stress of L bracket was found using Sigma= TR/J using Picture above
- Max moment also used for bolt selection.
- Based on moment, and to maintain a huge factor of safety we chose to mount the wing to a 9’’x30’’x.5’’ 1018 steel plate

# Analysis: Wing/Rig Interface

**Bolt Selection:**

- Bolt pattern analysis was conducted on each spar, allowing us to divide the total moment and shear stress produced by two.
- We finalized the design by placing four grade 8 -5/16’’ diameter-18x 3.5’’ long bolts on each spare in a square pattern
- We used the same type bolts, only 2’’ in length to connect the L brackets to the steel plate, to ensure maximum rigidity.

# Rig Team Bill of Materials

| Component | Description | Part Number | Price | Vendor | Count | Cost |
|---|---|---|---|---|---|---|
| T-slotted aluminum | 80 in | 3060 | $2.95 | 80/20 Inc. | 2 | $472.00 |
| T-slotted aluminum | 45 in | 3060 | $2.95 | 80/20 Inc. | 2 | $265.50 |
| T-slotted aluminum | 24 in | 3030 | $1.50 | 80/20 Inc. | 3 | $108.00 |
| T-slotted aluminum | 24 in | 1530s | $0.93 | 80/20 Inc. | 2 | $44.64 |
| T-slotted aluminum | 28 in | 1530s | $0.93 | 80/20 Inc. | 1 | $22.32 |
| T-slotted aluminum | 24 in 45 degree support | 2582 | $38.30 | 80/20 Inc. | 2 | $76.60 |
| T-slotted aluminum | 18 in 45 degree support | 2577 | $32.30 | 80/20 Inc. | 2 | $64.60 |
| cuts | surcharges for each cut | | varies | 80/20 Inc. | | $43.00 |
| counterbores for AF | machining for fasteners to insert | | $2.60 | 80/20 Inc. | 56 | $145.60 |
| Wheel | Triangular Top Plate Caster: 4.625" Swivel Radius | 2338 | $53.00 | 80/20 Inc. | 6 | $318.00 |
| hardware for wheel | 5/16 - 18 x 0.625 in bolt, t-nut, washer | 3462 | $0.56 | 80/20 Inc. | 18 | $10.08 |
| Anchor Fastener | connection method for frame joints | 3360 | $3.15 | 80/20 Inc. | 8 | $25.20 |
| double anchor fastener | connection method for frame joints | 3098 | $5.80 | 80/20 Inc. | 8 | $46.40 |
| long double anchor faste | connection method for frame joints | 3099 | $6.05 | 80/20 Inc. | 16 | $96.80 |
| T-slotted aluminum | 24 inch x 1.5 sq inch profile | 1515s | $12.72 | 80/20 Inc. | 6 | $76.32 |
| T-nuts | 5/16-18 slide in t-nut | 3285 | $1.35 | 80/20 Inc. | 30 | $40.50 |
| Bolts | 5/16-18 1" flanged hex head bolt | 3749 | $0.39 | 80/20 Inc. | 16 | $6.24 |
| T-handle hex wrench | 1/4" ball end hex wrench | 6030 | $7.65 | 80/20 Inc. | 2 | $15.30 |
| Bolts | Grade 8 2" 5/16" bolts | | | Atwoods | | $5.00 |
| washers and nuts | 5/16" | | | Lowes | | $6.00 |
| Angle Iron for interface | 6"x6"x1/2" 6061 T6 Aluminium 6 in length | 61a.5x6 | $20.94 | Speedy Metals | 1 | $20.94 |
| | | | | | **Total:** | **$1,909.04** |

# Significant Issues and Evaluation

- Only requirement not fully satisfied is the provision for drag loading. Making the interface plate capable of mounting the wing with the leading edge facing downward would allow for drag loading from the actuators.

- Construction of aluminum frame was as quick and simple as expected.
- Time needed for machining and assembling the interface plate was longer than expected. The team learned the importance of budgeting extra time for machining processes.
- Parts were ordered a few weeks later than scheduled.  While other teams weren't waiting on our parts, it would have been nicer to have it built earlier so we could have assisted the other teams more.

