# SKADI
# Critical Design Review

12/7/2021, AERO 111

ASEN 4018-012 Team 9

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# Outline

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

# Project Purpose & Objectives

Section Outline

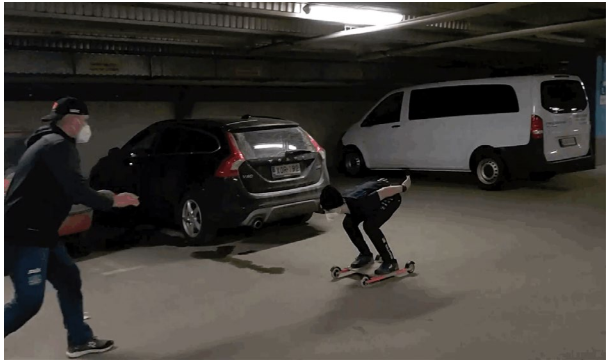
- Project Motivation
- Mission Statement
- ConOps

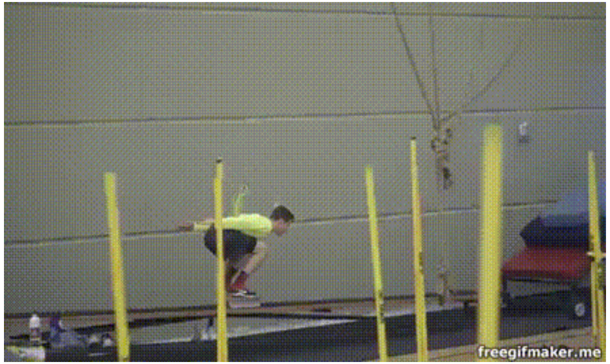
# Project Motivation

- **USA Nordic Ski** needs a better way to train their ski-jump athletes off the slopes

- Current training methods lack **visual aids,** cause the athlete to experience unrealistic **external forces**, and do not provide a way to collect **foot force distribution**

USA Nordic's Current Training Methods:





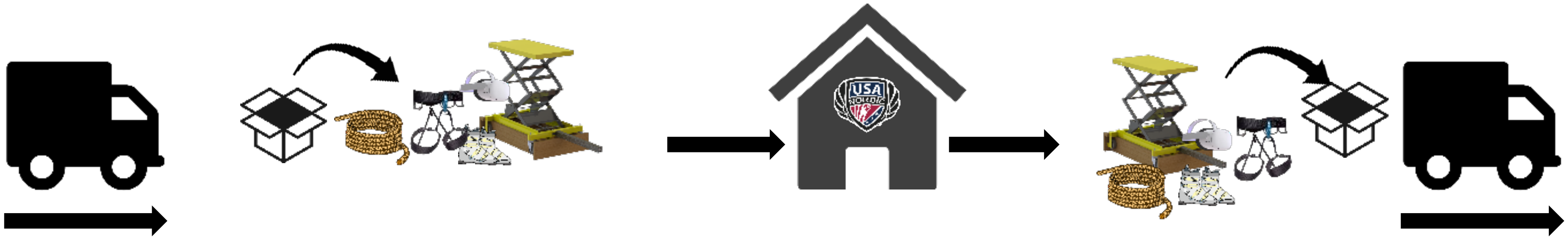

*Videos courtesy of USA Nordic*

# Mission Statement

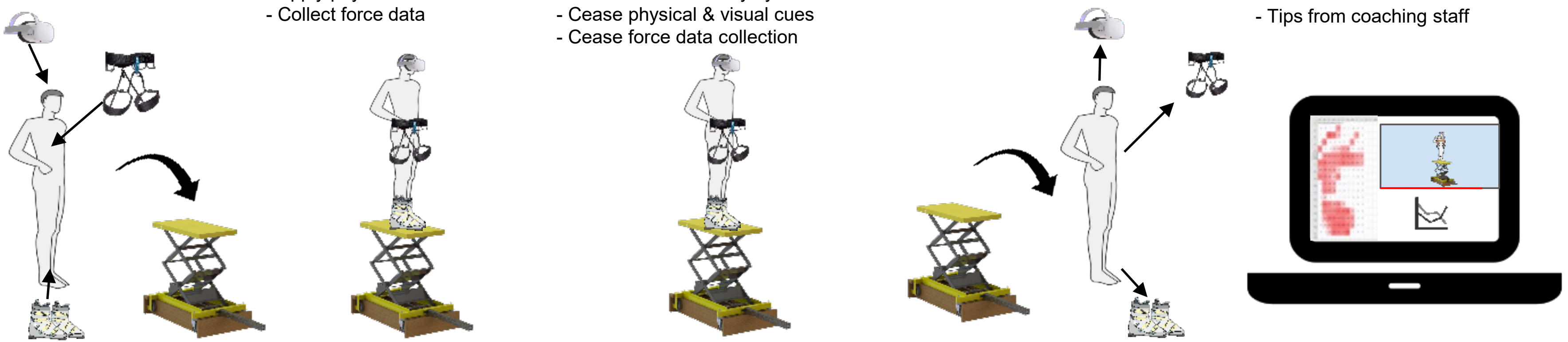
SKi jump Athletic Development Interface (**SKADI**) will provide the **USA Nordic** team with a training device that will **visually** and **physically** model the G-Forces of a ski jump takeoff while **measuring the foot force** applied by the athlete.

# ConOps

| 1. Delivery & Assembly | **2-7. Used in Training** | 8. Disassembly & Transport |
| --- | --- | --- |



| 2. Don Gear & Mount | 3. Run simulation | 4. End Simulation | 6. Dismount & Doff Gear | 7. Provide Feedback |
| --- | --- | --- | --- | --- |
| | - Apply physical & visual cues<br>- Collect force data | - Catch user with belay system<br>- Cease physical & visual cues<br>- Cease force data collection | | - Foot force distribution<br>- Tips from coaching staff |



Repeat Steps 2-7 until SKADI is moved to a different training facility

# Design Solution

Section Outline

- Overall Design Solution
- Subsystem Designs
- Functional Block Diagram

# Design Solution (Human)

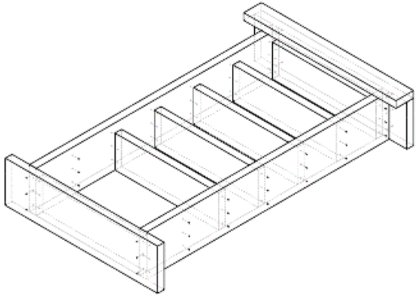
Visual Cue Provider
*(Oculus Quest 2 & Unity-made app)*

Safety Harness

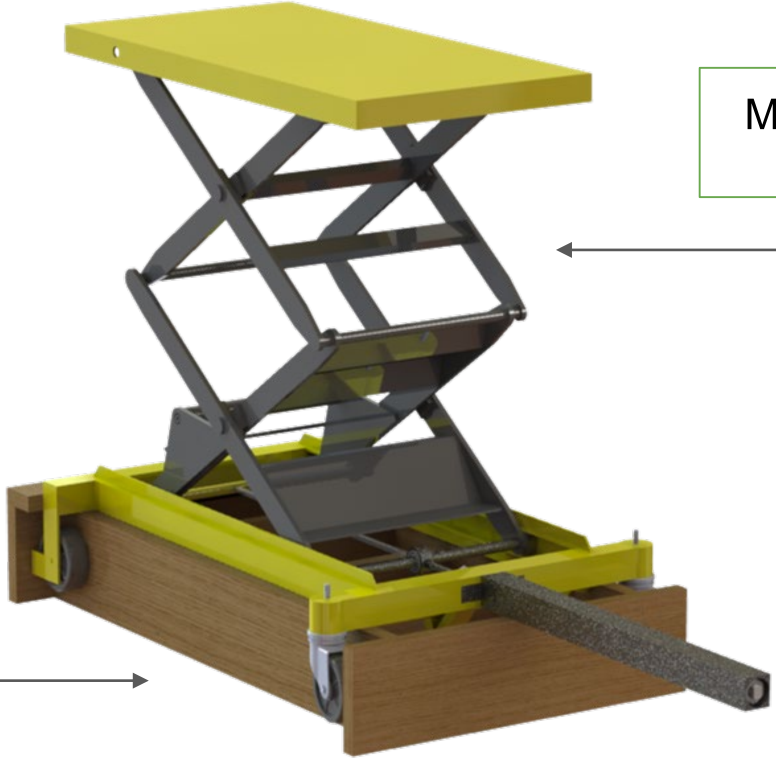
Force Data Collection
*(Kitronyx Insole Sensors)*

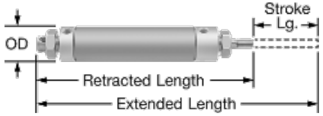
# Design Solution (Scissor Lift)

Modified COTS Scissor Lift
*(ApolloLift 1760 lbs)*



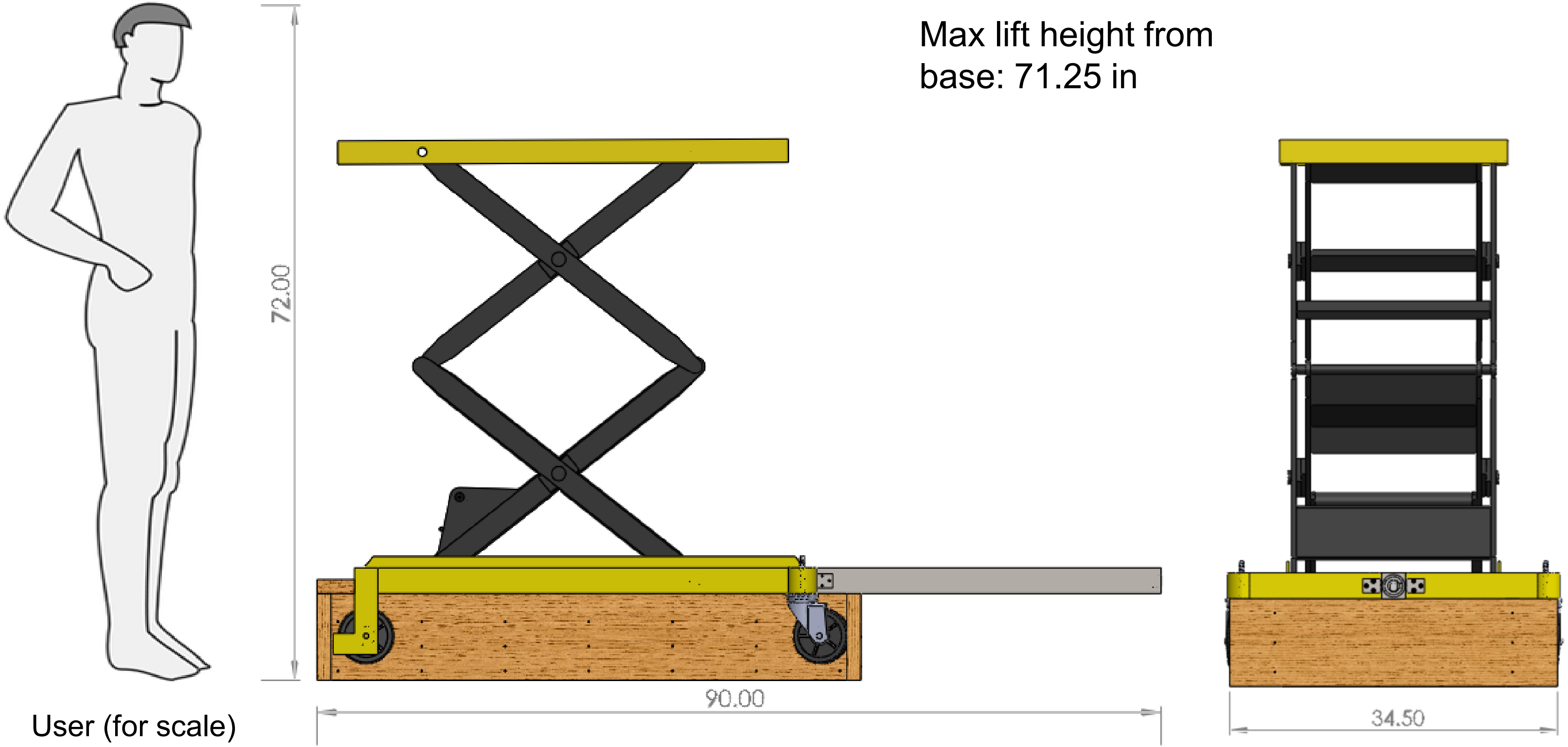
Wooden Base
*(Custom Built)*






Round Body Air Cylinder
*(McMASTER-CARR)*

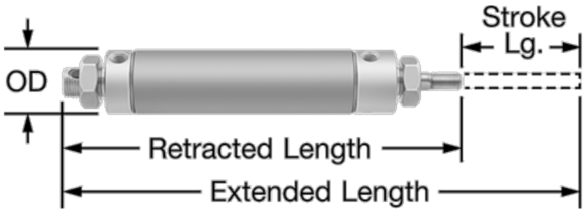
# Design Solution (Platform to Scale)

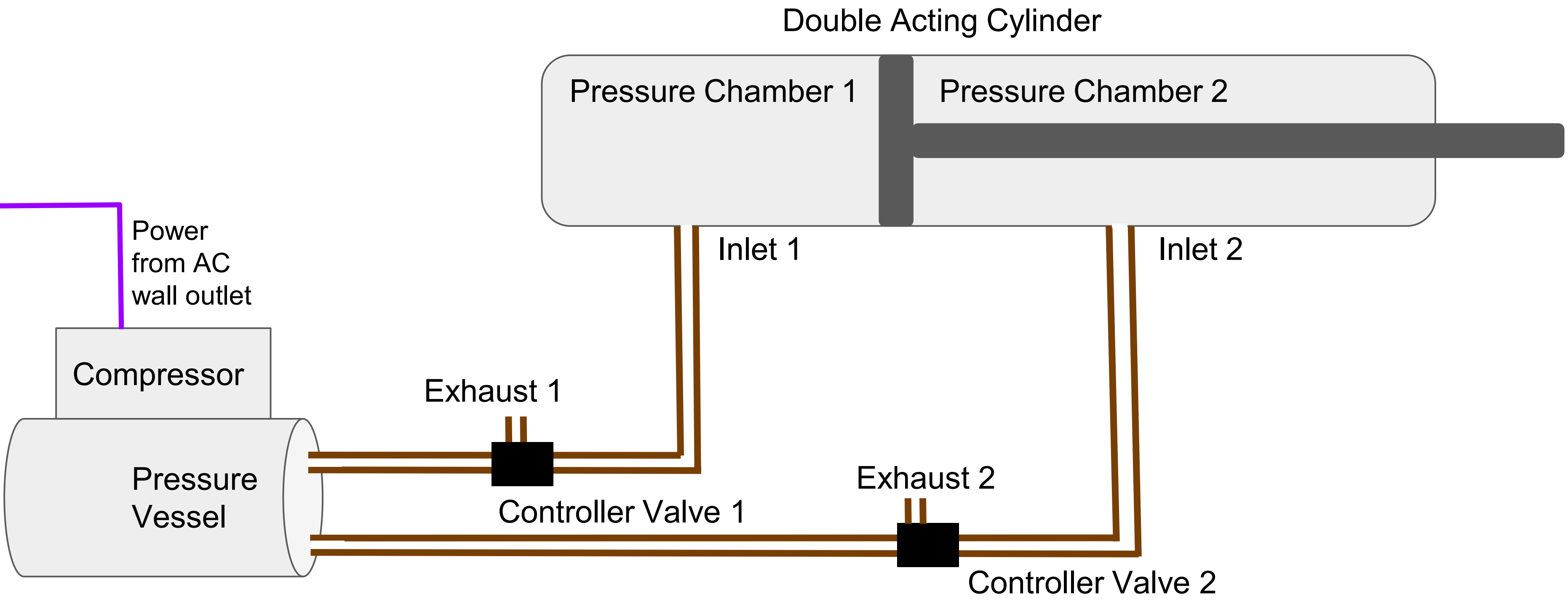



Max lift height from base: 71.25 in

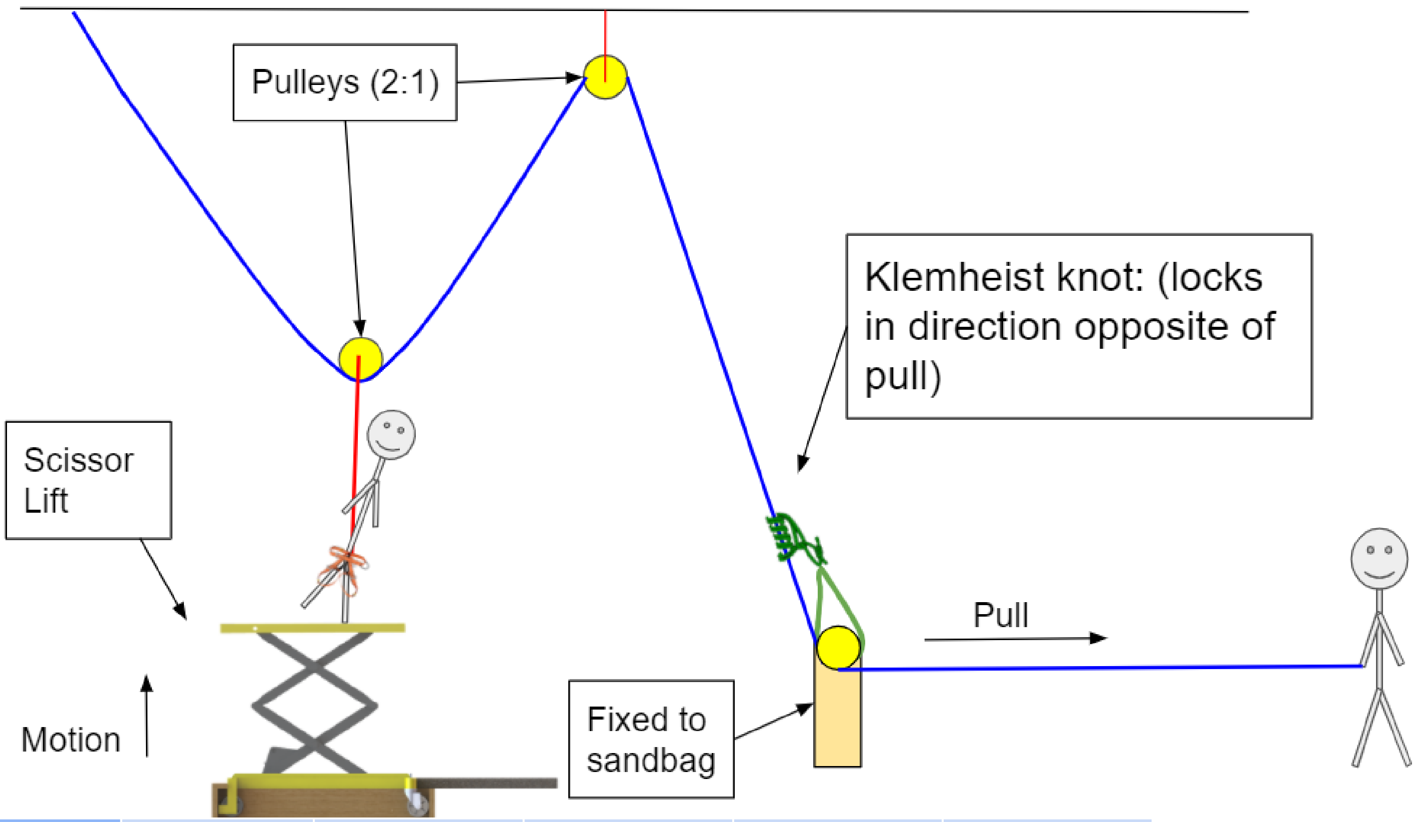
User (for scale)

