# COMPASS

*University of **CO**lorado **M**odel **P**ositioning - St**A**tic - **S**y**S**tem*

Customer: Dr. John Farnsworth

Critical Design Review
3 December 2015

Nicholas Gilland, Brandon Harris, Kristian Kates, Ryan Matheson, Amanda Olguin, Kyle Skjerven, Anna Waltemath, Alex Wood

# Agenda

- Purpose and Objectives
- Design Solution
- Critical Project Elements
- Design Requirements and Satisfaction
- Project Risks
- Verification and Validation
- Project Planning

# Purpose and Objectives

# Project Purpose

**COMPASS**

- **Position a Model in the Wind Tunnel on East Campus**
  - Statically position a model in 4 DoF
  - Interface with current wind tunnel
  - Mobility of entire system
  - Failsafes within hardware and software
  - Easily maintainable for future use

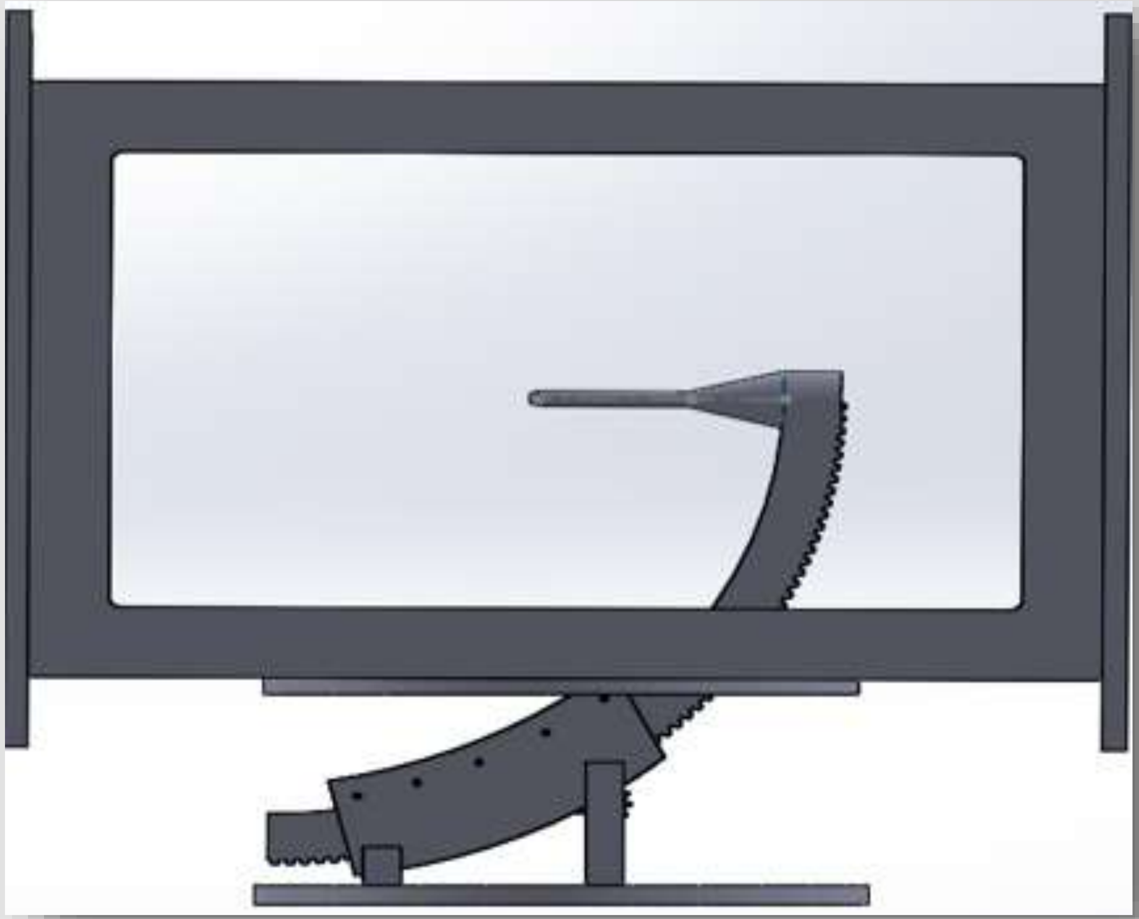
# Motivation

Provide a **model positioning system** for the new wind tunnel and provide support for aerodynamic models used for:

- Research performed by CU graduate students and professors
- Graduate student labs
- Undergraduate senior projects

# Design Solution

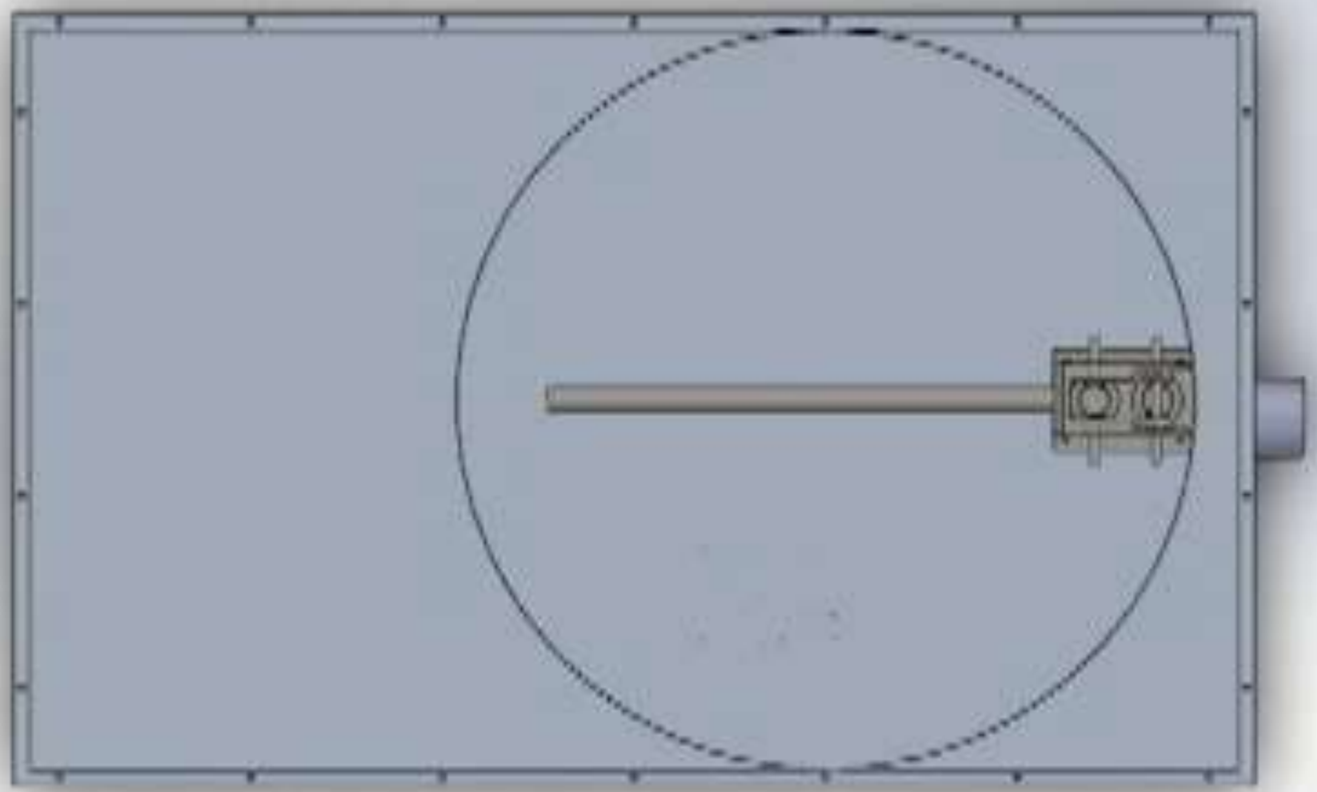
# Previous Design

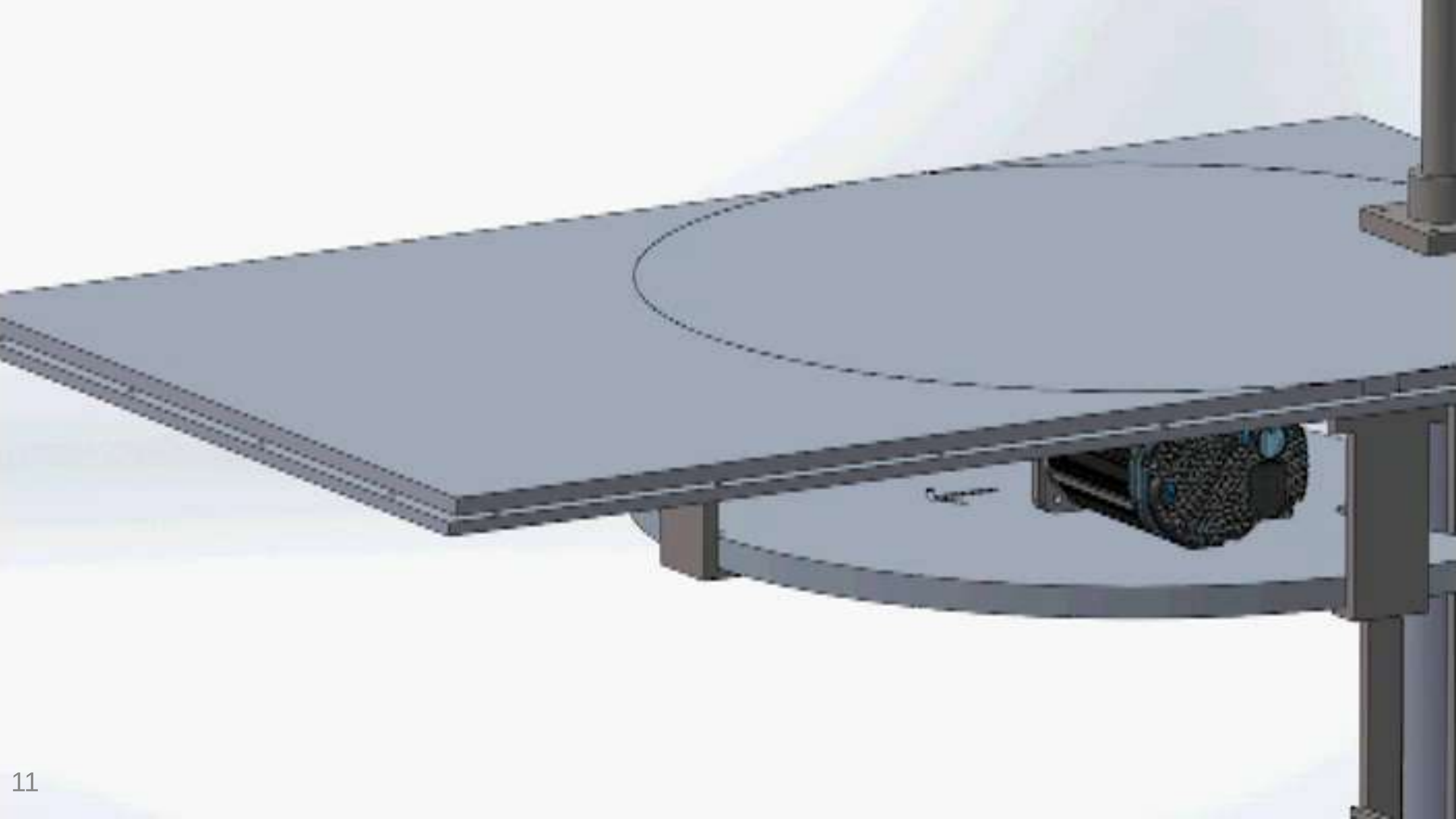


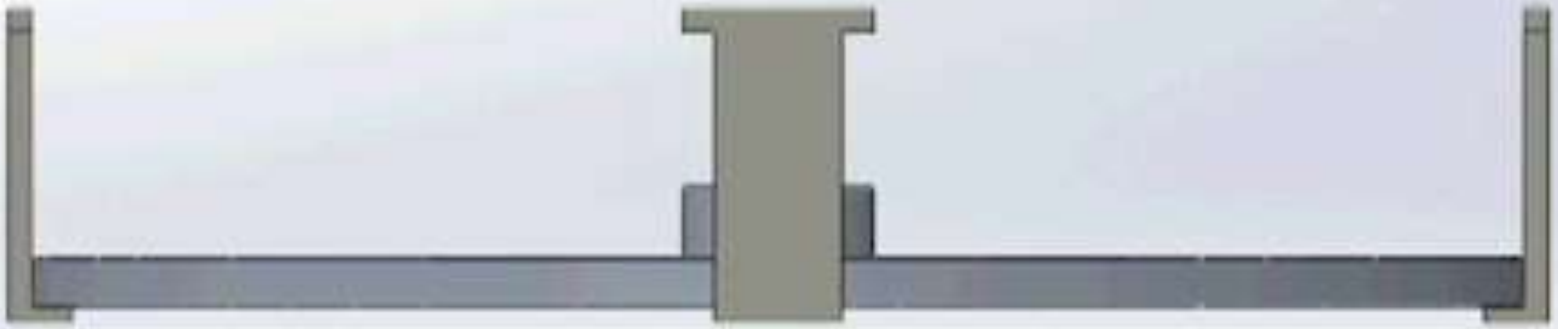
- Yaw axis and pitch axis did not intersect (did not collocate).
- Plunge mechanism had to lift weight of entire system.
- Slit allowing crescent arm to plunge would cause flow issues.
- Size of roll motor seriously limited available torque.

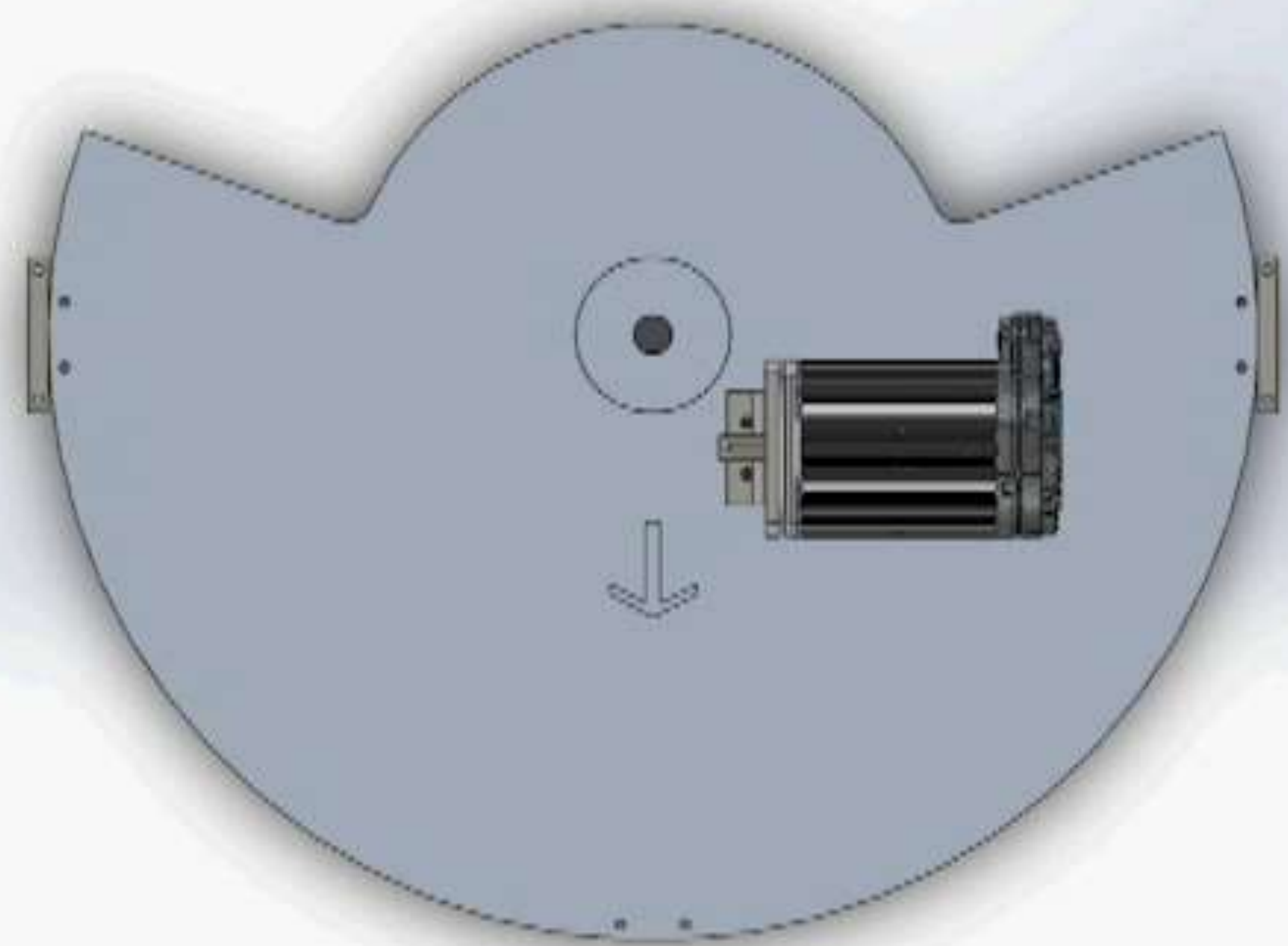
# Revised Design

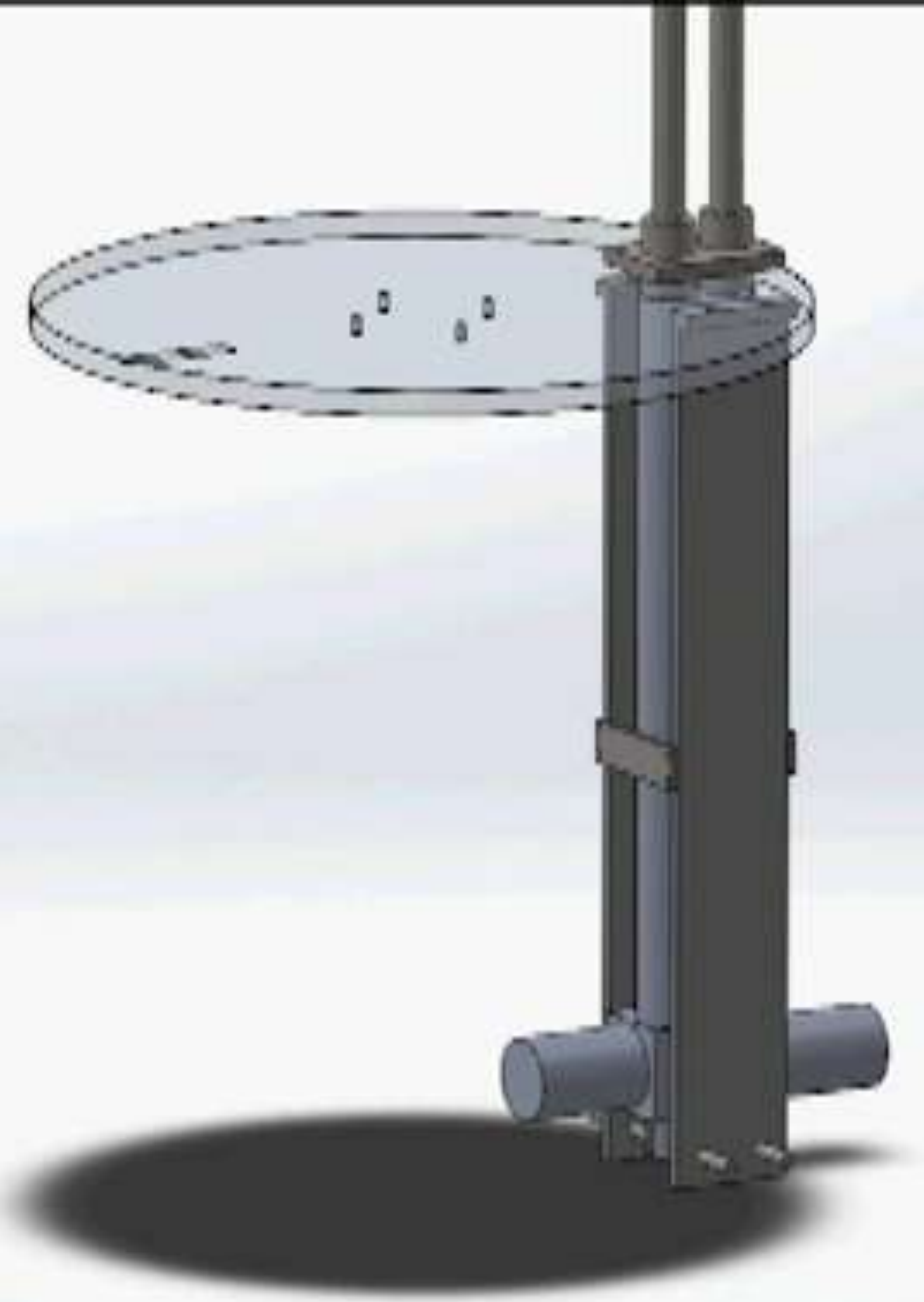
- Allows for collocation of axis.
- Pitch and Plunge accomplished by linear actuators.
- No slit needed for plunge.
- Roll motor removed and replaced with static roll.

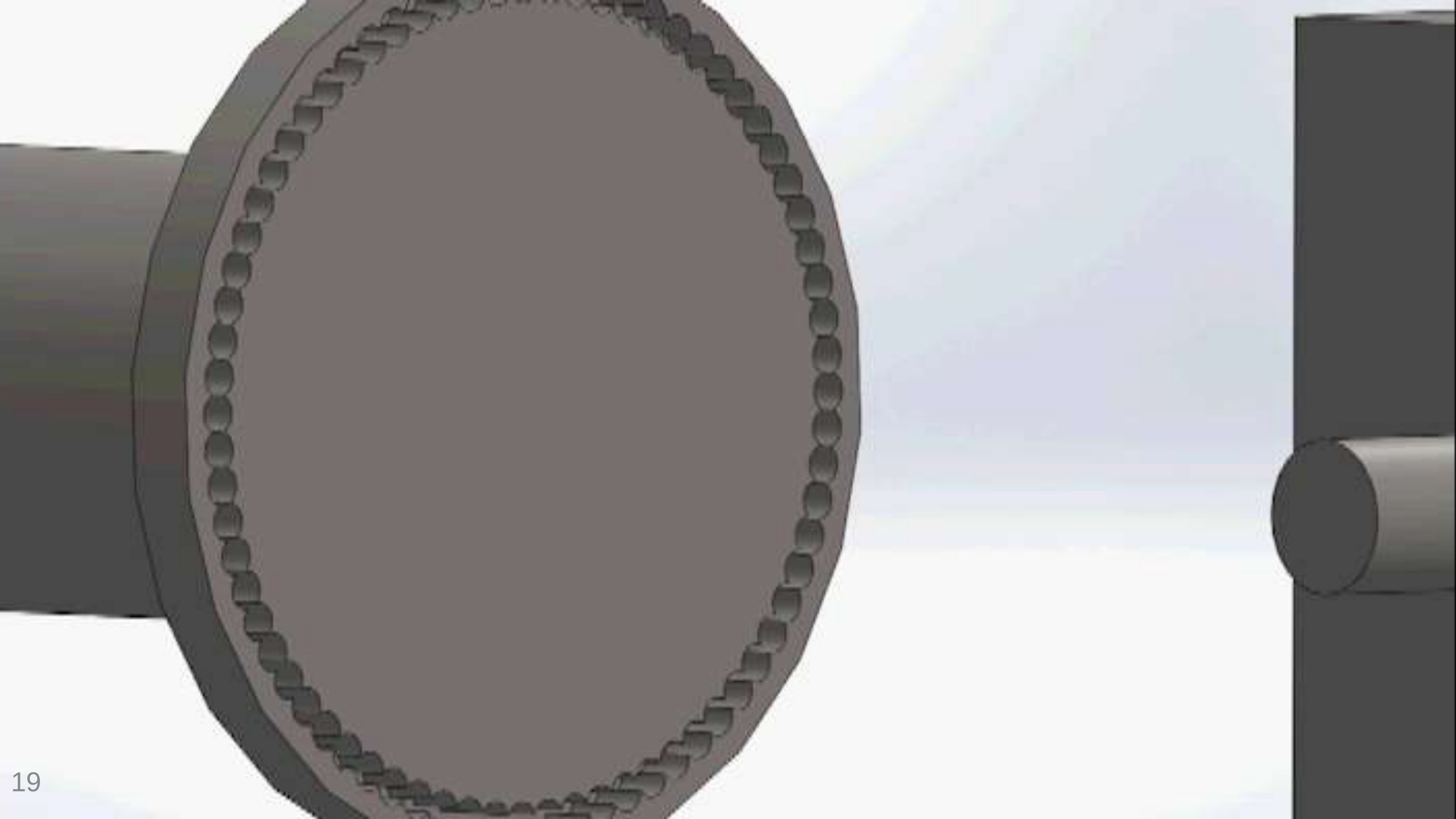


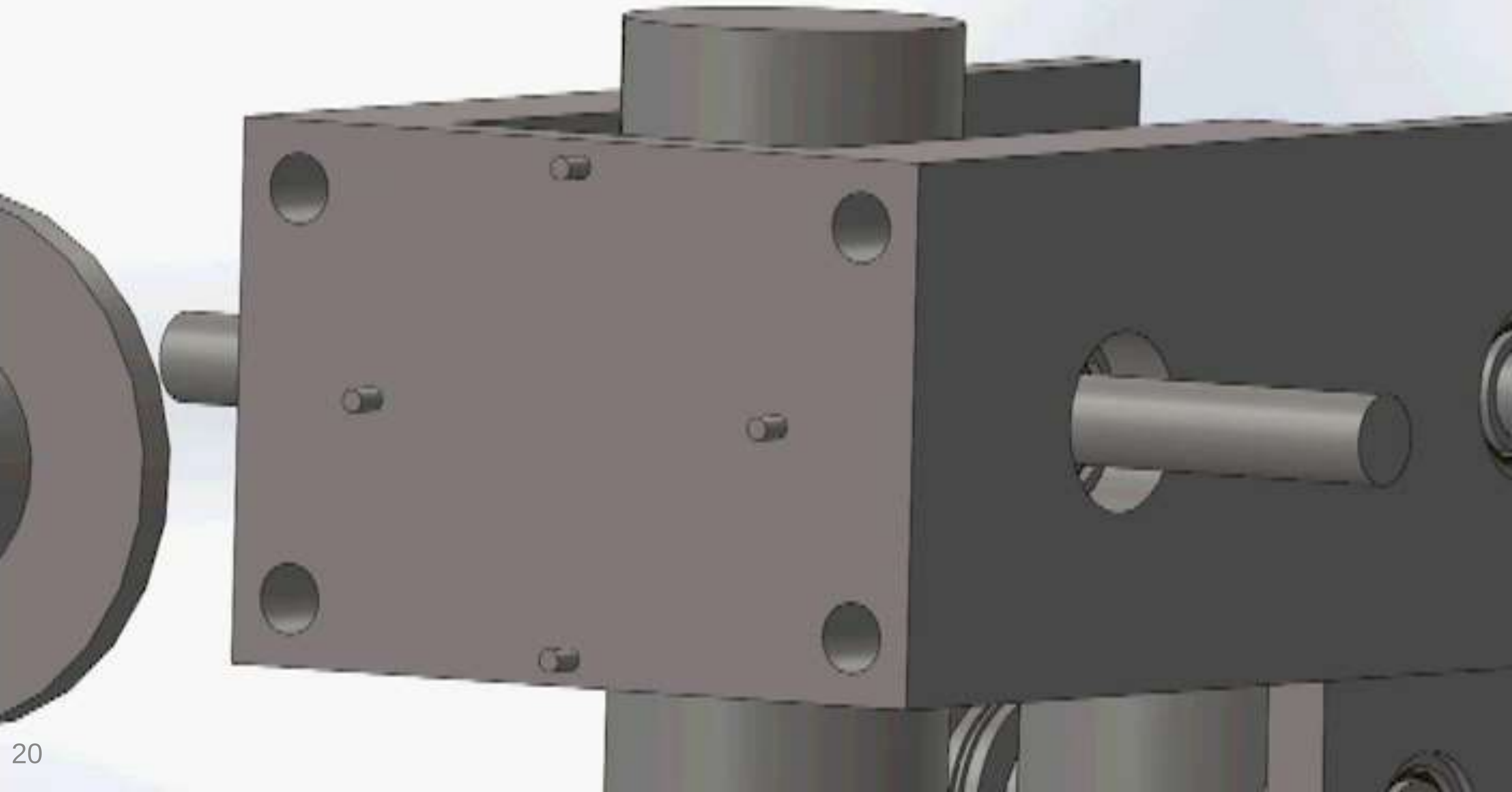


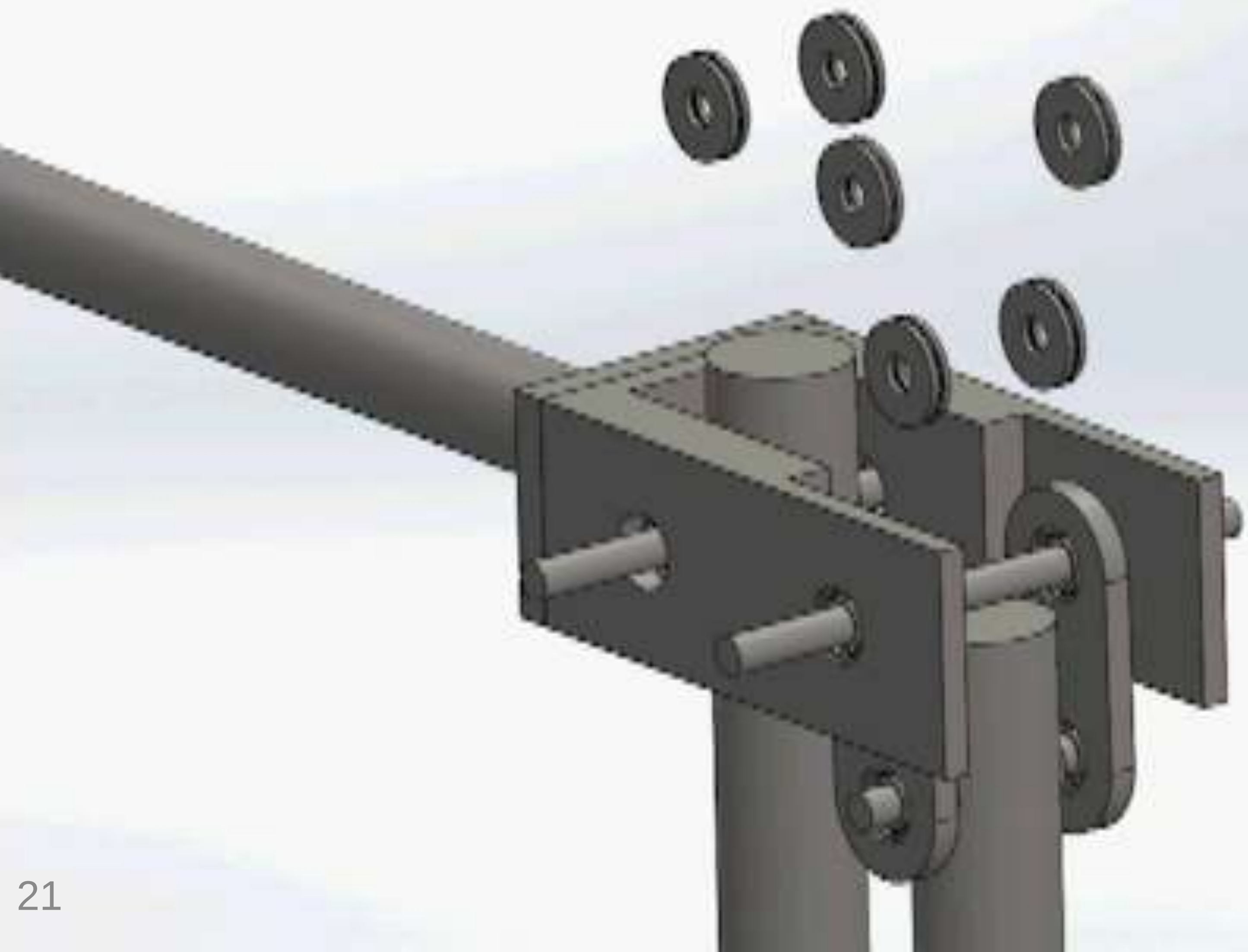


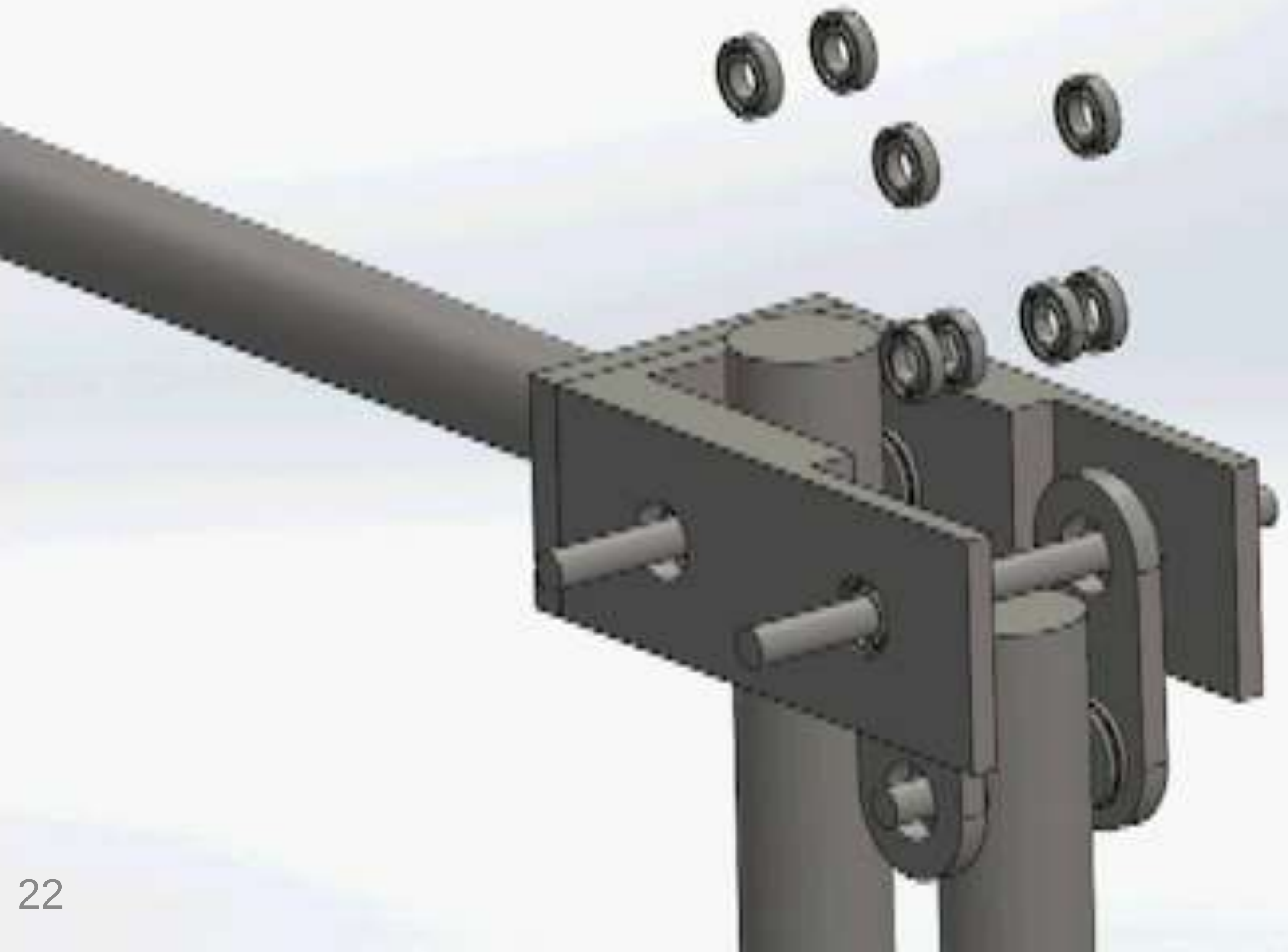


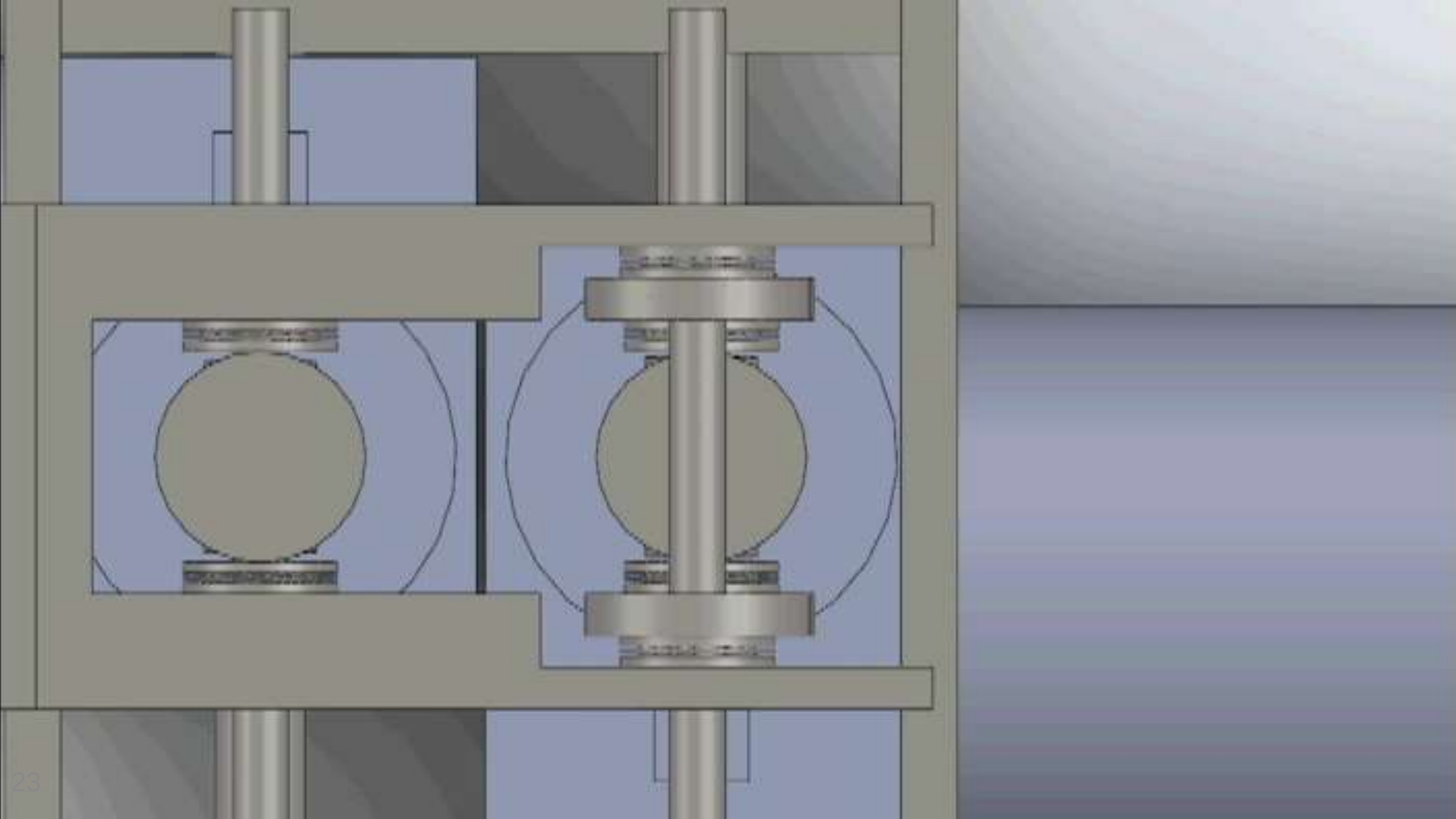




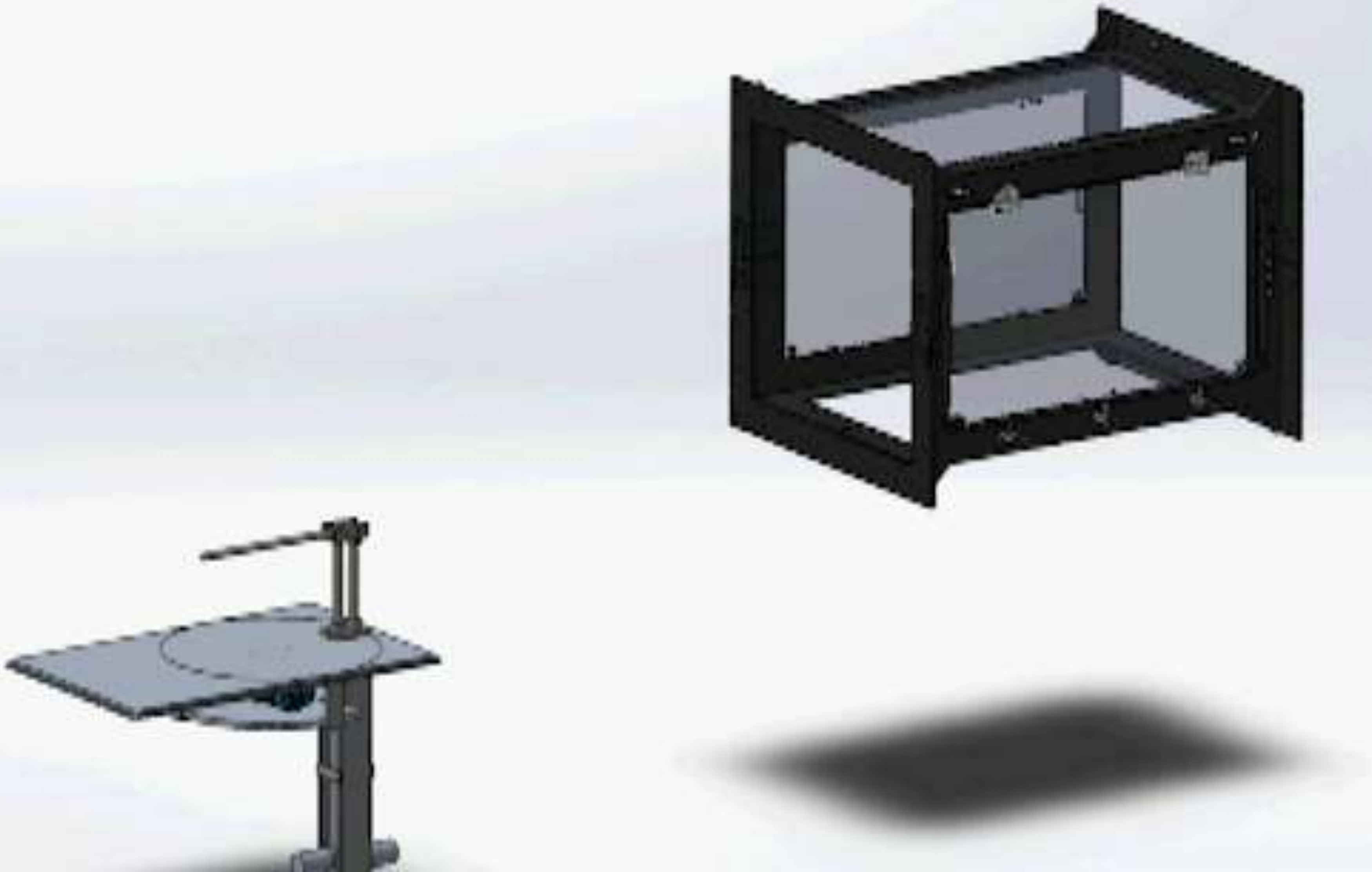


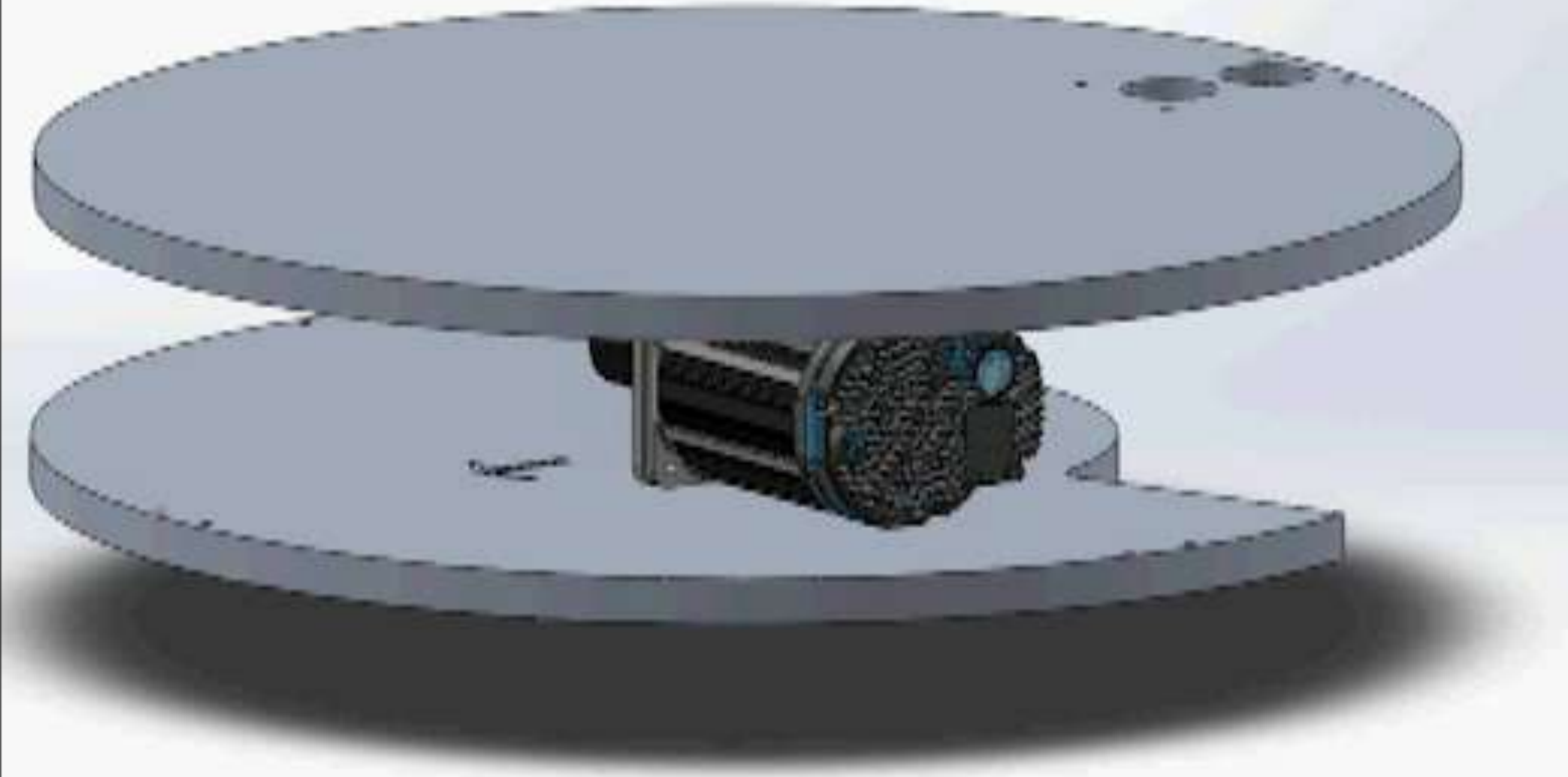




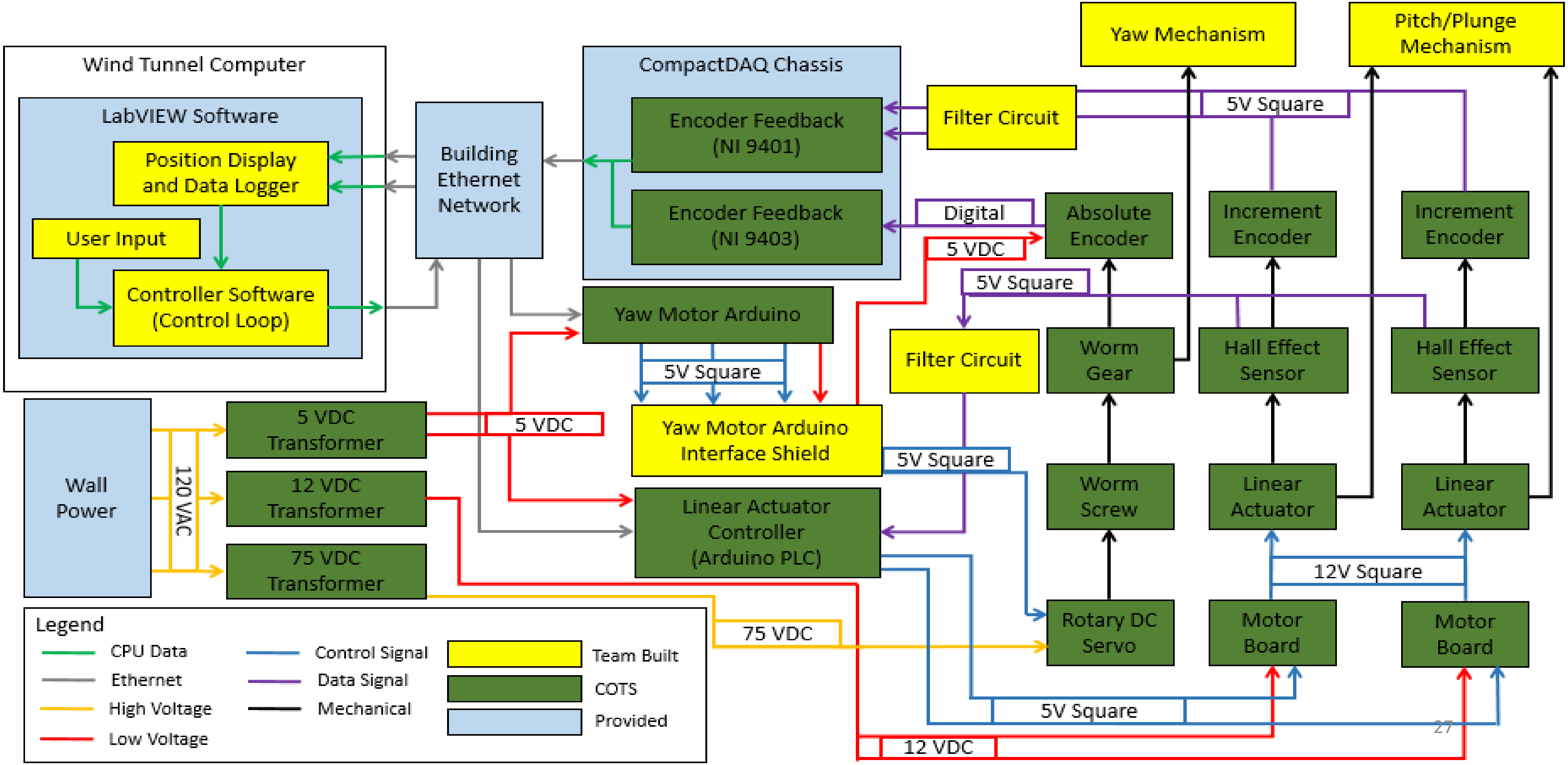


# CONOPS





# FUNCTIONAL BLOCK DIAGRAM



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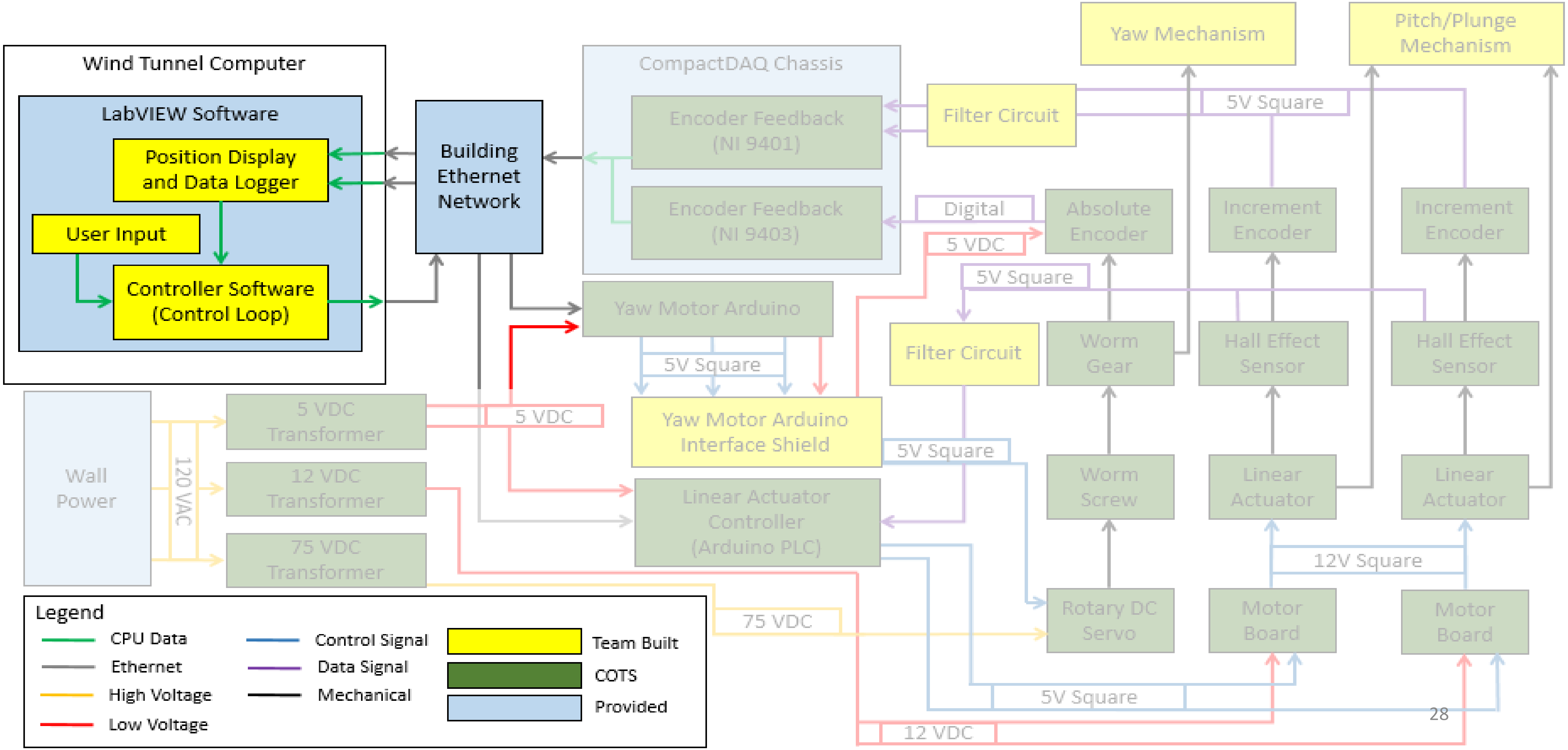