# Instrumentation and Controls - Requirements

## Customer Requirements

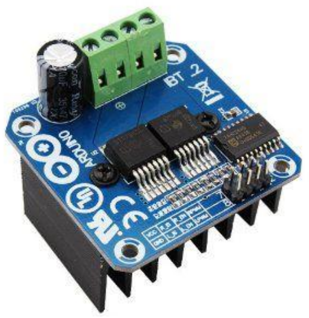
- Apply simulated distributed 6g lift load to wing.
- Measure strain in wing during applied 6g limit load.
- Ability to run in classroom.
- Desired: LabVIEW VI

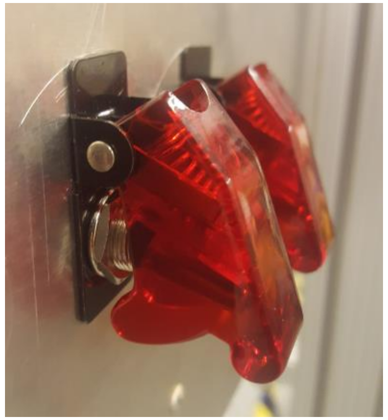
## Derived Requirements

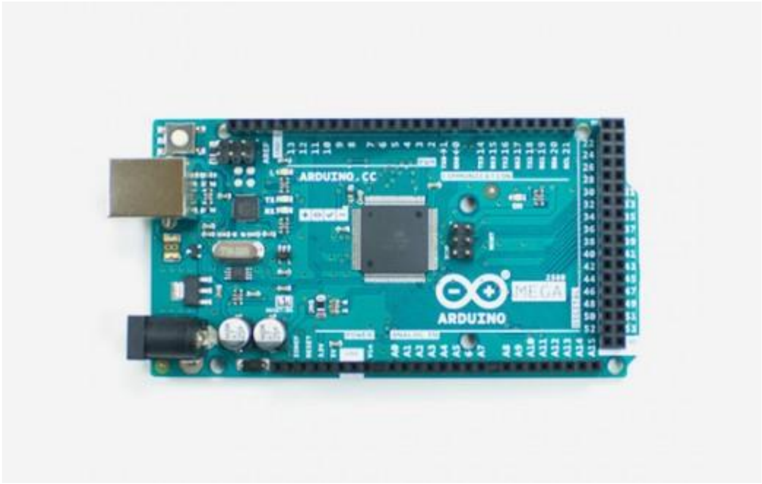
- Simple user interface for ease of operation.
- 110V compatible power supply.
- Can run on any laptop with LabVIEW and requisite extensions.

