MONTANA STATE UNIVERSITY

Department of Mechanical and Industrial Engineering

ETME 499R CAPSTONE: MECHANCAL ENGINEERING TECHNOLOGY DESIGN II

and

EMEC 499R CAPSTONE: MECHANICAL ENGINEERING DESIGN II

TIBIAL COMPRESSIVE OVERLOAD TESTING APPARATUS: Technical Addendum

by

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Prepared to Partially Fulfill the Requirements for EMEC 499/ETME499

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DESIGN AMMENDMENTS

Mechanical Stop: Originally, the mechanical stop was designed to provide a physical barrier to prevent the VCA piston from extending farther than 2.25mm. This concept was replaced with a displacement limit governed by the motion controller. The coded displacement stop was proven to be effective, less expensive than fabricating a physical stop, and more adjustable because the code can easily be modified to provide a shorter or longer displacement limit.

Ankle Holster: Because the mechanical stop was removed from the design, the ankle holster could be redesigned to be smaller, and require less hardware to mount. After conducting initial tests on cadaver mice it was determined that the mouse's ankle was not retained well laterally. Because of this, the ankle slot was redesigned to be thinner, and to have a lofted profile. These design amendments allow the ankle to be correctly positioned even if initially loaded off-center, and also ensure that the ankle is retained laterally.(See A1 for updated Drawing)

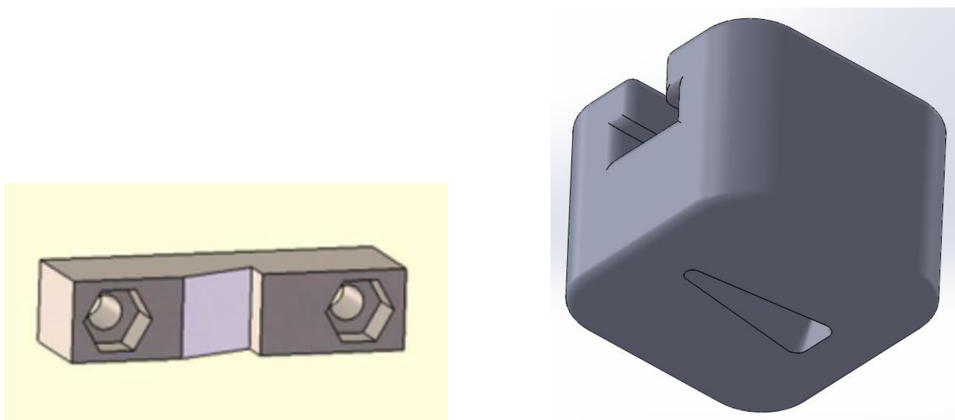


Figure 1: *old ankle holster design (left) vs new ankle holster design (right)*

Load Cell: The strain gauge was initially specified to be an Uxcell 5kg load cell without a method for amplification. The group decided to switch to a new load cell from the online supplier, RobotShop. This new load cell is also rated for 5kg loads and was chosen because the supplier is more reliable and the load cell seemed to be of higher quality.

Voice Coil Actuator: The Voice Coil Actuator has changed since last semester from the BEI Kimco LAS13-56, to the Moticont SDLM-051-095-01-01. This design change was made because the Moticont VCA is cheaper, has a built-in optical encoder, and has higher inductance which is compatible with the Galil Motion Controller (inductance must be greater than 0.2 mH to avoid "jittering," chosen VCA inductance is 4.6mH). The Moticont VCA also has a similar moving mass, the same form, a slightly lower peak current, and a longer stroke compared to the BEI Kimco VCA.

VCA Collar: The VCA Collar was redesigned to account for the Moticont VCA. Changes include moving the adjustment knob to the front face and incorporating a sleeve on the collar to protect users from pinching their fingers between the VCA piston and adjustment knob. The new collar also includes a built-in housing for the 15-Pin Adapter and 4 prong Molex connector, as well as a cutaway for the VCA wires that exit from the side, instead of from the top like the BEI

Kimco VCA. The new Collar also includes engraved labels to indicate where components attach, and other assembly details. (See A2 for updated drawing)

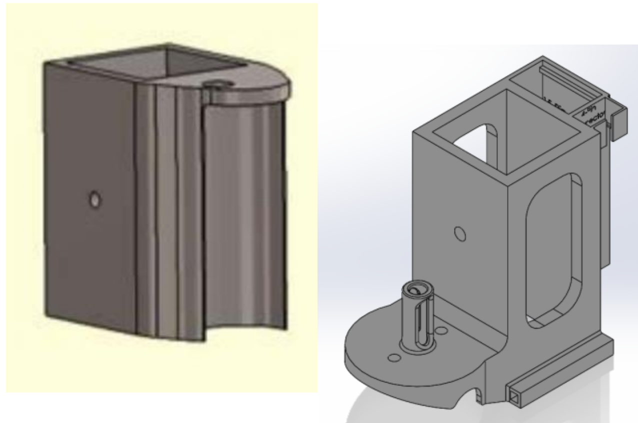


Figure 2: *old VCA collar design (left) vs new VCA collar design (right)*

Motion Control: Last semester, VCA motion was to be controlled with an amplifier from Moticont and an Arduino Duo Microcontroller. Instead, a motion controller-amplifier combination from Galil (DMC 30012) was chosen due to relative ease of use, and compatibility with quadrature encoding.

Power Supply: A 24V, 10A power supply with passive cooling has been specified to power the motion controller.