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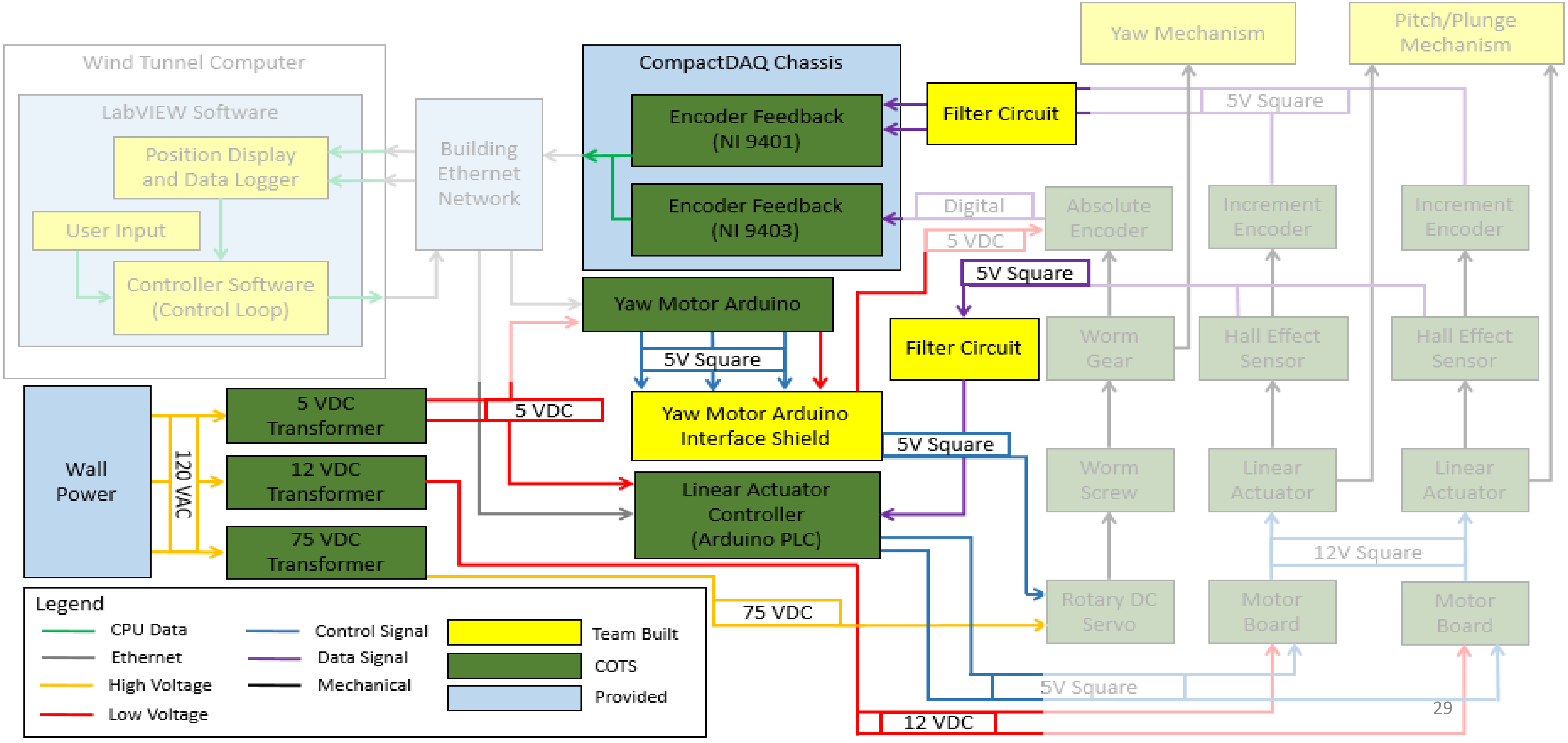

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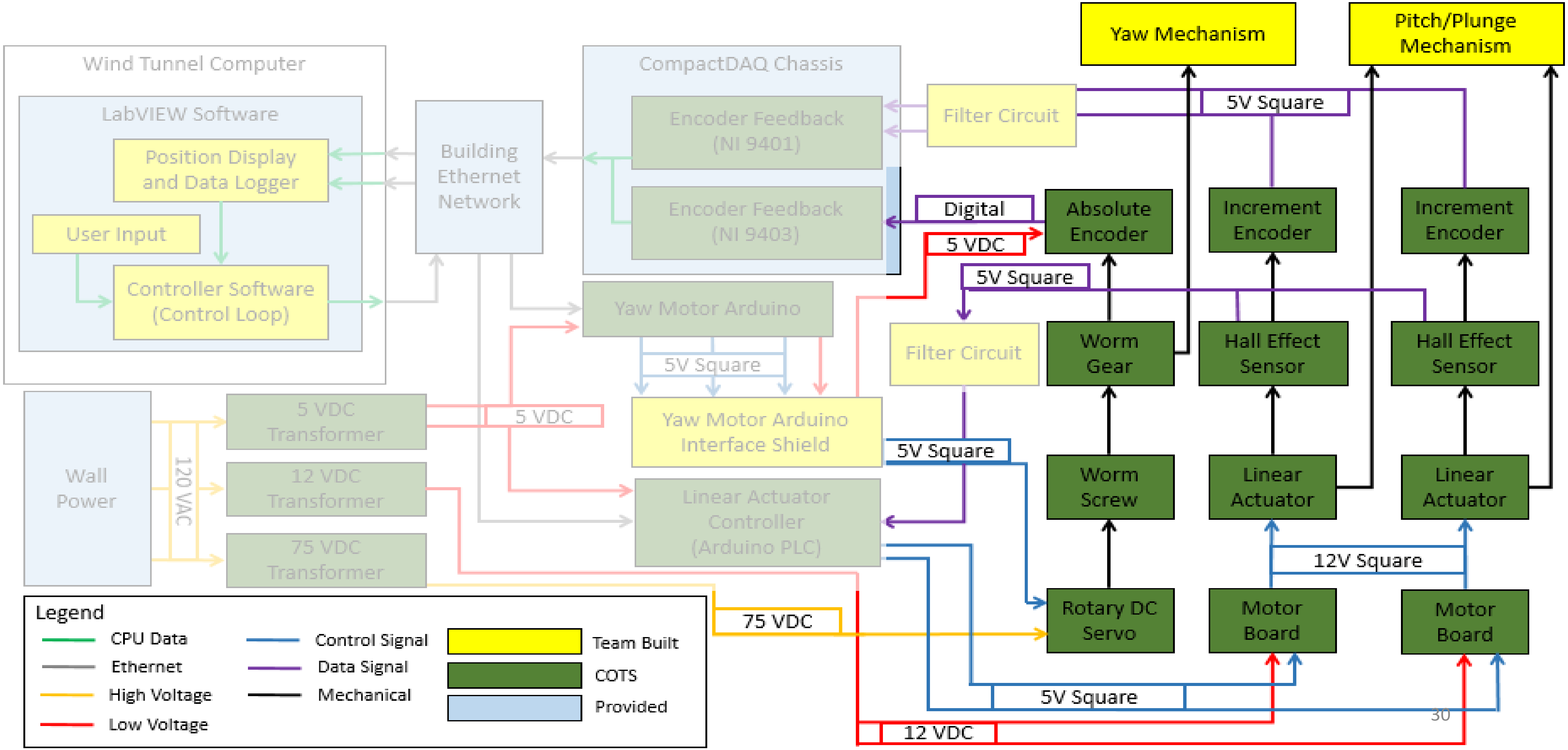

# Critical Project Elements

# Functional Requirement Overview

FR 1: **Statically** position the Model (in 4 DOF)

FR 2: **Interface** with current wind tunnel hardware

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FR 3: **Mobility** of the entire system

FR 4: **Failsafes** within hardware and software

FR 5: **Easily Maintainable** for future use

# Functional Requirements

## FR 1: COMPASS shall position the model

**DR 1.2.1 - DR 1.2.4:** COMPASS shall position the model within the **ranges** of:

- ± 30° in pitch
- ± 30° in yaw
- ± 45° in roll
- ± 10 cm in plunge

**DR 1.2.5**: The **accuracy** of the 4 DOF shall be:

- ± 0.1° in pitch
- ± 0.1° in yaw
- ± 0.5° in roll
- 0.5 mm in plunge

# Wind Tunnel Interface

## **FR 2**: COMPASS shall interface with the wind tunnel

**DR 2.1**: COMPASS **hardware** shall interface with wind tunnel hardware such that it:

- Modifies test section only through removal of bottom surface of a single test section

**DR 2.2**: COMPASS **software** shall interface with the wind tunnel such that it:

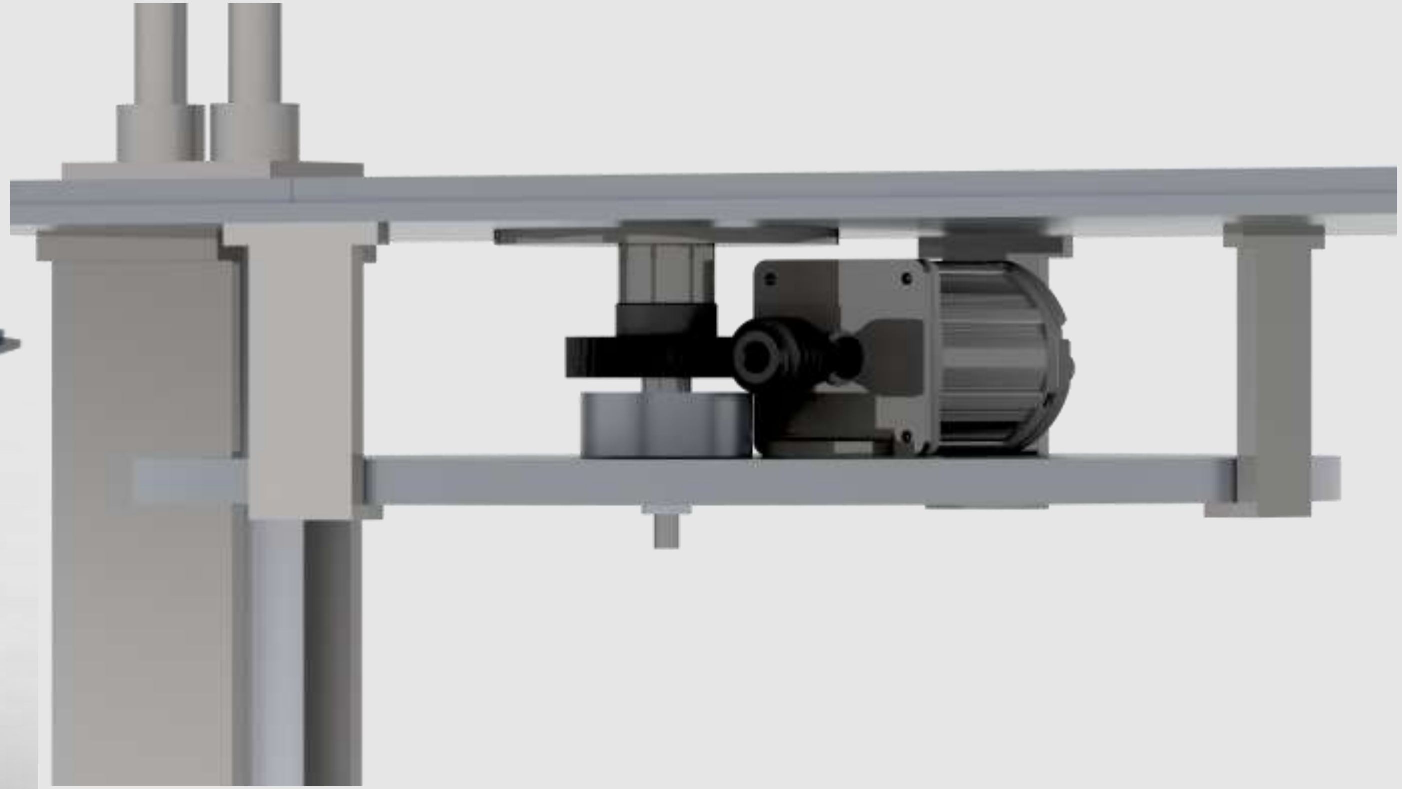
- Utilizes LabVIEW software

# Critical Project Elements

| Critical Element | Reasoning for Critical Status |
|---|---|
| **CPE.1:** Yaw Mechanism | Minimum success requires ability to **yaw** across a range of ±30° at an accuracy of 0.1° as specified in **DR 1.2** and **DR 1.2.5**, respectively |
| **CPE.2:** Pitch Mechanism | Minimum success requires ability to **pitch** across a range of ±30° at an accuracy of 0.1° as specified in **DR 1.2** and **DR 1.2.5**, respectively |
| **CPE.3:** Plunge Mechanism | Minimum success requires ability to **plunge** across a range of ±10 cm at an accuracy of 0.5 mm as specified in **DR 1.2** and **DR 1.2.5**, respectively |
| **CPE.4:** Wind Tunnel Interfacing | Integration with wind tunnel such that it meets sizing and interfacing specifications as outlined in **DR 2.1 — DR 2.3** is a requirement given by the customer |
| **CPE.5:** Software Implementation | Design for LabVIEW integration is a requirement specified by the customer |
| **CPE.6**: Structural Integrity | Successful operation of COMPASS dependent on linkages and other mechanical components not failing in shear or buckle |

# Satisfaction of Design Requirements

# Yaw Mechanism



# Yaw Design Requirement Satisfaction

- **ClearPath Integrated Servo Motor**
- Rated for **3.38 N-m** torque
  - Expected max torque: **75 N-m**
- Accuracy: **0.45°**
  - Needed accuracy: **0.1°**
- Yaw Motor has no turn restrictions so the 30° requirement will be met
- Worm gear ratio: **40:1**
  - Cont. Torque: **135.2 N-m**
  - Accuracy of **0.01°**
- **Margin = 80%**

| Critical Element | Satisfaction Justification |
|---|---|
| **CPE.1:** Yaw Mechanism<br><br>**SATISFIED** ✓ | Minimum success requires yaw across a range of ±30° at an accuracy of 0.1° as specified in DR 1.2 and DR 1.2.5, respectively This motor satisfies DR 1.2 and DR 1.2.5. |



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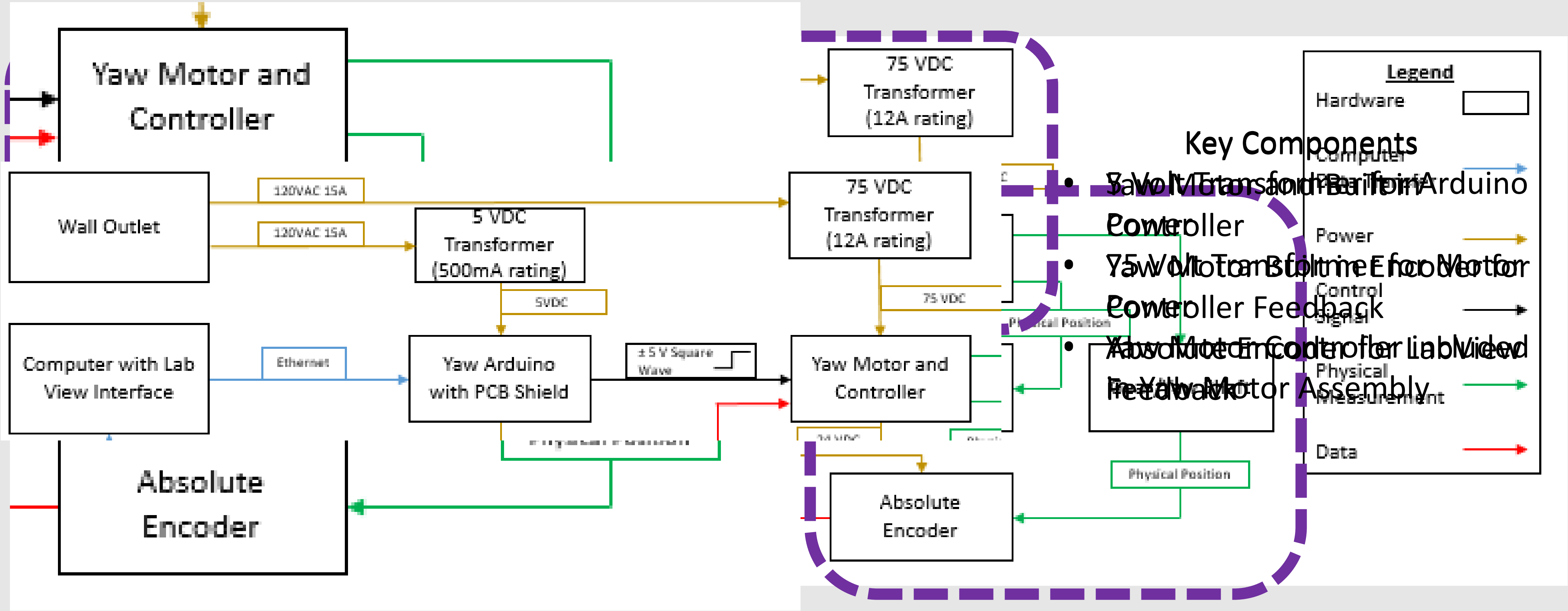
# Yaw Circuit

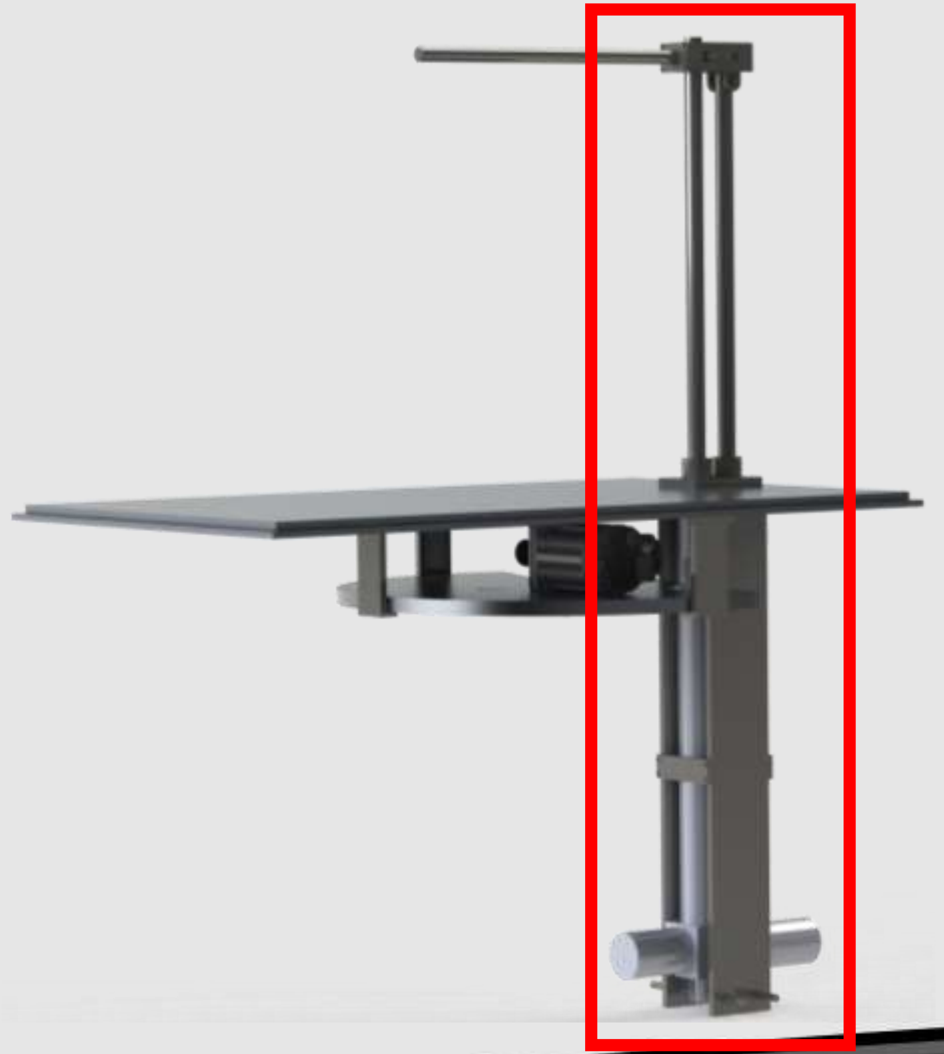



Key Components

- 5 Volt Transformer for Arduino Power
- 75 Volt Transformer for Motor Power
- Absolute Encoder for LabView Feedback

- Yaw Motor and Built-in Controller
- Yaw Motor Built-in Encoder for Controller Feedback
- Yaw Motor Controller in Yaw Motor Assembly

# Pitch/Plunge Mechanism

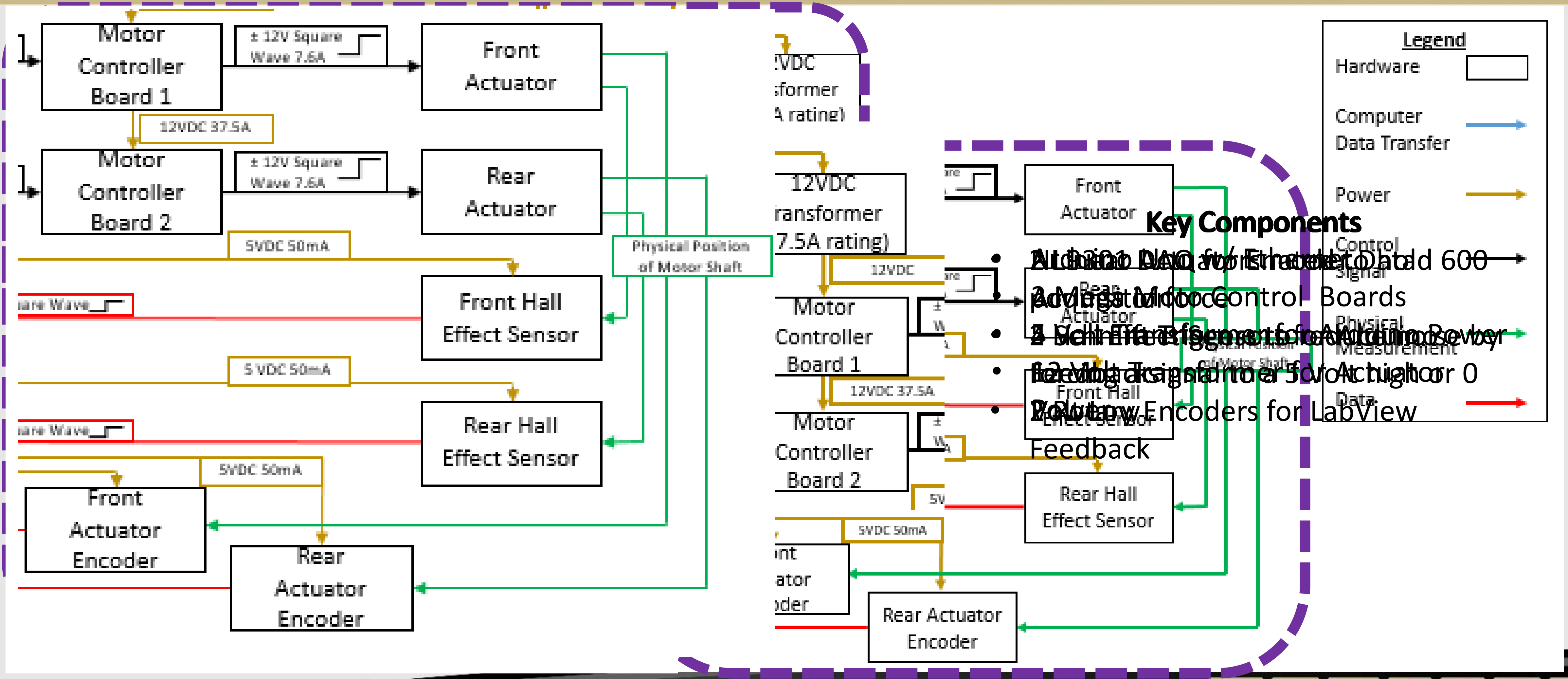


# Pitch and Plunge Design Requirement Satisfaction

- PA-03 Linear Actuator
- Rated for **600 lbs.** of force
  - Expected max force: **185 lbs.**
  - **Margin = 320%**
- Arduino control and hall effect sensor feedback allow for precise control.
  - **0.0016** inch precision from **38:1** gear ratio
  - Correlates to **$0.0465^0$** accuracy
- Total stroked needed for **$\pm 30^0$** is **21.26** inches
  - Actuators can be ordered with customizable stroke length up to **40** inches

| Critical Element | Satisfaction Justification |
|---|---|
| **CPE.2:** Pitch Mechanism **SATISFIED** ✔ | Minimum success requires **pitch** across a range of ±30° at an accuracy of 0.1° as specified in **DR 1.2** and **DR 1.2.5.** This actuator satisfies **DR 1.2** and **DR 1.2.5.** |

# Pitch and Plunge Circuit




**Key Components**

- ... 600
- ... Motor Control Boards
- ...
- 12 Volt Transformer for Actuator ... 5 Volt high or 0 ...
- 2 Rotary Encoders for LabView Feedback

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# FR 2 Satisfaction

| FR 2 | Solution | Satisfied? |
|---|---|---|
| **DR 2.1**: COMPASS **hardware** shall interface with wind tunnel hardware such that it modifies the test section only through removal of bottom surface of a single test section | COMPASS shall manufacture a baseplate that will interface with the wind tunnel by being screwed into the frame | **SATISFIED** ✔ |
| **DR 2.2:** COMPASS **software** shall interface with the wind tunnel such that it utilizes LabVIEW software | COMPASS shall be controlled through LabVIEW software VIs. Arduinos can also be controlled through LabVIEW | **SATISFIED** ✔ |

# Error Characterization for Each DOF

- Yaw can be characterized directly by absolute encoder
- Pitch and Plunge have more open-loop elements
  - Error can be characterized to validate/verify pointing accuracy

| Component (Yaw DOF) | Error (degrees) |
|---|---|
| Absolute Encoder | 0.022° |
| Radial Bearing Slop | 0.0° |
| Total | 0.022° |

| Component (P/P DOF) | Error (mm/degrees) |
|---|---|
| Linear Actuator | 0.0406 mm \| 0.045° |
| Incremental Encoder | 0.00857 mm \| 0.0095° |
| Radial Bearing Slop | 0 mm \| 0.0° |
| Total | 0.0406 mm \| 0.045° |

# Project Risks

# Primary Logistical Risks

Consequence

| Acceptable | Tolerable | Intolerable |
| --- | --- | --- |

**A**: Sufficient budget for motors, sensors and materials

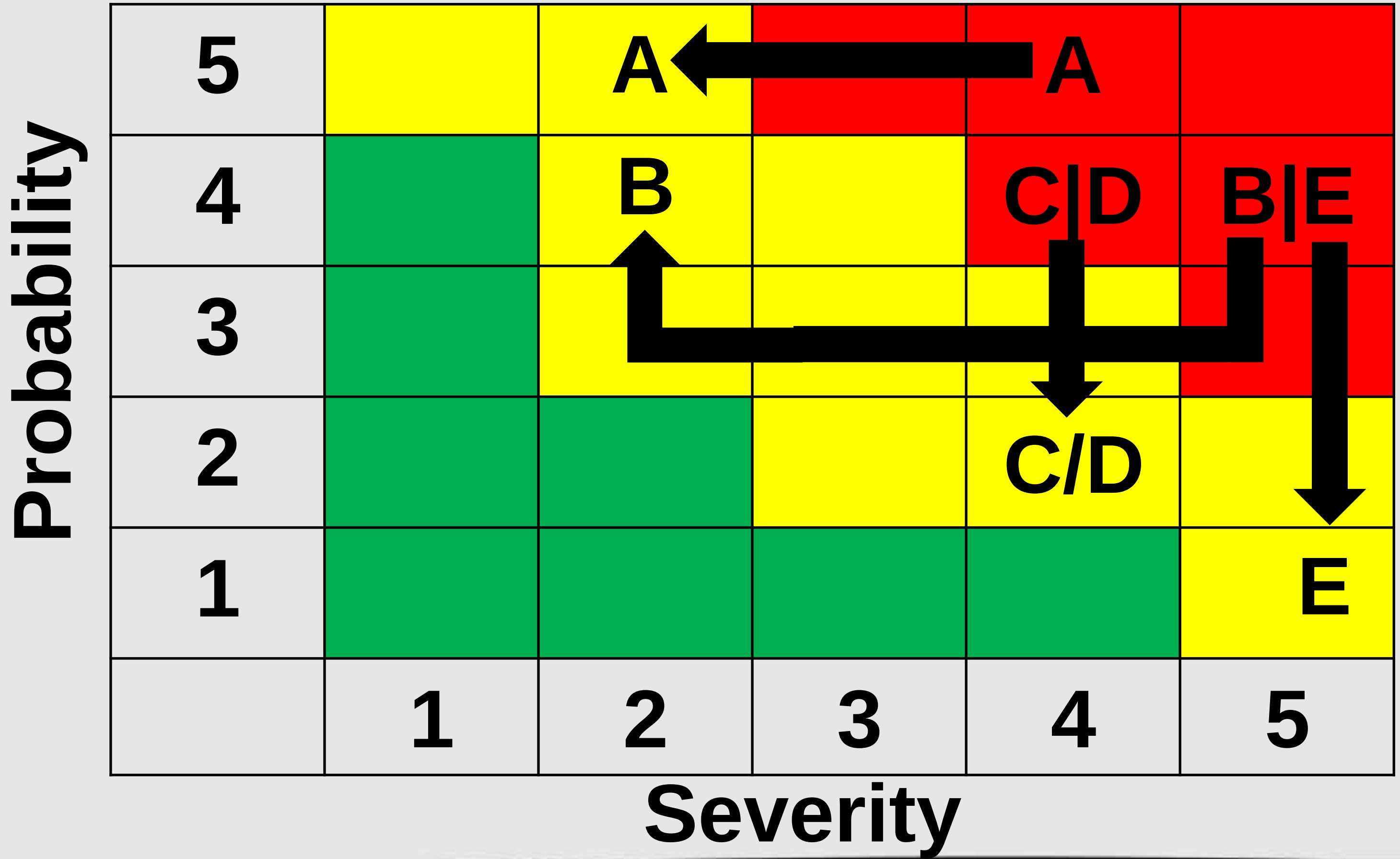
**B**: Delivery schedule of purchased items

**C**: Development time of software

**D:** Time required for testing and validation

**E**: Manufacturing capability of sting assembly, metal plates

## Risk Matrix



# Primary Logistical Risk Mitigation

| Risk | Mitigation |
|---|---|
| **A:** Sufficient budget for motors, sensors and materials | EEF funding of $3,000 granted |
| **B:** Delivery schedule of purchased items | Delivery dates of acquired components determined and accounted for in schedule |
| **C:** Development time of software | Scheduling buffer allocated for delays |
| **D:** Time required for testing and validation | Scheduling buffer allocated for delays |
| **E:** Manufacturability of sting assembly, metal plates | Manufacturing capability verified by Matt |

# Verification and Validation

# Verification and Validation

- Functionality Testing: Purchased Components
  - Yaw Motor/Encoder
  - Linear Actuator/Encoder/Arduino
  - NI DAQ

- Subsystems Testing
  - Software Testing
  - Electrical Interfacing Testing
  - **Mechanical Tolerance Testing**



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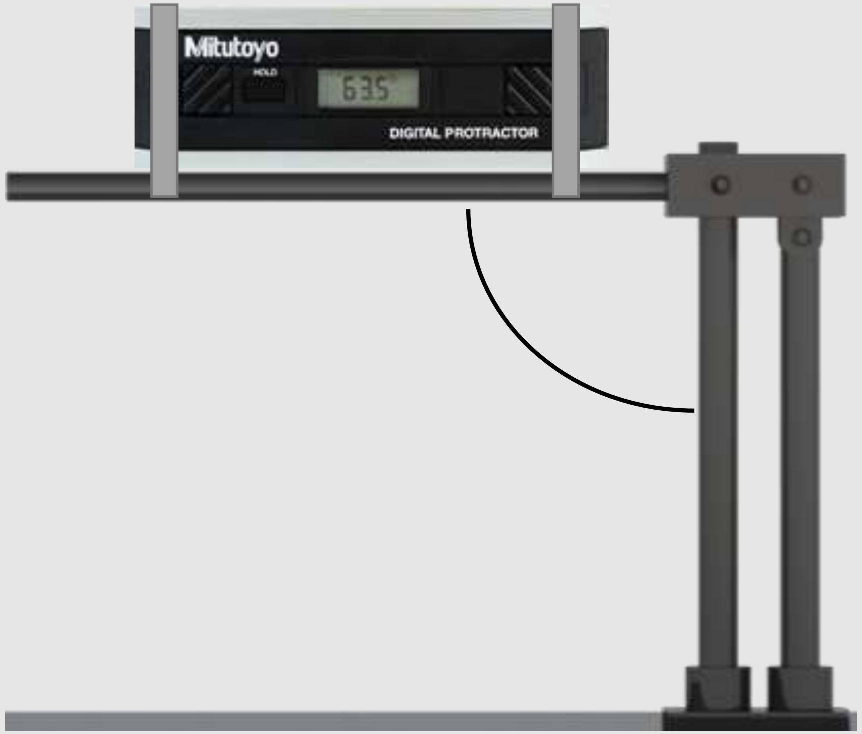
# Mechanical Subsystem: Pitch/Roll Tolerance

- **Main Objective:** Show accuracy/range in pitch/roll within requirements
- **Requirements verified:** DR 1.2.1, DR 1.2.5.1, DR 1.2.3, DR 1.2.5.3
- **Location:** Anywhere
- **General Procedure:** Securely clamp protractor to sting arm, then command desired angle. Cross reference commanded angle to digital protractor reading.
- Accuracy within ± 0.1°: **Validates Pitch & Roll** ✔
- **Systems Needed:** Pitch/Roll Mechanisms



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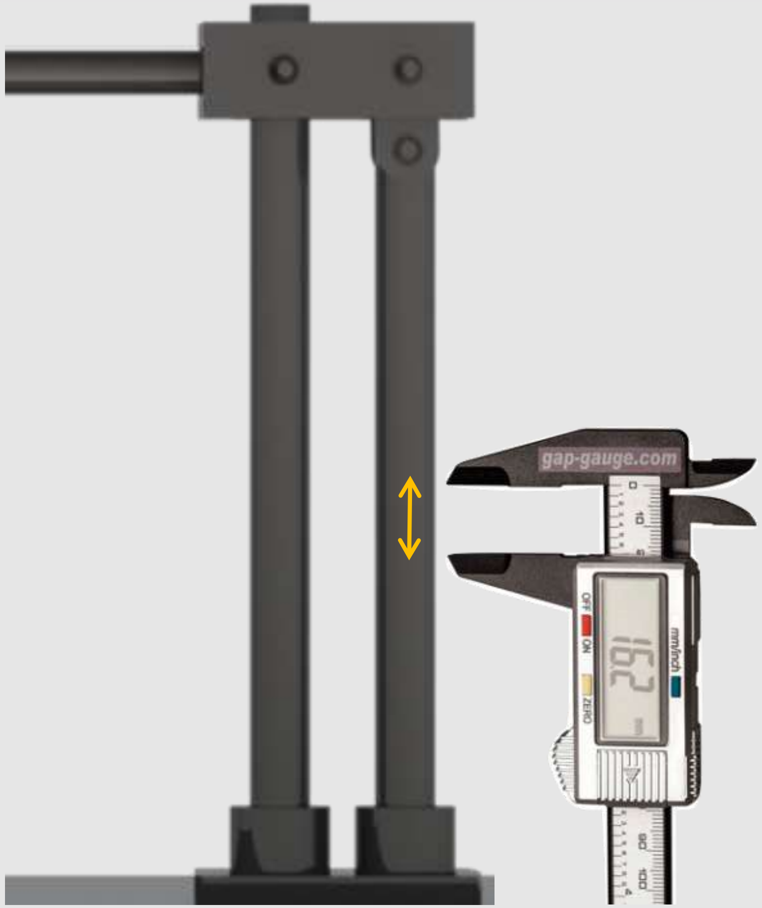
# Mechanical Subsystem: Yaw Tolerance

- **Main Objective:** Show accuracy/range in yaw within requirements
- **Requirements verified:** DR 1.2.2, DR 1.2.5.2
- **Location:** Anywhere
- **General Procedure:** Command yaw angle, read angle with angle finder. Compare angle finder's measurement to commanded angle.
- Accurate to within ±0.1°: **Validates Yaw** ✔
- **Systems Needed:** Yaw Mechanisms

# Mechanical Subsystem: Plunge Tolerance

- **Main Objective:** Show accuracy/range in plunge within requirements
- **Requirements verified:** DR 1.2.4, DR 1.2.5.4
- **Location:** Anywhere
- **General Procedure:** Command desired plunge, measure change in linear actuator height with calipers.
- Accurate within ±0.025 mm: **Validates Plunge** ✔
- **Systems Needed:** Plunge Mechanisms



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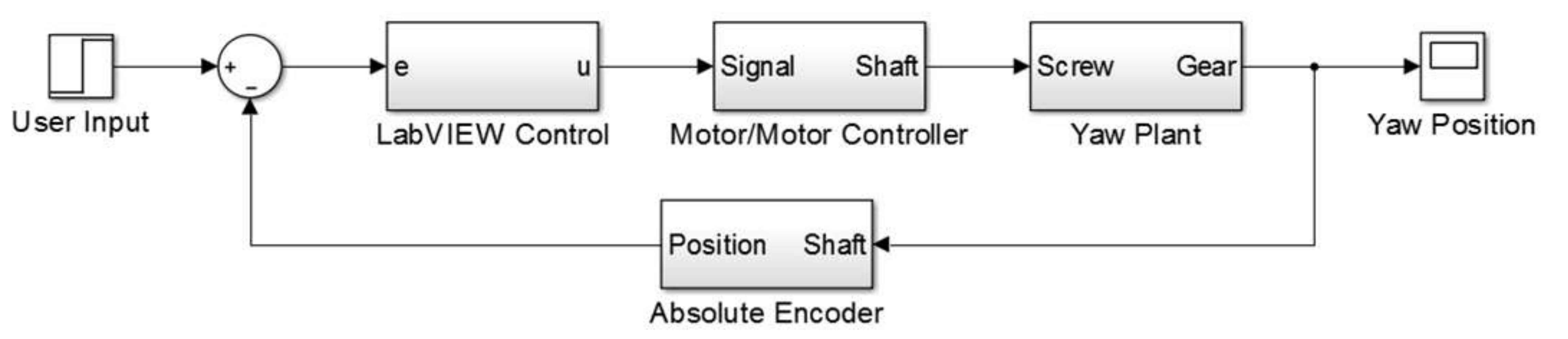
# Pointing System Model Motivation

- Baseline the performance of the system
  - How SHOULD the system be performing?
- Compare system performance to the model
  - How does the system ACTUALLY perform?
- Have a confident method of tuning control gains
  - How can the system perform ACTUALLY as it SHOULD?

- GOAL: Have a high fidelity model for evaluation and validation of system performance

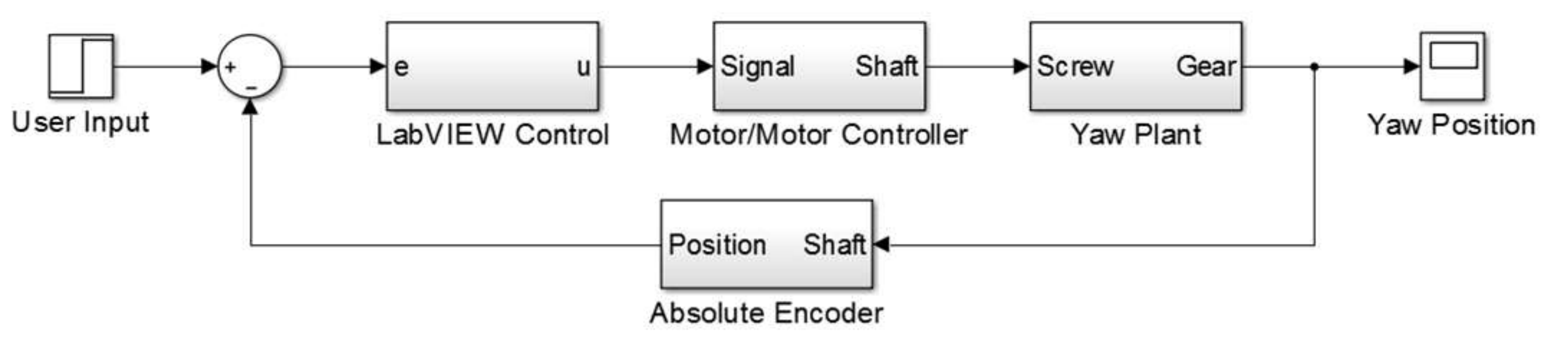
# Pointing System Model

- Simulink simulation of the system
  - System has two control loops: 1 outer and 1 inner
  - Outer loop handled by LabVIEW; Inner loop handled by motor controller
  - Necessary to model DC motor with motor controller and 1 DOF



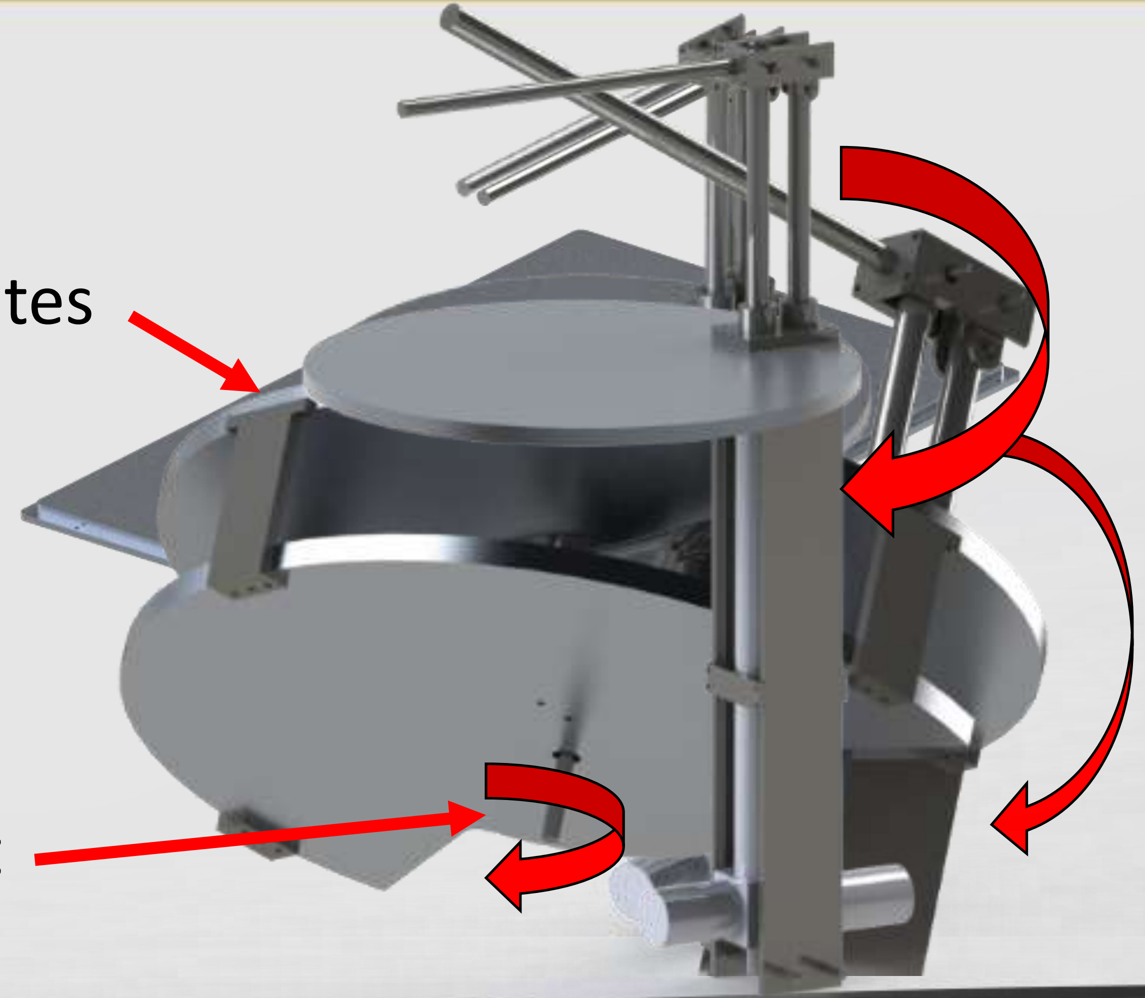
# Pointing System Model

- Key Assumptions of the Model:
  - Motor Controller assumed to have constant control gains
  - Values for DC Motor assumed to be constant
  - Movement of each DOF is not simultaneous/does not affect each other