# System Components

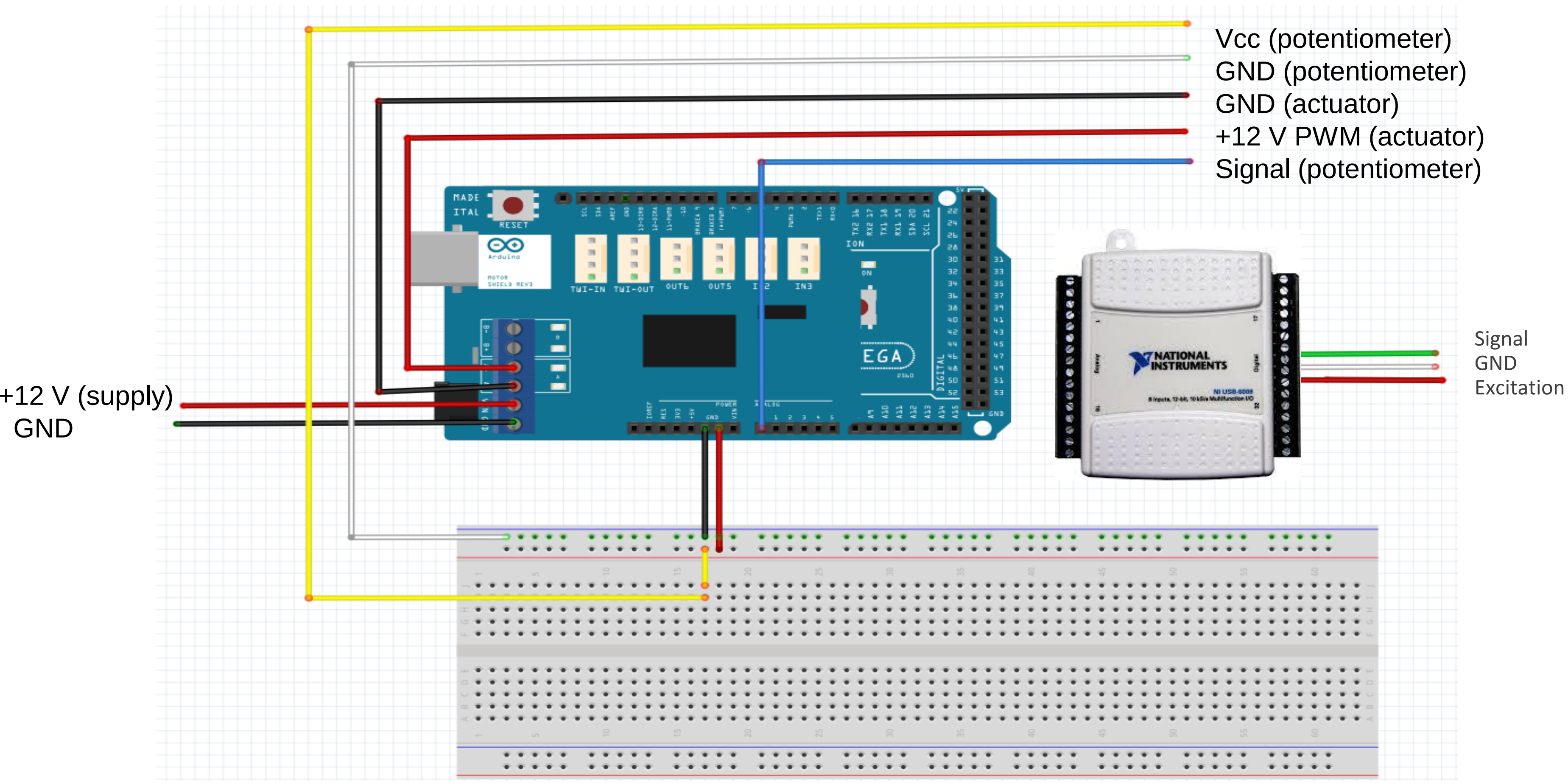
- Actuators provide 1010 lbs. of loading capability per actuator.
- Arduino Mega 2560 controls the actuators and measures the potentiometer feedback
- IBT2 High Power Motor Drivers control the speed and direction of the actuators, can reduce the speed from .67 inch/second to as slow as .003 inch/second
- Omega 6 mm grid linear strain gauges measure the strain of the area that it is attached to
- NI 9235 Quarter Bridge module outputs the strain gauge reading
- NI cDAQ 9174 passes strain gauge data to LabVIEW interface
- Emergency shut off switches allow for quick power disconnect if a problem occurs during use
- Custom housing box for system components







# Wiring Diagram



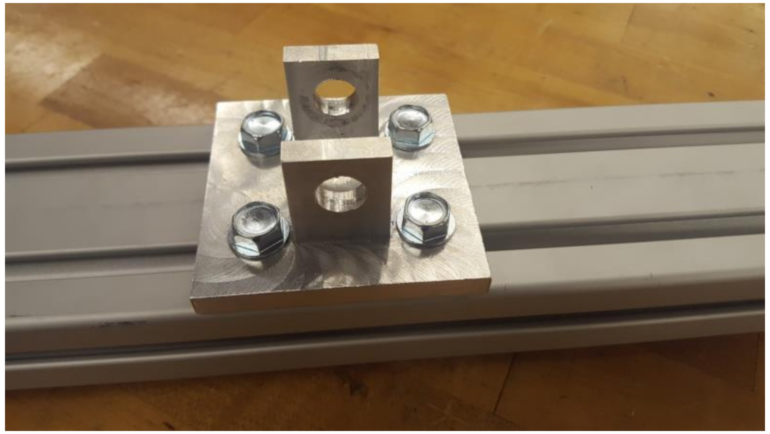
# Significant Issues: Load Monitoring System

