

Automated Jerboa Startling Device

ME 450 - Section 6

Team 23:

Nicholas Boston, Marcel Gonzalez, Joel Honigford,
Nathan Lange, and Jose Lasso

Sponsor:

Professor Talia Moore

EXECUTIVE SUMMARY

Dr. Talia Moore is a professor at the University of Michigan who specializes in the study of biomechanics, and more specifically, Jerboas, which are small, bipedal rodents, typically found in the desert. Dr. Moore is interested in studying the startle-response behavior of the Jerboa when perturbed by a loud noise or a puff of air. The data from studying the Jerboas' erratic movements and extreme athletic leaping abilities will be used to further the advancements of locomotion in robotics.

The goal of this project was to design a module to fit into an arena which more closely resembles a realistic environment for the Jerboas. The module must be able to sense when a Jerboa passes through it, automatically startle it with a puff of air and loud noise, and simultaneously trigger a high-speed video camera recording the hallway module as well as a force platform in the center of the hallway. Specifications for this project include adjustable air pressure for the air puffs (5-30 psi) and noise generation capable of producing sine-wave frequencies between 125 Hz and 10 kHz at a volume level up to 100 dB. Additionally, the system must activate in less or equal to 50 ms from sensor detection, and data collection must last for up to 25 seconds. The module must also be consistent among trials, with a maximum starting time error of less than or equal to 3% compared to the minimum start time. Lastly, the system must be able to handle up to 5 cameras and force plates. An initial budget of \$400 was given to this project, however, Dr. Moore specified that she was happy to spend more than this if needed and with proper justification, and it quickly became apparent that many of the components necessary for successful completion of these specifications would add up to more than that. Additionally, Dr. Moore requested a GUI integrated with the system with three modes of operation; manual, startle upon Jerboa entrance, and startle upon Jerboa exit.

The design concept chosen for this module was a hallway with the floor suspended above the ground to allow for pneumatic components to attach underneath, and features clear walls with one side having a checkered decal, which would allow the high-speed video camera to record the Jerboa's motion when startled and have a scale to measure distance with. The Jerboa will be startled from a puff of air coming out of the floor, as well as from noise from a speaker placed somewhere in or near the arena. The design also features sensors mounted at either end of the hallway at various heights to account for the Jerboa's jumping. All of these components are featured in our final design,

In testing our final prototype, all components and subsystems performed as expected, with the exception of the sensors. The GUI contained all of the features requested by Dr. Moore, necessary for controlling the system. From the electronic TR Pressure Regulator, combined with the GUI, we were able to meet the specification of emitting air at 5-30 psi, and this was confirmed by CFD analysis. Additionally, from the spec sheet of the JBL 8124 speaker selected, the frequency and volume specifications were met, where an option was added into the code/GUI to adjust speaker frequency, and a physical potentiometer limited volume. In testing the sensors however, the sensors selected were not able to perform as expected, and temporary sensors that a teammate owned were used to test overall system responsiveness, but the specifications relating to sensor speed and activation could not be met. Due to the hardware selected, the system should be able to handle more force plates and cameras, but since Dr. Moore has yet to select these components, this specification was unable to be tested. The budget of \$400 was not met, however Dr. Moore confirmed this to not be a problem.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
TABLE OF CONTENTS	2
PROBLEM DEFINITION	3
Problem Description And Background	3
Requirements And Specifications	5
CONCEPT EXPLORATION	7
Concept Generation and Development	7
Concept Evaluation / Selection	11
SOLUTION DEVELOPMENT AND VERIFICATION	16
Engineering Analysis	16
Risk Assessment	18
Detailed Design Solution	18
DISCUSSION AND RECOMMENDATIONS	24
CONCLUSION	25
AUTHORS	26
ACKNOWLEDGEMENTS	26
REFERENCES AND INFORMATION SOURCES	27
APPENDICES	28
[A1] FMEA	29
[A2] Drawings and Manufacturing Plans	31
REQUIRED SUPPLEMENTAL APPENDIX	38

PROBLEM DEFINITION

Problem Description And Background

The evolution of an animal species is a complex process that encompasses a long time. To analyse it and understand it, many factors are considered and so many others are not yet known. Yet, it is irrefutable that the role of predation as a strong selective force has always been present in evolutionary traits. The risk of being preyed upon has impacted the decision-making process of animals and changed the ways in which they interact with their environment [1]. Jerboas are not an exception to this evolution, as a matter of fact, it has been their evolutionary traits that have made them gain extraordinary abilities that have captured the interest of many researchers. In this evolution, the bipedal locomotion led the Jerboas to develop a high trajectory unpredictability and three different types of gaits. Since the Jerboas are exposed to predation through ballistic interception rather than a sustained pursuit, the gait transitioning favors more maneuverability and trajectory unpredictability than endurance. When the Jerboas are at risk of predation, their startle response exhibits the greatest span of these abilities. The gait transitioning occurs between running, skipping, and hopping, and as a result, a variable and transient locomotion that is difficult to quantify [2].

More studies that attempt to capture the Jerboas' response to predation that have been made using other types of simulated predation. These studies have demonstrated that the Jerboas have a higher trajectory unpredictability than their quadrupedal homologous: the Jird. The Jerboa's ability of easily turning and leaping is one cause of their unpredictable trajectories and increases their likelihood of evading ballistic interception predation [2]. Another impressive skill of the Jerboas that has been studied is that they can jump more than ten times their hip height. In this study, puffs of air were used to encourage the Jerboas to leap vertically [3].

The role that we play in the study of biomechanics is creating a mechanism that allows our sponsor, Professor Talia Moore, to improve the methods of her research on Jerboas. Professor Moore is one researcher among a small group of people in the world studying the biomechanics of Jerboas. The reason she studies the Jerboas is because of their bipedal locomotion and different gait patterns that separate them from other animals that also use bipedal locomotion to navigate. The startle response of the Jerboas is unique to any other animal that uses bipedal locomotion. They have the ability to jump ten times their own hip height. This startle response can be implemented into different systems and help improve robotics among other things. This is where the study of the biomechanics of the Jerboa is key because it allows us to understand why and how they move, which can then be implemented into other systems. Another aspect of the Jerboas locomotion is their ability to leap great heights. This could also be implemented into robotics to create robots that can jump extreme heights. The device that we are

creating allows Professor Moore to be able to take accurate data and recordings that will in turn take her studies to the next level. The device will allow her to startle the Jerboas, get roce plate readings from their different gaits, and record how and why they move the way they do, all without her having to be in the room. This series of connections will then lead to more trials and data that will be reliable, easily accessible, and customizable to give her exactly what she is looking for.

The goal is to create a device that automatically senses when the jerboa passes through a narrow passageway and automatically emits a puff of air and a sound to startle the jerboa. The integration of a force platform and a high-speed video camera system to capture the movements of the startled jerboa is required in the device implementation. The purpose of creating the device that automates the startling stimuli will aid in maintaining consistent conditions across trials and allow us to precisely control the stimuli to test various neuromechanical hypotheses.

Requirements And Specifications

Requirements

From meeting with the project’s primary stakeholders, Professor Talia Moore, and her Ph.D student Challen Adu, a list of requirements and specifications were constructed, which can be found below in Table 1, listed in order of importance. From the interview, it was emphasized that the main function of the device should be to physically startle the Jerboas consistently across multiple trials, while also adding as much customizability as possible.

Table 1. A prioritized list of stakeholder requirements and specifications for Jerboa starling device.

Priority	Requirement	Specification
1	Customizable puffs of air	<ul style="list-style-type: none"> ● 10-15 puffs per trial ● Adjustable air pressure (5-30 PSI)
2	Variable noise generation	<ul style="list-style-type: none"> ● Produce sine-wave frequencies between 125 Hz and 10 kHz ● Produce sound up to 100 dB
3	Instantaneous device activation	<ul style="list-style-type: none"> ● ≤ 50 ms from sensor detection to entire system activation ● Data collection lasts for up to 25 seconds
4	Consistency of device starting time across trials	<ul style="list-style-type: none"> ● Error of the maximum starting time compared to the minimum starting $\leq 3\%$

5	Scalability	<ul style="list-style-type: none"> System will be able to handle up to 5 cameras and force plates
6	Cost-efficient	<ul style="list-style-type: none"> ≤ \$400

- Due to the fact that startling the Jerboa is the main goal of the device, being able to emit customizable puffs of air was given first priority, which would replace Professor Moore’s previous method of startling the Jerboas by hand with a compressed air canister. Similarly, being able to generate noise at variable frequencies and volume levels was given next priority, in order to study how Jerboas react and whether certain frequencies cause more perturbation than others.
- Jerboas move at such high speeds, so it was important that the device is activated as instantaneously as possible, emitting air and sound, as well as starting data collection across the force-plate and high-speed camera. Additionally, to obtain precise results, the starting time of the device must be consistent across trials, with minimal error.
- Another factor that Professor Moore requested was the device’s scalability, where she indicated that the device is able to integrate with additional force-plates and cameras if desired. Although important, this requirement was given less priority as a result of the relatively short timeline of the ME 450 semester, so at least being able to integrate with one force-plate and camera is the first goal.
- Lastly, cost efficiency was given the lowest priority in the list, where Professor Moore stated the \$400 budget was a “soft cut-off,” and more expensive equipment could be purchased if given proper justification.

Specifications

- After the list of requirements was generated, it was used to create a list of specifications to reflect the sponsor’s desires. The specifications were then assigned testable values that were determined through various means. These values are displayed in Table 1.
- In order to determine the specifications of the auditory features of the system, a paper written on an experiment conducted on kangaroo rats was referenced [4]. Due to the similarities between the jerboa and the kangaroo rat, this data used to determine an appropriate range of values. This experiment found that the kangaroo rat was most reactive to noise frequencies between 125 Hz and 8,000 Hz. Thus, the value used for jerboa includes this range. The noise volume was recommended by Professor Moore. She had previous success shouting at jerboas. The average human shouts at about 80 dB, so the specification value decided slightly exceeds this value. The duration of the noise is just long enough for the jerboa to be startled and likely does not need to occur for the entire duration of data collection.
- For the puffs of air specifications, we referenced Professor Moore’s previous experiments. She discovered that using an air duster successfully startled the jerboas. The

typical pressure of these air canisters was then researched and found to be 30 psi [5]. Professor Moore specifically requested that each data collection period generate between 10 and 15 puffs.