# Design Solution (Pneumatic System)

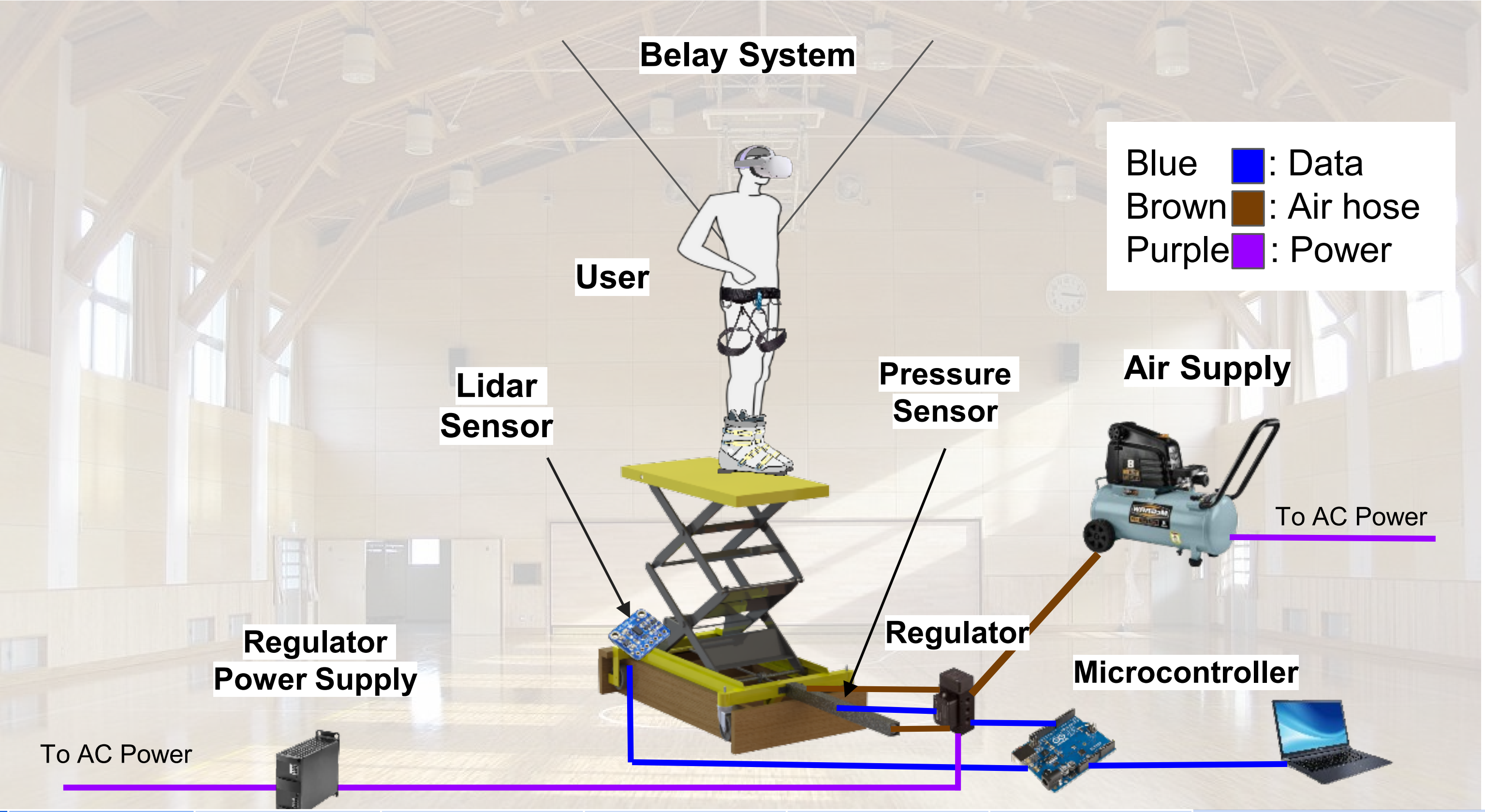


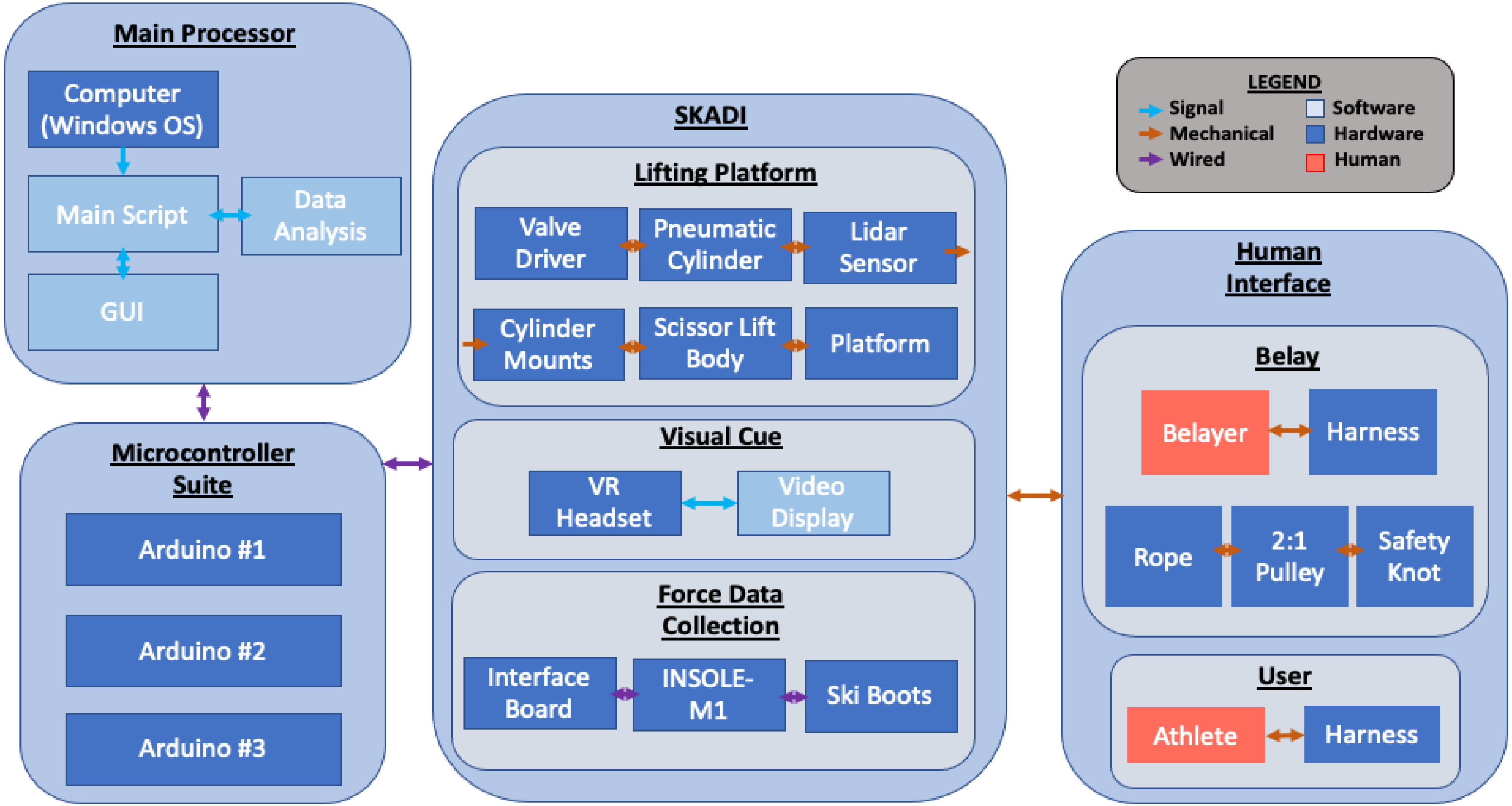
# Design Solution (Belay System)



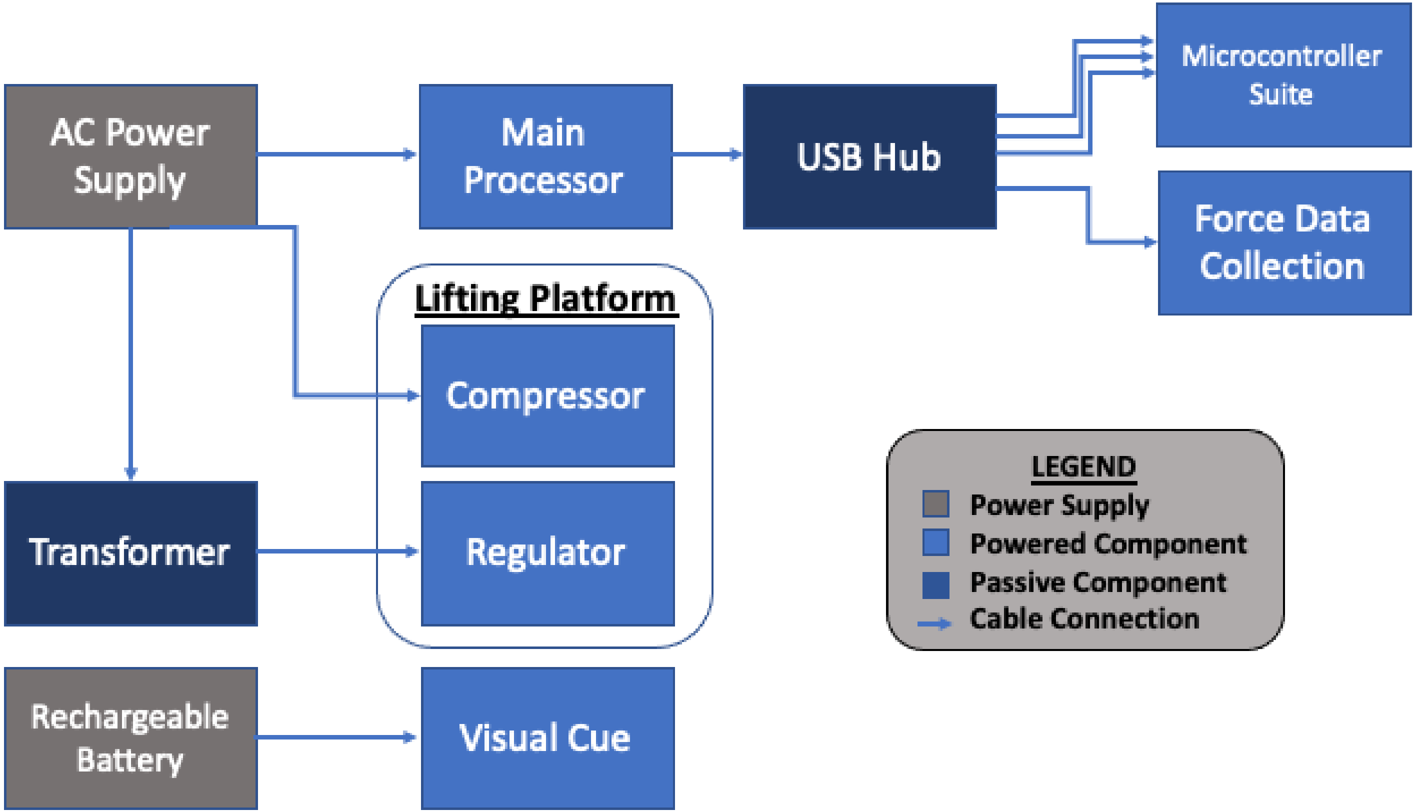
# Design Solution (Full)



# Functional Block Diagram



# Power Supply



# Critical Project Elements

<u>Section Outline</u>

- Critical Project Elements

# Critical Project Elements

| Func. Req. | CPE | Description |
|---|---|---|
| FR1, FR2, FR5 | SYNC | The synchronization of the visual, foot force, and mechanical subsystems via software |
| FR2 | GFORCE | The production of similar forces to those experienced by an athlete during ski jump takeoff |
| FR3, FR6 | SAFE | The ability of SKADI to structurally withstand the maximum expected loads during simulation and keep the user safe |
| FR1, FR5 | CUES | The ability of SKADI to provide visual cues and capture the force profile during simulation |

# Design Requirements & their Satisfaction

Section Outline

- Driving Requirements
- Acceleration Profile
- Synchronization of Subsystems
- Structural Integrity

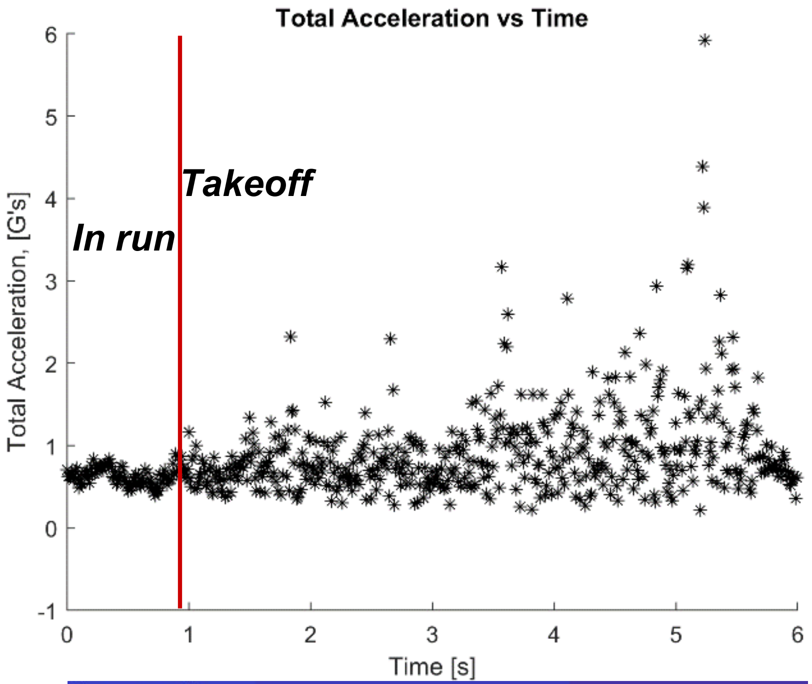
# Driving Requirements

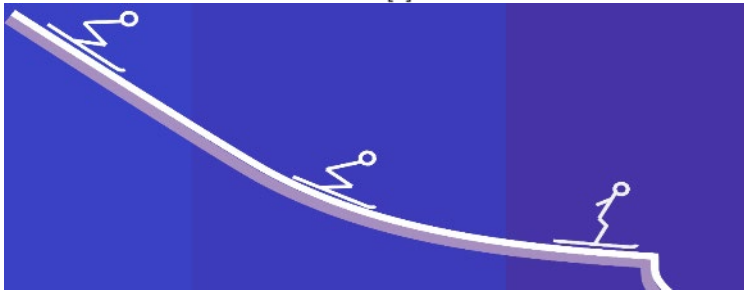
| Driving Requirement(s) | Description | CPE(s) |
|---|---|---|
| FR2 | Acceleration Profile | GFORCE, CUES |
| FR1 | Synchronization of Subsystems | SYNC, CUES |
| FR3, FR6 | Structural Integrity | SAFE |

# Acceleration Profile (FR2)

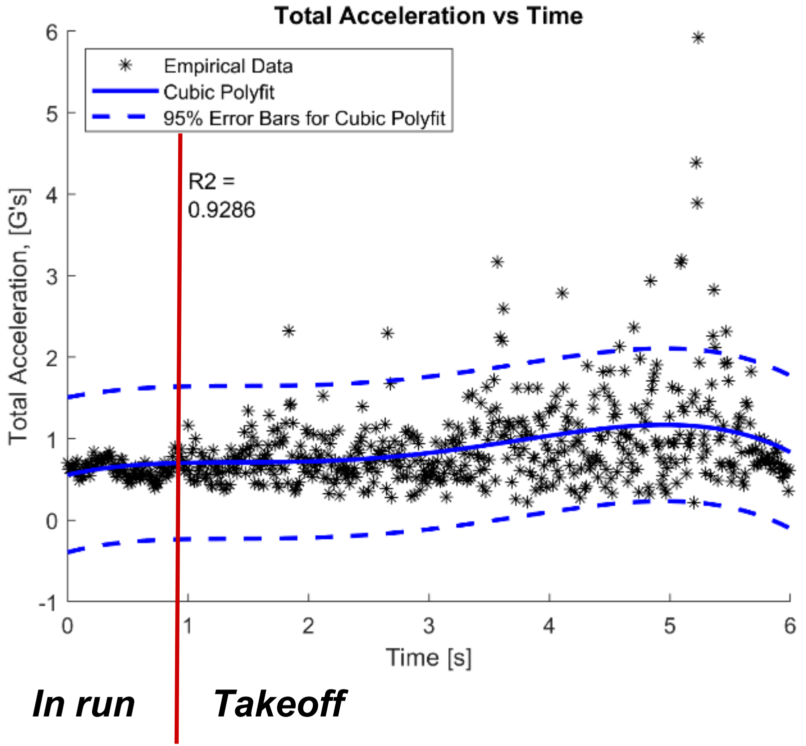
**DR2.1: Across the curved in run phase, the slope of force with respect to time that SKADI exerts will be within 20% of the slope of force with respect to time of a true ski jump ramp.**

# Empirical Data

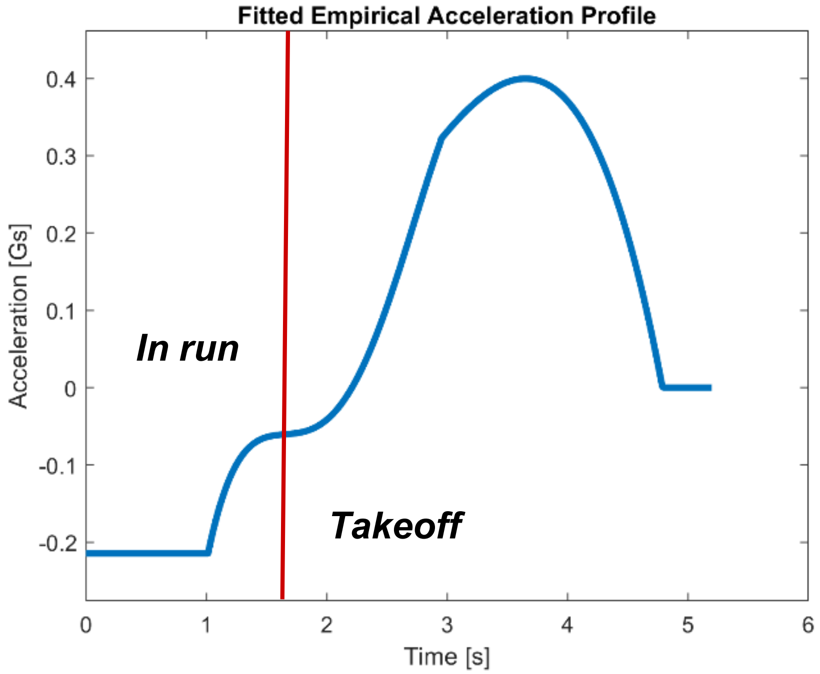


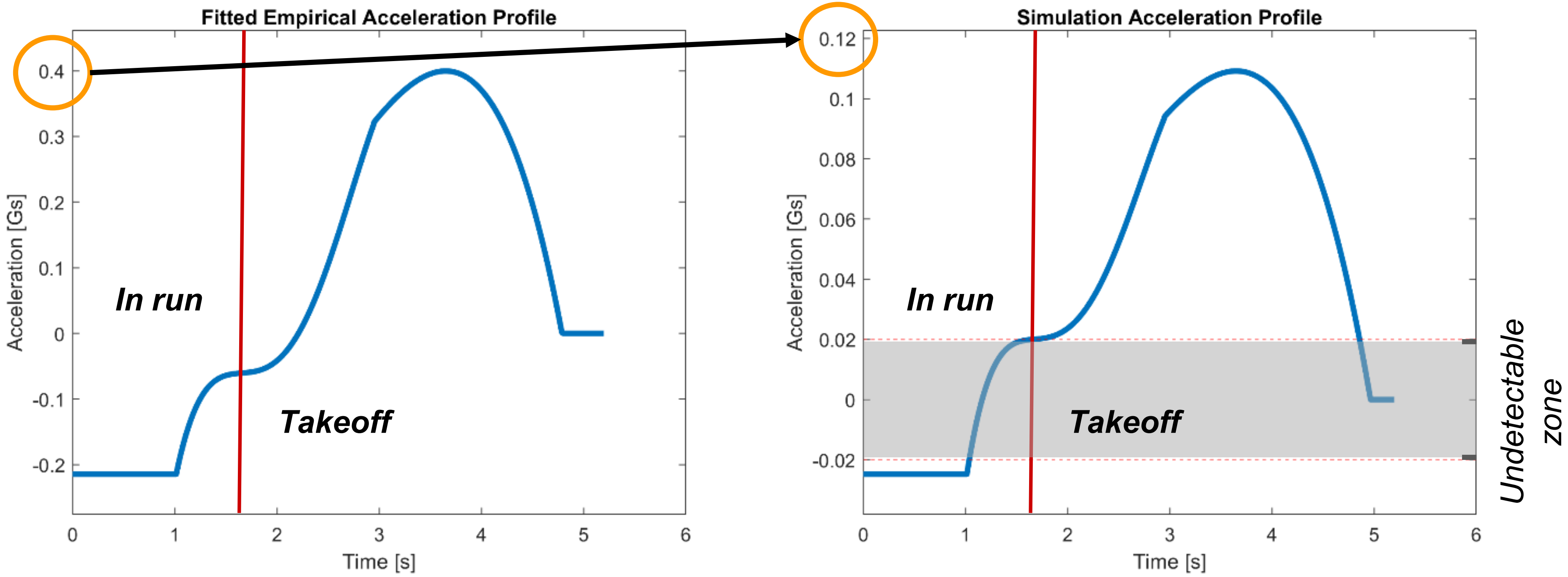
# Empirical Data



# Acceleration Profile

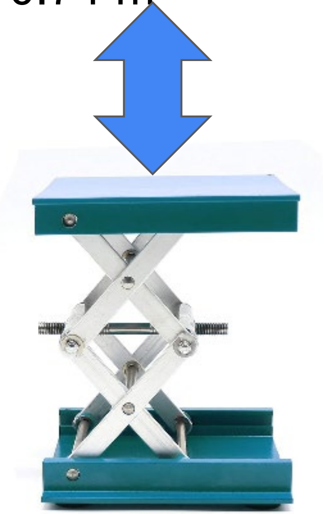


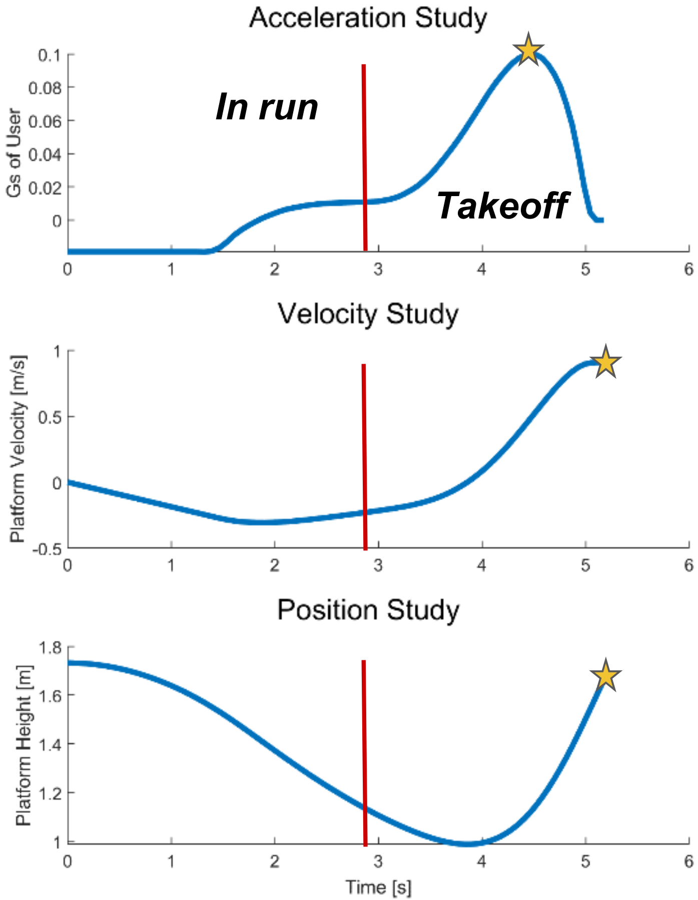
# Acceleration Profile



# User Experience

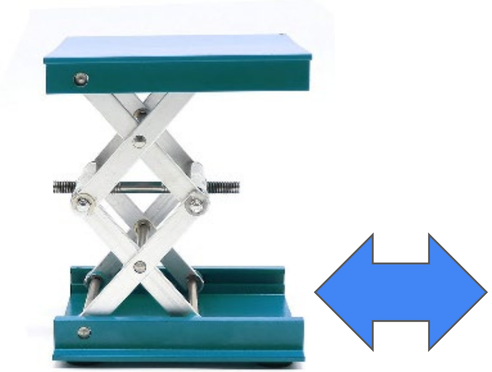
- Max accel of user: 0.098 Gs
  - Required 0.06 Gs
- Max velocity of user: 0.90 m/s
- Max displacement of user: 0.74 m
- Initial State
  - Velocity:
    - 0 m/s
  - Position:
    - 1.75 m