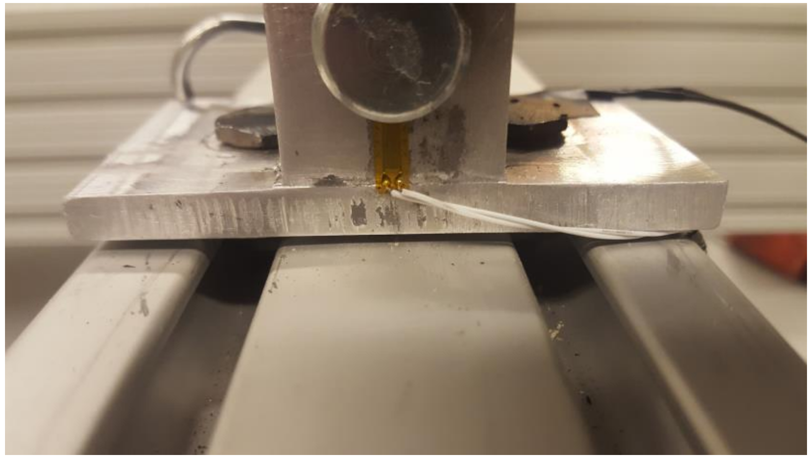
After being directed to build a load cell as opposed to buying an off the shelf load cell our best option was to design a custom clevis and use a strain gauge for load monitoring.

From the strain measurement we can predict the load using the following equation: $P = \varepsilon AE$

where, P=load measurement, Epsilon= strain measurement, A=Load bearing area (Bolt diameter by thickness), and E=modulus of Elasticity of Aluminum

Our plan was to center the actuator in the clevis with spacers to ensure equal load distribution between the clevis prongs, and measure the strain in one prong and then double the calculated load to obtain the load output from the actuator.

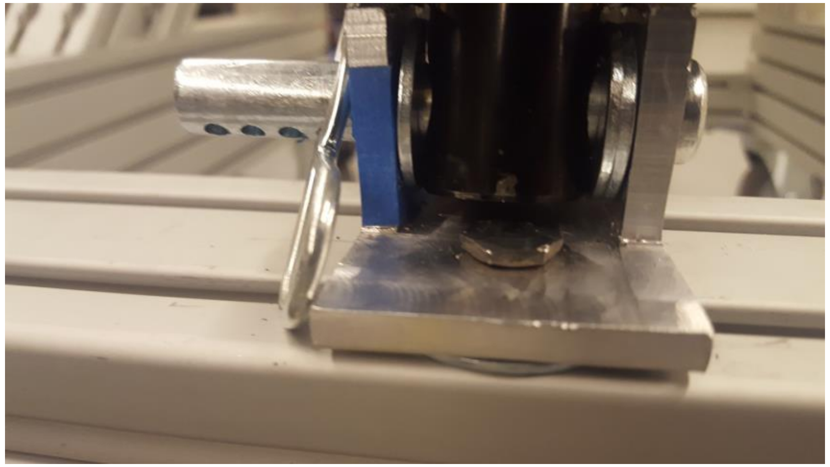


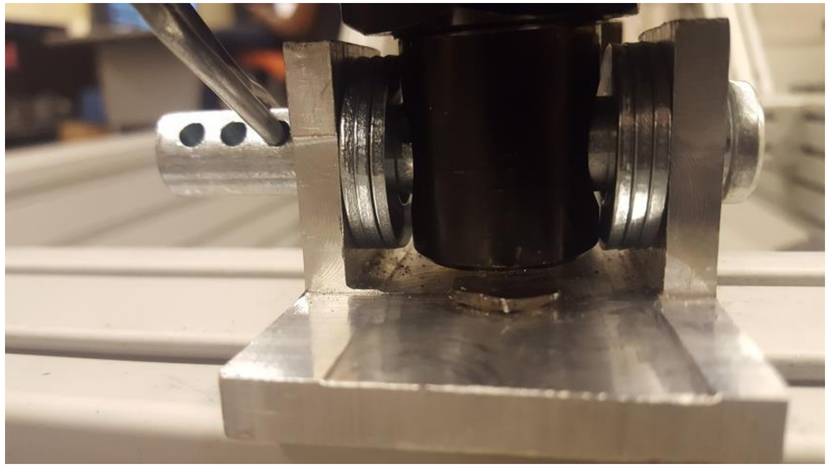


# Significant Issues: Load Monitoring System

What went wrong:

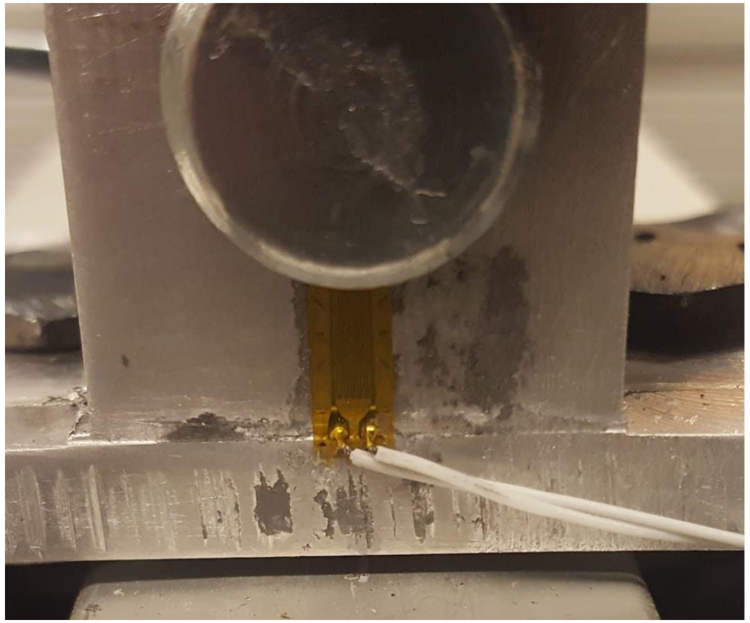
- It is extremely difficult to ensure the actuator is perfectly centered, any displacement from the center position causes massive errors (over 50%) in the load calculation.
- The Strain Gauges need to be calibrated before every assembly of the system, and then may become uncelebrated once bolts are tightened and apply a preload prior to testing.
- Manufacturing the brackets with limited experience caused defects including inconsistent clevis post spacing in the brackets; limited resources prevented remanufacture.