- For the general specifications of the system, mostly intuition and advice from Professor Moore were used to determine the values. It was decided that the system should be capable of activation within 50 ms of being triggered because if it takes any longer, valuable data would be lost. The system should collect data for at least 25 seconds to ensure that both the jerboa's behavior during the startle and as it is calming down is recorded and observable. Professor Moore requested that the designed system is capable of utilizing 5 cameras and force plates so that the entire arena is being utilized for data collection. Finally, the cost of the project should be less than 400 dollars, as determined by Professor Moore. However, she has given permission to exceed this cap with good reasoning.
- All of these values were screened by Professor Moore and she stated that each specification has a reasonable value that meets her expectations. These values were determined based on the initial information provided and research done. These values are subject to change due to the variability of the project.

CONCEPT EXPLORATION

Concept Generation and Development

- A. Dr. Moore's Module Concept:** This concept was introduced by our sponsor to give us an overview of the project design and the strategy to capture the Jerboas movement. Then, the team expanded on this idea and generated more module concepts that are presented below.

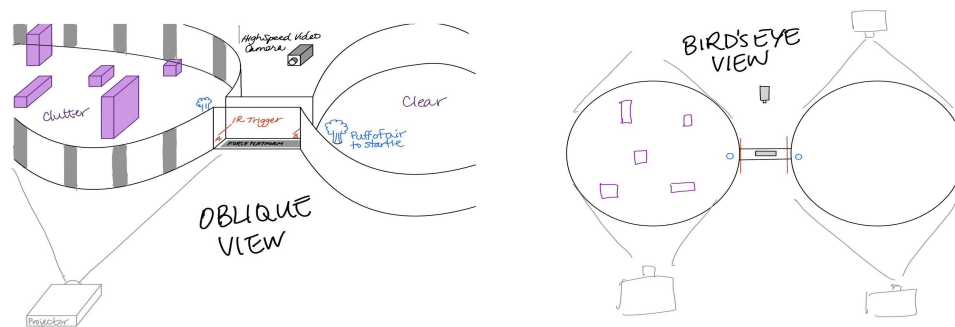


Figure 1. Dr. Moore's Module Concept from Oblique View and Bird's Eye View.

- B. Module Concept 1:** This concept was designed to fit in a pre-existing hallway connecting the two halves of the arena. It involves connecting all the important

components to one frame, which could be set down over the force plate and integrate with that and the camera. The concept features speakers on either end of the passage, IR sensors, and slotted holes for the air nozzle to allow for repositioning. A DAC board would also be attached to the side, with a hollow frame to allow for concealed wires.

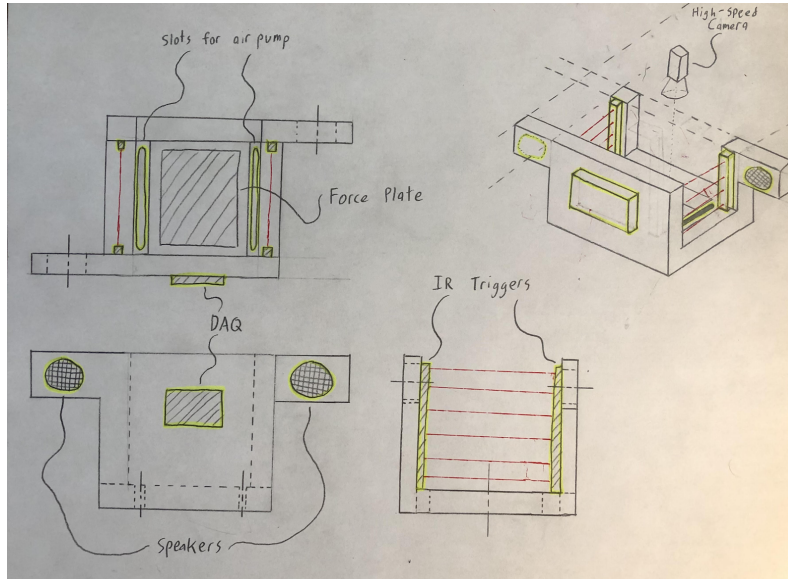


Figure 2. Module concept 1, showing all necessary components for sensing and startling the Jerboa.

C. **Module Concept 2:** This module focuses on placing the speakers at the ends of the arena but could be easily moved around the edges of that arena. In addition, the air pressure would be fixed at the same place to be placed inside the walls by doing a small hole and both valves are connected to an air pressure tank. All systems are connected to a DAC board which can be operated by Professor Moore using the GUI.

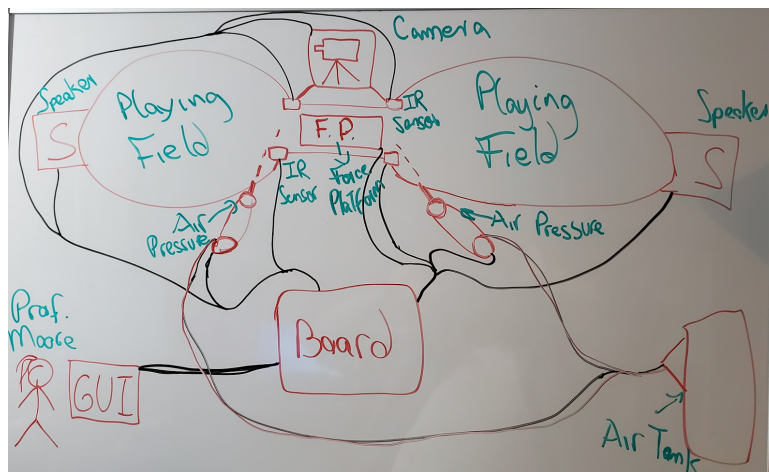


Figure 3. Module Concept 2 to integrate all the devices that the board must handle that are used and operated from the GUI.

D. Module Concept 3: This module incorporates two main features for the passageway. The passageway walls will be held together using velcro to allow easy modifications to the passageway's size if necessary. Using velcro was suggested due to the stakeholder stating that future experiments might involve the usage of multiple force platforms, so using velcro would allow the passageway's width to be increased or decreased as needed. The second main feature would be using multiple tubes connected to the built-in holes with valves on the floor of the entrances of the passageway to allow puffs of air to exit in multiple directions. This feature increases the randomness of the air puff's timing and location to prevent the jerboa from learning and getting accustomed to when and where the puffs of air will exit. A diagram of the concept is shown below in Figure 4.

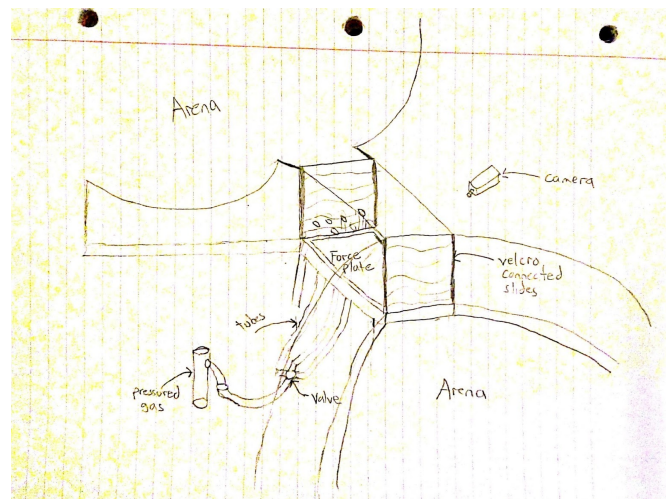


Figure 4. Module Concept 3 incorporates velcro connectors of the passageway walls for easy assembly and disassembly and multiple tubes connected to the holes on the floor of the entrance of the passageway enabling puffs of air to exit from multiple locations.

E. Module Concept 4: This module concept puts an emphasis on using multiple components that can be placed anywhere in the arena. This concept provides the ability for the user to place mechanisms wherever they deem necessary to produce the best results. The initial concept includes placing the speakers on the extreme ends of the arena, sensors, and the entrance of the hallway connecting the two larger arena areas, and an air nozzle just outside of the sensor lines. Then the speakers, camera, force plate, sensors, and air valve are connected to a data acquisition system that is connected to a personal computer.

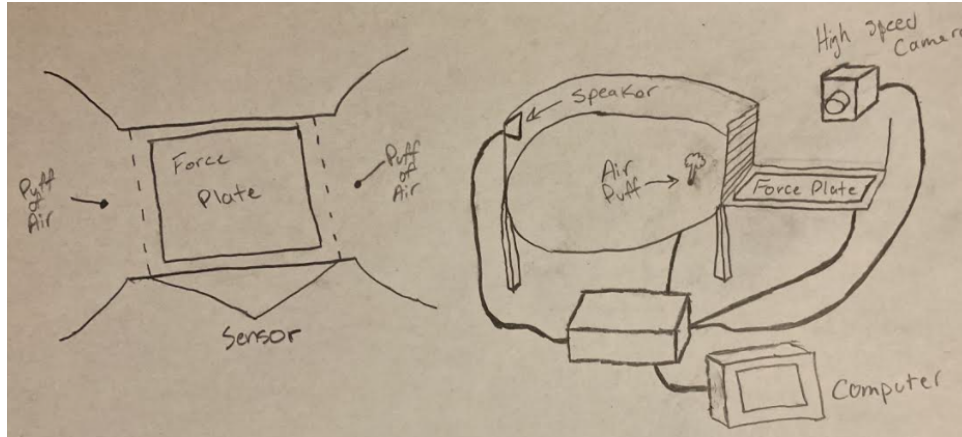


Figure 5. Module concept 4 displaying the positions of the various mechanisms used in startling and detecting a jerboa.

F. Module Concept 5: This module was based on the idea that the hallway was already built and that we were to install and wire up a system connecting all of the separate components. This module allows for all of the components to be wired together into a chassis that connects to a GUI in a computer. This concept features a four beam IR sensor on either side of the hallway along with airports near the sensors to startle the jerboas. The speakers are also built into the far ends of each side of the open areas. The view of the camera provides a slight aerial view from the horizontal to best view the perturbation of the jerboa. The benefit of this concept is that there is no messing wiring due to everything being attached to the chassis which runs one cord to the computer. Figure 6 below shows this concept of the placement and attachment of the separate components.