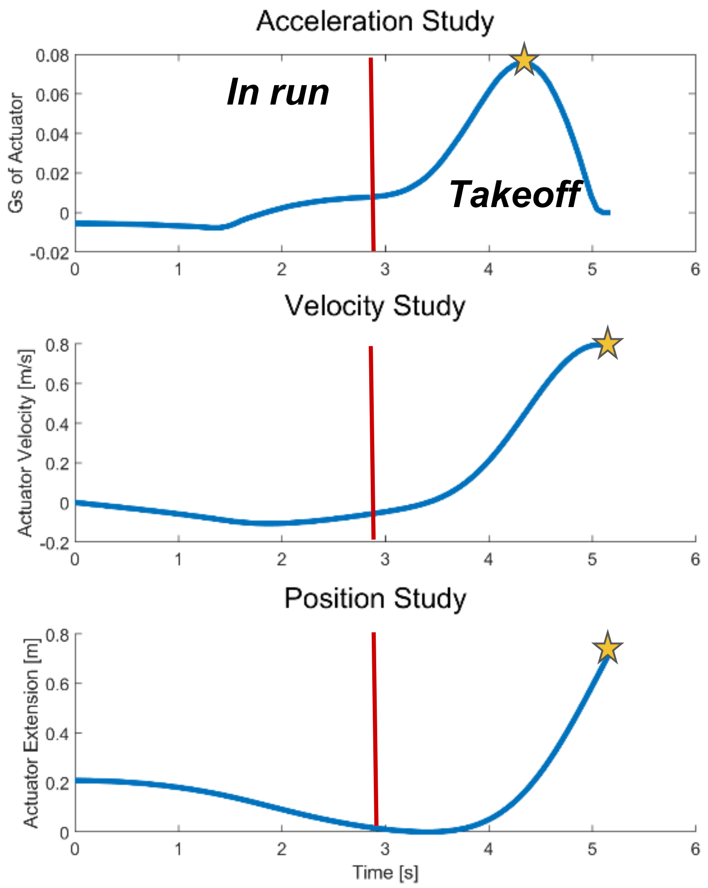




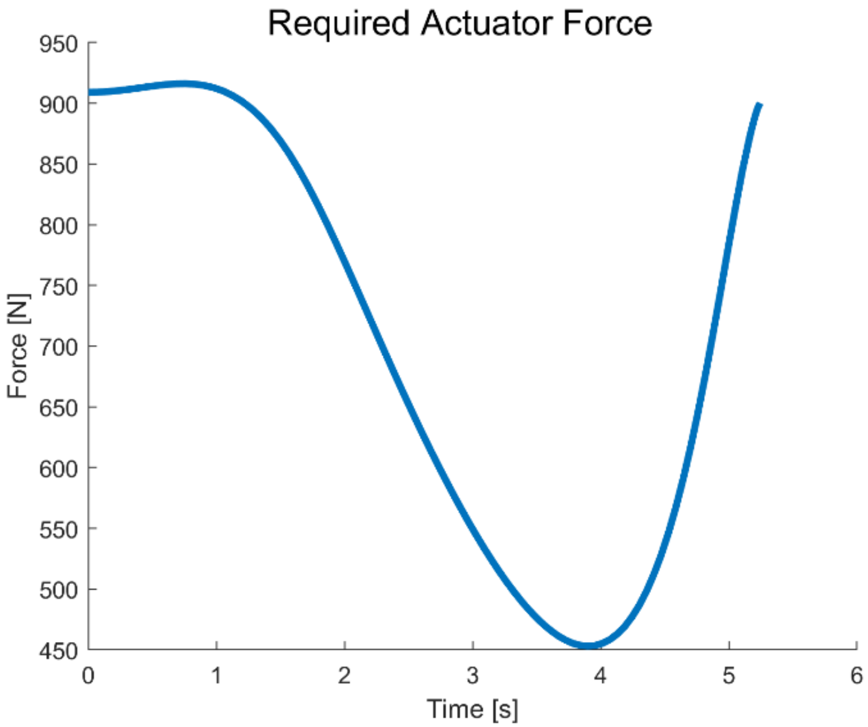
# Actuation

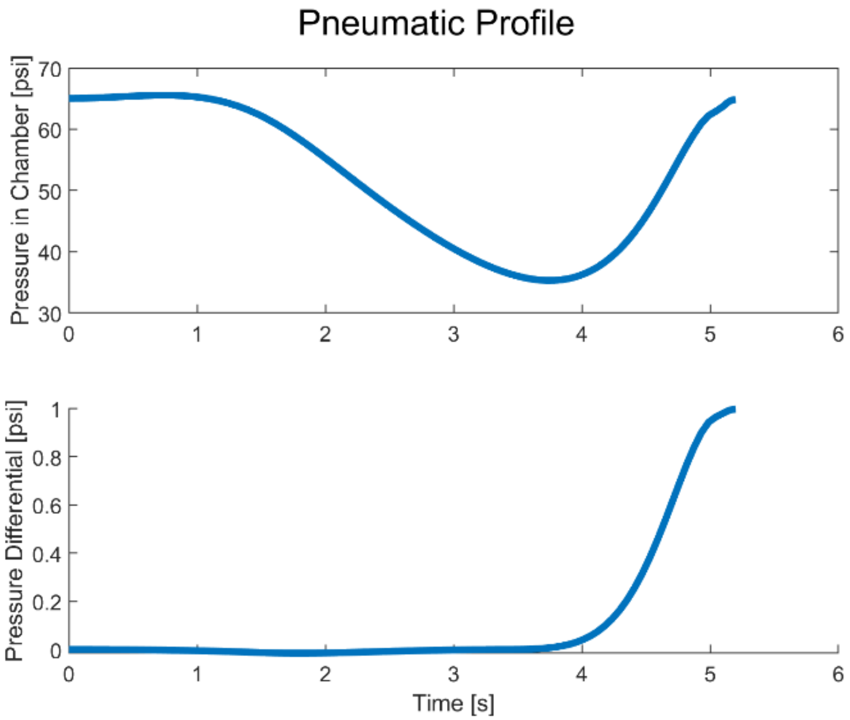
- Max accel of actuator: 0.074 Gs
- Max velocity of actuator: 0.80 m/s
- Max displacement: 0.75 m
- Max force needed: 920 N
- Initial State
  - Velocity:
    - 0 m/s
  - Position:
    - 0.2 m



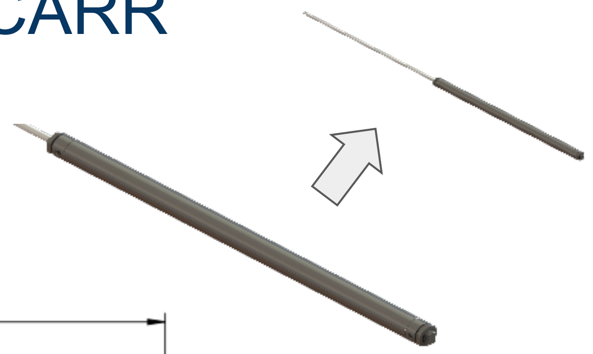


# Pneumatic Actuation

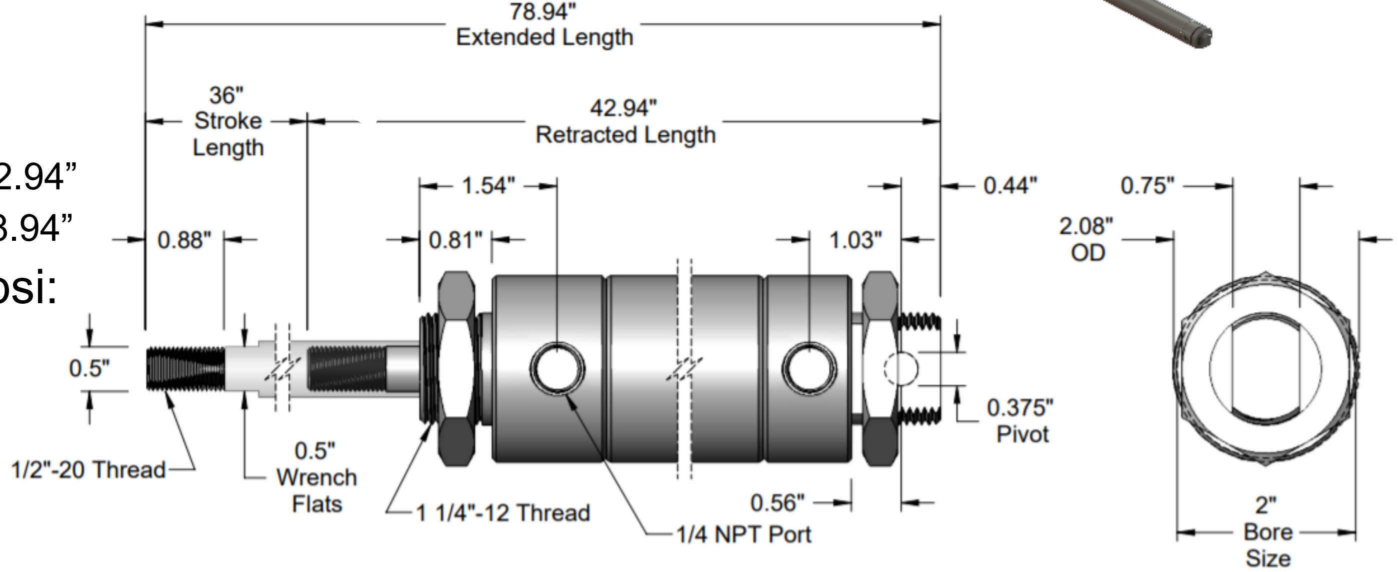


# Round Body Air Cylinder- McMASTER-CARR



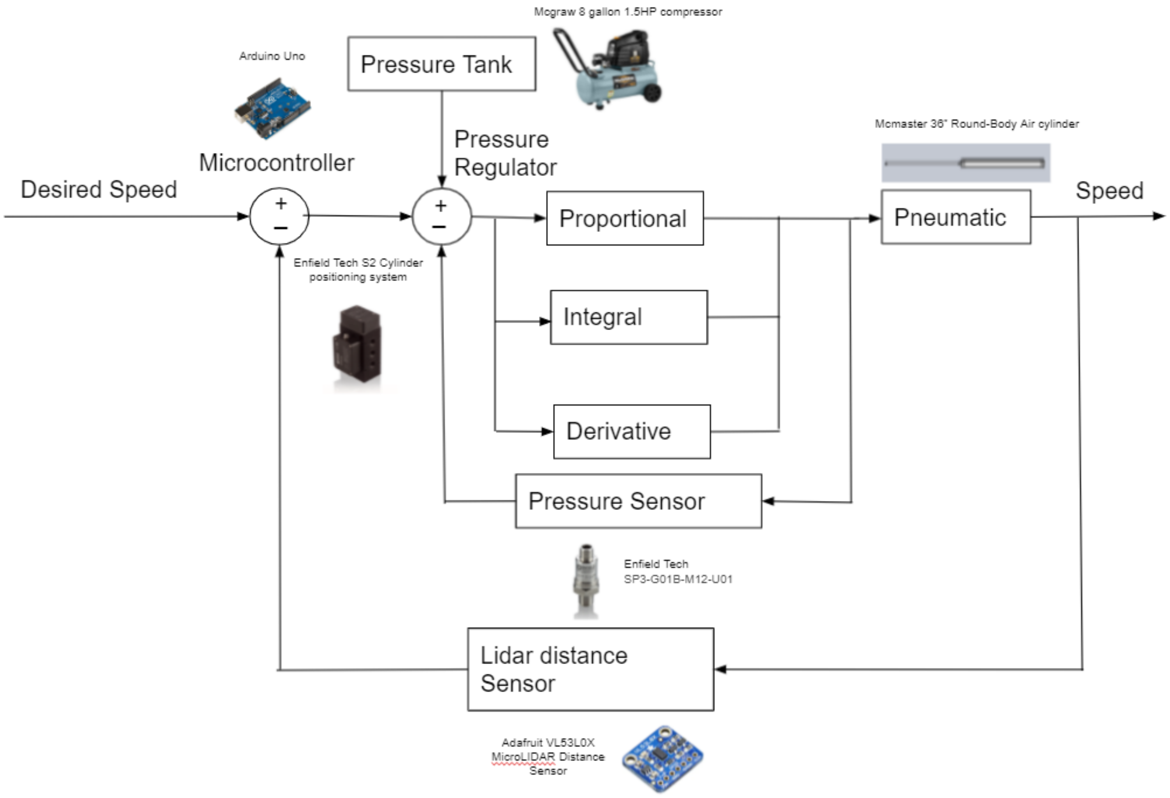
- Double-Acting, Universal Mount, 2” Bore
- Vendor: McMASTER-CARR
- Price: $234
- Length
  - Stroke: 36’’
  - Retracted: 42.94”
  - Extended: 78.94”
- Force @ 100 psi: 310 lbs



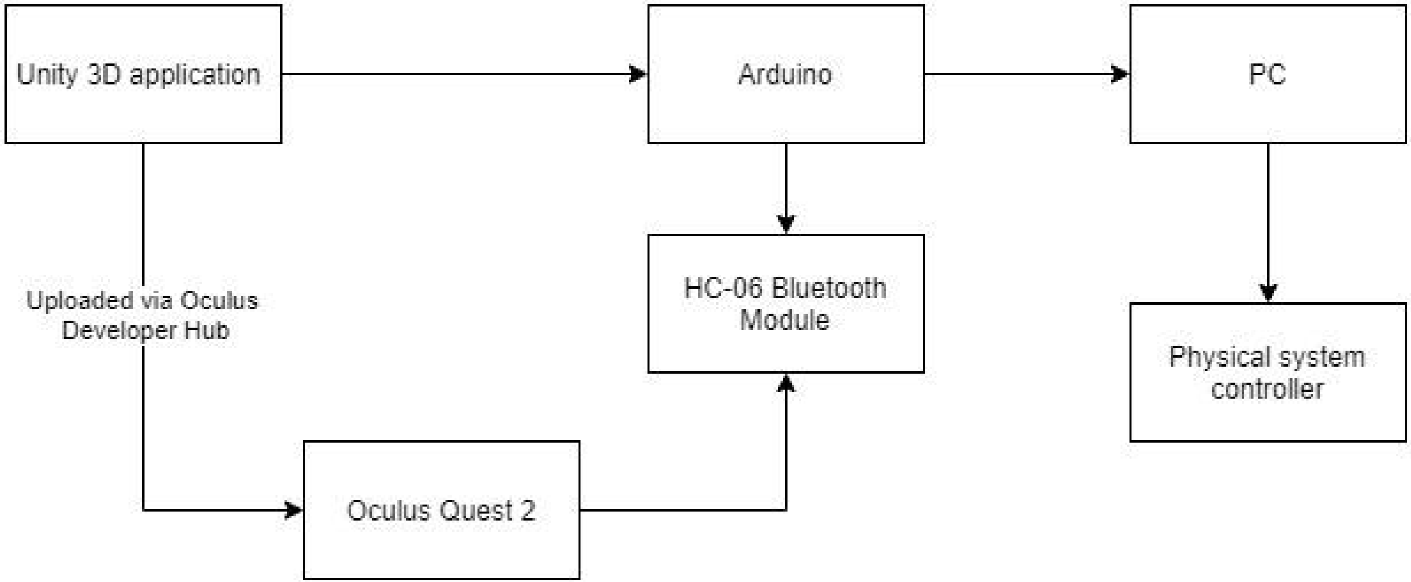
# Synchronization of Subsystems (FR1)

**DR1.1: The visual cue shall be synced to within ±300 milliseconds of the physical cue.**

# Pneumatics Control

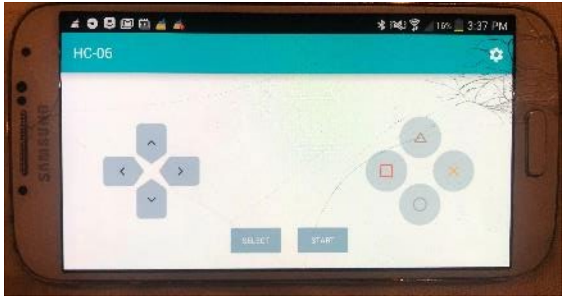


# Visual Software FBD

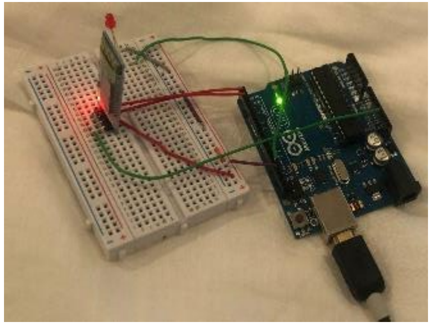


# Proof of Concept

Android Device (Samsung Galaxy S4)




Arduino with Bluetooth Connection



Program to Write File

```
PS C:\Users\mgree\Documents\Current\ASEN4018\ArduinoBTCpp> g++ main.cpp SerialPort.cpp
PS C:\Users\mgree\Documents\Current\ASEN4018\ArduinoBTCpp> ./a
Enter Filename
Test
Connection is Established
File Created
PS C:\Users\mgree\Documents\Current\ASEN4018\ArduinoBTCpp>
```

# Synchronization

**VR System**

- Pre-defined timing* -> user presses start -> some delay -> straight in-run phase begins -> continues to curved in-run and takeoff phases

**Mech System**

- Pre-defined timing -> movement begins when user starts descending ski jump in VR simulation

**Synchronization**

- VR system will create a file on PC when the user presses start, mechanical will read the newly created file, both will have the same delay before beginning simulation

*The pre-defined timing of the VR system will be modified by the programmed timing of the platform stages of movement

# Structural Integrity (FR3, FR6)

**DR3.1: SKADI shall be able to support up to 600 lbs including user and equipment.**
**DR6.1: The user will not have to adjust their takeoff or flight positions to accommodate for landing.**
**DR6.2: The user will be caught and brought to rest by a harness upon jumping**

# Structures Solution: COTS Scissor Lift

**ApolloLift 1760 lb Capacity Lift**

**Cost**: **$1239.74** after shipping and tax

**Specifications**:

- 1760 lb Load Capacity
  (Manufacturer FOS of 1.25)
    - Gives us a FOS of 2.9 (600 lb Load)
- Platform Dim: 48 in x 24 in
- Max Height Displacement: 59.1 in

FEA simulation was used to verify specs

# Structural Analysis - von Mises Stress

Assumptions:

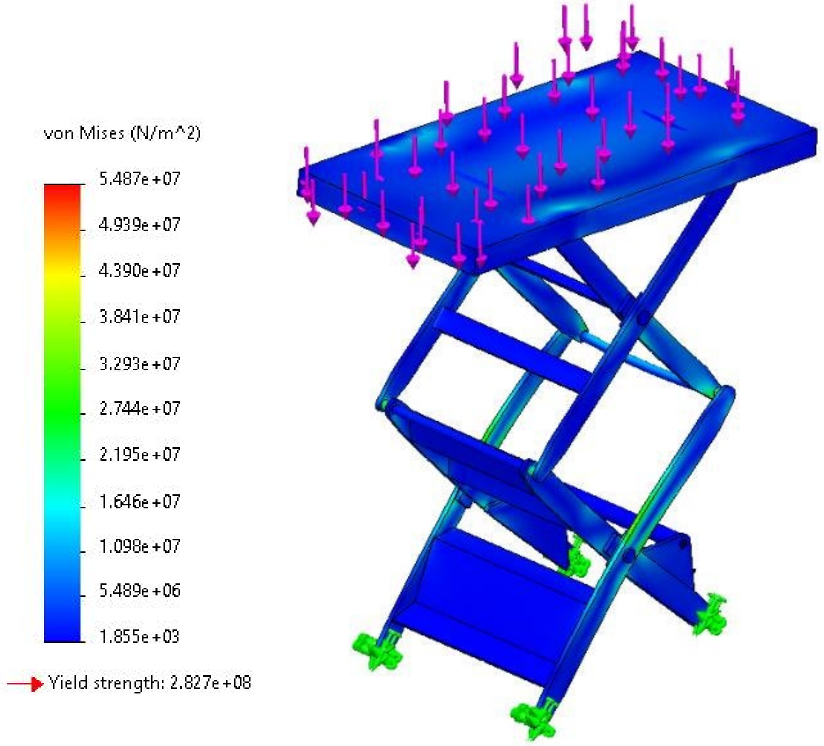
- Lift made of 1023 low-carbon steel
- Maximum platform load: 2669 N (600 lbs)
- Maximum dynamic load: 1000 N

Results:

Max Yield Strength: 28.27e+07 [N/m²]

Max von Mises Stress: 5.487e+07 [N/m²]

FOS: 5.15



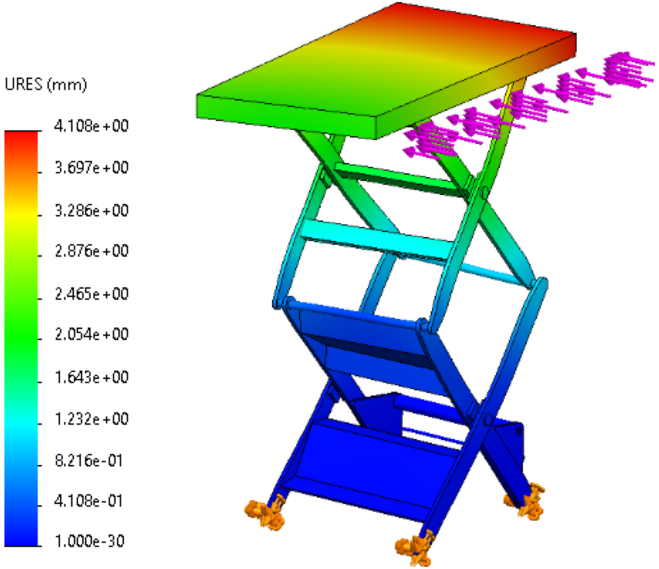
# Structural Analysis - Horizontal Displacement

Assumptions:

- Acceptable displacement up to 2”
- Max Lateral Load: 1708 N (384 lbs)
  - Coefficient of friction: 0.64
  - Force: 384 lbs
  - Moment arm:
- No “play” in platform connections

Results:

Max Displacement: 4.108 [mm] (0.16”)



# COTS Lift Modifications for SKADI

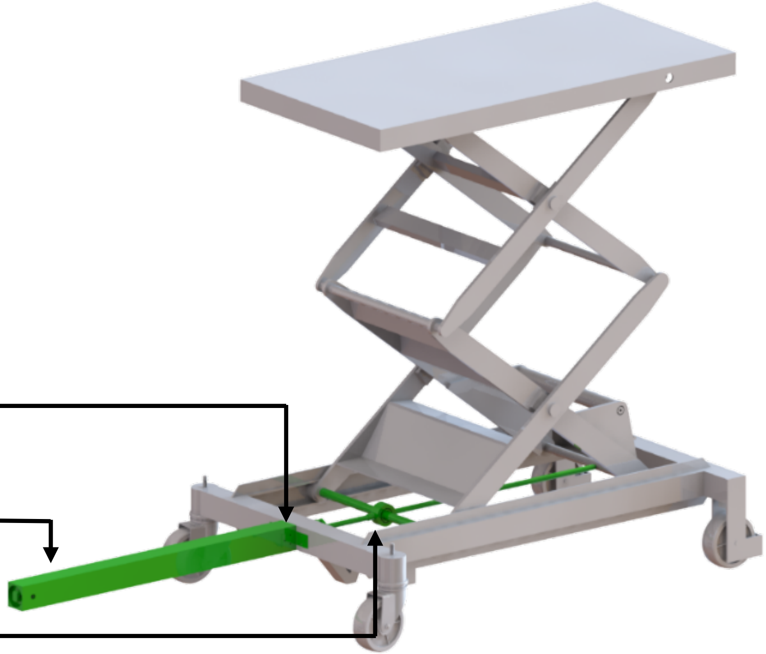

Remove Handle

Remove Manual Hydraulics
(Cylinder,Hand Release, Tubes, Foot Pump)