Electronics Housing: The housing of the electronics had not been specified last semester. Since then, several mounts were designed to hold the 44-Pin Adapter and instrument amplifier, 15 pin adapter, motion controller, power supply, and load cell. Mounts were designed to be printed from Nylon by Shapeways. (See A3-A5 for drawings)

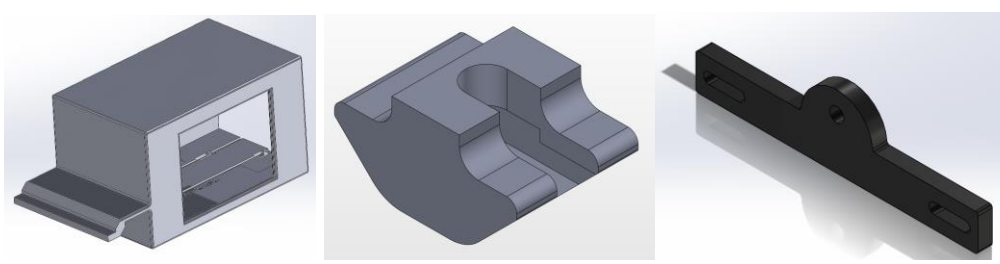


Figure 3: *"peripheral mount" used to retain strain gauge instrument amplifier chip and 44 pin adapter (left), load cell mount (center) used to mount load cell to frame via single 4mm bolt and wingnut, "universal mount" (right) used to mount motion controller and power supply to frame*

Wiring: Wiring specifics were not addressed in the original report, as the circuit was still being finalized. The final design utilizes HD44 and HD15 cables to connect the encoder and load cell to the motion controller. Molex 2 and 4 prong connectors are used to attach the motor and power supply to the motion controller. A 4-Pin wire harness is utilized with wire crimps to connect the load cell to the instrument amplifier.

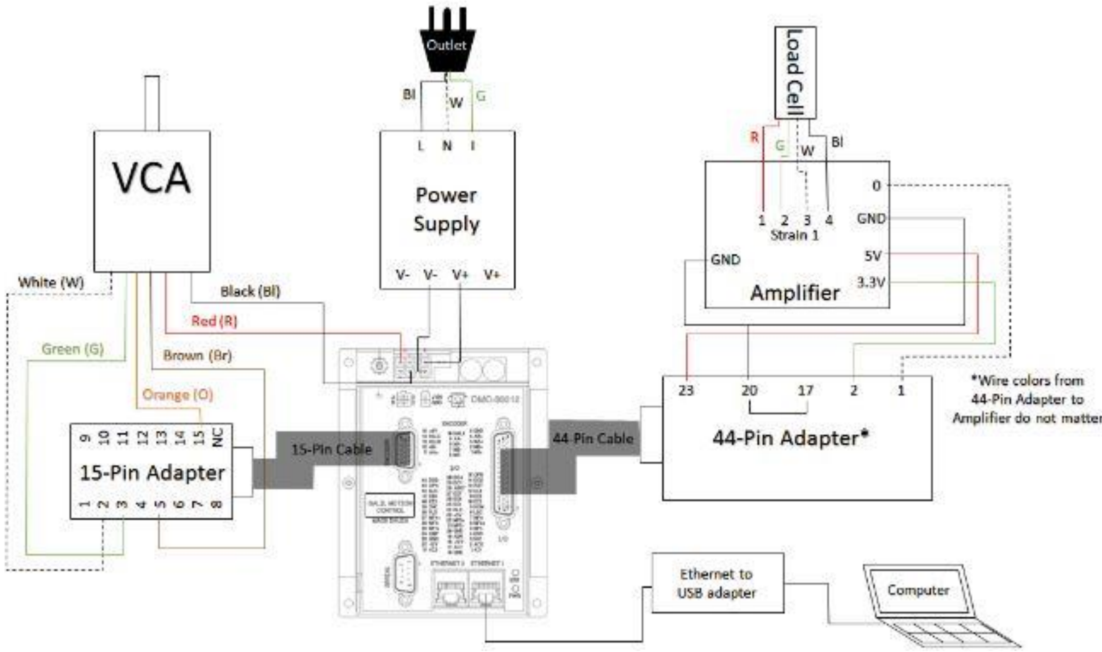


Figure 4: *finalized wiring diagram*

Cost: Last semester, the bill of materials reflected a project cost of $2868. After all design amendments, the final design costs $3420.

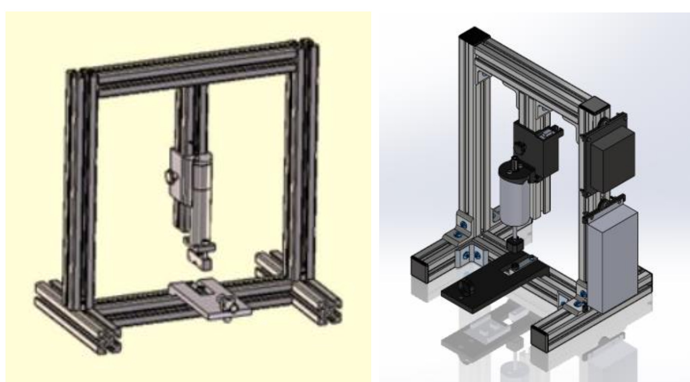


Figure 5: *Previous total apparatus design on the left costing $2868. Final apparatus design on the right costing $3440*

TESTING RESULTS

Testing was conducted first on dry fettuccini loaded into a 3-point bending setup (Figure 6) so that the fettuccini strands would break at a force close to 18 N. A slow-motion camera was used to see the overshoot in the VCA after rupture to verify that the system could detect rupture and stop within a reasonable distance. This video verified that the VCA was able to come to a complete stop from the specified 200 mm/s speed 0.5mm after rupture (Figure 8).

Next, the apparatus was tested on a cadaver mouse. Two legs were tested, and the first resulted in nearly complete ACL rupture, while the second showed no injury. It is likely that rigor mortis began to take affect during the time it took to align the mouse's leg in each test -- this process took about 10 minutes for the first test, and an additional 30-40 minutes for the second test. No bone damage was found as a result of either test. This was good because it showed that the apparatus was able to stop itself in the specified 2.25mm maximum displacement if it did not detect rupture. Since there was no rupture to detect in the second test, it did exactly what it was supposed to do and prevented the femoral condyles from being fractured. The first leg was tested and the VCA stopped due to the maximum displacement stop of 2.25mm. However, upon examining the knee afterwards a partial ACL rupture was evident. Figure 9 depicts the results from this test. A change in the slope of the force rate of change was observed and it is theorized that this is the point of partial rupture. The femoral condyles were again unharmed. This showed that the apparatus is capable of preventing collateral injury to other parts of the leg while only inflicting damage onto the ACL.