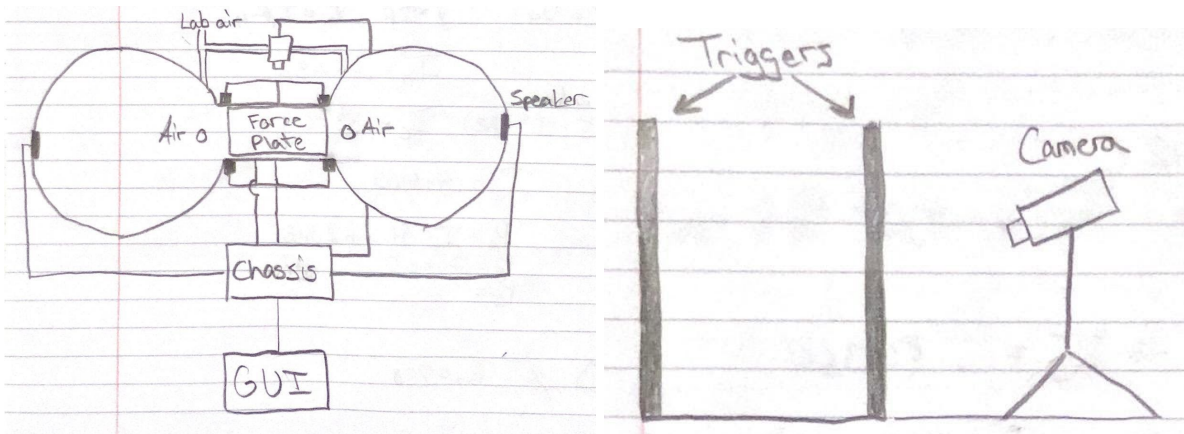


Figure 6. The components of the arena are shown to all connect together to one chassis which will connect to the GUI.

Concept Evaluation / Selection

To aid in evaluating concepts and selecting a final module concept to focus on, a Pugh Chart was utilized, where the criteria were selected based on adjustability, functionality, ease of manufacturing, as well as component organization. Component adjustability was given the highest weight to fit the requests of Professor Moore, of which having customizable puffs of air was given the second-highest weighting, having the option to move the air puffs to various locations in the hallway as the Jerboas get used to them in one spot, or as the research focus shifts. Manufacturability and organization were both given the lowest weights, due to the fact that none of the concepts are overly complicated to construct, and although the component organization is important, having the ability to move the components to various locations was more important for Professor Moore research.

Table 2. Concept evaluation of all the Module Concepts using a Pugh Chart shows that the best concept is Concept Module 3.

Criteria	Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Component Adjustability	4	0	+1	+1	+1	0
Customizable Air Puffs	3	0	-1	0	-1	-1
Manufacturability	2	0	+1	+1	+1	+1
Organization	2	0	-1	-1	-1	0
Total	-	0	1	4	1	-1

After generating and evaluating concepts for the module and how the components would look laid out, it was then important to actually select which components to use. This was done by first looking at the requirements and specifications as a starting point, and researching speakers, air valves, sensors, GUI software, and DAC's. Although a Pugh Chart was not utilized for the component selection, options were compared based on how well they met the requirements and specifications, price, as well as dimensions of fitting into the module.

A. The Speaker: Startling the Jerboa by sound is the second primary way Professor Moore wants to be able to perturb the Jerboa. When selecting the speaker, the specifications were the main factor to narrow down options. The speaker had to have a frequency range of 125 Hz to 10 kHz, at a volume level of up to 100 dB. One starting point for options came from having past experience using Eminence Speakers in a mechanical engineering lab class here at Michigan. These speakers were generally found to not meet the entire frequency range, focusing either on the low or high end, meaning two speakers would have to be used to cover the whole range. Additionally, these speakers were around \$140 each, which would be near the top of the budget. Professional studio monitors were also considered as an option, which met the frequency

response, however, they are expensive (\$150 each) and bulky. To reduce cost and bulk, a ceiling speaker was finally selected as the best option, with the JBL 8124 shown below.



Figure 7. JBL 8124 Ceiling Speaker, used to startle the jerboa.

The JBL 8124 covers a frequency range of 60 Hz - 18 kHz, with sensitivity, or volume, of 93 dB. This value was slightly below our initial specifications of 100 dB, however, Professor Moore confirmed that 93 dB is still more than acceptable. This speaker is only \$36, which is the cheapest option considered that met all of the specifications. Additionally, since this speaker does not include housing, custom housing was designed for added adjustability, as requested by Prof. Moore.

B. Air Valve: The air valve system includes anything that involves pressurized air that will startle a jerboa. This system is crucial, as it is the leading feature to startle the jerboa. This system must be capable of pressurizing air, transporting pressurized air, and releasing the pressurized air on command. In order to do this, many components must work in unison. The lab that Professor Moore will operate in has a supply of pressurized air, which the system will utilize. This air is pressurized to 50 psi. This is then connected to a TR - Electronic Pressure Regulator with Internal Pressure Sensor in order to achieve the desired air pressure.



Figure 8. Displays the TR - Pressure Regulator that will be used for this system.

However, before the TR - Pressure Regulator can receive any air, the air must be prepared. The devices used for this are dryer and filter. From the house are to the the pressure regulator, the components used in sequence are: 1/4" Aro Male Plug, Straight Barbed Adapter for 1/4" Hose ID and 1/4" NPTF Male, High-Pressure Air Hose with 1/4" ID, Anderson Metals 1/4" Barb x 1/4" MIP Nylon Connector, Motor Guard DD1003 Desiccant Filter, Anderson Metals 1/4" ID x 1/4" FTP Brass Hose Barb, High-Pressure Air Hose with 1/4" ID, Anderson Metals 1/4" ID x 1/8" MPT Brass Hose Barb, Anderson Metals 1/8" ID x 1/8" FPT Brass Hose Barb, provided 1/8" ID hose, Straight Barbed Adapter for 1/4" Hose ID and 1/4" NPTF Male, Miniature Coalescing Filter.



Figure 9. (Top) Displays the Motor Guard DD1003 Desiccant Filter that will be used in the air system. (Bottom) Displays the Miniature Coalescing Filter that will be used in the air system.

The pressure regulator is programmed to release the air into the arena at whatever pressure and delay is specified. The air is then split using a Tee Connector, and Worm-Drive Clamps for Firm Hose. When deciding on these parts, some important things to consider are the price, the fitting sizes, and the ability to complete the task. Due to the low cost of the hose, it was decided that 30 ft. should be purchased so there would be no concern of reaching around the lab or having to replace the hose in the future due to wear and tear. Some components were requested and provided by Professor Moore. These components were the TR - Pressure Regulator, ORANGE BIT, BLUE BIT, and GLASS BIT. The leading factor in the selection was their ability to handle pressurized air, and their connectivity.



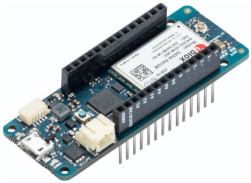
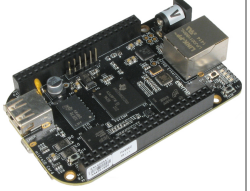
C. Sensor: The sensors are the component of the project that triggers everything to activate. The sensors have a very important role because they need to be able to detect the jerboa at any point in the hallway, as well as activating the whole system instantaneously. The concept generation of the sensors first began with looking at different types of sensors such as motion, photoelectric, and infrared (IR). From here it was then determined that the two best ways of detecting the height of the hallway were having the sensors aligned vertically from the top down and horizontally, side to side. After comparing the sensors it was determined that the best solution to our problem followed our sponsor's recommendations of IR sensors aligned horizontally. More specifically the 4 beam IR sensor that spans 22 inches in height of the hallway leaving minimal room for the jerboas to maneuver past undetected. Another reason this sensor was chosen was because it fits the dimensions of the hallway which will be 2.5 feet in height. The beam IR sensor will be more than sufficient for the task it is required to perform.

D. GUI: The GUI is responsible for controlling the testing arena's functionality to both startle the Jerboa and capturing the data from the force plate and high-speed camera. The requirement of the GUI is to be user-friendly to allow researchers to learn easily and efficiently on how to operate the testing arena. Two choices of GUI implementations were suggested, a LabView-based implementation or a MATLAB-based implementation. LabView is a graphical programming language that allows data acquisition, test automation, and instrument control. LabView's main components are the front panel in which the researcher will use to interact and run the testing arena, a block diagram which is the programming interface called G-code, and icons and connectors to enable input redirection and flow control of programs within the block diagram. MATLAB provides a mathematical and numerical computing environment. MATLAB GUI provides point-and-click control of custom software applications. Therefore, MATLAB provides the functionality to create an application interactively and programmatically which provides further flexibility and operations for the GUI task [6]. Our stakeholders are familiar with the MATLAB environment and MATLAB is compatible with external hardware, therefore the GUI will be implemented using MATLAB.

E. DAC: The DAC component is responsible for integrating all system components presented above as well as the high-speed camera and the force platform. This component must be able to handle all these components and quickly respond to the signals received from the sensors to activate the other devices. The research and benchmarking of the existing types of boards available to solve this problem were done considering several sources. These sources include the sponsor's recommendation board: CompactDAQ, a common multifunctional board: Raspberry Pi 4, the board used in most control classes in the Mechanical Engineering department: Arduino,

and a very common board used at the industry level: Beaglebone Black. A comparison of all these DAC boards is presented in Table 3 below.

Table 3. Comparison between preselected DAC boards based on the requirements of the project.

Type of Board	CompactDAQ	Raspberry Pi 4	Arduino MKR NB 1500	Beaglebone Black
				
Processor	1.33 GHz Dual Core	1.5 GHz Broadcom Quad Core	48 MHz ARM Cortex	1 GHz ARM Cortex A8
Scalability	18 In/Out Pins	40 In/Out Pins	52 In/Out Pins	46 In/Out Pins
Programming Language	LabVIEW	C, C++, Python, Matlab	Arduino, C, C++, Matlab	C, C++, Python, Matlab
Connectivity	2 Ethernet ports	Wireless, Ethernet, and Bluetooth	One USB port to connect to PC	Wireless, Ethernet, and Bluetooth
Storage	16 GB	Allows for SD Card	256 KB	16 GB
Price	\$ 6,489.00	\$ 35.00 - \$ 75.00	\$ 77.00	\$ 63.00

Based on the comparison established above and the requirements of this project as well as the input from the sponsors, the board selected for this project is the Beaglebone Black. This is the best DAC to use because it provides a processor that can easily handle multiple tasks and devices at the same time and allows enough pins to connect all the devices (sensors, high-speed camera, force platform, etc) in the project and more for future sponsor work. It is MATLAB friendly which will allow creating a GUI for multiple users to troubleshoot. In addition, it has nice features that are not required for the project but can be implemented for better use such as the 16GB memory storage and wireless connectivity. A setback of this device is that it is mostly

used in industry and no team member has experience using it, which can delay the implementation of its function.