# Simulation Focus: Yaw

Upper Plate Rotates

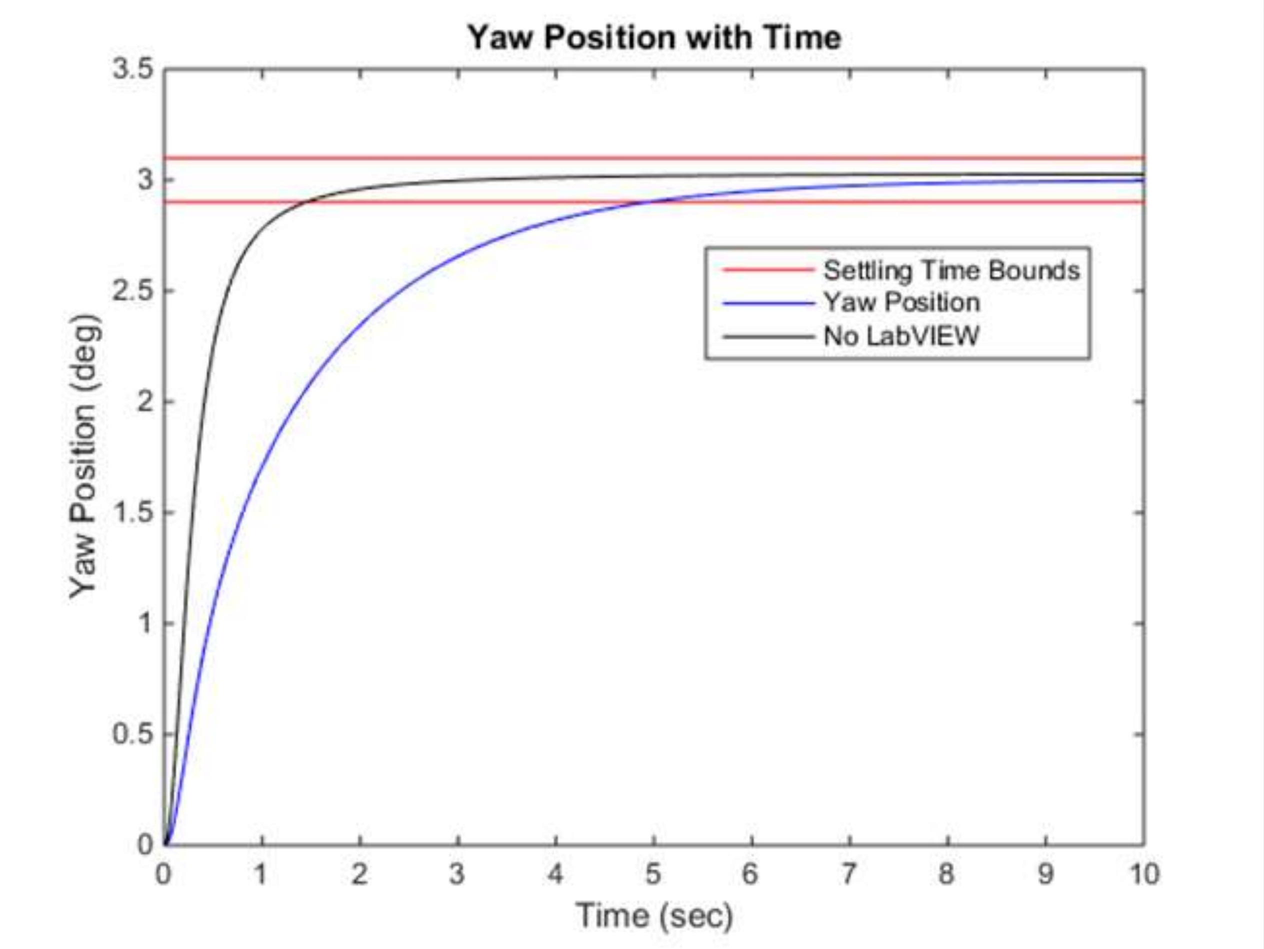


Encoder Shaft

# Simulation Responses

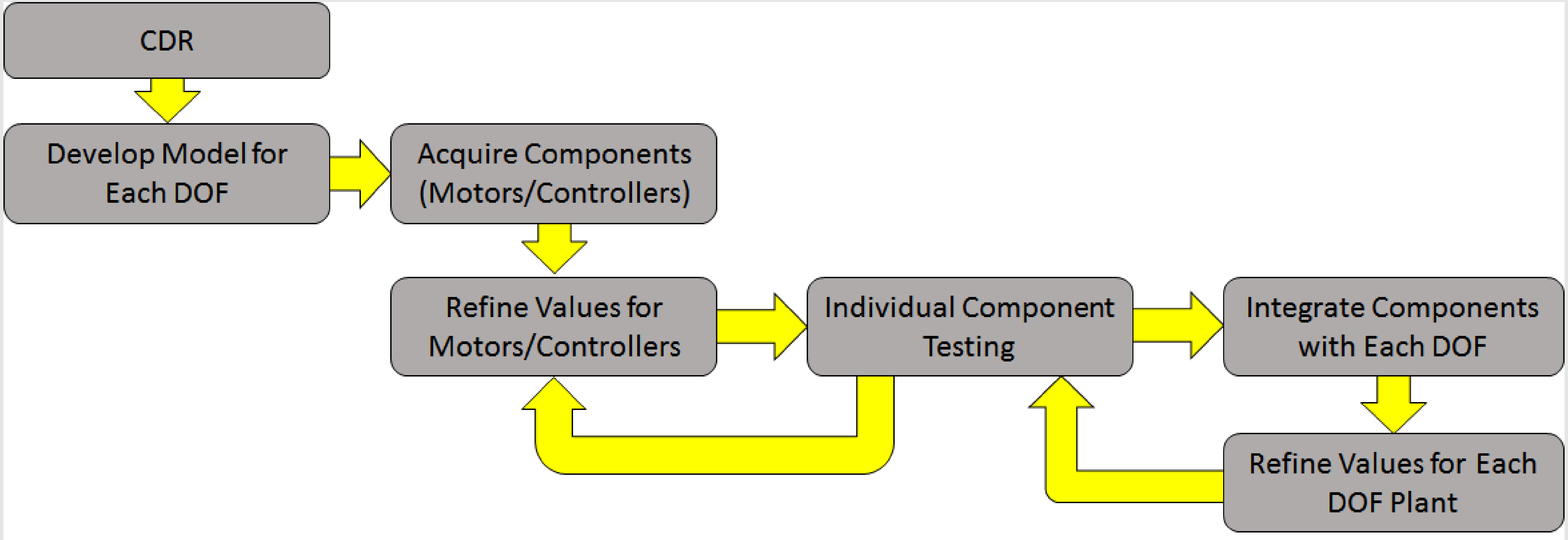
- Settling: +-0.1 degree
- Range: 3 degrees
- KP = 10, KI = 30, KD = 0
- Settling Time: 4.93 sec
- Overshoot: 0%

- Demonstration of model flexibility and capability



# Model Looking Forward

- GOAL: Increase fidelity of the model in place by determining and refining model estimates



# Project Planning

# Organizational Chart

**COMPASS**

- **Customer**: Dr. John Farnsworth
- **Advisor**: Dr. Jeliffe Jackson

- **Test Lead**: Nick Gilland
- **Project Manager**: Mandy Olguin
- **Systems Engineer**: Kristian Kates

- **Safety Lead**: Alex Wood
- **Electronics Lead**: Kyle Skjerven
- **Mechanical Lead**: Brandon Harris
- **Software Lead**: Anna Waltemath
- **Financial Officer**: Ryan Matheson

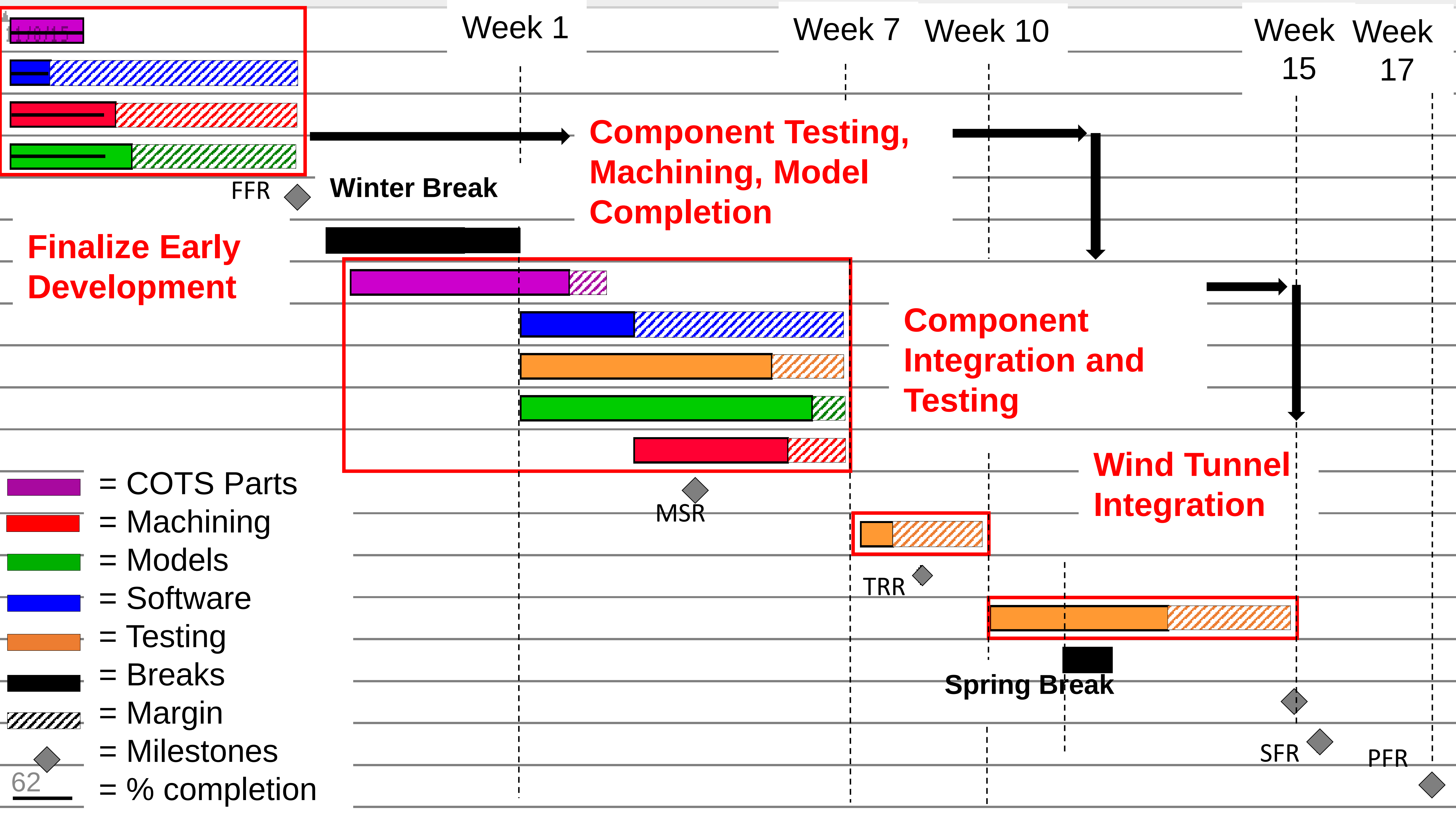
# Work Breakdown Structure

**COMPASS**

- Mechanical Subsystem
  - SolidWorks Model
  - Yaw
  - Pitch/Plunge
  - Roll
  - Base Plate
  - Base Plate Interface
  - Electronics Housing
  - Sting
- Software Subsystem
  - Software Architecture
  - LabVIEW VI
- Electrical Subsystem
  - Power Budget
  - Circuit Diagram
  - I/O Schematic Basic
  - I/O Schematic Advanced
- Management
  - Project Budget
  - Project Timeline
  - Risk Analysis Matrix
  - Procure Components
- Integration and Testing
  - Full System Test Plan
  - Functionality Testing
  - Software Testing
  - Electrical Interface Testing
  - Component Integration
  - Mechanical Tollerance Testing
  - Integration w/ Wind Tunnel
- Documentation
  - User Manual
  - Calibration Manual
  - Parts Specification
  - Interface Control Documents
- Fall Deliverables
  - Project Definition Document
  - Conceptual Design Document
  - Preliminary Design Review
  - Critical Design Review
  - Fall Final Report
- Spring Deliverables
  - Manufacturing Status Reveiew
  - Test Readiness Review
  - Spring Final Review
  - Spring Design Symposium
  - Project Final Report

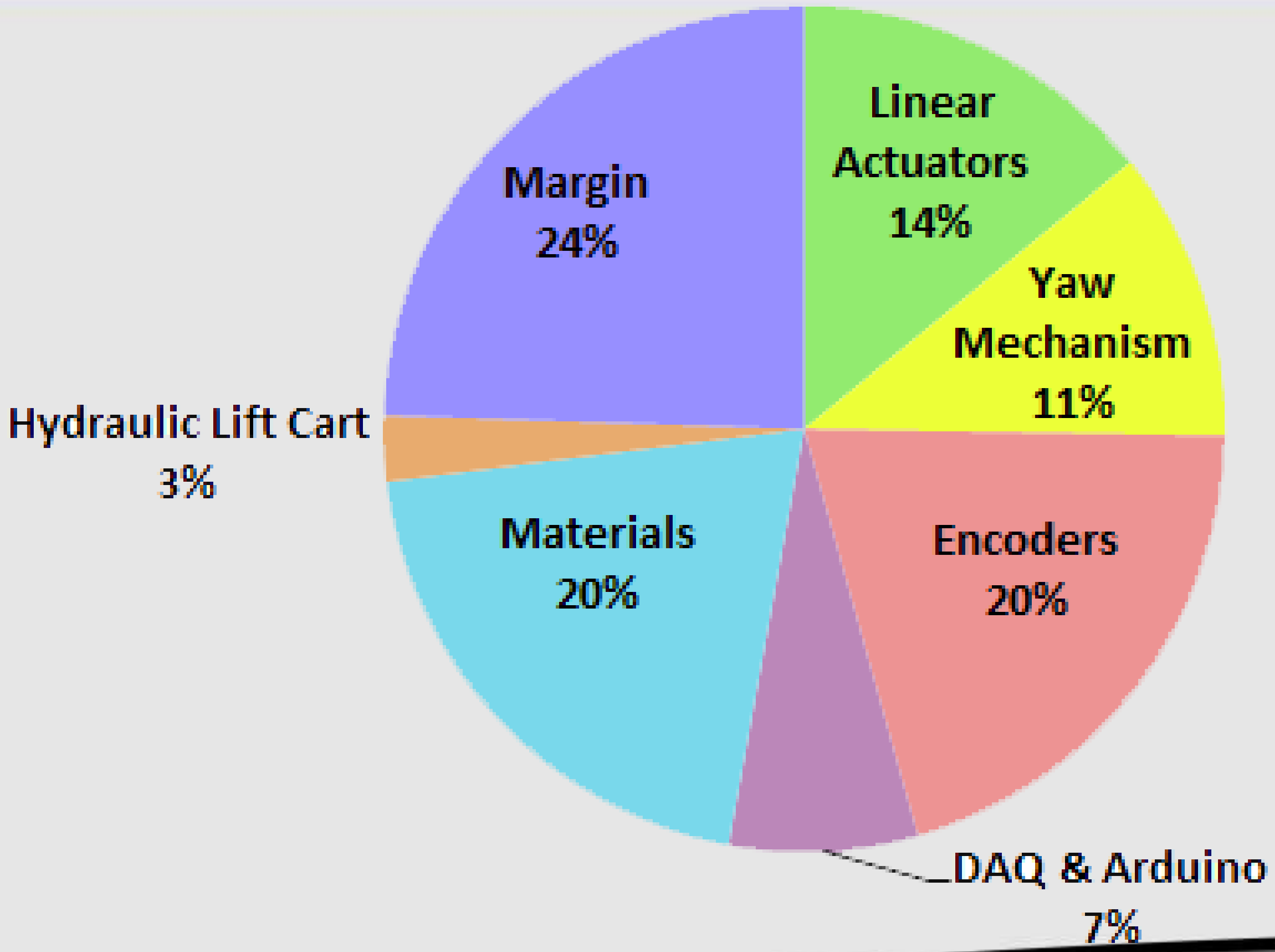
**LEGEND**

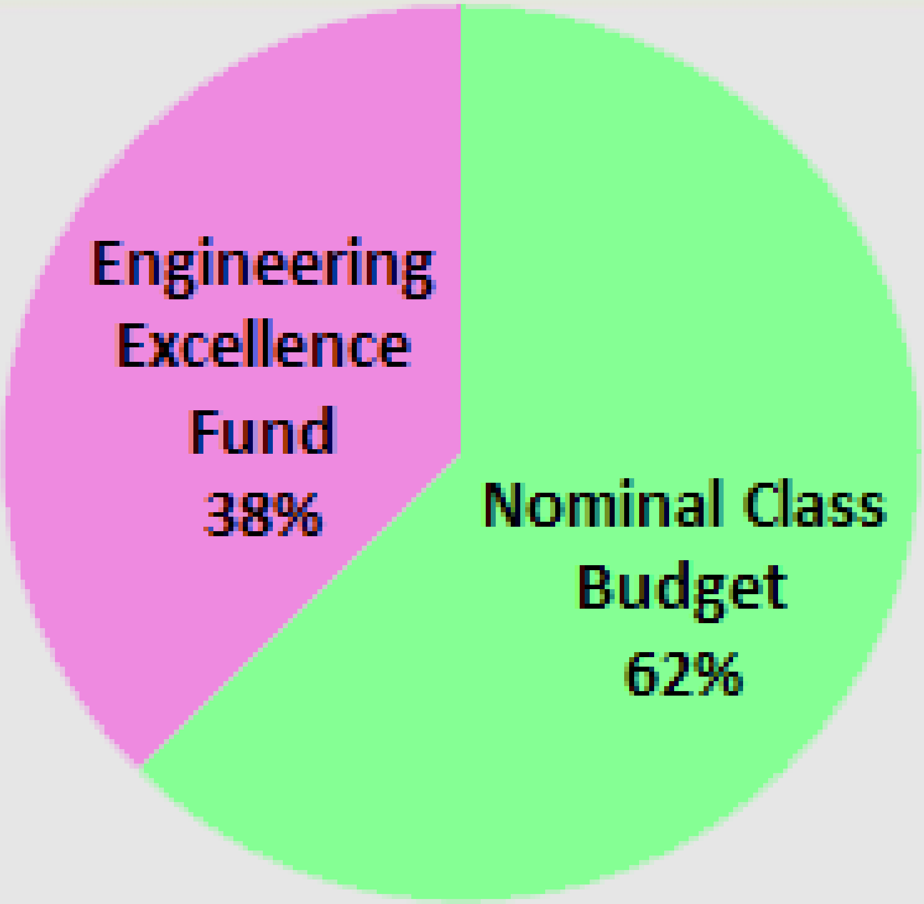
- Complete at CDR
- Incomplete at CDR

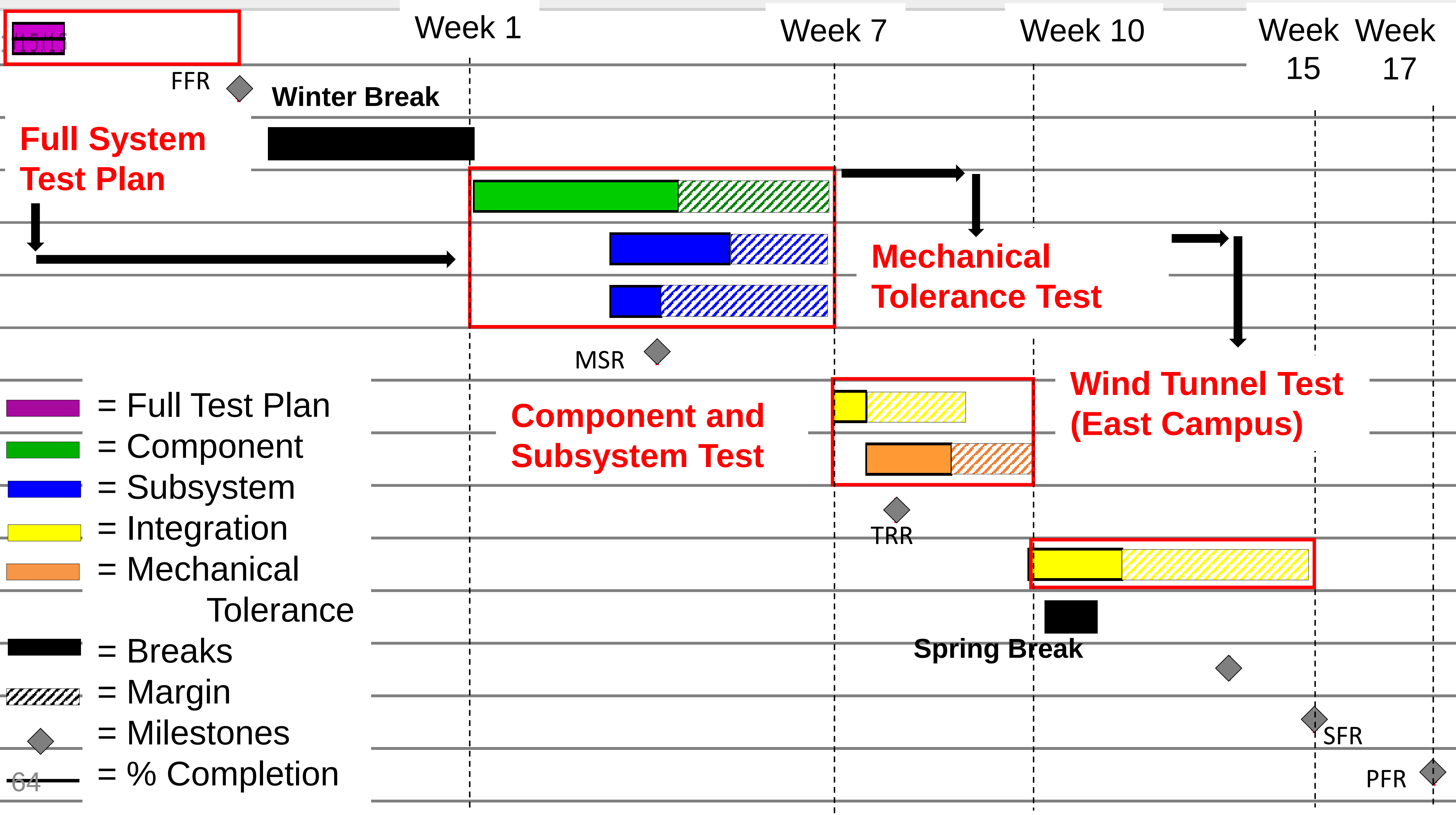


Week 1
Week 7
Week 10
Week 15
Week 17
Component Testing, Machining, Model Completion
FFR
Winter Break
Finalize Early Development
Component Integration and Testing
Wind Tunnel Integration
MSR
TRR
Spring Break
SFR
PFR
= COTS Parts
= Machining
= Models
= Software
= Testing
= Breaks
= Margin
= Milestones
= % completion

# Financial Budget





Week 1
Week 7
Week 10
Week 15
Week 17
FFR
Winter Break
Full System Test Plan
Mechanical Tolerance Test
MSR
Component and Subsystem Test
Wind Tunnel Test (East Campus)
TRR
Spring Break
SFR
PFR
= Full Test Plan
= Component
= Subsystem
= Integration
= Mechanical Tolerance
= Breaks
= Margin
= Milestones
= % Completion

# Questions?

# Back-up Slides

# COMPASS Levels of Success

| Categories: | Position/Angular Accuracy | Range | Testing Expectations | DOF |
|---|---|---|---|---|
| **Level 1** | Pitch: +/-0.1 deg<br>Yaw: +/-0.1 deg | Pitch: +/-30 deg<br>Yaw: +/-30 deg | Test system external of tunnel | Pitch<br>Yaw |
| **Level 2** | " "<br>Roll: +/- 0.5 deg | " "<br>Roll: +/- 45 deg | Test with VICON System | Roll |
| **Level 3** | " "<br>Plunge: +/- 0.5mm | " "<br>Plunge: +/- 10mm | Test in Wind Tunnel | Plunge |

# Functional Requirements Back-up Slides

# Functional Requirements [DR 1.1 - 1.2.4]

**FR 1** COMPASS shall position the model

**DR 1.1** COMPASS shall have 4 Degrees of Freedom: pitch, plunge, roll, and yaw.
Motivation: The intent is to be able to have 4 Degrees of Freedom.
V&V: Demonstration – The system shall be moved to prove that 4 Degrees of Freedom are allowed.

**DR 1.2** COMPASS shall position the system with the ranges defined in **DR 1.2.1** through **1.2.4**.
Motivation: The intent is to simulate real aerodynamic positions.
V&V: Successful verification of **DR 1.2.1** through **1.2.4**.

**DR 1.2.1** The pitch range of the model shall be ±30°.
Motivation: The intent is to give enough range in pitch to simulate real aerodynamic positions.
V&V: Test – With an input of ±30° pitch, using a digital protractor, the angle shall be checked.

**DR 1.2.2** The yaw range of the model shall be ±30°.
Motivation: The intent is to give enough range in yaw to simulate real aerodynamic positions.
V&V: Test – With an input of ±30° yaw, using a digital protractor, the angle shall be checked.

**DR 1.2.3** The roll range of the model shall be ±45°.
Motivation: The intent is to give enough range in roll to simulate real aerodynamic positions.
V&V: Test – With an input of ±45° roll, using a digital protractor, the angle shall be checked.

**DR 1.2.4** The plunge range of the model shall be ±10 cm.
Motivation: The intent is to give enough range in plunge to simulate real aerodynamic positions as well as maintain the model position in the center of the wind tunnel test section.
V&V: Test – With an input of ±10 cm, using calipers, the range of motion shall be checked.

# Functional Requirements [DR 1.2.5 - 1.3]

**DR 1.2.5** The accuracy of the 4 Degrees of Freedomshall be provided below in **DR 1.2.5.1** through **DR 1.2.5.4.**

*Motivation:* The intent is to provide accurate model positioning as close to the user's desired position as possible.

*V&V:* Successful verification of **DR 1.2.5.1** through **DR 1.2.5.4**.

**DR 1.2.5.1:** The accuracy for pitch shall be within ±0.1°.

*Motivation:* The intent is to ensure the model is positioned as close to the user's desired position as possible.

*V&V:* Test – After a given pitch movement, a digital protractor will be used to ensure accuracy.

**DR 1.2.5.2:** The accuracy for yaw shall be within ±0.1°.

*Motivation:* The intent is to ensure the model is positioned as close to the user's desired position as possible.

*V&V:* Test – After a given yaw movement, a digital protractor will be used to ensure accuracy.

**DR 1.2.5.3:** The accuracy for roll shall be within ±0.5°.

*Motivation:* The intent is to ensure the model is positioned as close to the user's desired position as possible.

*V&V:* Test – After a given roll movement, a digital protractor will be used to ensure accuracy.

**DR 1.2.5.4:** The accuracy for plunge shall be within ±0.5mm.

*Motivation:* The intent is to ensure the model is positioned as close to the user's desired position as possible.

*V&V:* Test – After a given plunge movement, a digital protractor will be used to ensure accuracy.

**DR 1.3** COMPASS shall have a zero reference point.

*Motivation:* The intent is to have accurate knowledge of COMPASS relative to the wind tunnel test section.

*V&V:* Test – After hitting "home", the Vicon system will be used to ensure the "home" position is at zero.

# Functional Requirements [DR 2.1 - 2.1.6]

**FR 2** COMPASS shall interface with the wind tunnel.

**DR 2.1** COMPASS hardware shall interface with the wind tunnel hardware.

*Motivation:* The intent is to design COMPASS around the wind tunnel.

*V&V:* Inspection– COMPASS fits into the test section.

**DR 2.1.1** COMPASS hardware shall occupy no more than the total volume under one test section of the wind tunnel,.

*Motivation:* The intent is to ensure COMPASS does not interfere with other test equipment.

*V&V:* Inspection – take COMPASS measurements and visual inspect after COMPASS is installed in the test section.

**DR 2.1.2** COMPASS hardware inside of the test section shall block no more than 10% of the total cross sectional area, 0.567 m2.

*Motivation:* The intent is to not restrict or disrupt the flow in the wind tunnel while testing.

*V&V:* Inspection– The max cross sectional area will be measured and compared to the total cross section l area of the wind tunnel.

**DR 2.1.3** COMPASS shall modify the test section only through removal of the bottom surface of one test section.

*Motivation:* The intent is making COMPASS usable for any of the three test sections through a standard bottom surface.

*V&V:* Demonstration– put the manufactured bottom surface in each of the test sections to verify it is compatible with all three.

**DR 2.1.4** COMPASS shall square with the wind tunnel test section when raised.

*Motivation:* The intent is to ensure COMPASS hardware is flushed with the wind tunnel test section.

*V&V:* Test – compare the level of the test section to the level of COMPASS , if they are the same then COMPASS is squared with the test sections.

**DR 2.1.5** COMPASS shall have a variable model mounting sting.

***Motivation:*** The intent is to provide the capability for different model mounting configurations.

*V&V:* Demonstration – provide various models for testing to prove they are compatible with COMPASS.

**DR 2.1.6** COMPASS hardware shall be installed and removed from the test section without risk of damaging the wind tunnel or COMPASS, if done according to **DR 5.1 .**

*Motivation:* The intent is to minimize the risk of unnecessary damage to the wind tunnel or COMPASS if done properly.

*V&V:* Test – Allow an uninformed person not from the COMPASS team to follow the user manual properly.

# Functional Requirements [DR 2.2 - 2.3]

**DR 2.2** COMPASS software shall interface with wind tunnel software using LabVIEW.

*Motivation:* The intent is to ensure the user can easily and effectively use the COMPASS system.

*V&V:* Validation of **DR 2.2.1** through **2.2.4**.

**DR 2.2.1** Implementation of the COMPASS LabVIEW software shall run independently of the pre-existing wind tunnel LabVIEW interface.

*Motivation:* The intent is to operate as independently as possible from the wind tunnel software. Neither should need to be present for the operation of the other.

*V&V:* Demonstration – The COMPASS and wind tunnel will be capable of operating separately from one another.

**DR 2.2.2** The COMPASS LabVIEW software shall accommodate user input commands of static position values.

*Motivation:* The intent is for the user to be able to either set a constant position for testing, or actively control the position during testing.

*V&V:* Test - Static and user input positions shall be achieved and measured at the required ranges as defined in **DR 1.2.1** through **1.2.5**.

**DR 2.2.3** The COMPASS LabVIEW software shall accommodate a user selected file of positions versus time at a given interval; this is to be input in a specified format.

*Motivation:* The intent is for automated control COMPASS during experiments.

*V&V:* Test – Automated control shall be achieved and measured at the required ranges as defined in **DR 1.2.1** and **1.2.5**.

**DR 2.2.4** The COMPASS LabVIEW software shall be user-friendly.

*Motivation:* The intent is for COMPASS to be intuitive and simple to operate through the LabVIEW user interface since the software and hardware will be completely new to users.

*V&V:* Test – A focus study shall be performed with the customer to determine ease of use and provide feedback.

**DR 2.3** COMPASS DAQs shall interface with the wind tunnel DAQ chassis**.**

*Motivation:* The intent is to maintain simplicity of installation.

*V&V:* Test – plug in the DAQs and prove they work with the wind tunnel DAQ chassis.

# Functional Requirements [DR 3.1 - 3.3]

**FR 3** COMPASS shall be portable.

**DR 3.1** COMPASS shall have the ability to be removed from underneath the wind tunnel section.

*Motivation*: The wind tunnel will be used for other testing which means COMPASS would have to be removed from the test section.

*V&V*: Demonstration – take out COMPASS and move it.

**DR 3.2** COMPASS shall have the ability to be stored when not in use.

*Motivation*: When not in use, COMPASS can be put into storage so it is not in the way of other testing going on in the facility

*V&V*: Demonstration – move COMPASS to a closet.

**DR 3.3** COMPASS shall have the ability to lock in place in reference to the ground.

*Motivation*: The intent is that COMPASS wheels can be locked to prevent the system from moving while testing or in storage.

*V&V*: Demonstration – put COMPASS cart on an uneven surface, lock the wheels and ensure it does not roll away.

# Functional Requirements [DR 4.1 - 4.2.3]

**FR 4** COMPASS shall have fail safes.

**DR 4.1** COMPASS shall protect hardware against incorrect LabVIEW user input.

*Motivation:* The intent is to protect the system from the user. If the user mistypes an input value or the input file intends to position and orient the model to a position outside of the capacities of the hardware, the system should not attempt to carry out that command.

*V&V:* Test – The software shall stop execution of the command and notify the user if the input commands or file would command the system to operate outside of its capabilities.

**DR 4.2** COMPASS shall have fail safes against power failure.

*Motivation:* The intent is to prevent damage to the wind tunnel and COMPASS hardware due to the cost of both systems.

*V&V:* Requirement verified in **DR 4.2.1** through **4.2.3.**

**DR 4.2.1** Pitch failsafe shall the prevent model from hitting the bottom of the test section.

*Motivation:* The intent is to preserve the model, COMPASS sting, COMPASS bottom surface, and the wind tunnel.

*V&V:* Demonstration – cut the power to the motor and ensure pitch does not damage the hardware.

**DR 4.2.2** Plunge failsafe shall prevent the system from falling down under its own weight.

*Motivation:* The intent is to preserve the model, COMPASS sting, COMPASS bottom surface, and the wind tunnel.

*V&V:* Demonstration – cut the power to the motor and ensure plunge does not damage the hardware.

**DR 4.2.3** Yaw failsafe will prevent model from the hitting sides of test section.

*Motivation:* The intent is to preserve the model, COMPASS sting, COMPASS bottom surface, and the wind tunnel.

*V&V:* Demonstration – cut the power to the motor and ensure yaw does not damage the hardware.

# Functional Requirements [DR 4.3 - 4.4]

**DR 4.3** COMPASS shall have fail sages against LabVIEW failure.
*<u>Motivation:</u>* The intent is to prevent damage to the wind tunnel and COMPASS hardware if LabVIEW unexpectedly stops responding.
*<u>V&V:</u>* Test – find various ways LabVIEW would fail.

**DR 4.4** COMPASS mechanical linkages shall be designed with a safety factor of 2 to ensure COMPASS does not break in the wind tunnel under the expected loads.
*<u>Motivation:</u>* A hardware failure could result in an expensive model or piece of COMPASS breaking off and causing significant damage to the wind tunnel or COMPASS hardware.
*<u>V&V:</u>* Test – Apply initial loads to COMPASS outside of the wind tunnel that would simulate the torques a model in the wind tunnel would put on COMPASS.

# Functional Requirements [DR 5.1 - 5.2]

**FR 5** COMPASS shall be easily maintained after COMPASS design team has left the university.

**DR 5.1** COMPASS design team shall provide a COMPASS user manual.

*Motivation:* The intent is to aid future users in the proper use of COMPASS.

*V&V:* Test – create testing guidelines and give an uninformed user the manual and confirm they can follow the manual.

**DR 5.1.1** COMPASS design team shall provide a calibration manual inside of the user manual.

*Motivation:* The intent is to ensure accuracy after many uses.

*V&V:* Demonstration – provide a copy of the calibration manual as well as prove the calibration manual will work properly.

**DR 5.2** COMPASS design team shall provide all specifications for COMPASS.

*Motivation:* The intent is to provide specifications in the case that a piece of COMPASS needs to be replaced.

*V&V:* Demonstration– show the specification sheets.

# Component Trade Studies and Selection Back-up Slides

# Linear Actuator Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Force | 0-50 lbf | 50-150 lbf | 150-250 lbf | 250-350 lbf | 350+ lbf |
| Cost | $500+ | $400-$500 | $300-$400 | $200-$300 | $100-$200 |
| Accuracy w/ Gear Ratio | 0-10 | 10-20 | 20-30 | 30-40 | 40+ |
| Lead Time | 4+ weeks | 3-4 weeks | 2-3 weeks | 1-2 weeks | 0-1 weeks |
| Weight | 8+ lbs | 6-8 lbs | 4-6 lbs | 2-4 lbs | 0-2 lbs |

# Linear Actuators

| Motor | PA-16-24-330 Mini Medium-Force *Progressive Automations* |  Metrics: | PA-03-24-600 Feedback Actuator *Progressive Automations* |  Metrics: |
|---|---|---|---|---|
| Force (30%) | 330 lbs | 4 | 600 lbs | 5 |
| Cost (20%) | $160 | 5 | $230 | 4 |
| Accuracy Using Gear Ratio (30%) | 35:1 | 4 | 38:1 | 4 |
| Lead Time (10%) | 1.5-4 weeks | 2 | 1.5-4 weeks | 2 |
| Size/Weight (10%) | Stroke Dependent 3.5 lbs | 4 | Stroke Dependent 3.75 lbs | 4 |
| Total (100%) | | 4 | | 4.1 |

# Linear Actuator Encoder Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | $800+ | $600-$800 | $400-$600 | $200-$400 | $0-$200 |
| **Resolution** | 0.08°+ | 0.06°- 0.08° | 0.04°- 0.06° | 0.02°- 0.04° | 0°- 0.02° |
| **Lead Time** | 3+ weeks | 2-3 weeks | 1-2 weeks | 3-7 days | 0-3 days |
| **Size/Weight** | 4-5 lbs | 3-4 lbs | 2-3 lbs | 1-2 lbs | 0-1 lbs |
| **Mounting** | Impossible | Difficult | Moderate | Fairly Easy | Easy |

# Linear Actuator Encoders

| Encoder | HSD38 Incremental *DYNAPAR* |  Metrics | HD25 Incremental *DYNAPAR* |  Metrics | HS35R Incremental *DYNAPAR* |  Metrics |
|---|---|---|---|---|---|---|
| Cost (20%) | $755 | 2 | $600 | 2 | $550 | 3 |
| Resolution (40%) | $\frac{360^\circ}{1000(40)} = 0.009$ | 5 | $\frac{360^\circ}{1000(40)} = 0.009$ | 5 | $\frac{360^\circ}{1000(40)} = 0.009$ | 5 |
| Lead Time (5%) | 1-1.5 weeks | 3 | 1-1.5 weeks | 3 | 1-1.5 weeks | 3 |
| Size/Weight (5%) | 4.5 lbs | 1 | 1.5 lbs | 4 | 2.5 lbs | 3 |
| Mounting (30%) | Hollow Shaft w/ Tether | 5 | Flange Mount | 2 | Hollow Shaft w/ Tether | 5 |
| Total (100%) | | 4.1 | | 3.35 | | 4.4 |

# Yaw Motor Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Torque** | 100-300 oz-in | 300-500 oz-in | 500-700 oz-in | 700-900 oz-in | 900+ oz-in |
| **Cost** | $800+ | $600-$800 | $400-$600 | $200-$400 | $100-$200 |
| **Accuracy** | 0.13°+ | 0.1° - 0.12° | 0.8° - 0.9° | 0.04° - 0.7° | 0.01° - 0.3° |
| **Lead Time** | 4+ weeks | 3-4 weeks | 2-3 weeks | 1-2 weeks | 0-1 weeks |
| **Size/Weight** | 20+ lbs | 15-20 lbs | 10-15 lbs | 5-10 lbs | 0-5 lbs |

# Yaw Motors

| Motor | Integrated Servo System<br>CPM-MCPV-3441S-RLN<br>*TEKNIC* | <br>Metrics | BLK42<br>*Anaheim Automation* | <br>Metrics |
|---|---|---|---|---|
| Torque (30%) | 478.5 (oz/in) | 2 | 850 (oz/in) | 4 |
| Cost (20%) | $730 | 2 | $543 | 3 |
| Accuracy (30%) | 0.03° | 5 | N/A | 0 |
| Lead Time (10%) | 3 business days | 5 | 6-16 wks | 1 |
| Size/Weight (10%) | 5.38” long<br>7.88 lbs | 4 | 7.4” long<br>17.48 lbs | 2 |
| Total (100%) | | 3.4 | | 2.1 |

# Yaw Motor Encoder

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | \$800+ | \$600-\$800 | \$400-\$600 | \$200-\$400 | \$0-\$200 |
| **Resolution** | 0.08°+ | 0.06°- 0.08° | 0.04°- 0.06° | 0.02°- 0.04° | 0°- 0.02° |
| **Lead Time** | 3+ weeks | 2-3 weeks | 1-2 weeks | 3-7 days | 0-3 days |
| **Size/Weight** | 4-5 lbs | 3-4 lbs | 2-3 lbs | 1-2 lbs | 0-1 lbs |
| **Mounting** | Impossible | Difficult | Moderate | Fairly Easy | Easy |

# Yaw motor encoder

| Encoder | AD35 Absolute *DYNAPAR* |  Metrics | AD34 Absolute *DYNAPAR* |  Metrics |
|---|---|---|---|---|
| Cost (20%) | $530 | 3 | $500 | 3 |
| Resolution (40%) | $\frac{360°}{2^{14}} = 0.022$ | 4 | $\frac{360°}{2^{14}} = 0.022$ | 4 |
| Lead Time (5%) | 3 weeks | 2 | 3 weeks | 2 |
| Size/Weight (5%) | 1 lb | 4 | 1 lb | 4 |
| Mounting (30%) | Hollow Shaft | 5 | Pin | 3 |
| Total (100%) | | 4 | | 3.4 |

# Motor Controller Criteria

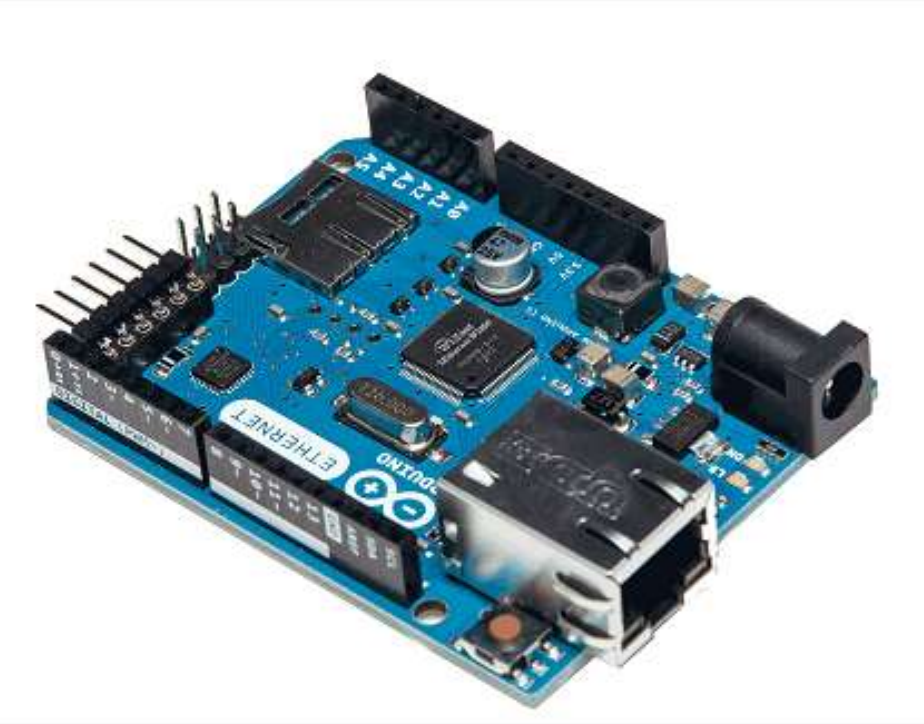
| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | $85+ | $65-$85 | $45-$65 | $25-$45 | $5-$25 |
| **Compatibility** | | | | Ethernet | Ethernet |
| **Lead Time** | 4+ weeks | 3-4 weeks | 2-3 weeks | 1-2 weeks | 0-1 weeks |
| **Size/Weight** | 20+ lbs | 15-20 lbs | 10-15 lbs | 5-10 lbs | 0-5 lbs |
| **Voltages** | | | | | |

# Motor Controllers

| Motor Controller | Arduino UNO Rev3<br>LC-066<br>*Progressive Automations* | <br>Metrics | Arduino Ethernet Rev3<br>LC-068<br>*Progressive Automations* | <br>Metrics |
|---|---|---|---|---|
| Cost (45%) | $30 | 4 | $60 | 3 |
| Compatibility (35%) | USB | 3 | Ethernet | 5 |
| Lead Time (10%) | 1 day | 5 | 1 day | 5 |
| Size/Weight (10%) | 0.088 lbs | 5 | 0.088 lbs | 5 |
| Total (100%) | | 3.85 | | 4.1 |

# Motor Controller Choice

- Arduino Unos from Progressive Automations
- Ethernet Interface
- 1 will be pre-programmed (pitch/plunge)
- 1 programed by team (yaw)



# Hollow Shaft Encoder Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | \$800+ | \$600-\$800 | \$400-\$600 | \$200-\$400 | \$0-\$200 |
| **Resolution** | 0.08°+ | 0.06°- 0.08° | 0.04°- 0.06° | 0.02°- 0.04° | 0°- 0.02° |
| **Lead Time** | 3+ weeks | 2-3 weeks | 1-2 weeks | 3-7 days | 0-3 days |
| **Size/Weight** | 4-5 lbs | 3-4 lbs | 2-3 lbs | 1-2 lbs | 0-1 lbs |
| **Mounting** | Impossible | Difficult | Moderate | Fairly Easy | Easy |

# Hollow Shaft Encoders

| Encoder | AD35 Absolute *DYNAPAR* |  Metrics | AD36 Absolute *DYNAPAR* |  Metrics |
|---|---|---|---|---|
| Cost (20%) | \$530 | 3 | \$610 | 3 |
| Resolution (40%) | $\frac{360°}{2^{14}} = 0.022$ | 4 | $\frac{360°}{2^{14}} = 0.022$ | 4 |
| Lead Time (5%) | 3 weeks | 2 | 3 weeks | 2 |
| Size/Weight (5%) | 1 lb | 4 | 1 lb | 4 |
| Mounting (30%) | Hollow Shaft | 5 | Hollow Shaft | 5 |
| Total (100%) | | 4 | | 4 |

# Pin Encoder Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | $800+ | $600-$800 | $400-$600 | $200-$400 | $0-$200 |
| **Resolution** | 0.08°+ | 0.06°- 0.08° | 0.04°- 0.06° | 0.02°- 0.04° | 0°- 0.02° |
| **Lead Time** | 3+ weeks | 2-3 weeks | 1-2 weeks | 3-7 days | 0-3 days |
| **Size/Weight** | 4-5 lbs | 3-4 lbs | 2-3 lbs | 1-2 lbs | 0-1 lbs |
| **Mounting** | Impossible | Difficult | Moderate | Fairly Easy | Easy |

# Pin Encoders

| Encoder | HD25A Absolute *US Digital* |  Metrics | AD34 Absolute *DYNAPAR* |  Metrics |
|---|---|---|---|---|
| Cost (20%) | \$462 | 3 | \$500 | 3 |
| Resolution (40%) | $\frac{360°}{2^{12}} = 0.088$ | 1 | $\frac{360°}{2^{14}} = 0.022$ | 4 |
| Lead Time (5%) | 3-4 wks | 2 | 3 wks | 2 |
| Size/Weight (5%) | 1.1 lbs | 4 | 1 lb | 4 |
| Mounting (30%) | Pin | 3 | Pin | 3 |
| Total (100%) | | 2.2 | | 3.4 |

# Material Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | $800+ | $600-$800 | $400-$600 | $200-$400 | $0-$200 |
| **Lead Time** | 4 weeks | 3-4 weeks | 2-3 weeks | 1-2 weeks | 0-1 week |
| **Yield Strength** | | | | | |
| **Machinability** | | | | | |

# Material: Baseplate/Yaw Plate

| Material | Multipurpose 6061 Aluminum *McMaster-Carr* |  Metrics | General Purpose Low-Carbon Steel *McMaster-Carr* |  Metrics |
|---|---|---|---|---|
| Cost (40%) | $1200 | 1 | $1100 | 1 |
| Lead Time (10%) | 1 week | 5 | 1 week | 5 |
| Yield Strength (20%) | 35000 psi | 4 | 36000 psi | 4 |
| Machinability (30%) | Good | 3 | Fair | 2 |
| Total (100%) | | 2.6 | | 2.3 |

# DAQ Criteria

| Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Cost** | $800+ | $700-$900 | $500-$700 | $300-$500 | $0-$300 |
| **# of Channels** | 0-4 | 4-8 | 8-12 | 12-16 | 16+ |
| **Lead Time** | 4+ weeks | 3-4 weeks | 2-3 weeks | 1-2 weeks | 0-1 weeks |

# DAQs

| DAQs | NI 9401 *National Instruments* |  Metrics | NI 9403 *National Instruments* |  Metrics |
|---|---|---|---|---|
| Cost w/ accessories (40%) | $420 | 4 | $512 | 3 |
| # of Channels (45%) | 8 | 2 | 32 | 5 |
| Lead Time (15%) | 2 weeks | 3 | 2 weeks | 3 |
| Total (100%) | | 2.95 | | 3.9 |

# Hydraulic Lift Cart

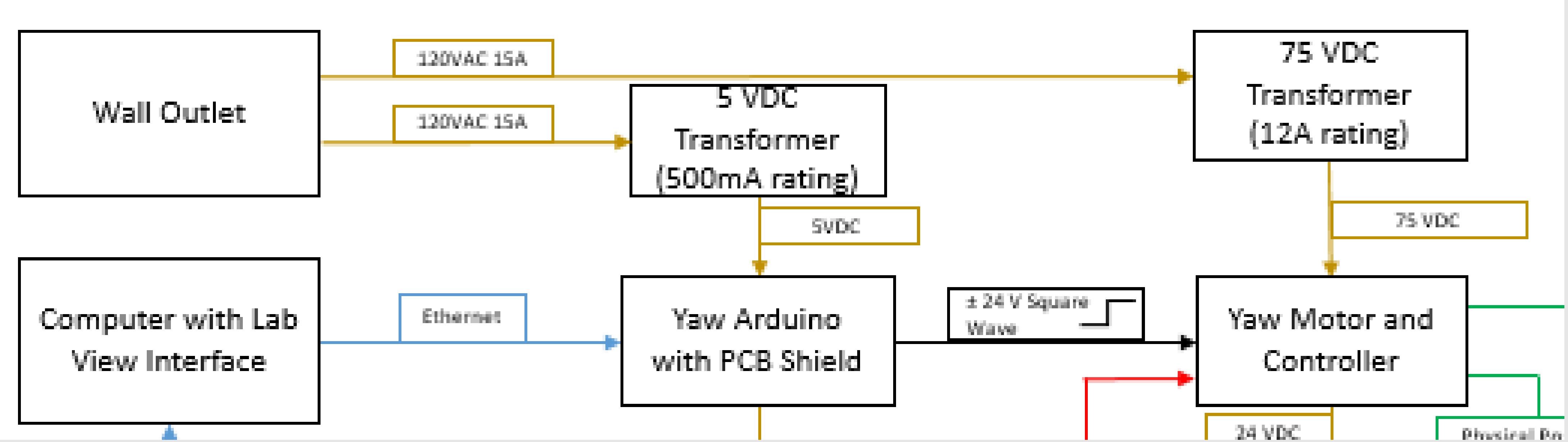
- 500 lb capacity
- Lift Height -27-1/2 in.
- Product width - 17-5/8 in.
- Current COMPASS weight: 151 lbs
- Design margin of lift greater than 3

# Component Lead Times

- Linear Actuators: 4 weeks
- Linear Actuator Encoder: 1.5 weeks
- Yaw Motor: 1 week
- Yaw Encoder: 3 weeks
- Motor Controllers: 1 week
- Materials: 1 week
- DAQs: 2 weeks
- Bearings: 1 week
- Lift Cart: 3 weeks