With this knowledge, researchers can select what maximum force and maximum displacement limits they want to apply to their experiments based on the strain of mouse that is in their lab. The group's idea is that the particular cadaver mouse tested on was possibly affected by rigor mortis making it tougher to rupture the ACL or that possibly this particular mouse was a bit stronger than the mice tested on in Dr. Christiansen's previous studies and for that reason the ACLs did not rupture within the expected 2.25mm range. However, the testing proved that the ACL is the only component damaged while protecting the rest of the knee and the force and displacement limits can be changed by the researchers to fine tune the experiment.

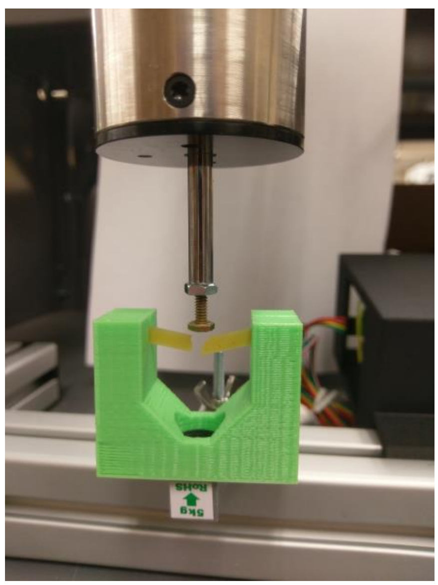


Figure 6: *3-Point bending test setup with. Test involved breaking a dry piece of fettuccini and verifying that the VCA stops quickly once rupture is detected*

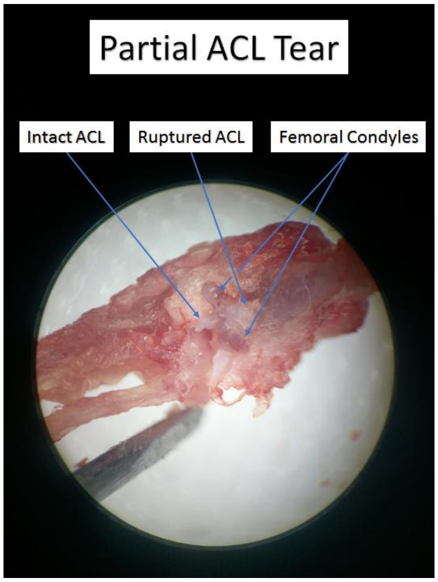


Figure 7. *Mouse cadaver test result. Biopsy showed partially torn ACL with femoral condyles, tibia, and fibula unharmed*

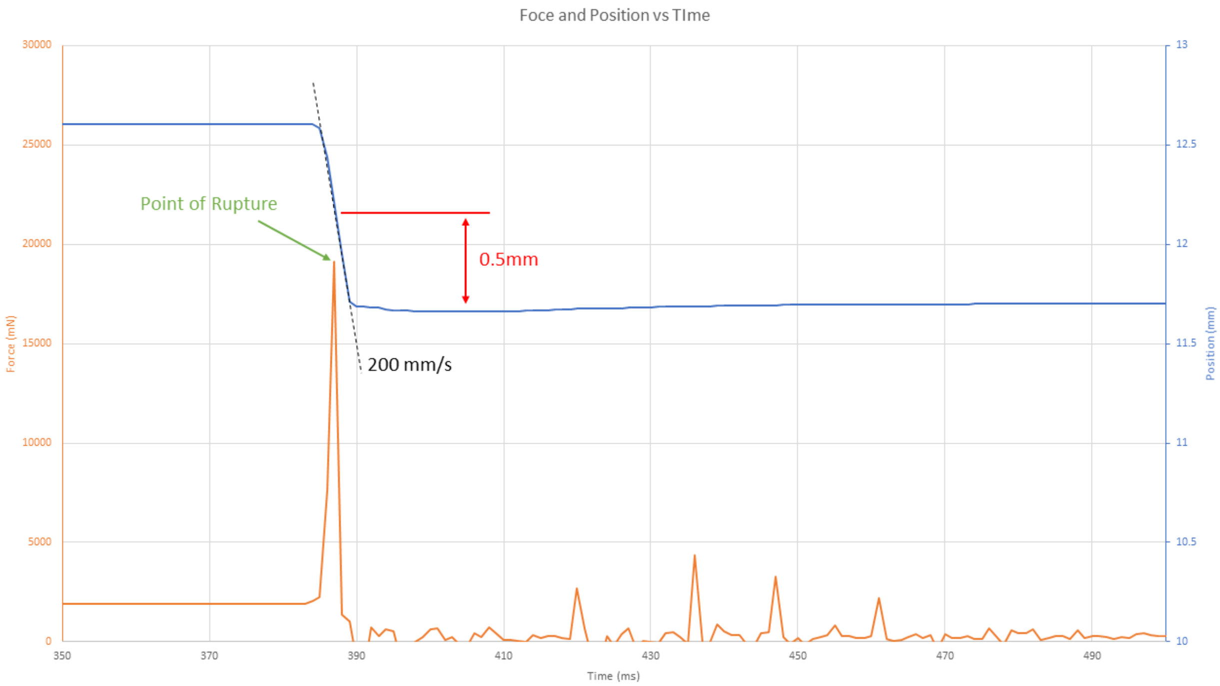


Figure 8. *Data from dry fettuccini test. Blue line shows overall displacement and orange line shows total force. Point of rupture, stopping distance after rupture detection (red arrow), and velocity achieved at rupture (grey line) are all shown*