SOLUTION DEVELOPMENT AND VERIFICATION

Engineering Analysis

One of the most complex subsystems in our design is the pneumatic system. This is mostly due to general inexperience the team has in this topic. Due to this fact, it was decided that this system should be looked at as much as possible to ensure that the system is capable of meeting the needs specified by the sponsor. After coming up with a preliminary design, a flowrate analysis was done to figure out whether or not the system could meet the 30 PSI specification. First, a flow chart was created to simplify the system. This simplified system can be seen in Figure 10.

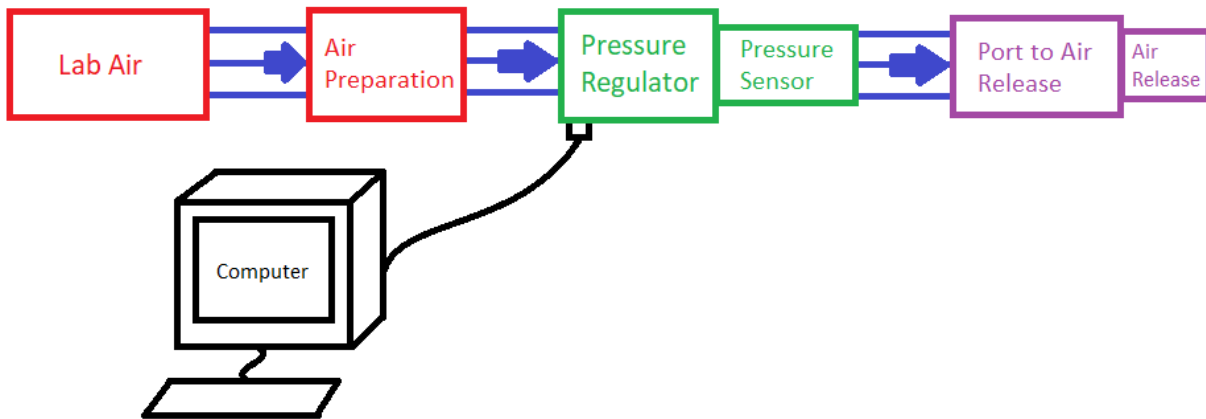


Figure 10. Displays a simplified pneumatic system. This system is grouped into different color groups in order to make analysis easier. These groups are red, green and purple, which represent before the pressure regulator, the pressure regulator system, and after the pressure regulator respectively.

Using this simplified pneumatic system representation, it was determined that the components after the pressure regulator would be the important part to do a pressure system analysis. A computational fluid dynamics analysis was performed on these components. It was determined that if the TR Pressure Regulator is set to an absolute inlet pressure of 27.34 PSI, the pressure at the outlet would be 12.11 PSI. This value was within our specification range, and can be increased or decreased by manipulating the inlet pressure of the regulator. A visual display of the CFD analysis is displayed below in figure 11.

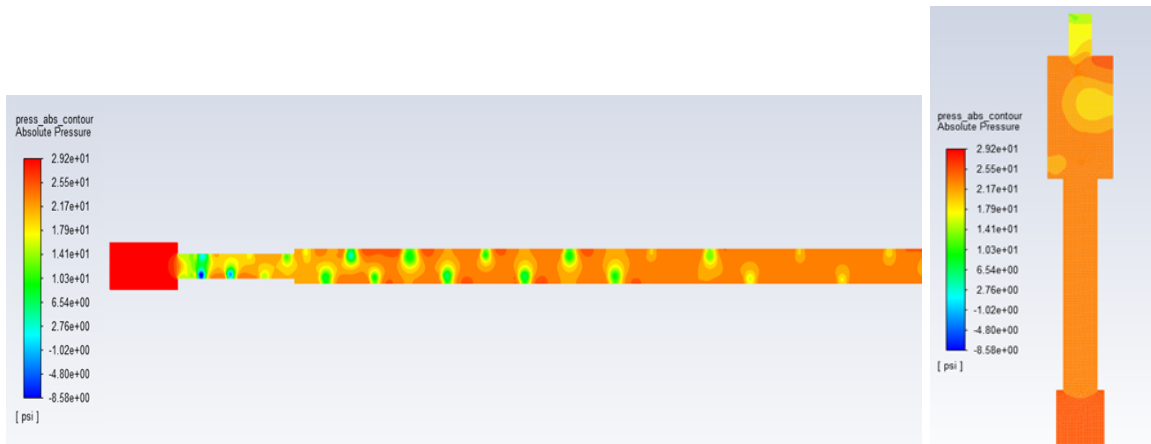


Figure 11. (Left) Displays the CFD analysis performed on the components after the TR Regulator and before the tee connector. (Right) Displays the CFD analysis performed after the tee connector up to the opening in the floor.

This analysis confirmed that the material that was used in the design would be able to withstand the pressure that is being targeted. Additionally, pressure at the exit hole was within the previously determined specification.

Risk Assessment

From the results of an FMEA, the aspect of our design with the highest risk was the floor connector where the compressed air tube attaches to the floor and air is emitted. The main failure mode of this component is the 3D printed plastic component cracking, either due to the pressure from the threaded, barbed hose connector, or from the air pressure. The severity of this failure mode was rated at 7/10 due to the fact that the primary function of emitting air to startle the Jerboa would degrade. In the initial prototyping phase, one of these connectors did crack, and a new one was printed at a greater infill density and with 3D-printed threads instead of the previous method of heating the metal hose connector and threading that into the plastic by force. The probability of this occurring again was fairly low, rated at a 2/10, but the main factor contributing to the high RPN is the detection value, rated high at a 7/10 due to the fact that it would be unlikely that this failure would occur in testing, and could be the result of fatigue and/or creep. One method for mitigating this risk could be to examine the part closely for any micro-fractures or cracks to eliminate propagation. Additionally, having the electronically controlled TR pressure regulator helps to ensure that the pneumatic pressure is always within safe levels. Currently, the design is just within acceptable limits, with an RPN of 98/100, with >100 being hazardous, however after making the failure easy to detect, it could be reduced to 84 or 70. Another design change that could reduce this mode of failure would be to use a metal connector instead of 3D printed plastic.

Detailed Design Solution

After the initial design concepts were created and analysed, and individual components were looked into and initially selected, a more specific drawing was then created for the selected design. This design includes more detail as well as dimensions to provide a sense of scale. This design was selected by combining many of the good concepts that the initial designs featured. Many of the dimensions that were decided on were requested by the sponsor, so the design was catered to these requests. This design is displayed in figure 12.

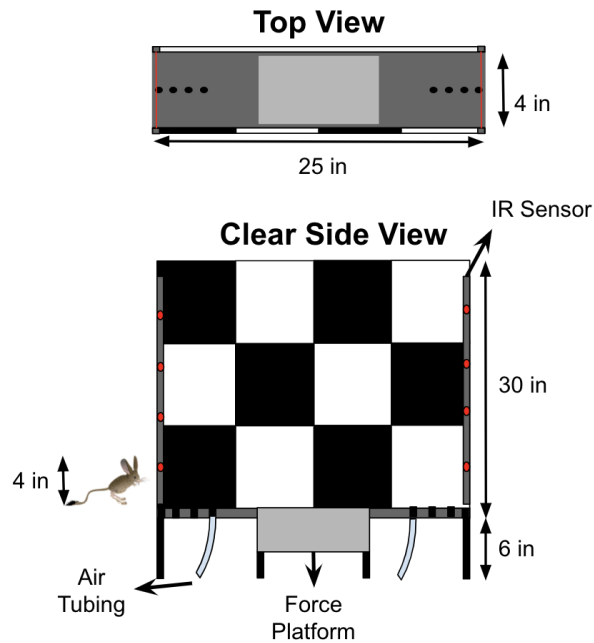


Figure 12. Displays the selected concept design that includes important dimensions, as well as a jerboa for scale.

This drawing was then used to create a detailed CAD model. Many of the features in the CAD design are identical to the drawing, namely the dimensions. However, there were minor alterations made as opportunities to improve the concept were discovered. Some of these modifications include adding feet to the legs in order to increase the stability of the hallway and including holes before and after the IR sensors. Additionally, the length of the hallway was slightly increased to allow for a larger viewing window for the high-speed camera. The CAD model can be seen below in figure 13.

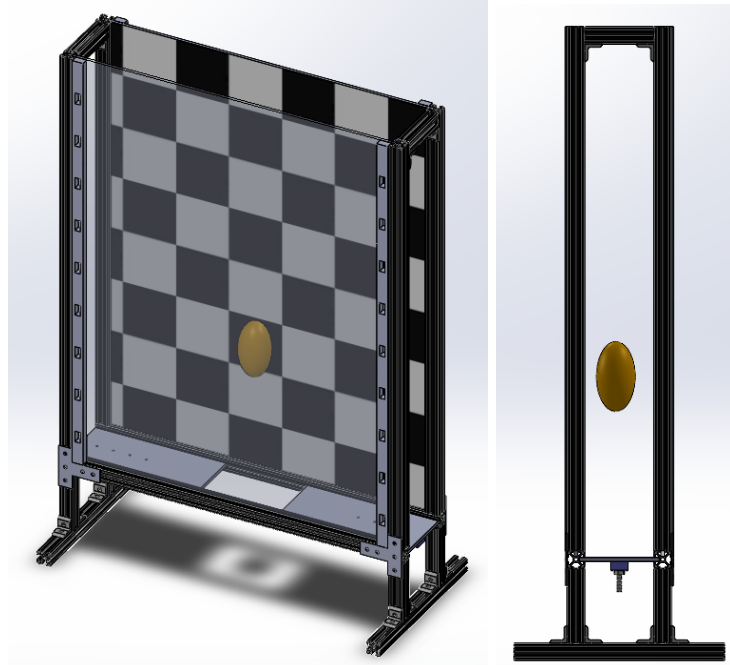


Figure 13. (Left) Displays an isometric view of the CAD model, with a yellow ovoid shape that represents a jerboa to provide a sense of scale. (Right) Displays the hallway if one was to look down it.