# Electrical Circuits Back-up Slides

# Circuit Image Yaw 1



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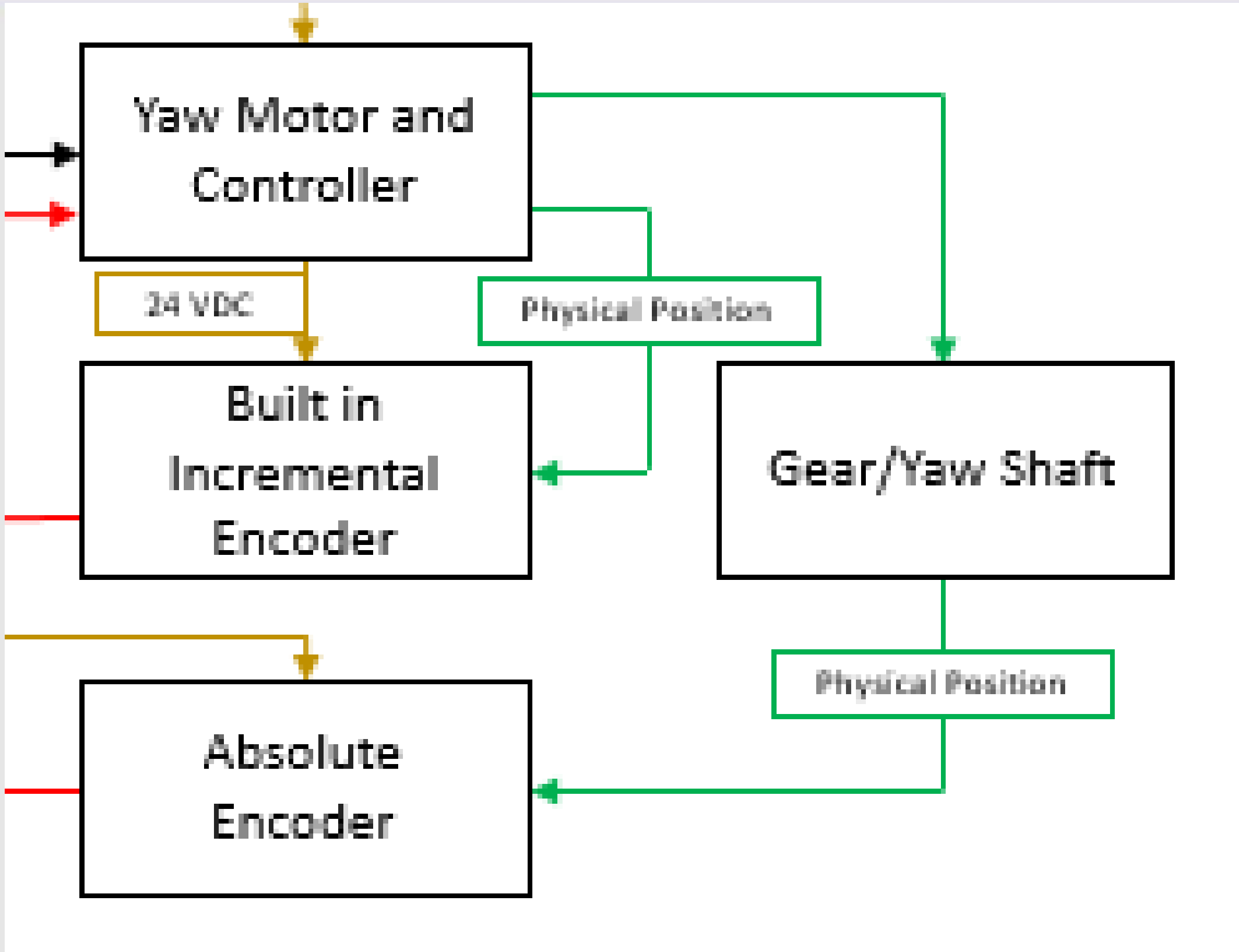
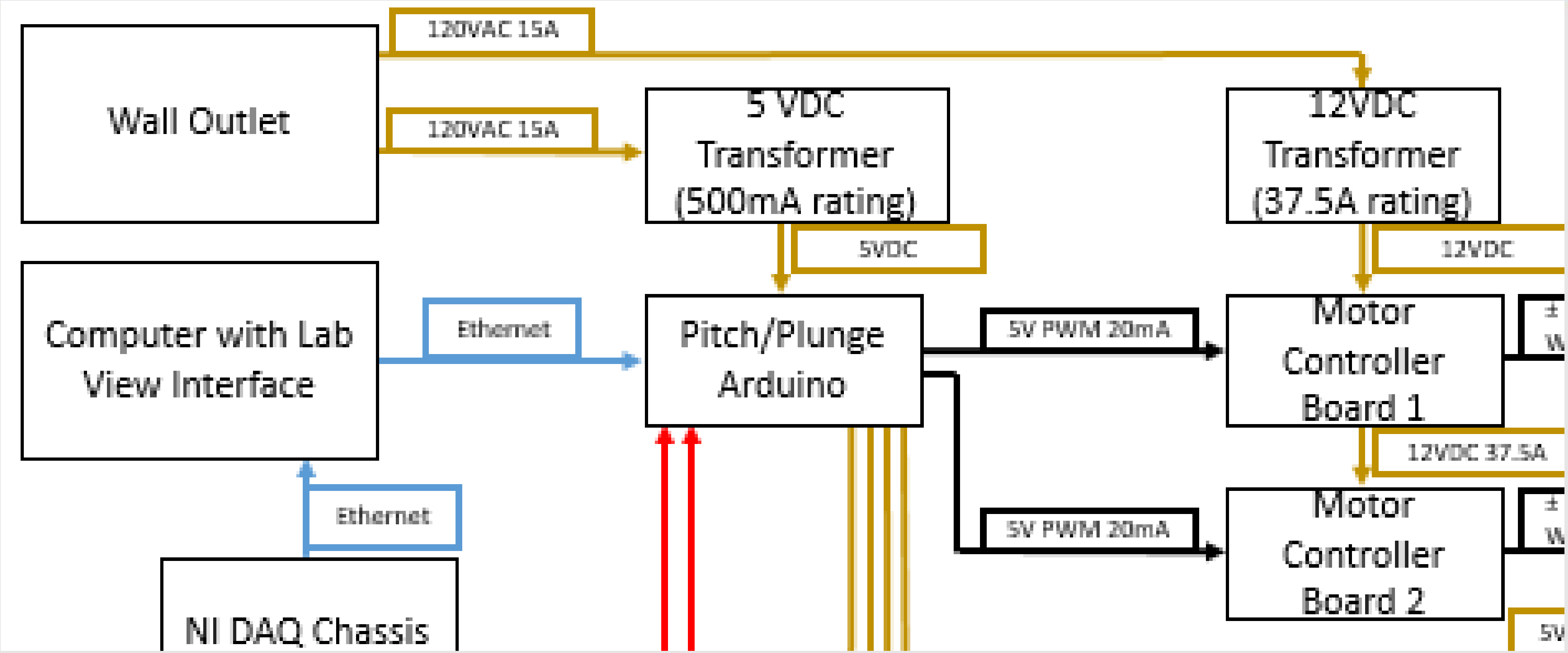
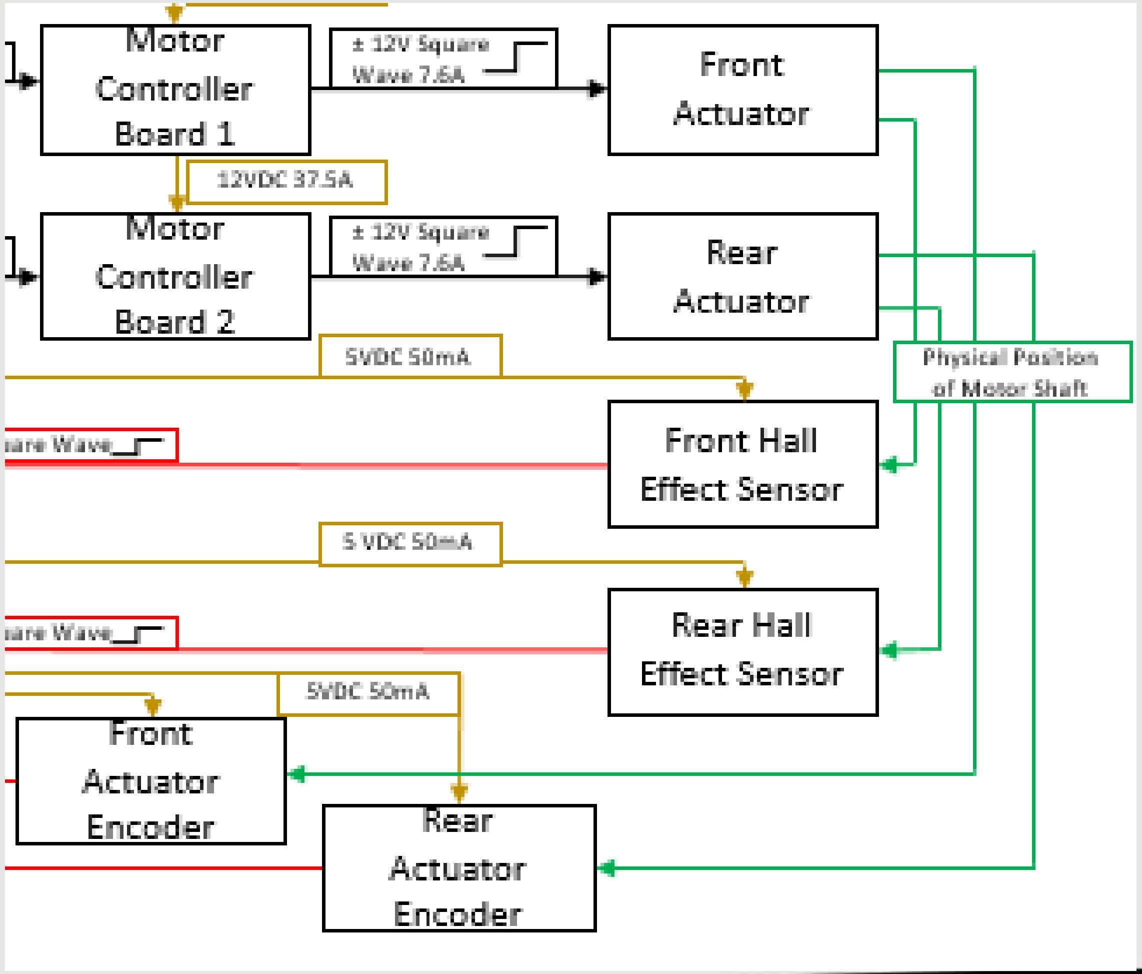
# Circuit Image Yaw 2



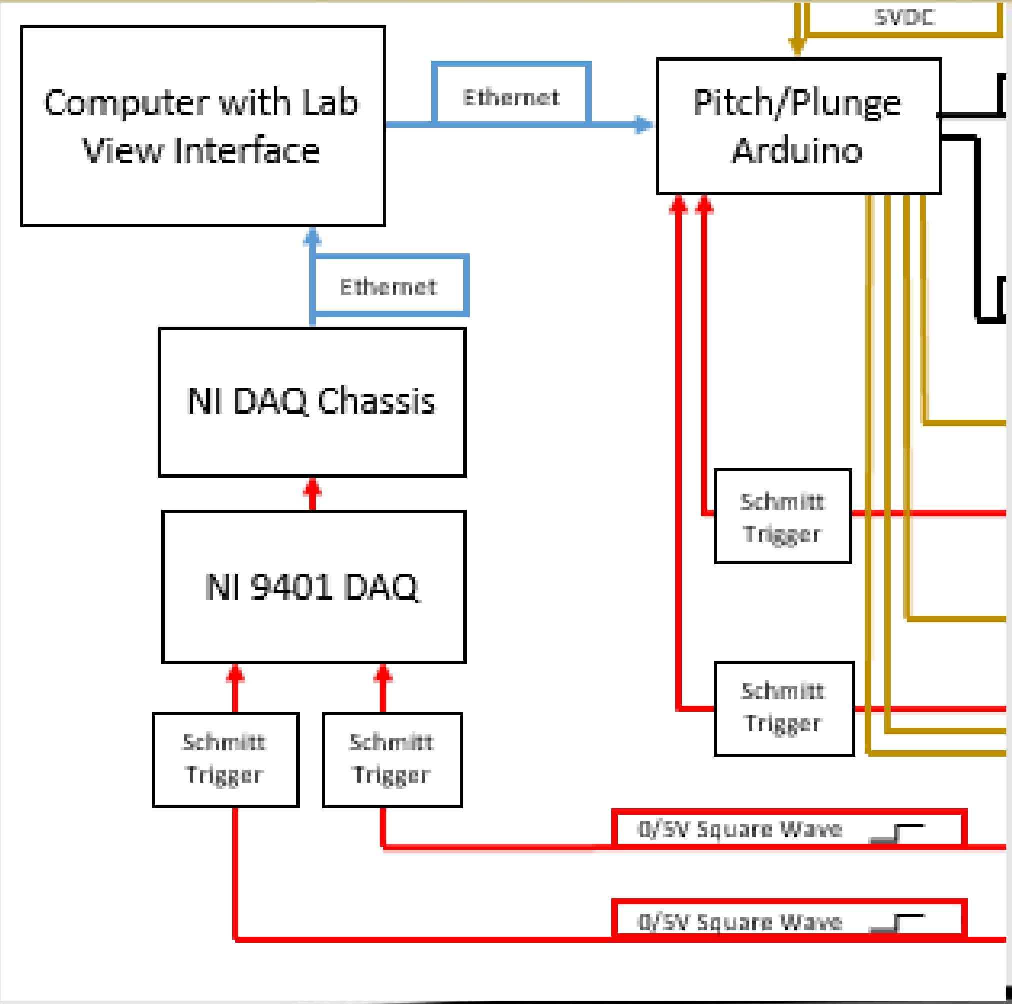
# Circuit Image Pitch/Plunge 1



# Circuit Image Pitch/Plunge 2

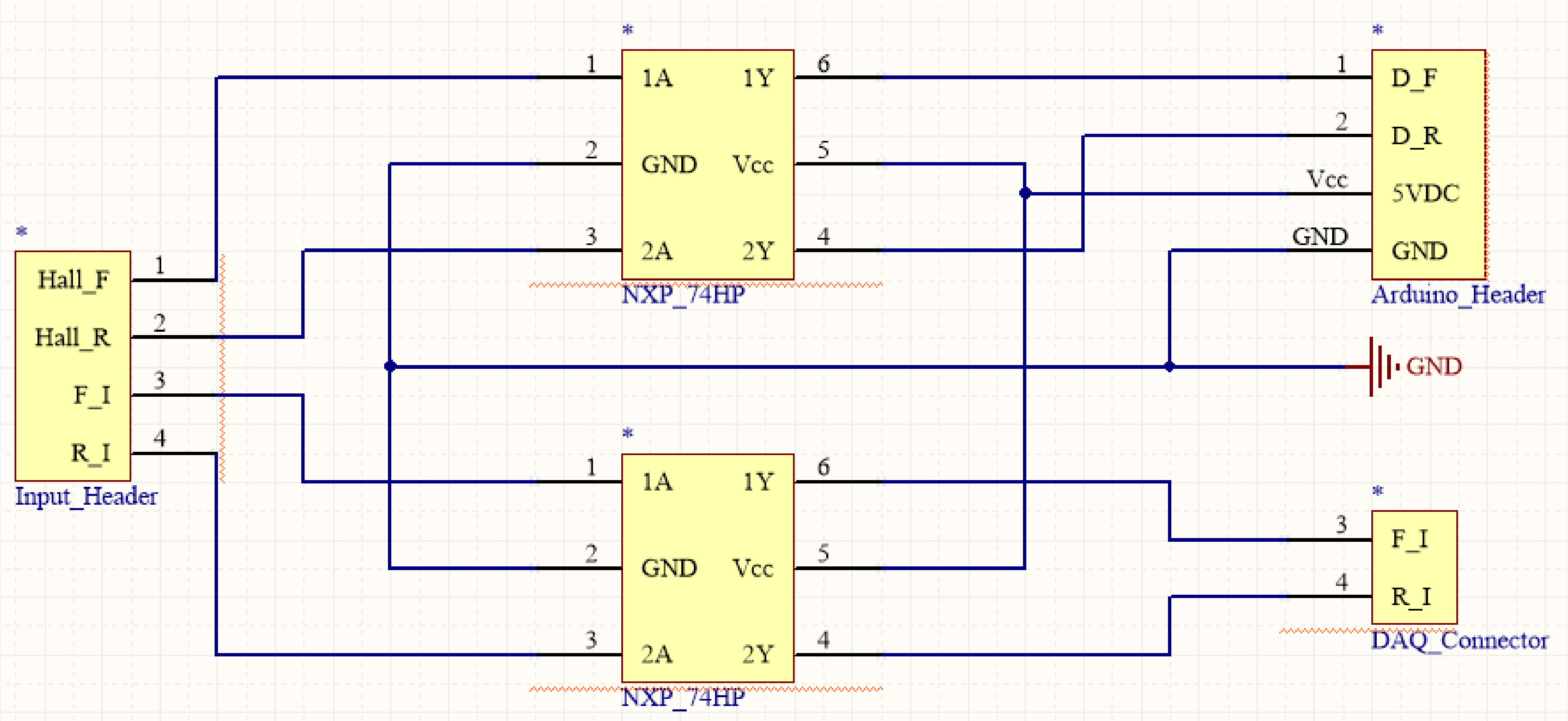


# Circuit Image Pitch/Plunge 3



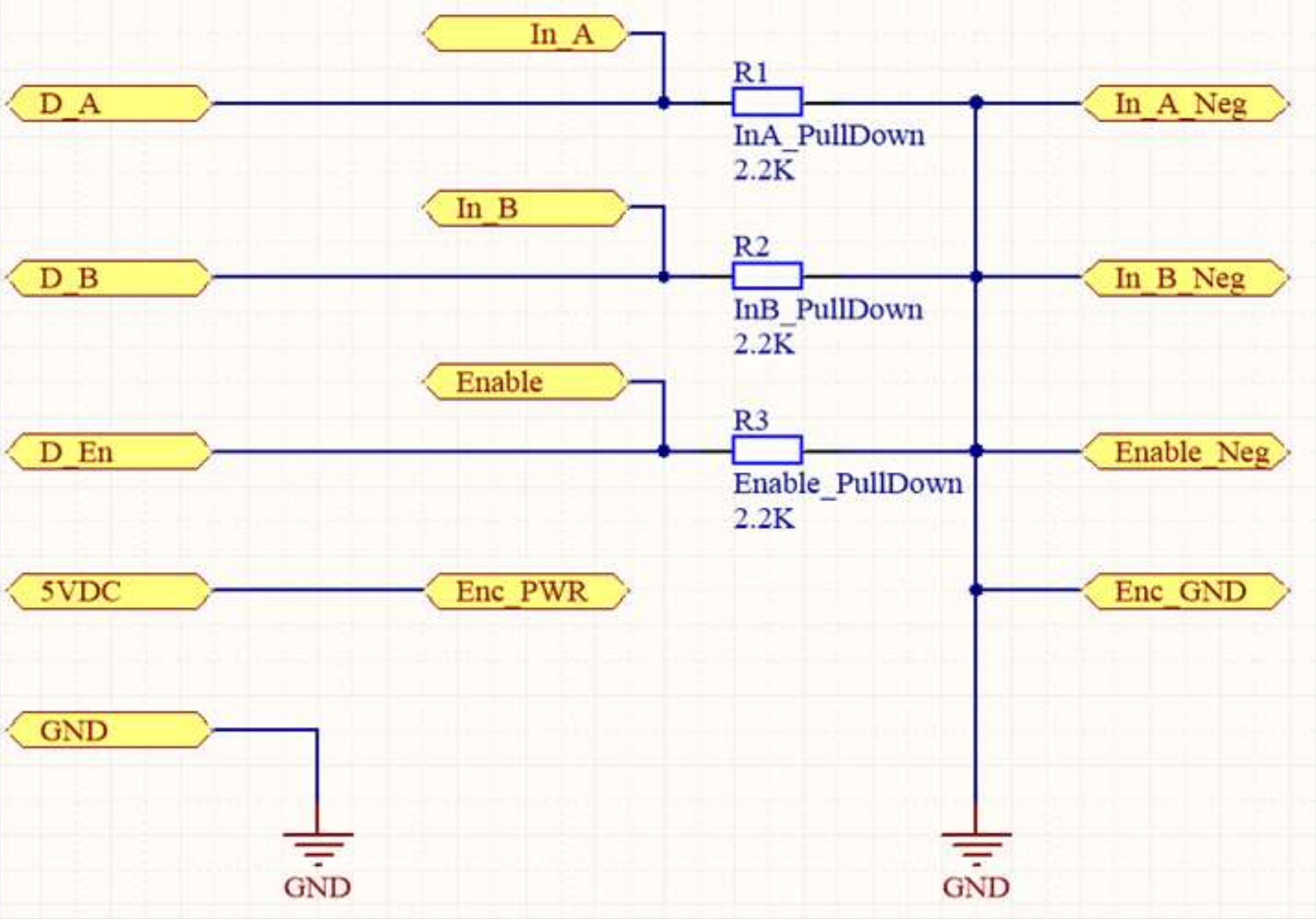
# Schmitt Trigger PCB Schematic

- Buffer Schmitt Trigger ICs
- Vcc and GND supplied by Arduino Uno
- Flying leads give flexibility for connectors
- NXP 74HC2G17-Q100 Dual Non-Inverting Schmitt Trigger



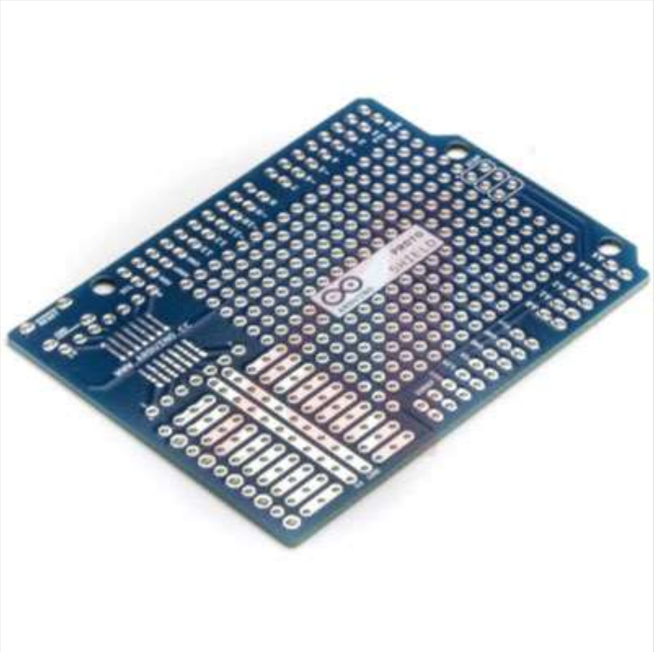
# Yaw Arduino Shield Schematic

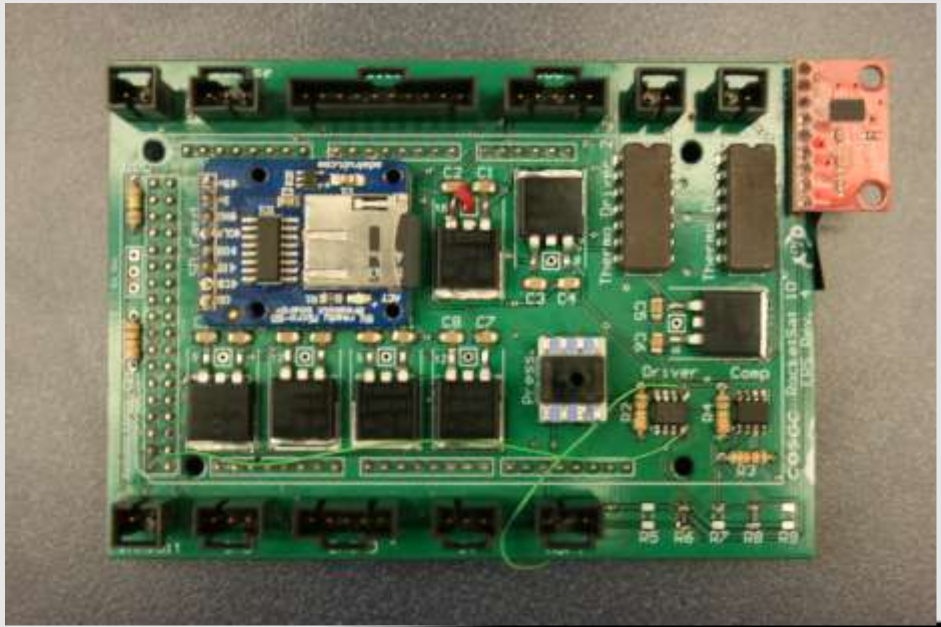
- Arduino GND netted to all GND and Neg ports
- D_A, D_B, D_En connect to Arduino digital lines
- 5VDC from Arduino 5V line
- Pull-down resistors used to guarantee no motor movement on start-up



# Yaw Arduino Shield Fabrication

- Options for manufacturing the shield:
  1. Custom PCB designed in Altium and fabricated by Advanced Circuits
  2. Populate prototype board necessary components (headers, resistors, etc)







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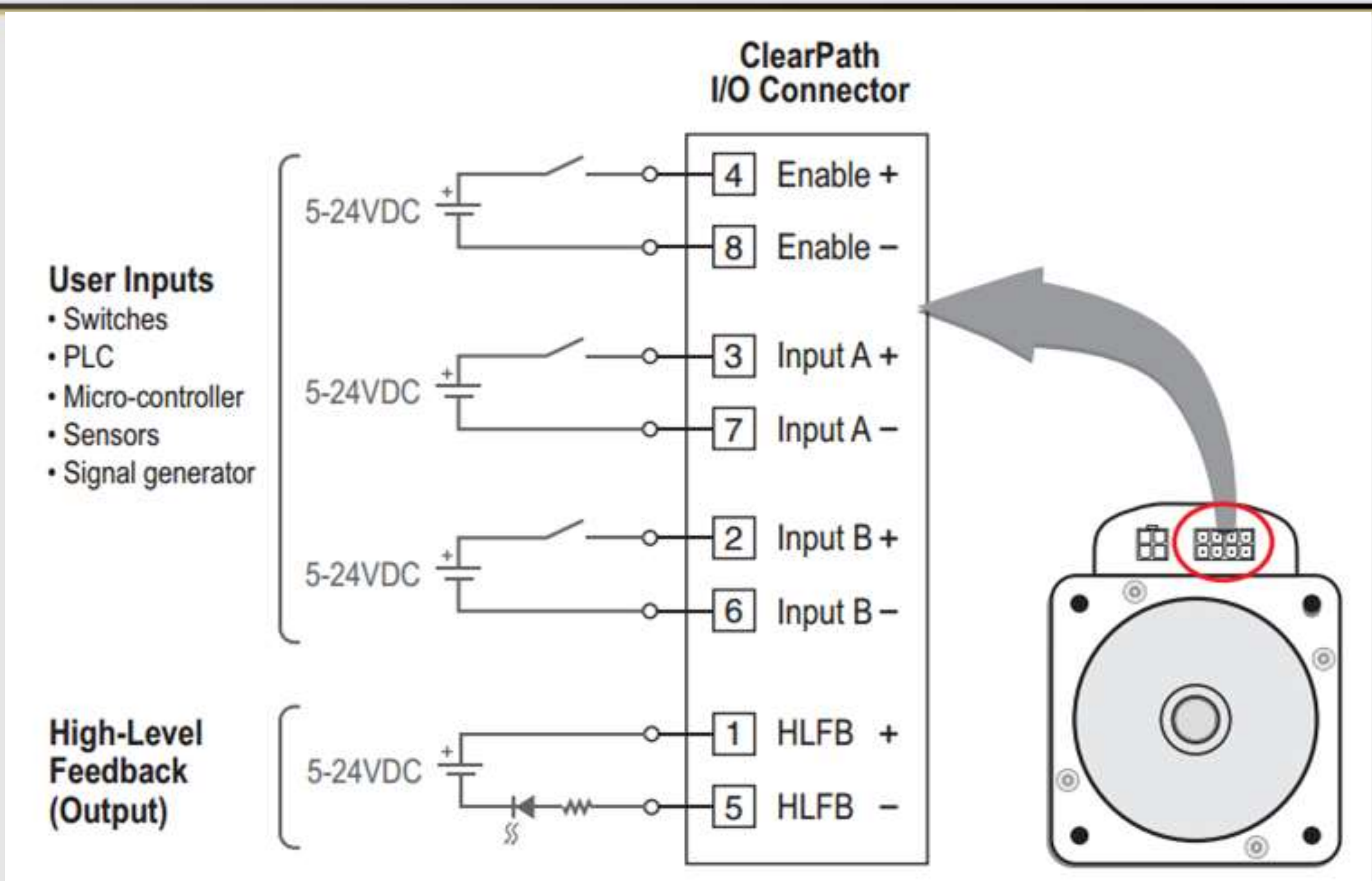
# Yaw Motor Control Pin-Out

- Molex connector on Teknic motor
- Can easily interface with shield
- Cable available with flying leads or Molex

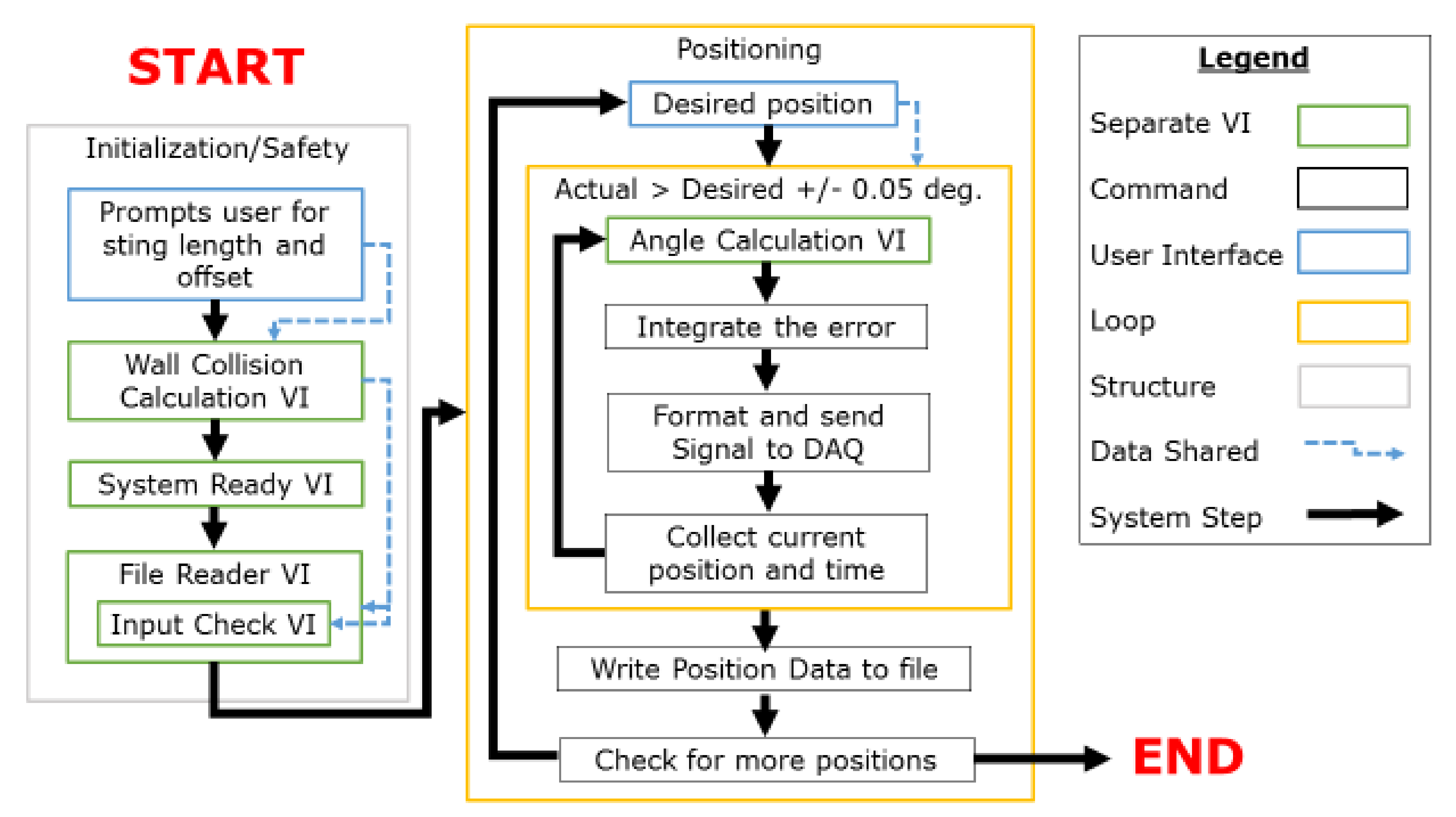


# Software Back-up Slides

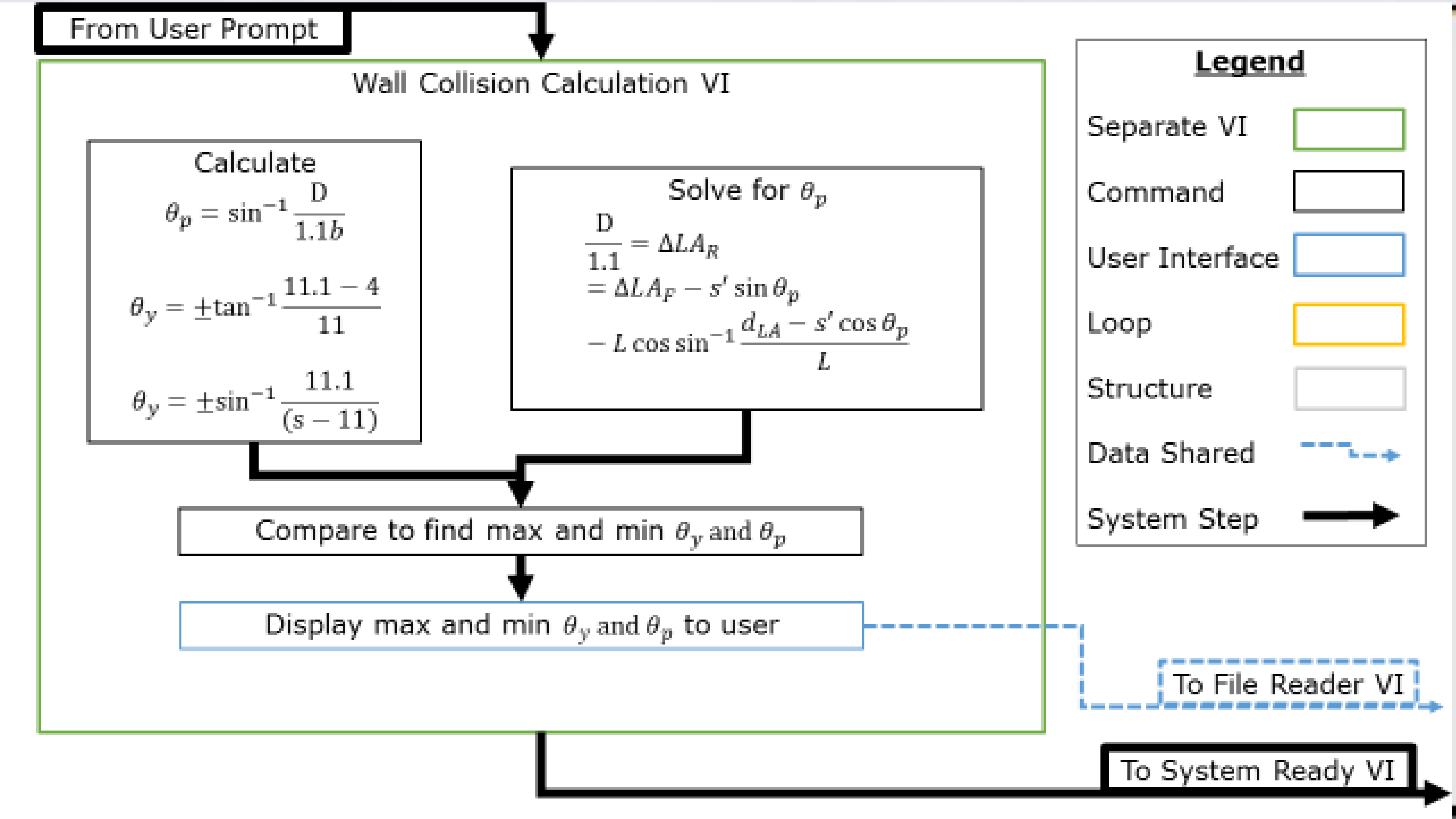
# Software Back-ups

- Home VI
- System Check
- File reader VI
- Input Check VI
- Wall Check
  - Pitch plunge
  - Yaw
  - VI
- Angle Calculation Old Design
- Interface
- Pop Up
- Interface with numbers

# Software: LabVIEW Flowchart



# Software: Wall Check Flowchart



# Software: Wall Check for Yaw

Customer does not want the model to be calculated, that is the responsibility of the user

To keep the system from hitting the wall or fillets

$$D > l$$
$$D' = D - f_{max} > l'$$

length to tip of Sting

$$l = (\mathrm{s} - \mathrm{d_{cp}}) \sin \theta_y$$

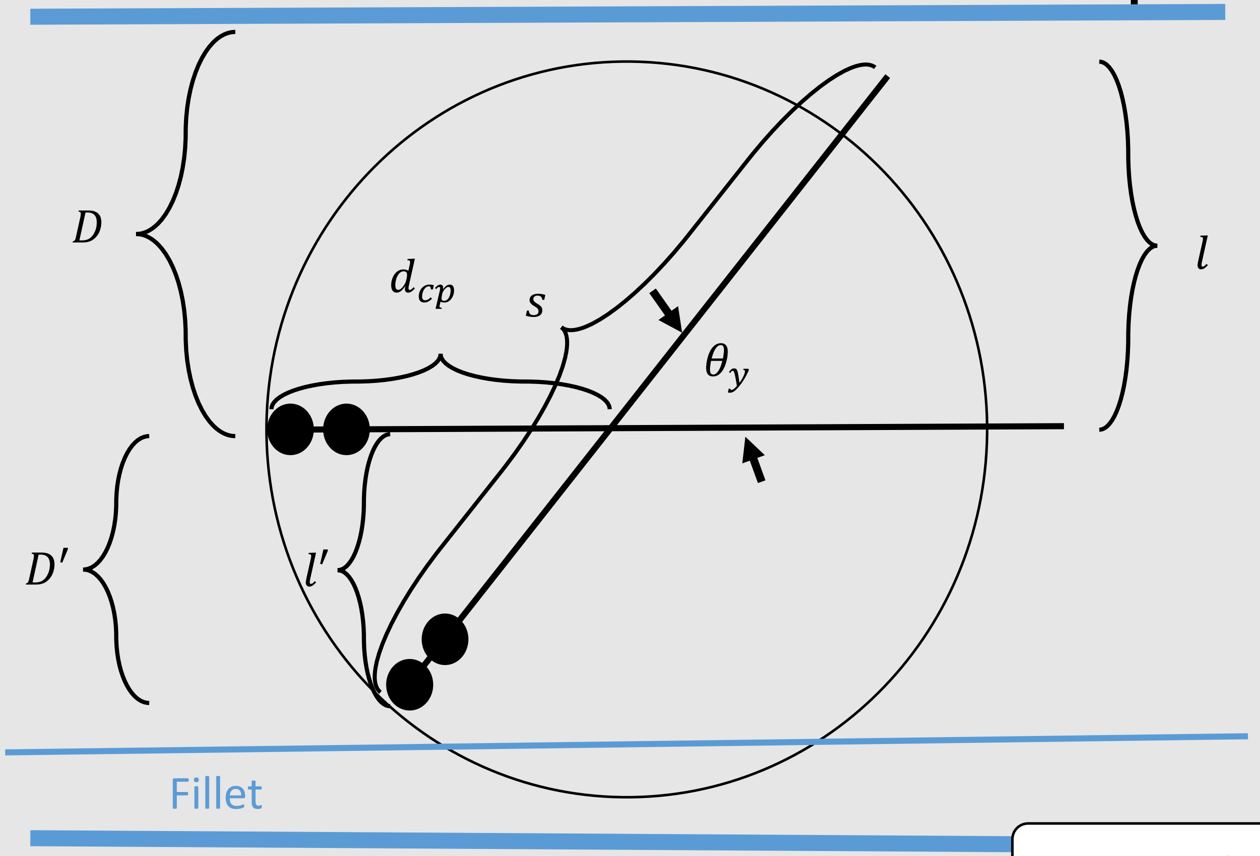
Distance Linear Actuators are from the wall/fillets

$$l' = \mathrm{d_{cp}} \tan \theta_y$$

Combining the equations and inserting the known system quantities, the allowable angles are:

$$\pm\tan^{-1}\frac{11.1 - 4}{11} > \theta_y < \pm\sin^{-1}\frac{11.1}{(\mathrm{s} - 11)}$$

Top View




Assume 0 error

# Software: Wall Check for Pitch/Plunge

Customer does not want the model to be calculated, that is the responsibility of the user

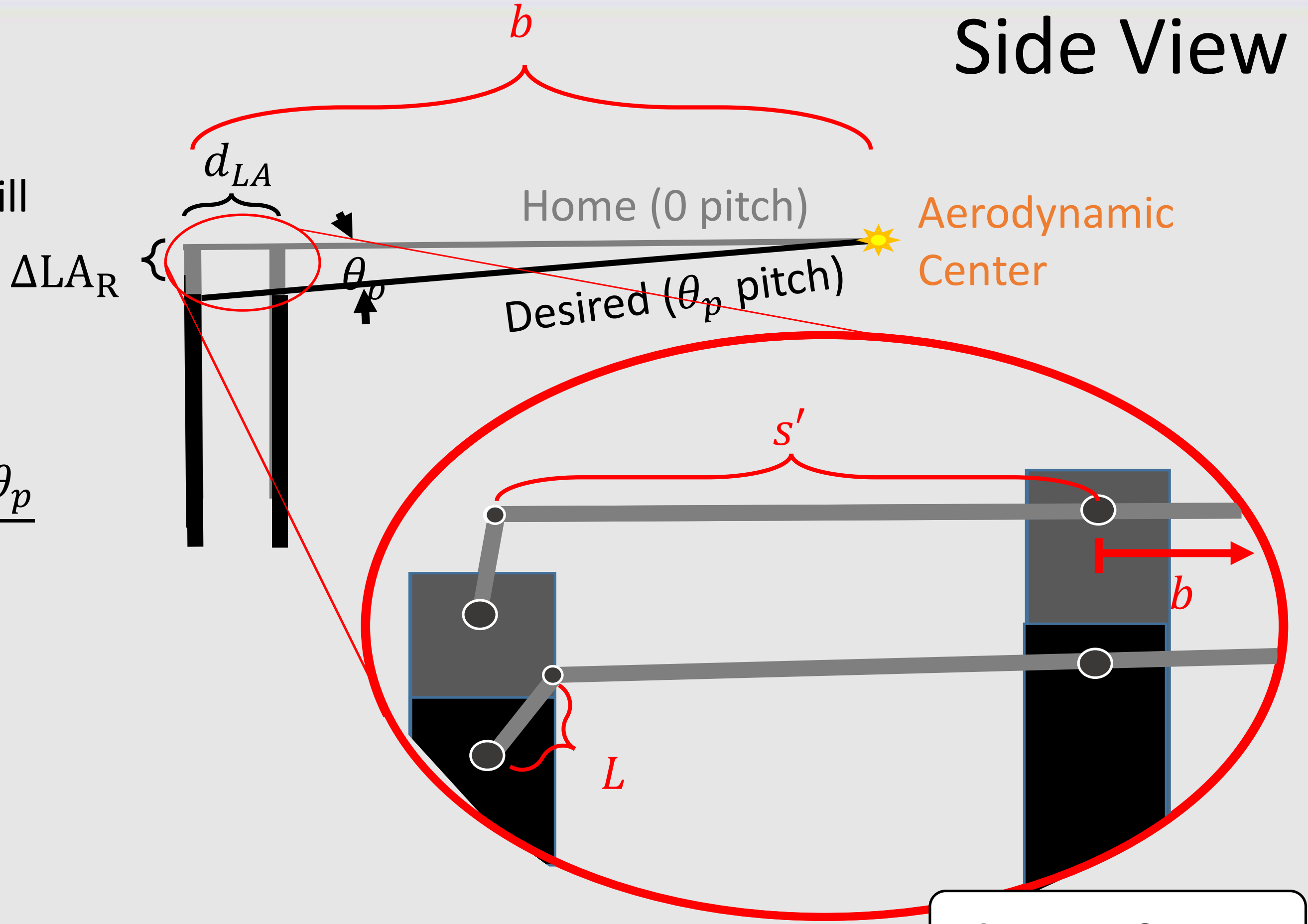
Keeping in mind $s'$, $L$, and $d_{LA}$ are system constants and $b$ will be provided by the user we can set $\Delta LA_R$ and $\Delta LA_F$ to the half the max height of the test section, D, with a 10% over shoot.

$$\frac{\mathrm{D}}{1.1} = \Delta LA_R = \Delta LA_F - s' \sin\theta_p - L \cos \sin^{-1}\frac{d_{LA} - s'\cos\theta_p}{L}$$

$$\frac{\mathrm{D}}{1.1} = \Delta LA_F = b \sin\theta_p$$

The allowable angles to prevent wind tunnel damage are

$\theta_p < \sin^{-1}\frac{\Delta LA_F}{\mathrm{b}}$ for the front actuator




Assume 0 error

# Software: Angle Calculation

** See slides ??? for additional software VIs

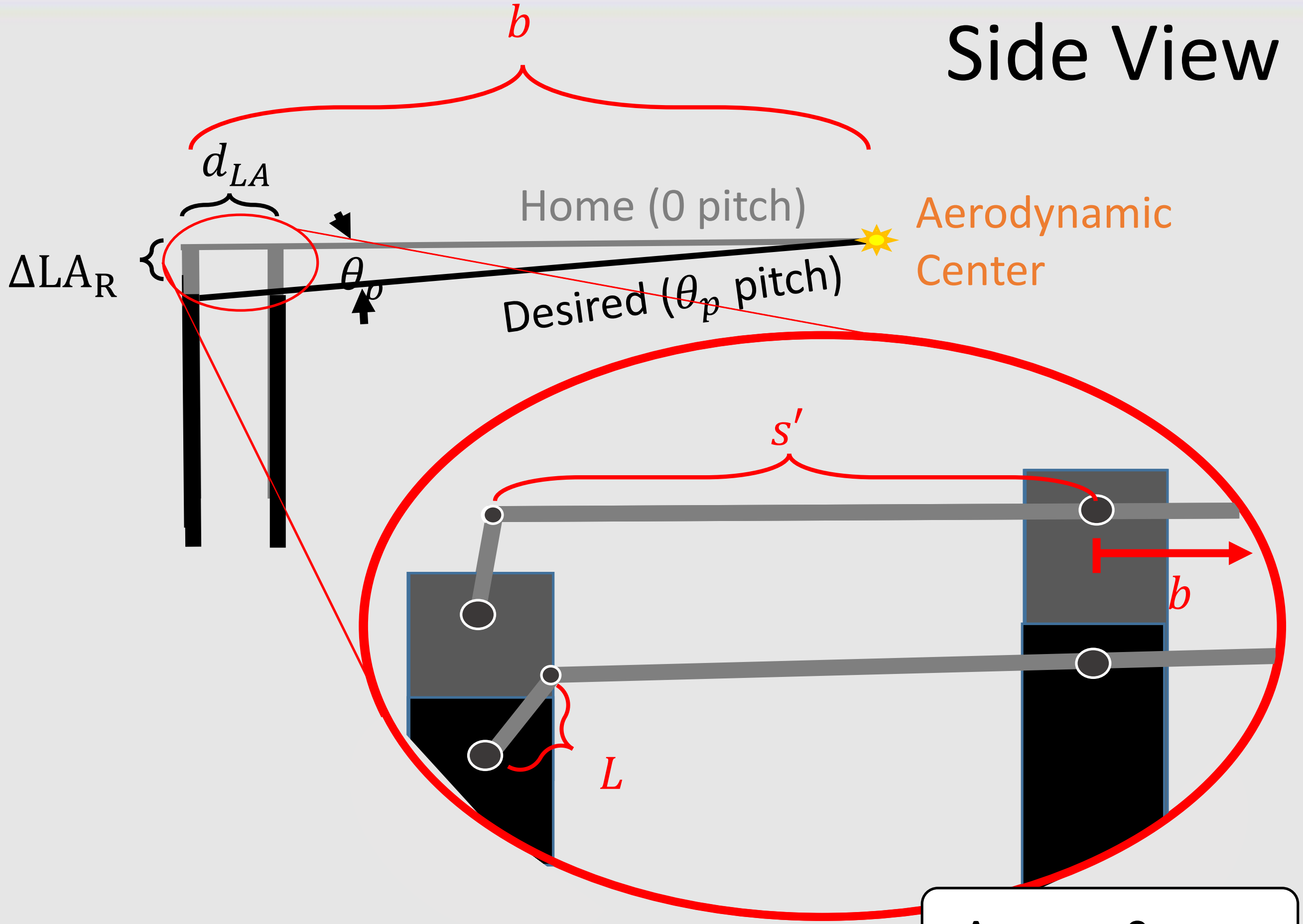
To satisfy FR 1 to position the article pitch will be accomplished by moving the rear Linear actuator (the left one in diagram). Both ends are pinned to the Linear Actuators and again a Distance L from the rear actuator to result in the following equation for pitching the model.

$$\Delta LA_R = \Delta LA_F - s' \sin \theta_p - L \cos \sin^{-1} \frac{d - s' \cos \theta_p}{L}$$

$$\Delta LA_F = b \sin \theta_p$$

Change in both linear actuators keeps the aerodynamic center in the middle of the test section