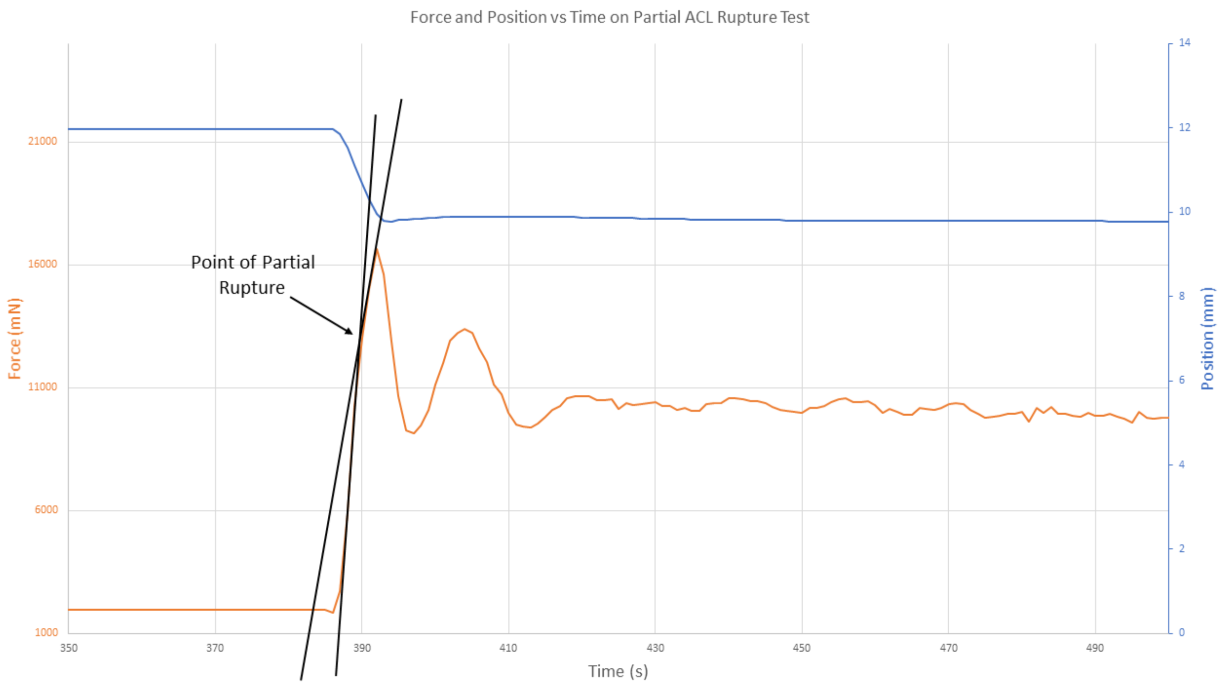
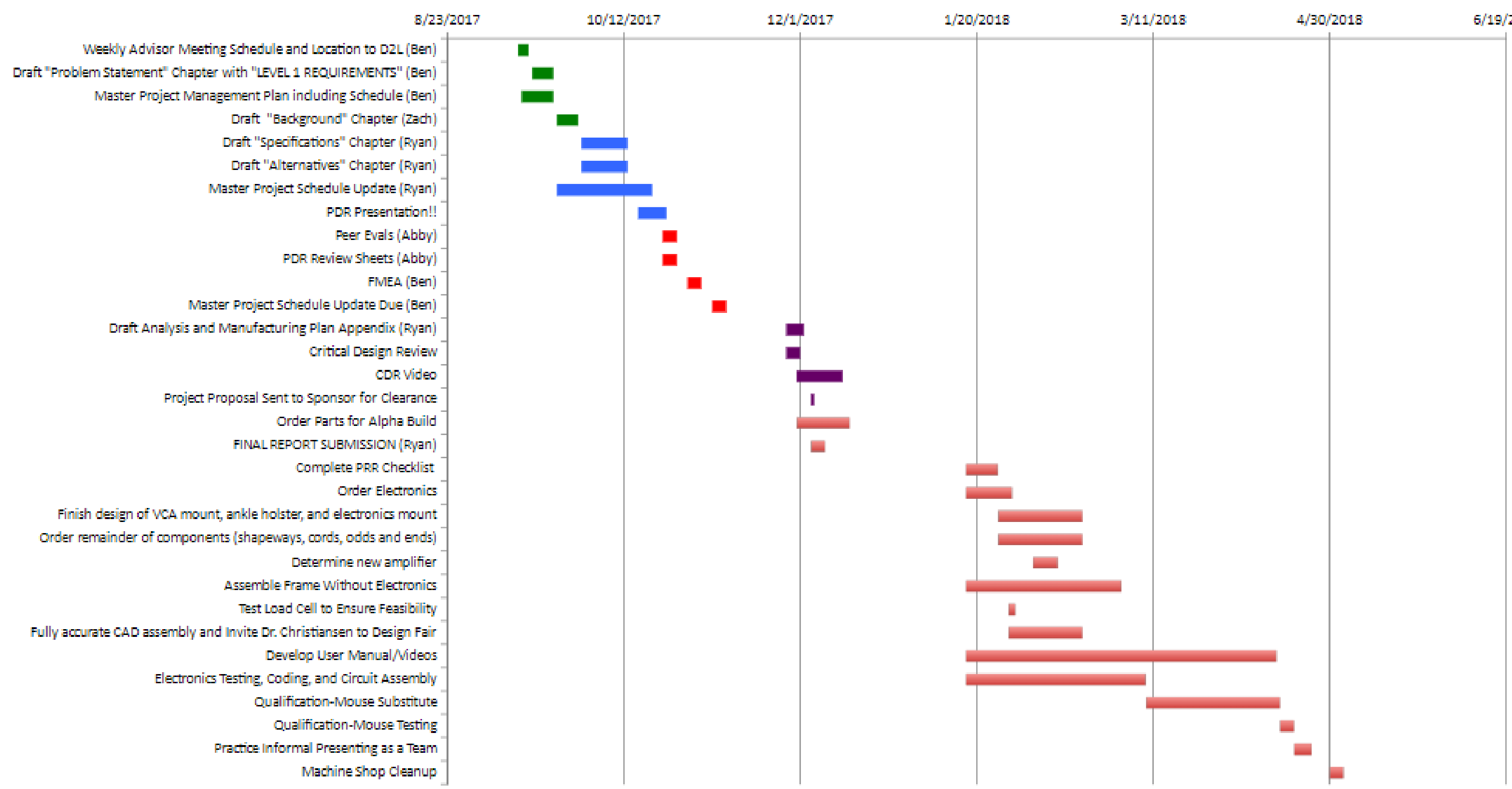