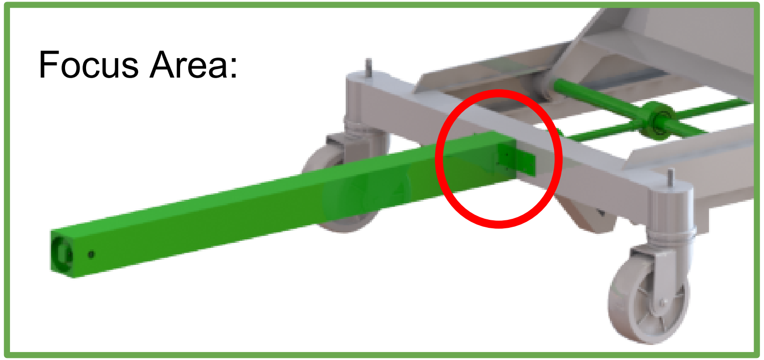
Drill Hole in Base for Cylinder

Attach Cylinder Case
*(Custom Built)*

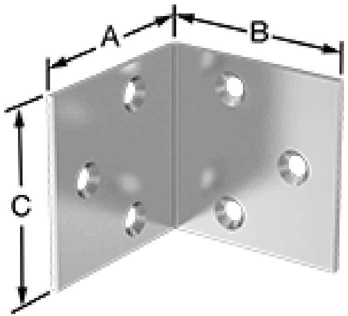
Install Actuation Attachment Rod
*(Custom Built)*



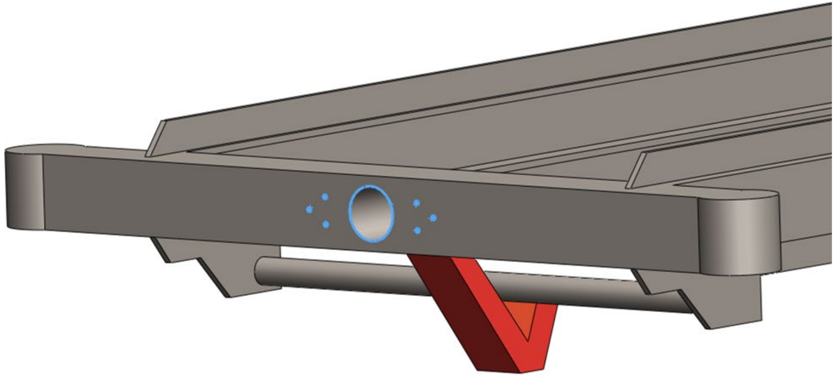
# Lift Base Modifications- Drill Hole in Base



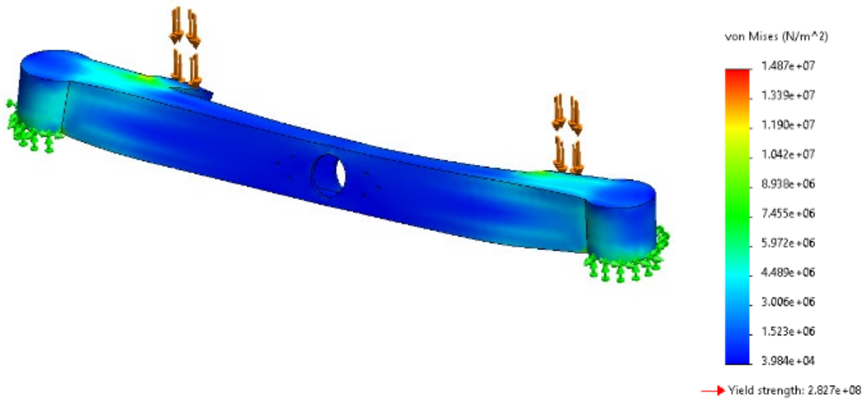

- Drill one 2” hole through center
- Drill six  0.16” holes for mounting brackets
- Remove COTS hydraulic pin mechanism (Red Highlight)

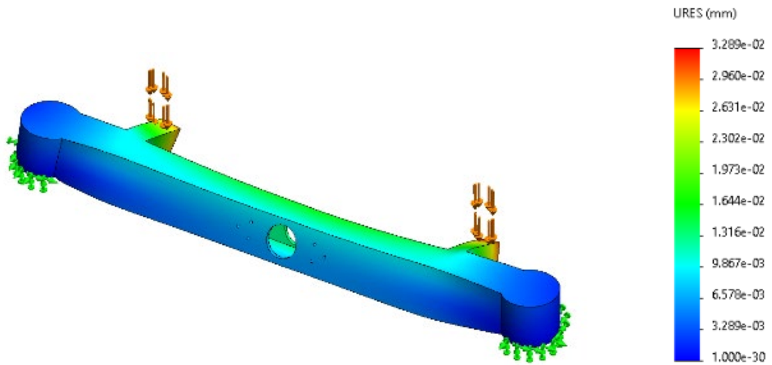



Mounting Bracket for Cylinder Case



# Lift Base Modifications - Force Analysis



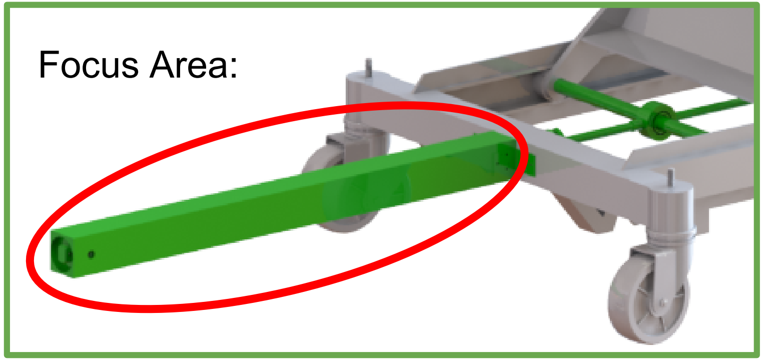



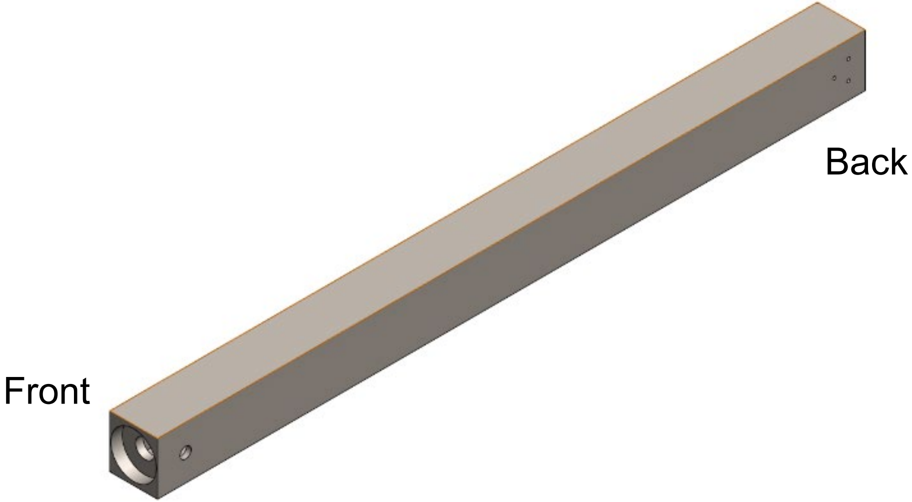

Yield Strength: 28.27e+07 [N/m²]
Max von Mises Stress: 1.487e+07 [N/m²]

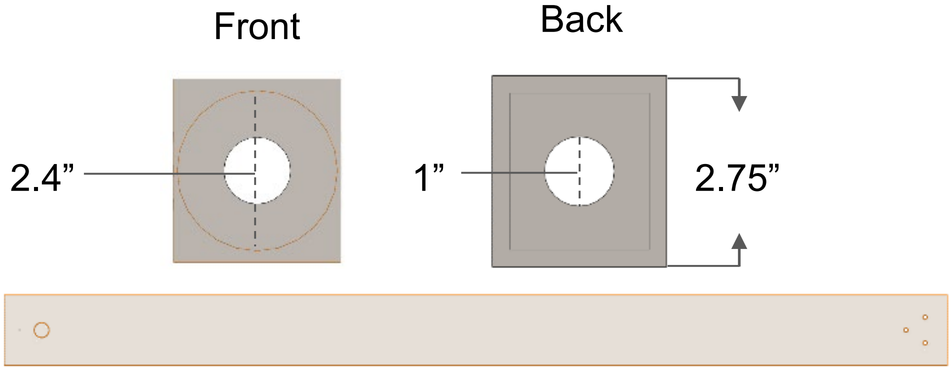
Max Displacement: 3.289e-02 [mm]

**Conclusion:** This modification does not impact the structural integrity of the lift.

# Air Cylinder Case




- Case to secure air cylinder to scissor lift base
- Made out of 0.25” cold rolled low-carbon steel sheet

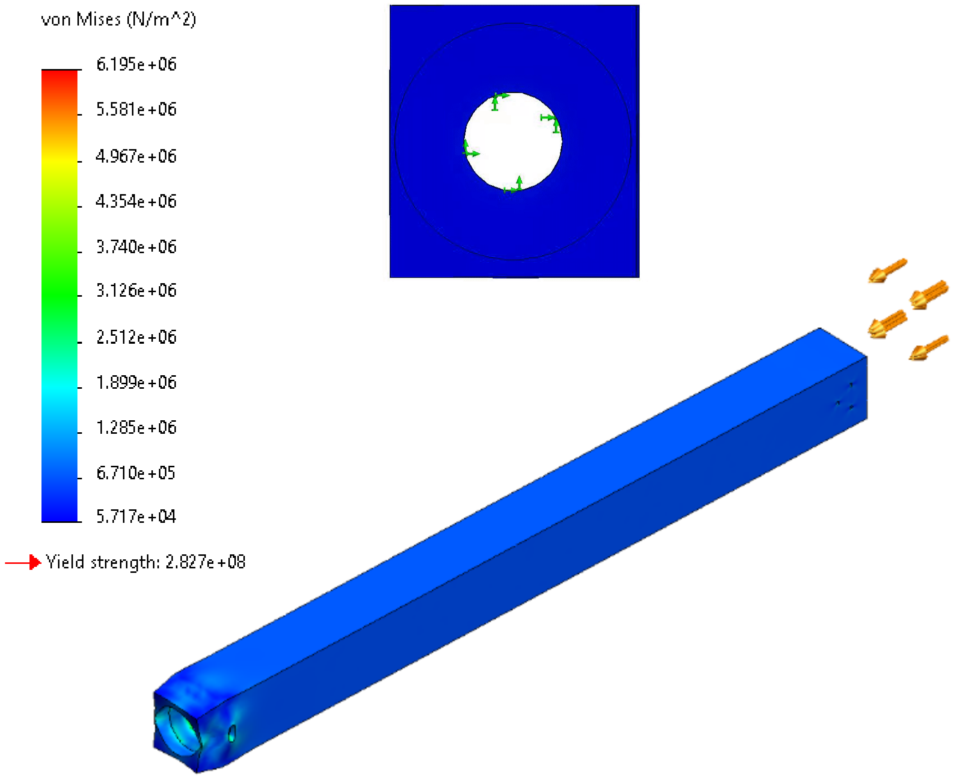
# Air Cylinder Case - Force Analysis

- Fixed at center hole
- Force: 1000 N (Air Cylinder Pushing on Connection)

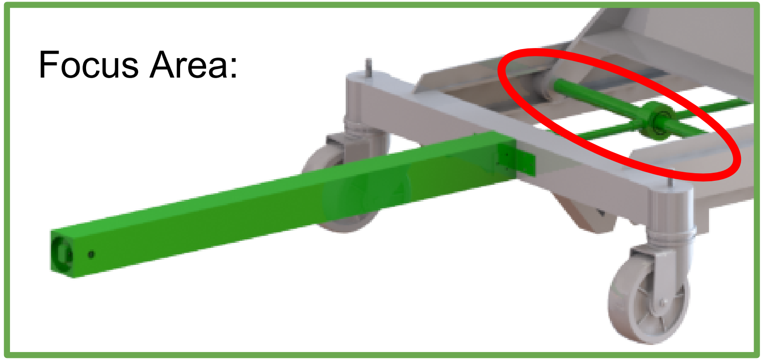
Results:

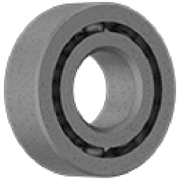
Yield Strength: 2.827e+08 [N/m²]
Max von Mises Stress: 6.195e+06 [N/m²]

Conclusion: The custom cylinder case can withstand the actuation loads

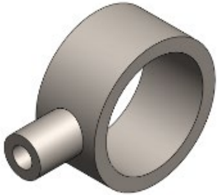


# Actuator Attachment Rod



McMASTER-CARR
High Load Bearing
(2950 N)



Custom 1020 Steel
Sleeve

- Rod will be welded laterally to bottom front strut
- High load bearings allow sleeve rotation
- Rod is made of 1018 cold-rolled steel

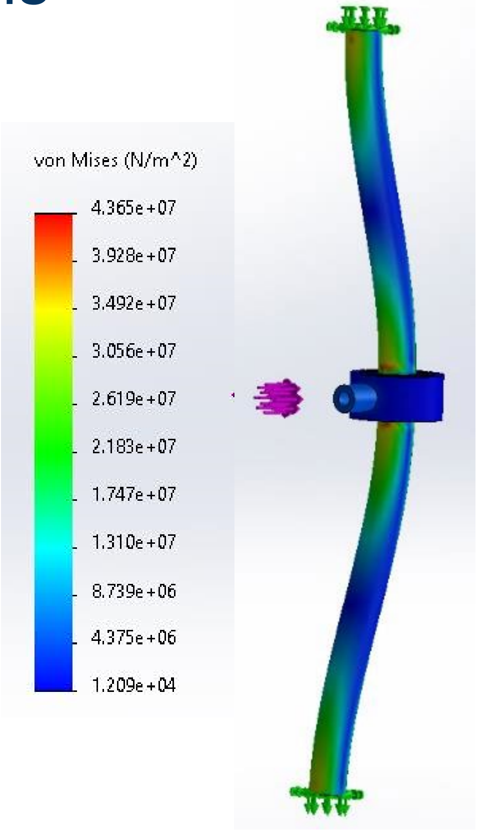
# Actuator Attachment Rod - Force Analysis

- **1020 Steel Specs**:
  Yield Strength: 3.5e+08 [N/m²]

- **1018 Steel Specs**:
  Yield Strength: 5.51e+08 [N/m²]

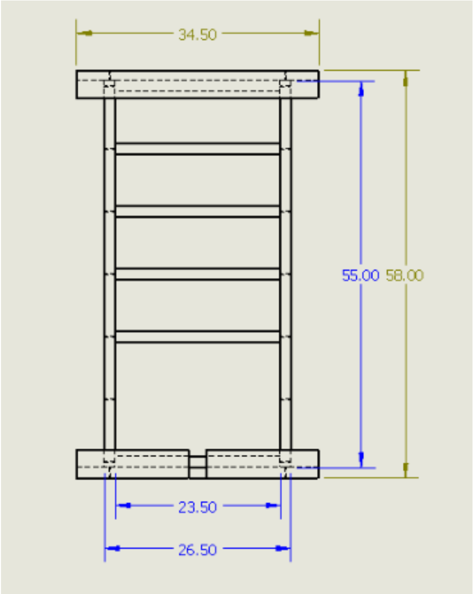
- **Max von Mises Stress**:
  4.365e+07 [N/m²]

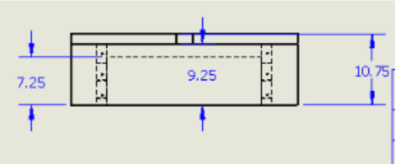
Conclusion: The max stress falls under the Y.S of both 1018 and 1020 steel

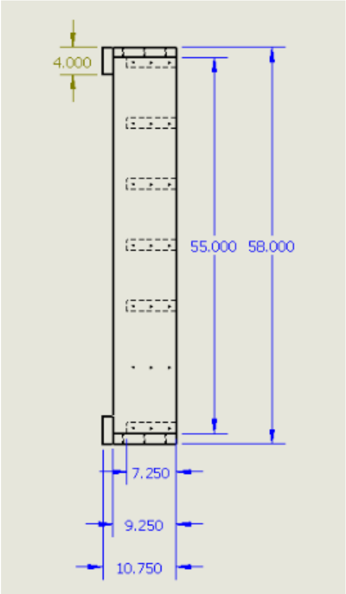


# Wooden Support Platform

## Schematic

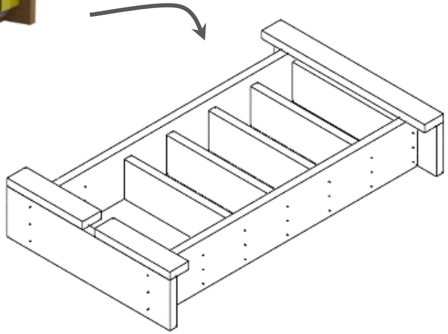



## Structure

Materials:
- Douglas Fir #2 Construction Lumber
- #8 2” Wood Screws



# Project Risks

Section Outline

- Risk Definitions
- Risk Identification
- Pre-Mitigation Risk Matrix
- Mitigation Strategies
- Post-Mitigation Risk Matrix

# Risk Definitions

| Risk Factor Range | Qualitative | Quantitative |
|---|---|---|
| <5 | Minimal | Minimal |
| >5, ≤12 | Minor to major reduction in technical performance | More work required, can still meet deadlines |
| >12 | Catastrophic | Milestone is unable to be achieved or over budget |

| Level | Likelihood | Severity |
|---|---|---|
| 1 | Extremely Improbable | Minimal |
| 2 | Low Likelihood | Minor |
| 3 | Likely | Major |
| 4 | Highly Likely | Serious |
| 5 | Near Certainty | Catastrophic |

# Risk Tables (Pre-Mitigation)

| Risk ID | Category | Description |
|---|---|---|
| ASYNC 1 | Asynchronous Subsystems | The VR, Foot Force, and Mechanical subsystems are not functioning simultaneously. |
| XTRA 2 | Unrealistic Forces | The platform is not able to achieve the desired magnitude of G-Force to cue the athlete to jump and/or introduces extraneous forces. |
| STRUCT 3 | Platform Structural Failure | The platform fails (e.g. tipping, shear or bending, slipping, motor stall, total collapse). |
| CATCH 4 | Human Error (Harness) | The belayer fails to to perform the necessary belay actions to catch the athlete. |
| ATHLT 5 | Human Error (Athlete on Platform) | The athlete fails to mount and jump the platform according to the proper use case. |
| VIS 6 | Visual Cue | The VR simulation runs out of battery and is not able to provide a visual for the athlete. |
| FOOT 7 | Foot Force Collection | The foot force insoles fail due to excessive forces or interference in connection. |

# Likelihood and Severity (Pre-Mitigation)

| Risk ID | Original Severity | Original Likelihood | Original Risk Level |
|---|---|---|---|
| ASYNC 1 | Serious | Highly Likely | **Catastrophic** |
| XTRA 2 | Catastrophic | Likely | **Catastrophic** |
| STRUCT 3 | Catastrophic | Low Likelihood | **Catastrophic** |
| CATCH 4 | Major | Likely | **Hazardous** |
| ATHLT 5 | Serious | Low Likelihood | **Hazardous** |
| VIS 6 | Serious | Low Likelihood | **Hazardous** |
| FOOT 7 | Major | Low Likelihood | **Hazardous** |

| Level | Likelihood | Severity |
|---|---|---|
| **1** | **Extremely Improbable** | **Minimal** |
| **2** | **Low Likelihood** | **Minor** |
| **3** | **Likely** | **Major** |
| **4** | **Highly Likely** | **Serious** |
| **5** | **Near Certainty** | **Catastrophic** |

# Pre-Mitigation Risk Matrix

| Likelihood | | | | | |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | | **ASYNC** | |
| 3 | | | **CATCH** | | **XTRA** |
| 2 | | | **FOOT** | **ATHLT, VIS** | **STRUCT** |
| 1 | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| | **Severity** | | | | |

| Level | Likelihood | Severity |
|---|---|---|
| 1 | Extremely Improbable | Minimal |
| 2 | Low Likelihood | Minor |
| 3 | Likely | Major |
| 4 | Highly Likely | Serious |
| 5 | Near Certainty | Catastrophic |

**Consequence:**

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

# Mitigation Strategies

| Risk ID | Category | Mitigation |
|---|---|---|
| ASYNC 1 | Asynchronous Subsystems | Redundant, modular software so that if one system fails, the others will not be triggered. |
| XTRA 2 | Unrealistic Forces | Adding more powerful pneumatics, testing with reduced loading, structural reinforcements, careful redesign if verification fails. |
| STRUCT 3 | Platform Structural Failure | High quality components, rigorous testing procedures, belay system. |
| CATCH 4 | Human Error (Harness) | Familiar technology and redundancy in system. Knotted ropes will catch athlete if they fall past a certain point. |
| ATHLT 5 | Human Error (Athlete on Platform) | User manual detailing safe user procedure, as well as additional safety measures like the harness. |
| VIS 6 | Visual Cue | Headset will be charged in between uses. |
| FOOT 7 | Foot Force Collection | High quality components and testing to verify loads from product specification sheet. |

# Severity and Likelihood (Post-Mitigation)

| Risk ID | Post-Mitigation Severity | Post-Mitigation Likelihood | Post-Mitigation Risk Level |
|---|---|---|---|
| ASYNC 1 | Minor | Low Likelihood | **Minimal** |
| XTRA 2 | Major | Extremely Improbable | **Minimal** |
| STRUCT 3 | Major | Extremely Improbable | **Minimal** |
| CATCH 4 | Minor | Extremely Improbable | **Minimal** |
| ATHLT 5 | Minor | Extremely Improbable | **Minimal** |
| VIS 6 | Minor | Extremely Improbable | **Minimal** |
| FOOT 7 | Minor | Extremely Improbable | **Minimal** |

| Level | Likelihood | Severity |
|---|---|---|
| **1** | **Extremely Improbable** | **Minimal** |
| **2** | **Low Likelihood** | **Minor** |
| **3** | **Likely** | **Major** |
| **4** | **Highly Likely** | **Serious** |
| **5** | **Near Certainty** | **Catastrophic** |

# Post-Mitigation Risk Matrix

| Likelihood | | | | | |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | | ASYNC | |
| 3 | | | CATCH | | XTRA |
| 2 | | ASYNC | FOOT | ATHLT, VIS | STRUCT |
| 1 | | CATCH, ATHLT, VIS, FOOT | XTRA, STRUCT | | |
| | 1 | 2 | 3 | 4 | 5 |
| | Severity | | | | |

| Level | Likelihood | Severity |
|---|---|---|
| 1 | Extremely Improbable | Minimal |
| 2 | Low Likelihood | Minor |
| 3 | Likely | Major |
| 4 | Highly Likely | Serious |
| 5 | Near Certainty | Catastrophic |