Similarly, after discussing design options with Prof. Moore, a CAD model was developed for the speaker housing, which can be seen below in figure 14. The design features a sliding door for speaker installation and maintenance, as well as hooks for mounting the speaker onto the arena wall, and attachable feet to set the speaker on the floor. One feature specifically requested was for the housing to be able to attach to a universal tripod mount, which was added on the top where a screw will be attached.

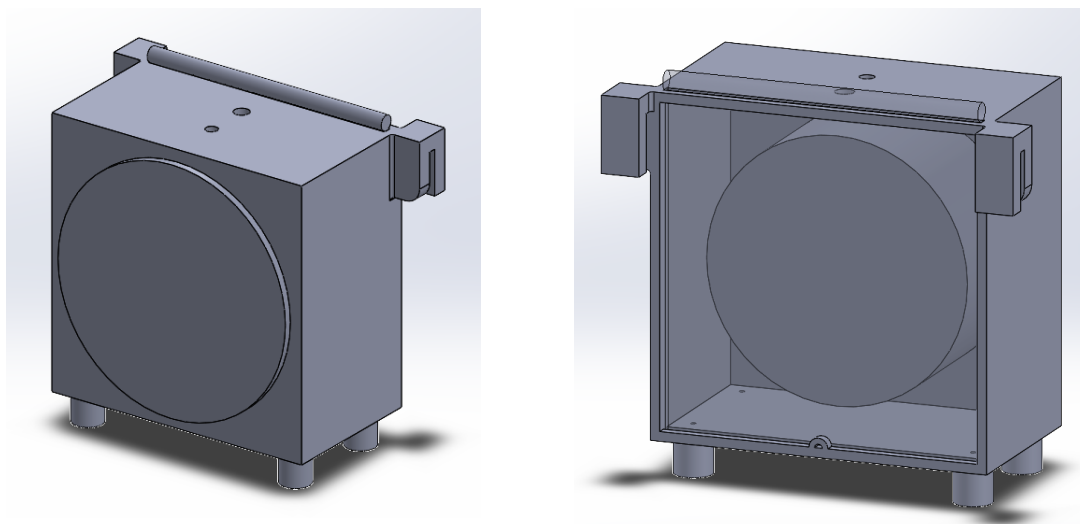


Figure 14. CAD model for the speaker housing, featuring attachable feet, hooks to mount on the arena wall, and integration for a universal tripod mount.

In addition to creating a CAD model of the hallway, a virtual concept was created for the GUI. When designing the GUI, each of the components that would play a part in the data collection were considered as well as meeting the previously decided specifications. An initial design was created which included customizable pressure, duration, delay, volume, and frequency. The GUI is displayed in figure 15.



Figure 15. Displays the GUI being used for the hallway software.

The reasoning behind having this many features that can be altered is because of the desire of having as much customizability as possible to ensure it can function at the best settings to generate an effective startling. In addition it displays an active display of the camera feed and force platform data. The system also includes a manual and automatic mode of triggering. The data will automatically be saved using a format requested specifically by the sponsor.

Verification

In order to decide the best method of verifying, as a team, we asked ourselves how many features could be tested and analysed analytically, and how many features could be tested experimentally with a low risk of damage in the event of failure. Due to the nature of this project, there was not very much that could be tested analytically, so we leaned towards a verification

method that was more experimentally based. Our verification method was to do experimental tests with each of the individual subsystems before combining them into one large system. After each of the subsystems were tested and proved successful, they were combined and tested again. One system that we were capable of analytically analyzing was the pressurized air flow. As previously discussed, we performed a computational fluid dynamics analysis to determine whether or not the system design was capable of meeting the specification of 5-30 psi. This was also done to determine whether the selected components could withstand the pressure we would be performing at.

Due to the nature of many of the specifications and requirements of this project, an experimental verification method proved beneficial. This is because many of the requirements and specifications were based on how the GUI functioned. This experimental format of verification allowed the GUI to be designed, built, and virtually tested. However, the important feature would be whether the GUI actually caused the physical system to react the way the inputs are entered. For example, the GUI can say that it meets the specifications of being able to select 10-15 puffs, produce sound at 125 Hz - 10 kHz, produce sound at 100 dB, or ≤ 50 ms delay for the sound and air puff. However, the only way to know if the system is actually capable of meeting these is to take some of these parameters, input them into the GUI, and physically test them. After running this experiment verification, we discovered that the GUI was capable of doing all of these to the extent that the testing components were capable of. Due to the speakers selected not being delivered soon enough, a personal speaker was tested and capable of changing in frequency and volume as input, but only up to that speaker's limits. We also found that the air system was capable of continuously running and saving data for our 10-15 puffs without the system needing to be reset.

This physical experimentation method of verification led to several limitations. The team was not able to enter the lab in which the project was actually being designed for, so we could not test the design where it was meant to be used. This has some limitations in terms of replicating how it would be used to some extent, but was worked around. The system was tested in G.G. Brown Laboratory, using its in-house pressurized air system. The key difference between these locations is that Professor Moore's lab is maintained at 50 psi, while G.G. Brown Laboratory is maintained at 115 psi. This meant using a temporary pressure regulator in order to prevent the filters from exceeding their maximum pressure of 100 psi. This was something that wouldn't have been done had testing been doable in the systems intended lab of use. Another limitation is that there were no jerboas to test the system on. It is difficult to know whether or not the system would actually startle a jerboa rather than simply puff air behind or in front of it. Finally, COVID-19 made getting into the lab and interacting as a team more difficult. Particularly in the testing phase, it was hard to get the entire team in the same location, when this is something that is meant to be prevented.

Overall, as a team we believe that the design was a success. While the system does not have all of the components installed, each of the components has been selected. For example, the speakers that were used for testing are not intended for use with actual data collection with a

jerboa, they proved that the frequency and volume of an installed speaker could be adjusted using the GUI. Once the components that were selected arrive, the installation method is planned for and should be rather simple. As a team, it was decided early on that the important specifications that needed to be met in order to feel that the project was a success was a functional air system, functional sound system, and as much customizability as possible. The air system was completely functional, was functional with the temporary speakers, and the GUI provides a way for each of the parameters of these two components to be altered.

The largest take away from this project and its verification process was beginning the testing phase as soon as possible. Many of the issues that the team encountered would have been much easier to overcome had the testing phase began sooner. One example of this, figuring out just how many pieces and connections would have to be made in order to successfully connect the lab air to the floor of the hallway where it would exit. There were many last minute purchases that had to be made in order to connect all of the components. Additionally, getting many things going at the same time would have helped with meeting deadlines. Testing each subsystem individually ended up taking too much time and resulted in less time actually testing and refining the system as a whole.

DISCUSSION AND RECOMMENDATIONS

The integration of all the systems was a challenging step to evaluate our system and see the performance of the system overall. Strengths of the device is the hallway design that meets all the specifications and it is rigid and stable. Also the frames were made so that the arena portion of the gymnasium can be easily connected to the hallway and the force platform that the sponsors select will be easy to access. Another strength is the pressure system, which works as desired from the air tank to the TR pressure regulator to the floor of the hallway. The GUI to implement and monitor the device working was very successful. It is able to set the noise frequency and the air pressure to startle the jerboa automatically or manually as selected by the user. The main weakness of our project consists of not being able to integrate working sensors in the system, which is a critical part of our system to work correctly.

- Adding some sort of quick release for attaching the house to the bottom of the floor
 - All hose connections in general are hard to work with right now
- Add frame between the left and right sides of the hallway at the top
- Checkered decal (paper or otherwise)

There are definite pros and cons to the design we chose, and more specifically the components of the design. As far as the main frame goes, the structure was well put together, sturdy, and very easy to assemble. Taking a deeper look into each individual component, there

are definitely some changes that could be made to further improve the quality of the hallway. The air connectors that 3D printed for the floor performed exactly how we expected them to and did a good job, the only drawback to this design is that these pieces could be manufactured out of a piece of aluminum in order to extend their lifetime with constantly since the PLA which was used to print with is not as rigid as we anticipated. Along with this topic, it would be much more beneficial to attach a quick release mechanism to the floor instead of having to screw the housing in and out of the desired hole. The hose that connects the air regulator to the floor itself is very stiff so anytime the hole needs to be changed that the air is puffed out, the floors need to be removed in order to screw the hosing in. The quick release would negate this and make it fast and easy in order to switch the holes.

The sensors gave us the most issues when designing and manufacturing the hallway module. After receiving the first set of sensors we chose, the wiring aspect was not going to work with the bread board so we had to return them. After further research was performed, we found a second sensor that seemed suitable for our project. On the initial testing, the sensors seemed to work perfectly, but when everything was wired together for the final testing the sensors did not work at all. After lots of trouble shooting and rewiring, it was determined that either the inexpensiveness of the sensors as a whole, or the poor quality of wires that it came with were the cause of the problems. As far as the recommendations go for the sensors, we recommend buying a break beam sensor that operates on a digital signal. This means that the output of the sensors returns a 0 or a 1 to the system. The second recommendation is that these sensors operate between five and twelve volts in order to be compatible with the arduino system.

The GUI was very successful and fully functional for what was needed for the project. Due to the fact that we did not have the force platform, we could not read any data into that section of the GUI, but we were able to wire it up to be triggered by LEDs and determine that it would in fact connect and collect data when the system required it to. The only issue with the GUI is that it would need to be upgraded if there are multiple systems connected to one. The interface of the GUI is set up so only one force platform and camera are displayed. In order to use multiple hallway modules in the future you can either run them all on their own individual GUI, or the GUI itself would have to be upgraded in order to display multiple cameras and force platforms.

