UtahStateUniversity

Revision: []
Effective Date: []

Design Baseline Document

Accessible Musical Instrument for a Severely Disabled Child

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Mechanical & Aerospace
ENGINEERING

PROJECT ROLES AND RESPONSIBILITIES

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CAD SPECIALIST	Jaden Scott	Author: 1, 5, 6.2, 6.3, appendix C
PROJECT MANAGER	Derek Scott	Technical Check & Editorial Review
FACULTY ADVISOR	Jackson Graham	Approval
CUSTOMER	Ruud Van Der Wel	Acceptance

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1 PROBLEM DEFINITION

The Team shall provide a switch-controlled 15 tone bell metallophone designed specifically to be played by a person with a disability. The mechanical system shall consist of 15 mallets that shall hit the tone bells to produce the desired sound when prompted by the user. The control box shall possess similar functions to the software SwitchEnsemble including: step, random, autoscan, autostep, step scan, and up and down. It shall be adaptable to different switch settings depending on the user and the number of switches used. The control box shall possess similar functions to the software SwitchEnsemble including: step, random, autoscan, autostep, step scan, and up and down. Finally, the design shall be adaptable to different switch settings depending on the user and the number of switches used.

1.1 FUNDAMENTAL ASSUMPTIONS

1.1.1 The metallophone will only be played indoors for personal use.

1.1.2 The mallet mechanism will be attached to the metallophone and will not be removable.

1.1.3 The mechanics of the design will be safe for the user.

1.1.4 The metallophone will produce a warm, rich sound.

1.1.5 The entire system will be powered by a standard United States wall outlet.

1.2 ENGINEERING REQUIREMENTS

The following requirements are sourced from the requirements found in the Capstone Design Requirements Contract [1]. Some of the requirements have been updated since creating the requirements contract to better define the necessary requirements.

1.2.1 The step function shall play the metallophone in ascending scale order.

Source: As per customer requirement 1.2.1, the device/system shall have a step function. The step function uses one switch, the switch plays the next tone in the scale in sequential order.

Verification Strategy: A test was performed that validated the step function works as prescribed.

1.2.2 The random function shall play the tones on the metallophone in random order

Source: As per customer requirement 1.2.2, the device/system shall have a random function. The random function uses one switch, the system plays a random tone on the metallophone when the switch is applied.

Fulfillment Strategy: A test was performed that validated the random function works as prescribed.

1.2.3 The autoscan function shall run with one switch and perform two separate functions: first, scan through the tones and then play the selected tone.

Source: As per customer requirement 1.2.3, the device/system shall have an autoscan function. The autoscan function uses one switch. The first time the user applies the switch, a visual scan runs through the available tones. The user applies the switch again when the scan hovers over the desired tone. An LED system will function as the scan.

Fulfillment Strategy: A visual test was performed that validated the LED scan functions as described in the source material. A test was also performed that validated the autoscan runs as described.

1.2.4 The autostep scan function shall run with one switch and shall perform three separate functions: first scan through the tones, then stop on the selected tone, and then play the selected tone.

Source: As per customer requirement 1.2.4, the device/system shall have an autostep function. The autostep scan function is a three-step process all applied by one switch. The first switch application starts a scan through the tones. The second switch application selects a tone. The third switch application plays the selected tone. The LED system will serve as the scan and will pause on the tone selected by the user.

Verification Strategy: A visual test was performed to validate that the LED scan functions as described in the source material. The timing of the scan was also tested in conjunction with requirement 1.12.

1.2.5 The step scan function shall run with two switches, one switch shall scan through the tones while the other switch shall play the selected tone.

Source: As per customer requirement 1.2.5, the device/system shall have a step scan function. The step scan function runs with two switches. The first switch scans through the notes one by one. The second switch plays the selected tone. After the tone has been played, the scan begins again at the first tone.

Verification Strategy: A test was performed to validate that a switch will activate the LED display and the LED lights will run through each tone one by one. The test also validated that a second switch will play the tone the first switch selected.

1.2.6 The up and down function shall run with two switches, one switch shall play the next tone in ascending order while the other switch shall play the next tone in descending order.

Source: As per customer requirement 1.2.6, the device/system shall have an up and down function. The up and down function runs with two switches. The first switch plays the next tone in the scale. The second plays previous tone in the scale.

Verification Strategy: A test was performed to validate one switch will play the tones in ascending order while another switch will play the tones in descending order.

1.2.7 A third and fourth switch shall be implemented into the design software.

Source: The SwitchEnsemble software only accounts for one or two switches. The sponsor has asked for a third and fourth switch in conjunction with the up and down function. The third switch will allow the user to repeat the same note played. The fourth switch will allow the user to skip a note and play the following note in the ascending scale.

Verification Strategy: A test was performed to validate the third and fourth switches function as described.

1.2.8 The mechanical attachment and its parts shall not emit sound greater than 50 dB.

Source: The mechanical sound shouldn't interfere with the tones played by the instrument. The mechanical sound would deter from the rich tone desired from the metallophone.

Verification Strategy: A decibel meter was used to validate that the mechanical attachment and its parts. The mechanical attachment emits an average sound of 70 dB.

1.2.9 The sound produced by the metallophone shall fall between 80-90 dB.

Source: Doctor Leslie Timmons, the specialist of Orff instruments at Utah State University, will play the metallophone in various musical dynamic levels including *piano*, *mezzo piano*, *mezzo forte*, and *forte*. A decimeter will measure the loudness of each musical dynamic and the same will be done for the mechanical system.

Verification Strategy: A decibel meter was used to measure the loudness of each musical dynamic. The general dynamic of the metallophone has an average sound of 80-85 dB. The dynamic is fixed and does not change.

1.2.10 The control box shall have a MIDI output device.

Source: MIDI is a music industry standard for interfacing with digital systems. Thus, allowing the user to work with other instruments. It allows for various sounds to be made with one simple controller. The pitch, dynamic, and note length are all controlled through the controller. The sponsor has verified this system should have a 1.8 s note length.

Verification Strategy: A test was performed to ensure the control box can connect through a MIDI output to a computer.

1.2.11 The mallets shall recoil off the tonebells in 0.15 s or faster.

Source: The mallets need to recoil off of the tonebells in order to create the desired rich sound. A high-speed camera was used to determine the desired velocity of the recoil while Dr. Leslie Timmons played on the metallophone.

Verification Strategy: A high speed camera was used to ensure the mallets recoil time is in the desired range.

1.3 GOALS

1.3.1 The system should be capable of playing a regular F major scale and up to 7 different pentatonic scales.

Source: A pentatonic and regular scale provide the notes that work best with one another. The sponsor has specified the 7 pentatonic scales to be Fmajor, Gmajor, Cmajor, Bb major, Japanese, Egypt, and Egypt 2.

Fulfillment Strategy: A test was performed that validated the system can perform all its functions defined in 1.2.1-1.2.7 on the regular scale and the 7 different pentatonic scale.

1.3.2 The scan function should scan between 0.5-5 s in 0.5 increments

Source: The software SwitchEnsemble allows the user to adjust the speed in the step function depending on the needs of the user.

Fulfillment Strategy: A test was performed to validate the timing on the LED strip for various time steps between 0.5 s and 5 s.

1.3.3 The system should be playable at a tempo of 200 BPM

Source: The user should be able to play the metallophone at various musical tempos. This tempo is dependent on the timing of the user and the requirements of the music being played. The sponsor provided video samples of different user tempo capability. The fastest tempo was determined to be 200 BPM.

Fulfillment Strategy: The tempo capability of the metallophone was tested with a metronome using various switch setups to ensure it can function at 200 BPM.

2 SYSTEM OVERVIEW

The complete metallophone design can be viewed in Fig. 1. The design has been broken into three different subsystems: electrical subsystem, base subsystem, and mallet subsystem. The electrical subsystem is located in the shelf below the mallets. The base subsystem includes the solenoids, LEDs, Metallophone, and the wooden base design. The mallet subsystem includes the mallets, the bar, and the 3-D printed parts used to position the mallets and the bar. Each subsystem is described in the following sections.

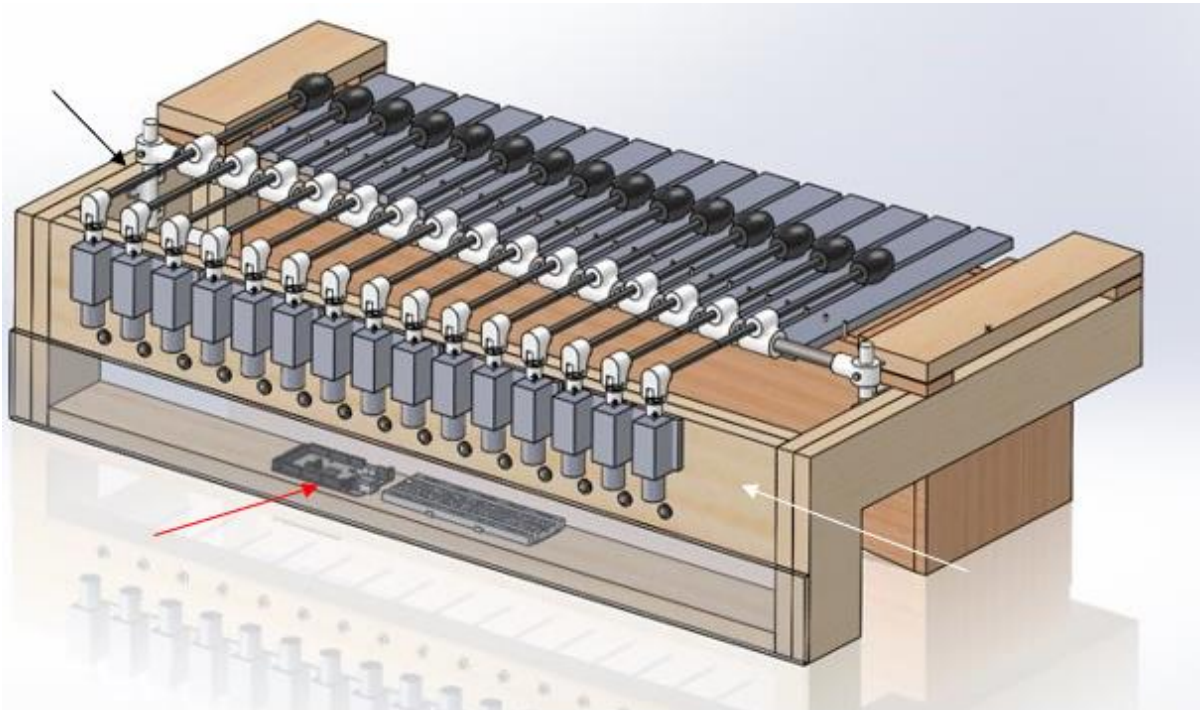


Fig. 1. Overall System, the red arrow refers the electrical subsystem, the white arrow refers to the base subsystem and the black arrow refers mallet subsystem.

The electrical subsystem controls the LEDs and the solenoids (base subsystem) when prompted by the user. The solenoids move the mallets when prompted, and finally the mallets play the desired note selected by the user.

3 ELECTRICAL SUBSYSTEM

The electrical system of our design consists of the following components: an Arduino Mega, two 8-channel relays, four button switches, four female 1/8th inch audio jacks, a bread board, a MIDI cable with corresponding female jack, two rotary switches, a potentiometer, 12V power supply, and a two plug power supply. Figure 2 shows a picture of all of the chosen components.

Fig. 2. Image of all electrical components used in the electrical subsystem.