Figure 9. *Data from a mouse test. The test of the first mouse leg resulted in partial ACL rupture. The point of partial rupture is theorized to be the point of change in slope of the force rate of change.*

UPDATED SCHEDULE

Task Name	Start	End	Duration (days)	Responsible Member
Weekly Advisor Meeting Schedule and Location to D2L (Ben)	9/12/2017	9/15/2017	3	
Draft "Problem Statement" Chapter with "LEVEL 1 REQUIREMENTS" (Ben)	9/16/2017	9/22/2017	6	
Master Project Management Plan including Schedule (Ben)	9/13/2017	9/22/2017	9	
Draft "Background" Chapter (Zach)	9/23/2017	9/29/2017	6	
Draft "Specifications" Chapter (Ryan)	9/30/2017	10/13/2017	13	
Draft "Alternatives" Chapter (Ryan)	9/30/2017	10/13/2017	13	
Master Project Schedule Update (Ryan)	9/23/2017	10/20/2017	27	
PDR Presentation!!	10/16/2017	10/24/2017	8	
Peer Evals (Abby)	10/23/2017	10/27/2017	4	
PDR Review Sheets (Abby)	10/23/2017	10/27/2017	4	
FMEA (Ben)	10/30/2017	11/3/2017	4	
Master Project Schedule Update Due (Ben)	11/6/2017	11/10/2017	4	
Draft Analysis and Manufacturing Plan Appendix (Ryan)	11/27/2017	12/1/2017	5	
Critical Design Review	11/27/2017	11/30/2017	4	
CDR Video	11/30/2017	12/12/2017	13	
Project Proposal Sent to Sponsor for Clearance	12/4/2017	12/4/2017	1	
Order Parts for Alpha Build	11/30/2017	12/15/2017	15	
FINAL REPORT SUBMISSION (Ryan)	12/4/2017	12/8/2017	4	
Complete PRR Checklist	1/17/2018	1/26/2018	9	
Order Electronics	1/17/2018	1/30/2018	13	Zach
Finish design of VCA mount, ankle holster, and electronics mount	1/26/2018	2/19/2018	24	Ben & Abby
Order remainder of components (shapeways, cords, odds and ends)	1/26/2018	2/19/2018	24	Ben & Abby
Determine new amplifier	2/5/2018	2/12/2018	7	Zach and Ryan
Assemble Frame Without Electronics	1/17/2018	3/2/2018	44	Done
Test Load Cell to Ensure Feasibility	1/29/2018	1/31/2018	2	Zach & Ryan
Fully accurate CAD assembly and Invite Dr. Christiansen to Design Fair	1/29/2018	2/19/2018	21	Zach, Abby, Ben
Develop User Manual/Videos	1/17/2018	4/15/2018	88	Ben & Abby
Electronics Testing, Coding, and Circuit Assembly	1/17/2018	3/9/2018	51	Zach and Ryan
Qualification-Mouse Substitute	3/9/2018	4/16/2018	38	Abby & Ben
Qualification-Mouse Testing	4/16/2018	4/20/2018	4	Abby & Ben
Practice Informal Presenting as a Team	4/20/2018	4/25/2018	5	Team
Machine Shop Cleanup	4/30/2018	5/4/2018	4	Team
Create Poster	3/19/2018	4/24/2018	36	Team
Design Fair	4/26/2018	4/26/2018	0	Team
Finalized documentation, ready for Kevin	3/7/2018	4/6/2018	30	Ben & Abby
Finalized BOM (final wire spec)	3/7/2018	4/5/2018	29	Zach
Testing Plan Complete (slow motion, mouse substitute, mouse, note CAD changes)	3/7/2018	3/29/2018	22	Team
Christiansen Skype Presentation (morning of design fair)	4/26/2018	4/26/2018	0	Team
VCA Collar Design Finalized, or reordered	3/7/2018	3/24/2018	17	Ben
Determine budget used to date	3/7/2018	3/9/2018	2	Zach
Prototype Packaged to ship	3/7/2018	5/2/2018	56	TBD
Prototype Shipped via insured and certified mail	3/7/2018	5/3/2018	57	TBD
Wiring diagram	3/19/2018	4/1/2018	13	Zach
Amplifier/44 Pin Adapter Mount Design (CAD)	3/26/2018	4/6/2018	11	Zach
Technical Adendum	4/23/2018	5/1/2018	8	Team