CONCLUSION

The Jerboa startling device was concluded to meet all requirements and specifications set by the team's sponsor, Dr. Moore, with the flexibility of going over budget. The Jerboa startling device can be broken down into three main systems. Each system has been proven to work separately during testing. The first system is the physical structure of the hallway. The hallway allows the Jerboa to move between arenas; the hallway has walls of clear acrylic glass to allow a high speed video camera to record the Jerboa inside the hallway, and the floor of the hallway enables the Jerboa to get startled by a puff of air while simultaneously triggering the noise of the speakers and the video camera to record the Jerboa and capture the force data from the force sensing

platform. The air subsystem for the puffs of air is able to be adjusted between 5-30 psi, the noise substem is implemented by speakers to produce sine-wave frequencies between 125 Hz and 10 kHz at a volume up to 100 dB. Infrared sensors aligned vertically from the top down and side to side were used to initiate the startling system and video recording. The hardware subsystems were connected with an OMEGA Arduino to communicate with the GUI. The third system is the software, the GUI. A GUI was created using MATLAB with a user friendly interface. The GUI included features to set the parameters required for each trial and has the ability to switch between automatic and manual mode. For implementation purposes the GUI generated random force data to simulate data acquired from the force platform due to not having access to the force sensing platform during the time period of this project. These three systems work concurrently to gather data on a Jerboa when being startled, but the team hasn't shown all components working together as a whole due to the sensors not working properly which could be fixed by purchasing higher quality sensors.

The sponsor received a detailed written tutorial on how to assemble the physical system, connect all the hardware components, and a wiring diagram. Furthermore, the trial includes videos that explain the user interface of the GUI and explaining each part of the tutorial. The tutorial shows that the functionality of each subsystem of the Jerboa startling device and its components. We also gave recommendations to our sponsors to improve on this initial Jerboa startling device. Overall, the Jerboa starling device functionality is a success.

AUTHORS

Jose Lasso:

A senior at University of Michigan pursuing his BSE in Mechanical Engineering and minoring in Computer Science from Long Island, NY. His interests include computational engineering, programming and solid mechanics. He will be pursuing his Ph.D. in Mechanical Engineering at University of Illinois Urbana-Champaign starting the Fall of 2021.

Joel Honigford:

A senior at the University of Michigan who will graduate with a BSE in Mechanical Engineering in December of 2021. He is also a member of the varsity football team and will finish his career in the fall of 2021. Other than engineering, Joel's interests are football and music.

Nick Boston:

A senior at the University of Michigan who will graduate with a BSE in Mechanical Engineering in December of 2021. Prior to his time at UofM, he attended Michigan State University for two years before transferring. Outside of engineering, his primary interests included music and running.

Marcel Gonzalez:

A senior at the University of Michigan graduating in April 2021 with a Bachelor of Science in Mechanical Engineering. He has accepted a full time position at Ford Motor Company in the Powertrain Manufacturing department to start in June 2021. His interests include Finite Element Analysis, Computational Fluid Dynamics, Controls, and programming.

Nathan Lange:

A senior at the University of Michigan graduating in December 2021 with a Bachelor of Science in Mechanical Engineering. He is still looking to find an internship to further his career experience in order to obtain a full time job. He has an interest in automotive manufacturing design.

ACKNOWLEDGEMENTS

- Prof. Talia Moore
- Challen Enniful Adu
- Prof. Alex Shorter
- Heather Cooper
- Don Wirkner
- Charlie Bradley
- Johnathon Yenkel
- Xun Fu

REFERENCES AND INFORMATION SOURCES

References

- [1] Lima, S., & Dill, L. (1990, January 01). [Pdf] behavioral decisions made under the risk of predation: A review and prospectus: Semantic scholar. Retrieved February 6, 2021, from <https://www.semanticscholar.org/paper/Behavioral-decisions-made-under-the-risk-of-a-and-Lima-Dill/12897c526c0e3f70eff702af2dffe2b38e43ef26>
- [2] Moore, T., Cooper, K., Biewener, A., & Vasudevan, R. (2017, September 05). Unpredictability of escape trajectory explains predator evasion ability and microhabitat preference of desert rodents. Retrieved February 3, 2021, from <https://www.nature.com/articles/s41467-017-00373-2>
- [3] Moore, T. Y., Biewener, A. A., & Rivera, A. M. (2017, July 3). Vertical leaping mechanics of the LESSER Egyptian JERBOA reveal specialization for maneuverability rather THAN elastic energy storage. Retrieved February 4, 2021, from <https://pubmed.ncbi.nlm.nih.gov/28680452/>
- [4] Webster, D. B., & Webster, M. (1972). Kangaroo rat auditory thresholds before and after middle ear reduction. *Brain, behavior and evolution*, 5(1), 41–53. <https://doi.org/10.1159/000123736>
- [5] Typical Pressurized Keyboard Cleaner is 30 PSI. OSHA, O. (n.d.). Using Compressed air for cleaning. Retrieved February 11, 2021, from <https://osha.oregon.gov/OSHApubs/factsheets/fs77.pdf>
- [6] Harley, E. M., & Loftus, G. R. (2000). MATLAB and graphical user interfaces: Tools for experimental management. *Behavior Research Methods, Instruments, Computers*, 32(2), 290–296. <https://doi.org/10.3758/bf03207797>
- [7] Moore, T., Organ, C., Edwards, S., Biewener, A., Tabin, C., Jenkins, F., & Cooper, K. (2015, October 08). Multiple phylogenetically distinct events shaped the evolution of Limb SKELETAL Morphologies associated With Bipedalism in The Jerboas. Retrieved February 8, 2021, from <https://www.sciencedirect.com/science/article/pii/S0960982215011483>
- [8] JBL Professional. (2008). 8124 & 8128 Full-Range, In-Ceiling Loudspeakers. Retrieved February 21, 2021, from https://jblpro.com/en/product_documents/jbl_8124_8128_v1-pdf-78311bd0-7da8-4b36-bd44-fd2935cf3889

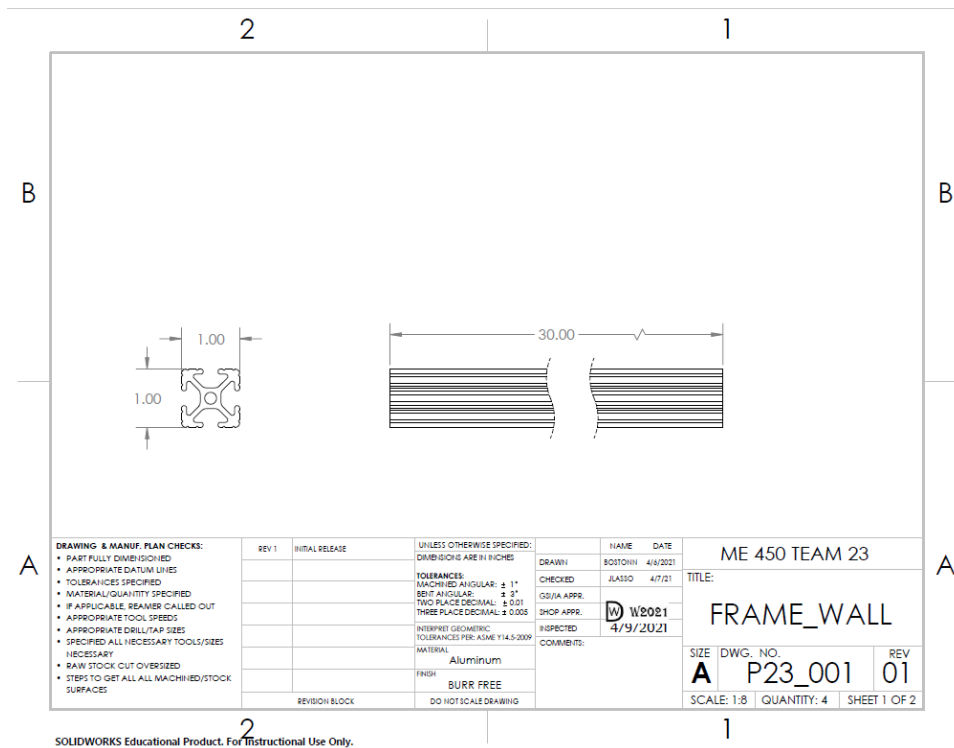
- [9] ¼ in. NPT Replacement Air Regulator with Steel-Protected Gauge. Retrieved February 23, 2021, from <https://www.homedepot.com/p/Primefit-1-4-in-NPT-Replacement-Air-Regulator-with-Steel-Protected-Gauge-CR1401G/205149488?source=shoppingads&locale=en-US>
- [10] Air Filter and Pressure Regulator, Campbell Hausfeld. Retrieved February 23, 2021, from <https://www.homedepot.com/p/Campbell-Hausfeld-Air-Filter-and-Pressure-Regulator-PA207803AV/100571465>
- [11] Enfield Technologies TR-Electronic Pressure Regulator with Internal Pressure Sensor. Retrieved February 23, 2021, from <https://www.enfieldtech.com/Products/TR-Electronic-Pressure-Regulators/TR-010-g10-s>
- [12] Speedway ¼ in. x 50 ft. Recoil Polyurethane Air Hose. Retrieved February 23, 2021, from <https://www.homedepot.com/p/SPEEDWAY-1-4-in-x-50-ft-Recoil-Polyurethane-Air-Hose-9389/205193349>
- [13] Harley, E. M., & Loftus, G. R. (2000). MATLAB and graphical user interfaces: Tools for experimental management. *Behavior Research Methods, Instruments, Computers*, 32(2), 290–296. <https://doi.org/10.3758/bf03207797>

