CAPSTONE FINAL REPORT

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Table of Contents

Introduction …………………………………………………………………..………….. Page 4

Problem Statement ……………………………………………………….……….. Page 4

Mechanical ……………………………………………………….……….. Page 4

Software and Hardware ……………………………………….………. Page 5

Literature Review …………………………………………………….……….. Page 6

Design Criteria and Scope of the Problem …………………………………….. Page 7

Essential and Unique Features of the Design ……………………………….... Page 10

Engineering analysis …………………………………………………………….. Page 11

1. Steady Force Analysis ……………………………………………….….. Page 11

2. Drop Analysis …………………………………………………..…….. Page 17

3. Thermal Analysis ……………………………………………………….….. Page 20

Test and Safety Procedures and Test results ………………………………..….. Page 22

Safety Procedures …………………………………………………………….. Page 22

1. Steady Force Test …………………………………………………….. Page 24

2. Impact Test ………………………………………………………..….. Page 29

3. Screen Angle Test …………………………………………………….. Page 34

4. Thermal Test …………………………………………………………….. Page 39

5. Vibration Test …………………………………………………..…….. Page 40

6. Drop Test ……………………………………………………….…….. Page 43

7. Ergonomics Test …………………………………………………..…….. Page 47

Validation of Engineering Analysis ……………………………………….. Page 51

Hardware and Software Integration ……………………………….…….. Page 53

Software Installation Guide …………………………………………….…….. Page 54

Comprehensive Design/Validation System Diagram ………………..……….. Page 64

Comprehensive Cost Analysis ……………………………………….…….. Page 65

Important Assembly, Operating, and Maintenance Features ………………..…….. Page 65

Product Specifications ………………………………………………………….. Page 66

Engineering Drawings ……………………………………………….…….. Page 70

Gantt Chart ……………………………………………………………..…….. Page 70

Human and Safety Factors ……………………………………...…………….. Page 70

References……………………………………………………………………….. Page 72

Appendix

I. Declaration of Work ………………………………………….………….. Page 75

II. Graduate Attributes First Lecture …………………………………………. Page 77

III. Graduate Attributes Second Lecture ………………………………..…….. Page 82

IV. Complete FEA Report (Steady Force Analysis) …………………...…….. Page 86

V. Complete FEA Report (Drop Analysis) …………………………...…….. Page 116

VI. Complete FEA Report (Thermal Analysis) ……………………….…….. Page 138

VII. Engineering Drawings (Revision 5) …………………………...…….. Page 150

VIII. Gantt Chart ……………………………………………………………….. Page 173

IX. Augmented Reality Headset Pictures…………………………...…….. Page 176

Introduction

In recent years, augmented reality technology has risen with multiple research being conducted to further improve it and with continuous innovations being accomplished in this field of technology. Augmented reality can be explained by the superposition of virtual information onto reality [1]. This is done using a heads-up display system which acts as the medium to “merge” both reality and the digital information into one. The information can be in the form of text, images and even as complex as 3D models [1]. This technology can come in many forms but for this project, this technology is incorporated into a wearable headset. This allows the user to interact with his surroundings with the help of the information being projected onto the heads-up display simultaneously as if they were one. There are many applications for augmented reality technology, for instance, in the arts, in STEM and simply in every day to day use as well.

For this capstone project, the initial idea was to be able to display a 3D model of a rotating cube onto reality. Its position should be fixed in space which will allow the user of the headset to interact with it by analyzing it from different views, in short, looking at the cube 360˚. The cube will remain in that location no matter the movements of the user. This feature is accomplished with the use of a motion and depth sensor. Currently, these are the features being programmed onto the AR headset. However, there are numerous functions which could be programmed and not only limited to the ones just mentioned.