Mouse Knee Buster



APPENDIX

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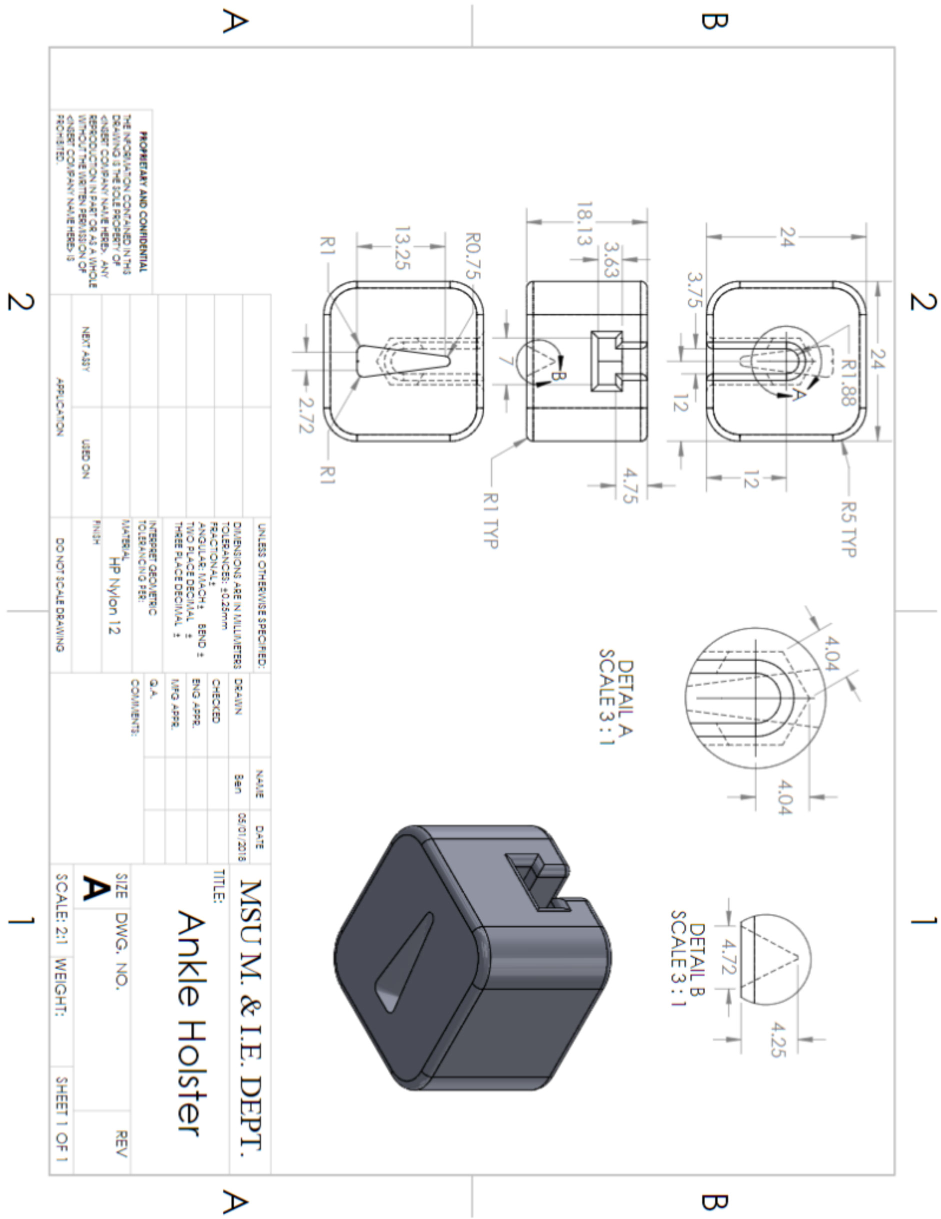
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