**Consequence:**

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

# Verification & Validation

## Section Outline

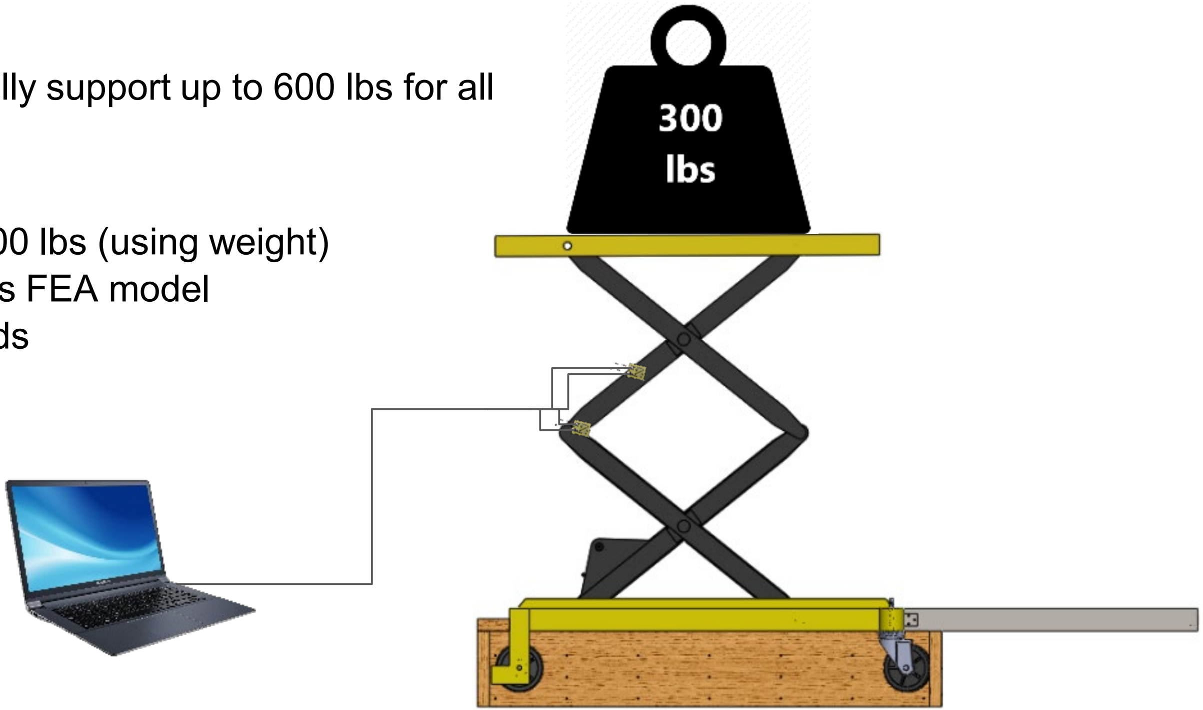
- Verification
    - Structural Integrity
    - Harness Belay Testing
- Validation
    - Synchronicity Test

# Subsystem Verification: Structural Integrity

**FR3: The simulator shall be able to support the forces generated when used by the full range of Nordic USA athletes**

**DR3.1: SKADI shall be able to support up to 600lbs.**

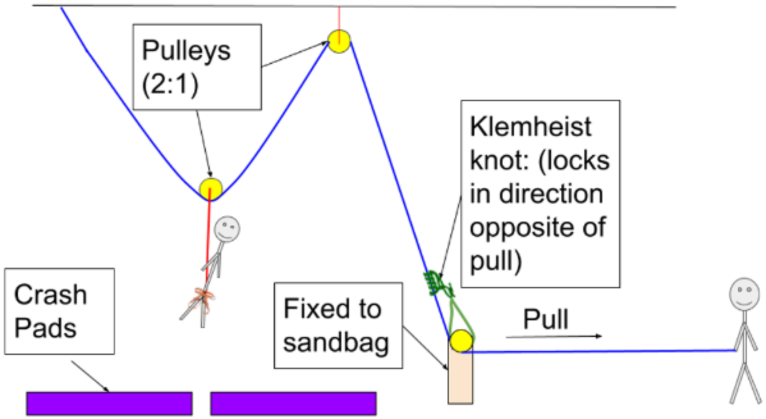
- **Objective**:
  - Verify structure can statically support up to 600 lbs for all possible loading locations
- **Plan**:
  - Incrementally load up to 300 lbs (using weight)
  - Validate/modify SolidWorks FEA model
  - Predict FOS for 600 lb loads
- **Required Hardware**:
  - Strain Gauges
- **Test Location**:
  - AERO Machine Shop
- **Pass Criteria**:
  - No yielding



# Subsystem Verification: Harness Belay Testing

**FR 6: The user will safely be brought to rest following the jump.**

- **Objective**:
  - Prove that belay system can sufficiently rise in height to safely catch jumping user
- **Plan**:
  - Operate belay with secondary safety mechanisms in place
- **Required Hardware**:
  - Belay system
  - Crash Pads
- **Required Measurements**:
  - Length of rope pulled through belay system
- **Test Location**:
  - In discussion with M. Rhode and N. Coyle
  - Potentially AERO 152, Wood & Composites Shop
- **Pass Criteria**:
  - Belayer can easily pull 2 x( 0.8 m + 1 m) = 3.6 m = 11.8 ft within 2.5 seconds



# System Validation: Synchronicity Test Campaign

**FR1: The simulator shall provide visual cues correlating to the phase in jump.**
**FR2: The simulator shall provide force and motion cues correlating to the phase in jump.**

- **Objective**:
  - Prove that visual cues and physical cues are in sync, and that both accurately correspond to motion on a real ski jump ramp
- **Plan**:

Component 1:
Empirical Data on Real Ski Jump Slope

Component 2:
Simulated Data in VR Experience

Component 3:
Empirical Data on SKADI Training Simulator Platform

# Synchronicity Test Campaign: Real Ski Jump Ramp

**FR1: The simulator shall  provide visual cues correlating to the phase in jump.**
**FR2: The simulator shall provide force and motion cues correlating to the phase in jump.**

**Objective**:

- Obtain empirical position and acceleration data on real ski jump

**Required Hardware**:

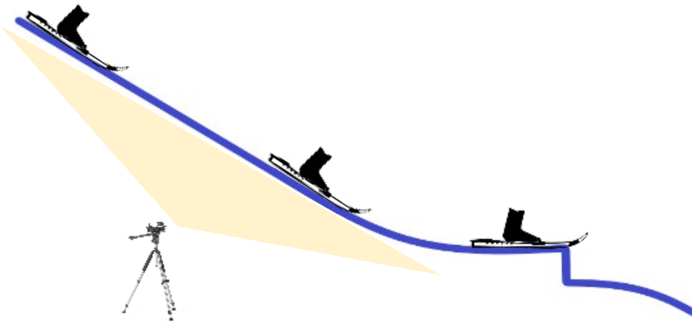
- Ski & Boot
- Camera capturing at least one frame per 300 milliseconds
- Accelerometer & Data Logger

**Required Measurements**:

- Position (via camera) & Acceleration (via accelerometer) on ramp vs time

**Test Location**:

- Steamboat Springs training facility



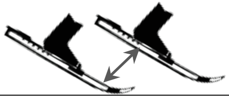
# Synchronicity Test Campaign: Real Ski Jump Ramp

**Plan**:

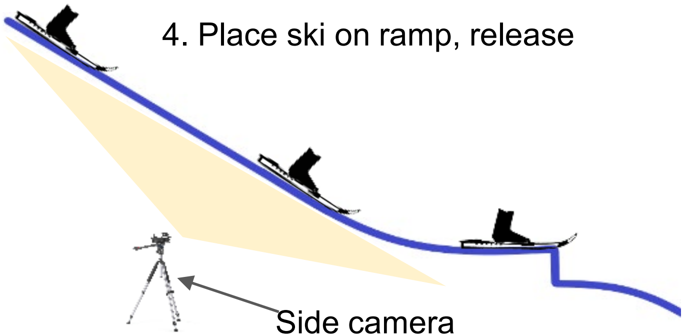
1. Set up Side camera to capture location data over time

2. Place accelerometer in ski boot on ski, begin data capture

3. Shake ski boot to provide timing signal for visual and accelerometer data



4. Place ski on ramp, release




5. Export accelerometer data to .csv, synchronize to visual position data from camera

# Synchronicity Test Campaign: VR Experience

**FR1: The simulator shall provide visual cues correlating to the phase in jump.**
**DR1.1: The visual cue shall be synced to within ±300 milliseconds of the physical cue.**

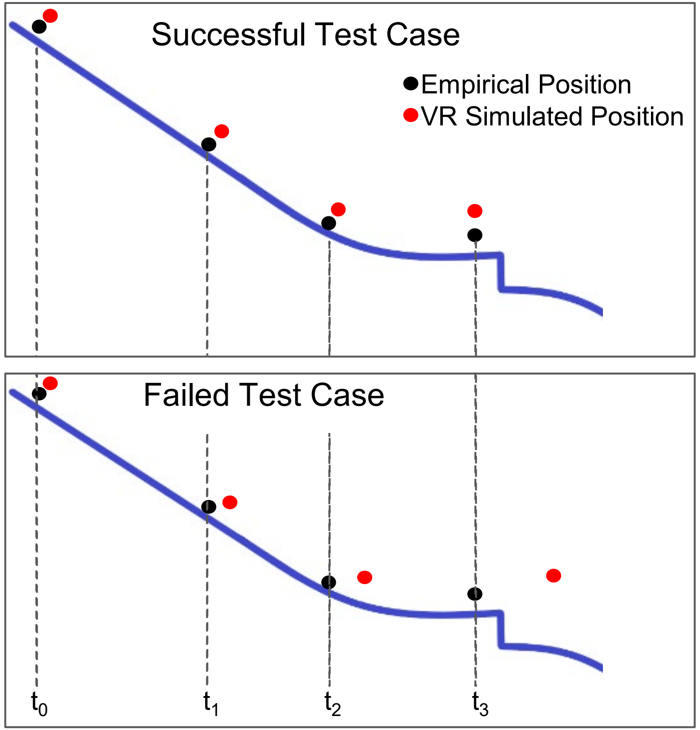
**Objective**:
- Prove VR simulated position over time matches that of ski jump

**Plan**:
- Output VR simulated position with timestamps at 3-4 points
- Compare timestamp of simulated positions to timestamp of true position from camera data

**Required Hardware**:
- VR Simulation

**Required Measurements**:
- VR simulated position with timestamps

**Pass Criteria**:
- At a given position, difference in timestamps is less than 300 milliseconds



# Synchronicity Test Campaign: SKADI Training Simulator

**FR2: The simulator shall provide force and motion cues correlating to the phase in jump.**
**DR2.1: Across the curved in run phase, the slope of force with respect to time that SKADI exerts will be within 20% of the slope of force with respect to time of a true ski jump ramp.**

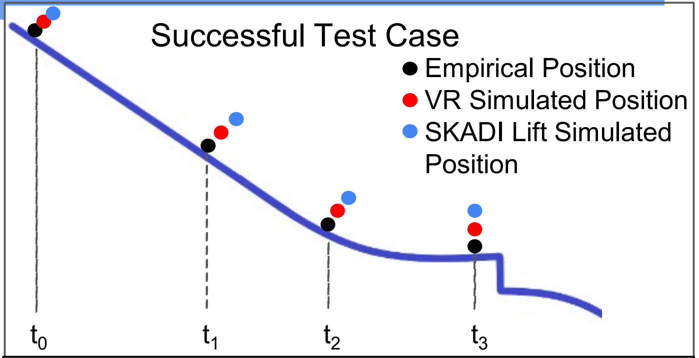
**Objective**:
- Prove SKADI lift simulated position over time matches those of ski jump and VR simulation

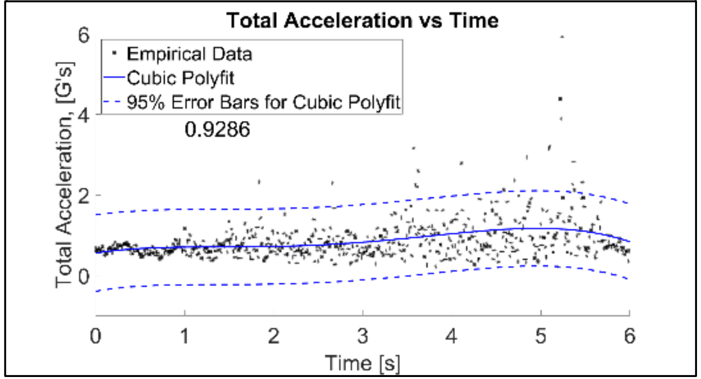
**Plan**:
- Compare timestamp of lift simulated positions to timestamp of true position from camera data and of VR simulated position
- Compare accelerometer data vs time on lift to real ski jump

**Required Hardware**:
- Accelerometer & Data Logger

**Test Location**:
- AERO Machine Shop

**Pass Criteria**:
- At a given position, difference in timestamps is less than 300 milliseconds
- At any time, slope of lift is within 20% of slope of jump



# Project Planning

Section Outline

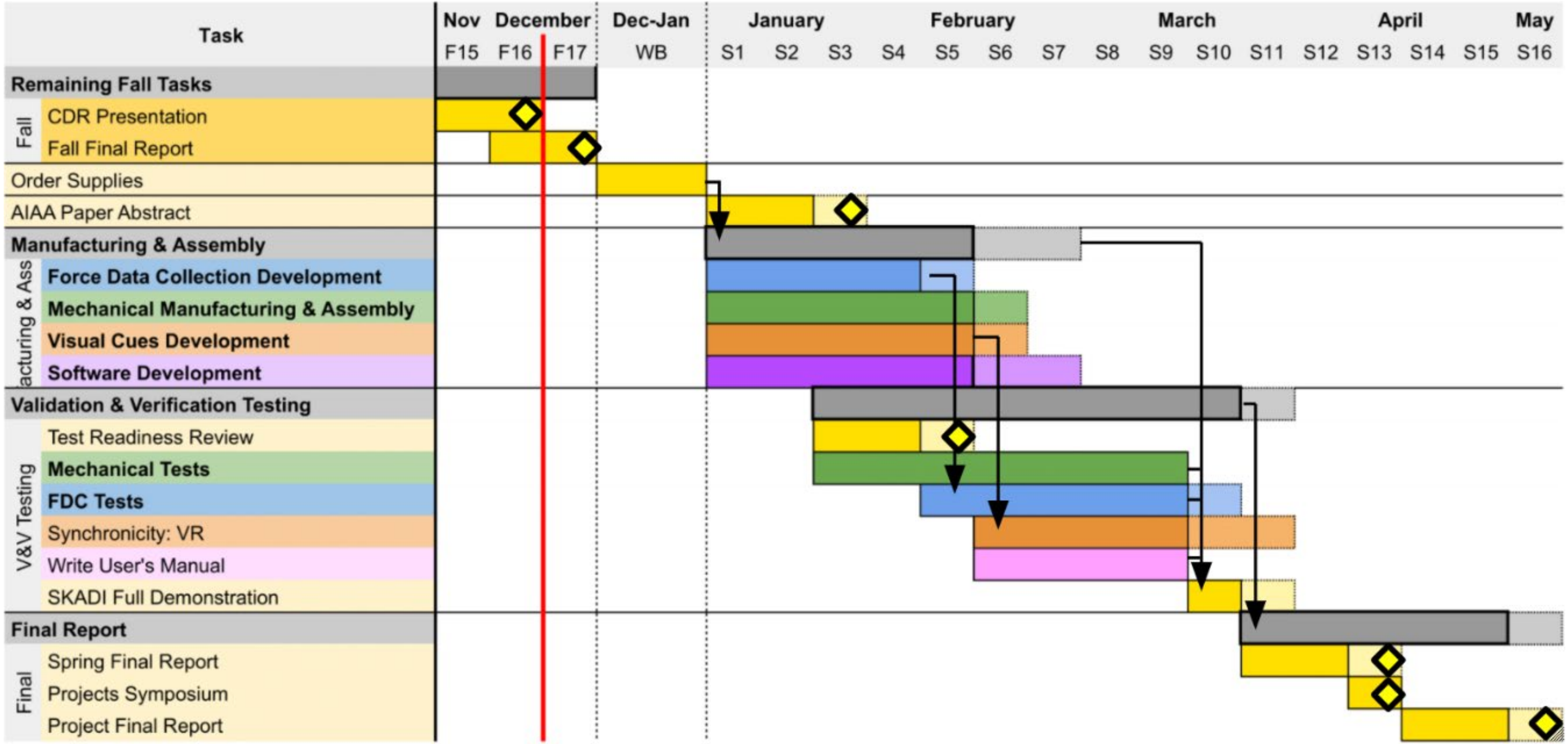
- Work Plan (WBS, Gantt)
- Cost Plan
- Testing Plan

# Work Plan - WBS

## SKADI

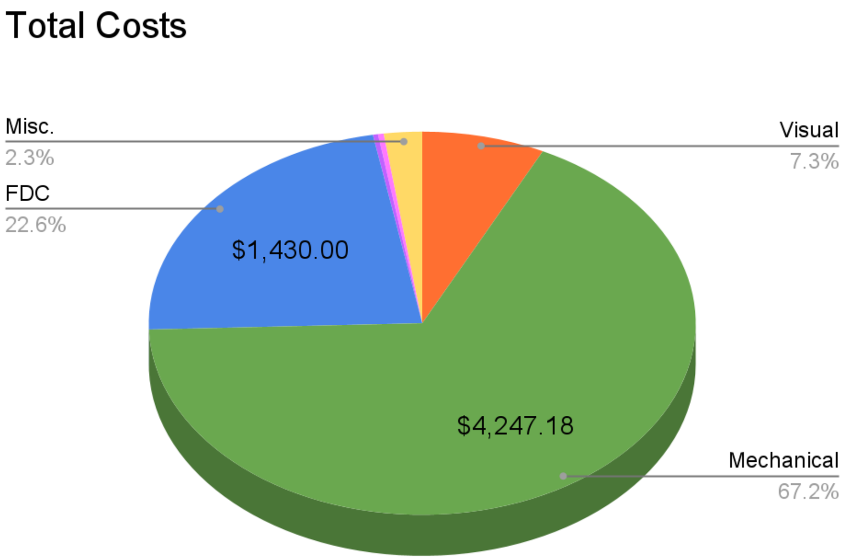
| Visual Cues | Force Data Collection | Mechanical | Software | Testing | Deliverables | |
|---|---|---|---|---|---|---|
| Component Selection | Component Selection | Component Selection | *Synchronization Code* | *Structural* | Fall | Spring |
| *Creation* | *Sensor-Boot Integration & Assembly* | Force Profile Comparison | *Pneumatic Control Code* | *Belay* | PDD | *AIAA Paper* |
| *Synchronization* | *Calibration* | Structural Analysis | *Headset Control Code* | *User Force* | CDD | *TRR* |
| | | Belay System Design | | *Sensor Accuracy* | PDR | *SPR* |
| | | *Manufacturing & Assembly* | | *User's Manual* | CDR | *SPP* |
| | | | | *Synchronicity* | *FFR* | *PFR* |
| | | | | *SKADI Demonstration* | | |

# Work Plan - Gantt Chart



# Cost Plan

| Subsystem | Expected Cost | Budgeted | Margin |
|---|---|---|---|
| Visual | $459.22 | $500.00 | 8% |
| Mechanical | $4247.18 | $5000.00 | 15% |
| FDC | $1430.00 | $1500.00 | 5% |
| Software | $19.00 | $500.00 | 96% |
| Testing | $20.99 | $1000.00 | 98% |
| Misc. | $142.94 | $1500.00 | 90% |
| **TOTAL** | **$6319.33** | **$10,000.00** | **37%** |



# Testing Plan

| Test Name | Description | Logistics | | |
|---|---|---|---|---|
| | | Location | Anticipated Date | Safety Risks |
| Structure | Validate FEA models by loading to use case weight | Machine Shop | March 2022 | Heavy loads (300 lbs) |
| Harness/Belay | Validate use case by demonstration | (In Discussion) Wood & Composites Shop | February/March 2022 | Mechanism Failure (crash pads in place) |
| Synchronicity: Empirical on Real Ramp | Gather empirical acceleration and position data | USA Nordic Training Facility, Steamboat Springs | December 2021/ January 2022 | Equipment damage |
| Synchronicity: Simulated in VR | Generate simulated position data | AERO 140 | February 2022 | N/A |
| Synchronicity: Empirical from SKADI | Gather empirical acceleration and position data, compare to real ramp and VR | Machine Shop | March 2022 | Heavy Loads (300 lbs) |

# Acknowledgments

*USA Nordic Team*: Tim Tetreault, Jed Hinkley

*Faculty Advisor*: Dr. Melvin Rafi

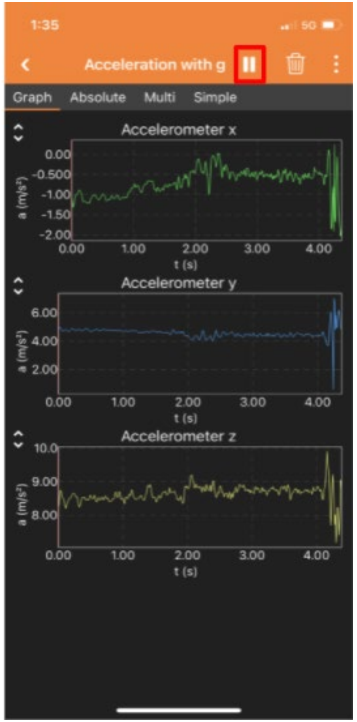
*PDR Reviewers*: Emma Markovich

*Additional Help*:  Dr. Jean Koster, Prof. Bobby Hodgkinson, Kathryn Wingate, Matthew Rhode, Nathan Coyle, Donna Gerren

# Questions?

# Supporting Materials

# Acceleration Data Collection


1:35
Acceleration with g
Graph
Absolute
Multi
Simple
Accelerometer x
a (m/s²)
0.00
-0.500
-1.00
-1.50
-2.00
0.00
1.00
2.00
3.00
4.00
t (s)
Accelerometer y
a (m/s²)
6.00
4.00
2.00
0.00
1.00
2.00
3.00
4.00
t (s)
Accelerometer z
a (m/s²)
10.0
9.00
8.00
0.00
1.00
2.00
3.00
4.00
t (s)