Problem Statement

Mechanical

With Microsoft developing one of the most technologically advanced augmented reality headset at the cost of approximately $3999, some may hesitate to purchase this device [2]. This prevents many people from being able to experience augmented reality, thus, may not understand it. Therefore, one of the main requirements of this capstone project is to make it open source and accessible. In other words, the design of the entire headset would be made public for everyone and anyone who wishes to build their very own augmented reality headset. For this to be true, the manufacturing process selected is through 3D printing making it very accessible and simple to produce. This process would be more efficient than any other manufacturing processes since they require external suppliers and are costly than simply 3D printing the headset. To ensure that it can be done, the headset was designed with minimal parts and without complex features. This would allow less printing requirements, for instance, supports, and reduce print time.

Software and Hardware

The most important aspect would be the hardware and software required to run an augmented reality headset. The hardware components used in the system should be available to purchase and at a reasonable price as well. These parts include an Odroid XU-4 which is the processing unit of the device, a screen to project the digital information onto the heads-up display system, a BNO 005 motion sensor and an Intel RealSense depth sensor. Most importantly, there is the software required to run the device which can be downloadable online as it will be open to anyone to have as well. This will be easy to use since there would be a set of instructions to follow. With these components and processes to follow, anyone can be able to have an augmented reality.

Literature Review

One of the most anticipated technology of this generation are Augmented Reality headsets (AR headsets). This technology allows user to bridge the gap between software simulation and reality. More specifically, augmented reality superimposes digital information into reality by projecting a virtual computer-generated image in real life. As a result, unlike virtual reality where the user is completely submerged into a new world, augmented reality still allows the user to interact with his surroundings. The types of computer generated images may include static data such as 3D models of objects or even dynamic data depending on the user's inputs into the device [3]. This technology enhances a person's view of reality with the help of images, texts or other type of medium that are integrated into the real world through the device. This gives the impression that they are part of the physical world. Another aspect is that the user can willingly alter the physical world, making AR technology interactive by changing the information present to his suiting [3]. For example, this can be done by importing something from the digital plane into the physical world allowing the user to interact with his surroundings. Everyone wearing an augmented reality device has their own perspective of the physical world that is being altered and the material being projected depends on the user's current position [3]. For instance, when something is being changed in a specific area of the real world, this change will remain in that location even if the user looks and moves to a different direction with the headset. In short, these are the traits which makes Augmented Reality different from similar technologies such as Virtual Reality.

Currently, there are many companies who have created their own augmented reality technology but the two largest companies which have created tools that utilizes this technology are Google with their application Tango and Microsoft with their HoloLens [5]. For instance, Google has created and incorporated augmented reality into two mobile phones [6]. Some of the features included are the ability to interact with virtual objects into reality and with information appearing through the mobile phone that appear as to be part of the environment which can all be done by simply pointing the mobile device's camera at a certain location [6]. Then there is the more advanced AR headset technology: Microsoft HoloLens. This device combines both the digital and physical world together through their headset which enables an interactive environment to be created where holograms can be generated [4]. Microsoft HoloLens would be the device that would revolutionize Augmented Reality.

Besides being implemented into headsets, augmented reality technology is also being recently incorporated into several consumer products such as smart phones. The two biggest companies paving the way forward to integrate augmented reality technology into mass smartphones are Apple and Samsung. For example, during the launch of the newest iPhone (8, X), Apple announced a new development platform for AR developers which can be used to build apps ranging from gaming to sports using AR technology to dynamically place high-fidelity virtual objects in the real world. Furthermore, unlike Google's Tango approach, this development platform will be accessible to millions of users to create and develop AR technology for everyday uses [7].

Design Criteria and Scope of the Problem

Earlier in the report, a few high-level problems with the current augmented reality industry were stated. In fact, the most important issue associated with current augmented reality headsets is the extremely high purchase cost which essentially prevents most people to have access to this technology.

The main objective of our capstone project is to completely redesign and improve an existing student-made augmented reality headset while respecting a set of constraints set by our team and our capstone professor. In addition, we want to ensure that the entire headset uses only open-source technology and easily purchasable parts so that it can be re-created by anyone in the world following a set of instructions. However, there are several problems/challenges with the existing headset set up which we set to improve during our capstone. These problems are:

- Lack of ergonomics/Uncomfortable: the current headset device is entirely 3d printed with a lack of padding around the device. The device is printed in a general cube shape which does not sit comfortably against the user's forehead. The straps used to attach the headset around the user's head are not very elastic which causes the device to be forced into the user's head.