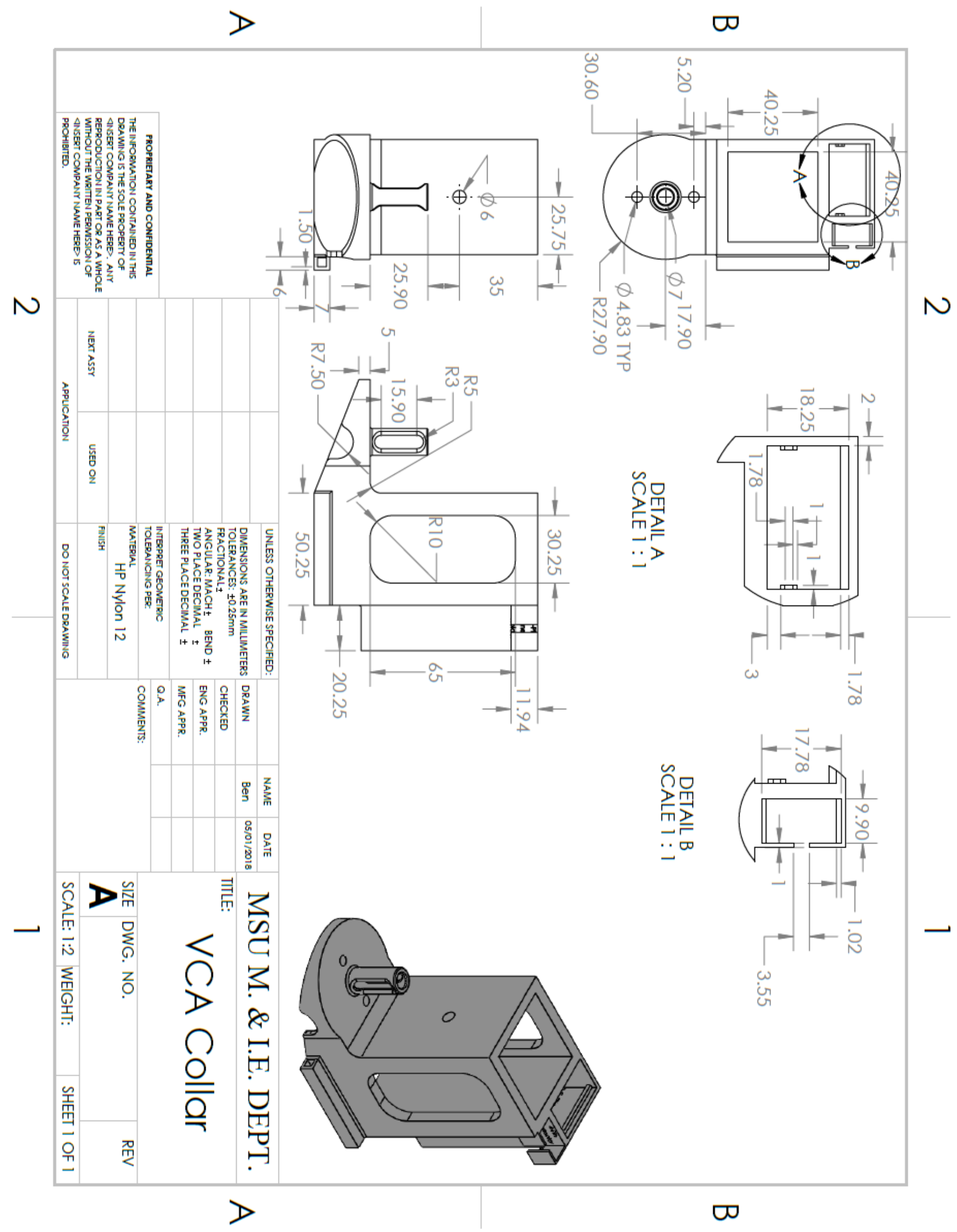
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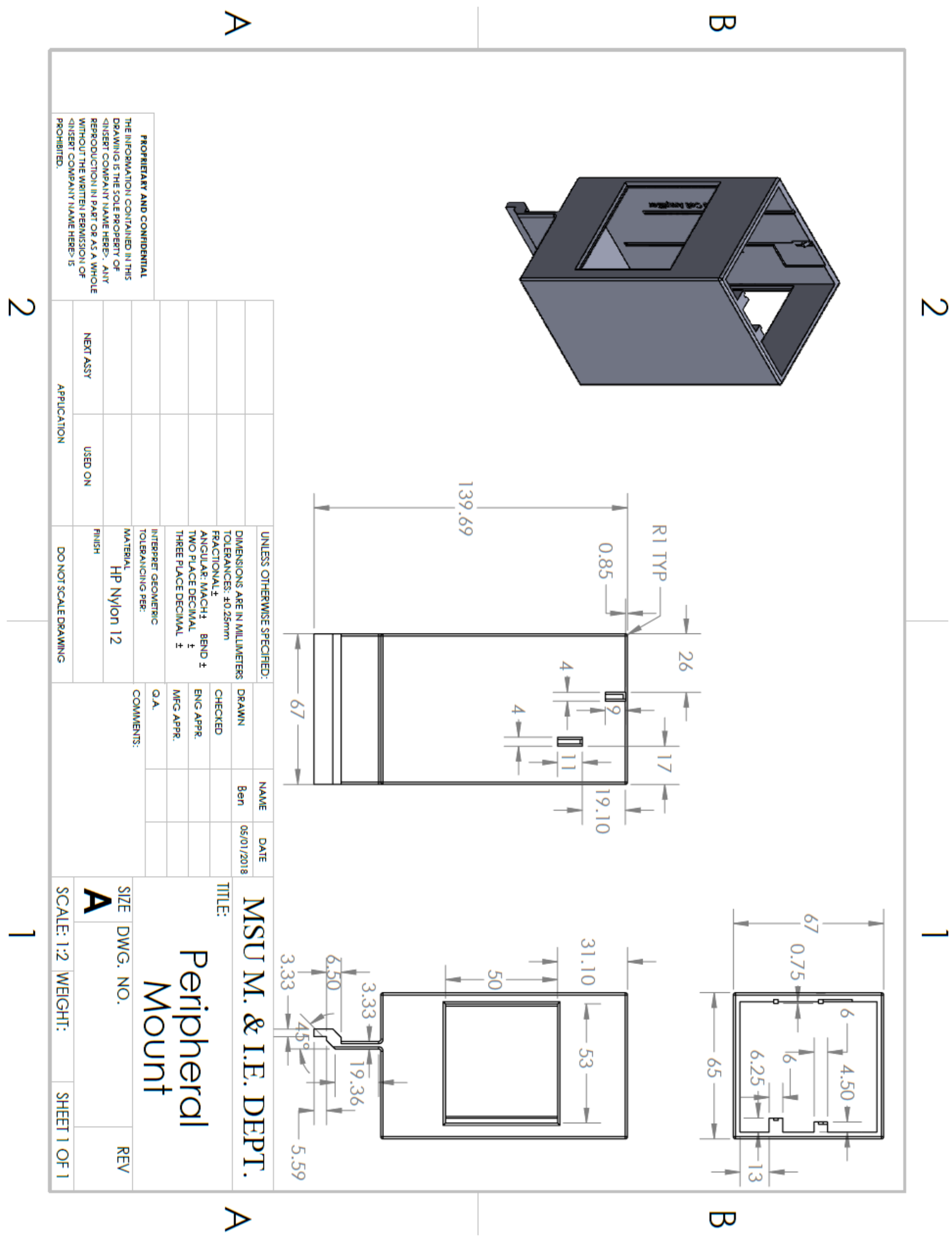
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