All the pieces shown in Fig. 2 are situated in the control box of our design, which shown in the base subsystem. The Arduino Mega functions as the logic of the control box. The Arduino receives inputs from the rotary switch, potentiometer, and audio jack buttons to know which Switch Ensemble function and scale to use, at what speed to play each note, and when a note is supposed to be played. The Arduino is powered from a 5V USB plug-in located on the power strip.

The 12V power supply is also connected to the power strip and is used to route power through the two 8 channel solid-state relays. The relays then dispense the 12V to the corresponding solenoid/LED's when called by the Arduino.

A small breadboard acts as a junction for all the wiring of the control box. There is a common ground along with a voltage rail that supply power to the system, and space necessary to mount all the needed components.

This subsystem fulfills requirements 1.2.1 - 1.2.7, as all those requirements will be controlled by the arduino. The audio jacks and audio jack buttons will also serve as the switches described. The rotary switch will allow for the user to choose which of the functions described to use in those requirements. The potentiometer also accounts for the scan listed in requirements 1.2.3 and 1.2.4 by allowing the user to select the speed of the scan.

This subsystem also accounts for requirement 1.2.10 with the midi cable. The cable is controlled through the arduino and has successfully been tested through garage band. This subsystem also accounts for requirement 1.2.11 as the arduino controls the time the solenoid is on.

This subsystem accounts for goals 1.3.1 - 1.3.3. Another rotary switch will allow the user to select the desired scale system in goal 1.3.1. The potentiometer will allow the user to select the speed of the scan in goal 1.3.2. The tempo described in goal 1.3.3 is also controlled by the arduino. The design can play 240 BPM.

4 BASE SUBSYSTEM

The base subsystem of our design consists of the following parts: a metallophone, joined wood-cutouts, 15 solenoids, 5 solenoid housing brackets, 15 LED's and a control box. The wooden base is made up of wooden cutouts of different sizes to fit the end-to-end dimensions of the metallophone. Wood screws and wood glue were used to assemble and join all the wooden cutouts to create a stable and cohesive base. In order to join the wooden base to the metallophone, the wooden base was clamped into a tight fit at both ends of the metallophone. Figure 3 demonstrates the position of each part of the base subsystem.

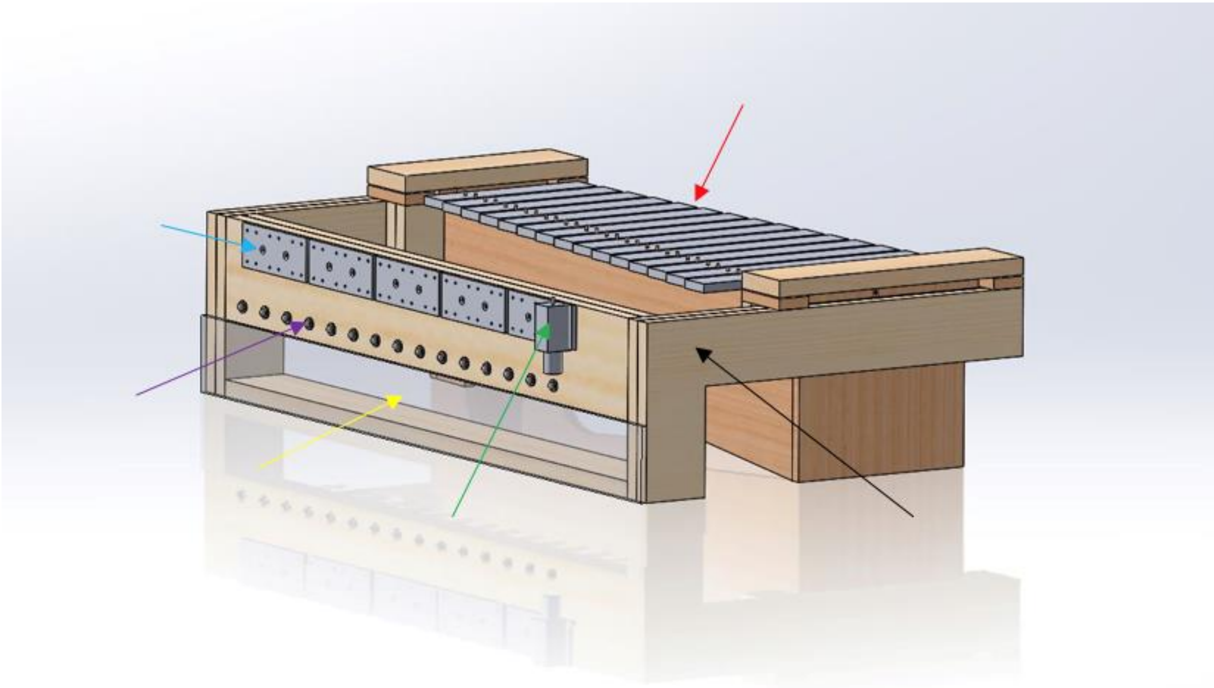


Fig.3. Base subsystem where the red arrow indicates the metallophone, black arrow indicates the wooden base, green arrow indicates solenoid, blue arrow indicates solenoid housing bracket, purple arrow indicates LED's, and the yellow arrow indicates the control box.

A section of the wooden base (shown in figure above) was used to house the solenoids and LED's. In order to mount the solenoids onto the wooden base, a series of five 3-D printed brackets were created such that each bracket supports up to three solenoids. Wood screws were used to mount the brackets onto the wooden base, and flat-head screws were used to mount the solenoids onto the brackets. In addition to the solenoids and brackets, the LED's, which match the number of solenoids, lie directly beneath the solenoids and placed within the wooden base section.

Furthermore, the solenoid and LED wiring run down to the control box (shown by yellow arrow in figure above). The control box is the section at the bottom of the wooden base designed with a Plexiglas cover containing all of the electrical components (as shown in Fig. Y. red arrow and Fig. W. yellow arrow).

This subsystem accounts for requirements 1.2.1 - 1.2.7 through the Solenoids and the LEDs. The Solenoids are controlled by the electrical subsystem and play the desired notes when prompted by the arduino. The LEDs are controlled by the electrical subsystem and act as the scan for requirements 1.2.3 - 1.2.5.

The solenoids also account for requirements 1.2.8 and 1.2.9. The solenoids have felt "socks" placed around the spring to dampen the sound of the mechanical system as defined in requirement 1.2.8. The solenoid has also been tested to be fast enough to play the desired decibel range in requirement 1.2.9.

5 MALLET SUBSYSTEM

The mallet subsystem of our design consists of the following parts: the mallets, the bar, and the 3-D printed parts used to position the mallets and the bar. The mallet heads themselves are made of yarn since that material produces the highest quality sound. The bar is 1144 carbon steel and has a total length of 29-5/8 inches. This material was selected in order to handle the load without straining the rod. The 3-D printed parts were specifically made to fit the mallets, the solenoids, and the bar. The 3-D printed parts for the mallets allow for rotation so that the linear solenoids can push the mallets into the tone bells to create a rich, warm sound. See Fig. 4 for a detailed picture of the 3-D printed parts.

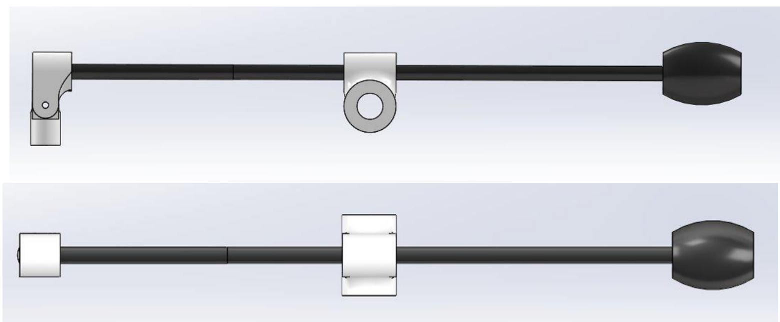


Fig. 4. 3-D printed parts for mallets.

Another 3-D printed component was for the bar. These parts are meant to hold the bar in a specific location. This location is dependent on the user's desired sound level. The user can adjust the how loud the device can be played via pin joint. The piece to hold the bar in place is attached to the base of the system. The holes for the pin joint can be seen in Fig. 5.

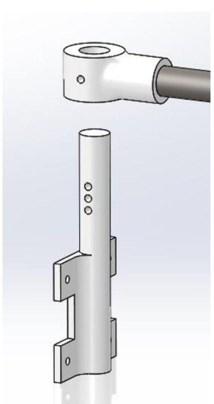


Fig 5. 3-D printed parts for bar.

This subsystem accounts for requirements 1.2.1 - 1.2.7 as the mallets actually come into contact with the tonebells and play the desired note.

This subsystem also accounts for 1.2.8 and 1.2.9 as the 3D printed parts on the bar are designed to be snug on the bar to prevent any rattling or mechanical noise off of the bar. The 3-D printed parts described in Fig. Q also allow the height of the bar to be raised or lowered to change the volume of the notes played as defined in requirement 1.2.9.

Finally, this subsystem accounts for requirement 1.2.11. The bar acts as a pivot point for the mallets to recoil off of the tonebell.

6 ANCILLARY TOPICS

6.1 ENVIRONMENTAL AND SOCIETAL IMPACT

This product has a very positive impact on society as it will allow someone disabled to play a musical instrument. There is no measurable impact on the environment.

6.2 SAFETY

Possible safety issues include pinching from the mechanical system or shock from the electrical system. The solenoids are exposed which means there is a possibility to be pinched. This safety risk is minimal and unlikely to happen so there is no cause to address a solution for this. As for the electrical system, it will be incased in Plexiglas so there no exposure to possible shock.

6.3 LESSONS LEARNED

The biggest lessons learned throughout the project was time and that simplification is key. Although we worked diligently and put in a lot of time, any less and we would have fell behind significantly. Also, when considering time, we did not account for trial and error. We knew the code would take a lot of time and figuring out, but the amount of time spent on CAD parts was not accounted for. Specifically, making sure parts were measured correctly. Getting the right tolerances was a major issue and took us multiple attempts to get the right fit needed. Most parts did not work the first time and needed to be corrected and re-printed.

6.4 RECOMMENDED FUTURE WORK

There are three particular updates that would greatly improve the design. First, the solenoids need to be dampened to a range between 50-60 dB. Originally the solenoids fired at 90 dB. By placing a felt sock over the spring, the solenoid was dampened to 70 dB. This is a significant change but the design asks for it to be even lower. The team has attempted multiple solutions to this problem. They suggest encasing the solenoids in an insulated box to dampen out the sound.

The dynamic change would also be an excellent improvement to the design. The holes on the 3D printed dynamic piece are spaced in such a way that does not allow for the dynamic to be changed. Finding the correct heights of the bar to allow for different dynamics would allow for multiple dynamics to be played. The correct heights would then have to be integrated onto the Dynamic 3D printed part.

There is an LED light that blinks consistently through in all of the functions. The team has determined this is a hardware issue. The ground for the 5V and 12V connection feed through each other and any excess current is causing the light to blink. By isolating the 5V ground and the 12V ground, this issue may be averted. This issue could also lie in the LEDs themselves. A potential solution would be to test the system with a different LED strip.

7 REFERENCES

[1] USU Capstone Design. *Accessible Musical Instrument for a Severely Disable Child Requirement Contract*. Utah State University, 2018.

[2] Van der Wel, Ruud. *Accessible Musical Instrument for a Severely Disabled Child Guide 1.* My Breath My Music, 2018.

[3] Van der Wel, Ruud. *Accessible Musical Instrument for a Severely Disabled Child Guide 2.* My Breath My Music, 2018.

Appendix A
Attached References

[2]

Accessible Musical Instrument for a Severely Disabled Child

Guide 1 20-01-2018

Find the best sounding xylophone (sonar ?) wooden toonbells? Metall? Don't be afraid to spend some money on that.