- Not upgradable: the current device operates using a HUD material, a screen to project the image, a raspberry pi 3 and an accelerometer. However, with the existing setup, there is no way to interchange/upgrade the hardware to other configurations such as using using a more powerful computer chip (Odroid XU-4) which can incorporate a depth sensor.
- Poor thermal management: since the current headset operates on raspberry pi 3 which has limited computing power. The device quickly overheats while the AR software is running and, ultimately, throttles to prevent heat damage to the computer chip which causes the software to crash.
- Inefficient cable management: the AR headset requires several cables to be connected between the raspberry pi, the accelerometer and the screen. It also requires cables for a mouse and keyboard which is poorly managed and there are several cables sticking out of the device.
- No portable power source: the device requires multiple power cable to be connected to an outlet to power the raspberry pi, the screen and any other additional accessories.
- Poor heads-up display material: the headset currently is using a thin transparent plastic wall as the heads-up display where the screen projects. However, the HUD bends easily and isn't sturdy enough for everyday use.

With that said, the scope of this capstone project was to completely redesign an existing student-made headset to create a completely open-source proof of concept Augmented Reality headset that can be built by anyone in the world from scratch. This met that our objectives were to:

- Use only easily accessible manufacturing methods (such as 3D printing) that can essentially be downloaded by anyone to re-create the headset.
- Source only electronic components and parts that are widely available are a relatively low cost so that is accessible.
- Ensure that all software, programs and code is downloadable on GitHub.

Furthermore, we wanted our headset to improve on several points which the existing headset was lacking:

- Improve the ergonomics of our headset so it is suitable for extended use.
- Improve thermal management such that the CPU was operate without throttling itself while integrating a motion and depth sensing camera.
- Reduce the amount of cables within the assembly to the essentials.
- Source components such that only one power cable is coming out of the headset.
- Improve the heads-up display such that it is suitable for multiple purposes (good and bad lighting conditions)
- Ensure that the headset is sturdy enough for everyday use and will not be damaged when reasonable everyday loads are applied.

Ultimately, as discussed with our Capstone professor, our main objective, as a team of mechanical engineering students, was to build a proof of concept AR headset that could integrate and use all the hardware components within the headset to simulate Augmented Reality. Once our team would finish building the headset and integrating the software with the hardware, the headset could be passed on to a team of Software Engineering/Computer Science students which could further develop the software.

Essential and Unique Features of the Design

In terms of design, there are several essential features we must make sure to incorporate into our augmented reality headset to ensure that our device can deliver a similar experience when compared to industry leading devices such as the Microsoft HoloLens. As such, the essential features we've determined necessary in our headset are:

1. Adjustability: The headset should be able to fit a variety of head sizes by having a mechanism that allows the internal diameter of the headset to be adjusted.
2. Appropriate thermal management: The augmented reality headset should not overheat causing unnecessary discomfort on the user. Furthermore, the headset should be passively cooled to not affect the user's experience (fan noise, etc.).
3. Reliability: The headset should be sturdy enough to not break under normal everyday use.
4. Ergonomics: The augmented reality headset will be used by an array of people which all have different preferences on comfort. Therefore, surveys regarding ergonomics are used in the design of the augments reality headset.
5. Ease of Maintainability: The augmented reality headset will be designed with regards to maintainability. As such, the user should be able to effortlessly perform hardware diagnostic on the augmented reality headset and find the root cause of failure. Moreover, the time required to change the failed component should be relatively quick.

In addition, the purpose of this capstone project is to add several unique features that would differentiate our AR headset from the rest of headsets in the market:

1. Affordability/Accessibility: The headset should primarily be made of easy to access and inexpensive material to keep the fabrication cost as low as possible. As technology is rapidly advancing in the field of 3D printing and cost of manufacturing components is decreasing, our AR headset casing will be 3D printed.