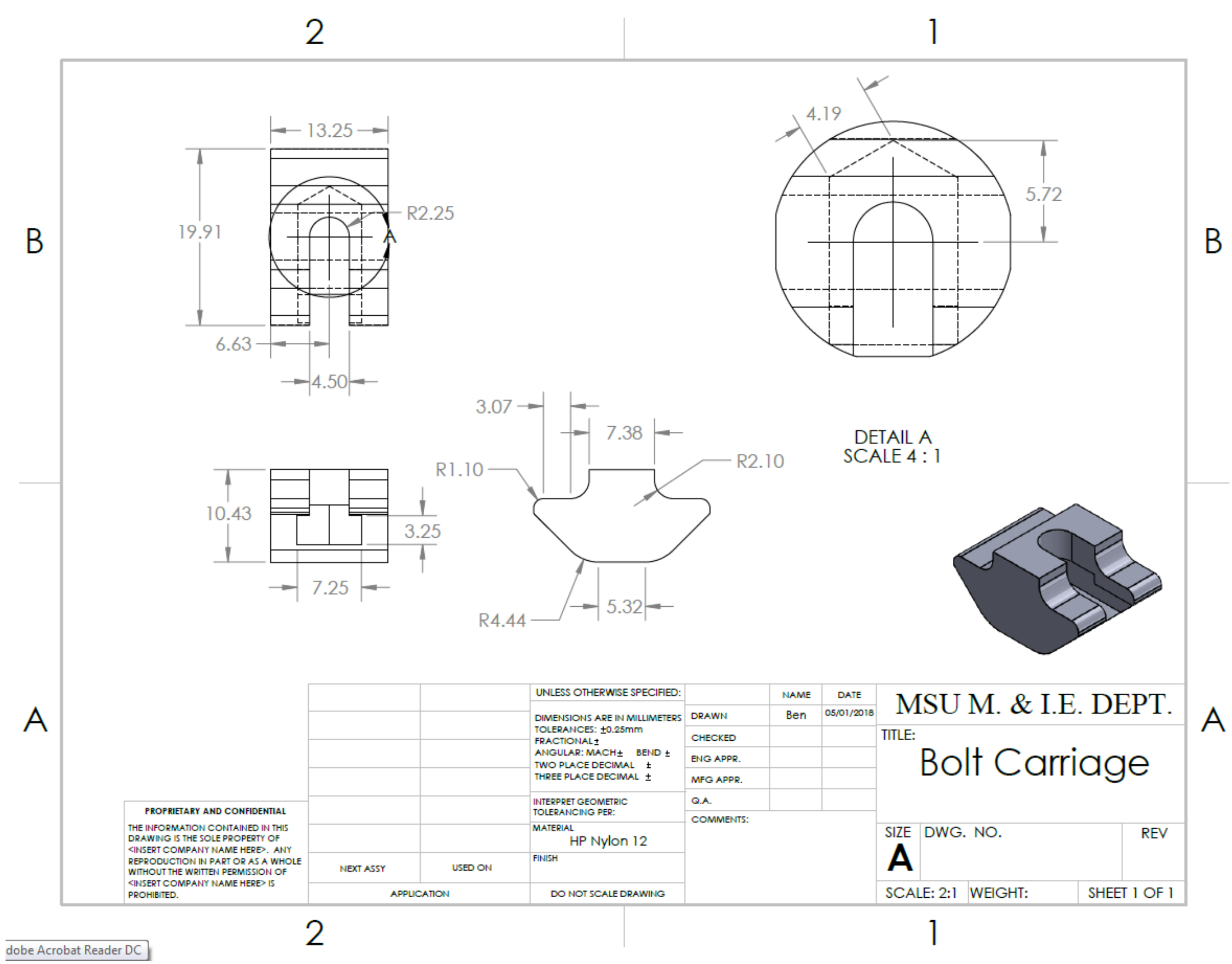
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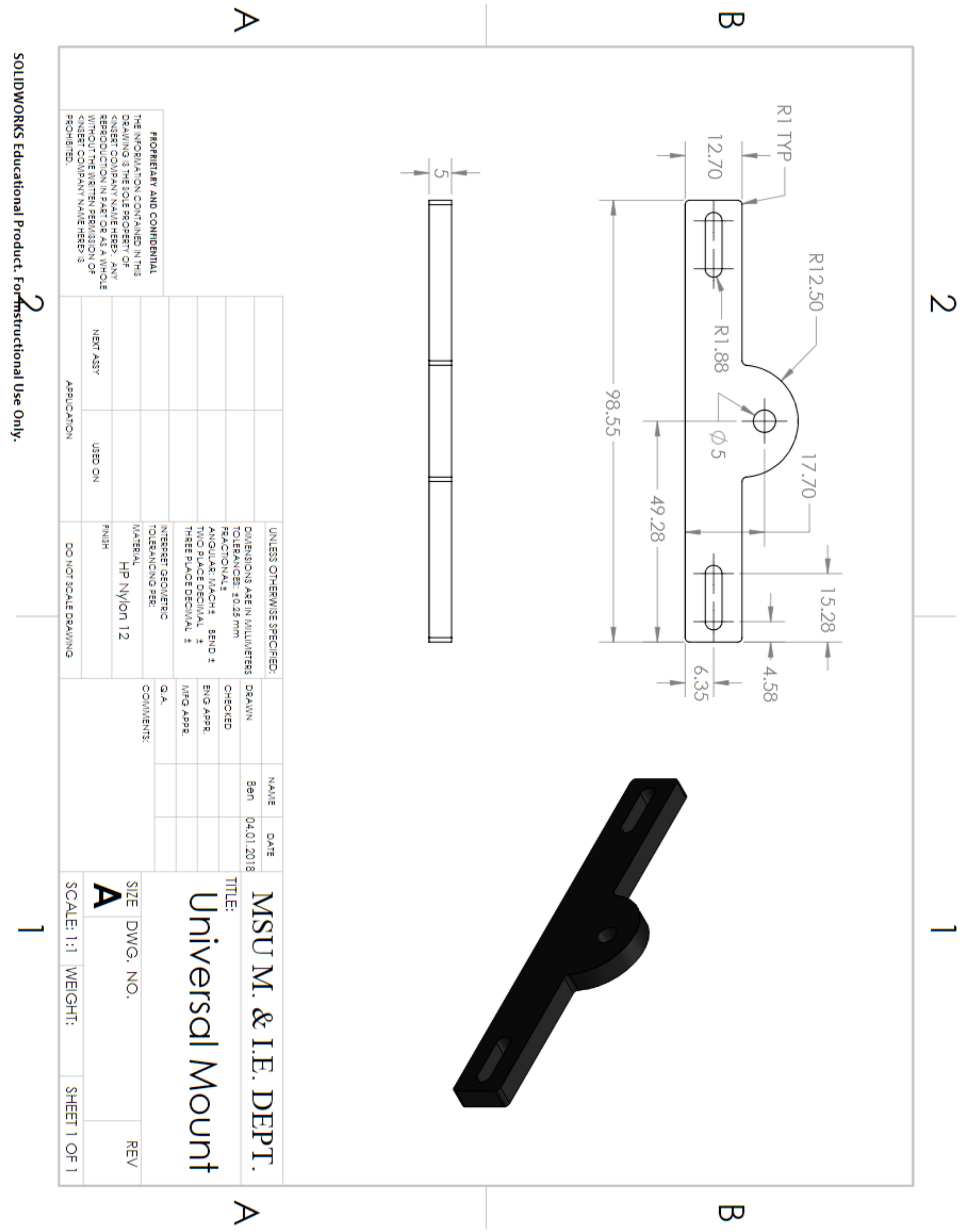

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