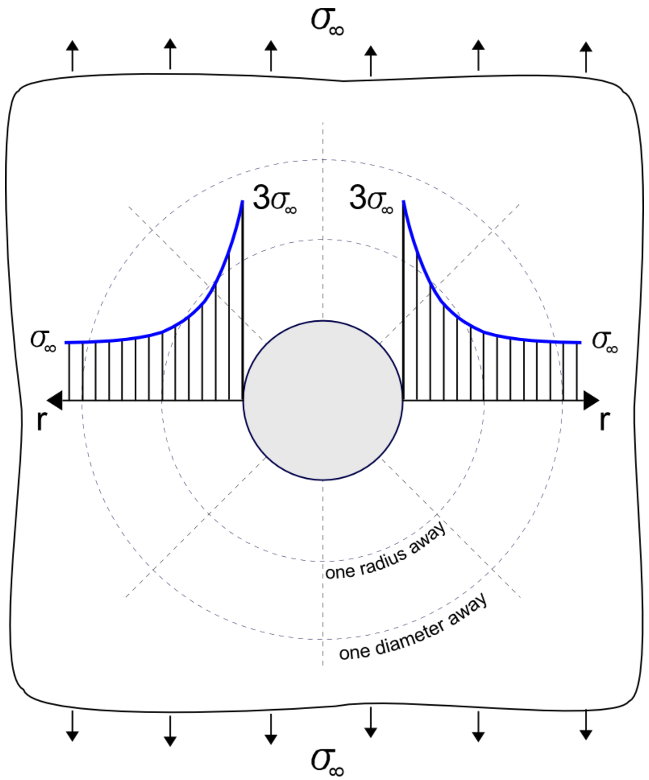




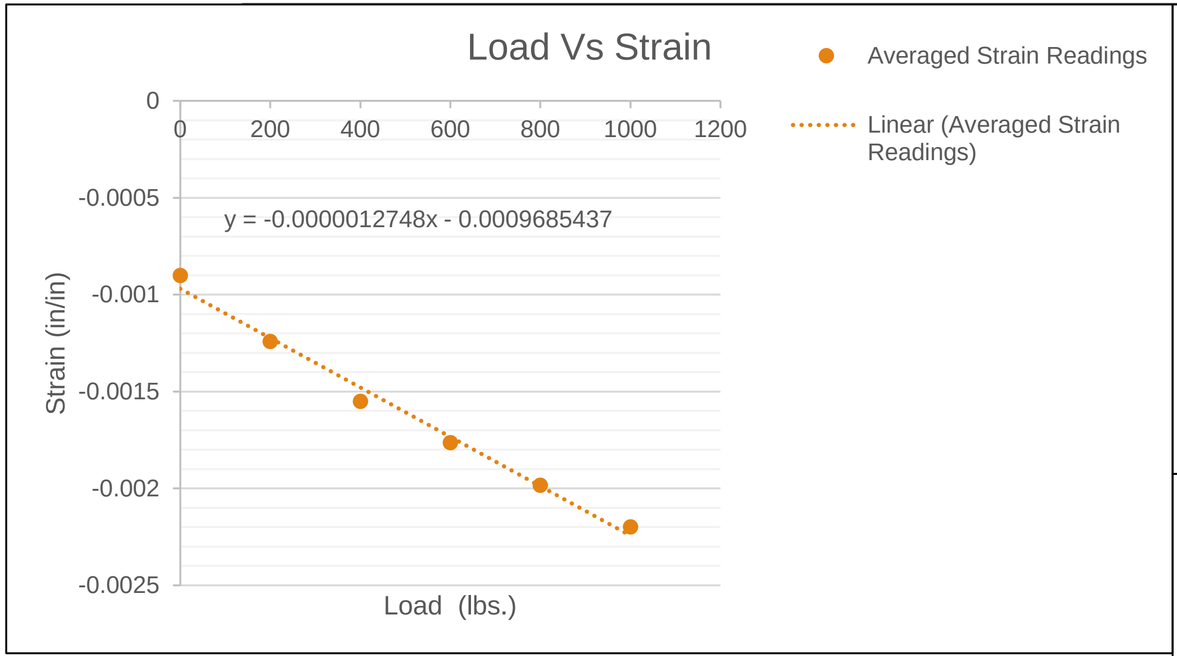
# Strain Gage Placement

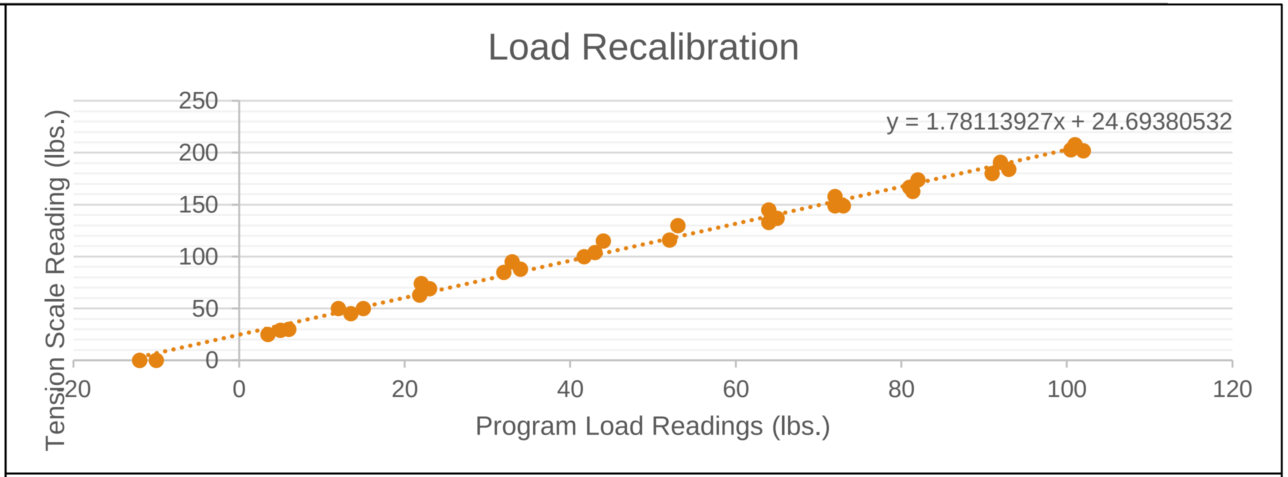
- A possible reason for calibration difficulties is the proximity to the bolt hole as well as the base of the clevis.
- The entire strain gage is within 1 Diameter distance of the hole, which lies in a non linear range.
- For future iterations, the clevis should be made taller so that there is space to apply the strain gage in a location where the strain will have a linear behavior.