To get a better idea of the concept, install the program Switchensemble on a computer.

This is a digital version of a xylophone.
Children play this instrument using one, two or more switches that are connected to a switch interface.

For testing you will use a keystroke on the computerkeyboard.

Experiment with: step (1 switch) random (1) autoscan (1) autostep scan (1) step scan (2 switches) up and down (2)

NOT in this software, but I want something extra:
In order to create more possibilities I want to make it optinal to use a third switch to repeat a note. And with a fourth switch, it's possible to skip notes in a scale!
The layout:
1 switch to go up one step in the scale (A)
1 switch to go down one step in the scale (B)
1 switch to repeat the last note played (C)
1 (interval) switch to skip one or more Tonebells when the next note is played (D).

Ruud van der Wel

[3]

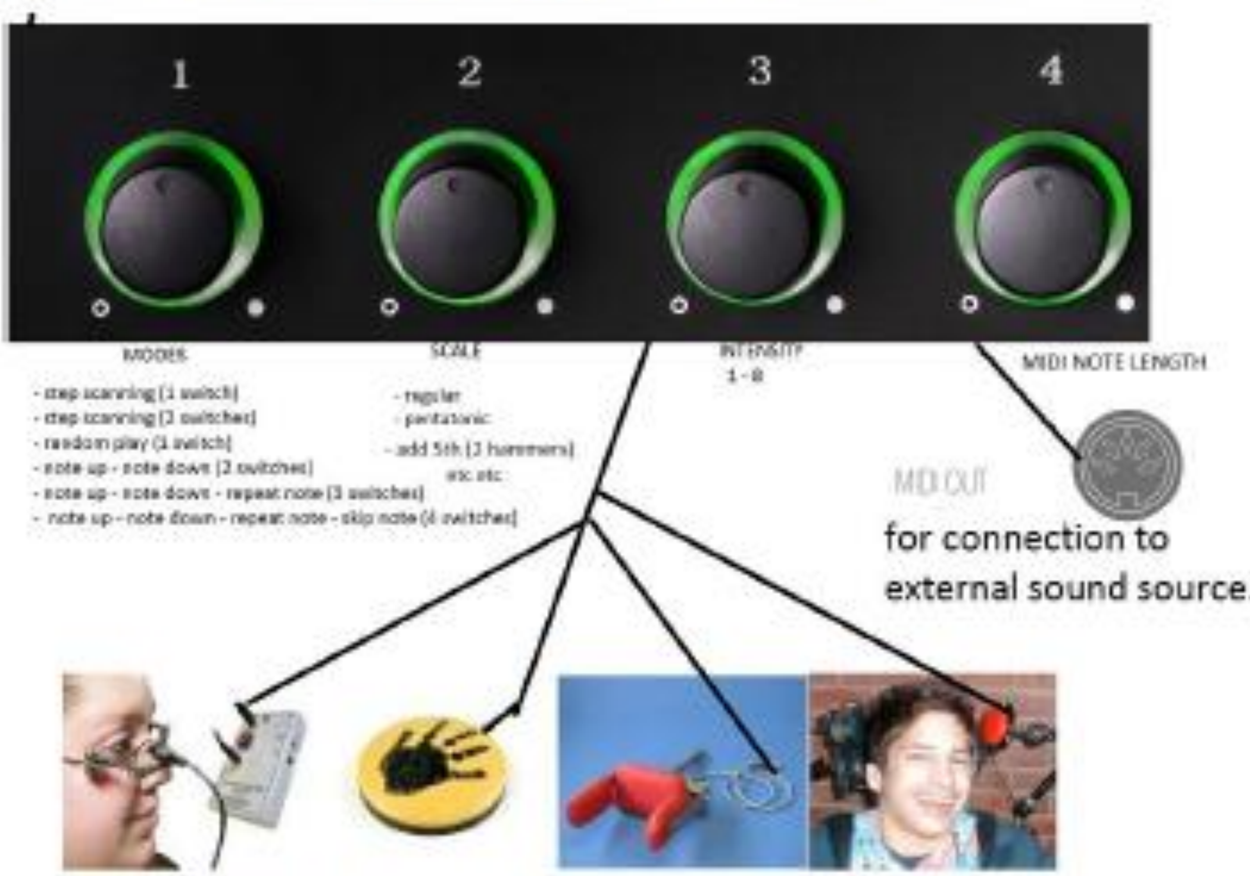
Accessible Musical Instrument for a Severely Disabled Child

Guide 2 24-01-2018

Find the best sounding xylophone suggestion. https://youtu.be/Ty6vm-_iVL8

The idea
Children play this instrument using one, two or more switches that are connected to a switch interface.

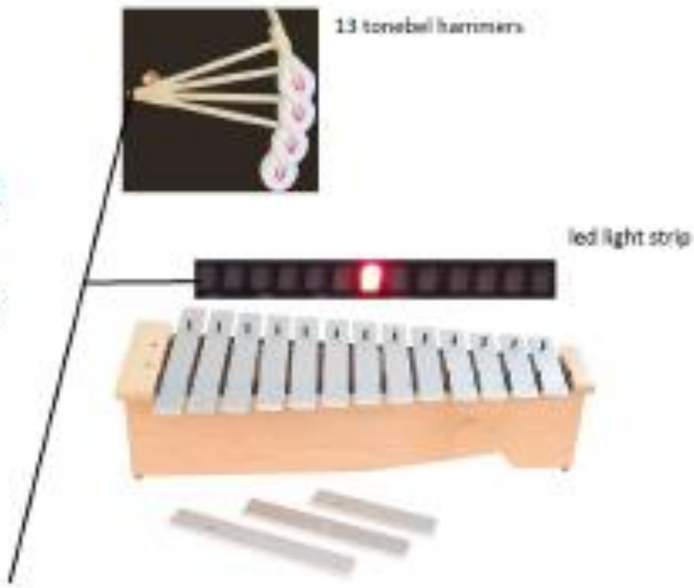
The interface will also have MIDI out (standard 5 pin) so it could work as MIDI controller with or without the adapted xylophone.
You could connect up to 4 switches. (4 x 1/8 inch mini jack mono inputs) Some children will use one switch only. This depends strongly on there physical ability and cognition.



These are all different switches. They all have a 1/8 inch mini jack.

The hammer system

- mechanism not to noisy!
- Make a nice warm tone
- safety ?(.....fingers hammered)
- led indicator shows which note is played and used for step scanning (see switchensemble software)
- latency as minimal as possible
- easy to fit , user friendly



The end result will be open source and published on www.mybreathmymusic.com and presented with a step guide and code so other people can build the system too.

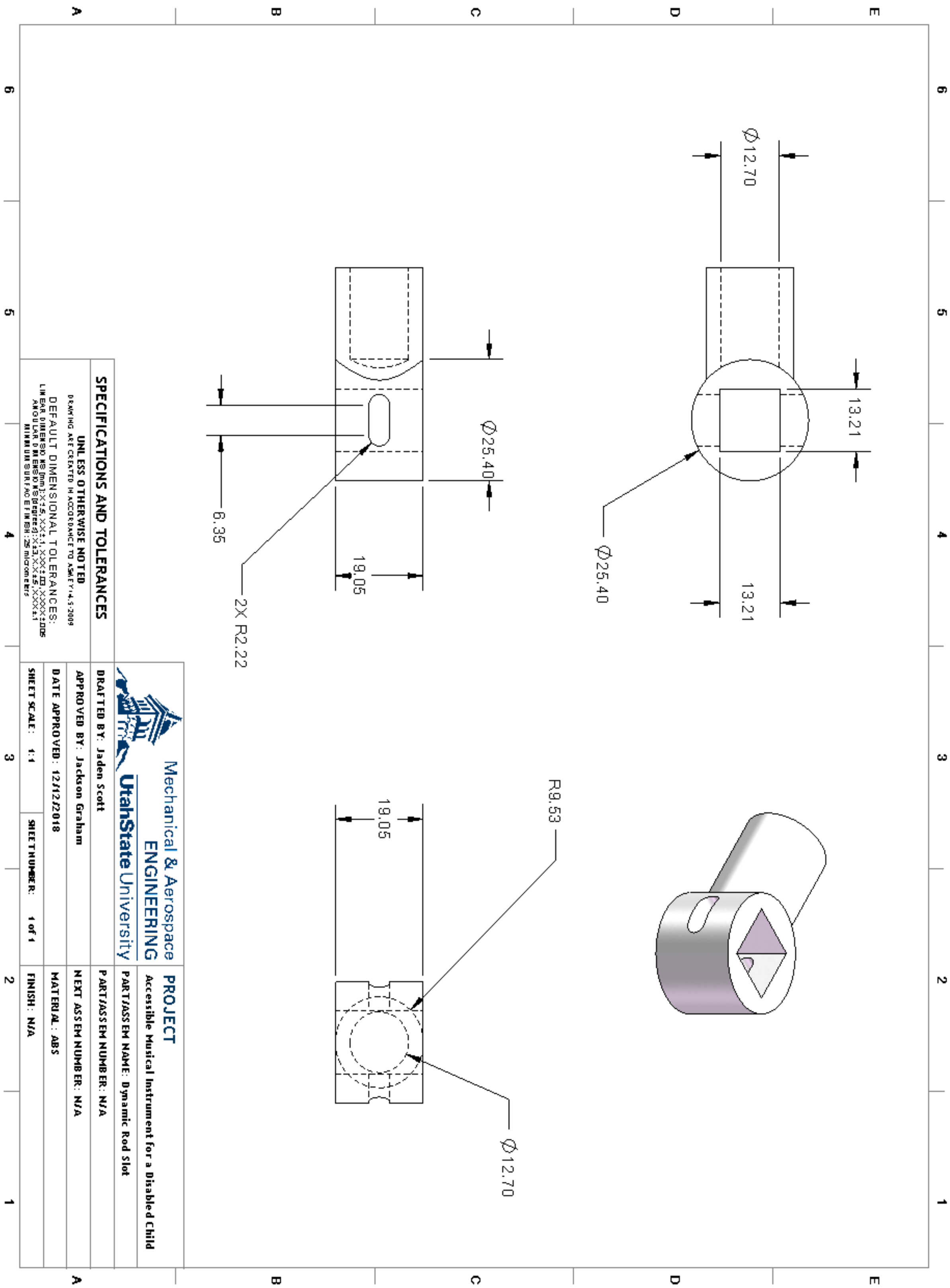
Ruud van der Wel

Appendix B

Bill of Materials

Quantity	Description	Cost
1	Arduino Mega	$29.98
1	MIDI to USB cable	$13.90
1	MIDI female jack	$8.49
1	Metallophone	$656.25
2	8 Channel Solid State Relays	$23.98
MISC	3D Printed Parts	$39.80
1	16 Gauge Wire	$19.95
15	45N Solenoids	$276.30
15	Percussion Mallets	$116.49
1	Screws	$26.41
1	Maple Plywood (8ft x 4ft)	$55.98
1	LEDs	$42.98
1	12V Power Supply	$17.95
1	Power Strip	$14.99
4	1/8 Audio Jack	$18.92
2	Rotary Switch	$7.44
4	Button Switches	$86.42
1	Potentiometer	$6.26
1	1144 Carbon Steel Bar	$11.84
1	1/8 Cast Acrylic	$37.21
15	Metal Pin	$11.37
1	Potentiometer, Terminal Board Block Kit	$29.98
MISC	Heat Shrink, Protoboard, 30 Pins	$13.38
1	Sticker	$0.89