Side View




Assume 0 error



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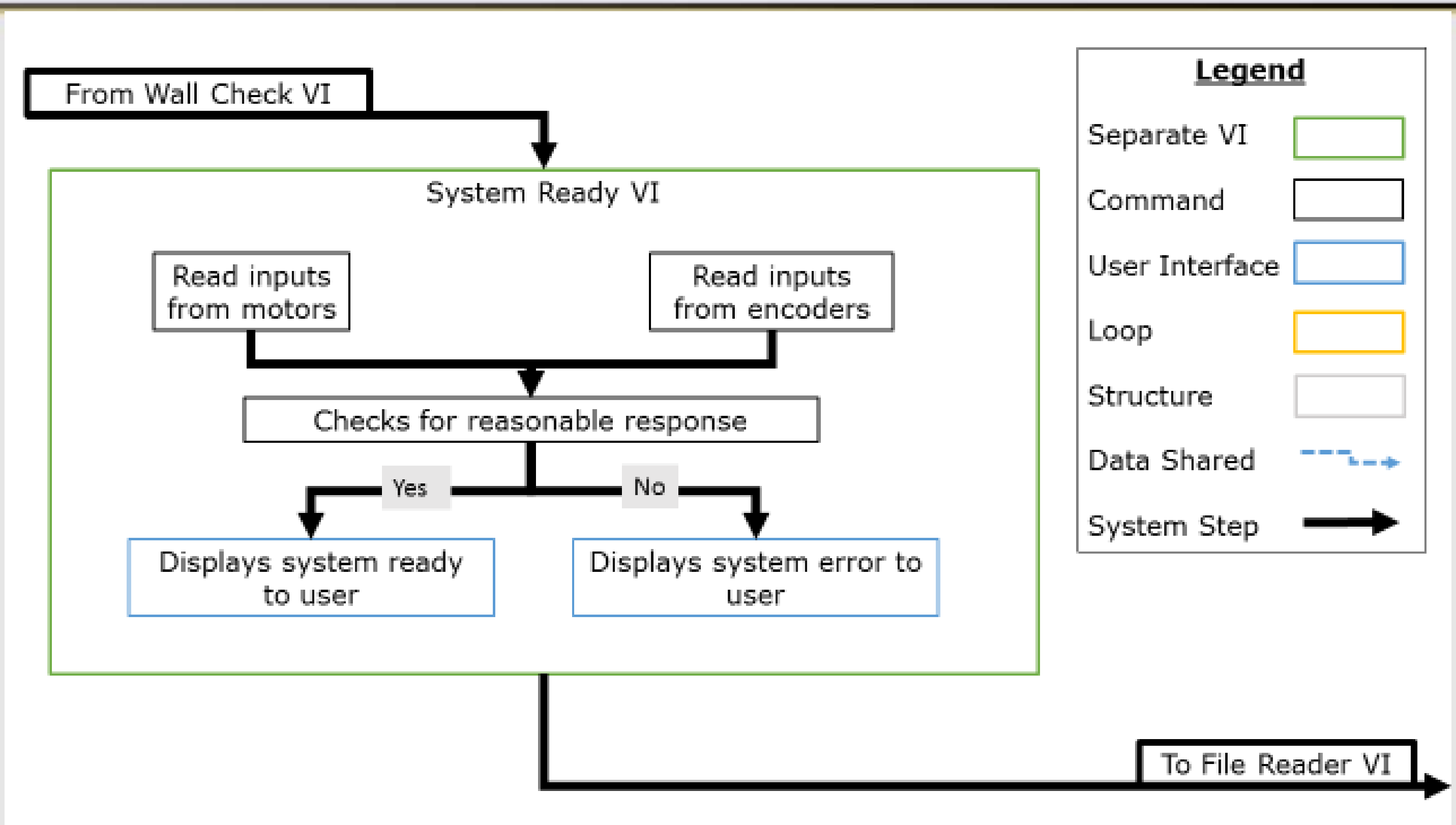
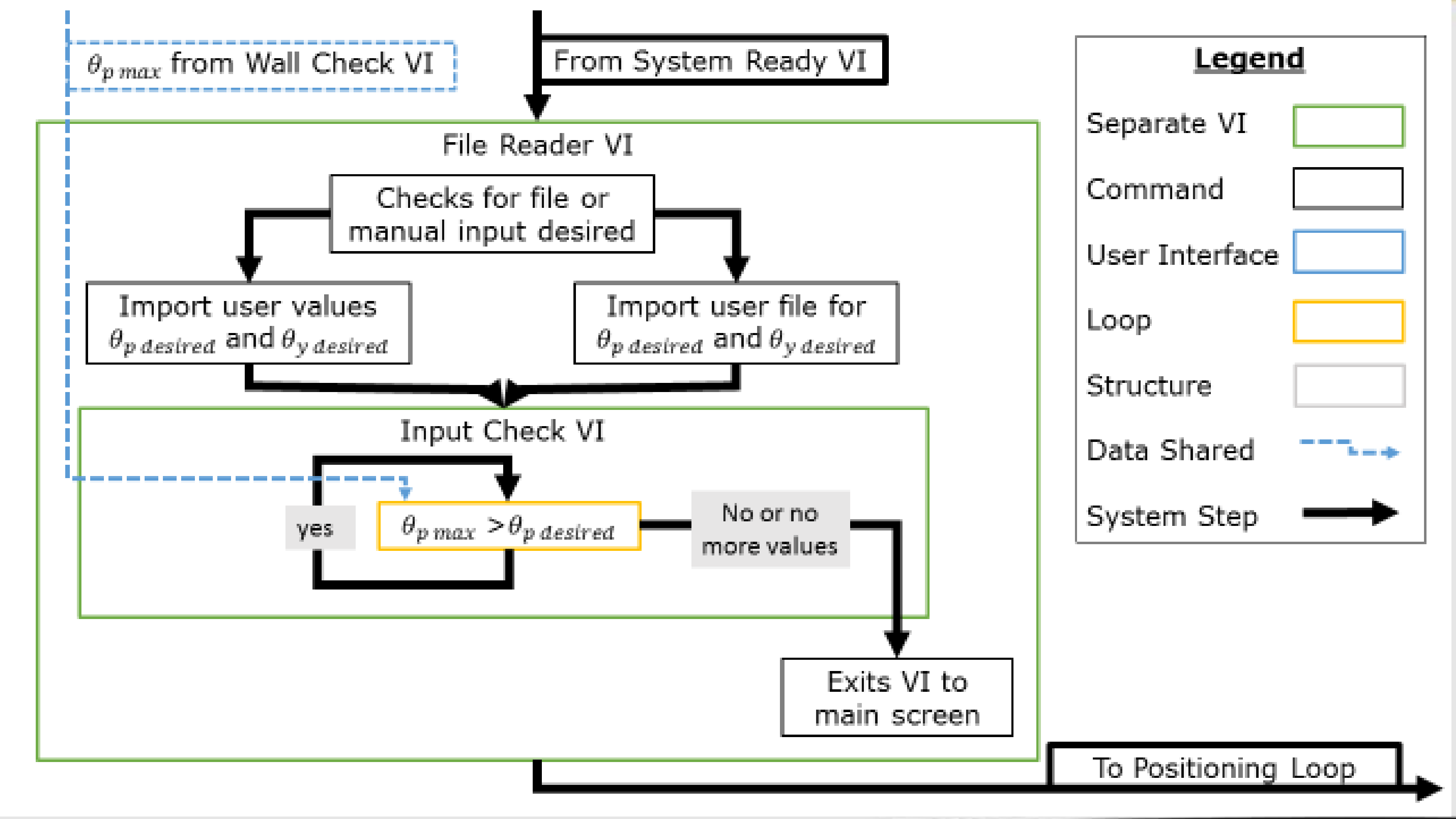
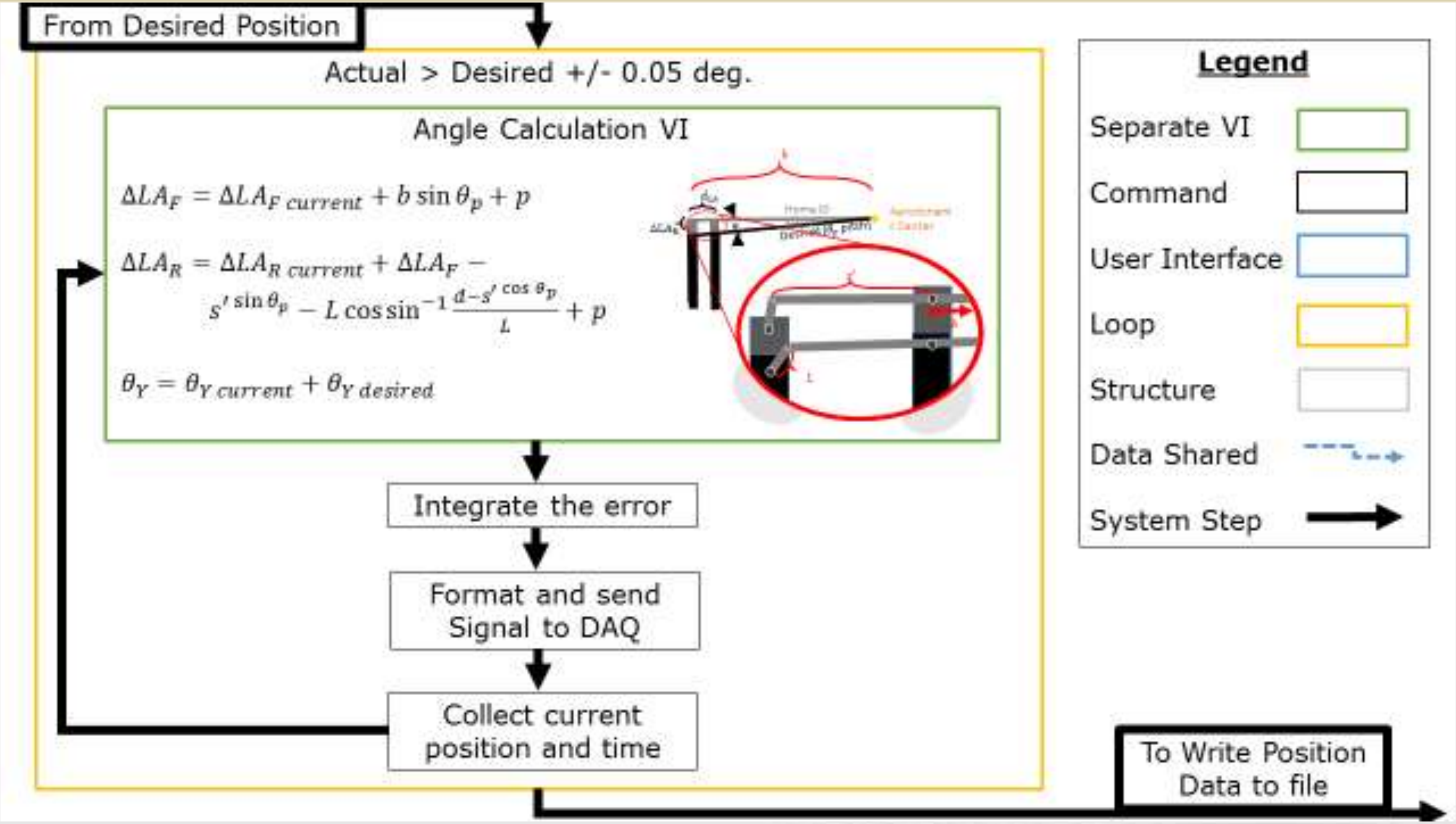
# Software: System Readiness Flowchart



# Software: Input/File Reader Flowchart



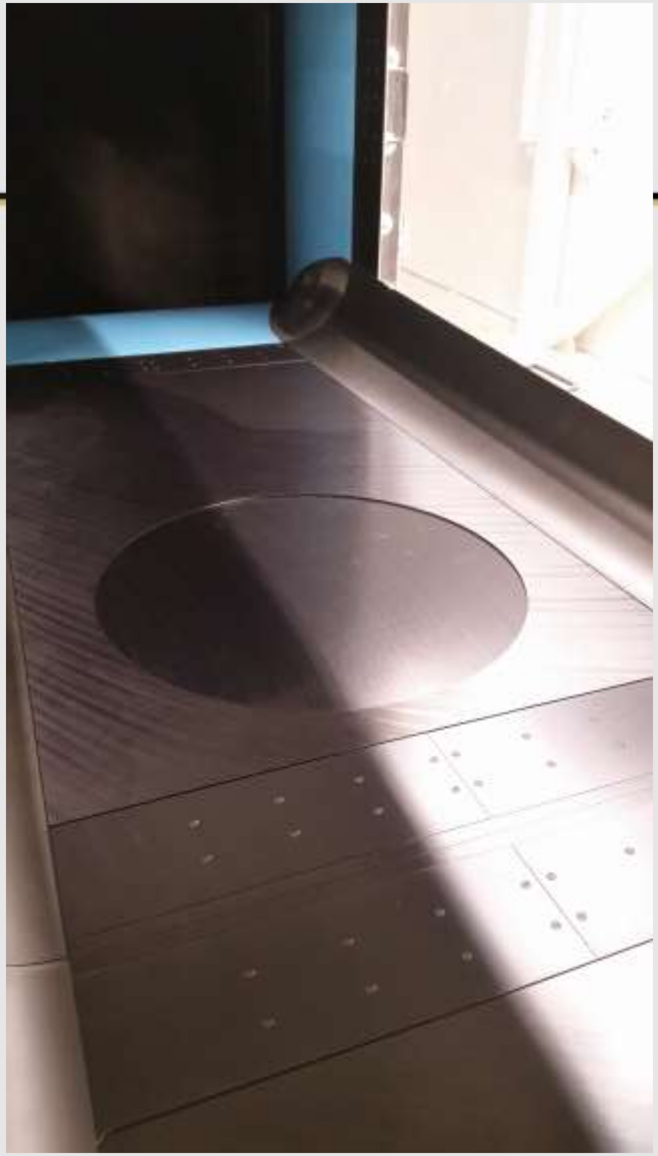
# Software: Pitch Calculation Flowchart



# Other Design Considerations

Fillets:

- Thicker at beginning of 1st test section, smooths to no thickness at end of last test section
- Smooth out corners to prevent flow disturbances



# Software: Wall Check with Model

Model approximated as a rectangular box

## Yaw/walls

Angle to far yaw corner

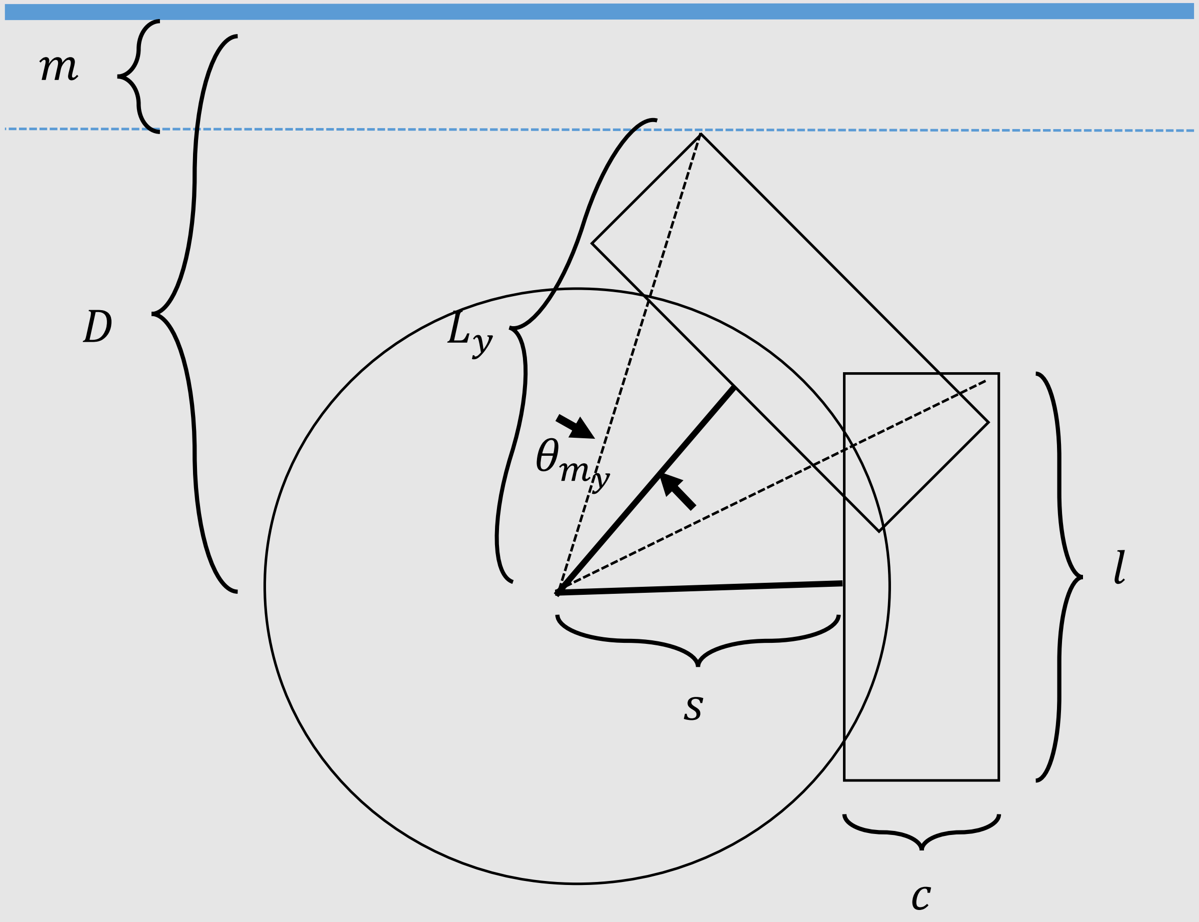
$$\theta_{m_y} = \tan^{-1}\frac{l}{2(c+s)}$$

length to far yaw corner

$$L_y = \sqrt{(c+s)^2 + \left(\frac{1}{2}l\right)^2}$$

Angle at which model becomes to close to wall

$$\theta_{d_y} = \sin^{-1}\frac{D-m}{L_y} - \theta_{m_y}$$



# Software: Wall Check with Model

Model approximated as a rectangular box

## Pitch + Plunge/Ceiling

length to far pitch corner

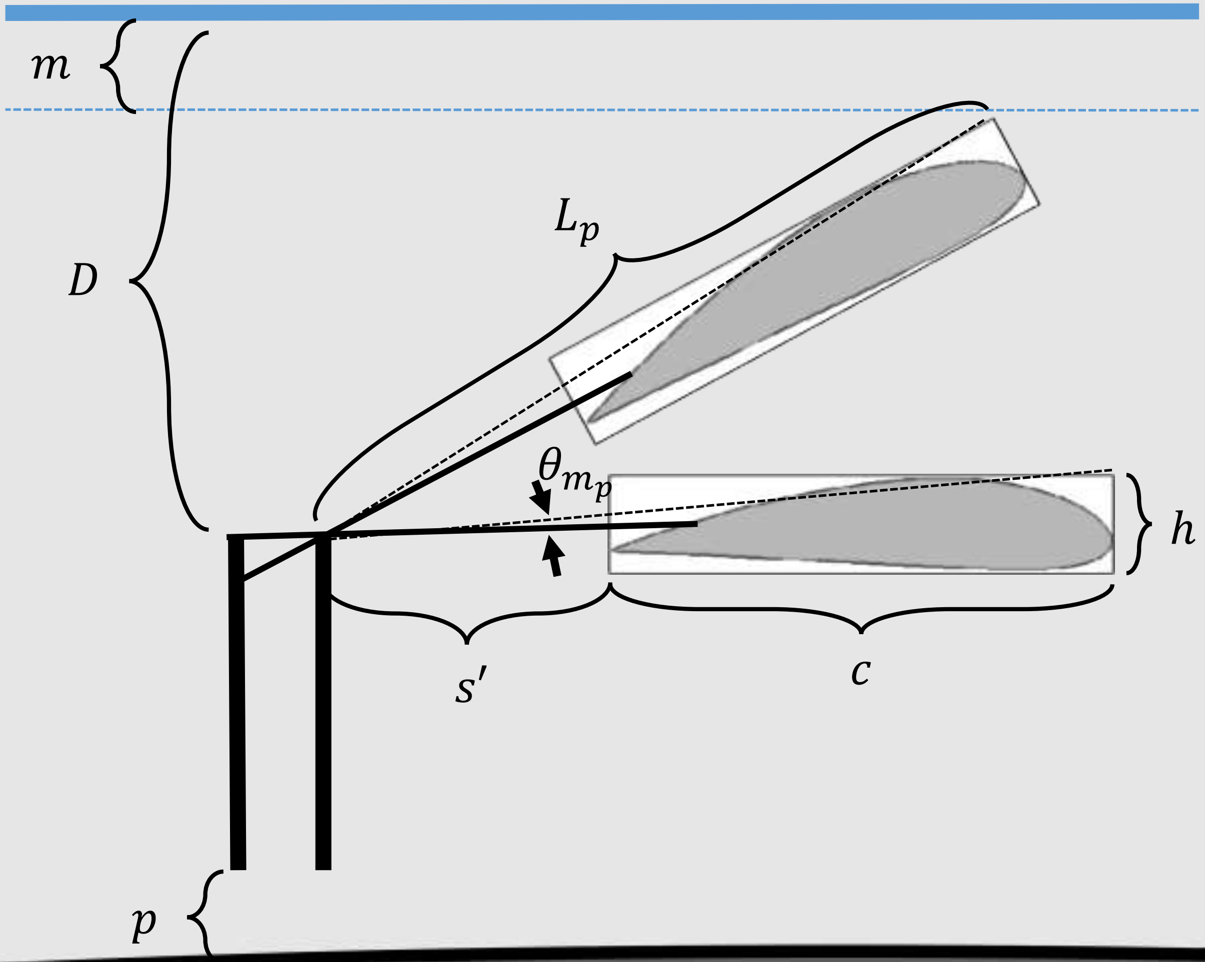
$$L_p = \sqrt{(c+s')^2 + \left(\frac{1}{2}h\right)^2}$$

Angle to far pitch corner

$$\theta_{m_p} = \tan^{-1}\frac{h}{2(c+s')}$$

Angle at which model becomes to close to ceiling

$$\theta_{d_p} = \sin^{-1}\left(\frac{D-m}{L_p} - p\right) - \theta_{m_p}$$



# Software: Wall Check - old design

Customer does not want the model to be calculated, that is the responsibility of the user

## Pitch + Plunge/Ceiling

To keep the system from hitting the wall

$$D > l$$

length to tip of Sting

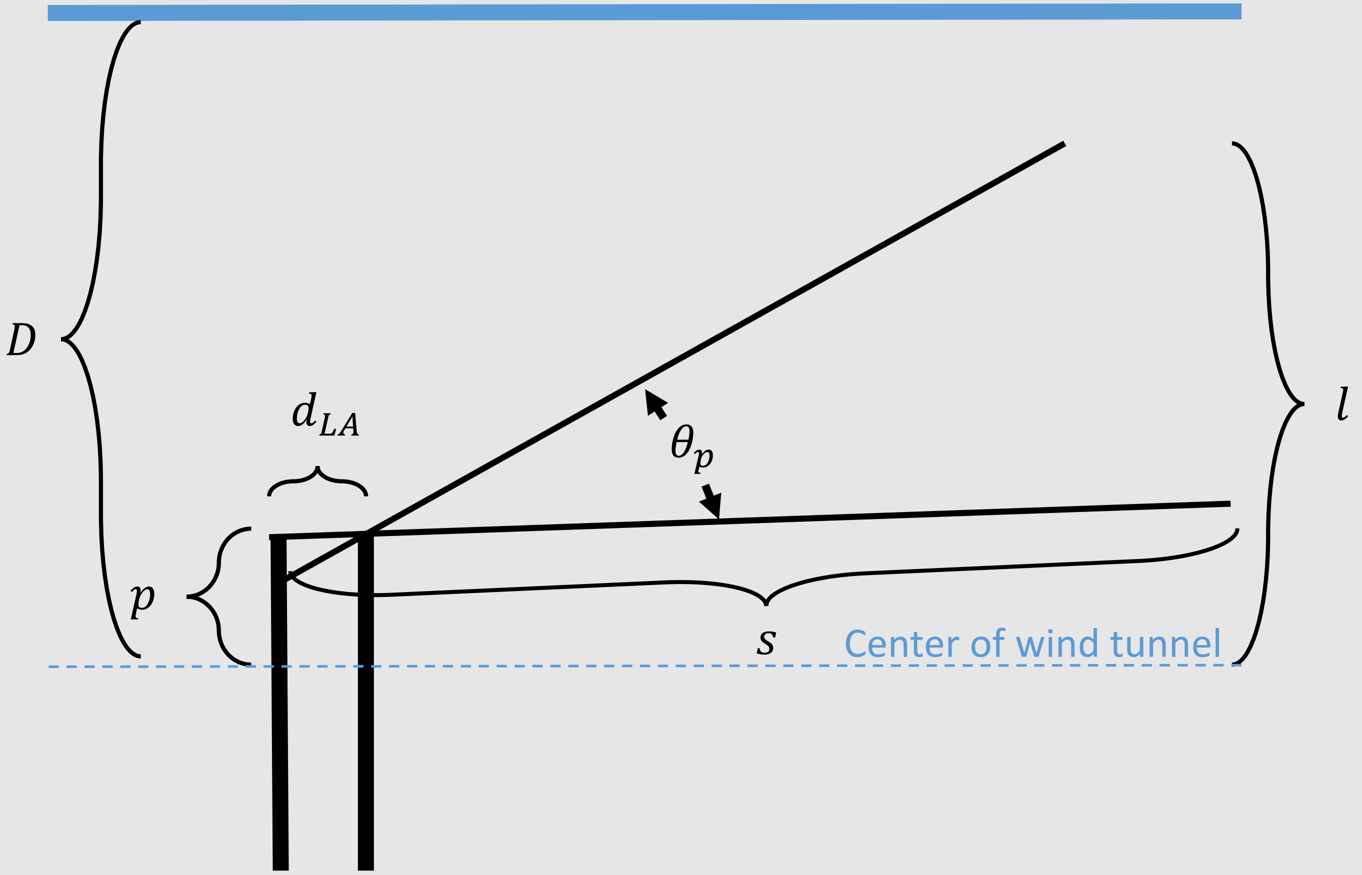
$$l = p + (\mathrm{s} - \mathrm{d_{LA}}) \sin \theta_p$$

Combining the equations and inserting the known system quantities

$$11.1 > p + (\mathrm{s} - 3) \sin \theta_p$$

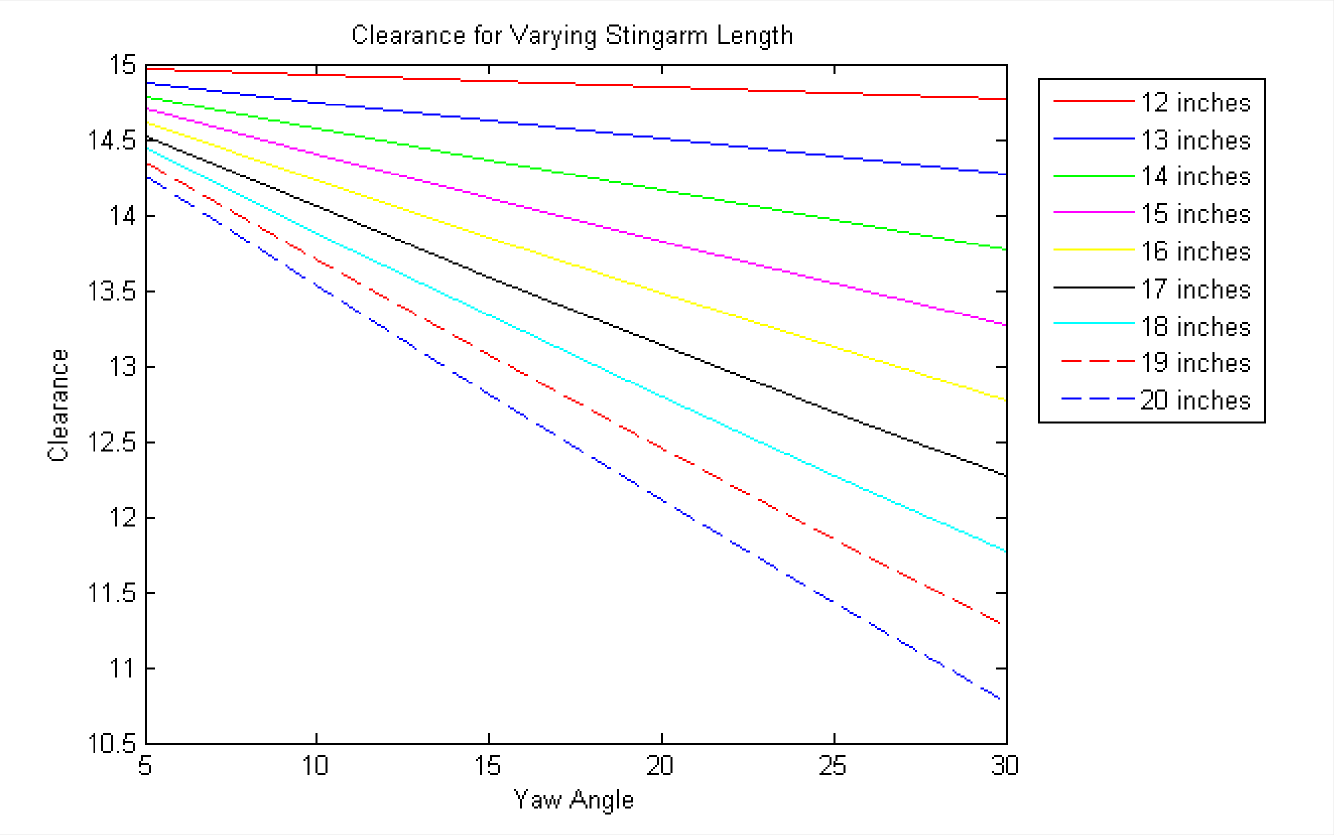
Allowable angles are

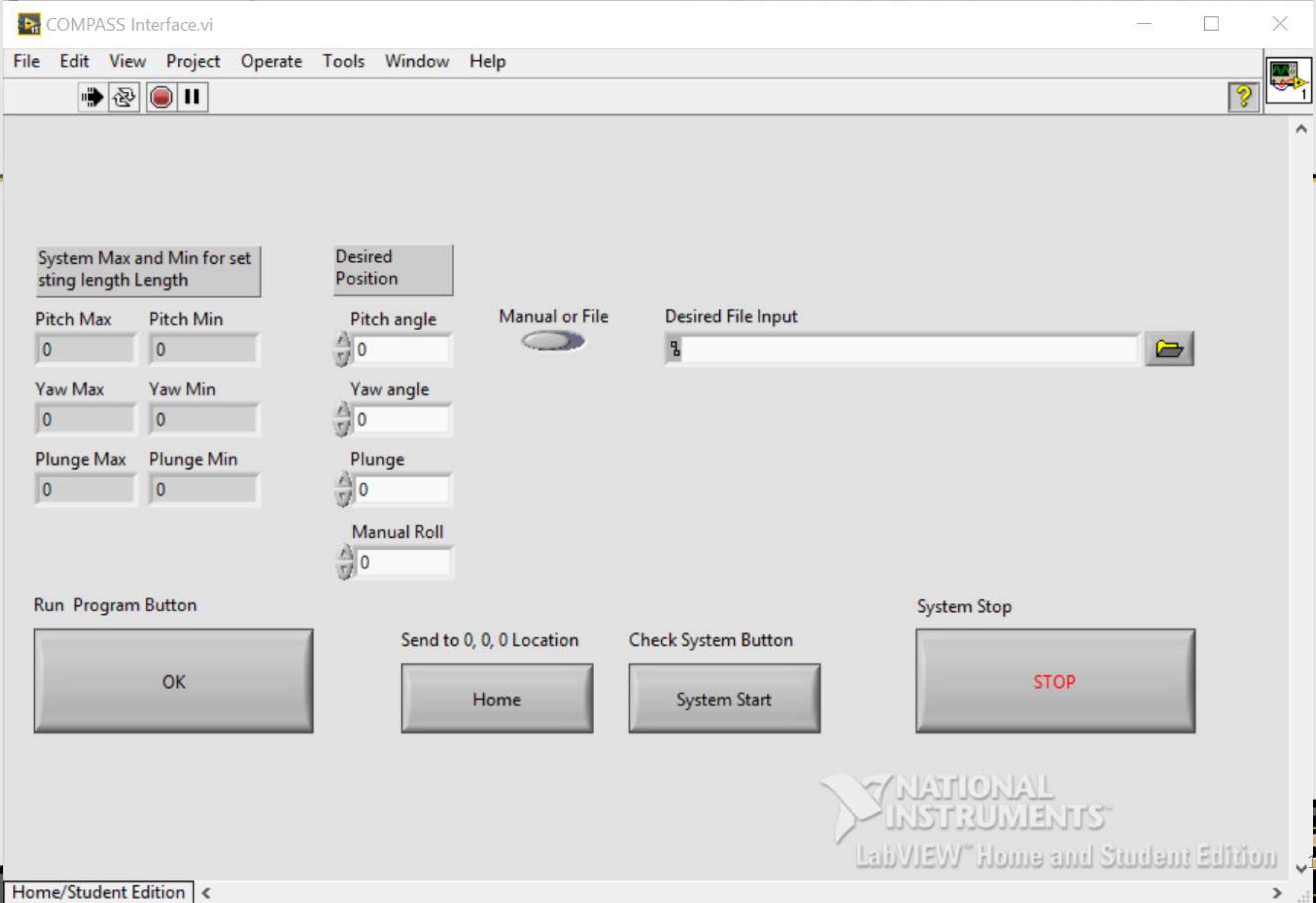
$$\theta_p < \sin^{-1} \frac{11.1 - p}{(\mathrm{s} - 3)}$$

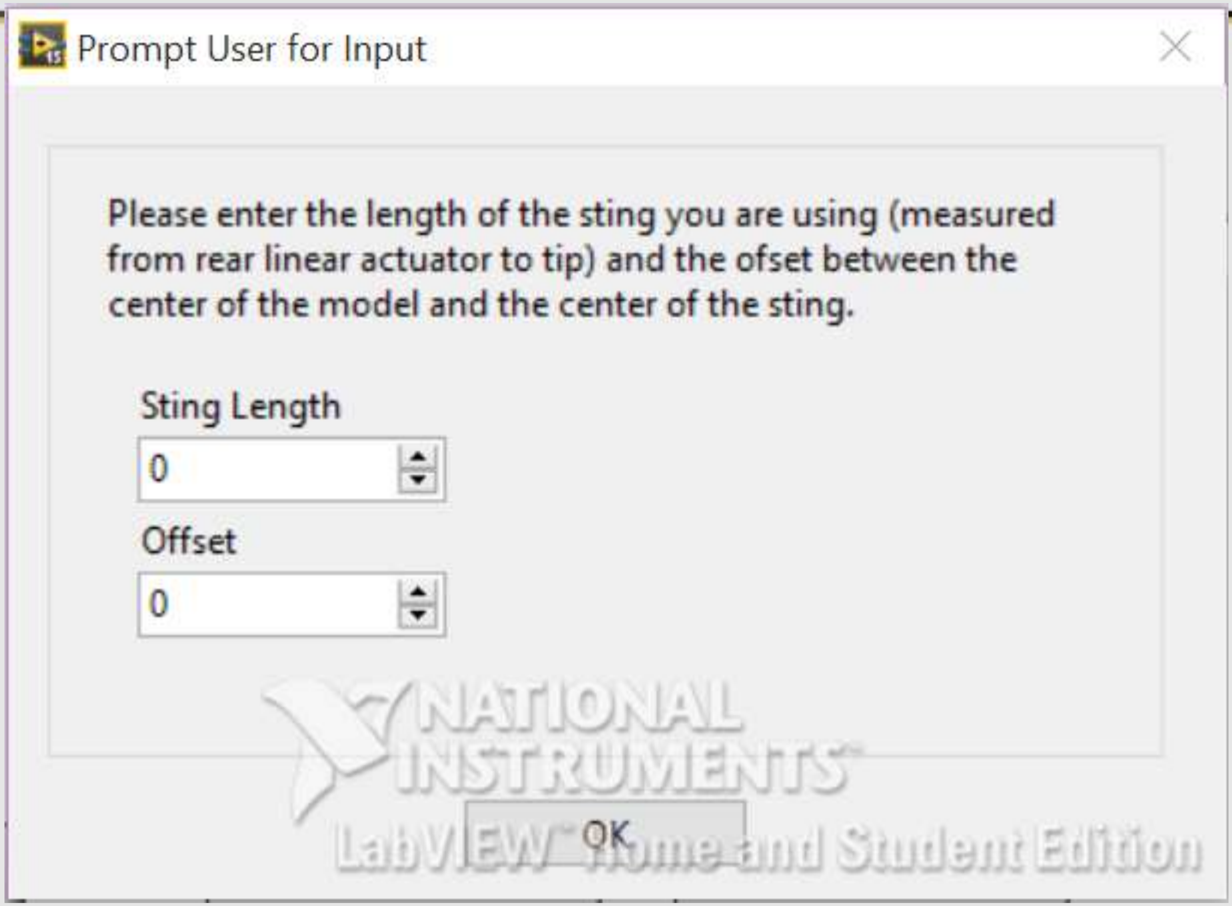


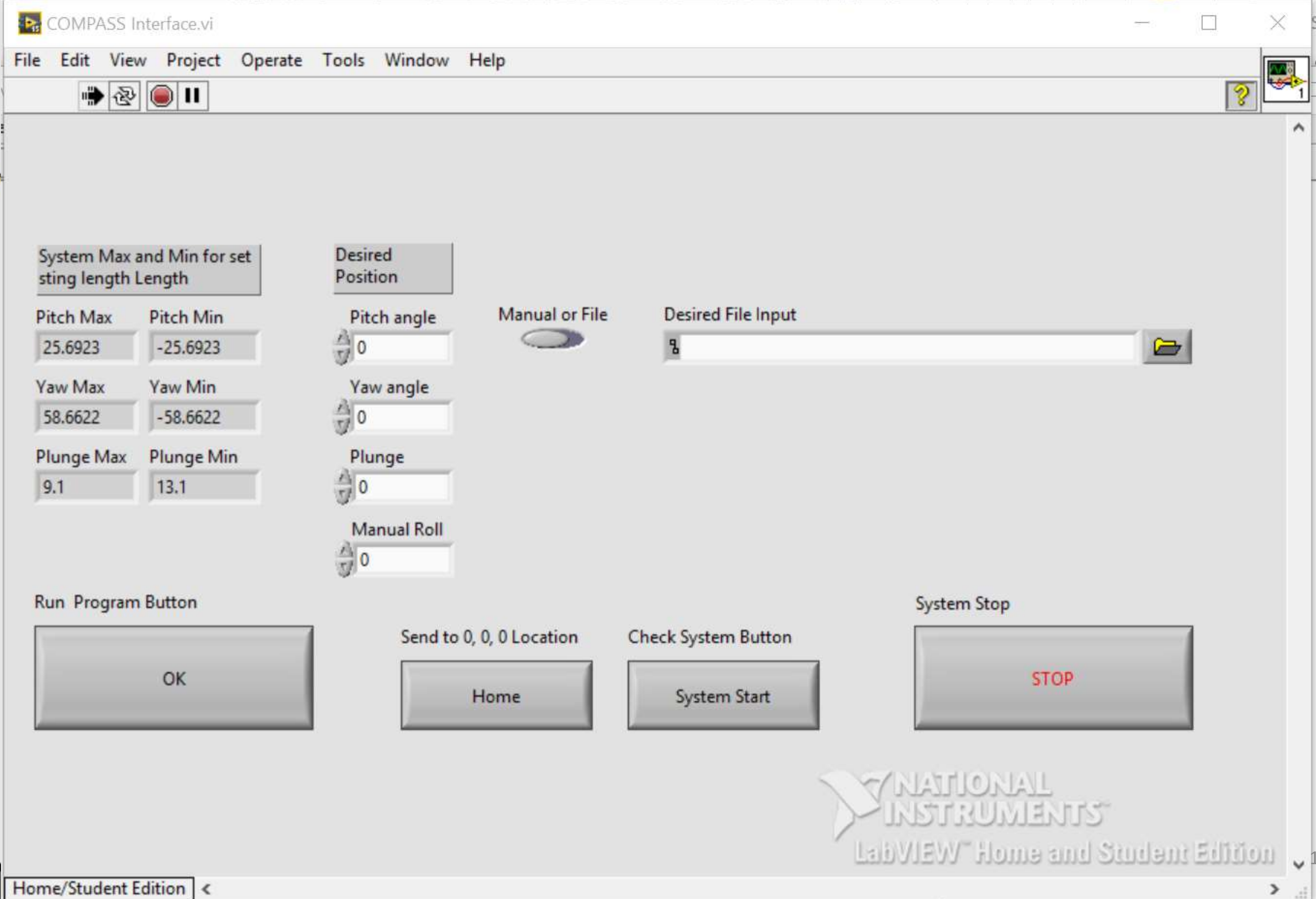
# Yaw Clearance Calculation

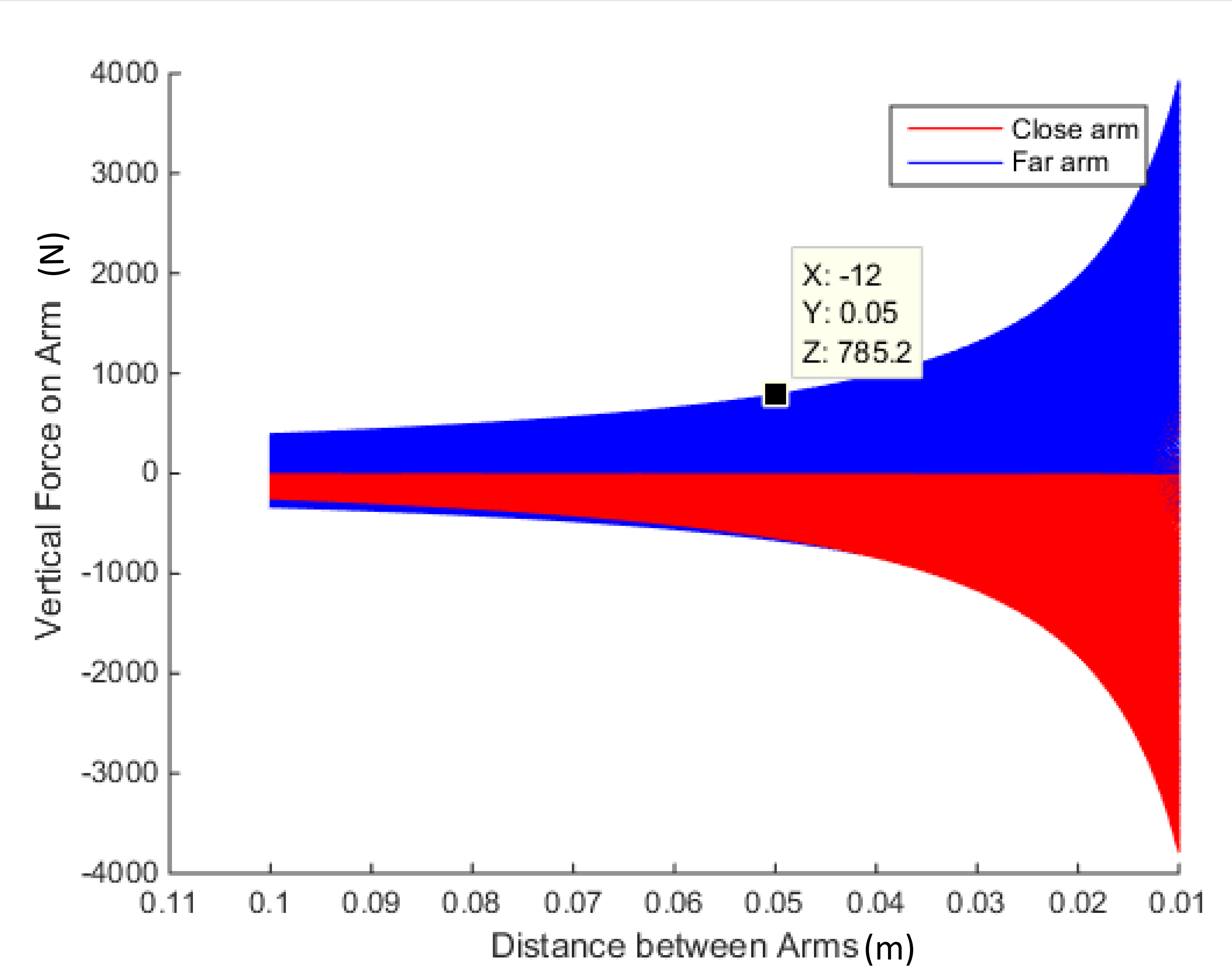
- Matlab Script Calculation
- Calculated the distance from the tip of the sting to the side of the wind tunnel
- Varied theta
- Varied total sting length




COMPASS Interface.vi
File Edit View Project Operate Tools Window Help
System Max and Min for set sting length Length
Desired Position
Pitch Max
Pitch Min
Yaw Max
Yaw Min
Plunge Max
Plunge Min
Pitch angle
Yaw angle
Plunge
Manual Roll
Manual or File
Desired File Input
Run Program Button
OK
Send to 0, 0, 0 Location
Home
Check System Button
System Start
System Stop
STOP
NATIONAL INSTRUMENTS
LabVIEW Home and Student Edition
Home/Student Edition


Prompt User for Input
Please enter the length of the sting you are using (measured from rear linear actuator to tip) and the ofset between the center of the model and the center of the sting.
Sting Length
0
Offset
0
NATIONAL INSTRUMENTS
OK
LabVIEW Home and Student Edition


COMPASS Interface.vi
File
Edit
View
Project
Operate
Tools
Window
Help
System Max and Min for set sting length Length
Pitch Max
25.6923
Pitch Min
-25.6923
Yaw Max
58.6622
Yaw Min
-58.6622
Plunge Max
9.1
Plunge Min
13.1
Desired Position
Pitch angle
0
Yaw angle
0
Plunge
0
Manual Roll
0
Manual or File
Desired File Input
Run Program Button
OK
Send to 0, 0, 0 Location
Home
Check System Button
System Start
System Stop
STOP
NATIONAL INSTRUMENTS
LabVIEW Home and Student Edition
Home/Student Edition

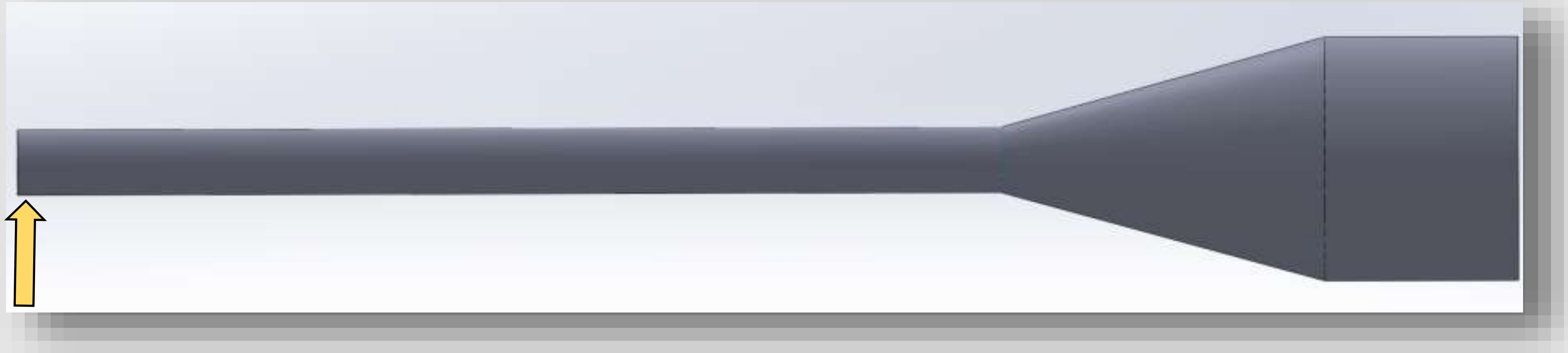



785N -> 185 lbf

5 cm (1.95 in) is about the limit of closeness for actuators

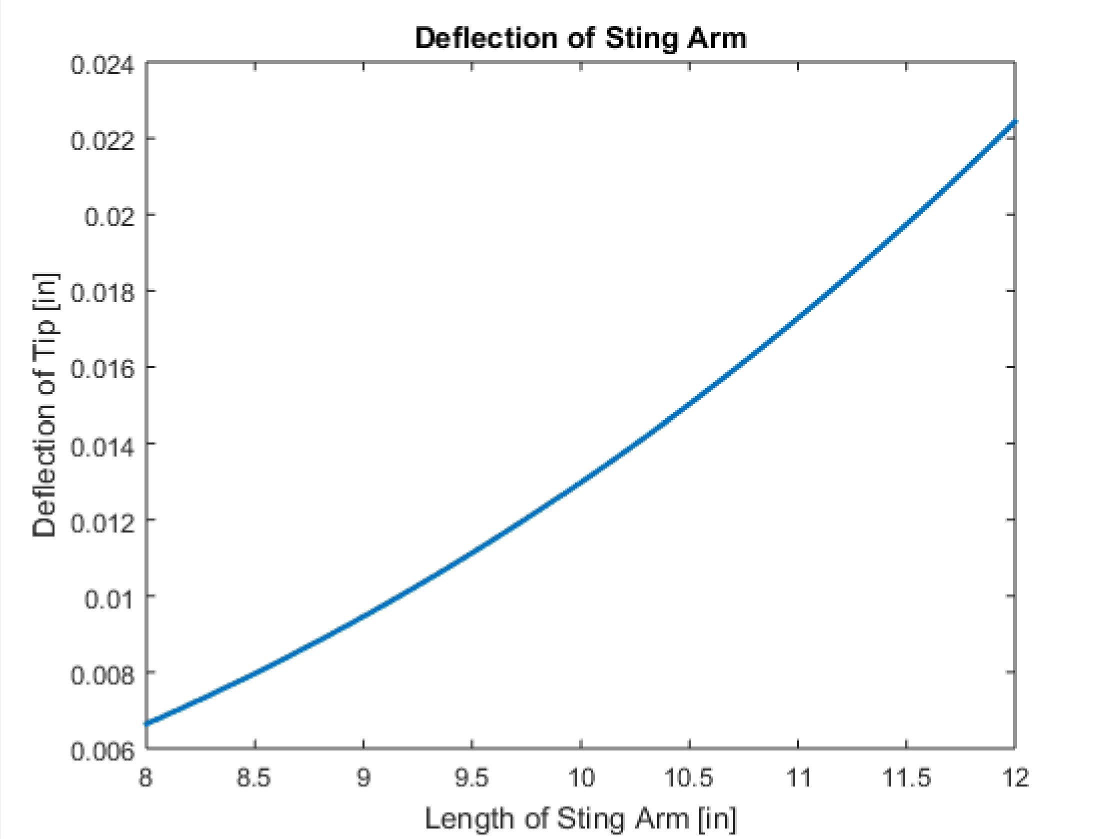
# Deflection of Sting

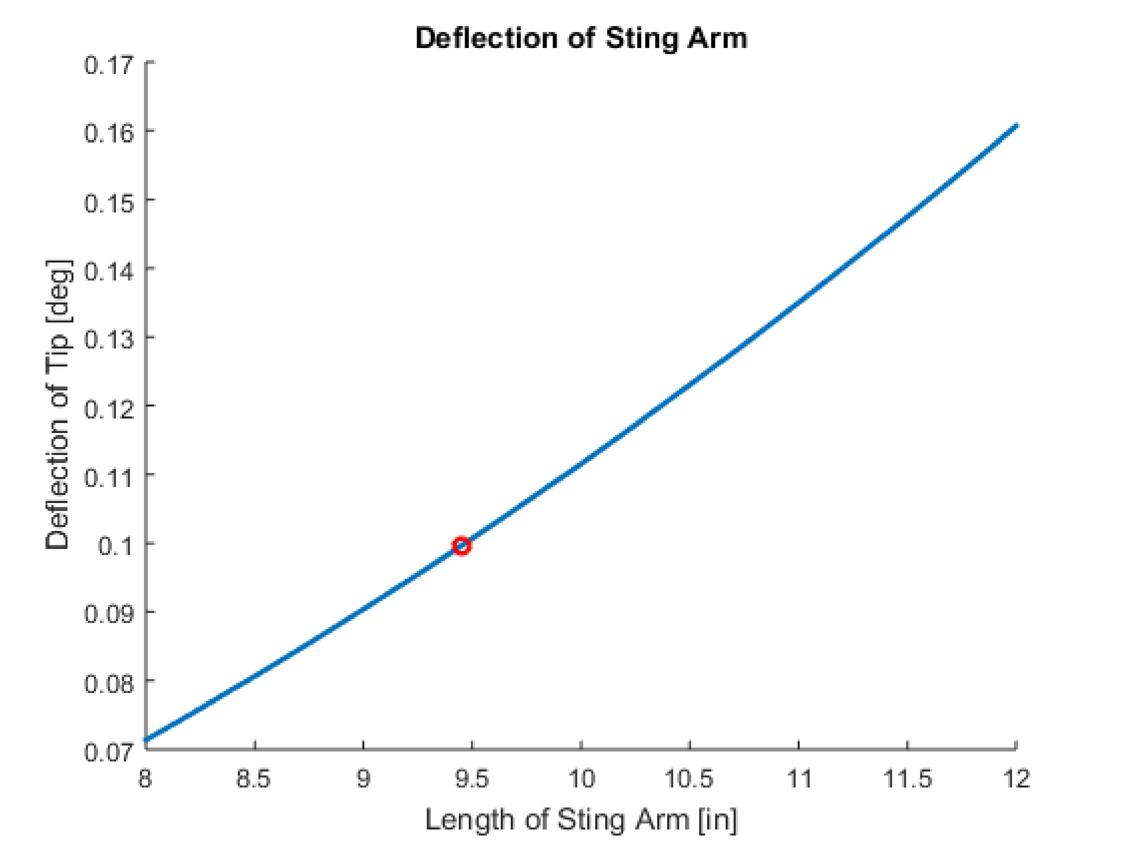
- Assumptions: 12 inch stainless steel sting, cantilever beam
- 160 N force acting at tip