2. Ease of Manufacturability: The headset should be manufactured using the principles of design for manufacturability. Therefore, the design of the headset takes into consideration the type of material used for manufacturing, such that it is easily producible. Additionally, the use of simple and modular shapes as well as flexible tolerances are used in the design of the headset as per the principles of design for manufacturability.
3. Open source and Upgradable: the AR headset should be extensible by adding different sets of hardware combinations. It must contain standard hardware that anyone can purchase/access and it must use only open source software as it's platform.

Engineering Analysis

1. Steady Force Analysis

It is important to analyze the performance of the parts at this step of the design process to better understand how the parts behave under different loading conditions and environments. The material of choice was polylactic acid (PLA). The parts were manufactured using fused deposition modelling (FDP) which is a type of additive manufacturing technology commonly used by 3D printers. Due to this being a relatively new technology for manufacturing end-use products, the material properties of 3D printed PLA need to be estimated. The material properties of 3D printed PLA were determined using three main parameters; Infill %, infill pattern and layer height [8]. The table below shows approximate values of mechanical properties for 3D printed PLA using 25% infill, grid pattern and 0.3 mm layer height.

Ultimate tensile strength (MPa)	15
Elongation at break (%)	2.6
Young's Modulus (GPa)	3.4
Yield Stress (MPa)	13

Table 1: Approximate Values for 3D Printed PLA [8]

The first test was 250 N distributed load on the top cover of the headset. FEA was carried out for V1, V2, V4 and V5 of the headset design. Please refer to appendix IV for more details of the analysis. The table below shows a summary of the values obtained for each analysis.

Version	Von Mises Stress (MPa)	Total Displacement (mm)	Total Reaction Force (N)	Equivalent Strain (mm/mm)	Total Contact Pressure (MPa)	Comments
V1	Max: 1.22 Min: 1.202E-4	Max: 0.06385 Min: 0	Max: 3.293 Min: 0	Max: 6.75E-4 Min: 5.843E-8	Max: 1.154 Min: 0	Design easily withstands applied loads
V2	Max: 1.202 Min: 1.235E-8	Max: 0.07292 Min: 0	Max: 3.762 Min: 0	Max: 5.633E-4 Min: 5.245E-12	Max: 0.8256 Min: 0	Design easily withstands applied loads
V4	Max: 5.401 Min: 1.008E-7	Max: 0.1548 Min: 0	Max: 24.89 Min: 0	Max: 0.002906 Min: 5.448E-11	Max: 2.767 Min: 0	Design easily withstands applied loads
V5	Max: 3.661 Min: 7.998 E-7	Max: 0.2114 Min: 0	Max: 15.85 Min: 0	Max: 0.001942 Min: 3.275E-10	Max: 4.295 Min: 0	Design easily withstands applied loads