Appendix C
Drawing Package


Ø12.70
13.21
Ø25.40
13.21
Ø25.40
6.35
19.05
2X R2.22
R9.53
19.05
Ø12.70
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
Mechanical & Aerospace ENGINEERING
UtahState University
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:1
SHEET NUMBER: 1 of 1
PROJECT
Accessible Musical Instrument for a Disabled Child
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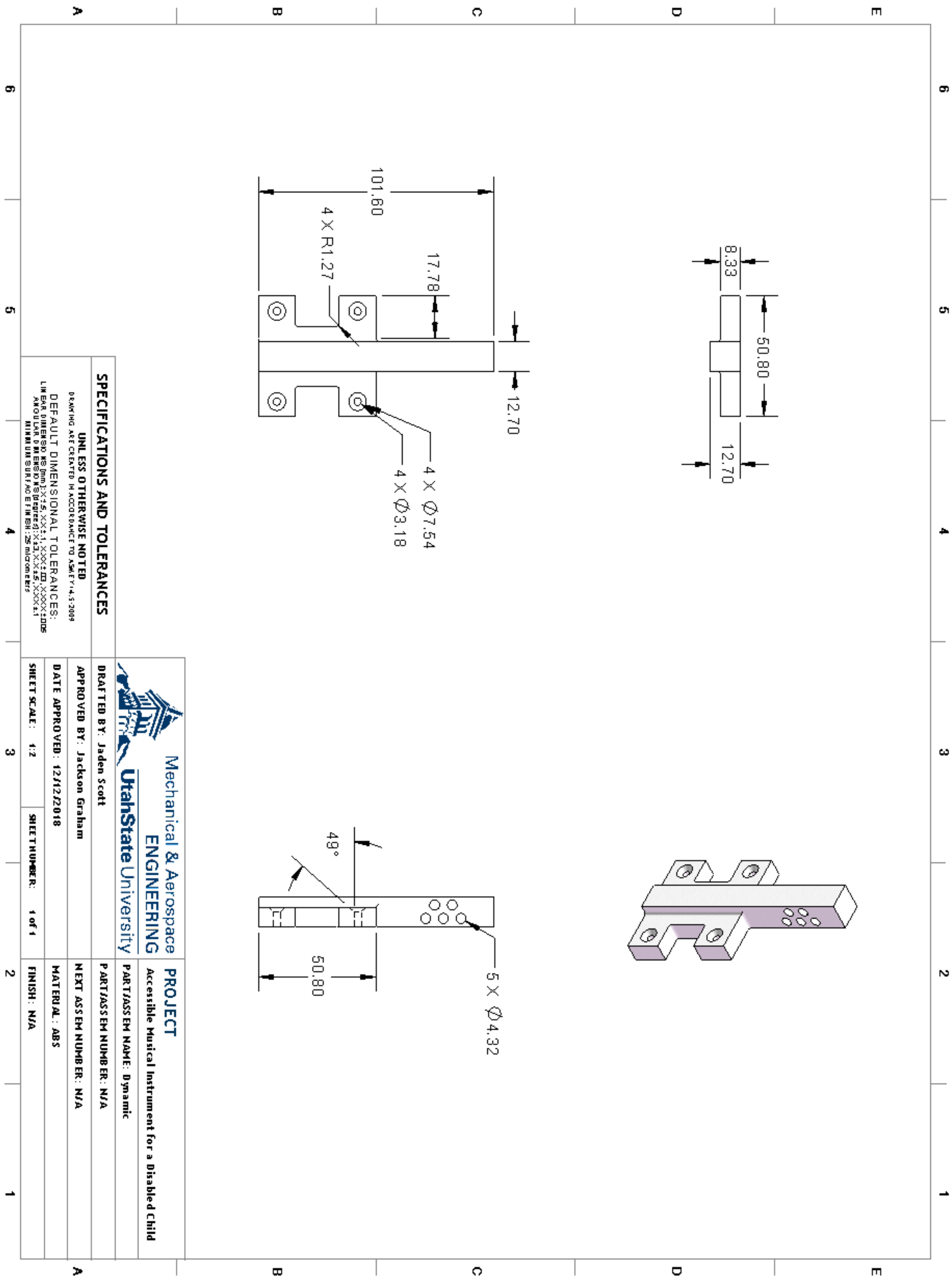
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: ABS
FINISH: N/A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49°
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5 X ∅4.32
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
PROJECT
Accessible Musical Instrument for a Disabled Child
Mechanical & Aerospace ENGINEERING
UtahState University
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:2
SHEET NUMBER: 1 of 1
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PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
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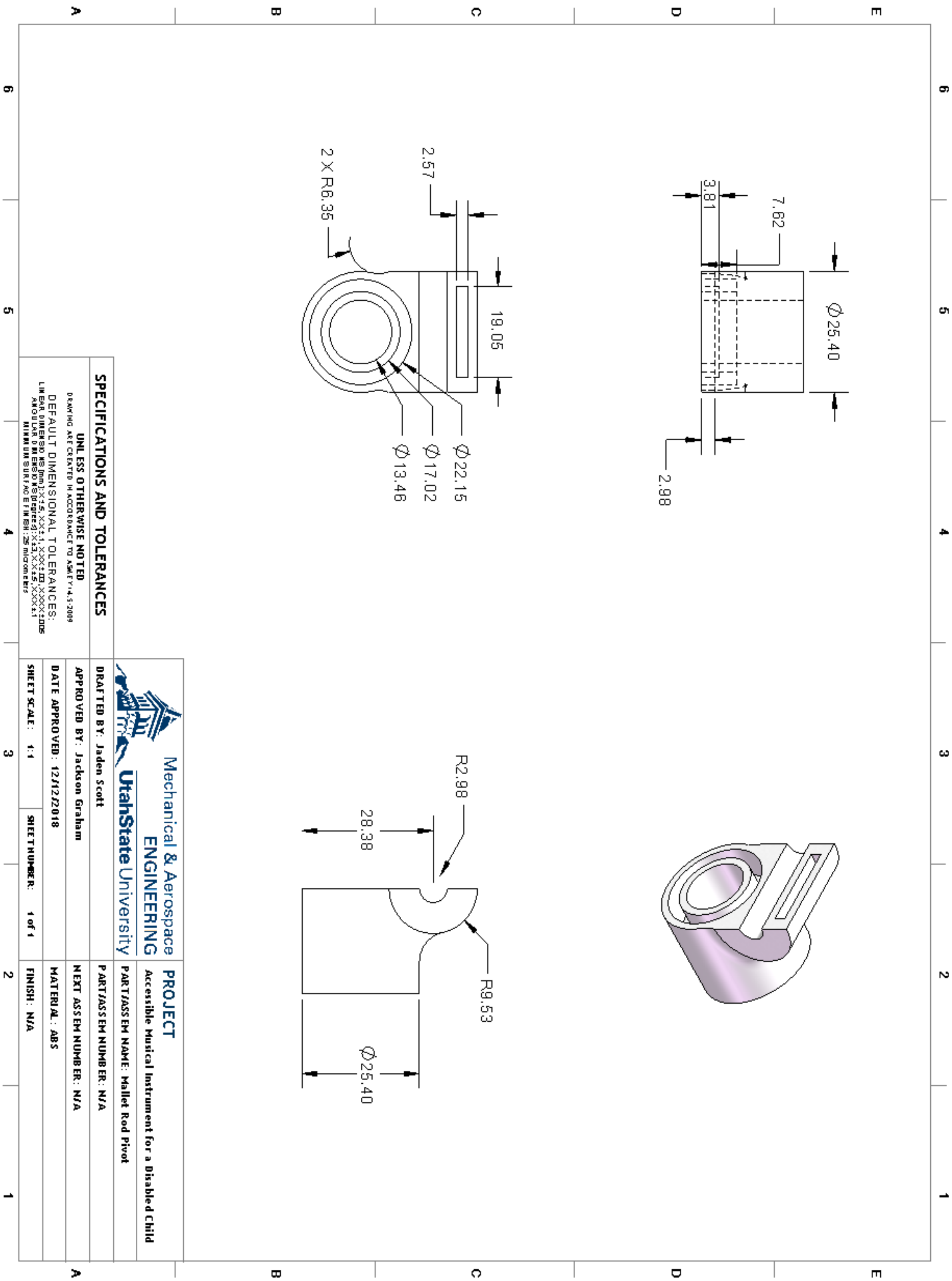

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SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
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DEFAULT DIMENSIONAL TOLERANCES:
Mechanical & Aerospace ENGINEERING
UtahState University
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Accessible Musical Instrument for a Disabled Child
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:1
SHEET NUMBER: 1 of 1
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NEXT ASSEM NUMBER: N/A
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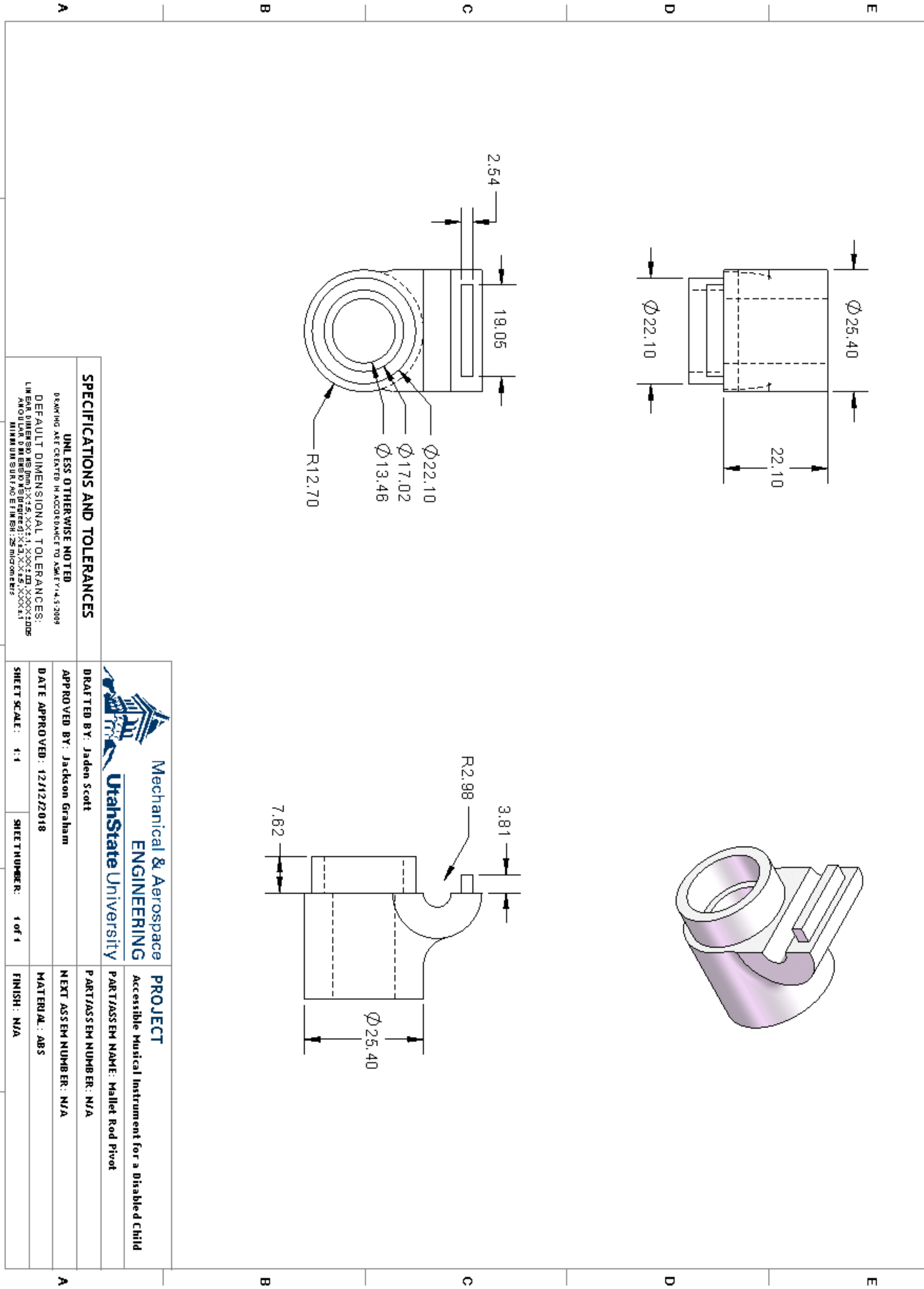
FINISH: N/A