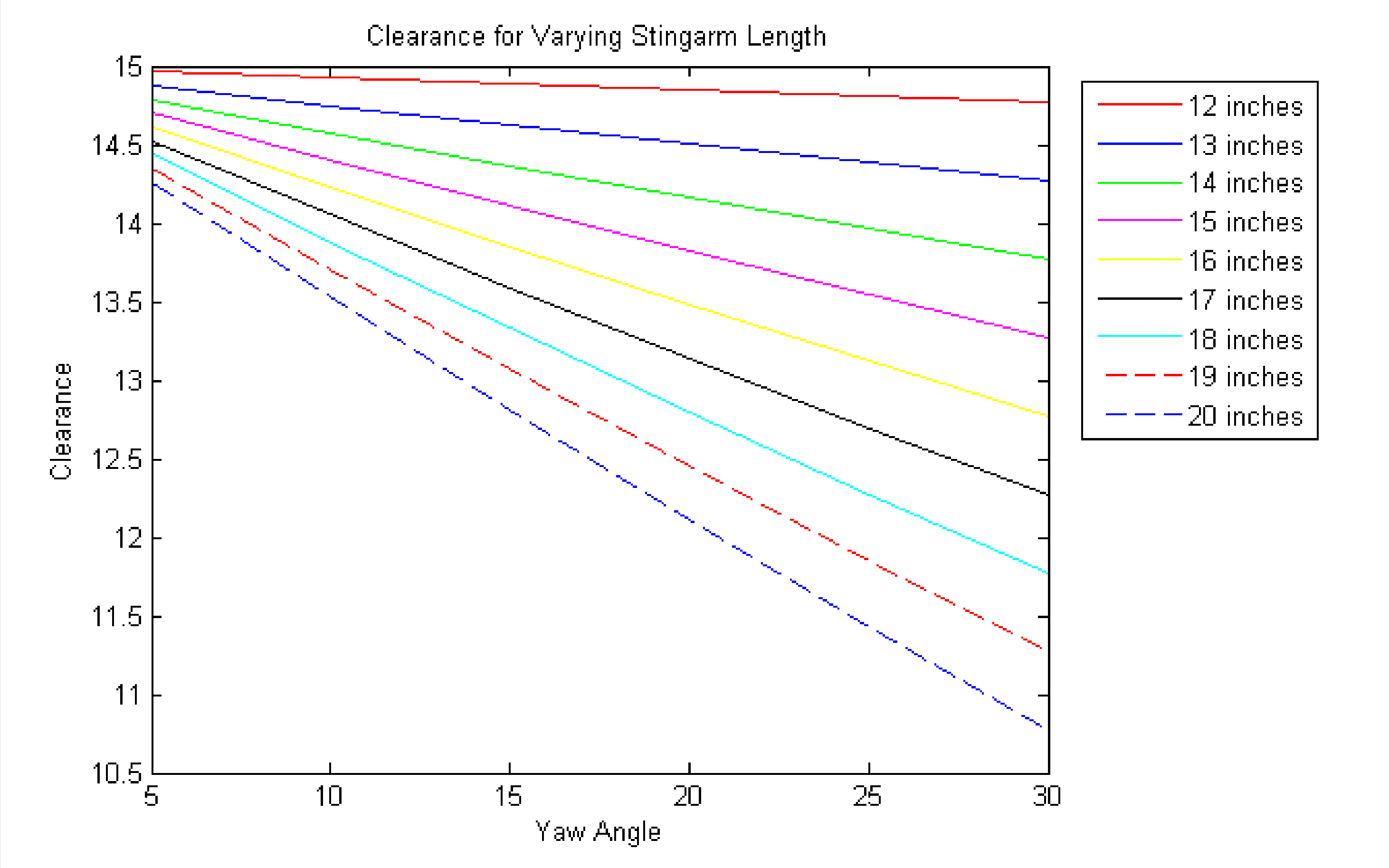
- Deflection: 0.022 inches

# Deflection of Sting Figures



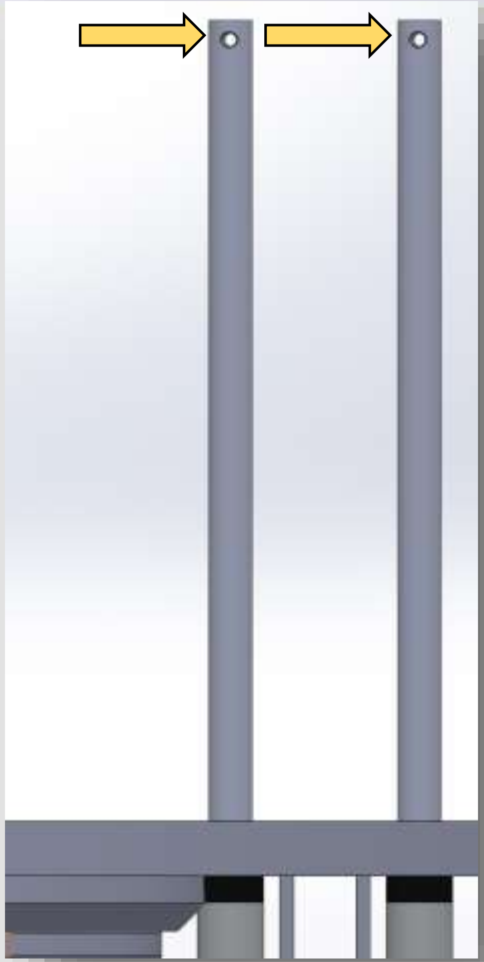
# Sting Length Variation




- Matlab code that changed the length of the sting and varied the yaw angle to figure out how far the end of the sting would be from the edge of the wind tunnel

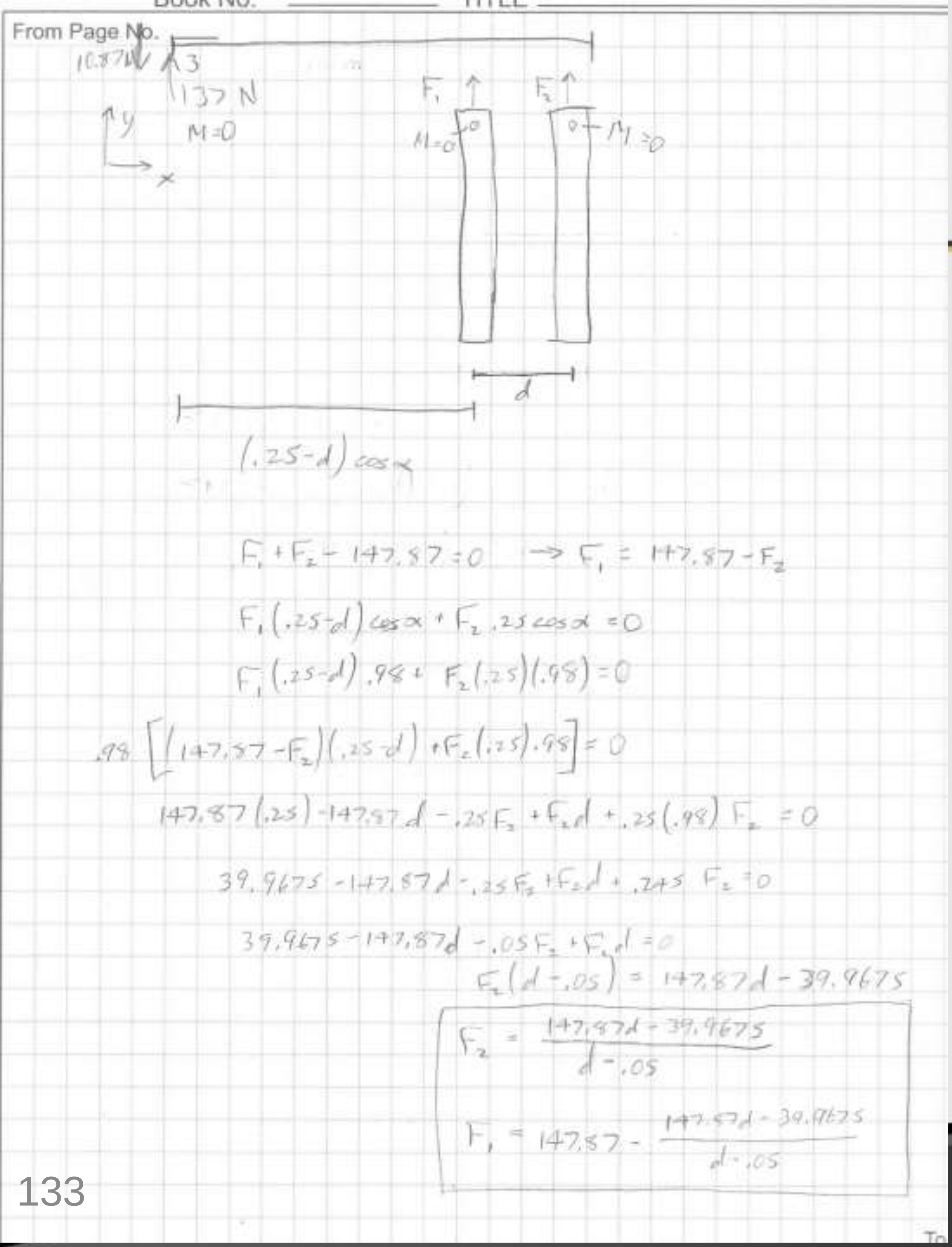
# Deflection of Actuators

- Assumptions:
- Stainless Steel
- 24 inch Cantilever Beam
- Drag force 160 N



- Deflection: 0.062 inches

# Actuator Force Calculation



# Bolt Tensile Strength Safety Factor

$A_s$ = Bolt Area (unit length)

A = Bolt Area

$d_m$ = Nominal diameter

$d_p$ = Pitch diameter

$$A_s = \frac{\pi}{4}\left(\frac{d_m + d_p}{2}\right)^2 = 0.0199 \frac{in^2}{unit\ length}$$

Click to add text

For 0.375 in engagement → $A = 0.0075\ in^2$

$$\tau_{max} = \frac{150\ lbs^*}{0.0075\ in^2} = 20\ ksi$$

$$S.F. = \frac{\tau_{yield}}{\tau_{max}} = \frac{40\ ksi}{20\ ksi} = 2$$

*150 lbs per screw

# Bolt Tensile and Shear Strength

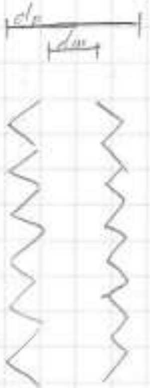
Page No. ___

## Bolt Tensile Strength

From Matt's book, per unit length

$$A_s = \frac{\pi}{4}\left(\frac{d_m + d_p}{2}\right)^2$$

where $d_m = d - 1.299038 \times P$ $\quad d_p = d - .649519 \times P$




$d$ = major (nominal) diameter
$P$ = screw pitch = $1/N$ where $N$ = tpi

Or get values online!

Approximates as cylinder, with mean diameter between minor and pitch diameter

For 10-32 basic diameter = .19
$d_p = .1697$
$d_m = .149$

$A_s = .0199$ in²/in length

For .375 in engagement → .0075 in²

$\tau_{yield} = 40$ ksi $\quad (40\text{ ksi})(.0075\text{ in}^2) = .3$ kip

For tensile failure (without threads), .0199 (40 ksi) = 796 lb → 398 lb

300 lb per screw

150 lb with F = 2

# Sting Body Safety Factor

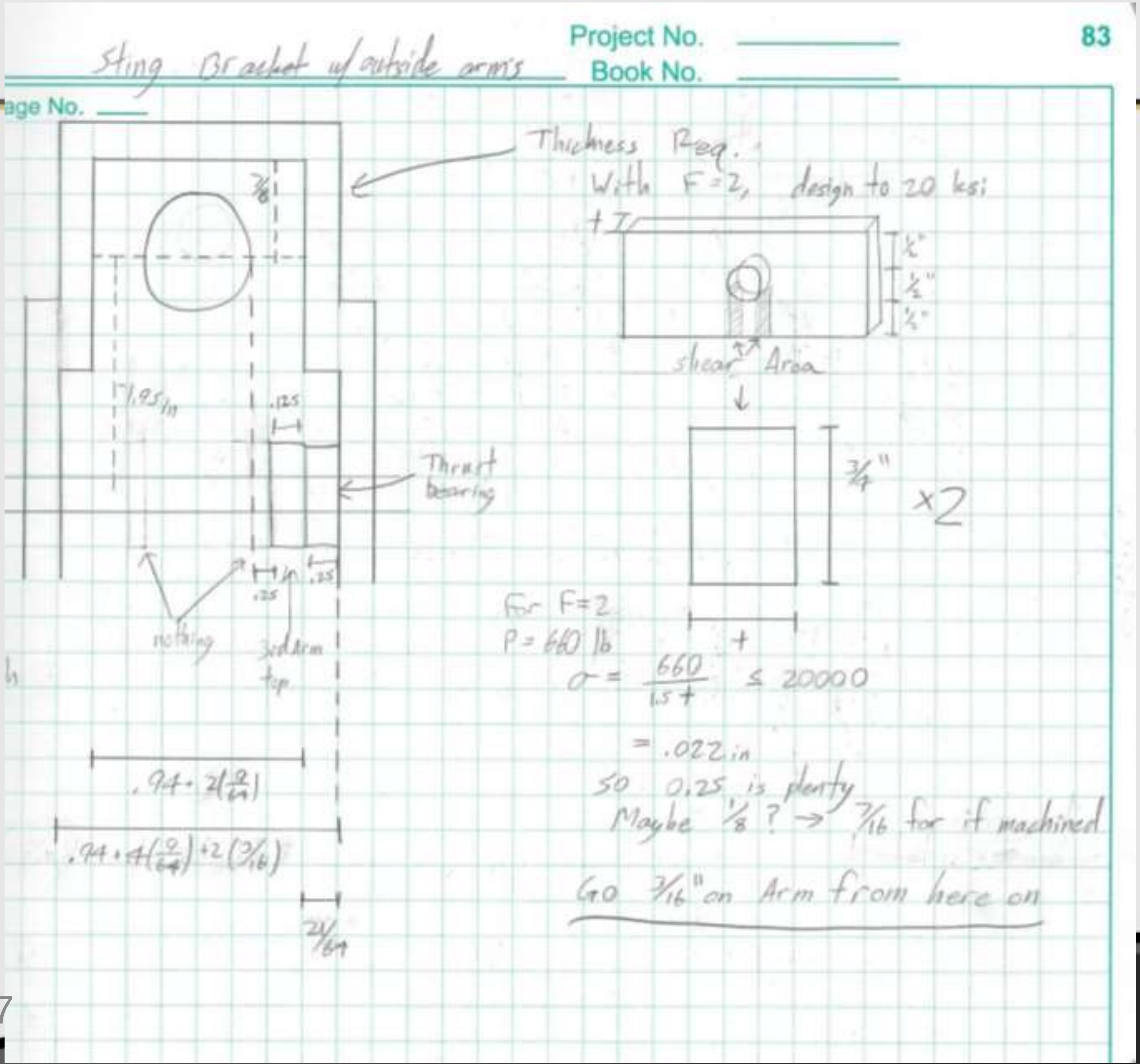
$A_{tot}$ = Sting area
D = Sting body diameter
b = Diameter of bearing
p = Diameter of gap in rod
t = Diameter of rod
$\tau$ = Shear stress

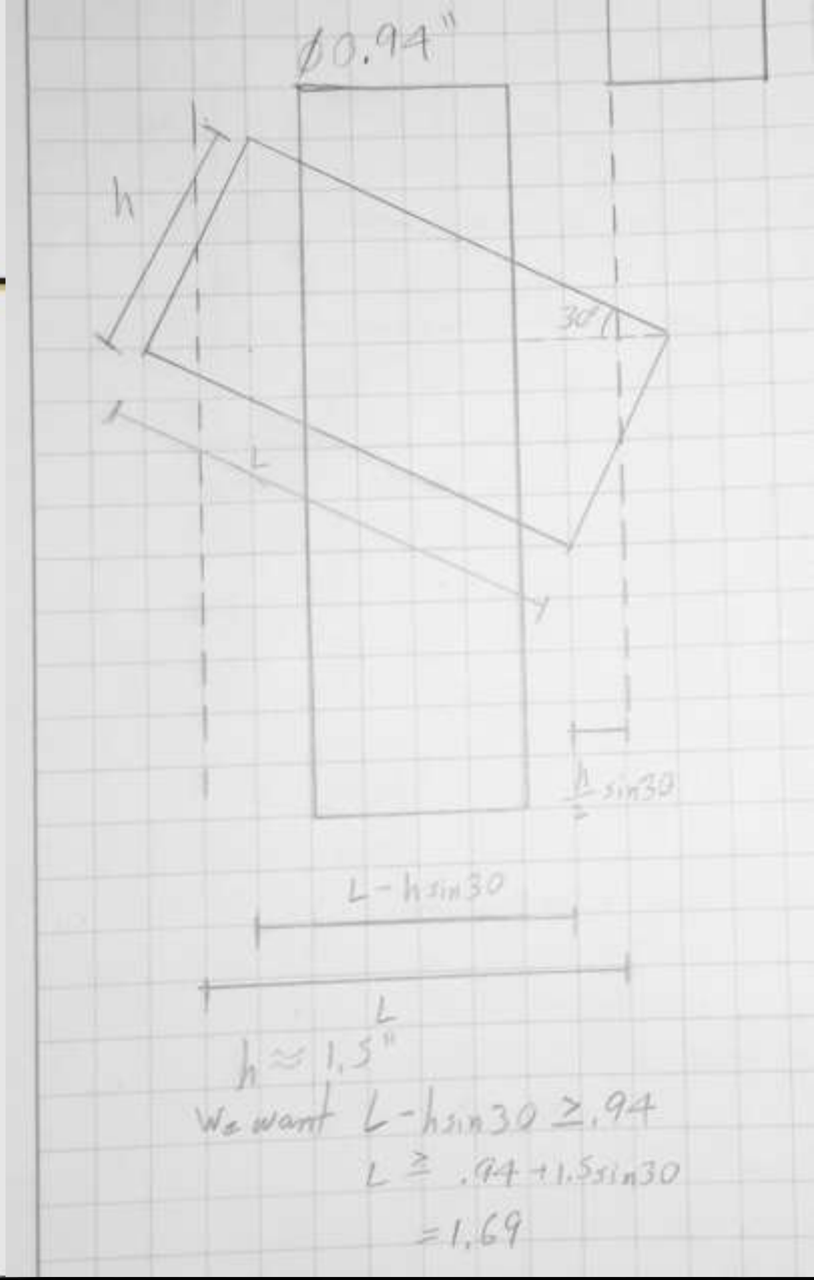
$$A_{tot} = 2\left[\left(\frac{D-p}{2}\right)\left(\frac{D-t}{2} - b\right)\right] = 1.1304\ in^2$$

$$\tau_{max} = \frac{F}{A_{tot}} = \frac{660\ lbs}{1.1304\ in^2} = 20\ ksi$$

$$S.F. = \frac{\tau_{yield}}{\tau_{max}} = \frac{40\ ksi}{20\ ksi} = 2 \quad \Rightarrow \quad \mathrm{D} = 1.13\ \mathrm{in}$$

# Sting Body Sizing



# Sting Pin Size

Finding Minimum Pin Diameter For Sting (Bracke

SS 316 Tensile strength $\tau$ = 480–620 MPa

$P \leq 660$ lb


Shear $\sigma \approx \frac{\tau}{\sqrt{3}} \rightarrow$ 277–358 MPa
= 40.2 – 52 ksi

$A = \pi r^2$
$= \pi \frac{d^2}{4}$ $d = \sqrt{\frac{4A}{\pi}}$

$\sigma = \frac{P}{A}$

$A = \frac{P}{\sigma}$

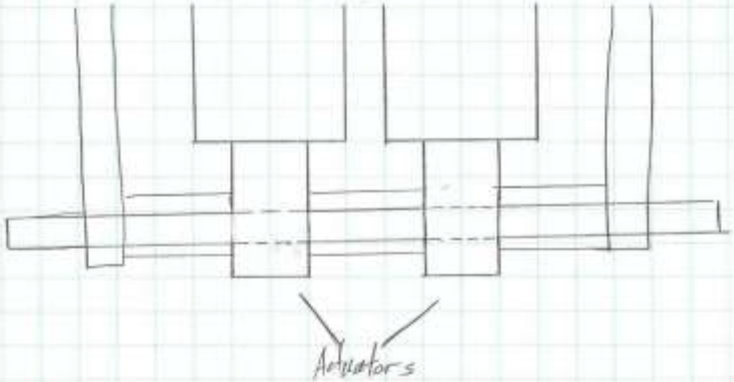
$A = \frac{660}{40200} = .0165 \rightarrow d = .145$ in

or $\frac{660}{20100} = .033$ For FS = 2

$\rightarrow d = .205$ in

Most standard bearings → .25 in

Matt says For press fit, rod diameter about $\frac{.5}{1000}$ bigger than hole for Al, $\frac{2-3}{10000}$ for st



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# Actuator Brackets Safety Factor

$$S.F. = \frac{F}{F_{max}} = \frac{660\ lbs}{165\ lbs} = 4$$

n = End condition factor

= 4 (for top end)

= 2 (for bottom end)

L = Length of bracket

E = Modulus of elasticity

= 29,700 ksi

b = Thickness of bracket

I = Moment of Inertia

$$F = \frac{n\pi^2 EI}{L^2} \Rightarrow 660\text{ lbs} = \frac{4\pi^2 * 29{,}700\text{ ksi} * \text{I}}{16.74\text{ in}^2}$$

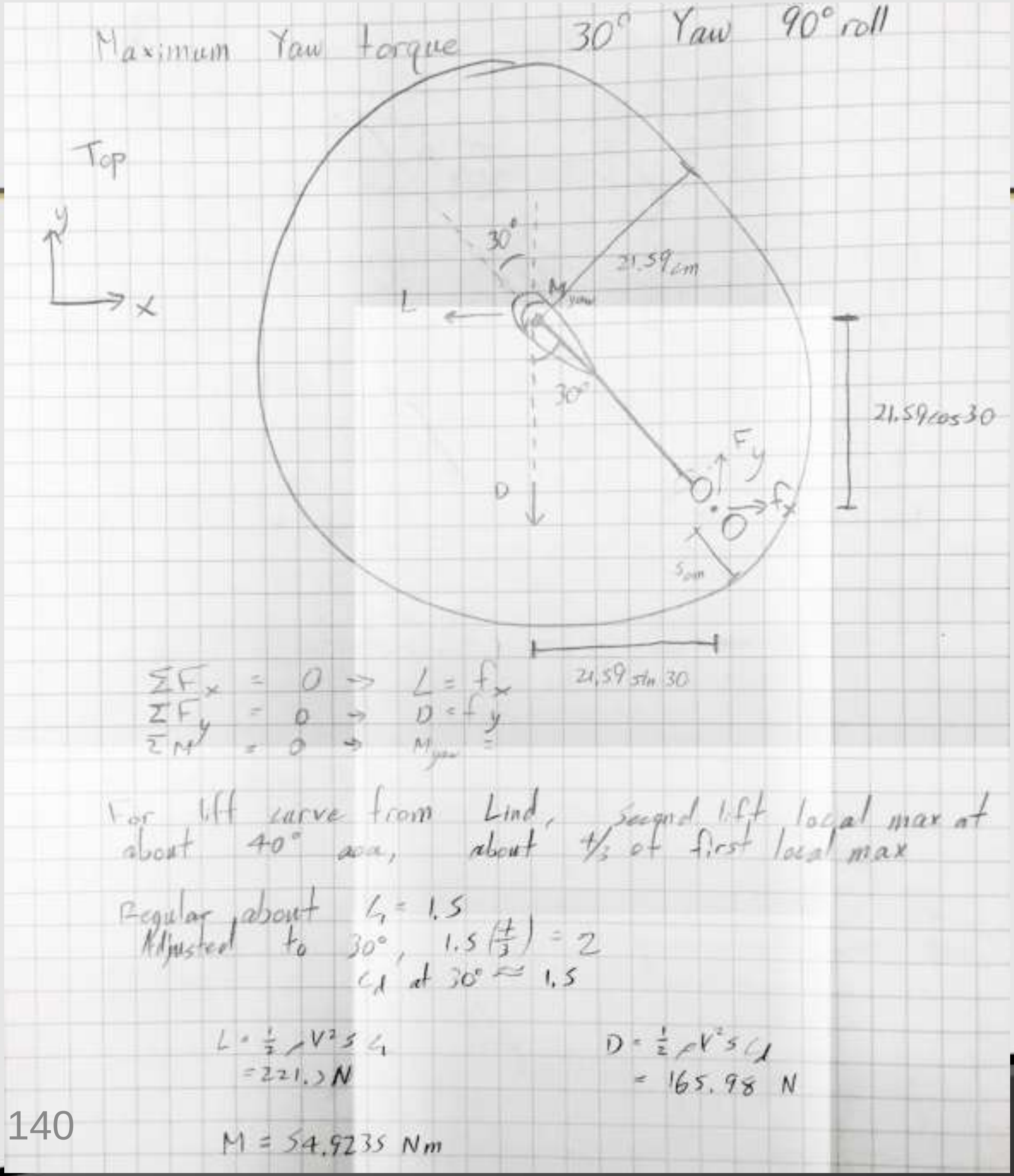
$$\text{Solving for } I \Rightarrow I = 1.58 * 10^{-4}\ in^4$$

$$I = \frac{b^3}{12} \Rightarrow \text{Solving for b} \Rightarrow \text{b} = 0.124\text{ in (top)}$$

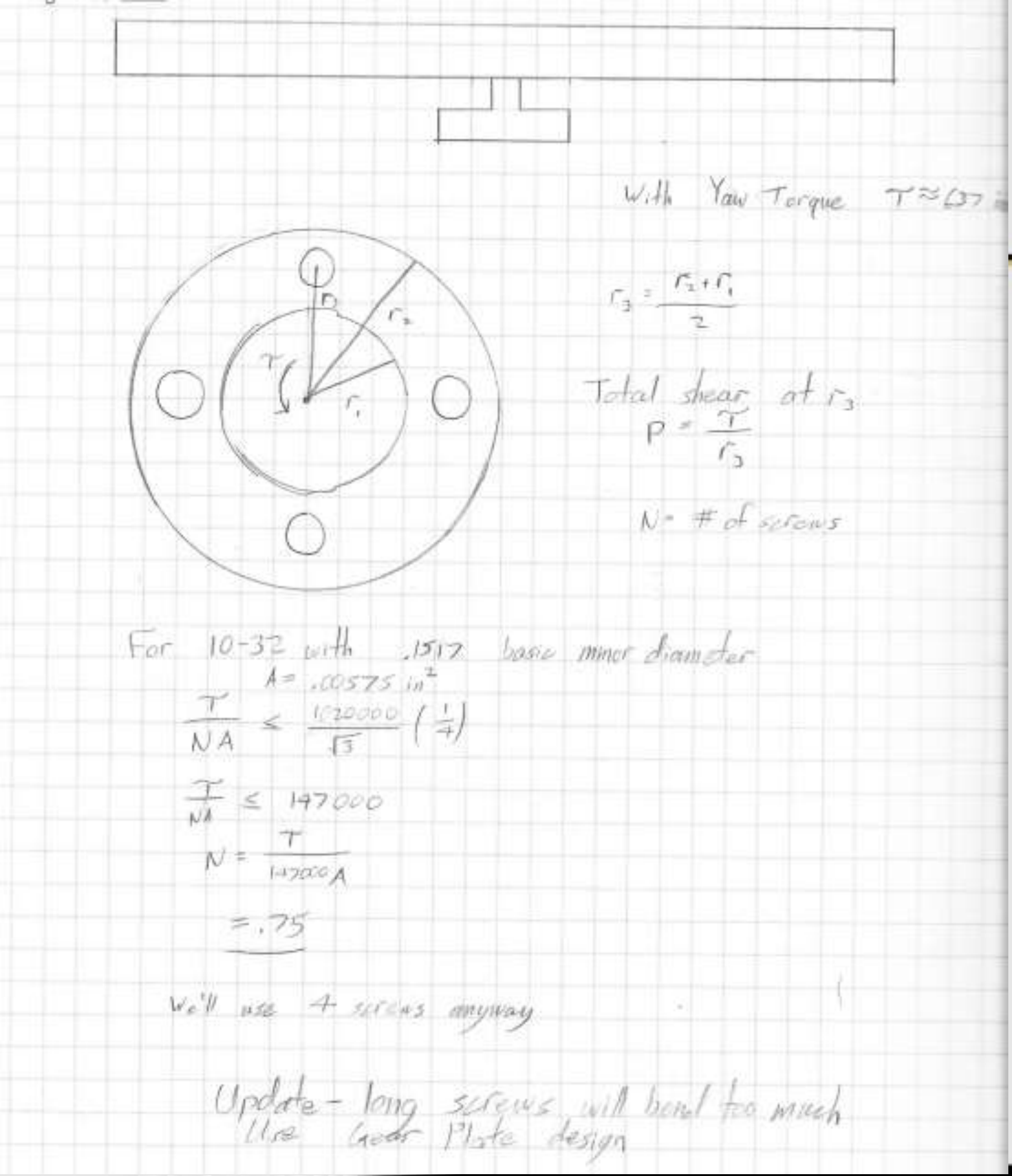
$$660\text{ lbs} = \frac{2\pi^2 * 29{,}700\text{ ksi} * \text{I}}{16.74\text{ in}^2} \Rightarrow I = 3.15 * 10^{-4}\ in^4$$

$$\text{Solving for b} \Rightarrow \text{b} = 0.156\text{ in (bottom)}$$

# Aerodynamic Yaw Torque



# Yaw Bolt Sizing



With Yaw Torque $T \approx 137$

$r_3 = \frac{r_2 + r_1}{2}$

Total shear at $r_3$

$P = \frac{T}{r_3}$

N = # of screws

For 10-32 with .1517 basic minor diameter

$A = .00575 \text{ in}^2$

$\frac{T}{NA} \leq \frac{1020000}{\sqrt{3}} \left(\frac{1}{4}\right)$

$\frac{T}{NA} \leq 147000$

$N = \frac{T}{147000 A}$

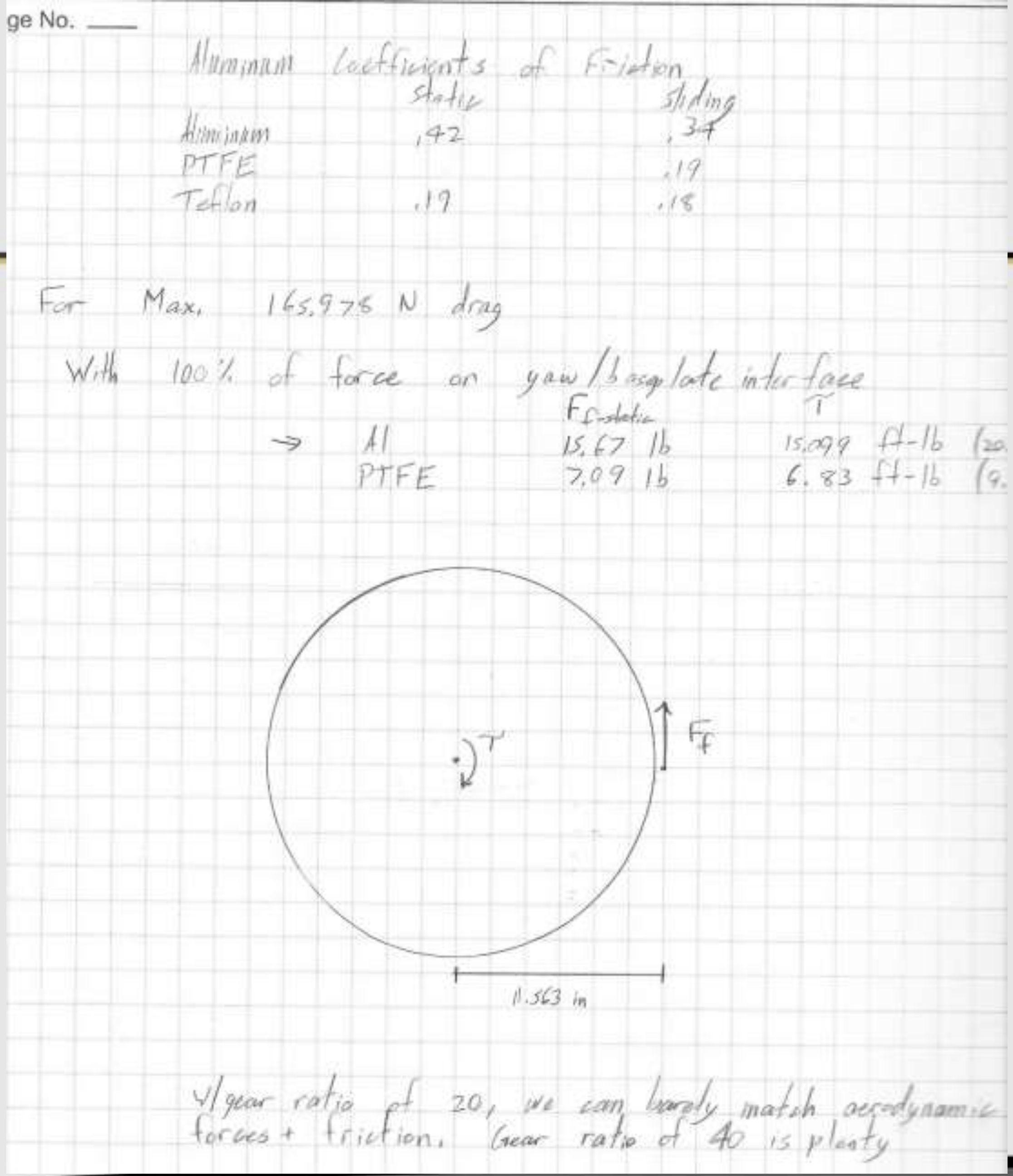
$= .75$

We'll use 4 screws anyway

Update - long screws will bend too much

Use Gear Plate design

# Yaw Plate Friction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Aluminum Coefficients of Friction

| | Static | Sliding |
|---|---|---|
| Aluminum | .42 | .34 |
| PTFE | | .19 |
| Teflon | .19 | .18 |

For Max. 165.978 N drag

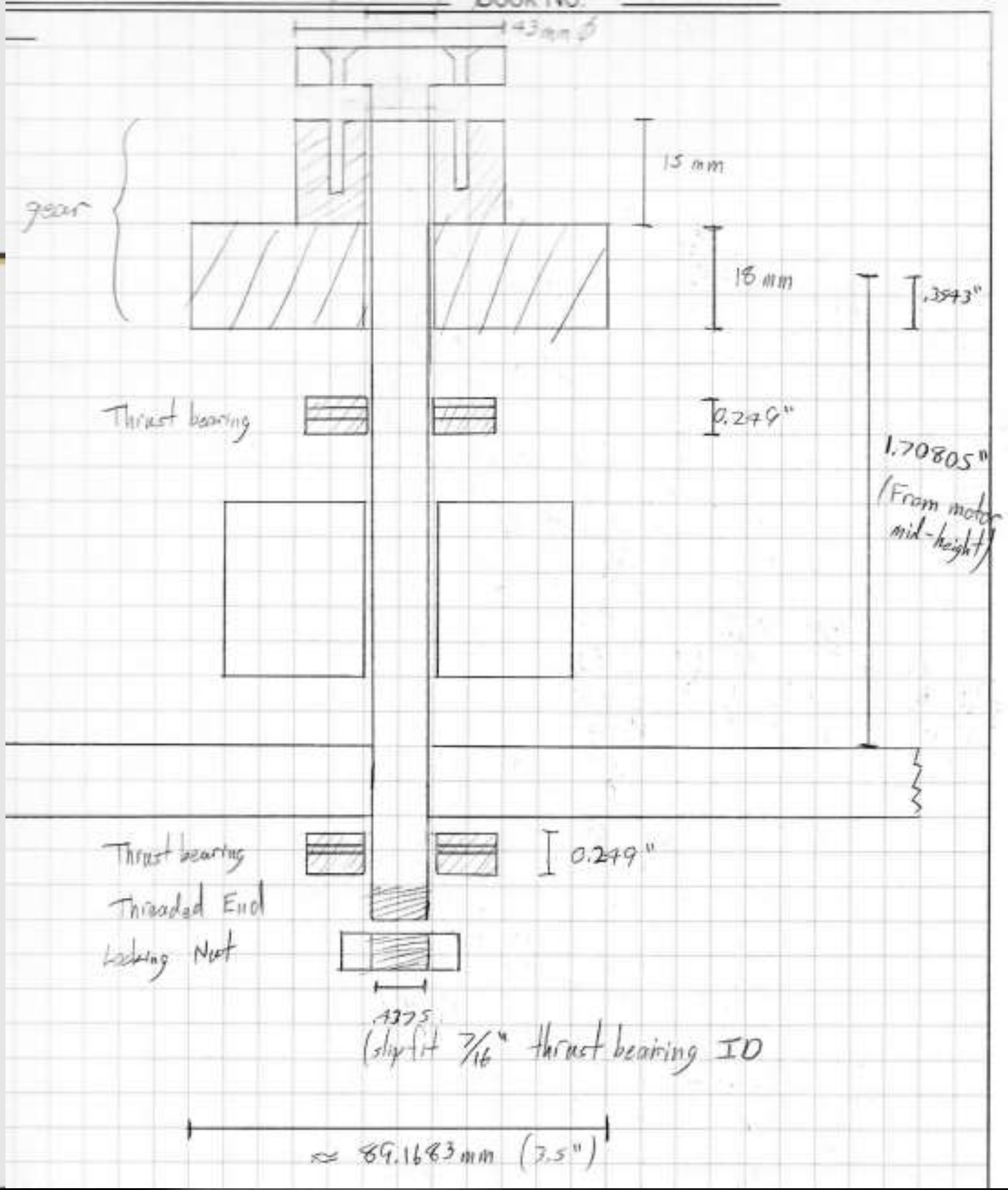
With 100% of force on yaw/baseplate interface

| | | $F_{f\text{-static}}$ | $T$ |
|---|---|---|---|
| → | Al | 15.67 lb | 15.099 ft-lb (20. |
| | PTFE | 7.09 lb | 6.83 ft-lb (9. |

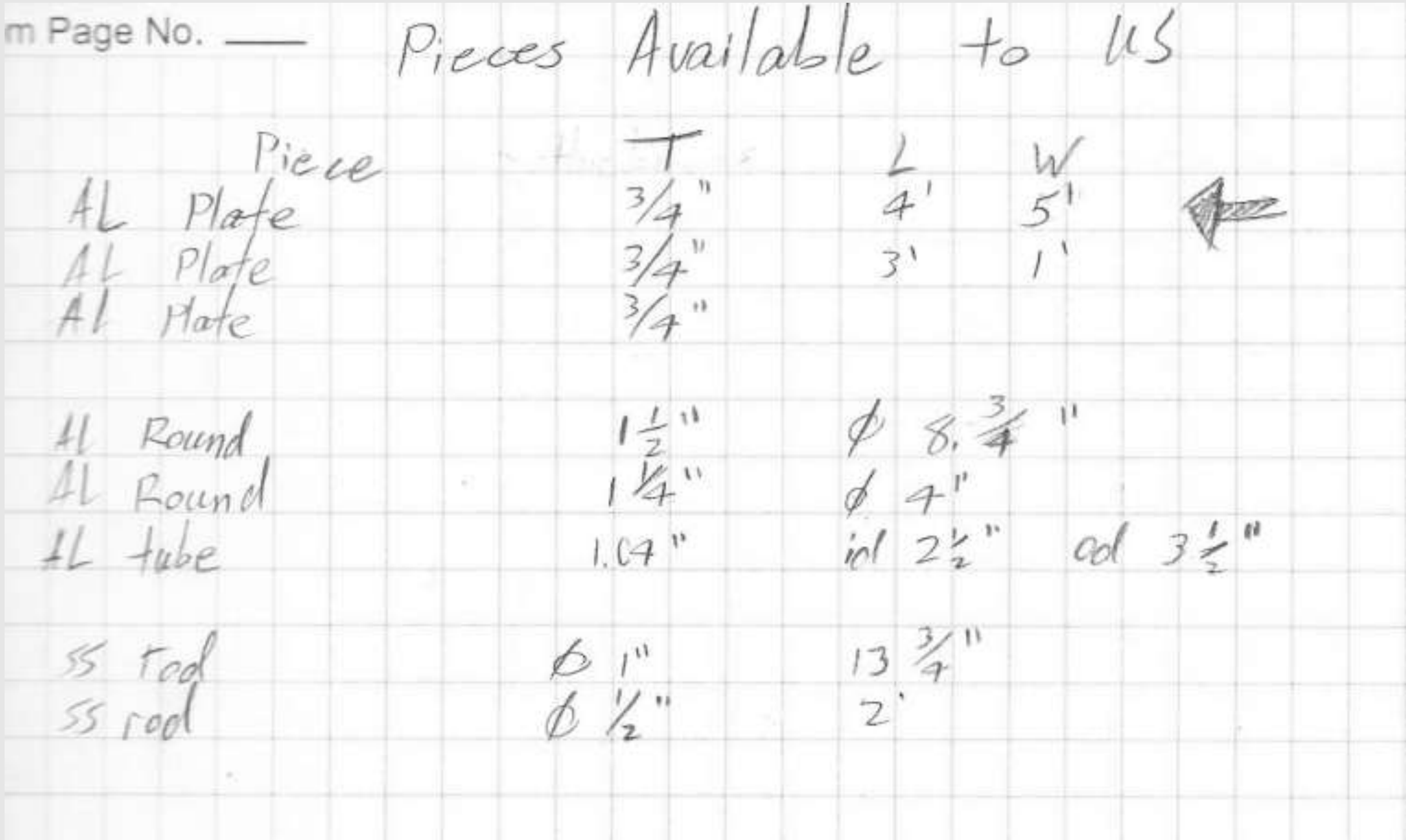


w/ gear ratio of 20, we can barely match aerodynamic forces + friction. Gear ratio of 40 is plenty

# Yaw Sandwich



# Available Parts



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Pieces Available to us

| Piece | T | L | W |
|---|---|---|---|
| AL Plate | 3/4" | 4' | 5' |
| AL Plate | 3/4" | 3' | 1' |
| Al Plate | 3/4" | | |
| Al Round | 1 1/2" | ϕ 8 3/4" | |
| Al Round | 1 1/4" | ϕ 4" | |
| AL tube | 1.04" | id 2 1/2" | od 3 1/2" |
| SS rod | ϕ 1" | 13 3/4" | |
| SS rod | ϕ 1/2" | 2' | |

# Linear Bearing



LME25UUAJ adjustable Linear Motion Ball Bushing works with 25mm shafts, this is an adjustable sealed linear ball bushing, with the inner diameter of 25mm, outer Diameter of 40mm, and a length of 58mm, the LME25UUAJ can be used in many CNC router applications like CNC wood router,plasma and any application that requires smooth linear motion and positioning.

- Item: LME25UUAJ Ball bushing
- Type: Adjustable ball bushing
- Closures: Double Sealed
- Number of Ball Circuit: 6
- Inner Diameter (shaft): 25mm
- Outer Diameter: 40mm
- Length: 58mm
- Dynamic load rating Cr: 980 N
- Static load rating Cor: 1570 N
- Most common applications: CNC routers
- Equals: LAG25x40x58.2RS, KBS2558PP and 0612-025-10

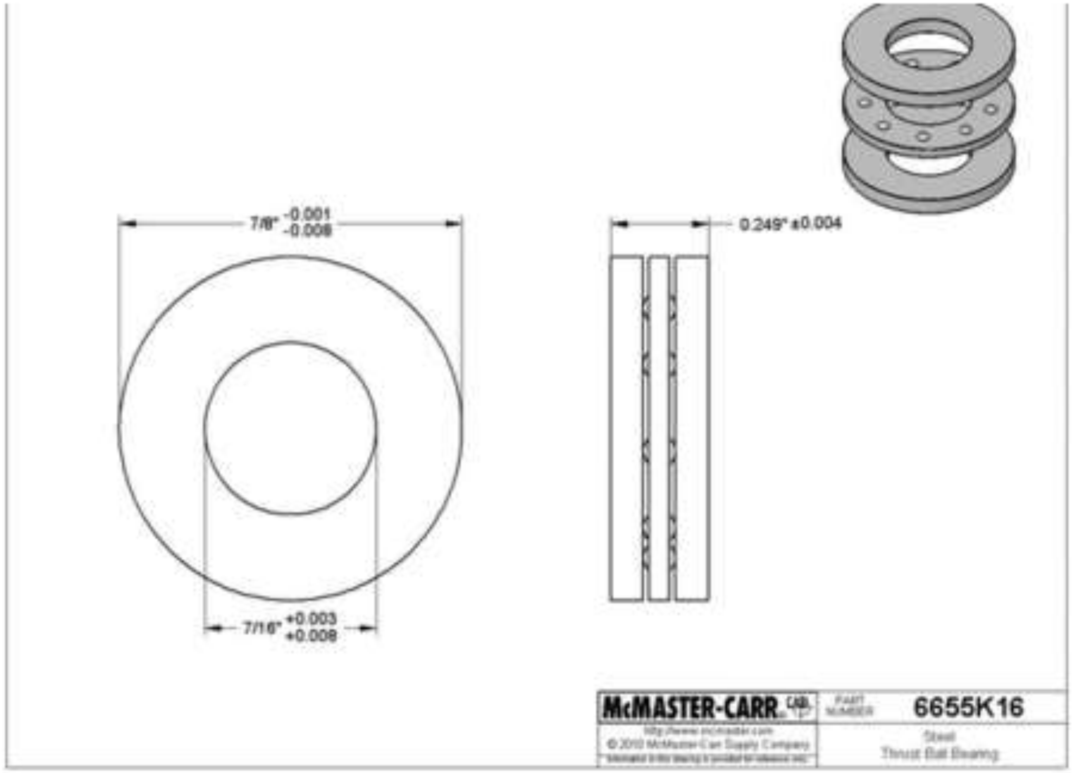
# Yaw Assembly Thrust Bearing

Each

ADD TO ORDER

In stock
$2.69 Each
6655K16

| | |
|---|---|
| Bearing Type | Ball |
| For Load Direction | Thrust |
| Ball Bearing Type | Thrust |
| Construction | Three Piece |
| For Shaft Shape | Round |
| Shaft Mount Type | Press Fit |
| For Shaft Diameter | 7/16" |
| ID | 0.438" |
| ID Tolerance | 0.0030" to 0.0080" |
| OD | 7/8" |
| OD Tolerance | -0.0010" to -0.0080" |
| Thickness | 0.249" |
| Thickness Tolerance | -0.004" to 0.004" |
| Material | Plastic |
| Lubrication | Required |
| Maximum Speed | 2,500 rpm |
| Temperature Range | -40° to 220° F |
| ABEC Rating | Not Rated |
| Washer Material | Steel |
| Ball Material | Steel |
| Dynamic Thrust Load Capacity | 30 lbs. |
| RoHS | Compliant |




The information in this 3-D model is provided for reference only. Details

# Sting Assembly Thrust Bearing


Thrust Needle Roller Bearing

- Item: Thrust Needle Roller Bearing
- Size: 1/4" x 11/16" x 9/64" inch
- Quantity: One Bearing
- Dynamic load rating: 1,370 LBF
- Static load rating: 3,000 LBF

# Radial Bearing

R188 Open Ball Bearing, R188 is a popular size that could be used in many application that uses this size 1/4" x 1/2" x 1/8" inch. Bearing is made of Chrome Steel.