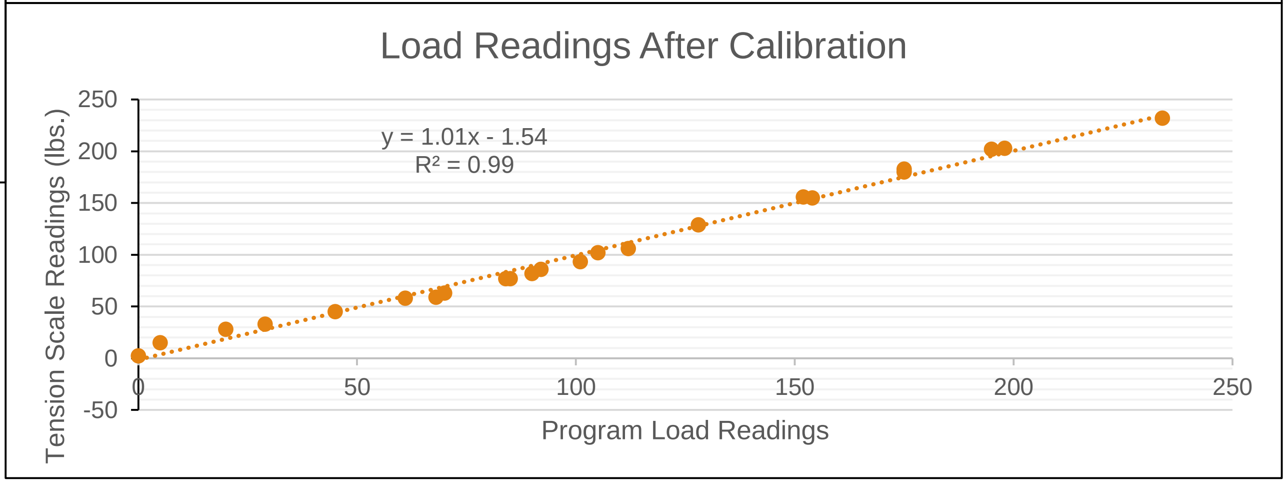




# Strain Gage Calibration



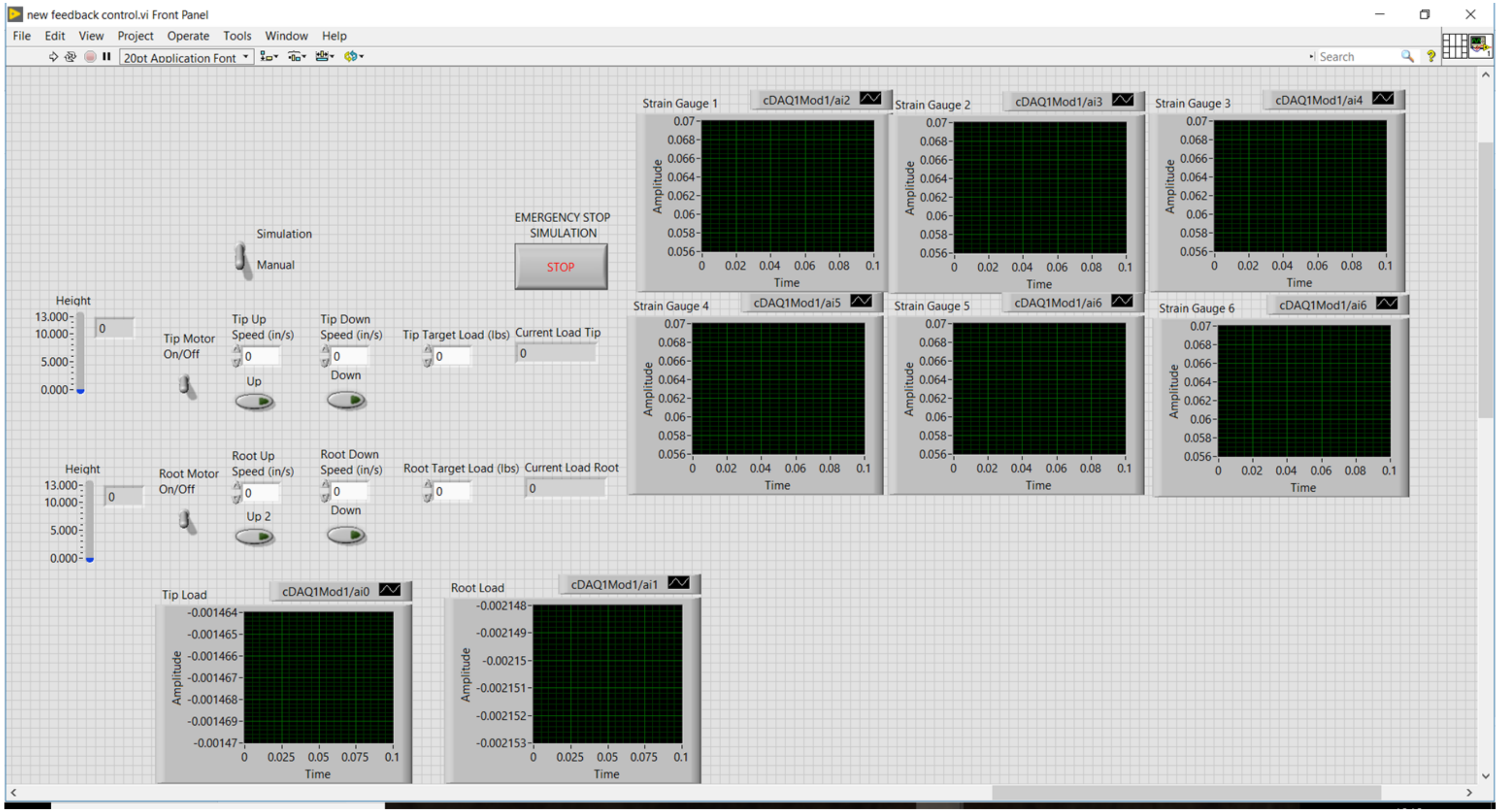




1. Initial strain gage calibrations measured on load cells in Fab Lab
2. Correction factor integrated into load reading in VI, then second calibration was performed with tension scale.
3. Additional corrections integrated into VI.

# Software Overview

- LabVIEW VI used for control and data acquisition.
- Controls for actuator extension and retraction speeds, target loads.
- Manual actuator activation available for initial setup.
- Simulation mode automatically runs test with initial settings.



# Software Development Process

- Initial VI was built to manually control actuators through Arduino. Built based on examples found online for DC motor control. Potentiometer readings were also added into this VI.
- Second VI for testing strain gauges assembled using DAQ assistant built into LabVIEW. This VI was also used in combination with Fab Lab equipment to calibrate strain gauges.
- Third VI used to develop loading logic between actuators as well as case structure to allow manual control within the same VI.
- Fourth (and first full system) VI created using copies of the first two and integrated with the format of the third VI.
- Finding initial case structure incompatible with real-time gathering of data through DAQ, fifth (and final) VI created using new case structure that increases functionality at the cost of ease-of-use. Minor revisions made to loading logic and to add strain gauge zeroing.