# Zero Velocity Solution

# Final Velocity Justification

Max velocity: 0.9 *m/s*

$$\frac{1}{2}mv^2 = KE = PE = mgh$$

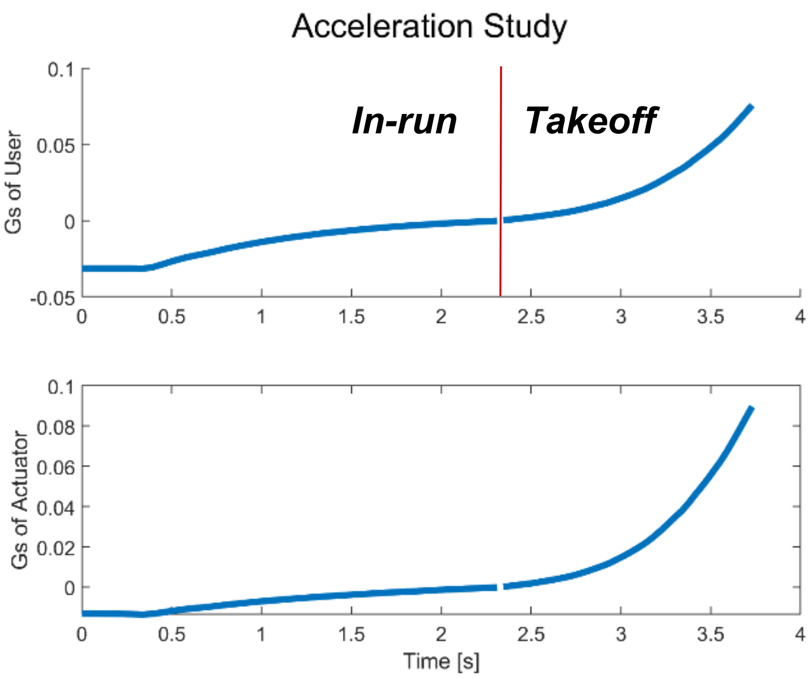
Resultant height: 0.04 *m*

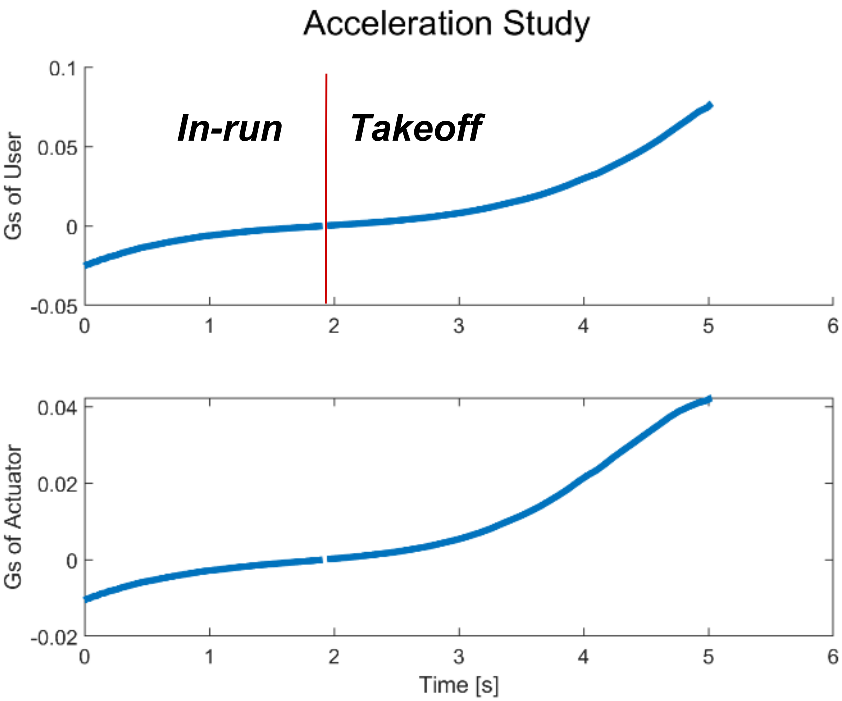
1.5 *in*

$$h = \frac{v^2}{2g}$$

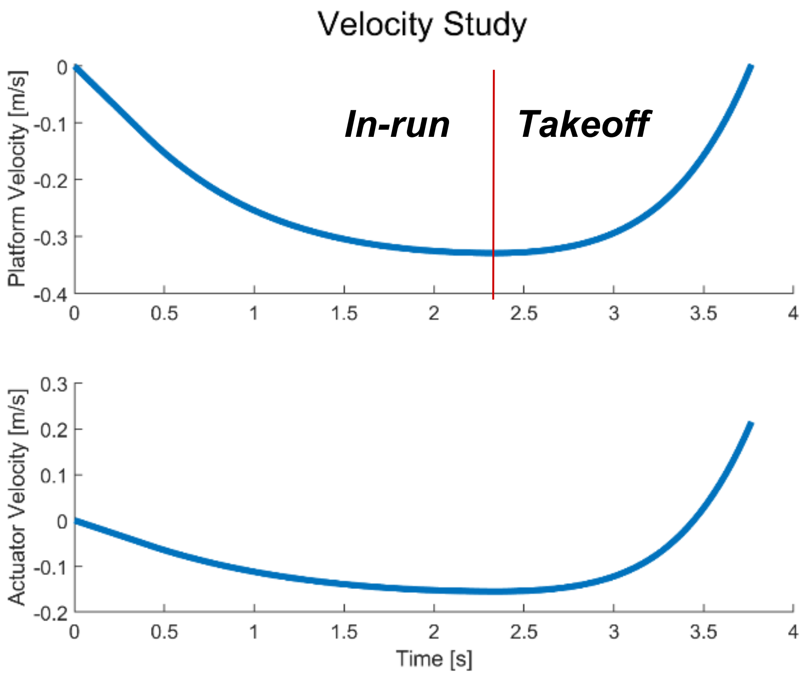
# 0 Velocity

# Original



# 0 Velocity

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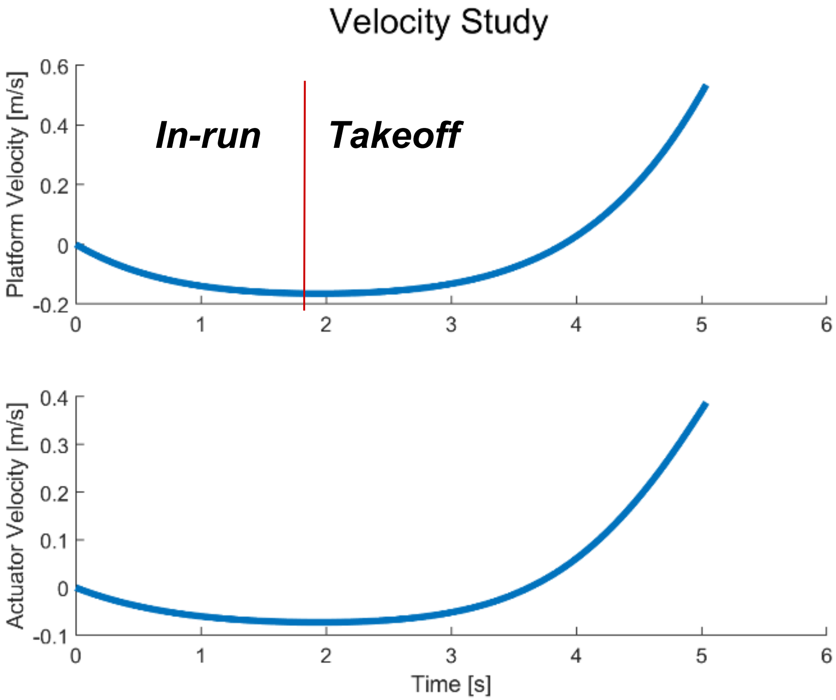
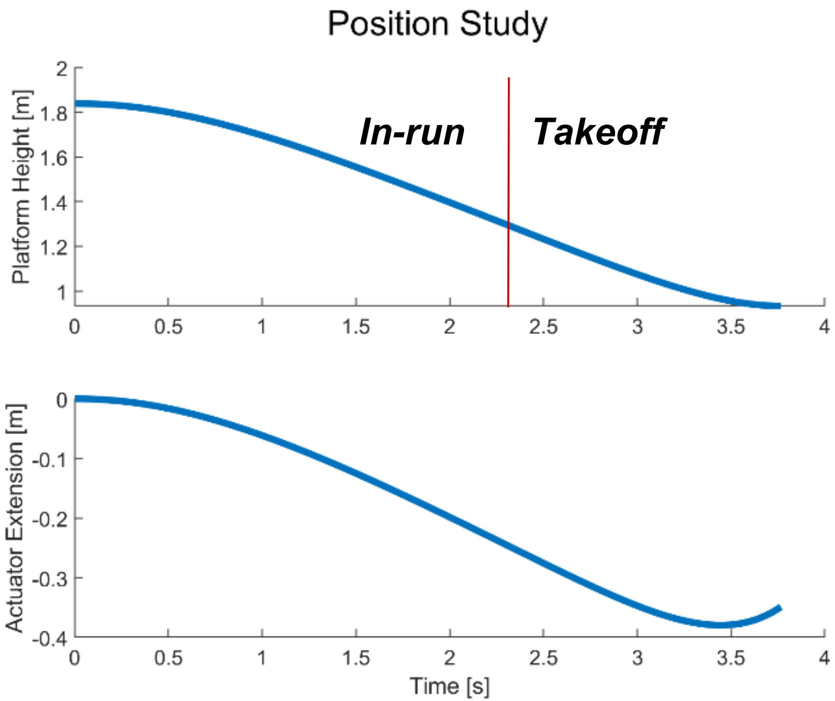
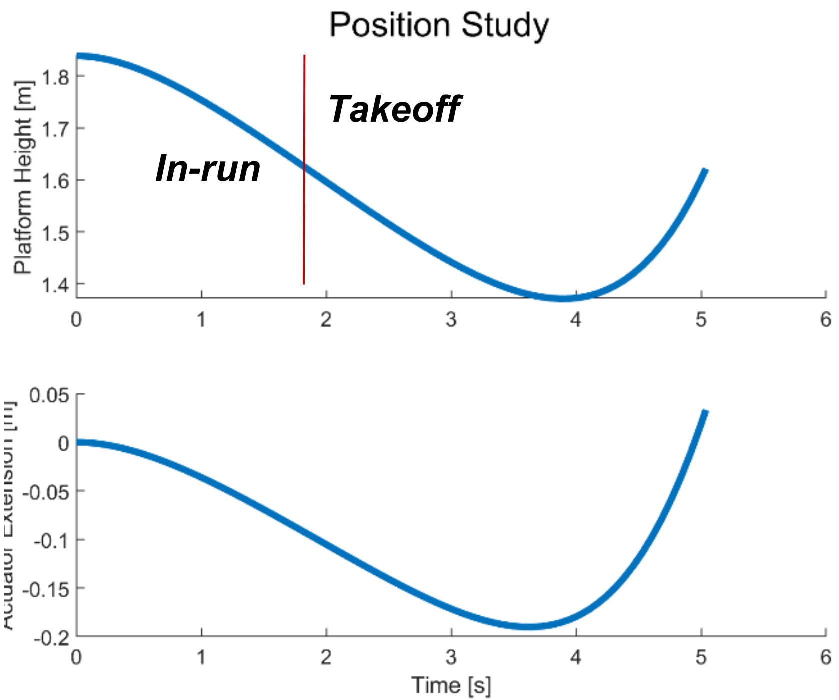


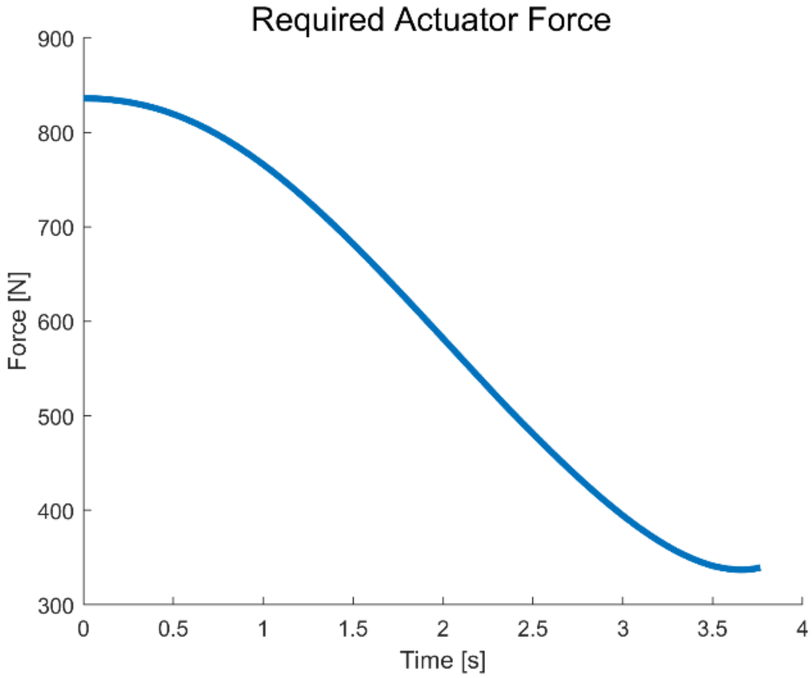
# 0 Velocity



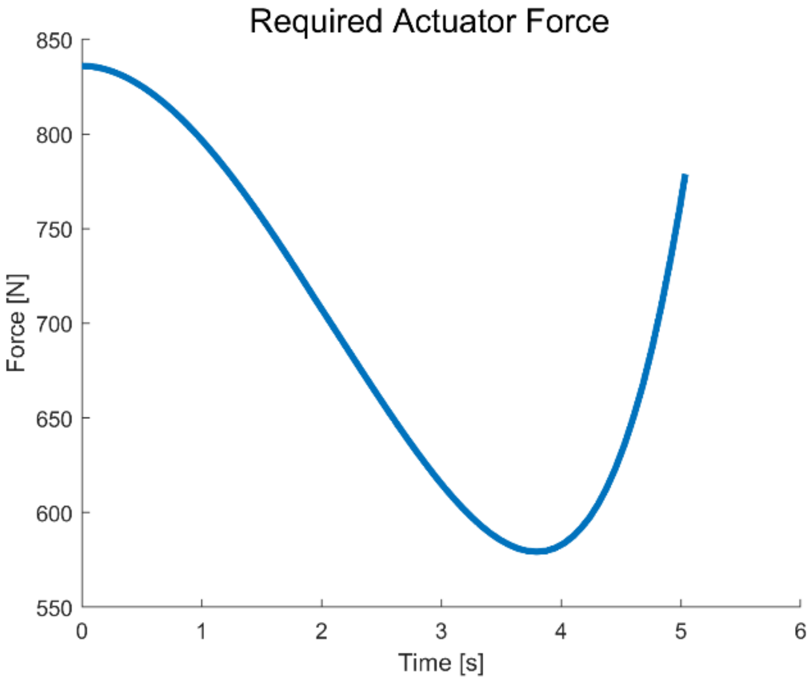

# Original



# 0 Velocity

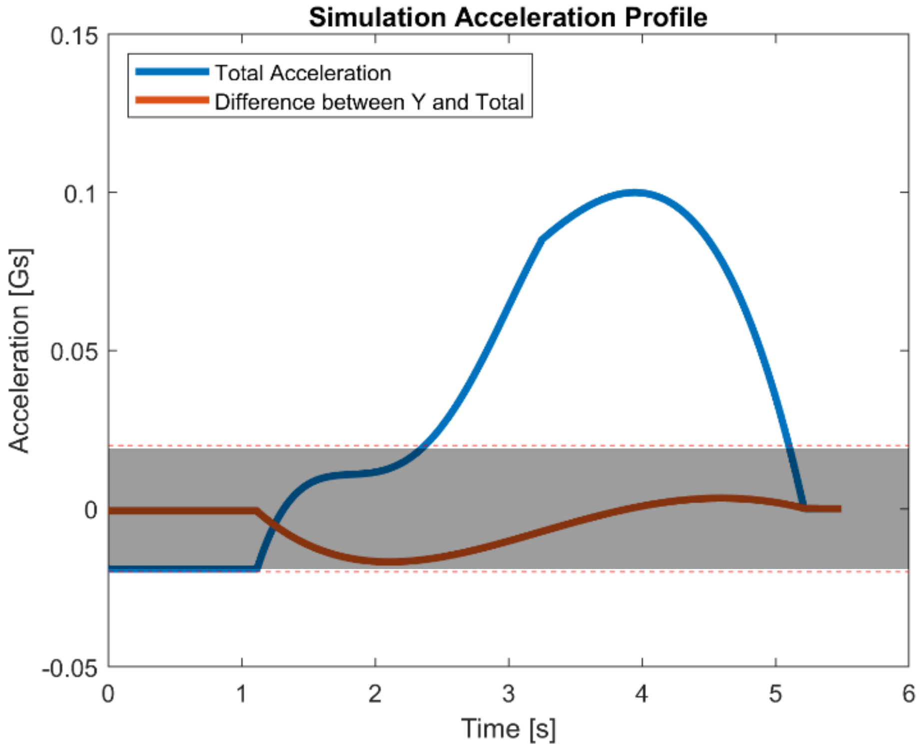



# Original

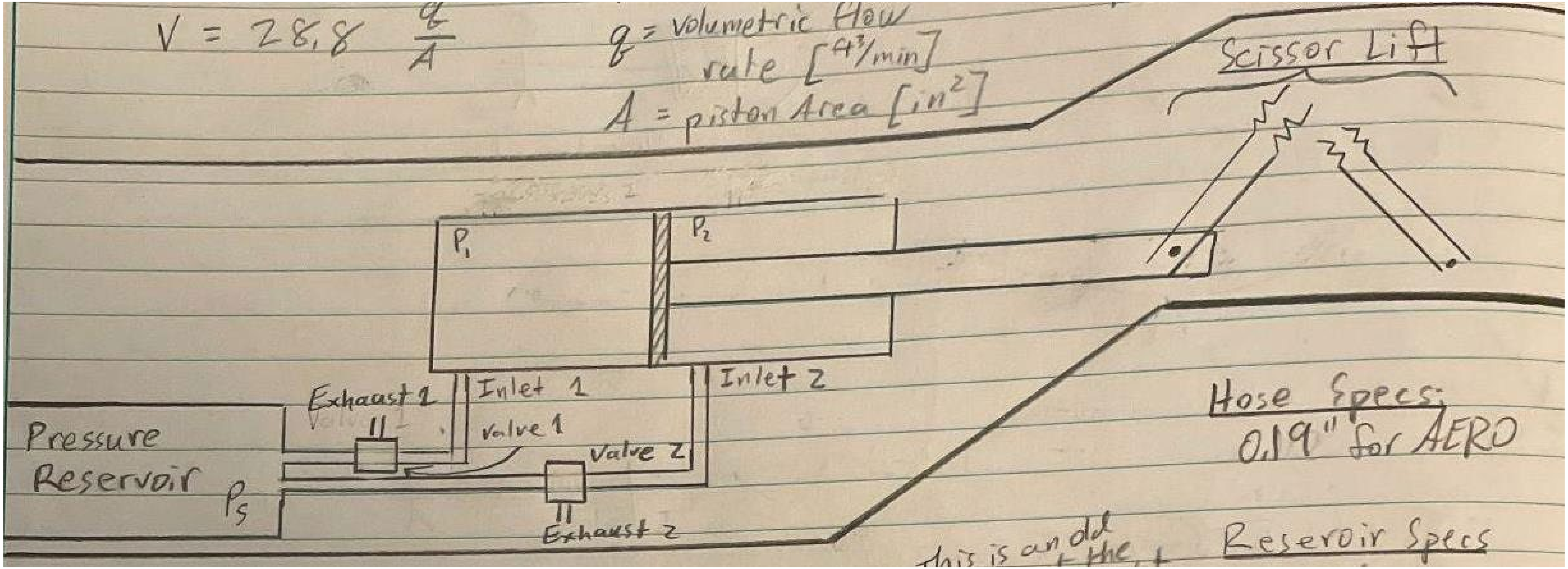


# Vertical Verification

# Vertical Focus Verification



# Pneumatics



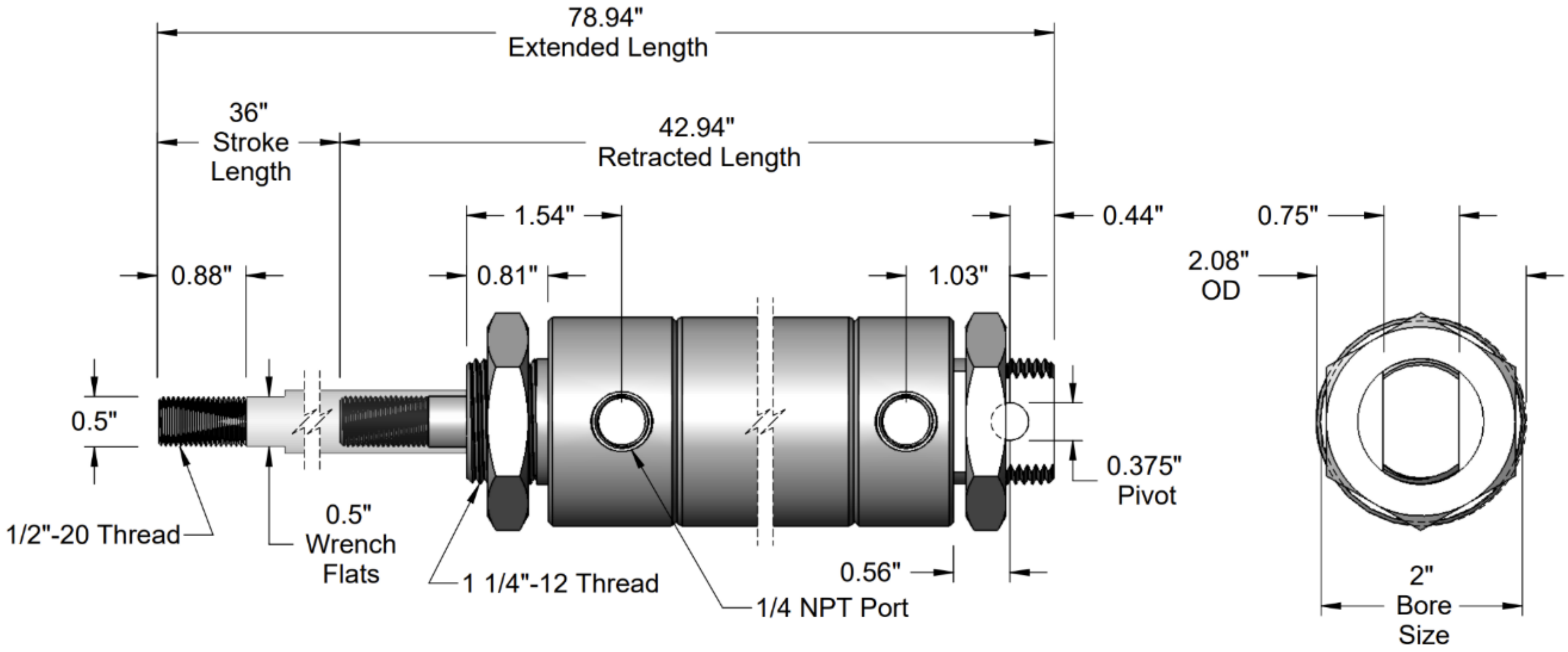
V = 28.8 q/A
q = volumetric flow rate [ft³/min]
A = piston Area [in²]
Scissor Lift
P1
P2
Inlet 1
Inlet 2
Exhaust 1
Valve 1
Valve 2
Exhaust 2
Pressure Reservoir
Ps
Hose Specs:
0.19" for AERO
Reservoir Specs