APPENDICES

[A1] FMEA

Subsystem	Function	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes of Failure	Occurance (O)	Current Design Controls	Detection (D)	RPN = (S)x(O)x(D)
GUI	Allows user to customize parameters of the Module such as air pressure, duration, delay, volume level, speaker tone	Software bug/glitch	output of system is not as user intended	5	coding bug/glitch	2	Working GUI	3	30
	Displays video recording from high-speed camera and force data from force plate	Video/force data is not displayed/saved	experiment has to be re-done	4	coding bug/glitch	2	working GUI	3	24
Arduino and Breadboard	Integrates all electrical components to allow for control from a Computer	faulty electrical connections	Certain system components do not activate or work as intended	7	wiring issue, bad soldering connection,	2	None	2	28
Pneumatics	Provides air to startle Jerboa	air at too high pressure or velocity is emitted	Jerboa is harmed	10	Pressure regulator malfunctions	2	Adjustable air pressure from GUI	2	40
	Filters/Drys the air before it gets to the pressure regulator	unfiltered/wet air enters TR pressure regulaor	TR regulator breaks/is less effective	7	air filter or dryer malfunctions	1	None	6	42
	Regulates the air pressure to allow for adjustable/safe air puffs and pneumatic system	Glass components shatter	Could hurt users eyes or other body parts	10	Unregulated air pressure from the lab	1	Initial regulator before any important/hazardous components (filter, dryer, TR pressure regulator)	1	10
Speaker	Emits noise to startle the Jerboa	Volume level is too high	Jerboa/user hearing is damaged	10	GUI volume knob and physical potentiometer malfunction	2	GUI volume knob, physical potentiometer, component specification within safe range	2	40
	Adjustable mounting configurations	Speaker housing breaks	speaker falls and breaks speaker/housing Falls onto and hurts a Jerboa or user	7	speaker housing too thin	2	None	4	56
Sensors	Detects when a Jerboa enters the hallway and automatically activates system	Sensors don't activate system	force data and high-speed video playback are lost and not saved	8	Coding bug, wiring issue (soldering connection, etc.), physical component malfunctions	5	Tape to protect wires from becoming unplugged or soldered connections broken	1	40
Structure/Frame	Clear walls allow for sensors to work properly and high speed video recording	sensors or camera do not work/record properly	video data is not useable, system is not activated	7	acrylic is too reflective	2	Can add paper or checkered decal to reduce reflection	4	56
	Frame supports weight of sensor mounts and walls	Frame breaks, wall/floor falls out or is damaged	Components fall and break, could injure Jerboa	9	Frame is not strong enough	1	Lightweight materials/components selected	2	18
	Floor supports motion of Jerboa	Jerboa's foot gets stuck in air holes or gaps between floor and force plate	Jerboa is harmed	10	floor holes too big, floor becomes warped	1	Design constrains air holes to be less than 3mm in diameter	7	70
	compressed air comes out of the floor	air-floor connector breaks	air is no-longer emitted from the floor	7	3D printed connector does not withstand air pressure or threading	2	Printed component with greater plastic density	7	98

[A2] Drawings and Manufacturing Plans



2 1

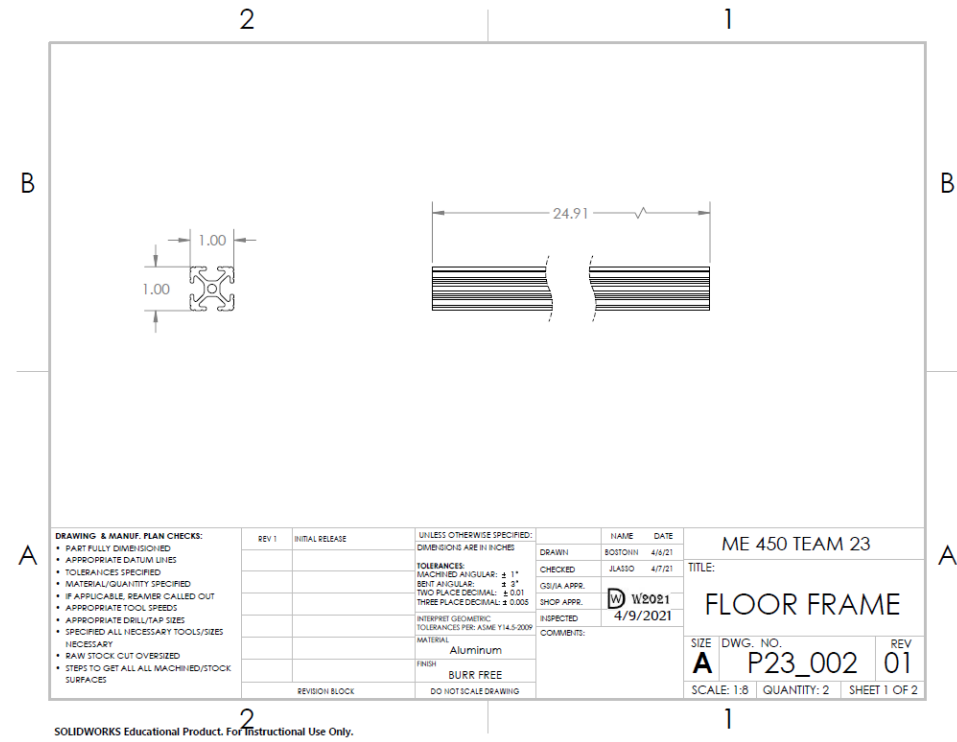
MANUFACTURING PLAN
RAW MATERIAL STOCK: 3ft Aluminum T-Slotted Rail

STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	Cut to length plus 1"	horizontal band saw			
2	zero datum	mill		edge finder	1200
3	mill to length	mill	5/4" parallels/vice	5/4" Ø End Mill	500 1500
Edge finder is not used on saw cut edges. Mill one end of part, swap ends and mill a clean up pass. Measure with ruler or calipers.					

SHEET 2 OF 2

2 1

SOLIDWORKS Educational Product. For Instructional Use Only.



2
1

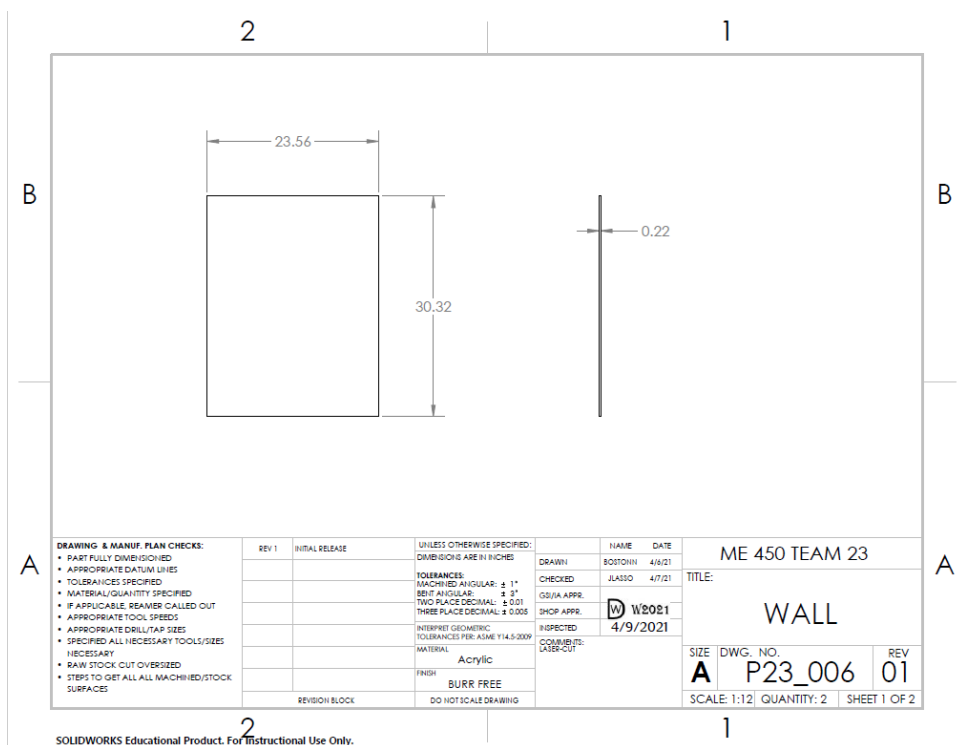
MANUFACTURING PLAN
RAW MATERIAL STOCK: 5" Aluminum T-Slotted Rail

STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	Rough cut with horiz bandsaw find zero	mill		edge finder	1200
2	cut to length	mill	3/4" parallels/vice	3/4" 0.015" end mill	500 1200
Edge finder is not used on saw cut ends. Mill end smooth, flip and mill other end. Measure and mill to length.					

2
1

SHEET 2 OF 2

SOLIDWORKS Educational Product. For Instructional Use Only.



2 1

MANUFACTURING PLAN
RAW MATERIAL STOCK: 24 x 48" Acrylic Sheet

STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	Cut stock to size (shop staff)	Table Saw			

B B A A

SHEET 2 OF 2

2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

2 1

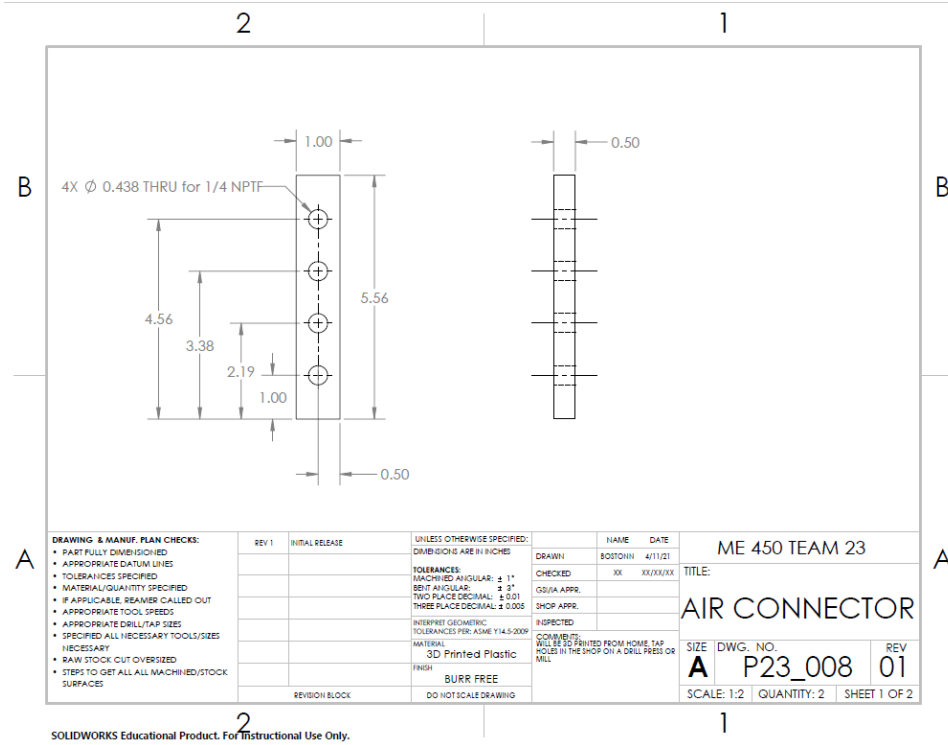
DRAWING & MANUF. PLAN CHECKS: <ul style="list-style-type: none"> • PART FULLY DIMENSIONED • APPROPRIATE DATUM LINES • TOLERANCES SPECIFIED • MATERIAL/QUANTITY SPECIFIED • IF APPLICABLE, REAMER CALLED OUT • APPROPRIATE TOOL SPEEDS • APPROPRIATE DRILL/TAP SIZES • SPECIFIED ALL NECESSARY TOOLS/SIZES NECESSARY • RAW STOCK CUT OVERSIZED • STEPS TO GET ALL ALL MACHINED/STOCK SURFACES 	REV 1	INITIAL RELEASE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES	NAME BOSTON	DATE 4/7/21	
			TOLERANCES: MACHINED ANGULAR: ± 1° 95/1A APPR. TWO PLACE DECIMAL: ± 0.01 THREE PLACE DECIMAL: ± 0.005	CHECKED JLASSO	4/7/21	
			INTERPRET GEOMETRIC TOLERANCES PER: ASME Y14.5-2009	INSPECTED		
			MATERIAL Acrylic	COMMENTS: LASER CUT EVERYTHING		
			FINISH BURR FREE			
			DO NOT SCALE DRAWING			

ME 450 TEAM 23
 TITLE:
FLOOR
 SIZE DWG. NO. **A** P23_007 REV
 SCALE: 1:4 QUANTITY: 2 SHEET 1 OF 2

B B A A

2 1

SOLIDWORKS Educational Product. For Instructional Use Only.