# Significant Issues: Software

- All members of I&C sub team only had experience with LabVIEW from MAE 3113, which teaches us to measure and analyze data using LabVIEW. Members had to self teach how to use LabVIEW to control hardware and implement feedback control.
- LabVIEW DAQmx interface does not integrate with logic loops well.
- As more logic and math was added for calibration and control features, the program would lag by as much as 20 seconds before data would show and screen and feed back to a control.
- Removing features from program functionally requires rebuilding program from scratch without undesired features. Too much interconnectivity makes removal of functions difficult.

# Budget and Schedule Assessment

- Initial budget estimate:  $2,200 (CDR Estimate)
- Actual Budget: $1,130
- Well under budget, with plenty of resources to purchase load cells for future application.
- Originally planned on receiving components by March 23rd to begin system integration and tests, however final components did not arrive until April 20th.
- Delayed schedule by a month and limited our integration and testing time to less than 2 weeks.
- If our components would have been ordered on time, it would have allowed for adequate testing and troubleshooting time to solve critical issues that arose.

# I&C Future Improvement

- Software
  - Separate manual control and simulation into distinct VIs for improved function at cost of simplicity-of-use.
  - Consult with more experienced LabVIEW user to improve case structure and loop formatting.
- Load Cell
  - Provide a reliable load reading
  - Less sensitive to small readjustments of the actuator
  - Simplified installation process as opposed to strain gauge application process