- Item: R188 Ball Bearing
- Type: Deep Groove Ball Bearing
- Closures: Open
- Size: 1/4" x 1/2" x 1/8" inch
- Inner Diameter: 1/4" inch
- Outer Diameter: 1/2" inch
- Width: 1/8" inch
- Dynamic load rating: 108.2 KGF
- Static load rating: 44.2 KGF
- Most commom application: Associated RC500 (GAS) 4WD
- Quantity: One Bearing

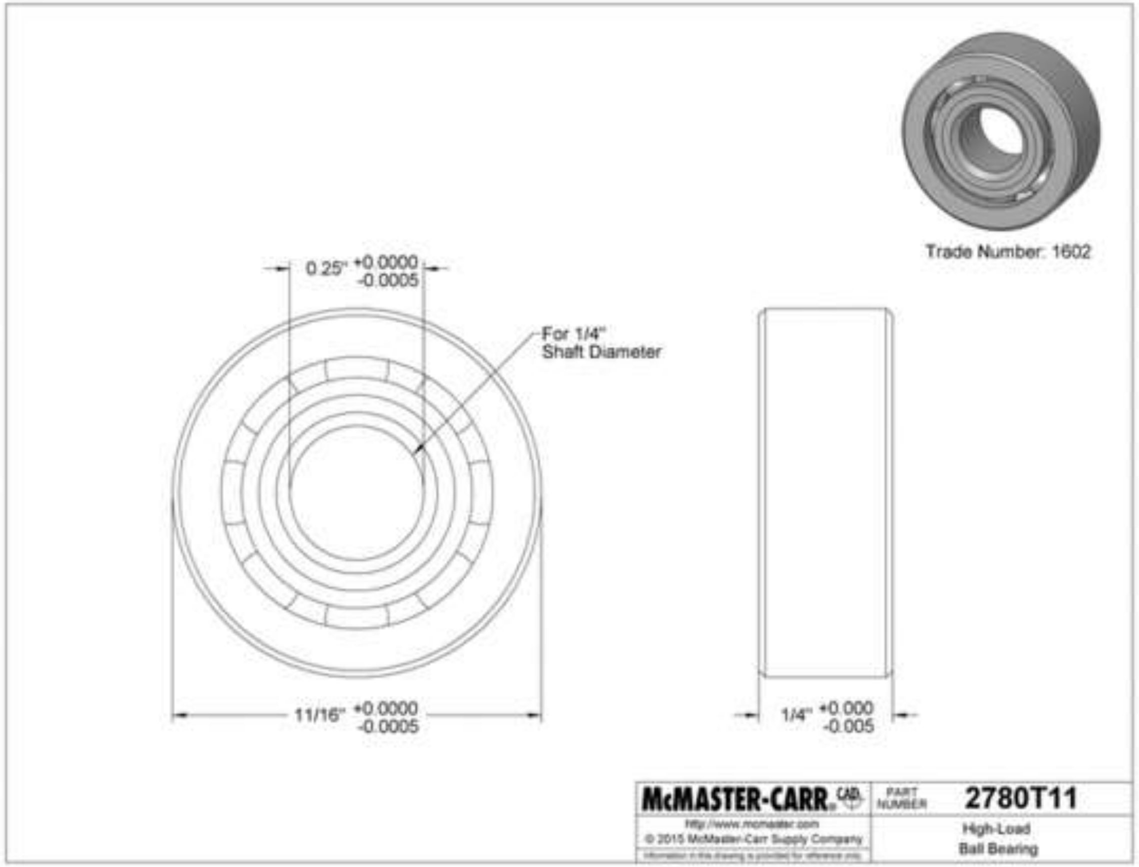
# Stronger, Bigger, Expensiver Radial Bearing

Each

ADD TO ORDER

In stock
$12.70 Each
2780T11

| | |
|---|---|
| Bearing Type | Ball |
| For Load Direction | Radial |
| Ball Bearing Type | Standard |
| Construction | Single Row |
| Seal Type | Open |
| For Shaft Shape | Round |
| Trade No. | 1602 |
| For Shaft Diameter | 1/4" |
| ID | 0.25" |
| ID Tolerance | -0.0005" to 0" |
| OD | 11/16" |
| OD Tolerance | -0.0005" to 0" |
| Width | 1/4" |
| Width Tolerance | -0.005" to 0" |
| Material | 52100 Steel |
| Ball Material | Steel |
| Cage Material | Plastic |
| Radial Load Capacity, lbs. | |
| Dynamic | 510 |
| Static | 170 |
| Maximum Speed | 5,000 rpm |
| Shaft Mount Type | Press Fit |
| Lubrication | Lubricated |
| Lubrication Method | Filled |
| Lubricant Type | Grease |
| Lubricant | Shell Alvania EP2 |
| Temperature Range | -20° to 250° F |

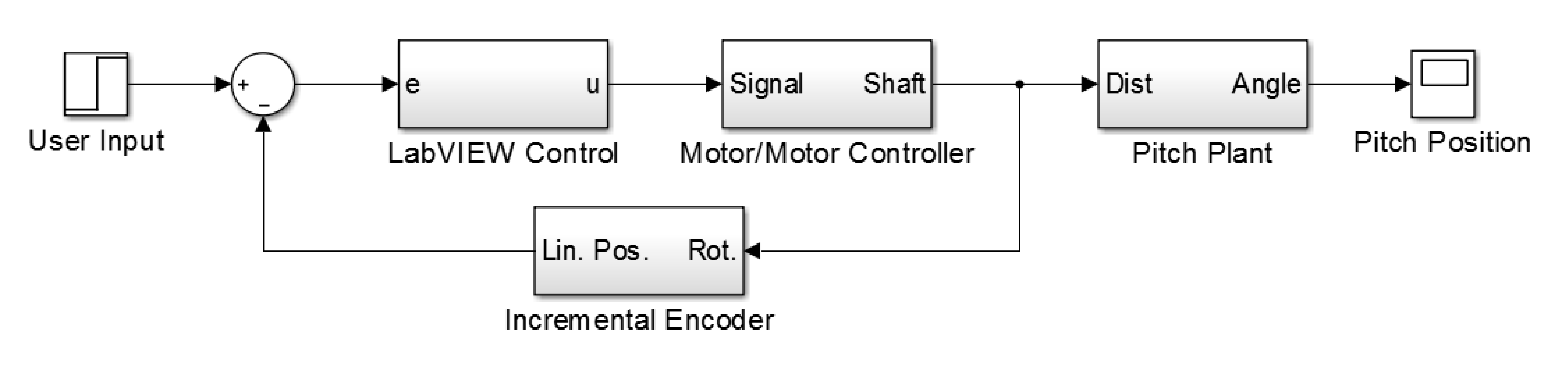



The information in this 3-D model is provided for reference only. Details

# Simulink Back-Up Slides

# Overview of Pitch Model

- Still in development and have equations of motion
- Placement of feedback loop different from yaw model

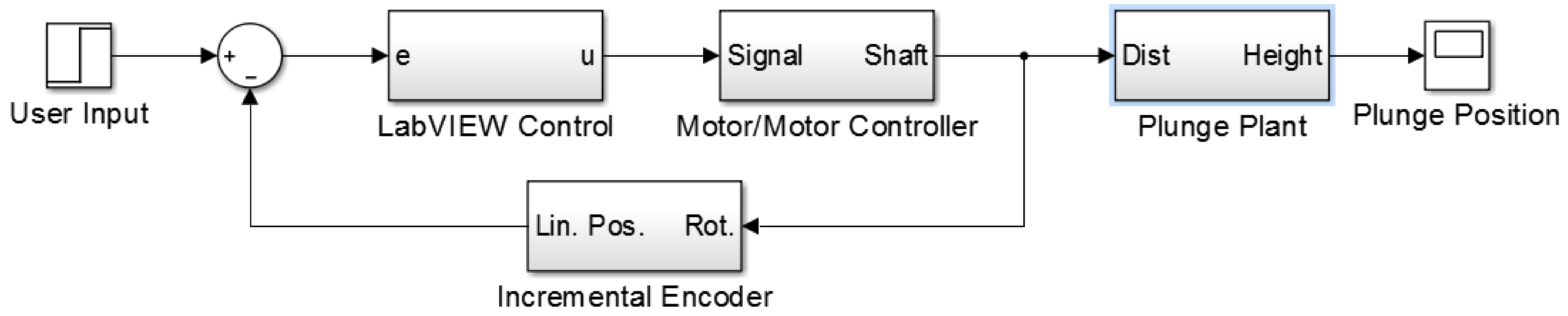





University of Colorado at Boulder

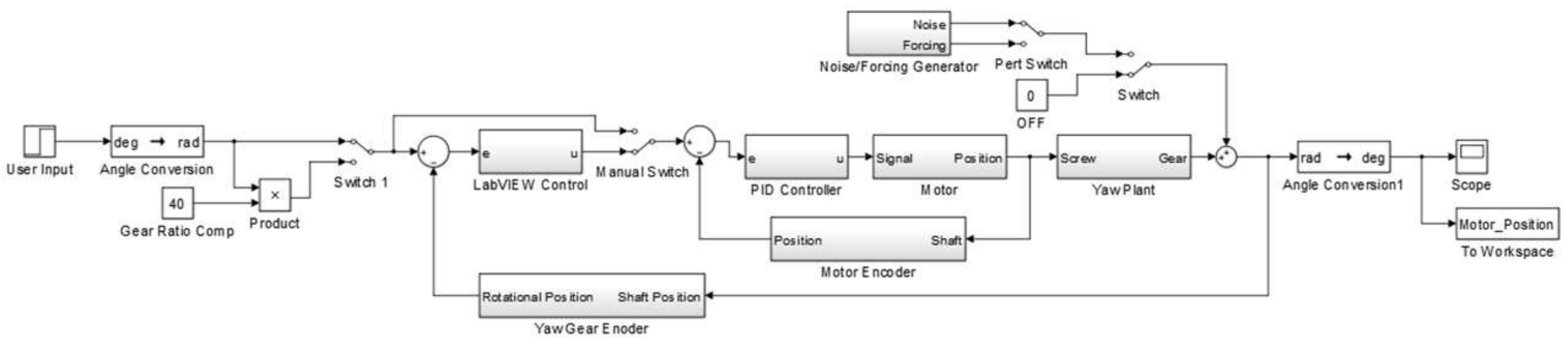
# Overview of Plunge Model

- Very similar to the pitch model
- Placement of feedback loop different from yaw model



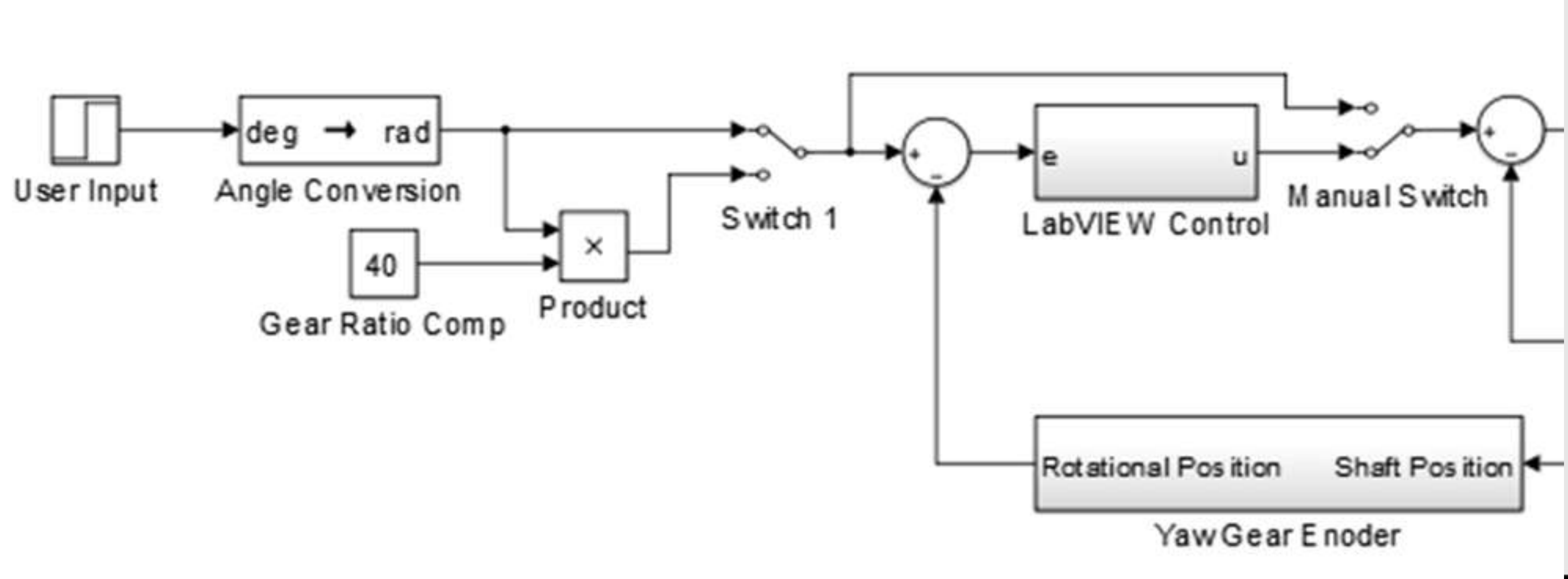
# Detailed System Model

- Detailed breakdown of Yaw DOF model



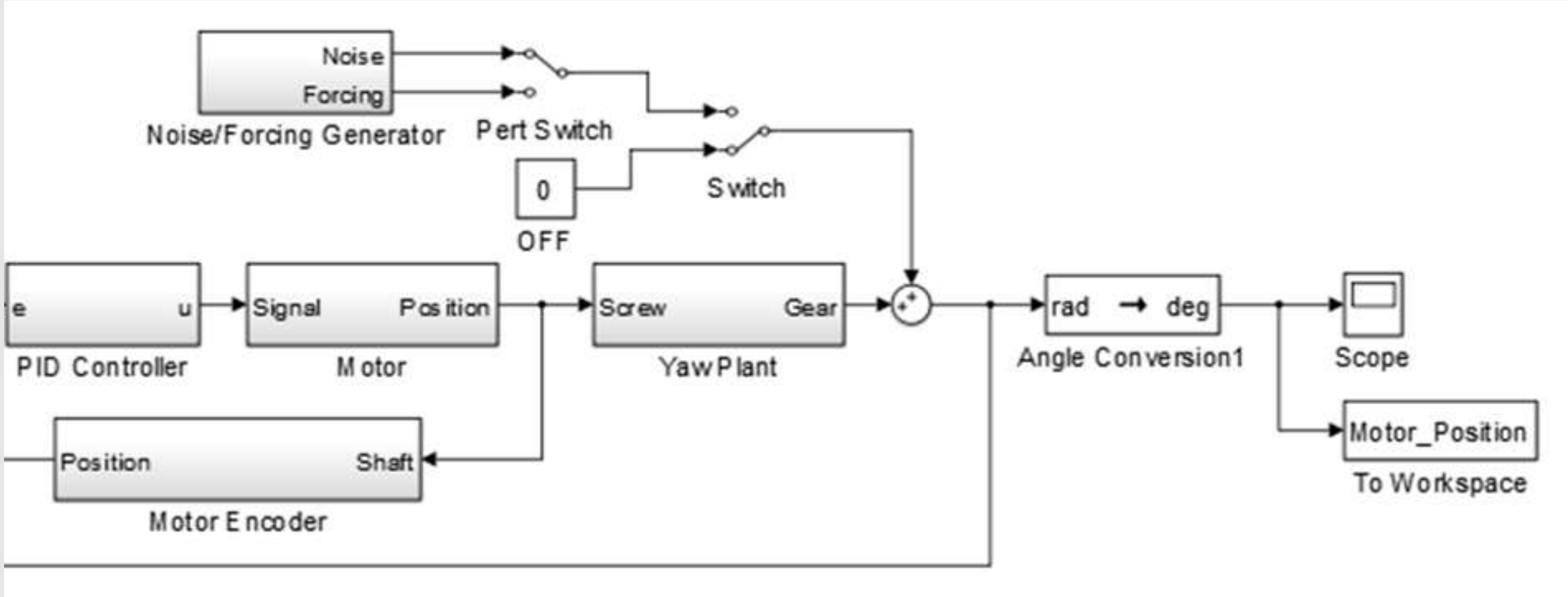
# System Model Major Sections

- Front-end of the simulation
  - Accounts for hardware external of motor/motor controller subsystems
  - Accounts for LabVIEW control loop



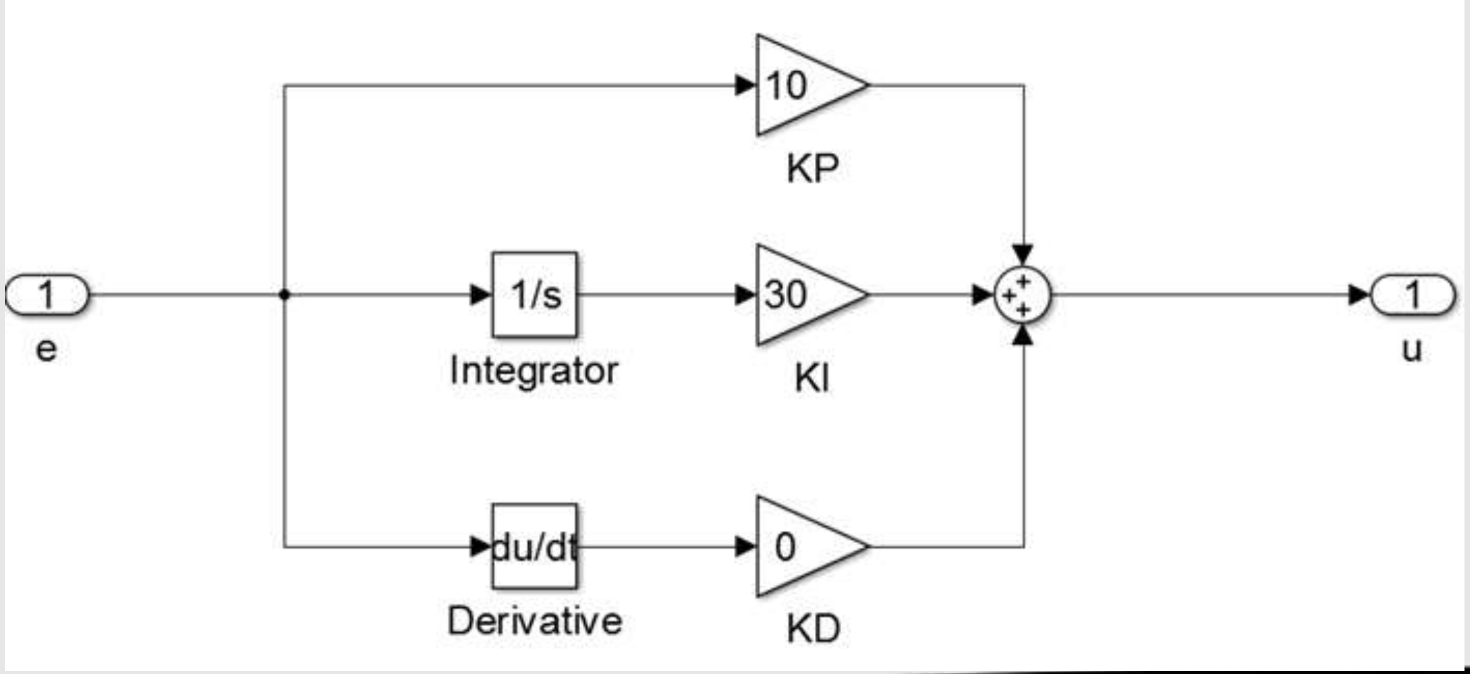
# System Model Major Sections

- Back-end of the simulation
  - Incorporates motor/motor controller subsystem
  - Accounts for perturbations and possible sources of error



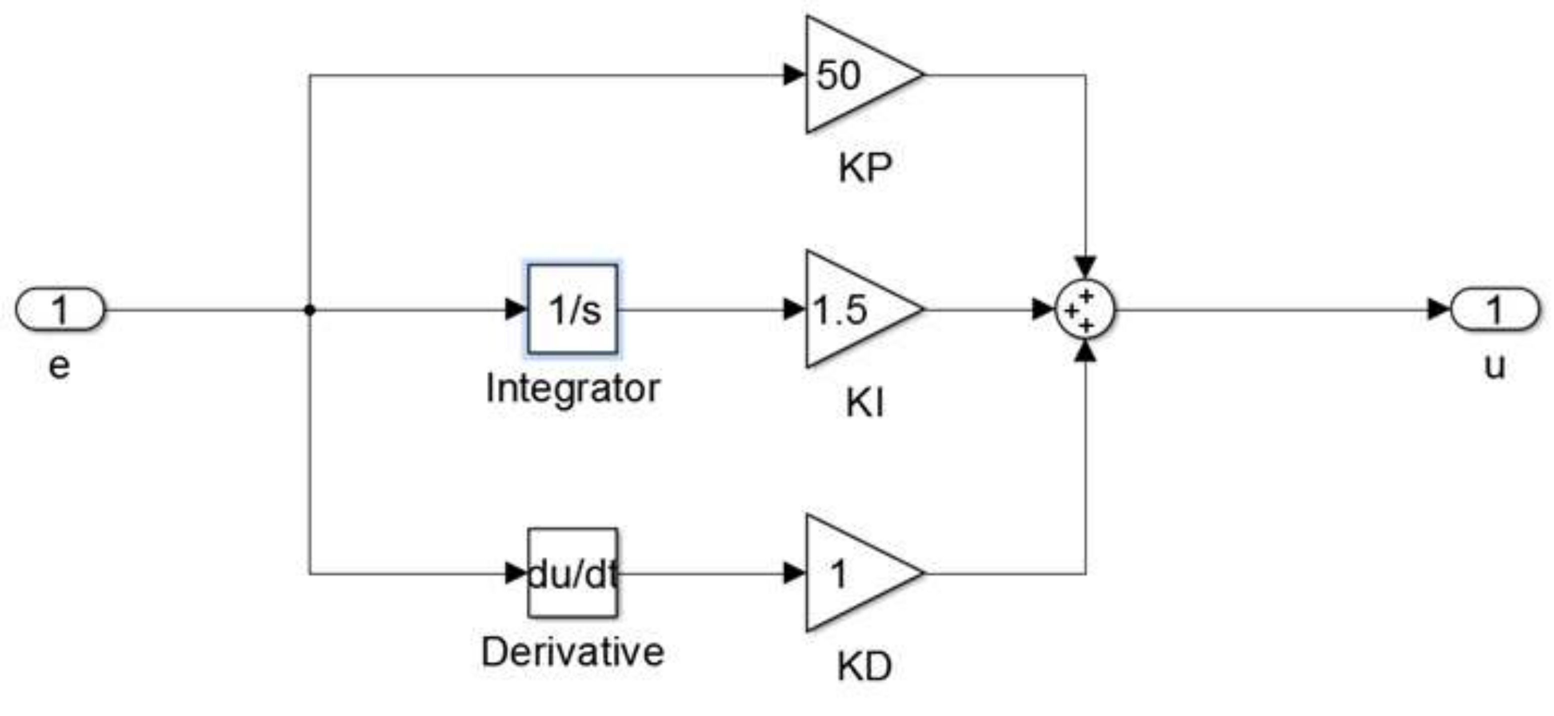
# Motor Control

- Adjustable LabVIEW control law
- Gains adjusted to observe settling time and overshoot
- Aiming to explore response of the motor controller system



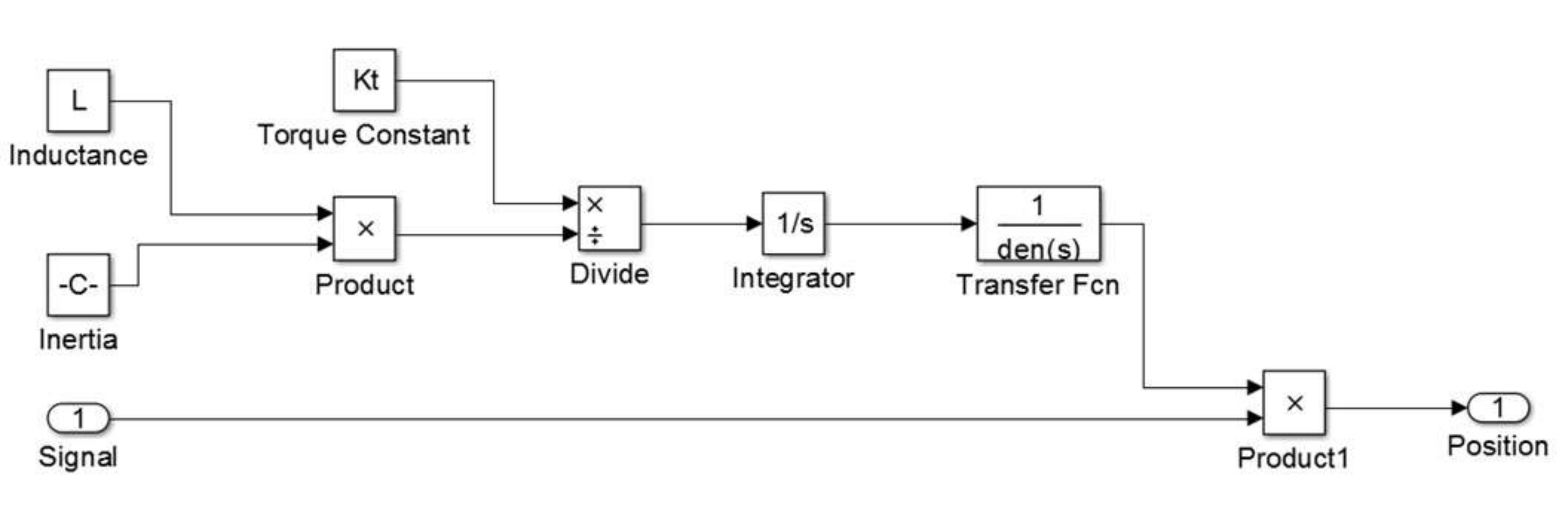
# Simulink Elements (PID Controller)

- Motor Controller with assumed PID Control
- KP = 50, KI = 1.5, KD = 1



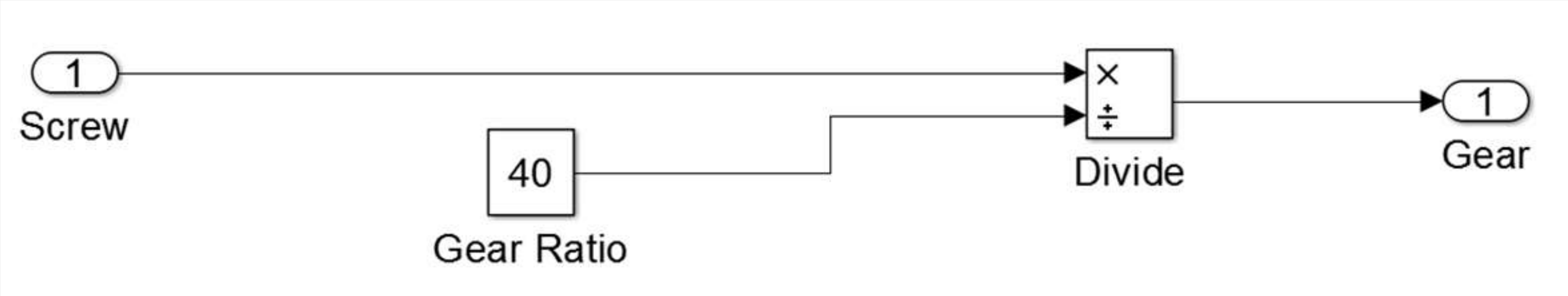
# Simulink Elements (DC Motor)

- Motor values based upon Teknic Servo Motor and assumptions
- Transfer function for DC motor built in Simulink
- L = 0.002 H, R = 1 Ohm, Kt = 0.423 N-m/A, Kb = 1 V/rad/s, J = 0.7882 kg-m^2



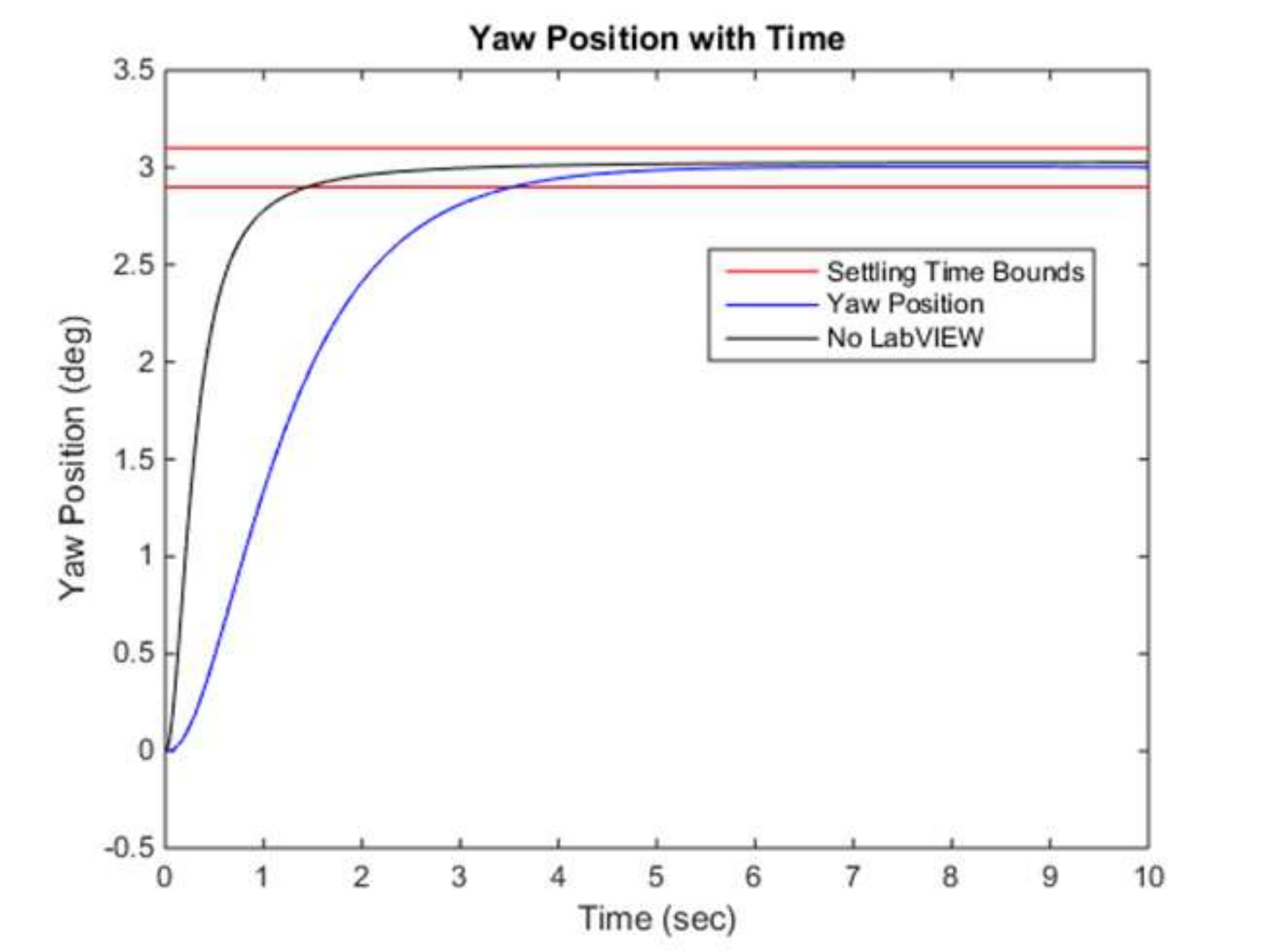
# Simulink Elements (Yaw Plant)

- Used to account for gearing ratio between worm screw and worm gear
- Inertia of yaw plate account for in DC Motor inertia
- Future versions to include frictions and gear efficiencies



# Backup Simulation Results

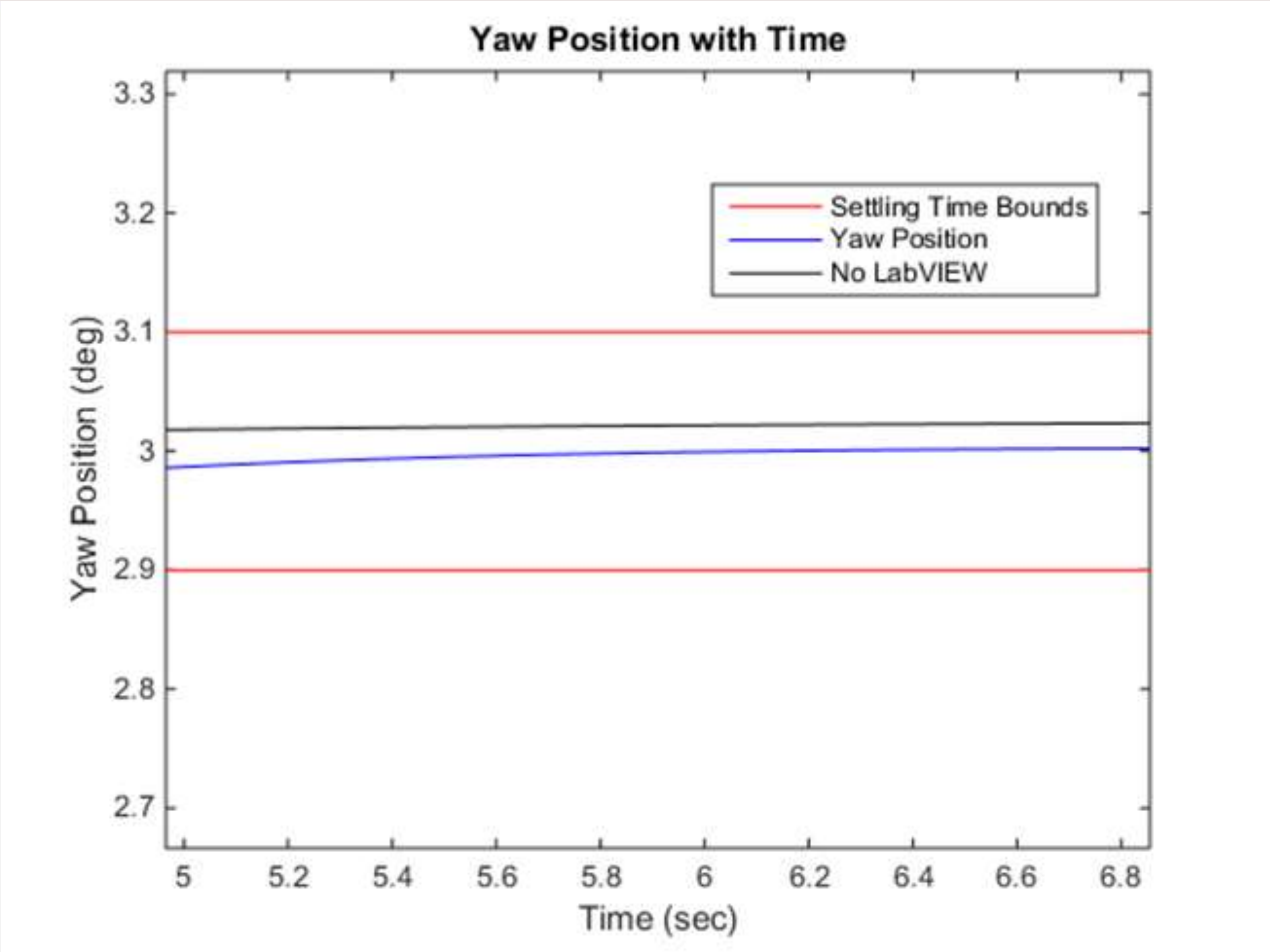
- Settling: ± 0.1°
- Range: 3°
- KP = 0, KI = 30, KD = 10
- Settling Time: 3.54 sec
- Overshoot: 0%



# Backup Simulation Results

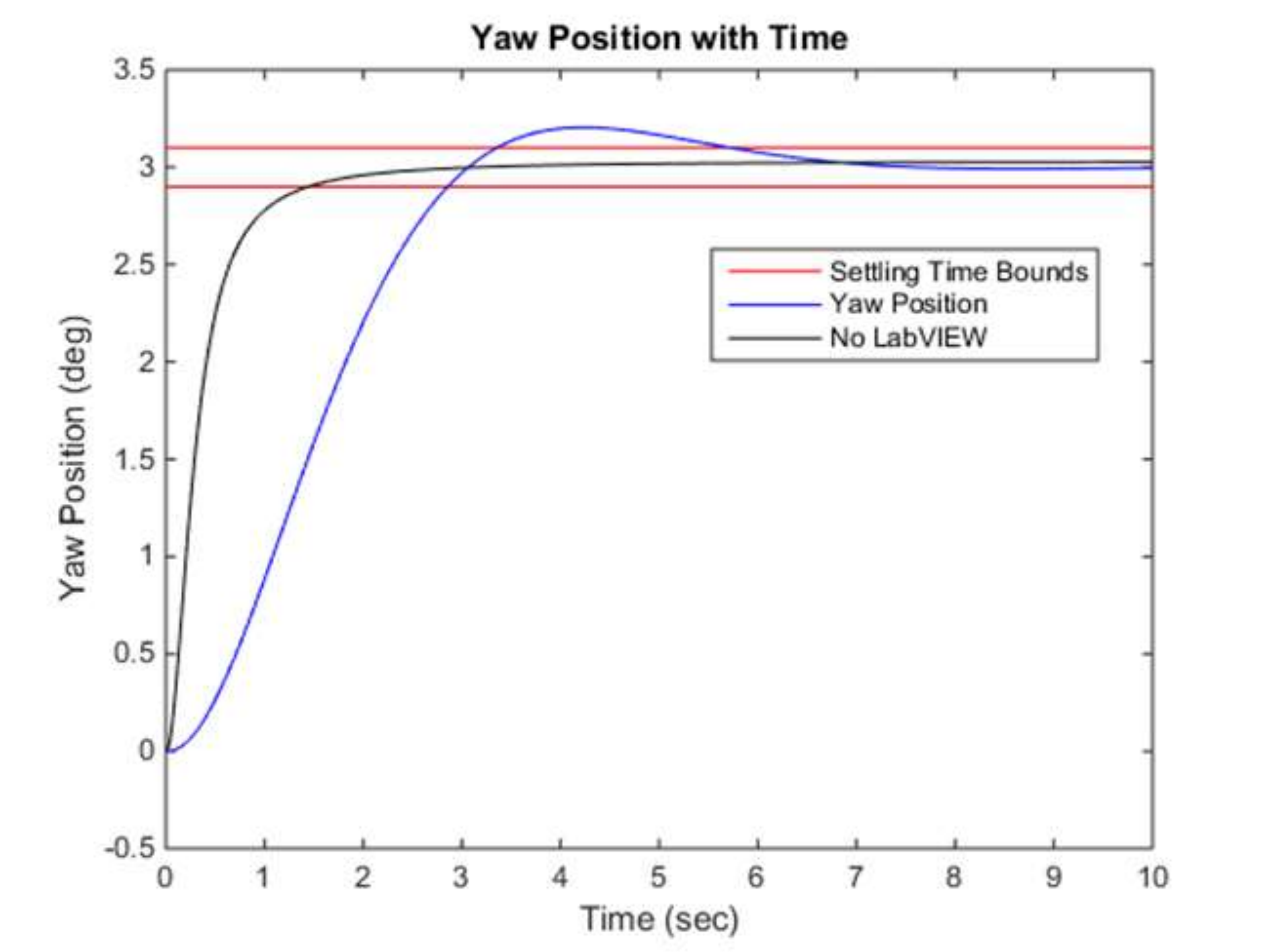
- Settling: ± 0.1°
- Range: 3°
- KP = 0, KI = 30, KD = 10
- Settling Time: 3.54 sec
- Overshoot: 0%

- Demonstrates need for integral control to decrease time to target



# Backup Simulation Results

- Settling: ± 0.1°
- Range: 3°
- KP = 0, KI = 30, KD = 30
- Settling Time: 5.73 sec
- Overshoot: 6.7%



# Risk Analysis Back-up Slides

# Primary Operational Risks

**Consequence**

| Acceptable | Tolerable | Intolerable |
|---|---|---|

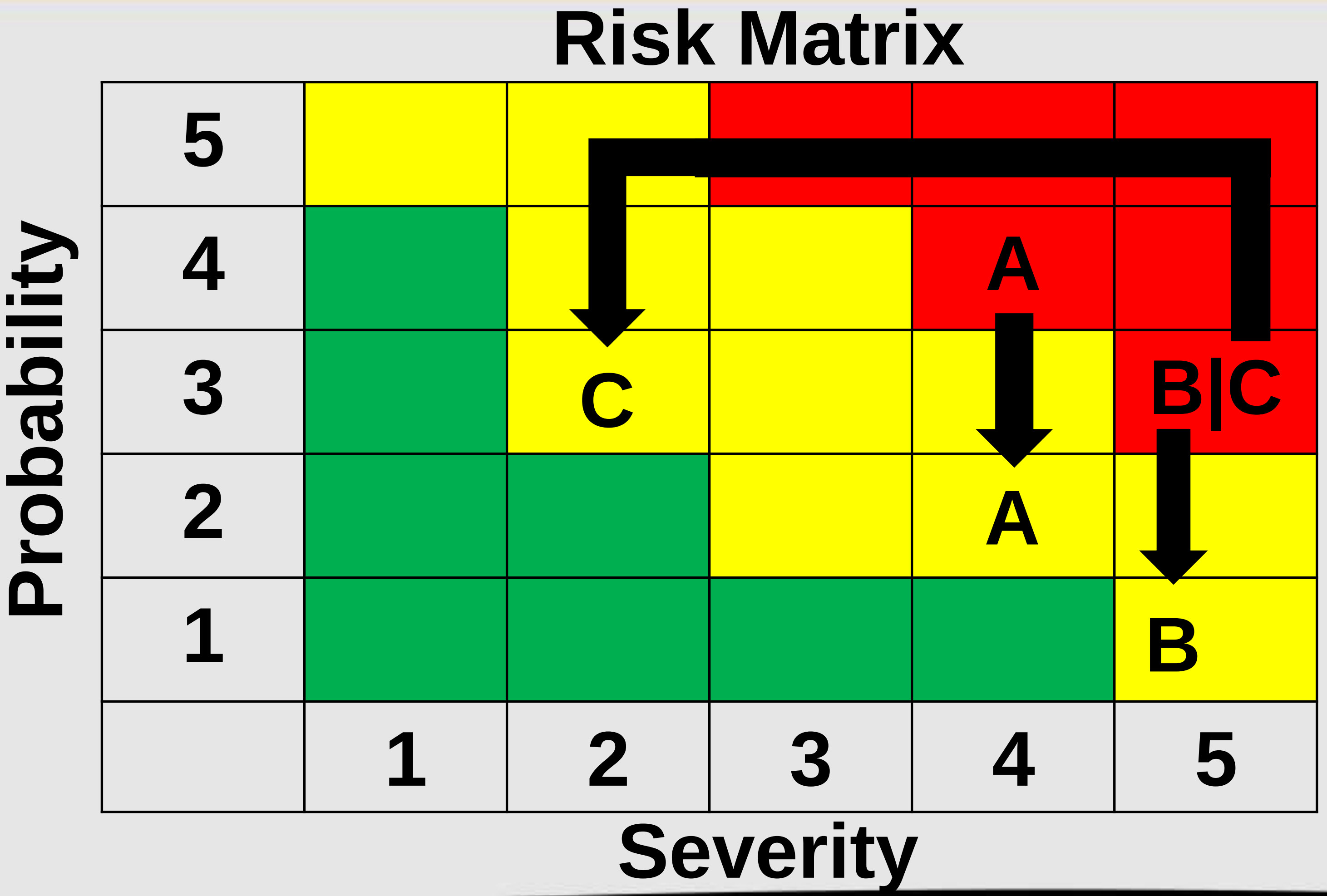
**A**: Bending

- Linear actuator, sting

**B**: Shearing/Buckling

- Sting body, sting pins, bolts, and actuator brackets

**C**: LabVIEW Crash




See Backup Slides for remaining operational and logistical risks

# Primary Operational Risk Mitigation

| Risk | Mitigation |
|---|---|
| **A:** Bending | Bending of sting and actuators characterized<br>See Backup Slides |
| **B:** Shearing/Buckling<br>- Sting body, bolts and pins | Material and dimensions designed for factor of safety (S.F.) = 2<br>See Backup Slides for S.F. and margin calculations |
| **C:** LabVIEW crash | Use of limit switches within linear actuators, manual emergency stop, and physical limit on yaw gear range |

# Motor Operational Risk

**Consequence**

| Acceptable | Tolerable | Intolerable |
|---|---|---|

**A:** Power Failure
**B:** Overheating
**C:** Contamination
**D:** Adequate Lubrication
**E:** Power Supply Anomalies
**F:** Back-EMF

**Pre-Mitigation Risk Matrix**

| Probability | | | | | |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | | | |
| 3 | C | | | B | |
| 2 | | | D | E\|F | |
| 1 | | | | | A |
| | 1 | 2 | 3 | 4 | 5 |
| | Severity | | | | |

**Post-Mitigation Risk Matrix**

| Probability | | | | | |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | | | |
| 3 | | B | | | |
| 2 | C | E | | | |
| 1 | | A | D | F | |
| | 1 | 2 | 3 | 4 | 5 |
| | Severity | | | | |

# Motor Operational Risk Mitigations

| **Risk** | **Mitigation** |
|---|---|
| **A:** Power Failure | Linear actuators with internal lead screw and worm gear are self-locking - able to hold load unpowered |
| **B:** Overheating | Over-speccing the motors such that they do not have to run at full capacity |
| **C:** Contamination | Sealed enclosure |
| **D:** Lubrication | Proper initial lubrication determined from manufacturer – maintenance every 2 years |
| **E:** Power Supply Anomalies | Voltage input monitored by LabVIEW |

# Linkages Operational Risk

| Consequence | | |
|---|---|---|
| Acceptable | Tolerable | Intolerable |

A: Shearing/Buckling

- Sting body, sting pins, bolts, actuator brackets

B: Bending

- Linear actuators, sting

C: Adequate Lubrication

- Yaw gear and motor, linear actuators

**Pre-Mitigation Risk Matrix**

| Probability | | | | | |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | | B | |
| 3 | | | | | A |
| 2 | | | C | | |
| 1 | | | | | |
| | 1 | 2 | 3 | 4 | 5 |

Severity

**Post-Mitigation Risk Matrix**

| Probability | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| 4 | | | | | |
| 3 | | | | | |
| 2 | | | | B | |
| 1 | | | C | | A |
| | 1 | 2 | 3 | 4 | 5 |

Severity

# Linkages Operational Risk Mitigations

| Risk | Mitigation |
|---|---|
| A: Shearing/Buckling<br>- Sting body, sting pins, bolts, actuator brackets | Material and dimensions designed for factor of safety (S.F.) = 2<br>See slides ??? for S.F. and margin calculations |
| B: Bending<br>- Linear actuators, sting | Bending of sting and actuators characterized |
| C: Lubrication<br>- Yaw gear and motor, linear actuators | Proper initial lubrication determined from manufacturer–maintenance every 2 years |

# Software Operational Risk

**Consequence**

| Acceptable | Tolerable | Intolerable |
|---|---|---|

A: LabVIEW crash

B: Invalid range input

C: Program interaction after start

**Pre-Mitigation Risk Matrix**

| Probability | | | | | |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | | | |
| 3 | | | | C | A |
| 2 | | | | | B |
| 1 | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| **Severity** | | | | | |

**Post-Mitigation Risk Matrix**

| Probability | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| 4 | | | | | |
| 3 | C | A | | | |
| 2 | | B | | | |
| 1 | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| **Severity** | | | | | |

# Software Operational Risk Mitigations

| Risk | Mitigation |
|---|---|
| A: LabVIEW crash | Use of limit switches within linear actuators, manual emergency stop, and physical limit on yaw gear range |
| B: Invalid range input | User protection coding implemented |
| C: Program interaction after start | Removal of interfaces upon execution of program (with the exception of STOP action) |

# Project Management Back-up Slides

# Work Breakdown Structure: Mechanical Subsystem

- 1 Mechanical Subsystem
  - 1.1 SolidWorks Model
    - 1.1.1 1st Draft
    - 1.1.2 2nd Draft
    - 1.1.3 Final Design
  - 1.2 Yaw Mechanism
    - 1.2.1 Specifications
    - 1.2.2 Machining test
    - 1.2.3 Machine component
    - 1.2.4 Test component
    - 1.2.5 Analyze test data
    - 1.2.6 Check off on component
  - 1.3 Pitch/Plunge Mechanism
    - 1.3.1 Specifications
    - 1.3.2 Machining test
    - 1.3.3 Machine component
    - 1.3.4 Test component
    - 1.3.5 Analyze test data
    - 1.3.6 Check off on component
  - 1.4 Roll Mechanism
    - 1.4.1 Specifications
    - 1.4.2 Machining test
    - 1.4.3 Machine component
    - 1.4.4 Test component
    - 1.4.5 Analyze test data
    - 1.4.6 Check off on component
  - 1.5 Base Plate
    - 1.5.1 Specifications
    - 1.5.2 Machining test
    - 1.5.3 Machine component
    - 1.5.4 Test component
    - 1.5.5 Analyze test data
    - 1.5.6 Check off on component
  - 1.6 Base Plate Interface
    - 1.6.1 Specifications
    - 1.6.2 Machining test
    - 1.6.3 Machine component
    - 1.6.4 Test component
    - 1.6.5 Analyze test data
    - 1.6.6 Check off on component
  - 1.7 Electronics Housing
    - 1.7.1 Specifications
    - 1.7.2 Machining test
    - 1.7.3 Machine component
    - 1.7.4 Test component
    - 1.7.5 Analyze test data
    - 1.7.6 Check off on component
  - 1.8 Sting
    - 1.8.1 Specifications
    - 1.8.2 Machining test
    - 1.8.3 Machine component
    - 1.8.4 Test component
    - 1.8.5 Analyze test data
    - 1.8.6 Check off on component

# Work Breakdown Structure: Software Subsystem

- 2 Software Subsystem
  - 2.1 Software Architecture
    - 2.1.1 Pseudo code draft 1
    - 2.1.2 Pseudo code draft 2
    - 2.1.3 Final pseudo code
  - 2.2 LabVIEW VI
    - 2.2.1 Main System VI
      - 2.2.1.1 VI Test
      - 2.2.1.2 Check off on VI
    - 2.2.2 Angle Calculation VI
      - 2.2.2.1 VI Test
      - 2.2.2.2 Check off on VI
    - 2.2.3 Home VI
      - 2.2.3.1 VI Test
      - 2.2.3.2 Check off on VI
    - 2.2.4 Wall Check VI
      - 2.2.4.1 VI Test
      - 2.2.4.2 Check off on VI
    - 2.2.5 System VI
      - 2.2.5.1 VI Test
      - 2.2.5.2 Check off on VI
    - 2.2.6 File Reader VI
      - 2.2.6.1 VI Test
      - 2.2.6.2 Check off on VI
    - 2.2.7 Input Check VI
      - 2.2.7.1 VI Test
      - 2.2.7.2 Check off on VI

# Work Breakdown Structure: Electrical Subsystem and Management

- 3 Electrical Subsystem
  - 3.1 Circuit Diagram
    - 3.1.1 1st Draft
      - 3.1.1.1 Data Acquisitions Sheet
      - 3.1.1.2 Circuit
    - 3.1.2 Final Diagram
    - 3.1.3 Complete Slides
  - 3.2 I/O Schematic
    - 3.2.1 1st Draft
    - 3.2.2 2nd Draft
    - 3.2.3 Final Version
- 4 Management
  - 4.1 Project Budget
    - 4.1.1 Component Trade Study
      - 4.1.1.1 Select components
    - 4.1.2 Budget Leaving Fall Semester
    - 4.1.3 Final Budget
  - 4.2 Project Timeline
    - 4.2.1
  - 4.3 Risk Analysis Matrix
    - 4.3.1 Logistics
    - 4.3.2 Safety
  - 4.4 Procure Components
    - 4.4.1 Order linear actuators
      - 4.4.1.1 Test component
      - 4.4.1.2 Analyze test data
      - 4.4.1.3 Check off on components
    - 4.4.2 Order yaw motor
      - 4.4.2.1 Test component
      - 4.4.2.2 Analyze test data
      - 4.4.2.3 Check off on component
    - 4.4.3 Order sensors
      - 4.4.3.1 Test component
      - 4.4.3.2 Analyze test data
      - 4.4.3.3 Check off on components
    - 4.4.4 Order material
      - 4.4.4.1 Test component
      - 4.4.4.2 Analyze test data
      - 4.4.4.3 Check off on component
    - 4.4.5 Order DAQs
      - 4.4.5.1 Test component
      - 4.4.5.2 Analyze test data
      - 4.4.5.3 Check off on component