Table 2: 250 N Distributed Load on Top Cover

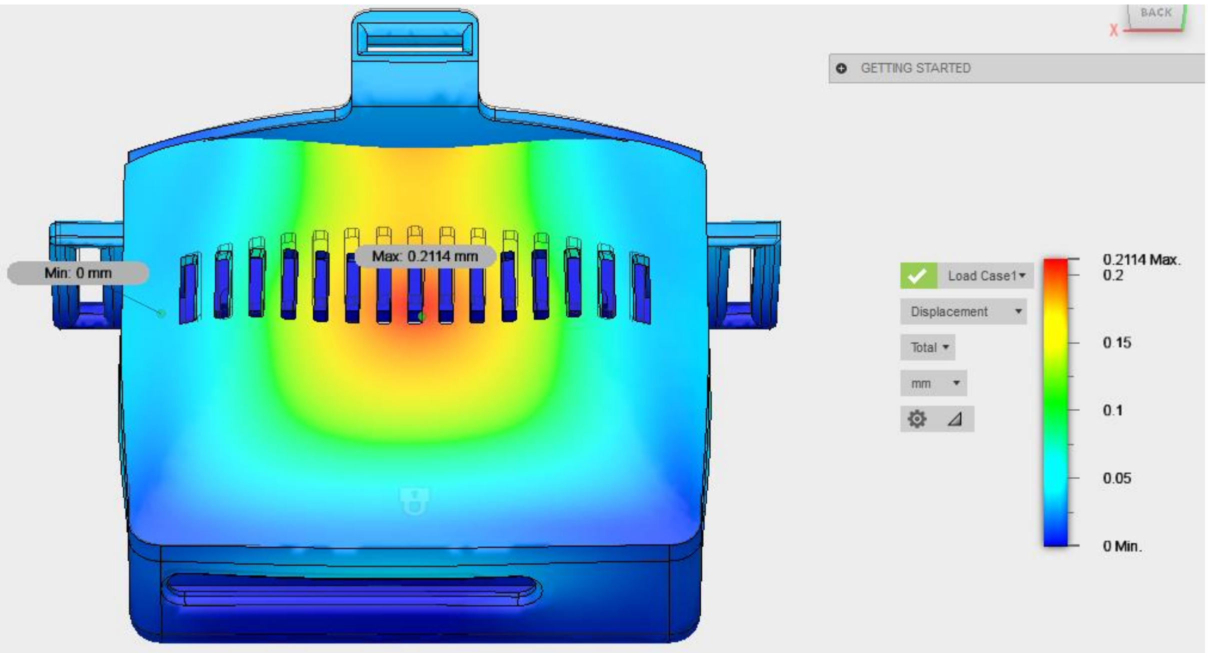

Figure 1: Displacement of Top Cover, Headset V5.

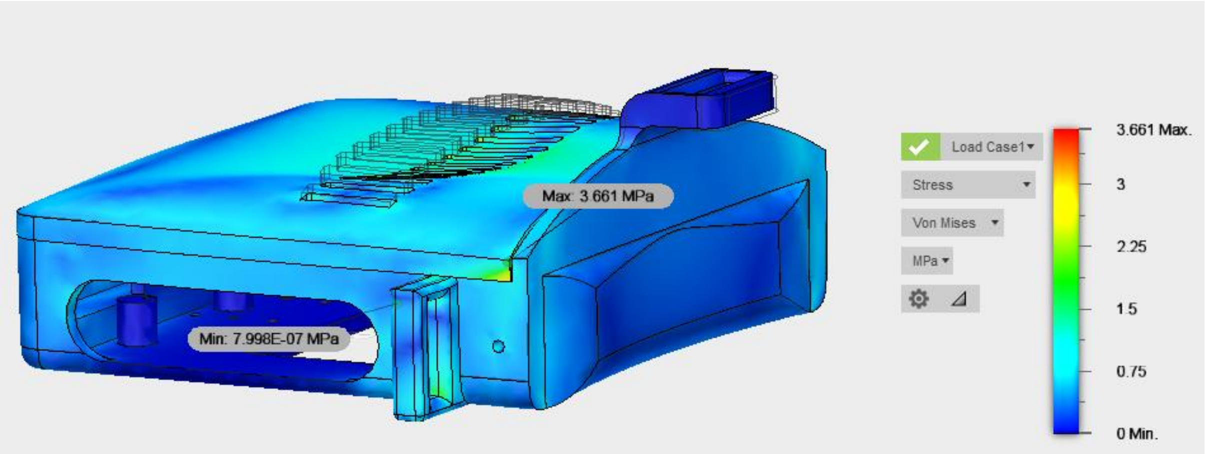

Figure 2: Von Mises Stresses on Headset V5 and Location of Maximum Stress.