<u>From Engineering Toolbox</u>

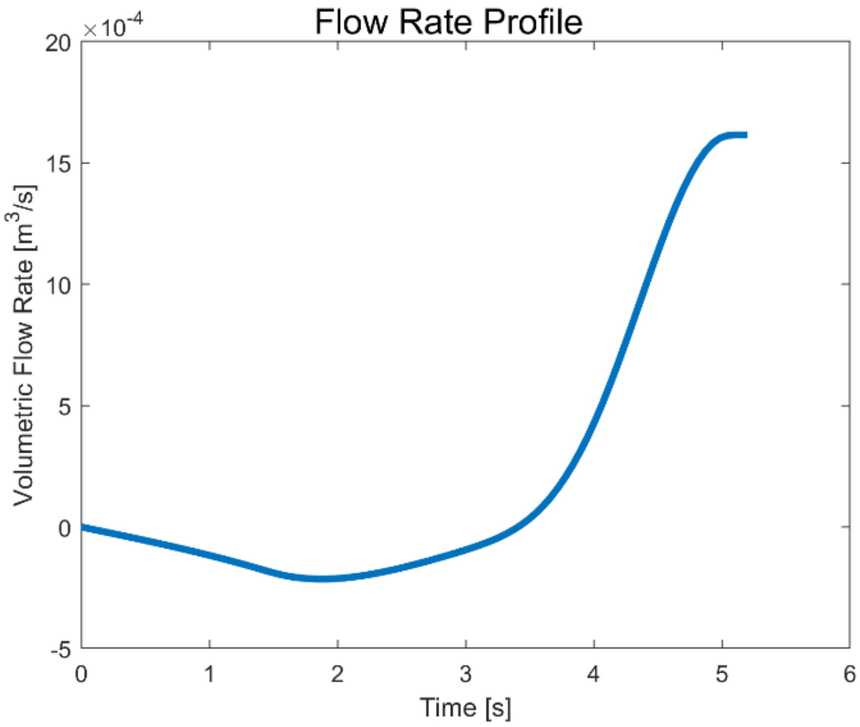
$$V = 28.8 \frac{q}{A}$$

$$q_{feasible} = \left[ \frac{2}{\rho} (\Delta P) \right]^{1/2} \left( \pi \left( \frac{d_{outlet}}{2} \right)^2 \right)$$

# Pneumatic Cylinder Specs



# Flow Rate


Flow Rate Profile
×10^-4
20
15
10
5
0
-5
Volumetric Flow Rate [m^3/s]
0
1
2
3
4
5
6
Time [s]

# Feedback Control: Backup Distance Sensor

Cost: ~$1000 (800 more)

Accuracy: ±1 mm

Range: 0-5000 mm

# Structural Calculations

# Bolt Analysis

- Each bolt takes 100 lbs in tension
- Each bolt takes 50 lbs in shear
- We need to support 220 lbs
- 6 bolts gives a FOS of 2.7 in tension and 1.36 in shear

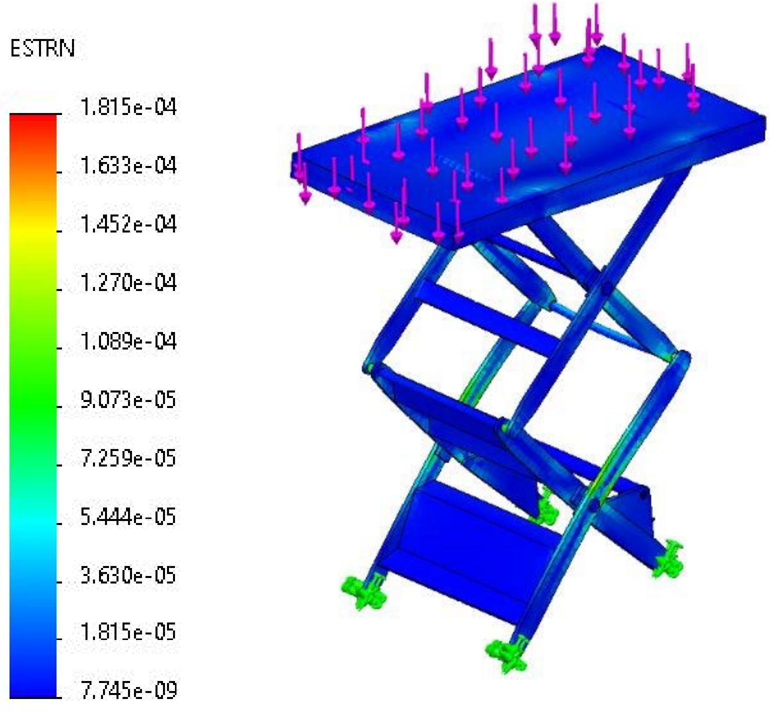
# Structural Analysis - Vertical Load Strain

Assumptions:

- Lift made of 1023 low-carbon steel
- Maximum platform load: 2669 N (600 lbs)
- Maximum dynamic load: 1000 N

Results:

Max Strain: 1.815e-04

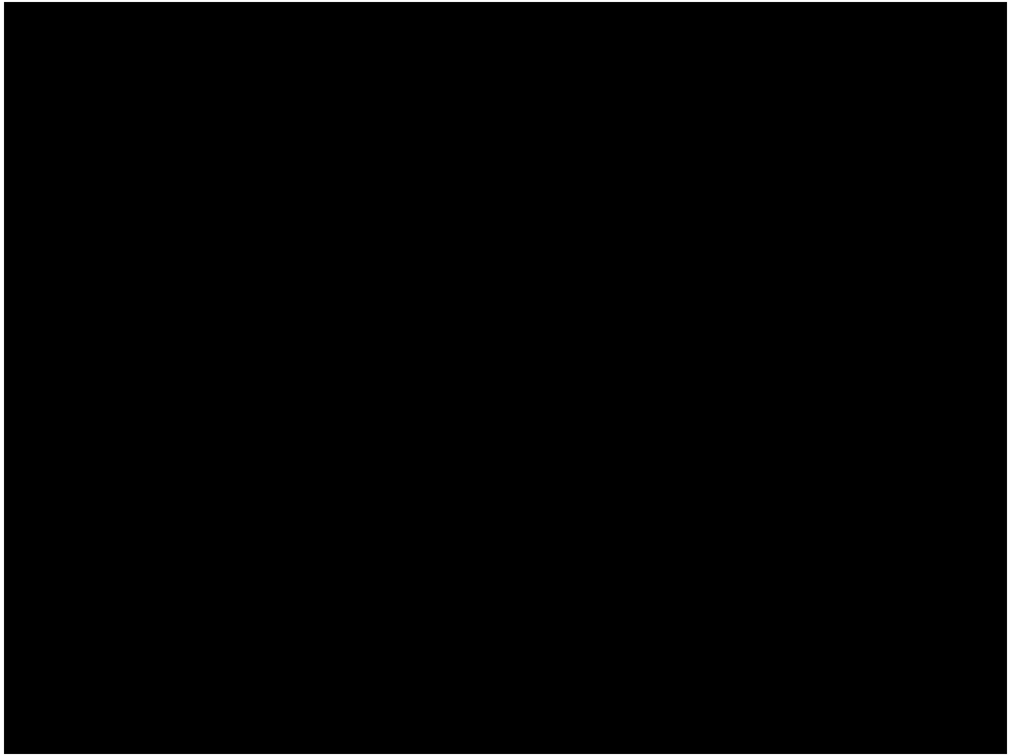


# Horizontal Force From User

- Designed max weight: 600 lbs
- Coefficient of friction: 0.64
  - https://www.engineersedge.com/coeffients_of_friction.htm
- F = μN

| | | |
|---|---|---|
| Rubber (60 A Belt) | Stainless Steel 316 | .64 |

# Belay System Demonstration



# Mech risks

- Tipping
  - Base design
- Failure in shear
  - FEA
- Failure in bending
  - FEA
- Total collapse
  - Belay system and shocks

# Visual

**Links to Slides**

# Visual Software Creation Steps

| **Arduino to PC:** | **Arduino to Bluetooth:** |
|---|---|
| • Can read and write arduino data to C++ program<br>• Data can be transferred at desired intervals | • Arduino can successfully connect to Oculus via bluetooth<br>• Successfully send data from other android device to arduino via bt |
| **Arduino+Unity to Oculus:**<br>• Purchase and explore Unity arduino bluetooth plugin<br>• Can successfully send data from unity application on oculus to arduino | |

# Visual Software Next Steps

- Create VR graphics in Unity
- Add backend to unity program using unity asset ‘Arduino Bluetooth Plugin’
- Export unity to app lab (done before)
- Use file created as command to trigger pneumatic subsystem

# Visual Cues Hardware

**Hardware:** Oculus Quest 2

**Cost:** $500 for goggles + accessories

**Important Specs:**

**RAM:** 6GB

**Storage:** 128GB

**Maximum Render Resolution:** 5408 x 2736

# Mechanical

**Links to Slides**

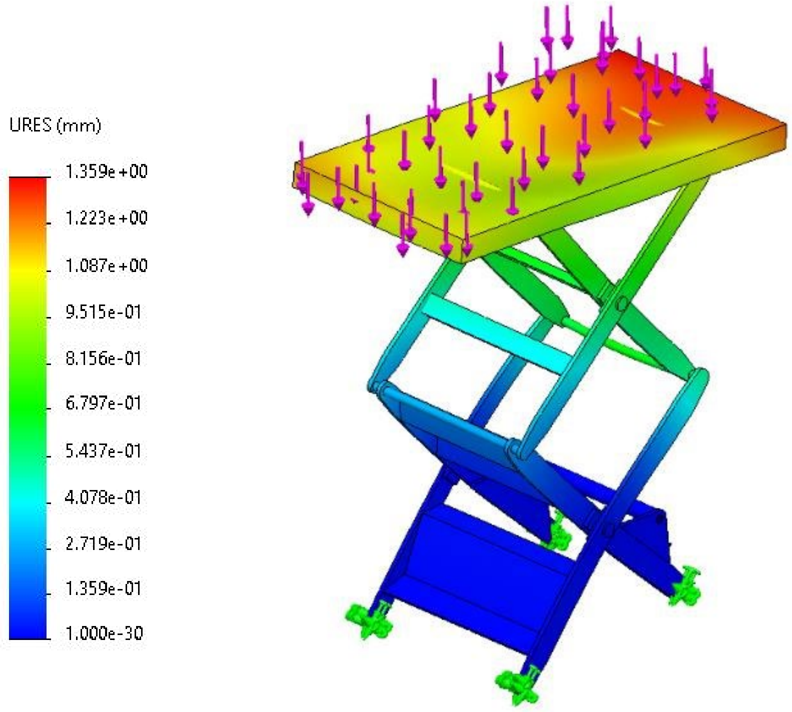
# Structural Analysis - Vertical Displacement

Assumptions:

- Lift made of 1023 low-carbon steel
- Maximum platform load: 2669 N (600 lbs)
- Maximum dynamic load: 1000 N

Results:

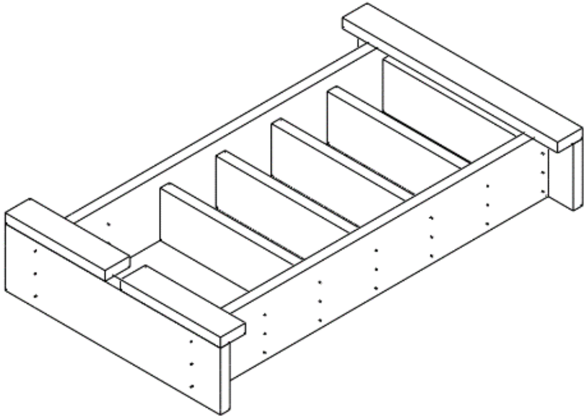
Max Displacement: 1.359 [mm]

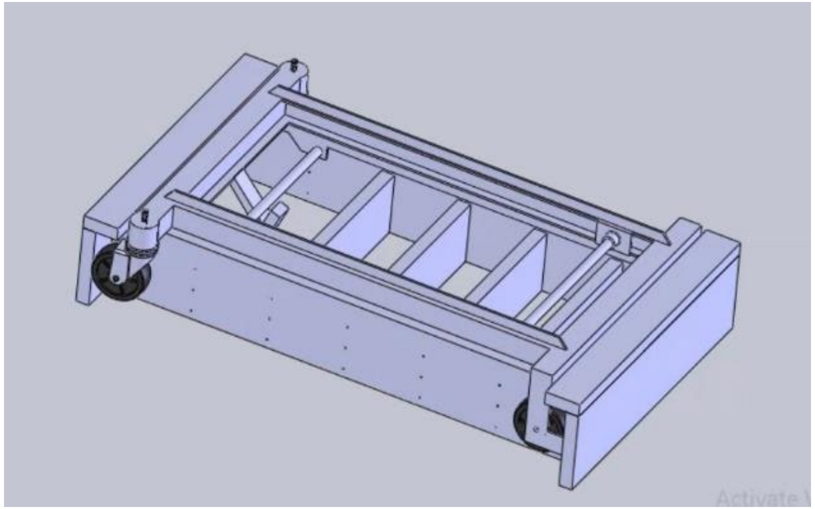


# Belay System Strength Analysis

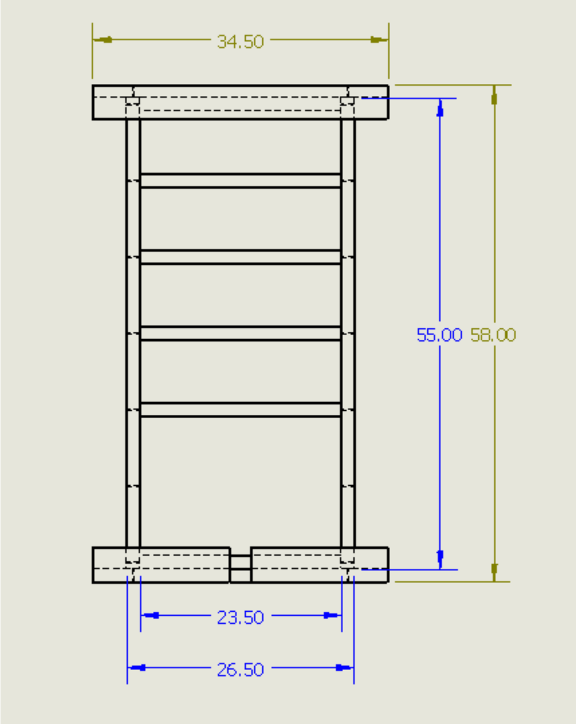
- Knowns:
  - Rope strength: With an 80 kg mass, the impact force is 5.6kN with a fall factor of 0.3 (Length of fall/length of rope), max is 25kN
  - Carabiner strength: 25kN
  - Anchor attachment strength: 22kN
  - Cordelette/Klemheist strength: 7.5kN
  - Harness Strength: 21kN
- Assumptions:
  - Rope length  at shortest point is about 12m assuming a ceiling gym height of 20 feet
  - The maximum slack/fall is 1 meter
  - Shock loading is most extreme case
- Conclusion/Results:
  - At maximum, the fall factor would be 0.083 which is much lower than 0.3
  - The weakest point is the cordelette which can still support 7.5kN which is an FOS of 1.33 for the rope tested at factor fall of 0.3
  - The cordelette provides a redundant system and is not the primary hardware absorbing the force

# Wooden Base With Scissor Base

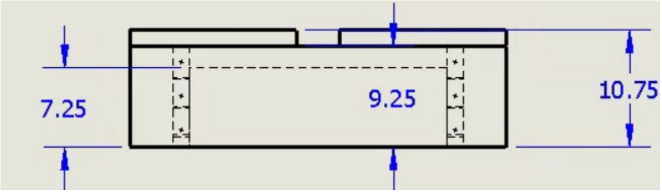


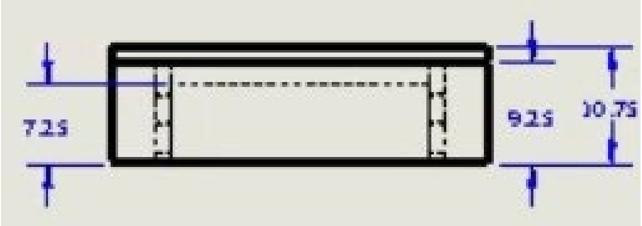


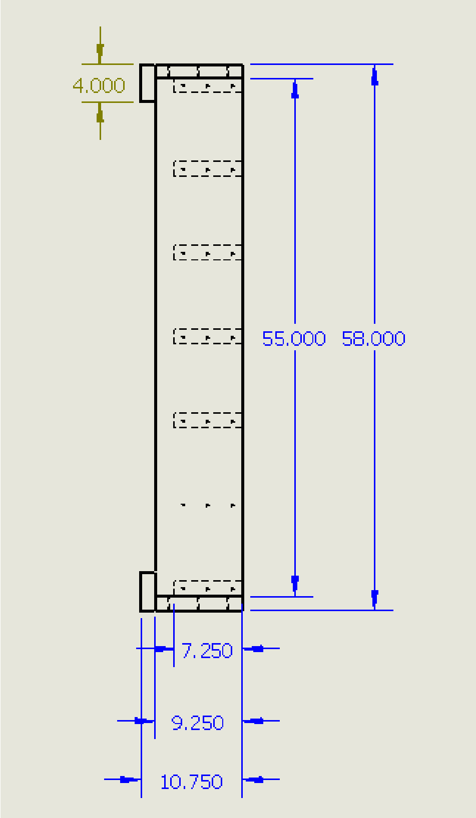
# Wooden Base: Drawing




CAD Drawings and Dimensions: All in Inches



# Wood Orientation as referenced in Calculations

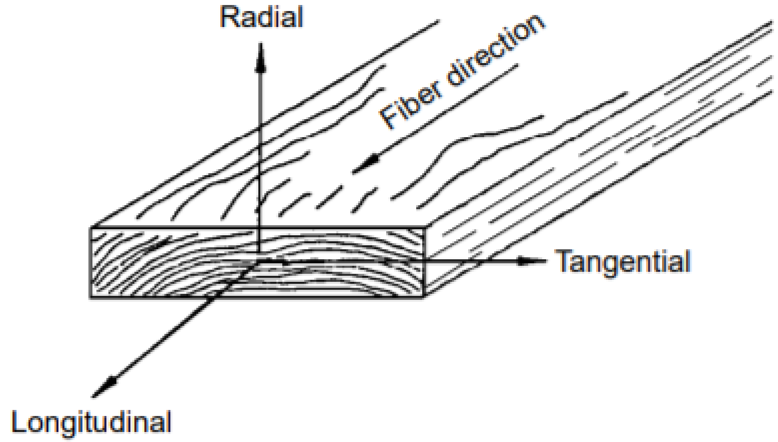



**Figure 4–1. Three principal axes of wood with respect to grain direction and growth rings.**

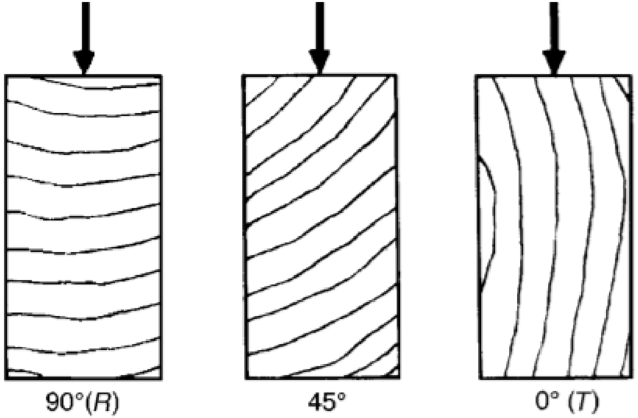



**Figure 4–6. Direction of load in relation to direction of annual growth rings: 90° or perpendicular (*R*), 45°, 0° or parallel (*T*).**

Figures from Wood Handbook, pg 4-2 and 4-31

# Deck Design: Douglas Fir Specs

| | Imperial Units |
|---|---|
| Tension Parallel to Grain | 575 psi |
| Shear Parallel to Grain | 180 psi |
| Compression Perpendicular to Grain | 625 psi |
| Compression Parallel to Grain | 1350 psi |
| Modulus of Elasticity | 1.6 Mpa |
| Modulus of Elasticity (min) | 580 kPa |

National Design Specification Design Values for Wood Construction

# Stress Analysis: Wooden Base

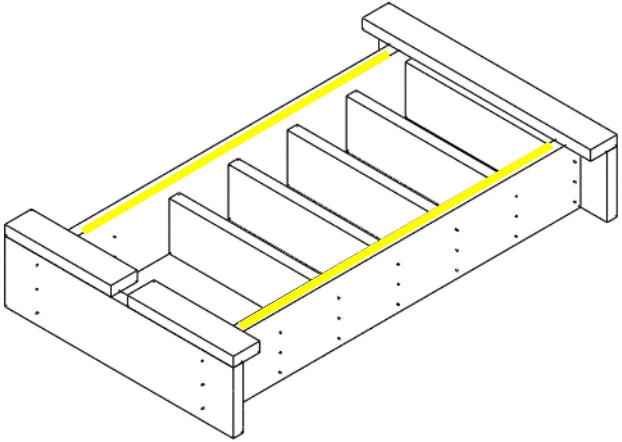
Assume a 21,234.8 lbf force is evenly distributed (F = 600 lbs * 1.1(32.174 in/s^2))

Douglas Fir Compression Perpendicular to Grain = 625 psi

Minimum Area = 21234.8/625 = 33.9757 in^2

Surface Contact Area = (2.5*1.5*4)+(1.75-1.3)*44*2 = 54.6 in^2

$$\tau = \frac{F}{A}$$



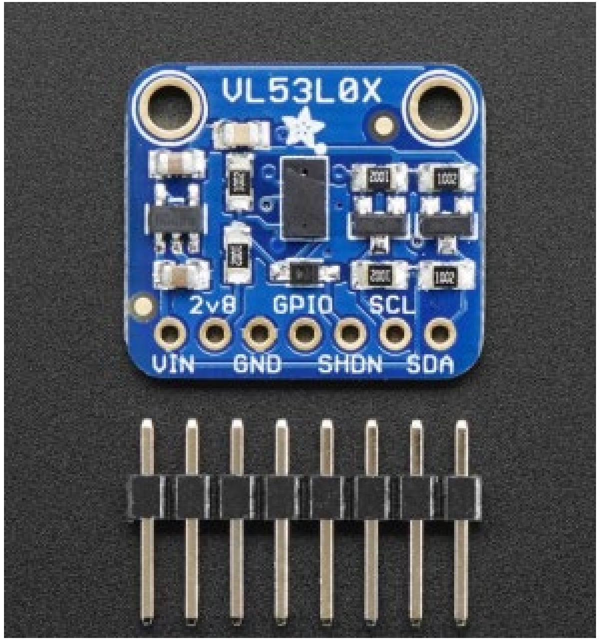
Surface contact area is highlighted

# S2 High- Flow Cylinder Positioning system

- Features
  - “The S2 servo pneumatic positioning system combines together a proportional valve, sensors and embedded control electronics to linearly position cylinders and actuators, creating an air servo actuator that can be controlled from the PLC”
  - Controls pressure differences between two-air cylinder
  - Uses custom software for PID control and tuning
- Specifications
  - Speeds up to 2m/s
  - Position accuracy of 0.1-1%
  - ¼” NPTF Mounts
  - Command voltage input and output: 0-10VDC

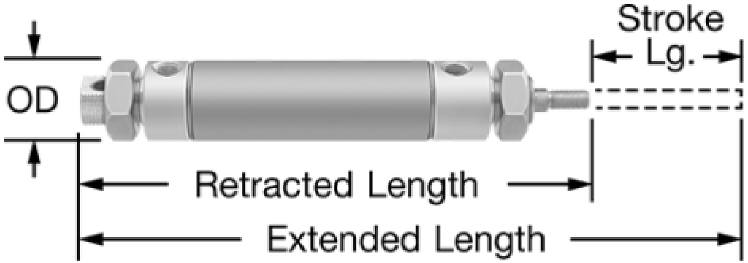
# Adafruit VL53LOX Micro-LIDAR Distance Sensor

- Features
  - Measures how long the light takes to bounce back
  - Accurate for small, single point targets
- Specifications
  - Range: 50-1200mm
  - Powered with 3-5V
  - SCL-12C clock pin
  - SDA-12C data pin
  - 3-12% accuracy, dependent on lighting