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FINISH: N/A
Mechanical & Aerospace ENGINEERING
UtahState University
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:1
SHEET NUMBER: 1 of 1
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UNLESS OTHERWISE NOTED
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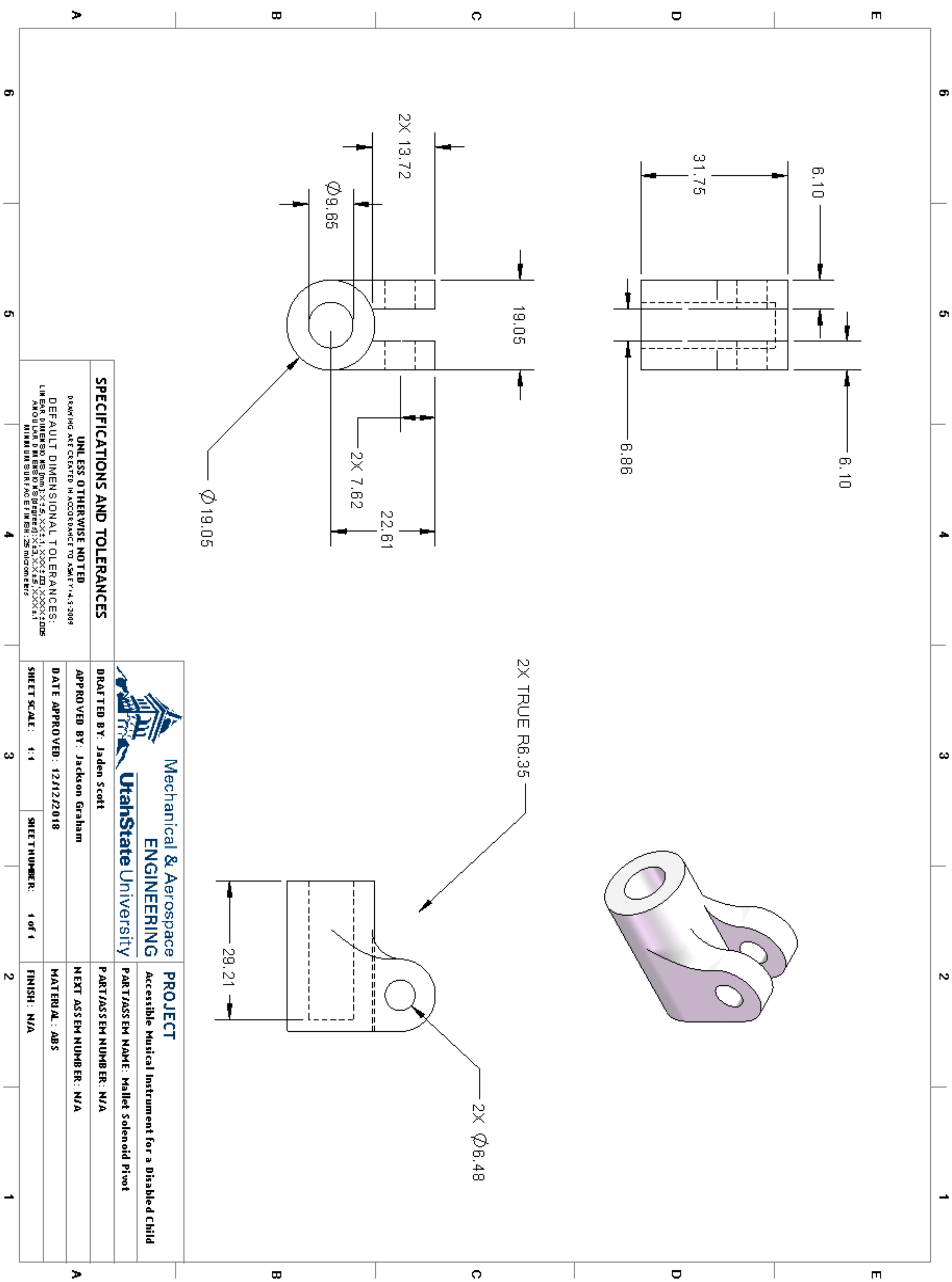