# Work Breakdown Structure: Documentation

- 6 COMPASS Documentation
  - 6.1 User Manual
    - 6.1.1 1st Draft
    - 6.1.2 2nd Draft
    - 6.1.3 User Manual Testing
      - 6.1.3.1 Test
      - 6.1.3.2 Analyze test results
      - 6.1.3.3 Check off on user manual
    - 6.1.4 3rd Draft
    - 6.1.5 Final Document
  - 6.2 Calibration Manual
    - 6.2.1 1st Draft
    - 6.2.2 2nd Draft
    - 6.2.3 Calibration Manual Testing
      - 6.2.3.1 Test
      - 6.2.3.2 Analyze test results
      - 6.2.3.3 Check off on calibration manual
    - 6.2.4 3rd Draft
    - 6.2.5 Final Document
  - 6.3 Parts Specification
    - 6.3.1 Motor Specifications
      - 6.3.1.1 Drawings/Images
      - 6.3.1.2 Information about manufacture
    - 6.3.2 Controller Specifications
      - 6.3.2.1 Drawings/Images
      - 6.3.2.2 Information about manufacture
    - 6.3.3 Machined Parts Specifications
      - 6.3.3.1 Drawings/Images
      - 6.3.3.2 Manufacturing Techniques
    - 6.3.4 Electronics Specifications
      - 6.3.4.1 Drawings/Images
      - 6.3.4.2 Information about manufacture
  - 6.4 Interface Control Documents
    - 6.4.1 Computer to Motors
      - 6.4.1.1 1st Draft
      - 6.4.1.2 2nd Draft
      - 6.4.1.3 Final Version
    - 6.4.2 Motors to Moving Systems
      - 6.4.2.1 1st Draft
      - 6.4.2.2 2nd Draft
      - 6.4.2.3 Final Version
    - 6.4.3 Wind Tunnel to COMPASS system
      - 6.4.3.1 1st Draft
      - 6.4.3.2 2nd Draft
      - 6.4.3.3 Final Version

# Validation Back Up Slides

# VICON System

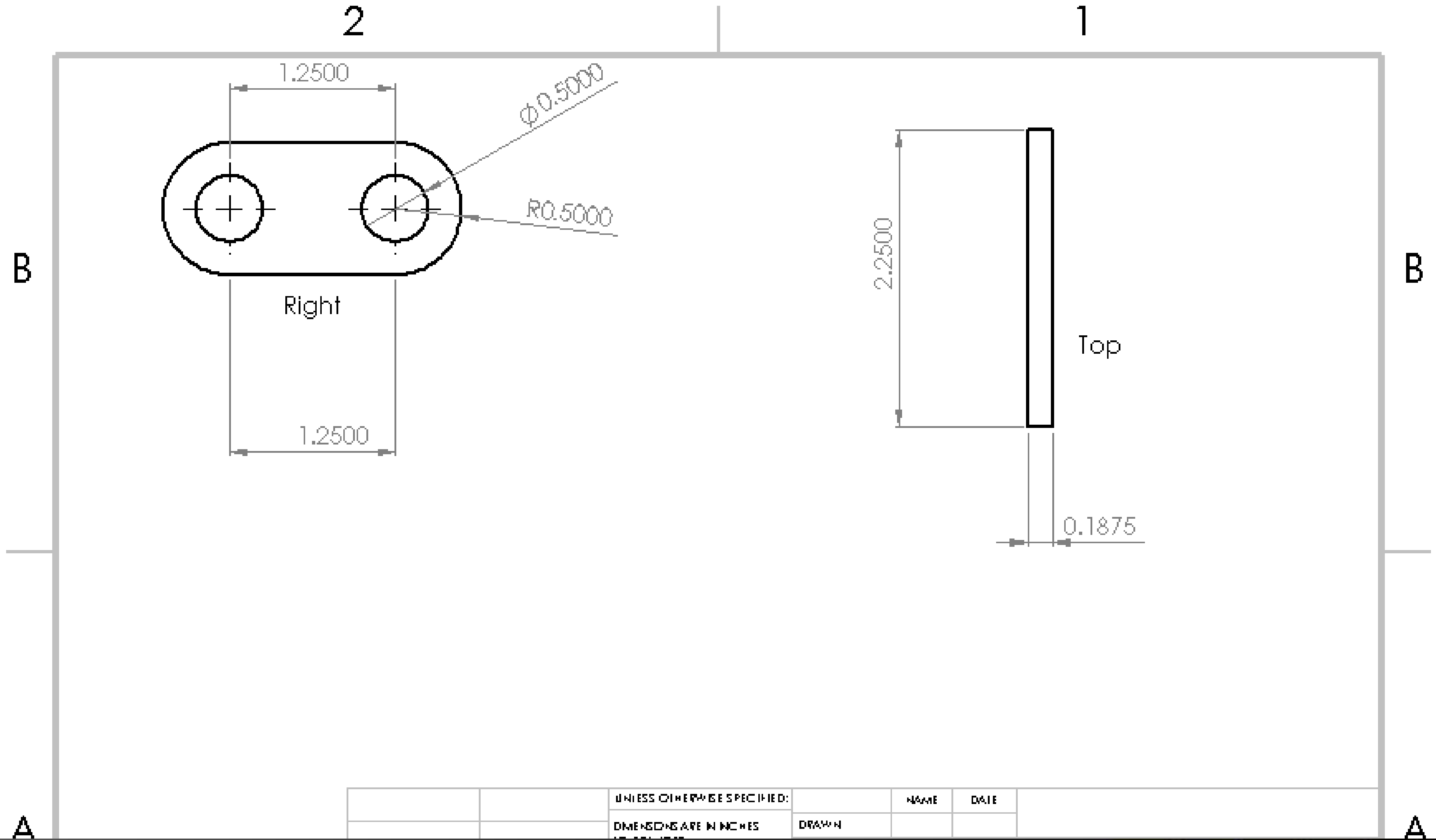
- High resolution motion capture system
- 9 mm nodes strategically placed on system
- Camera tracks nodes as they move
- Provides accurate measurements in translation and rotation

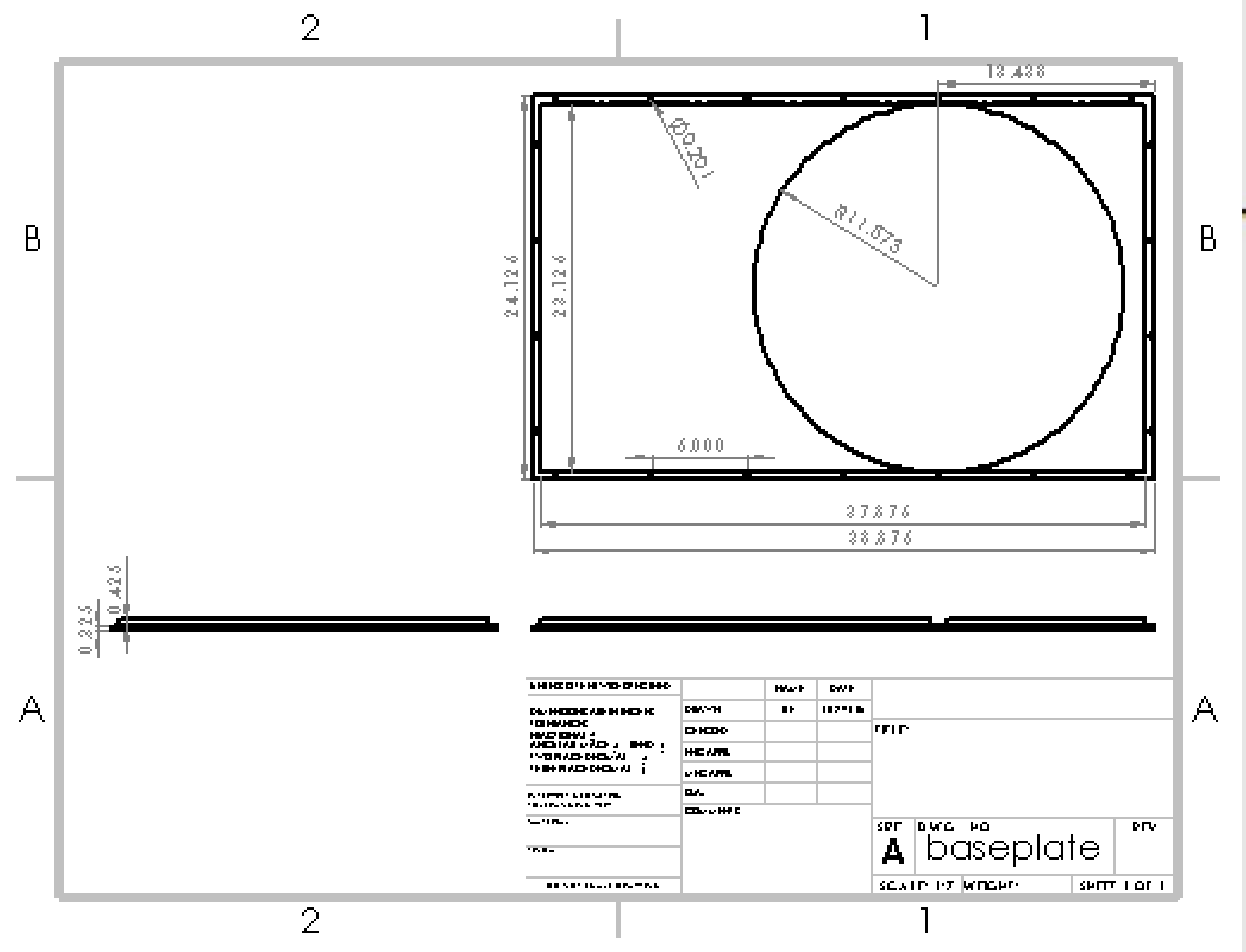
# VICON B10 Full System Test

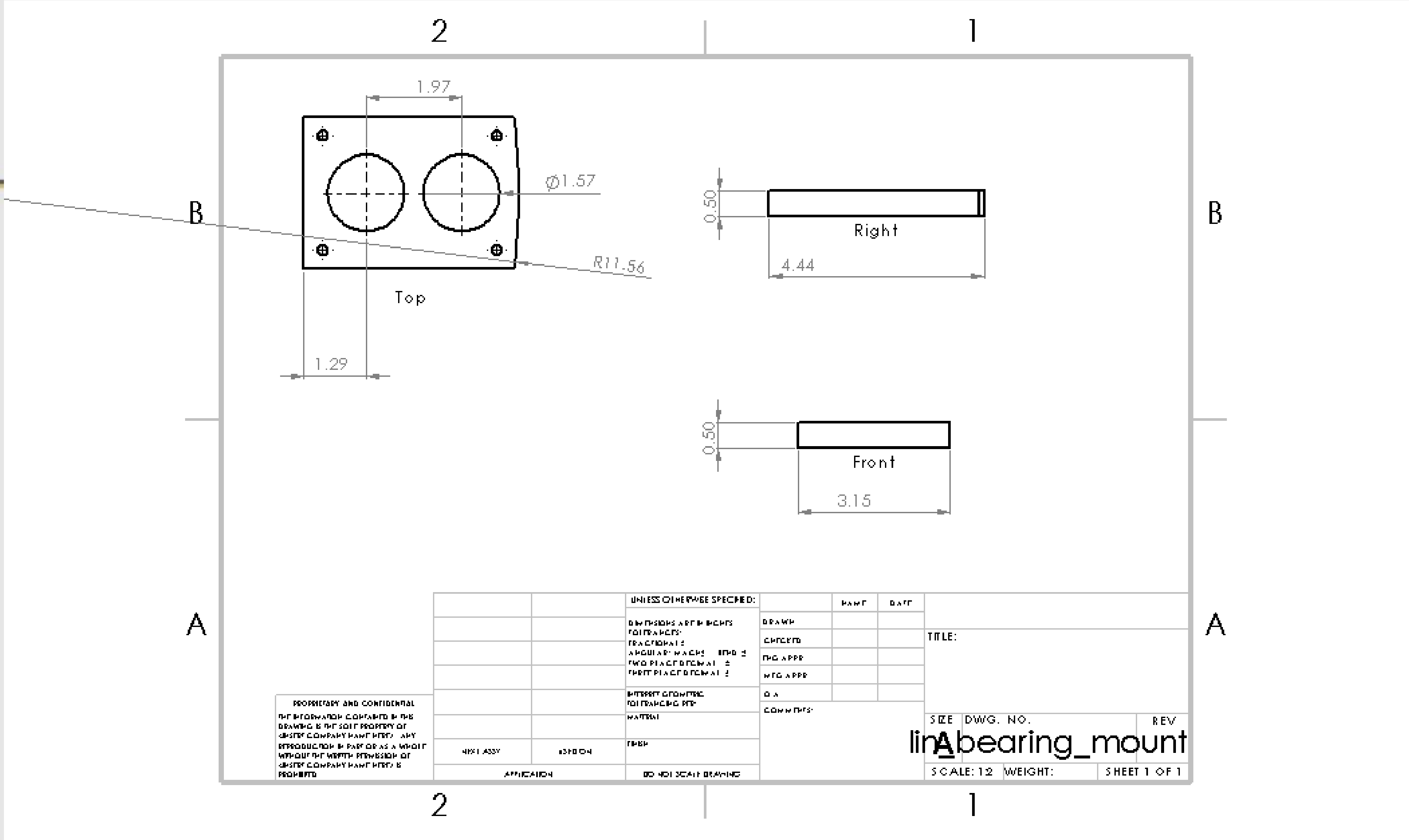
- **Main Objective:** Show accuracy/range within requirements in roll and plunge.
- **Requirements verified:** DR 1.2.3, 1.2.4, 1.2.5.3, 1.2.5.4
- **Location:** Idea Forge; CU Campus
- **General Procedure:** Place 9mm nodes onto COMPASS, command desired position. Obtain data from VICON and compare to test accuracy of COMPASS movement.
- **Systems Needed:** All

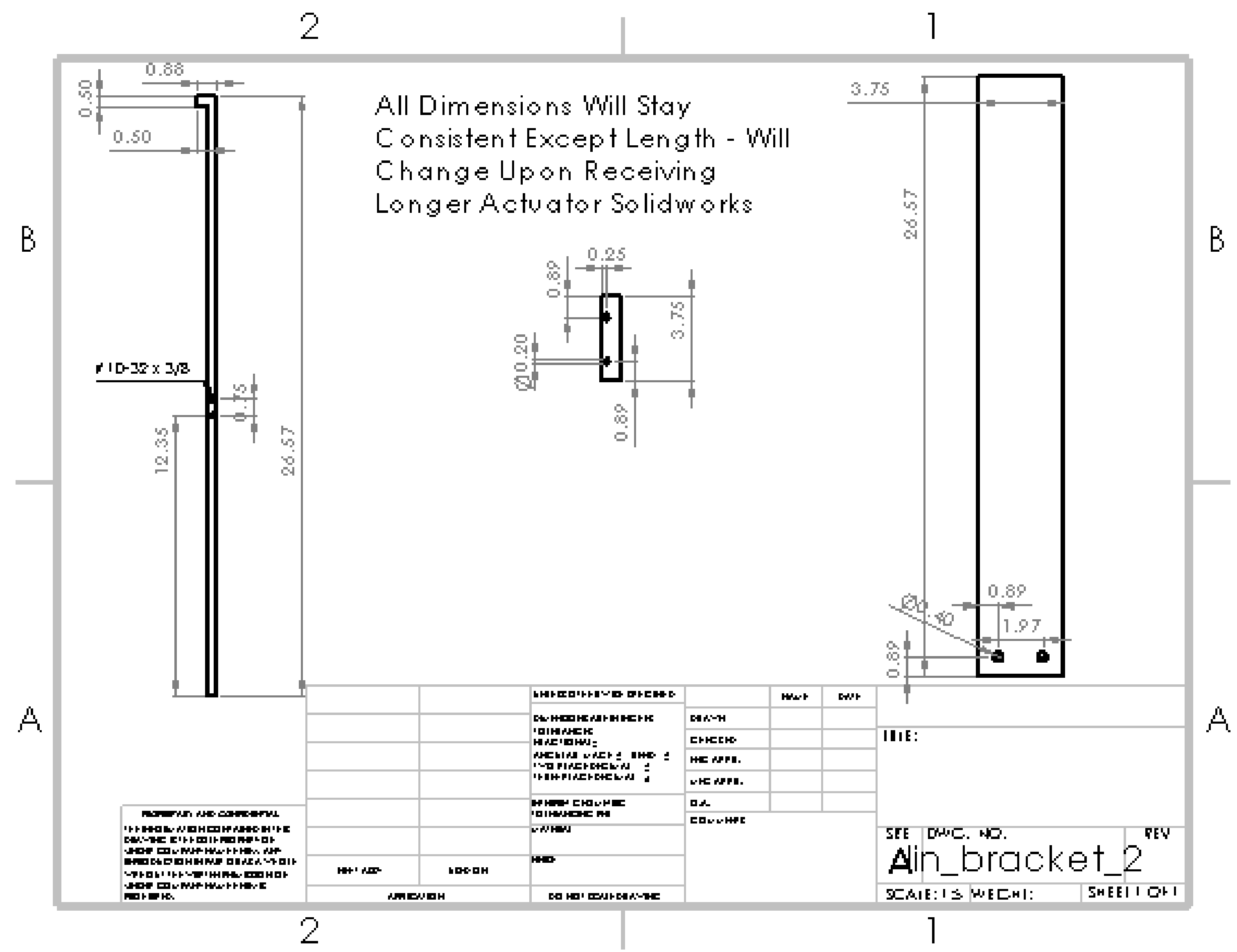
# VICON B10 Full System Test

- **VICON B10 can capture:**
- ± 0.5 mm of translation: **Validates Plunge** ✔
- ± 0.5 degrees of rotation:
- Pitch **X**
- Yaw **X**
- **Validates Roll** ✔

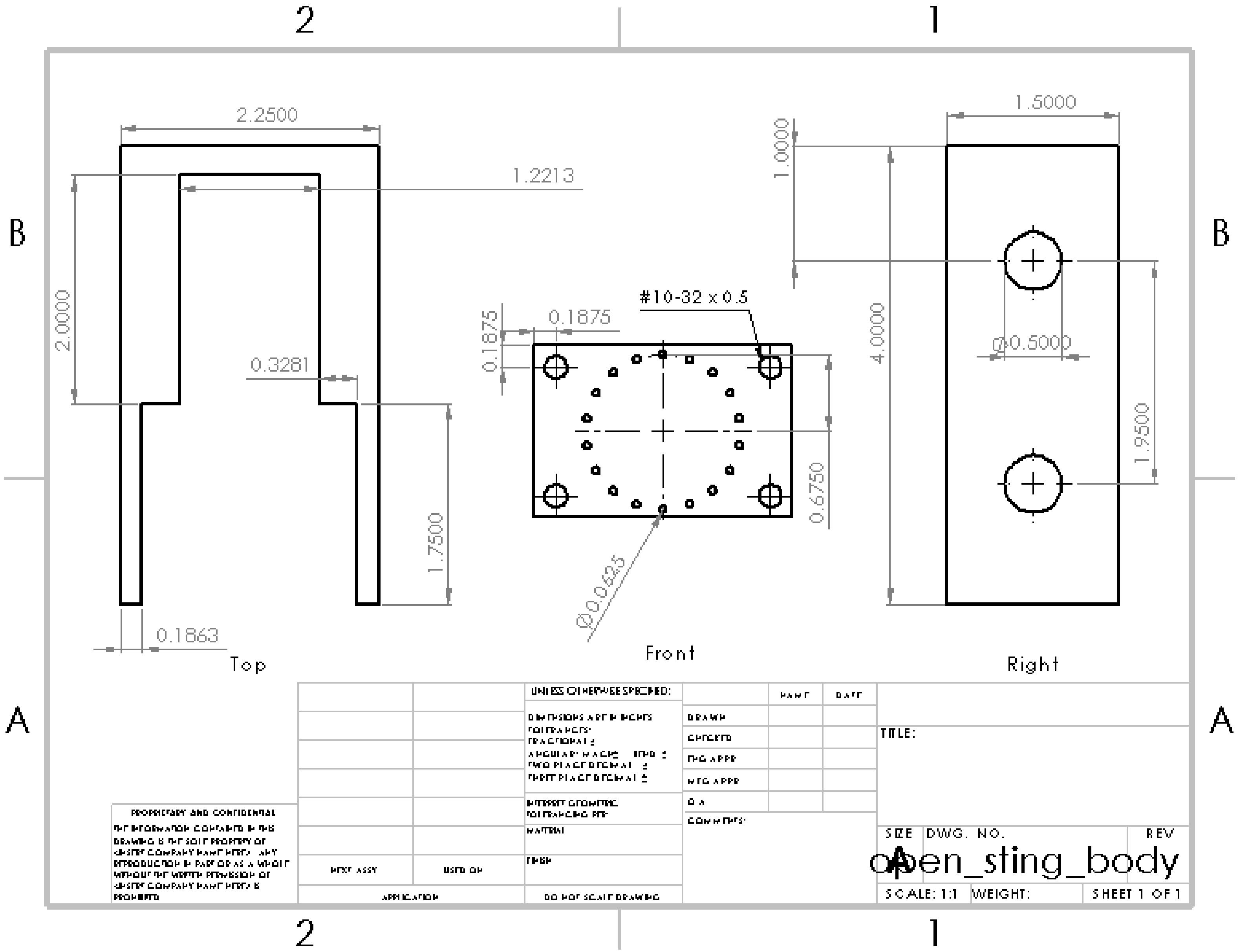

2
1
B
B
A
A
1.2500
Ø0.5000
R0.5000
Right
1.2500
2.2500
Top
0.1875
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN


13.438
Ø0.201
R11.573
24.126
23.126
6.000
37.876
38.876
0.425
0.225
TITLE:
SIZE
A
DWG. NO.
baseplate
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 1

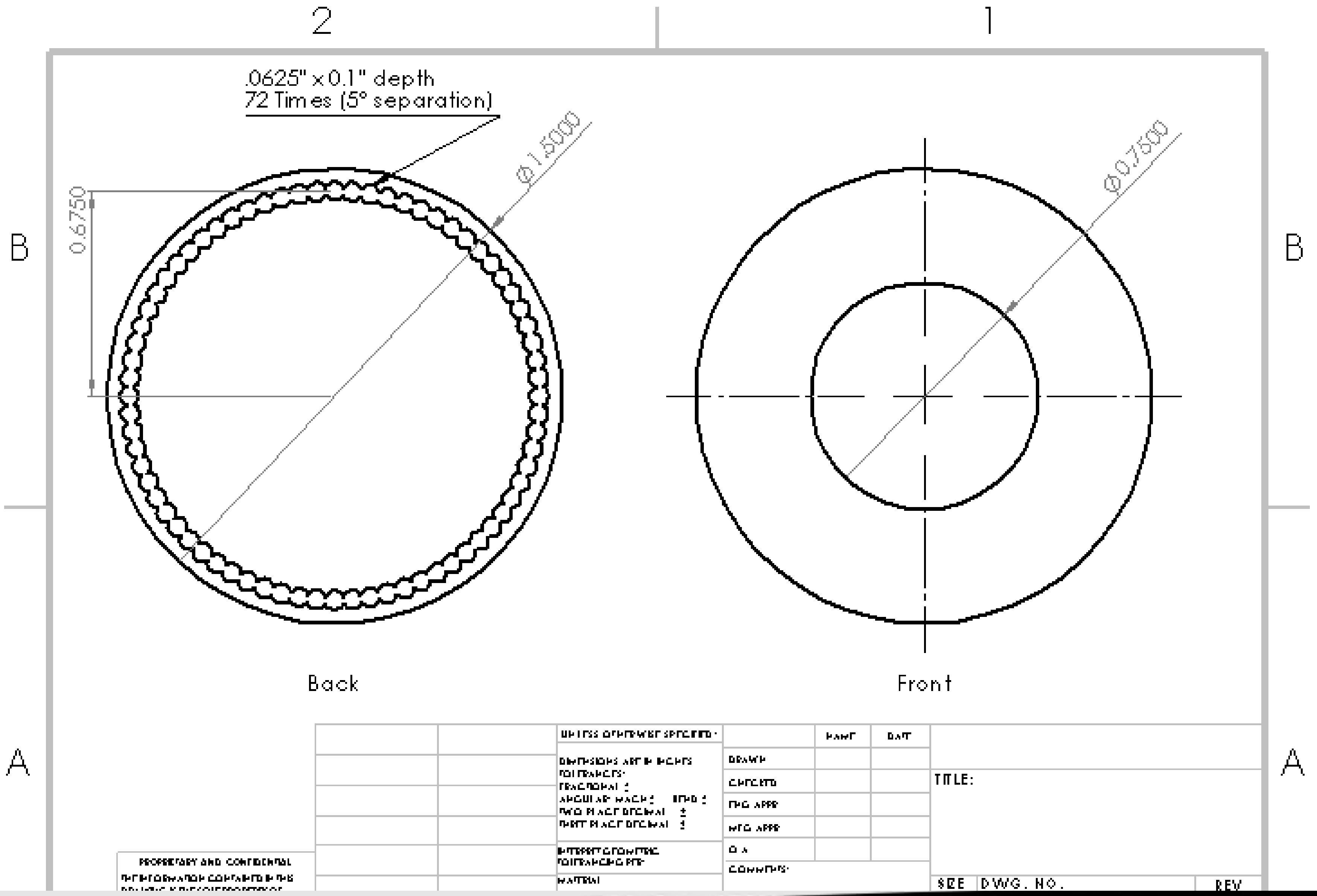

1.97
Ø1.57
R11.56
Top
1.29
0.50
Right
4.44
0.50
Front
3.15
TITLE:
SIZE
DWG. NO.
REV
linAbearing_mount
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH



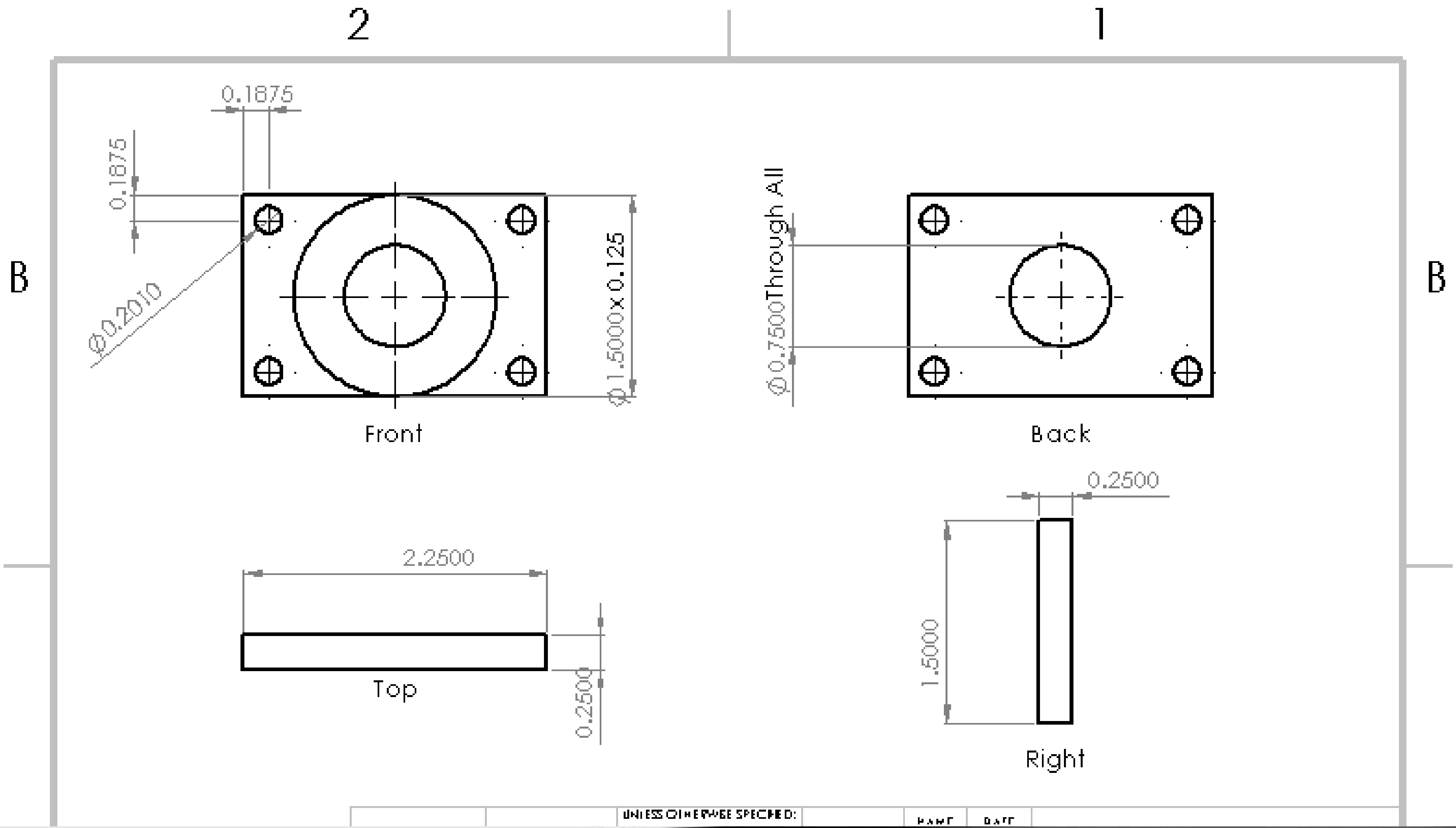
All Dimensions Will Stay Consistent Except Length - Will Change Upon Receiving Longer Actuator Solidworks
0.88
0.50
0.50
#10-32 x 3/8
0.75
12.35
26.57
0.25
0.89
3.75
Ø0.20
0.89
3.75
26.57
0.89
Ø0.40
1.97
0.89
TITLE:
DWG. NO.
REV
Alin_bracket_2
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

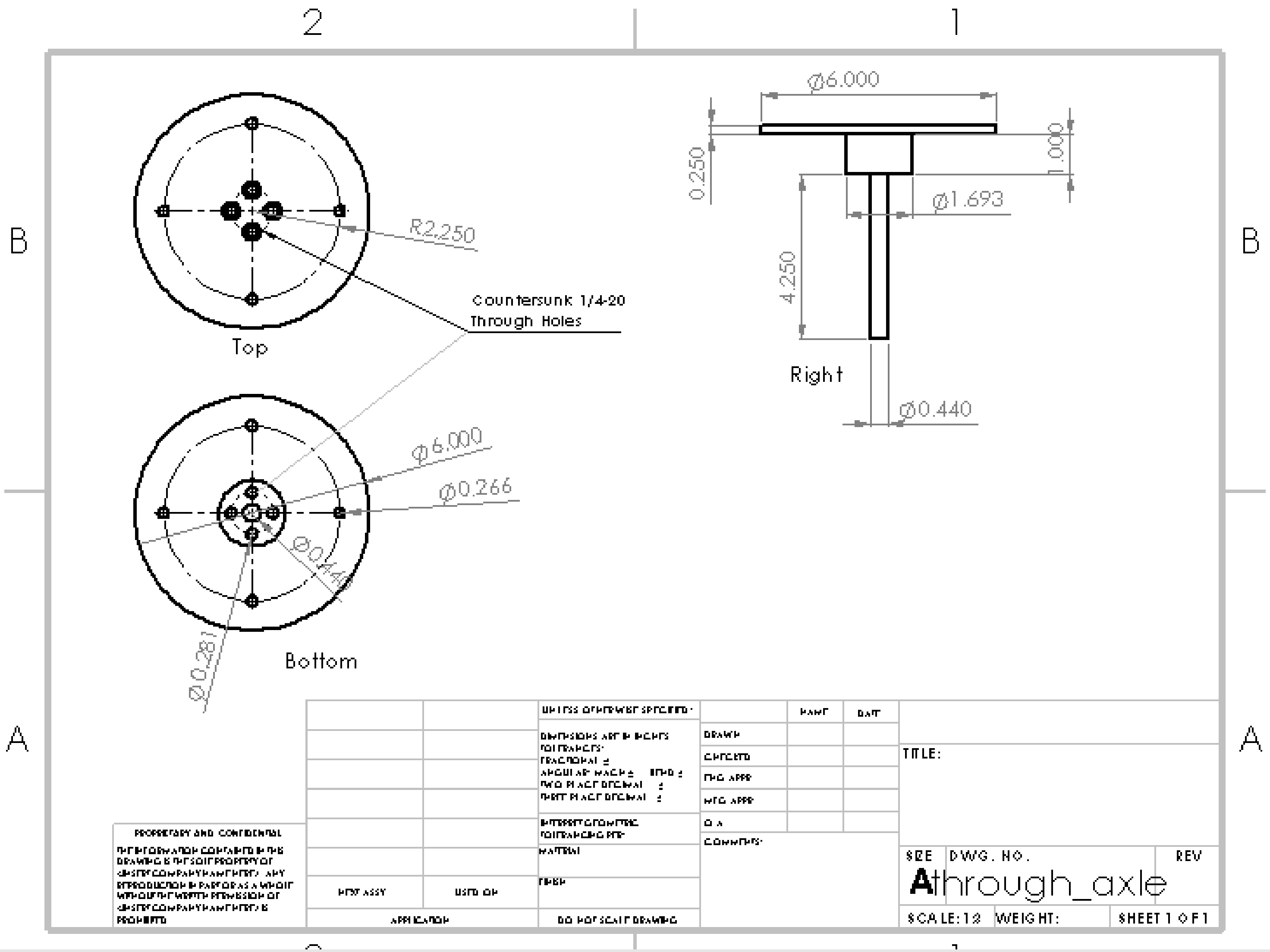


2.2500
1.2213
2.0000
0.3281
1.7500
0.1863
Top
0.1875
0.1875
#10-32 x 0.5
0.6750
Ø0.0625
Front
1.5000
1.0000
4.0000
Ø0.5000
1.9500
Right
UNLESS OTHERWISE SPECIFIED:
TITLE:
SIZE
DWG. NO.
REV
A
open_sting_body
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

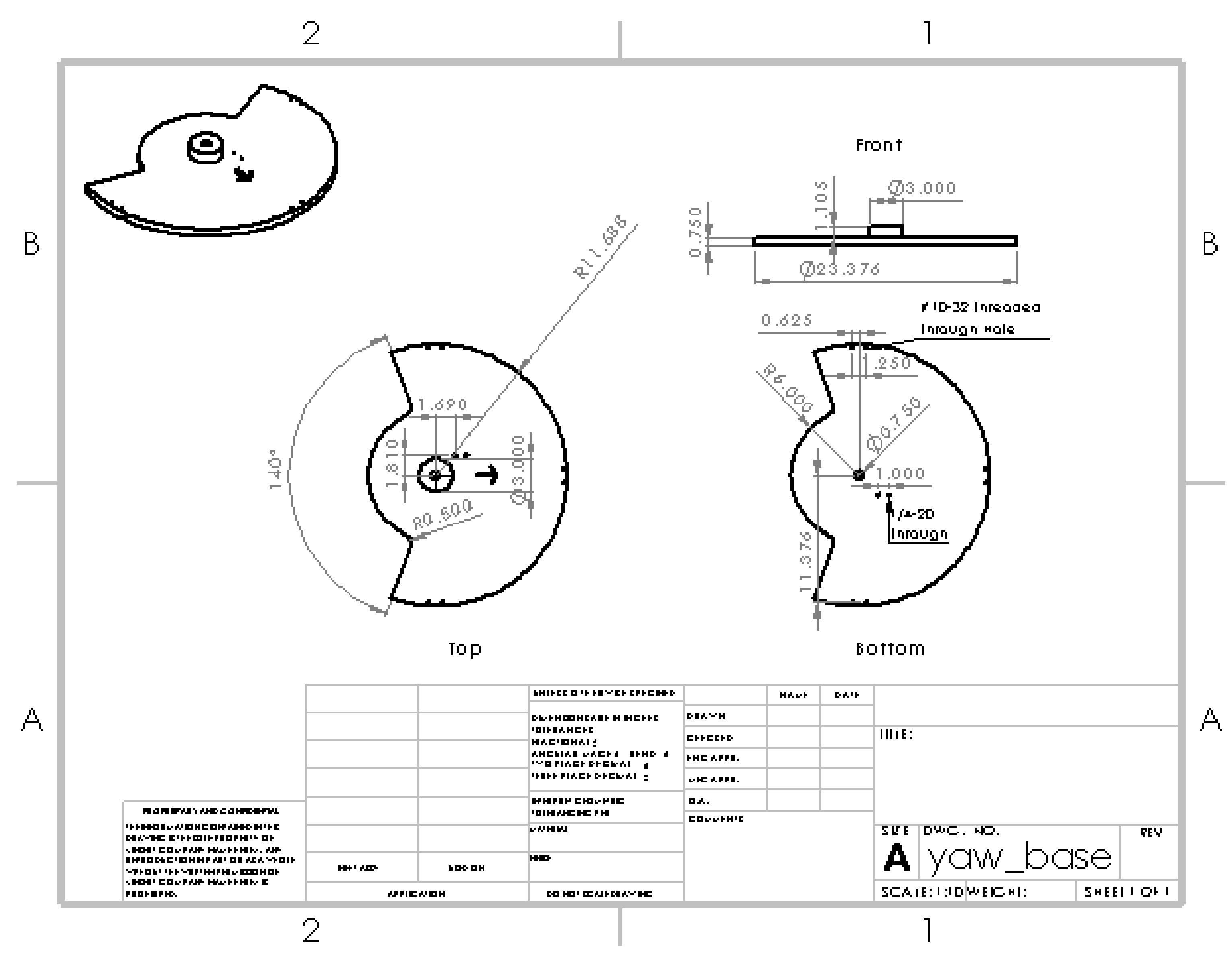


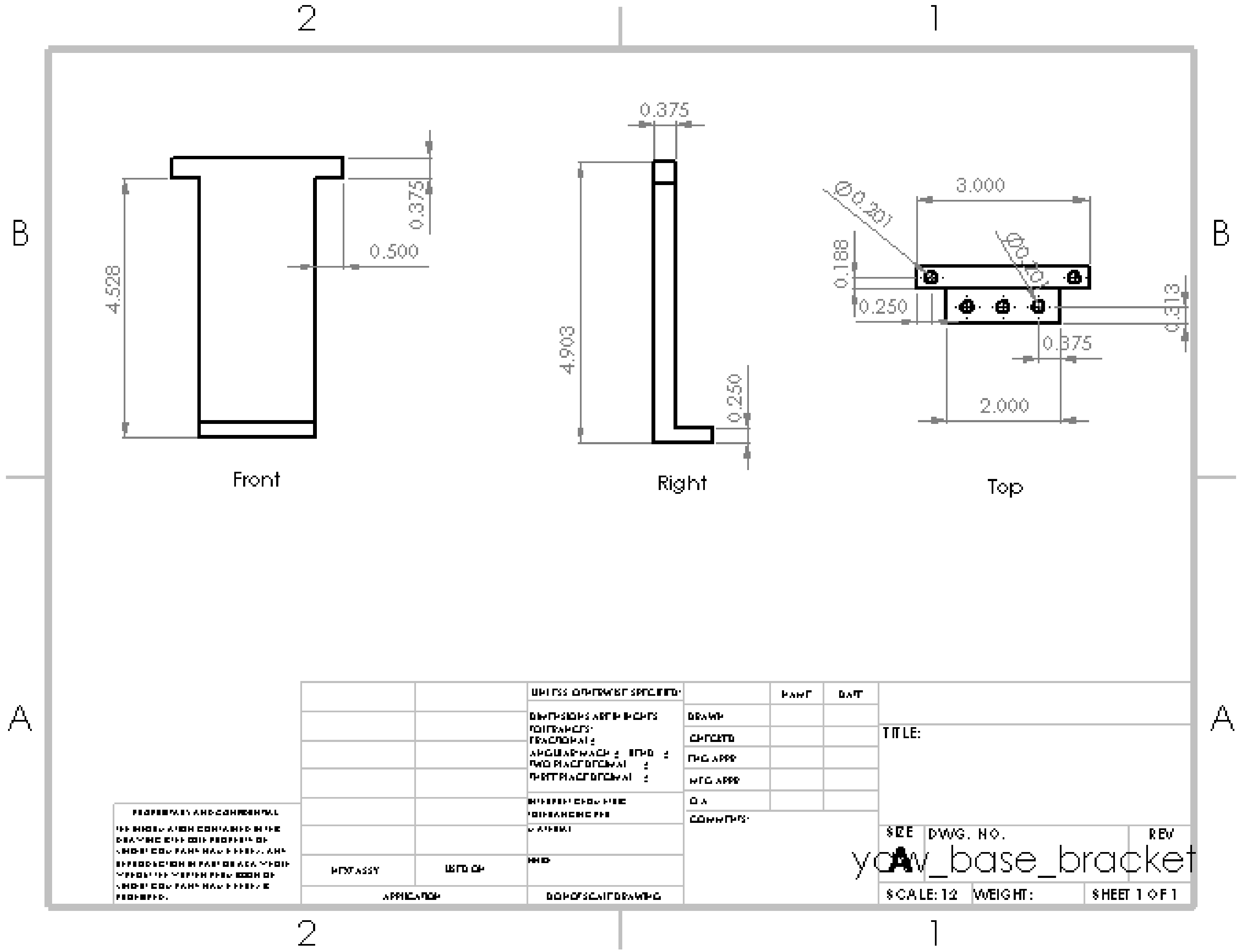
2
1
.0625" x 0.1" depth
72 Times (5° separation)
Ø1.5000
Ø0.7500
0.6750
B
B
Back
Front
A
A
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
TITLE:
PROPRIETARY AND CONFIDENTIAL
SIZE
DWG. NO.
REV


2
1
B
B
0.1875
0.1875
Ø0.2010
Ø1.5000x 0.125
Ø0.7500Through All
Front
Back
0.2500
2.2500
0.2500
1.5000
Top
Right
UNLESS OTHERWISE SPECIFIED:

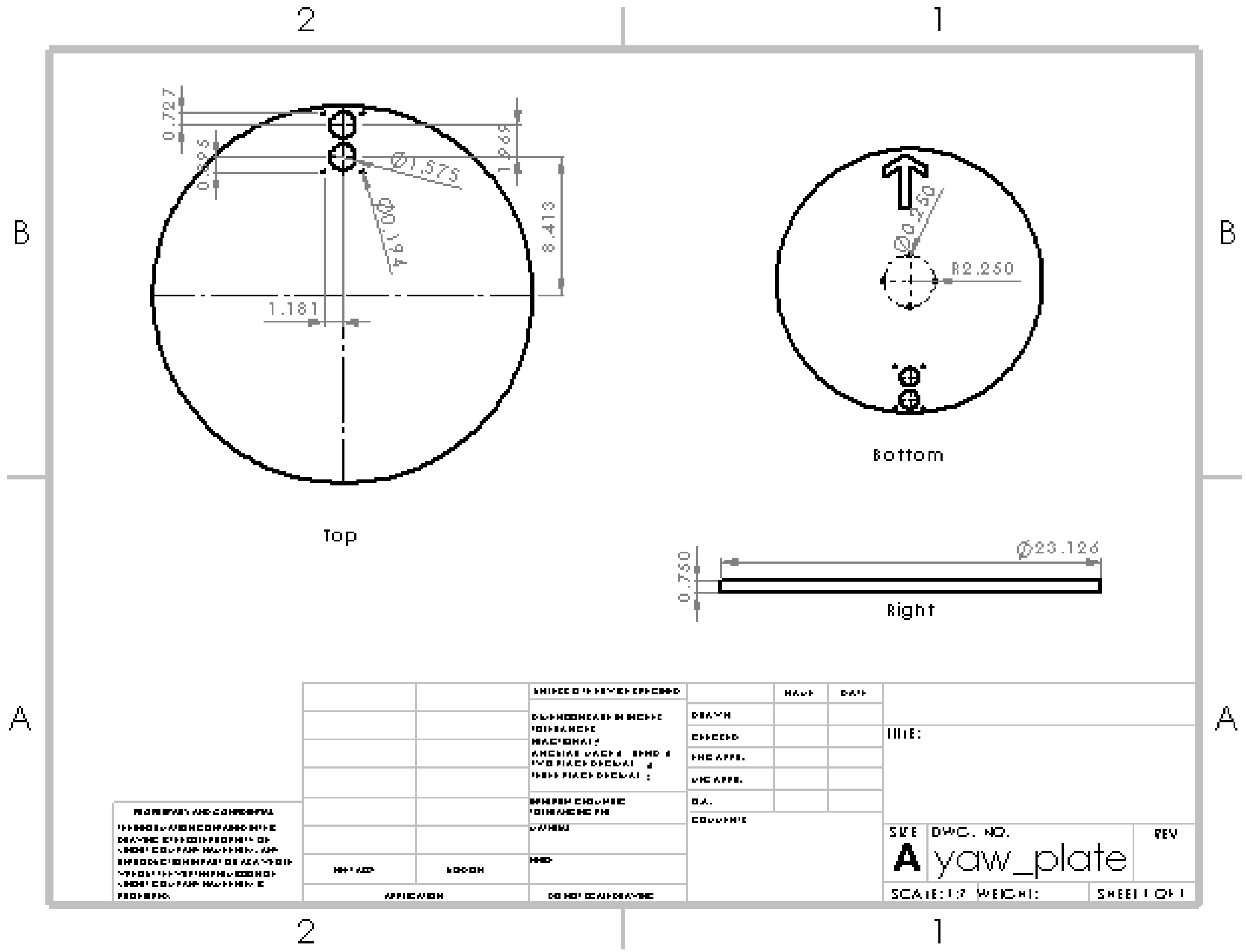


2
1
B
A
Ø6.000
0.250
1.000
Ø1.693
4.250
Right
Ø0.440
R2.250
Countersunk 1/4-20
Through Holes
Top
Ø6.000
Ø0.266
Ø0.440
Ø0.281
Bottom
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
through_axle
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


Front
Ø3.000
1.105
0.750
Ø23.376
R11.688
1.690
1.810
Ø3.000
R0.500
140°
Top
0.625
#10-32 Threaded
Through Hole
.250
R6.000
Ø0.750
1.000
11.376
Bottom
TITLE:
SIZE
A
DWG. NO.
yaw_base
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1



Front
Right
Top
0.375
0.500
4.528
4.903
0.250
3.000
Ø0.201
0.188
0.313
2.000
TITLE:
yaw_base_bracket
SIZE A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


2
1
B
A
0.727
0.395
1.969
Ø1.575
Ø0.194
8.413
1.181
Top
Ø0.250
R2.250
Bottom
Ø23.126
0.750
Right
TITLE:
SIZE
A
DWG. NO.
yaw_plate
REV
SCALE:1:7
WEIGHT:
SHEET 1 OF 1

# Weights Breakdown

- Baseplate - 35.24 lbs
- Yaw Plate - 30.43 lbs
- Yaw/Gear Base - 23.07 lbs
- Yaw Motor - 7.88 lbs
- Through Axle - 2.67 lbs
- Linear Bearing Flange - 1.42 lbs
- Yaw Brackets - 1.18 lbs (x3)
- Linear Brackets - 11.02 lbs (x2)

# NACA 0012 High Angle Lift and Drag

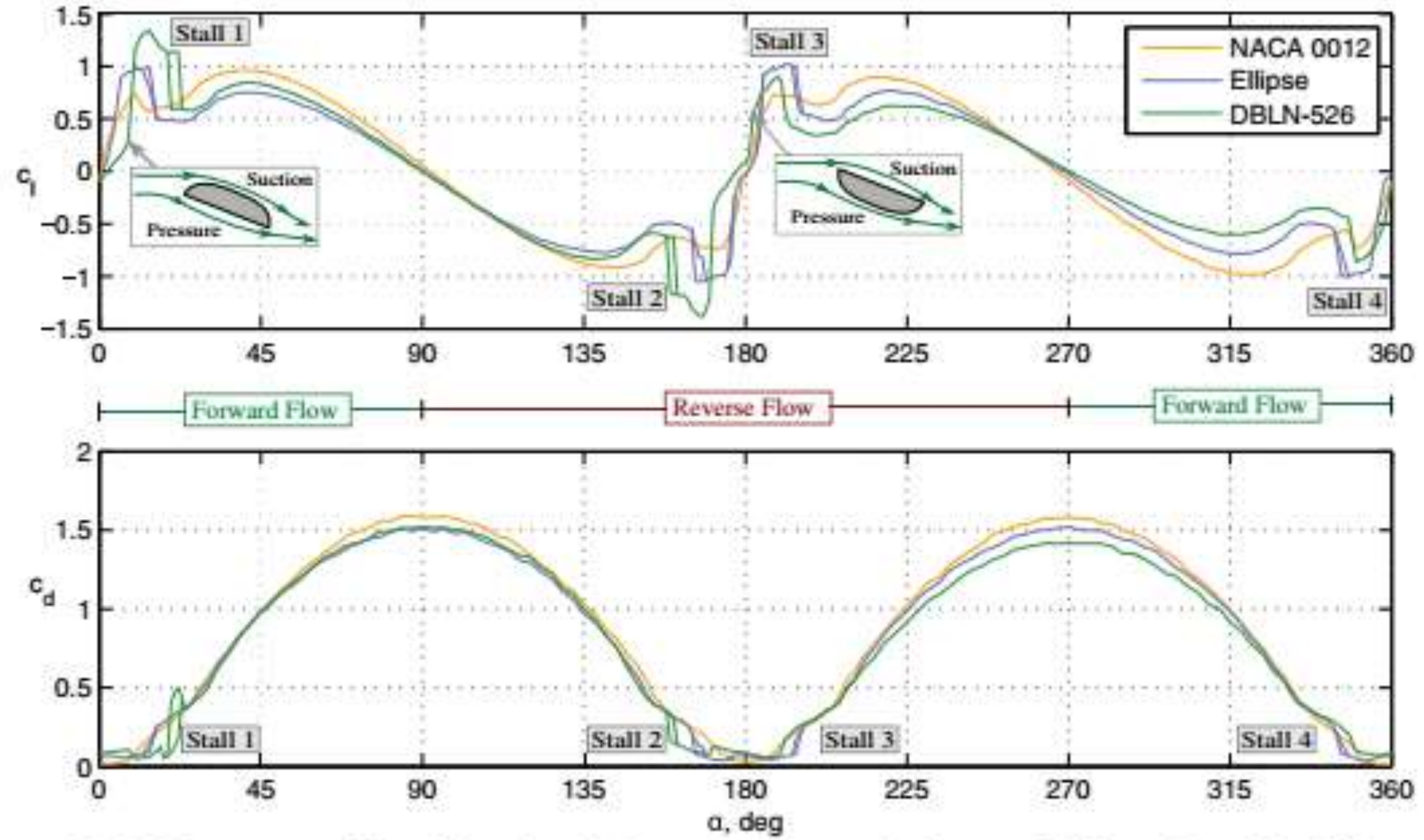



**Fig. 8** Time-averaged lift and drag force balance measurements for $0 \leq \alpha \leq 360$ deg at $Re = 1.1 \times 10^5$.