2 1

MANUFACTURING PLAN					
RAW MATERIAL STOCK:					
STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	Tap holes	drill press		1/4" NPTF Tap	

2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

SHEET 2 OF 2

[A3] Bill of Materials with Budget

Total Cost:		\$730.47						
Product/Part	Our PN	Manufacturer PN	Quantity	Price	Order Status	Paid For By	Link	Notes
Speaker	P23_009	JBL 8124	2	\$73.44	ordered	Nick	https://www.https://jblpro.com/en/prc	
24" x 48" Acrylic			2	\$142.00	Delivered	Joel	https://www.https://www	home depot
Wall	P23_006		2		Delivered			
Floor	P23_007		2		Delivered			
Wall Frame	P23_001	MMC - 47065T101 - 3ft	4	\$42.28	Delivered		https://www.https://www	
Floor Frame	P23_002	MMC - 47065T101 - 3ft	2	\$21.14	Delivered		https://www.https://www	
Stilt Frame	P23_003	MMC - 47065T801 - 5"	4	\$11.40	Delivered		https://www.https://www	
Foot Frame	P23_004	MMC - 47065T101 - 1ft	2	\$11.68	Delivered	Nick	https://www.https://www	
Cross Frame	P23_005	MMC - 47065T801 - 5"	2	\$5.70	Delivered		https://www.https://www	
Silver Corner Bracket	P23_010	MMC - 47065T236	12	\$62.52	Delivered		https://www.https://www	fasteners are included
Silver Flush Tee Bracket	P23_011	MMC - 3136N159	4	\$47.12	Delivered			fasteners are included
Speaker Housing	P23_012		2					3d printed
Speaker feet	P23_013		8					3d printed
Speaker door	P23_014		2					3d printed
Barbed Connection Pack	P23_015	5346K14	1	\$13.17	Delivered		https://www.https://www	
Air Hose	P23_016	5283K31	1	\$30.00	Delivered		https://www.https://www	
T-Barbed Connection	P23_017	5058K571	1	\$9.41	Delivered	Nathan	https://www.https://www	
Hose Clamps	P23_018	5388K14	1	\$6.26	Delivered		https://www.https://www	
High Flow Regulator	P23_019	846212060360	1	\$27.54	Delivered		https://www.https://www	Home Depot
1/4" Male Aro Plug	P23_020	589365	1	\$1.99	Delivered		https://www.https://www	Carpenter Bros.
Floor Air Connector	P23_008		2		Delivered			3d printed
Velcro	P23_021		1	19.98	Delivered	Marcel	https://www.https://www	
Webcam	P23_022		1	27.55	Delivered	Marcel	https://www.https://www	
Speaker Potentiometer	P23_023		5	9.99	Delivered	Marcel	https://www.https://www	
Arduino Mega 2560 R3	P23_024		1	39.98	Delivered	Marcel	https://www.https://www	
Arduino USB Cable 16ft	P23_025		1	9.41	Delivered	Marcel	https://www.https://www	
Arduino 12V Power Cord	P23_026		1	17.99	Delivered	Marcel	https://www.https://www	
Arduino Case	P23_027		1	5.99	Delivered	Marcel	https://www.https://www	
IR Sensors	P23_028		20	35.2	Delivered	Marcel	https://www.https://www	
Breadboard	P23_029		3	6.99	Delivered	Marcel	https://www.https://www	
22AWG Wires 30ft (x5)	P23_030		1	14.49	Delivered	Marcel	https://www.https://www	
22AWG Wires 100ft (x2)	P23_031		1	12.86	Delivered	Marcel	https://www.https://www	
Jumper Wires (x120)	P23_032		1	6.98	Delivered	Marcel	https://www.https://www	
1.25" long #4-40 screws	P23_033		8					x50 room
#4-40 nut	P23_034		8					x50 room
1" long 3/8-16 screw	P23_035		2					x50 room
3/8-16 nut	P23_036		2					x50 room
12325 Nipple, 1/4" Male	P23_037	589365	1	1.99	Delivered	Nick		Carpenter Bros.
1/4IDx1/8MPT Hose barb	P23_038	466141	1	2.49	Delivered	Nick		Carpenter Bros.
1/8IDx1/8FPT hose barb	P23_039	466220	2	7.98	Delivered	Nick		Carpenter Bros.
1/4IDx1/4FPT hose barb	P23_040	466221	1	3.29	Delivered	Nick		Carpenter Bros.
NY220CC 1/4, BARBXMIF	P23_041	451355	1	0.69	Delivered	Nick		Carpenter Bros.
1/2x520 PTFE Teflon Tape	P23_042	811	1	0.99	Delivered	Nick		Stadium Hardware

REQUIRED SUPPLEMENTAL APPENDIX

Engineering Standards

Due to the fact that this project was not designed for commercial use, and humans will only be using this system primarily through a GUI, engineering standards were not referenced for this project. Since Jerboas will be running through/on the module, ethics were given greater

consideration to ensure the Jerboa was safe, however there was no specific standard used to ensure this. The summation of the ethics considerations can be found below.

Engineering Inclusivity

Throughout the semester and project duration, it was important for all teammates to get along well and become closer as professionals to achieve project success. Our team tried to be mindful of all members' individual identities, as well as their unique situations, whether that be race, religion, gender, socioeconomic status, etc.. Since we were primarily only able to interact virtually this semester, it was important to make sure everyone's voices were heard, and their opinions valued. Additionally, all of this was important to keep in mind when meeting with our stakeholders as well, to ensure that they felt comfortable expressing their opinions on the design and were able to offer their ideas or constructive feedback.

Environmental Context Assessment

1. Does the system make significant progress towards an unmet and important environmental or social challenge?

In general, we tried to focus our project only on using materials which were relatively not harmful to the environment. For instance, we tried to minimize 3D printed plastic components, using only one. Additionally, the aluminum selected for the frame is able to be recycled. We also tried to be mindful of the carbon impact of shipping by picking up any components we could in person at local stores.

2. Is there potential for the system to lead to undesirable consequences in its lifecycle that overshadow the environmental/social benefits?

Since this product will not be commercially available and will only be used for private research, it is unlikely that there will be undesirable consequences later in its lifecycle. If at any point the product becomes obsolete, Dr. Moore or the University of Michigan should take steps to ensure that any components able to be recycled are, and that components can be reused if possible. It will not be mass produced, so its carbon impact will be very low for its lifecycle.

Social Context Assessment

1. Is the system likely to be adopted and self sustaining in the market?

Since this system is only intended for use by Prof. Moore, it will not likely be commercialized in the market. However, if for any reason the product was sold commercially, the cost of the materials is relatively low, with the exception of some of the electrical components. It is unlikely that many individuals have access to the lab air system needed.

2. Is the system so likely to succeed economically that planetary or social systems will be worse off?

The system is not likely to succeed economically on a large scale. This design was created to cater the needs of Professor Moore and her research. As it currently stands, there is a limited number of people doing research on jerboas, so it wouldn't likely be used for that. Additionally, the design doesn't serve much of a purpose beyond startling small animals. The only realistic change that could result from this system would be a breakthrough in Professor Moore's research that could lead to more innovations. However, we do not see these innovations causing substantial harm in current planetary or social systems.

3. Is the sustainable technology resilient to disruptions in business as usual?

Many of the components used in this design are readily available, and are common enough that they will still be available through any major economic cycles, natural disasters, or any other kind of social change

Ethics

Studying the perturbation of a jerboa and gathering the respective data is accomplished by observing their movements in real-time within a controlled environment. This data is required because the startle response can be implemented into different systems and help improve robotic applications among other things. Therefore, placing a jerboa inside an arena with the goal of acquiring the data of the perturbation response is required for the advancement of Prof. Moore's research. Our role as engineers and scientists is to create a system and environment that accomplishes this task without physically injuring or emotionally impacting the rodents. A set of rules has been used as a guide for the ethical treatment of animals used for testing and experimentation. These rules are the 3 Rs, which are replacement, reduction, and refinement. Replacement involves avoiding using the animals when experimenting by using other testing methods such as simulations which lower the chances of the animals from getting harm. Reduction involves using the fewest animals possible during the experiment and refinement involves taking actions to decrease any unnecessary pain inflicted on the animal. For our project, reduction and refinement will be the main implementation for ethical treatment.

The stakeholder only requires one jerboa present in the passageway and the overall arena when running the experiment. When deciding on what air pressure and volume to use to startle the jerboa, knowledge from previous experiments was used. The volume in which the speakers were used was determined by referencing an experiment conducted by D.B. Webster and Molly Webster[10]. In their experiment, they discovered that a kangaroo rat could be safely and effectively startled by using a speaker volume of 100 decibels[10]. To determine a safe air pressure to use, Professor Moore's previous research was used. In her previous experiments, she discovered that she could startle the jerboa with a keyboard cleaner, which is roughly 30 psi, and had no negative impact on the jerboa's mental and physical state. Furthermore, our team will work with the sponsor to provide a detailed text description that will be reviewed by the University's animal welfare committee for the IACUC approval before any jerboas are tested.