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19.05
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SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
Mechanical & Aerospace ENGINEERING
UtahState University
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Accessible Musical Instrument for a Disabled Child
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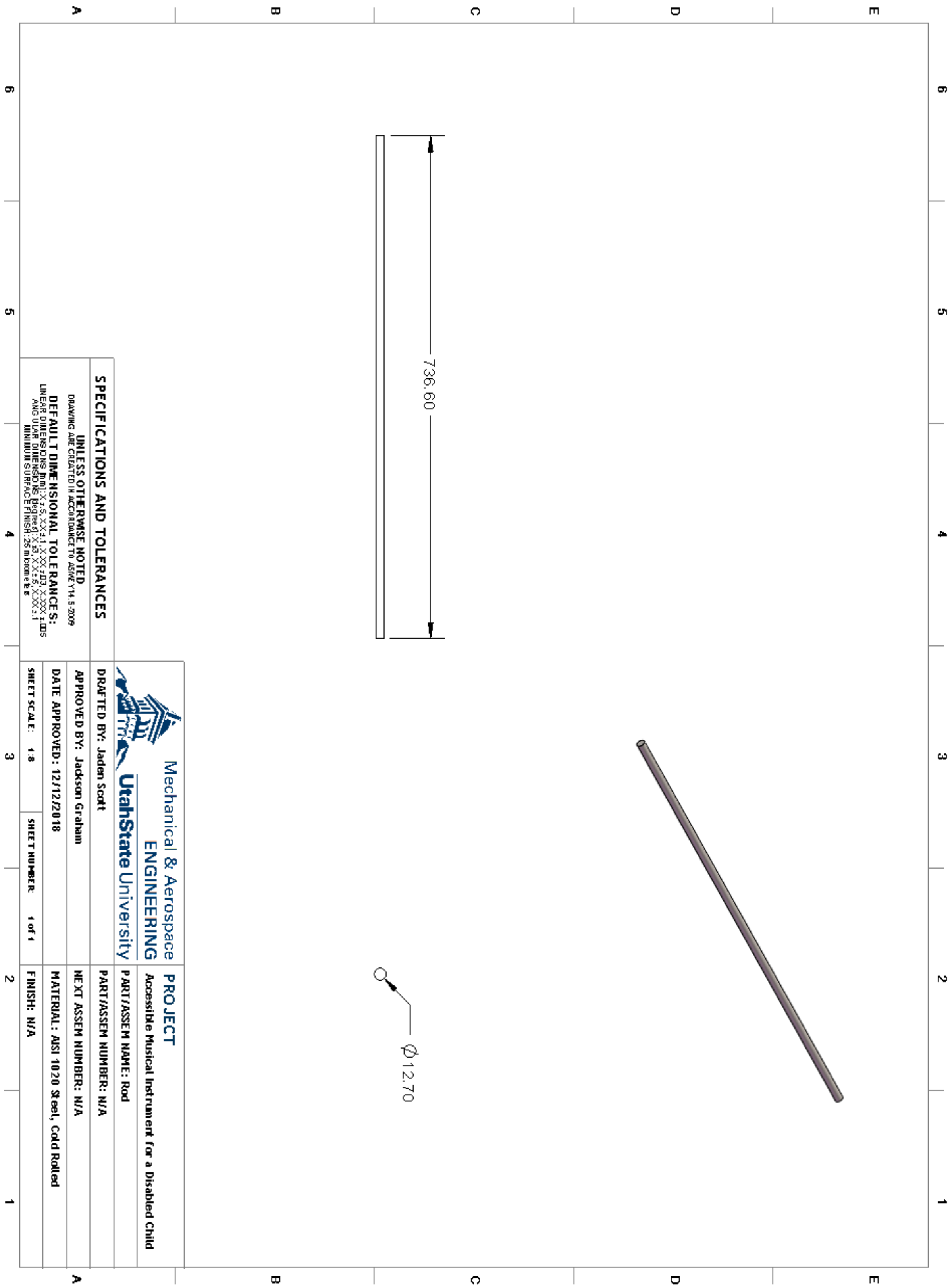
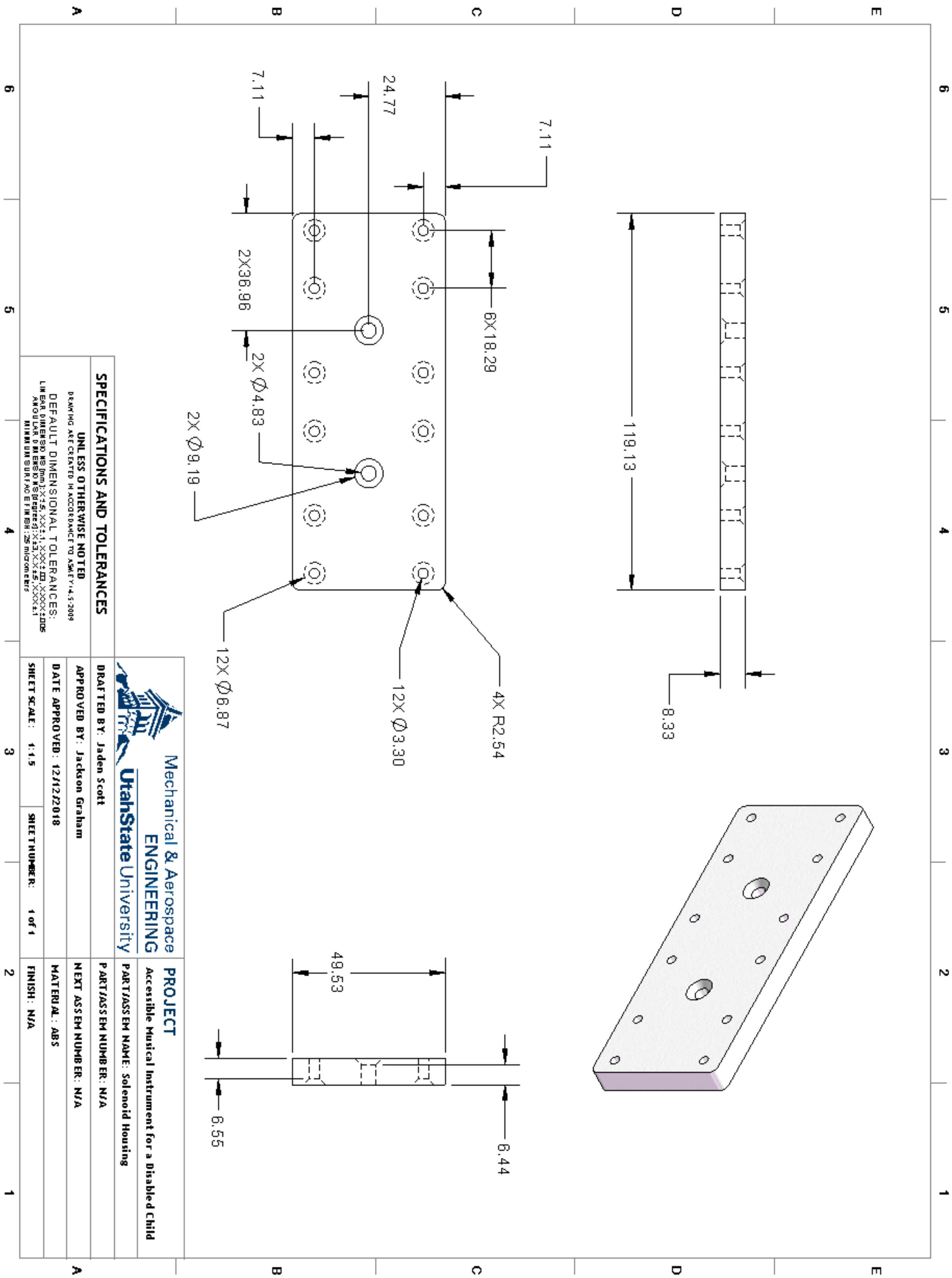
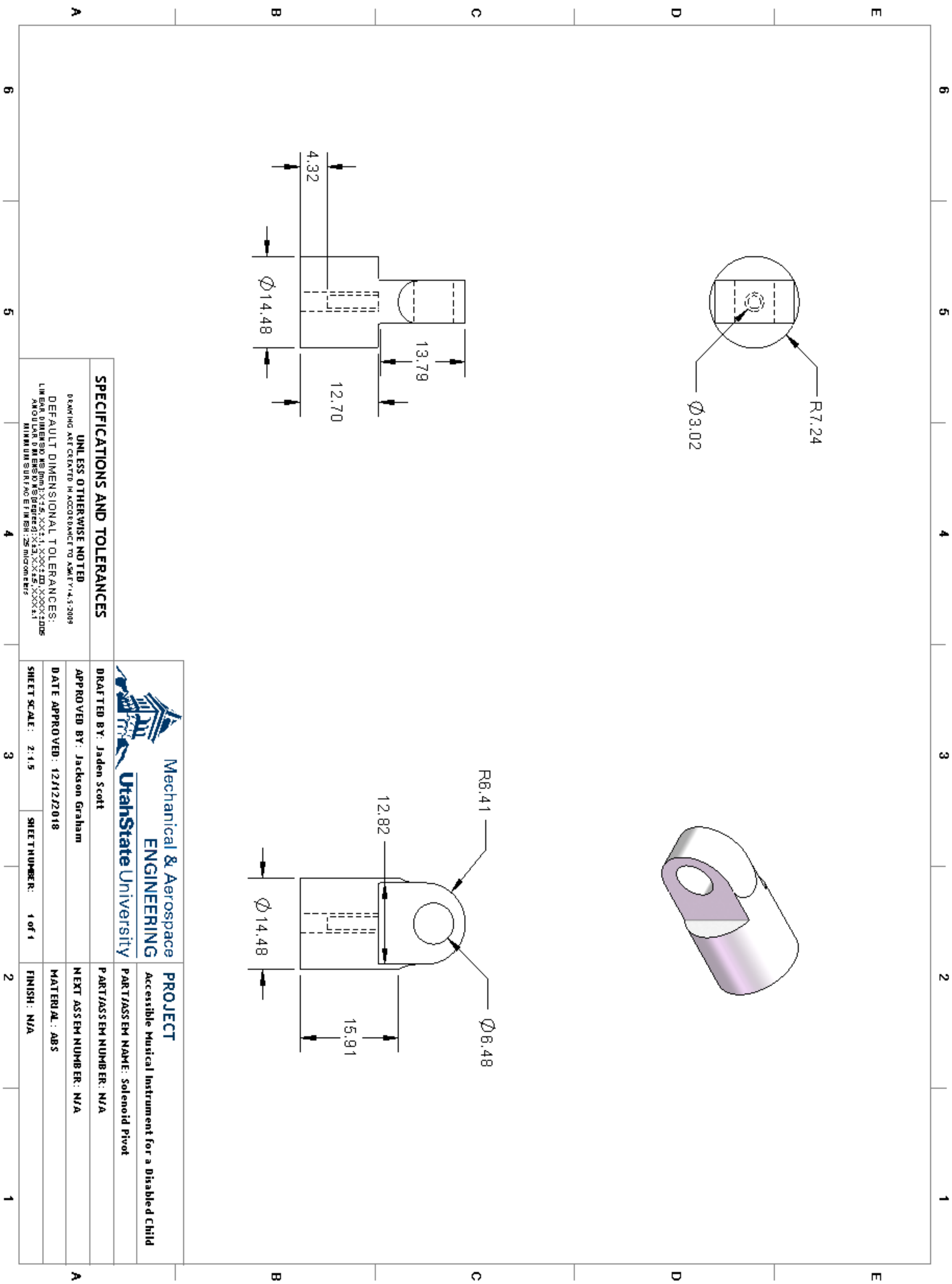
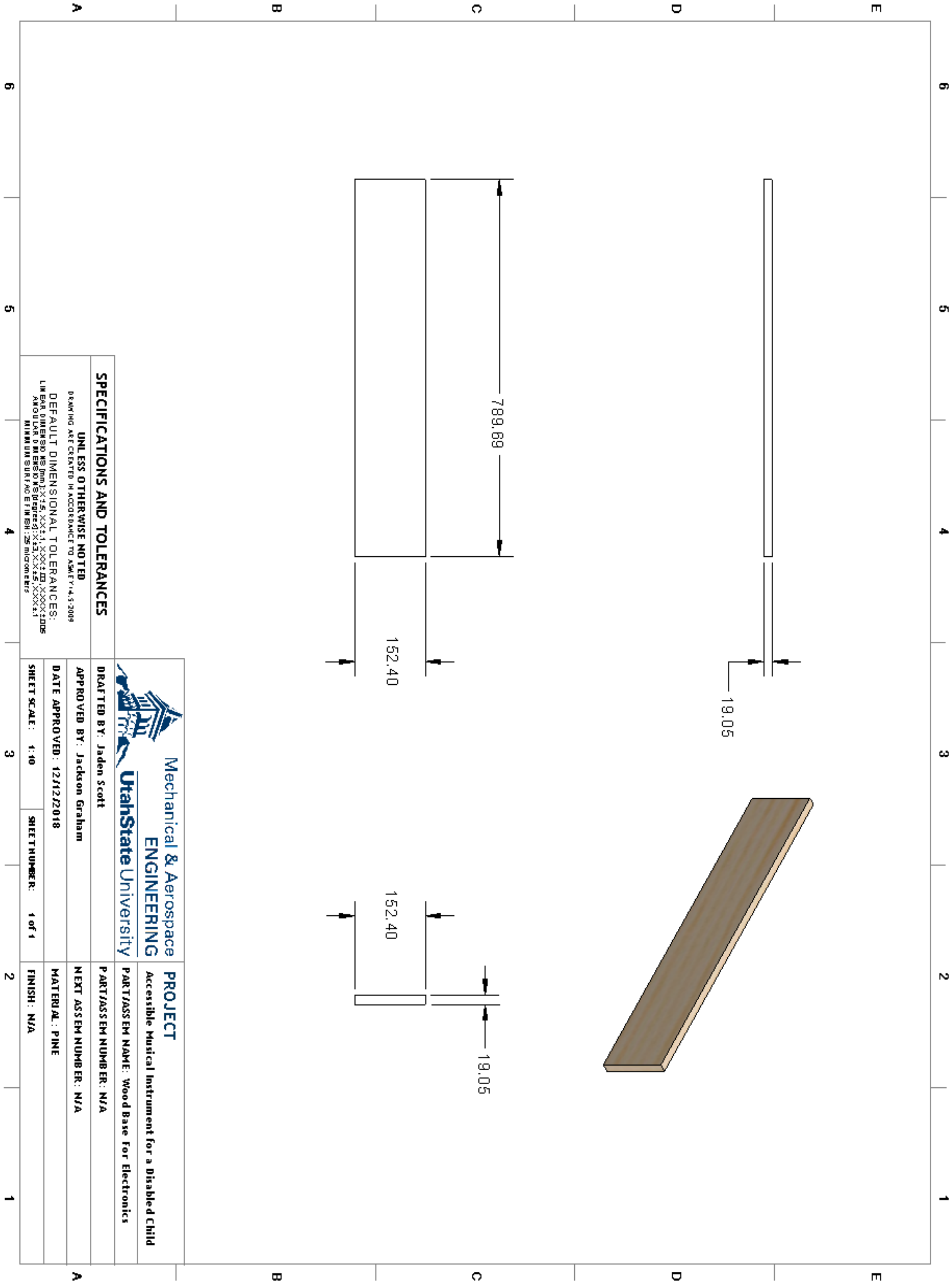
NEXT ASSEM NUMBER: N/A
MATERIAL: ABS
FINISH: N/A
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:1
SHEET NUMBER: 1 of 1

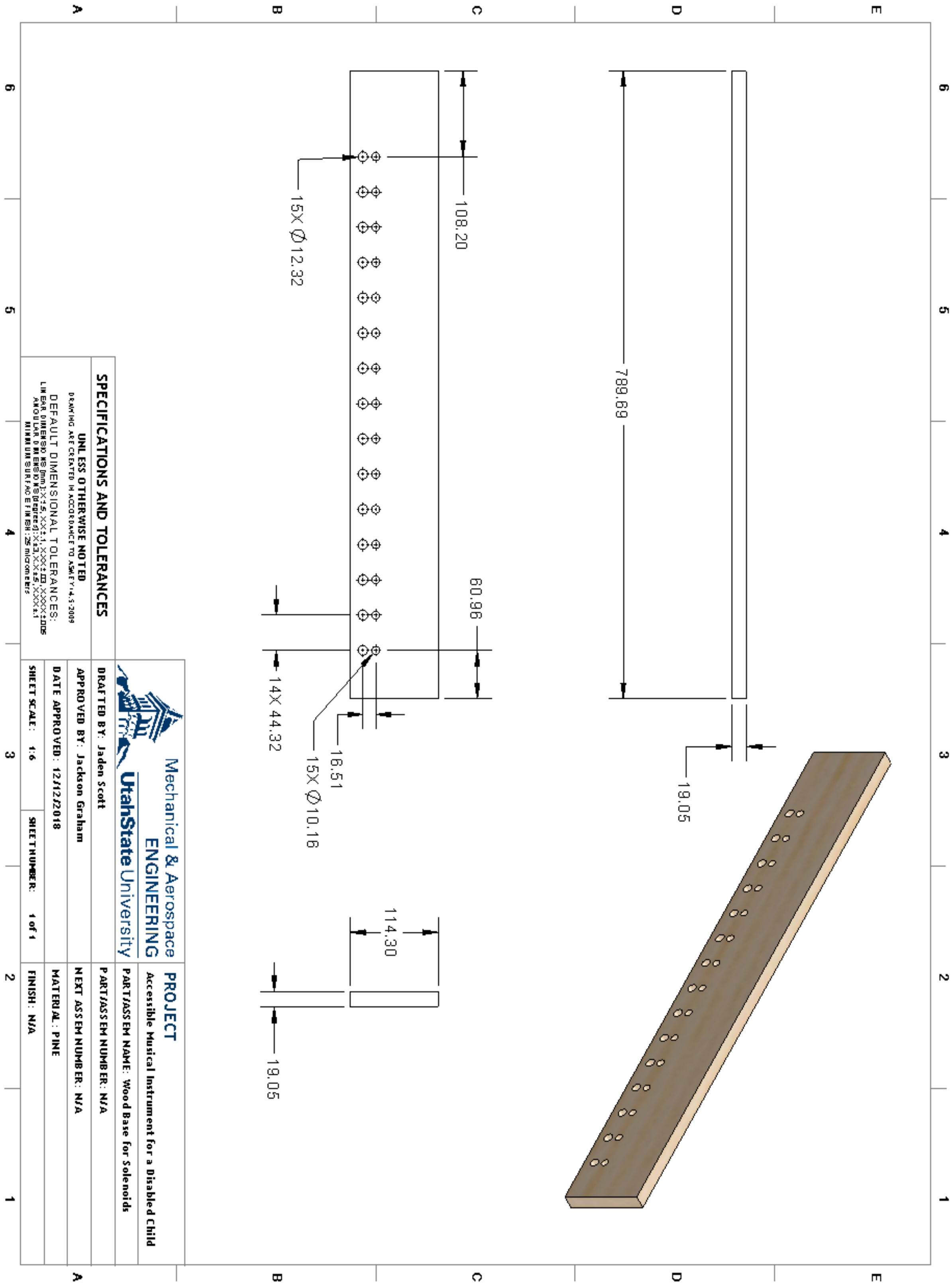

736.60
Ø12.70
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
Mechanical & Aerospace ENGINEERING
UtahState University
PROJECT
Accessible Musical Instrument for a Disabled Child
PART/ASSEM NAME: Rod
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: AISI 1020 Steel, Cold Rolled
FINISH: N/A
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:8
SHEET NUMBER: 1 of 1