# Sensor-Ready Round Body Air Cylinder

- Features
  - Implements two cylinders and pistons in order to produce the linear actuation
  - Is compatible to mount sensors which will allow for pressure feedback
- Specifications
  - Bore size: 2”
  - Stroke: 36”
  - Rod diameter: 0.63”
  - Double acting
  - ¼” NPT threads
  - Max pressure: 250 PSI



# Mcgraw Compressor

- Features
  - Is portable and can be easily operated
  - Can store enough compressed air in order to pressurize the pneumatic system
- Specifications
  - Volume: 8 gallons
  - Max Pressure: 150 PSI
  - Flow Rate: 4.1 SCFM
  - Power: 1.5 HP

# Pressure Sensor

- Features
  - Measures the pressure from the pneumatics and converts to a voltage
  - Prices range from $30-$300 (depends on accuracy)
- Specifications
  - Measures 0-145 PSI
  - Signals 0-10VDC
  - ¼” NPT

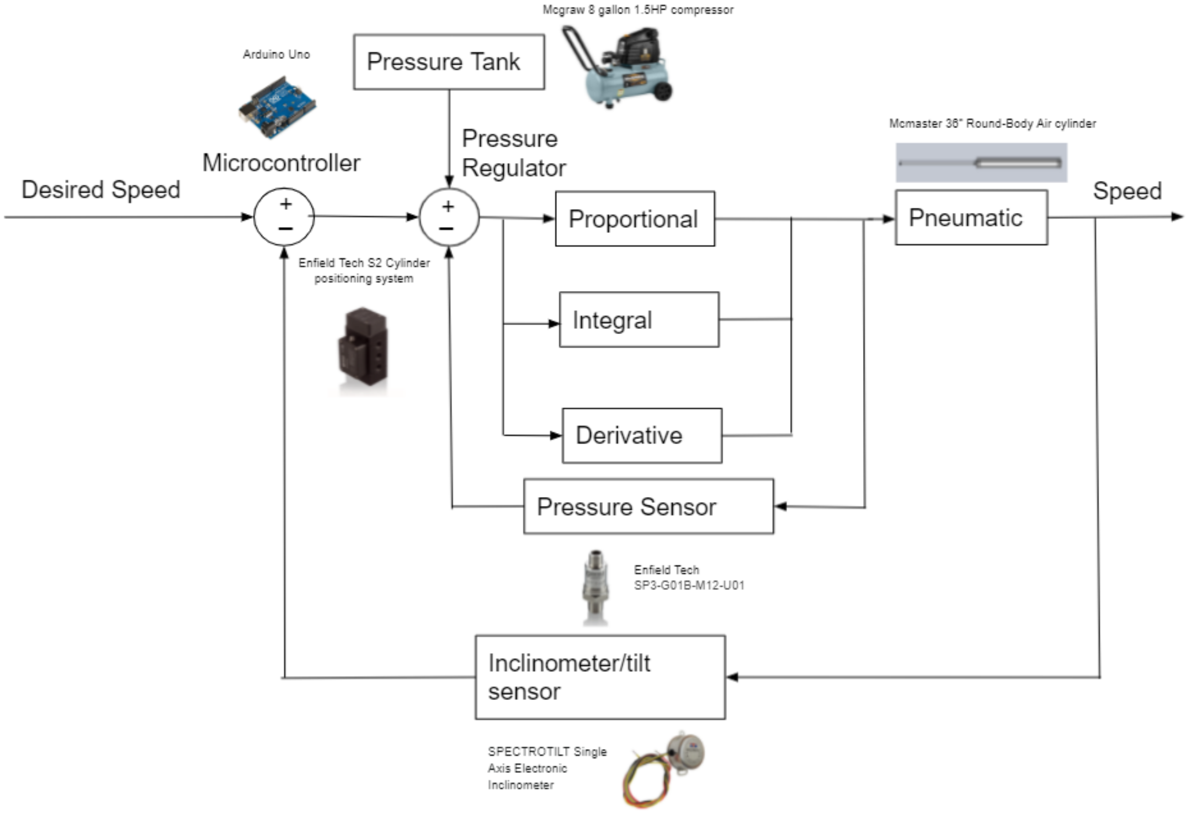
# DC Regulator Power Supply

- Features
  - Produces power in order to operate pressure regulator
- Specifications
  - 120 VAC Input
  - 24 VDC output
  - 31.2W

# Pneumatic Controls Alternative

- Replace current ultrasonic distance sensor with inclinometer (Spectrotilt single axis actuator) mounted on scissor lift bracket

- Replace current ultrasonic distance sensor with more accurate and more expensive lidar/ultrasonic sensor (wenglor sensoric laser sensor)



# Force Data Collection

**Links to Slides**

Next Steps

Kitronyx Insoles Specifications

Calibration

Factor of Safety

Force Trade Study

# Force Data Collection FR5

**DR5.1: Sensors under the users feet shall be used to collect data. DR5.2: The sensors shall be integrated into the user's footwear DR5.3: The sensors collecting data shall be comfortable.**

DR5.1, DR5.2, DR5.3

- Kitronyx Insole Sensor will inserted into the athletes footwear and collect data throughout the simulation

DR5.4

- If a user weights 100 kg, the maximum error in the measurement will be 9.81 N
- Achieved through calibration

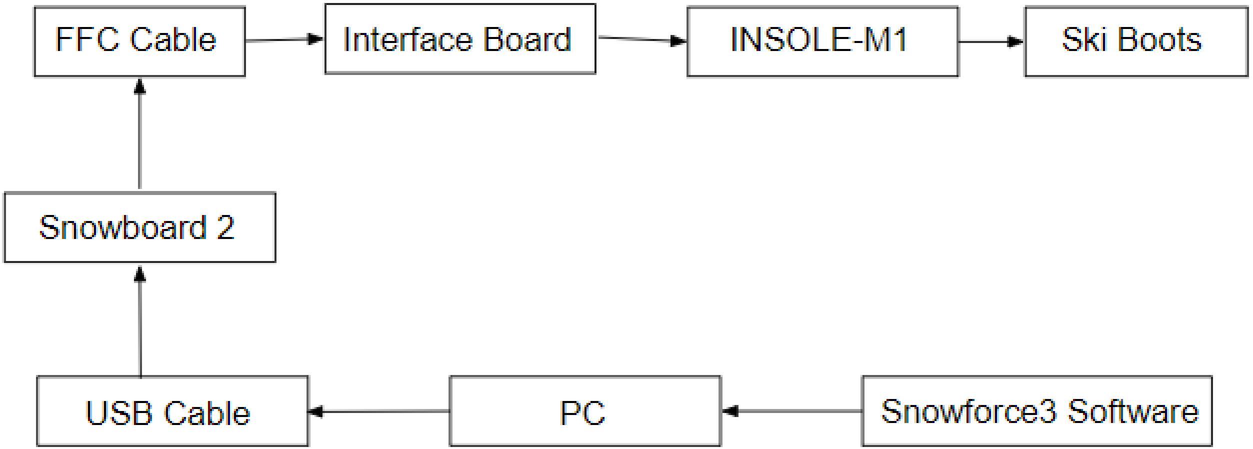
# Requirement Satisfaction

- Kitronyx Insole Sensor will inserted into the athletes footwear and collect data throughout the simulation

- Sensors are <1 mm thick

- If a user weights 100 kg, the maximum error in the measurement will be 9.81 N
    - Achieved through calibration

# Force Data Collection FBD



# Kitronyx Insoles Specifications[8]

Electronics

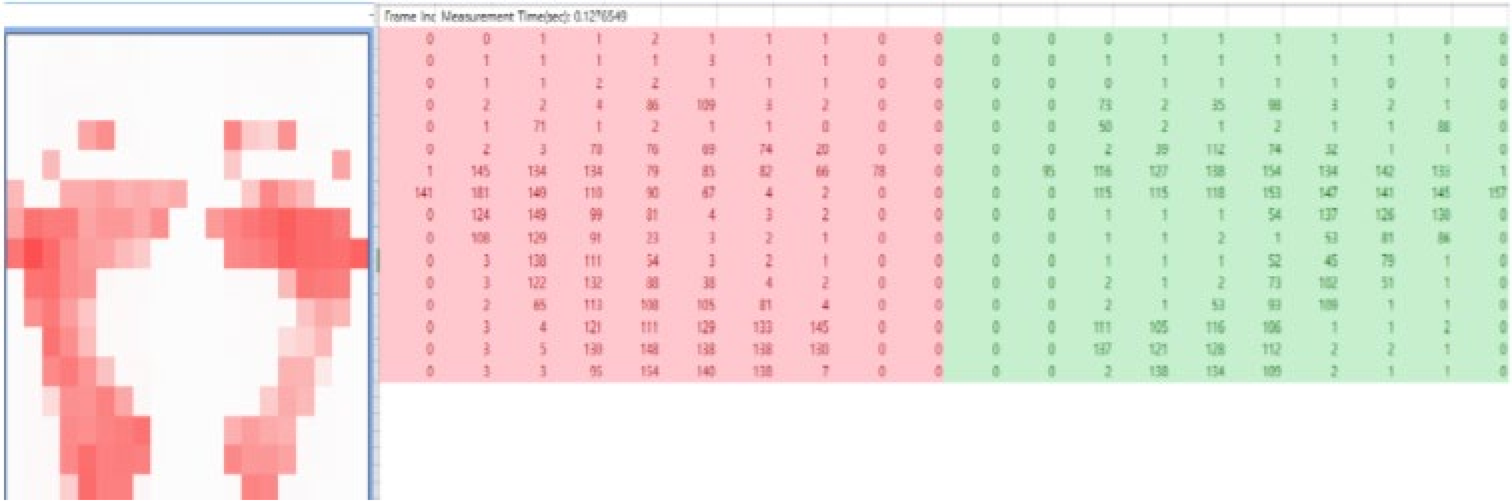
| Specifications | Value |
|---|---|
| Dimensions (mm) | 109x71x29 |
| Number of Sensing Pixels | 160 (16x10) |
| Frame Rate (Hz) | 40 |
| Computer Interface | USB |
| Operating System | Windows 7-10 |
| Power Supply | USB Powered |

Sensors

| Specifications | Value |
|---|---|
| Sensor Size (mm) | 235, 270, 280 |
| Thickness (mm) | <1 |
| Cable Length (mm) | 150 |
| Pressure Range (kg) | 180 |

# How to Save Data CSV File

- Data is saved under My Documents - snowforce3 - in two folders, log and snapshot
  - Log: Log data contains real time measurements in CSV format. There will be two CSV files, one as a column vector and one as a matrix.



Example data from Snowforce3 User Manual

# Pressure Distribution Generated from Logged Data

MATLAB generated map of pressure distribution from CSV file.

Example Data from Snowforce3 user manual: [Snowforce3 User Manual]

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 2 | 0 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 0 | 0 |
| 3 | 0 | 1 | 2 | 1 | 2 | 1 | 1 | 0 | 0 | 0 |
| 4 | 0 | 2 | 2 | 4 | 116 | 111 | 61 | 20 | 85 | 88 |
| 5 | 0 | 1 | 68 | 1 | 2 | 1 | 1 | 0 | 0 | 0 |
| 6 | 0 | 2 | 2 | 65 | 88 | 98 | 77 | 89 | 92 | 103 |
| 7 | 1 | 119 | 131 | 143 | 94 | 96 | 111 | 116 | 147 | 1 |
| 8 | 134 | 186 | 151 | 111 | 97 | 72 | 57 | 57 | 2 | 0 |
| 9 | 0 | 121 | 136 | 106 | 79 | 3 | 3 | 2 | 1 | 0 |
| 10 | 0 | 55 | 124 | 91 | 35 | 1 | 2 | 1 | 1 | 0 |
| 11 | 0 | 2 | 76 | 118 | 96 | 63 | 4 | 2 | 1 | 0 |
| 12 | 0 | 2 | 3 | 97 | 104 | 103 | 89 | 4 | 1 | 0 |
| 13 | 0 | 3 | 3 | 99 | 114 | 122 | 131 | 143 | 2 | 1 |
| 14 | 0 | 2 | 3 | 84 | 146 | 134 | 138 | 129 | 2 | 0 |
| 15 | 0 | 2 | 3 | 4 | 145 | 132 | 141 | 6 | 1 | 1 |

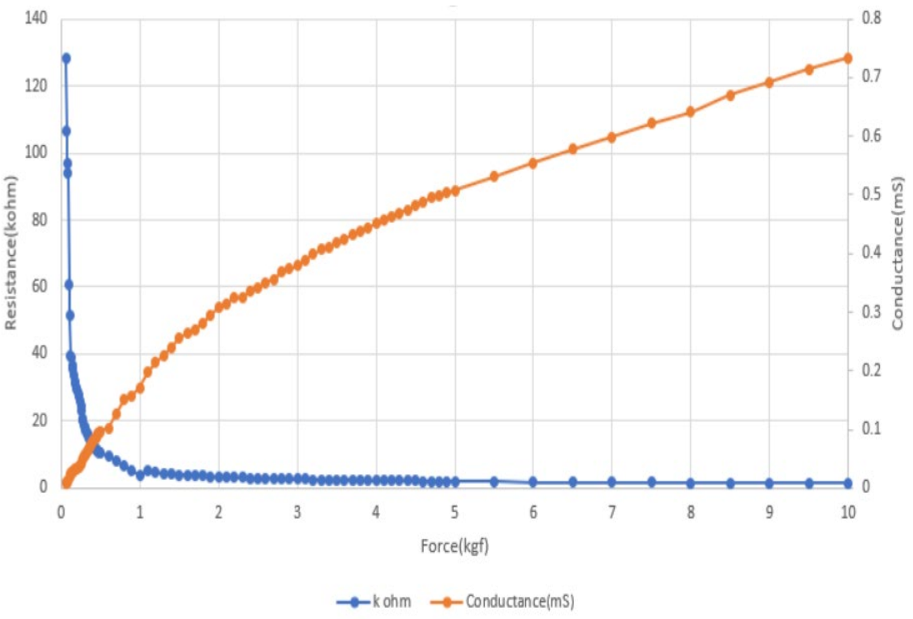
# Calibration

Calibration is necessary to get physical pressure values from the pressure distribution

- Put an object of know mass on the sensor
- Record force and measure the ADC sum
- Using A and F you can get a linear relationship

Physical pressure not an accurate result

- Sensor ADC curve nonlinear
- Each pixel has a different response




Relationship between force and ADC output [10]

# Calibration Test Plan

- Open the Snowforce software and select proper port
- Place a target object over the entirety of the sensor. This object is used to load the sensor in actual measurement process
- Press the object with a known total force, f
- Mesaue ADC Sum, A, using the Snowforce software
- Export the CSV file of the ADC Sum
- Calculate the total force using f = 0.01A
- Iterate the equation until the computed force best represents the applied force
- Loop through each sensel and apply the equation

```
f_total = ADCsum.*.01;
```

# FOS: 1.1

FOS is 1.1 because the customer would like the ability of collect force data from a real ski jump.

An athlete (100 kg) pulls a maximum of 1.6 G will generate a maximum force of 1569.6.

From data sheet, sensor can accommodate up to 180 kg of mass or 1765.8 N.

$$1765.8\ N / 1569.6\ N = 1.125$$

Therefore FOS > 1.1

# DR5.2 and DR5.3 Comfortably integrated into the users footwear

Sensor insole size ordered: 235 mm

The ensures that the insole is accessible to as many athletes possible without risking deforming the sensor. This size will accommodate most adult women and men. The insole is designed to be laid inside of the ski boot or users shoes as it collects dynamic data. Size 235 is the most comfortable size for most users because it will lay flat within the boots.

# Bluetooth

Pro:

1. Cleaner: no lingering cable connections
2. Safer: less likely for cables to get caught in the mechanical mechanisms
3. Less risk to equipment: computer collecting data not directly attached to athlete

Con:

1. More bulky: battery pack, arduino, bluetooth shield, snowboard 2 attached to athletes calves
2. More complex user interface
3. Greater points of failure
4. ~$200 cost: 2 x arduino uno, 2 x battery packs, 2 x bluetooth shield and cables

**Conclusion Bluetooth is out of the scope of this project**

# Logistics

**Links to Slides**

[Organization Chart]

# Organization Chart

**Project Manager**
Michael Schlittenhart

**Systems Engineer**
Mary Sobernheim

**Sourcing Lead/CFO**
Max Page

**Accounting Lead**
Maya Greenstein

| Technical Leads | Team Members |
|---|---|
| Mechanical Lead<br>Joaquin Ramirez | Hunter Daboll, Landon Nurge, Mary Sobernheim, Max Page |
| Visual Cues Lead<br>Maya Greenstein | Michael Schlittenhart, Max Page, Julia Sheeran, Landon Nurge |
| Force Data Collection Lead<br>Julia Sheeran | Mary Sobernheim, Max Page, Maya Greenstein |
| Manufacturing Lead<br>Max Page | Joaquin Ramirez, Hunter Daboll, Julia Sheeran |
| Human Factors Lead<br>Hunter Daboll | Michael Schlittenhart |
| Software Lead<br>Landon Nurge | Maya Greenstein |

# Budget

**Links to Slides**

| Supplier | Part Number | Part Name | Justification | Items per Order | Orders | Link | Unit Cost | Shipping | Total Cost |
|---|---|---|---|---|---|---|---|---|---|
| HiLetgo | HC-06 RS232 | Wireless Bluetooth Serial RF Transceiver Module Bi-D | For Oculus control communication | 1 | 1 | https://www.ama | $8.39 | $0.00 | $8.39 |
| Oculus | | Oculus Quest 2 128 GB | Visual Cues Display Method | 1 | 1 | https://www.ocul | $299.00 | $0.00 | $299.00 |
| *Oculus* | | Quest 2 Elite Strap with Battery and Carrying Case | *Increases comfort, portability, battery life* | *1* | *1* | *https://www.ocul* | *$129.00* | *$0.00* | *$129.00* |
| *Kiwi Design* | | Upgraded Elite Strap for Oculus Quest 2 | *Increases comfort, portability* | *1* | *1* | *https://www.kiwi* | *$51.00* | *$0.00* | *$51.00* |
| Kitronyx | MP2513PLUS | Insole Sensor Kit | Force Data Collection method | 1 | 1 | https://www.kitro | $1,280.00 | $150.00 | $1,430.00 |
| Arduino | A000066 | Arduino Uno Rev3 | Need arduino to interface with oculus | 1 | 1 | https://store-usa | $19.55 | $3.28 | $22.83 |
| McMaster-Carr | 6498K586 | Round Body Air Cylinder, Double-Acting, Universal Mount, 2 | Actuation of platform motion | 1 | 2 | https://www.mcm | $234.00 | | $468.00 |
| McMaster-Carr | 4952K743 | Sensor-Ready Round Body Air Cylinder, Double Acting, 2" E | Same as 6498K586 but faster shipping, $ | 1 | 2 | https://www.mcm | $354.76 | | $709.52 |
| Unity | | Arduino Bluetooth Plugin | Connect oculus to arduino | 1 | 1 | https://assetstore | $19.00 | $0.00 | $19.00 |
| McGraw | | 8 Gallon 1.5 HP 150 PSI Oil-Free Portable Air Compre | Necessary for compressing and storing a | 1 | 1 | https://www.harb | $149.99 | $0.00 | $149.99 |
| Adafruit | 1528-1814-ND | Adafruit VL53L0X Time of Flight Micro-LIDAR Distanc | Used for feedback control loop of platforn | 1 | 3 | https://www.digik | $14.95 | | $44.85 |
| Apollo | A-2010 | Double Scissors Lift Table 1760lbs. 59" lifting height | COTS lifting platform, structure of mecha | 1 | 1 | https://www.apol | $1,239.74 | $300.00 | $1,539.74 |
| Enfield | **S2-025-U-04** | S2 - HIGH-FLOW CYLINDER POSITIONING SYSTE | Control system for pneumatic actuation | 1 | 1 | https://www.enfie | $994.00 | $15.94 | $1,009.94 |
| Petzl | R39AO 040 | Petzl Club 10mm 40m | Rope for belay | 1 | 1 | https://www.petz | $139.95 | | $139.95 |
| Trango | | Trango Regulock HMS Screwlock | Carabiners for belay system | 1 | 5 | https://www.rei.c | $11.95 | | $59.75 |
| REI | | Accessory cord | Locking system | 1 | 4 | https://www.rei.c | $0.40 | *$0.00* | $1.60 |
| Black Diamond | | Momentum Harness (Mens Medium) | Belay | 1 | 1 | https://www.blac | $51.96 | | $51.96 |
| Lowes | | 2x10x8 Douglas Fir | Wooden Base | 1 | 2 | https://www.lowe | $14.17 | $0.00 | $28.34 |
| Lowes | | 2x8x8 Douglas Fir | Wooden Base | 1 | 2 | https://www.lowe | $10.32 | | $20.64 |
| Amazon | | #8 2" Wood Screws | Wooden Base | 100 | 1 | https://www.ama | $12.99 | | $12.99 |
| Mcmaster-Carr | 1593N4 | EPDM Air Hose with 1/4 x 1/4 NPTF Brass Male Fittin | Pneumatic hose | 1 | 2 | https://www.mcm | $18.97 | | $37.94 |
| Mcmaster-Carr | 1593N4 | EPDM Air Hose with 1/4 x 1/4 NPTF Brass Male Fittin | Pneumatic hose | 1 | 1 | https://www.mcm | $20.41 | | $20.41 |
| | 7010K117 | Power Supply, Single Phase, 100-240VAC Input, 24VI | Regulator power supply | 1 | 1 | https://www.mcm | $34.67 | | $34.67 |
| Amazon | | [2 Pack] USB 3.0 Cable, USB to USB Cable, USB A M | Date transfer for all systems | 2 | 3 | https://www.ama | $9.99 | $0.00 | $29.97 |
| GetMetals | | 1018 Steel Round Bar | Actuator rod at bottom of lift | 1 | 2 | https://getmetals | $18.07 | $0.00 | $36.14 |
| Lowes | 241572 | 24-in x 36-in Cold Rolled Steel Solid Sheet Metal | Connect lift to actuator cylinder | 1 | 2 | https://www.lowe | $27.14 | $0.00 | $54.28 |
| GetMetals | | 1020 2.25" diameter .25" thickness tube | Sleeve to allow rolling of actuator rod | 1 | 1 | https://getmetals | $32.89 | $0.00 | $32.89 |
| GetMetals | | 1020 .75" diameter 4" length | Perpendicular tube for thread | 1 | 1 | https://getmetals | $6.24 | | $6.24 |
| Mcmaster-Carr | 1641 | 1" load bearing | Allow sleeve to rotate freely | 1 | 2 | https://www.mcm | $24.98 | | $49.96 |
| Mcmaster-Carr | 91310A128 | High-Strength Class 10.9 Steel Hex Head Screw | Connect cylinder holder to lift | 10 | 2 | https://www.mcm | $9.55 | | $19.10 |
| Amazon | | RIGERS Training Sandbags Heavy Duty | Secure belay system to gym floor | 1 | 1 | https://www.ama | $70.99 | $0.00 | $70.99 |