7.11
24.77
7.11
2X36.96
6X18.29
2X Ø4.83
2X Ø9.19
119.13
12X Ø6.87
12X Ø3.30
4X R2.54
8.33
49.53
6.55
6.44
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
Mechanical & Aerospace
ENGINEERING
UtahState University
PROJECT
Accessible Musical Instrument for a Disabled Child
PART/ASSEM NAME: Solenoid Housing
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: ABS
FINISH: N/A
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:1.5
SHEET NUMBER: 1 of 1

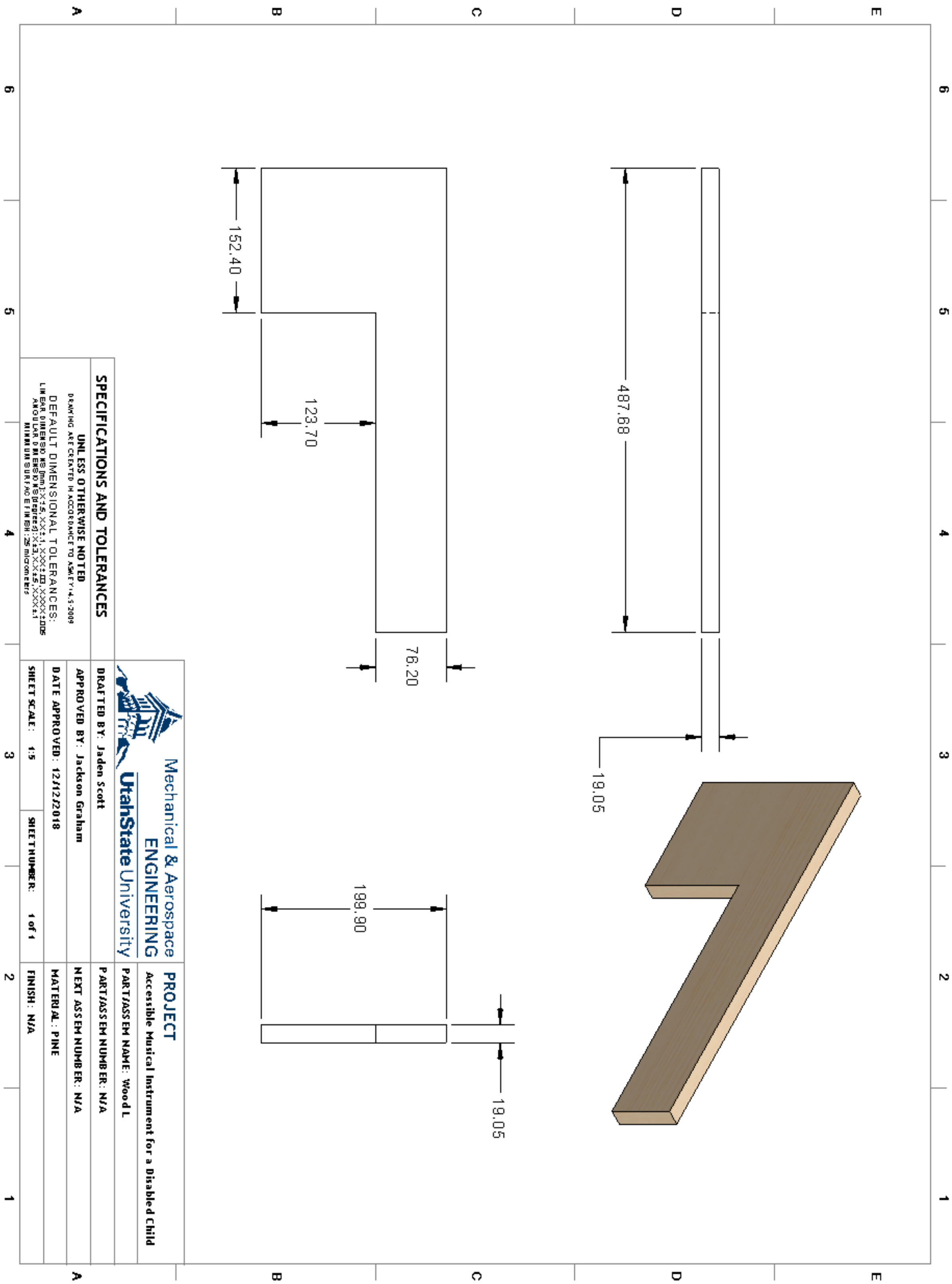


SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
Mechanical & Aerospace ENGINEERING
UtahState University
PROJECT
Accessible Musical Instrument for a Disabled Child
PART/ASSEM NAME: Solenoid Pivot
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: ABS
FINISH: N/A
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 2:1.5
SHEET NUMBER: 1 of 1
4.32
Ø14.48
13.79
12.70
Ø3.02
R7.24
R6.41
12.82
Ø14.48
15.91
Ø6.48

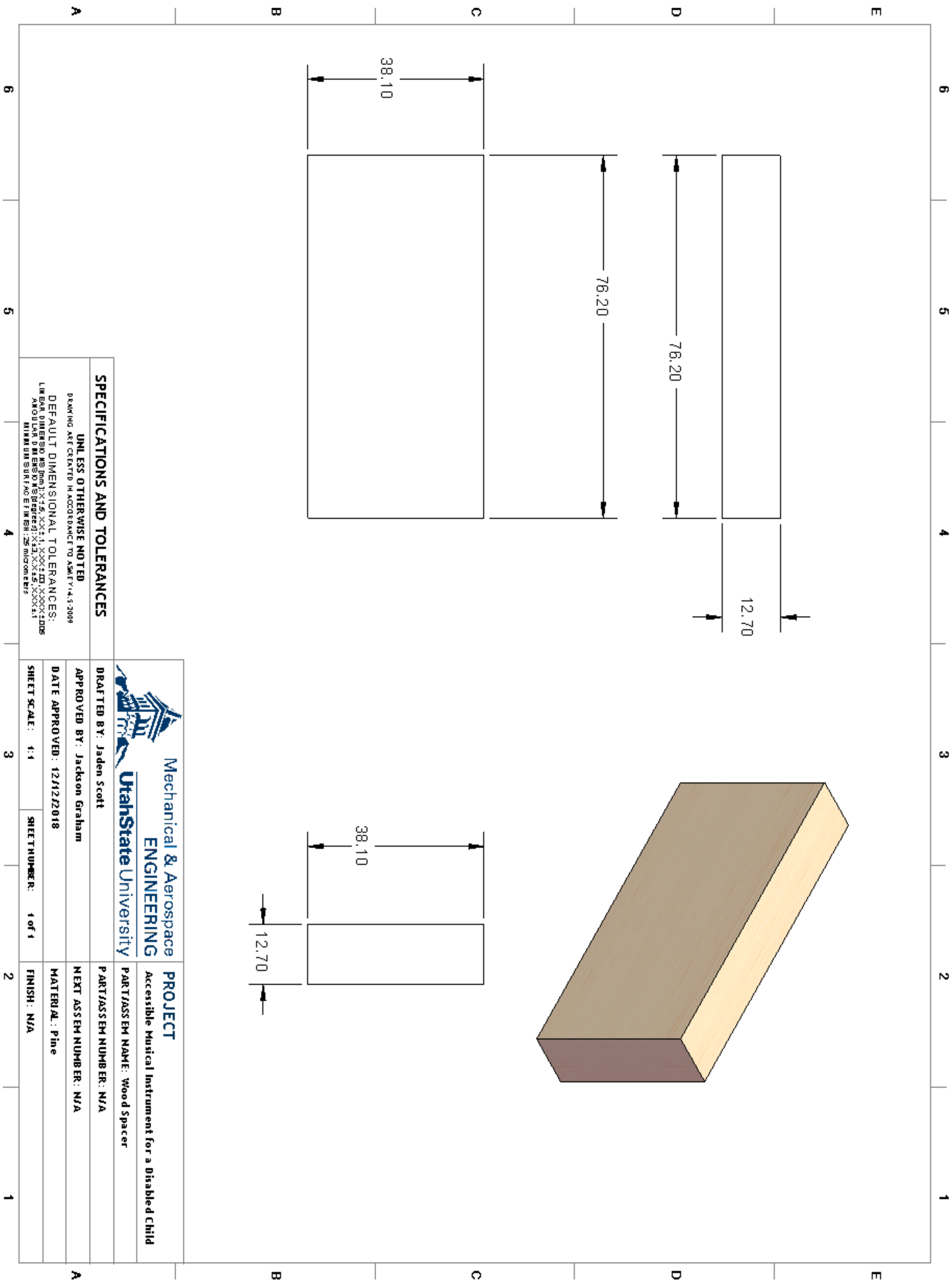

789.69
152.40
19.05
152.40
19.05
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009
DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [mm]: X±.5, XX±.1, XXX±.03, XXXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, XXX±.1
MINIMUM SURFACE FINISH: 25 micrometers
Mechanical & Aerospace ENGINEERING
UtahState University
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:10
SHEET NUMBER: 1 of 1
PROJECT
Accessible Musical Instrument for a Disabled Child
PART/ASSEM NAME: Wood Base For Electronics
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: PINE
FINISH: N/A

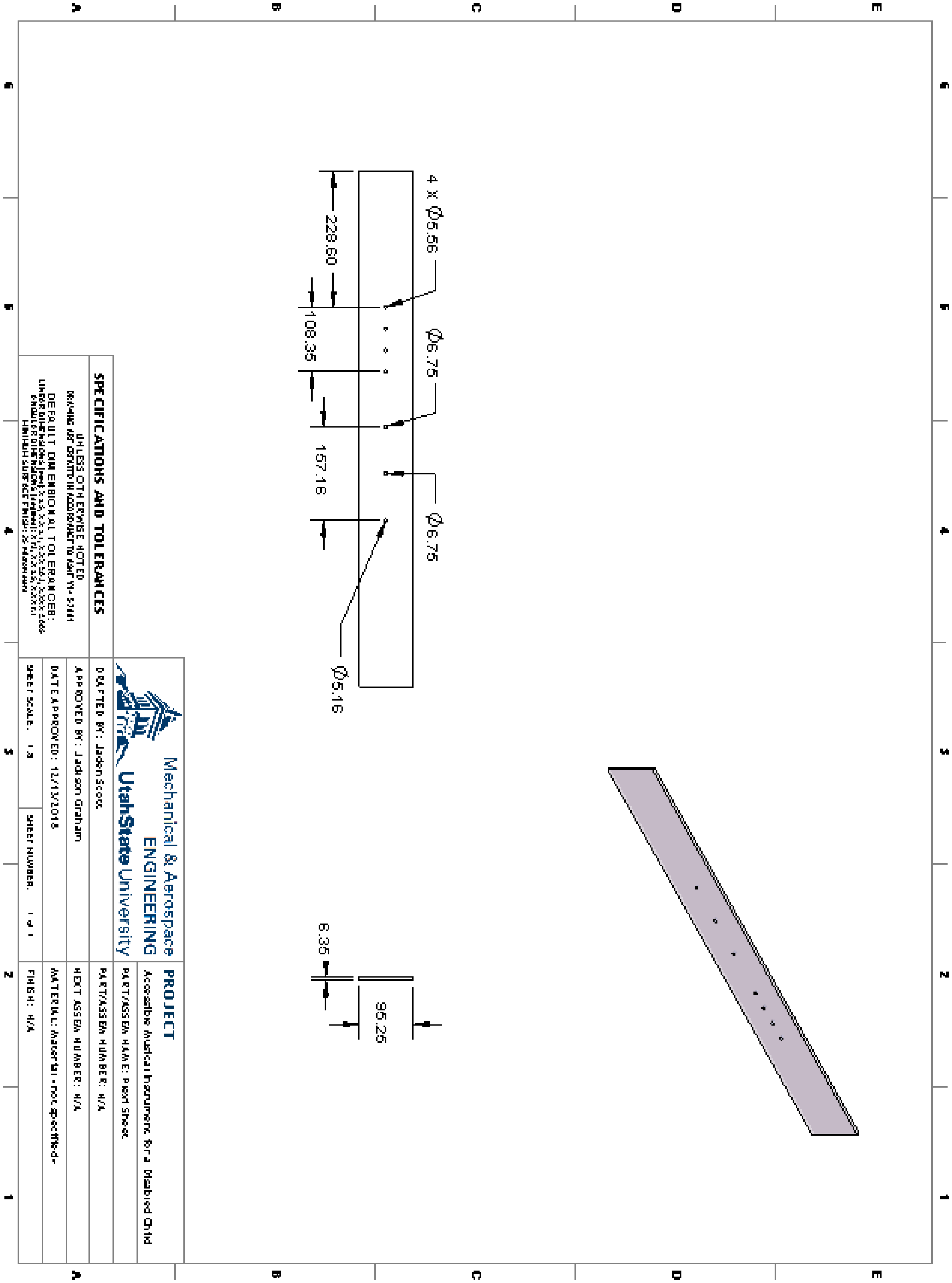


108.20
15X Ø12.32
789.69
60.96
14X 44.32
16.51
15X Ø10.16
19.05
114.30
19.05
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
Mechanical & Aerospace ENGINEERING
UtahState University
PROJECT
Accessible Musical Instrument for a Disabled Child
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:6
SHEET NUMBER: 1 of 1
PART/ASSEM NAME: Wood Base for Solenoids
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: PINE
FINISH: N/A



152.40
123.70
487.68
76.20
19.05
199.90
19.05
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009
DEFAULT DIMENSIONAL TOLERANCES:
MINIMUM SURFACE FINISH: 25 micrometers
Mechanical & Aerospace ENGINEERING
UtahState University
PROJECT
Accessible Musical Instrument for a Disabled Child
PART/ASSEM NAME: Wood L
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: PINE
FINISH: N/A
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:5
SHEET NUMBER: 1 of 1


38.10
76.20
76.20
12.70
38.10
12.70
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
Mechanical & Aerospace ENGINEERING
UtahState University
PROJECT
Accessible Musical Instrument for a Disabled Child
PART/ASSEM NAME: Wood Spacer
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: Pine
FINISH: N/A
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/12/2018
SHEET SCALE: 1:1
SHEET NUMBER: 1 of 1



4 x Ø5.56
Ø6.75
Ø6.75
Ø5.16
228.60
108.35
157.16
95.25
6.35
Mechanical & Aerospace
ENGINEERING
UtahState University
PROJECT
SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED
DEFAULT DIMENSIONAL TOLERANCES:
DRAFTED BY: Jaden Scott
APPROVED BY: Jackson Graham
DATE APPROVED: 12/13/2018
PART/ASSEM NUMBER: N/A
NEXT ASSEM NUMBER: N/A
MATERIAL: Material <not specified>
FINISH: N/A

Appendix D

Bar Analysis Report

Deflection Analysis

- Length: 29.134 in.
- Diameter: 0.5 in.
- Max Deflection: 0.118 in.
- Safety Factor: 5
- Deflection Equation: $\delta_{max} = \frac{Pl^3}{48EI}$

```python
import numpy as np

Length = 0.74           #length of the rod (m)
Modulus = 180000000000  #modulus of elasticity of the rod (Pa)
Density = 7700          #density of the rod (kg/m^3)
R_diameter = 0.0127     #diameter of rod (m)

Force_Solenoid = 50     #point load force in the center of the rod (N)

Velocity = 2            #max velocity of the mallet as it hits the tonebell (m/s)
Mass_Mallet = 0.05      #mass of the mallet (kg)
Collision_Time = 0.015  #time the mallet is in contact with the tonebell (sec)
Force_Impact = Mass_Mallet*Velocity/(Collision_Time)    #calculates the force of the mallet hitting the tone bell
Force_Impact = Force_Impact*5                           #adds a safety factor of 5 to the collision force

Force_Total = Force_Solenoid+Force_Impact               #calculates the total force on the bar
Area_Inertia = (np.pi/4)*(R_diameter/2)**4                          #calculates the area moment of inertia of the rod
Deflection_Point = (Force_Total*Length**3)/(48*Modulus*Area_Inertia)     #calculates the deflection at the center of the rod

print('\n\nPoint Load deflection at the center of the rod:',Deflection_Point*1000,'milimeters\n\n')
```

Appendix E

Metallophone Sound Test Report

Metallophone Sound Testing

1 PURPOSE

The purpose of the sound test is to determine the sound range of different musical dynamic levels (*Piano, Mezzo Piano, Mezzo Forte, and Forte)* on the metallophone. The test will define the decibel parameters of requirement 3.9 (requirements contract). The test will further define the methods of creating sound on a metallophone. Such as whether the size of the hammerhead is significant, how much force is exerted on the tonebells to produce a certain dynamic, and whether the tempo being played affects the dynamic level.

This test will also define the speed at which the hammers will need to recoil off the metallophone. This recoil is a significant part of creating a rich sound off the metallophone.

2 SCOPE

We are testing for the musical dynamic (loudness) of the metallophone, the speed the hammer recoils off the metallophone, and the force the hammers produce on the tonebells. We are not testing the dynamic of the metallophone in conjunction with other instrumentation.

The dynamic of the metallophone will be measured with a decimeter. The height of the hammer before striking the tonebell will also be measured with a high-speed camera and a meterstick to determine the force the hammer strikes on the tonebell to produce a certain musical dynamic.

The high-speed camera and meterstick will also be used to determine how quickly the hammer recoils off of the metallophone.

3 PRECAUTIONS AND LIMITATIONS

To ensure the data is as accurate as possible and no harm comes to anyone or the metallophone, a practiced musician/percussionist should perform all musical requirements of the test.

4 Prerequisites

4.1 [Environmental Conditions]

- Lab will be performed in musical practice room.

4.2 [Materials List]

- Decimeter
- Meterstick (measuring tape or source of measurement)
- Highspeed Camera (iphone)
- Metallophone
  - Include multiple hammerhead sizes
- Scale
- Something to stabilize camera
- Force Plate

4.2.1 [Consumables]

- Painter's or masking tape

4.3 [Setup]

4.3.1 Align meterstick with metallophone.

4.3.1.1 The meterstick may need to be taped into place to ensure consistency.

4.3.1.2 The meterstick has two potential locations depending on the camera imagery, either down the middle of the metallophone or on the end of one of the tonebells.

4.3.2 Align camera with metallophone, exactly opposite the measuring instrument.

4.3.2.1 This alignment may be subject to change, the camera needs to be able to see the centimeter marks on the meterstick.

4.3.3 Setup decimeter.

5 General Instructions

5.1 [Musical Dynamic Test]

The purpose of this test is to determine what most variables affect the musical dynamic (loudness) of the metallophone. The variables include: The size of the hammer, the height of the hammer before striking the tonebell, and the force of the hammer as it strikes.

5.1.1 Use the scale to measure the weight of the different hammerhead sizes.

5.1.2 Have the musician play a scale on the metallophone with a smaller hammer. Record the decibel level with the decimeter.

5.1.2.1 Repeat 5.1.2 with multiple hammerhead sizes. Determine how large of an effect the size of the hammerhead size has on Dynamic.

5.1.3 Have the musician play at the musical dynamic *Piano* (p) at a tempo of 120 BPM.

5.1.3.1 Record the decibel level with the decimeter.

5.1.3.2 Use the camera to record the hammer as it strikes the tonebell and its height before striking.

5.1.3.3 Play at the same rhythm and decibel level on the force plate and record the measured force.

5.1.3.4 Repeat 5.1.3.1 and 5.1.3.4 for the musical dynamics: *Mezzo Piano* (mp), *Mezzo Forte* (mf), and *Forte* (f).

5.1.4 Repeat 5.1.3.1, 5.1.3.2, 5.1.3.3, and 5.1.3.4 at a tempo of 200 BPM.

5.2 [Hammer Recoil Test]

5.2.1 Using the camera, record the musician playing a single note on the metallophone.

5.2.2 Using the camera, record the musician playing a note at 120 BPM.

5.2.3 Using the camera, record the musician playing a note at 200 BPM.

5.2.4 Using the video from 5.2.1 determine how quickly the hammer recoiled off of the metallophone.

6 Acceptance

6.1 Testing Outcomes

- Musical Dynamic (loudness) Levels
    - Decibel levels for p, mp, mf, f
    - Measured force on tonebell to perform each dynamic level
- Speed at which the hammer recoils off of the tonebell

<u>Mallet Info</u>

Blue Rubber Mallet

Mass = 0.035 kg Decibel max = 96 dB Decibel Avg = 80 dB

Pink Yarn Mallet

Mass = 0.031 kg Decibel Max = 91 dB Decibel Avg = 70 dB

Red Yarn Mallet

Mass = 0.029 kg Decibel Max = 96 dB Decibel Avg = 85 dB

Discussion:

This test determined that all of the mallet styles are capable of playing at similar levels. The true difference in the mallets lies in the sound quality. Each mallet created a different sound off the metallophone. From this test, we determined the pink yarn mallet to produce the preferred sound.

Average Decibel levels at 120 BPM (dB)

P avg = 75 dB max = 85 dB **mp** - **mf** avg = 86 dB max = 97dB **f** avg = 90 dB max = 103 dB

Average Decibel levels at 200 BPM (dB)

P avg = 82 dB max = 94 dB **mp** - **mf** avg = 76 dB max =98 dB **f** avg = 94 dB max = 100 dB

Force per Dynamic Level (N)

P avg = 9.6 N max = 13.8 N **f** avg = 14.71 N max = 18.5 N

Recoil Speed (m/s)

Running at 240 frames per second, it was difficult to determine how long the mallet was in contact with the tonebell. In each case the result was in a fraction of a second.

Overall Discussion

This test has provided essential data in designing the mechanical system on the metallophone. The force and decibel calculations provide necessary parameters to determine what design will be best.

The decibel test also brought the dynamic levels into question. Is it absolutely necessary that the system change dynamic? The team found that any dynamic over 90 decibels was very loud and difficult to listen too. The *piano* range produced a pleasing sound, whereas the *forte* range was more loud and annoying.