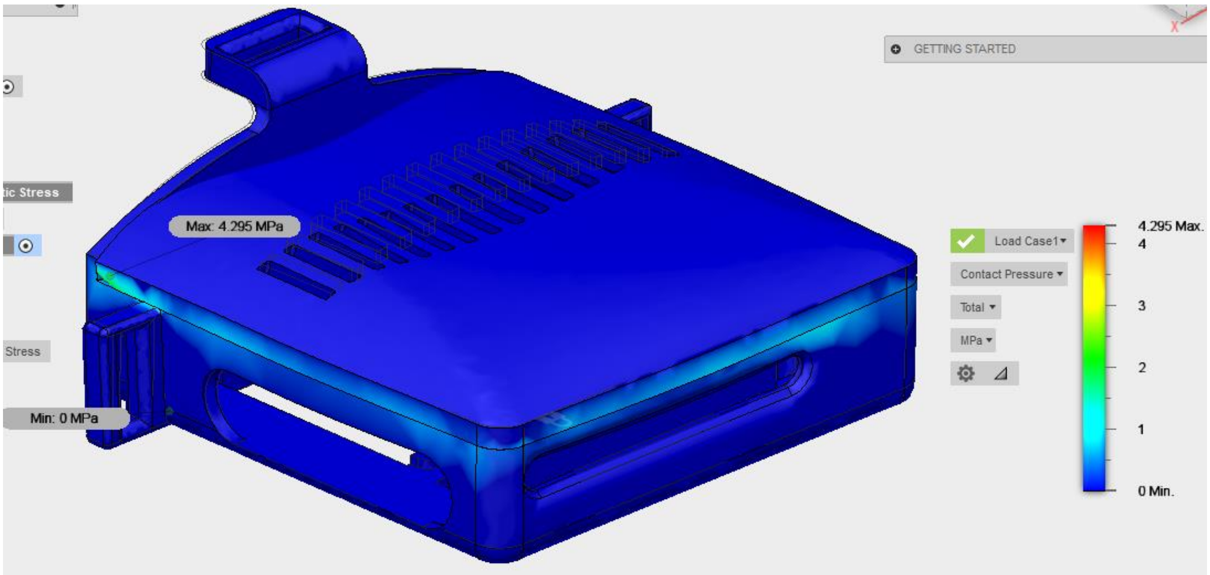

Figure 3: Contact Pressure due to Load on Headset V5.

In this analysis, the two most important parameters for the design criteria are the maximum stresses and total displacement. Table 2 shows the maximum stress was lowest for V1 at 1.22 MPa, and highest for V4 at 5.401 MPa. The maximum displacement was lowest for V1 at 0.064 mm and highest for V5 at 0.211 mm. Several variables contributed to the variance of stress and total displacement values such as the shape, curvature, total area of the top cover, and structural support by the back cover. It is important to note that 3D printed PLA has anisotropic mechanical properties. The process of 3D printing inherently tends to create weaknesses in the build direction (z-axis) due to weak interlayer bonding [8]. This means that the part tends to be 20-30% weaker in the build direction with 50% less maximum elongation [8]. Comparing the highest maximum stress from table 2, which was 5.4 MPa for V4 with 70% of the yield stress from table 1, shows that the maximum stress is well below the yield stress considering the weakness in the build direction. The maximum total displacement was the highest for V5 since the top cover is not structurally supported by the back cover compared to previous versions. The maximum total displacement was 0.2114 mm which meets the design criteria.

The second test was 10 N static load on the Odroid-XU4. Please refer to appendix IV for more details of the analysis. The table below shows a summary of the values obtained for each analysis.

Version	Von Mises Stress (MPa)	Total Displacement (mm)	Total Reaction Force (N)	Equivalent Strain (mm/mm)	Total Contact Pressure (MPa)	Comments
V1	Max: 5.672 Min: 3.185E-8	Max: 0.07224 Min: 0	Max: 0.3615 Min: 0	Max: 3.89E-4 Min: 9.918E-12	Max: 5.393 Min: 0	Design easily withstands applied loads
V2	Max: 11.91 Min: 4.18E-9	Max: 0.1082 Min: 0	Max: 1.52 Min: 0	Max: 5.007E-4 Min: 2.253E-12	Max: 10.08 Min: 0	Design easily withstands applied loads
V4	Max: 27.81 Min: 0	Max: 0.1893 Min: 0	Max: 0.5583 Min: 0	Max: 3.399E-4 Min: 0	Max: 6.97 Min: 0	Design sufficiently withstands applied loads
V5	Max: 33.74 Min: 0	Max: 0.2135 Min: 0	Max: 1.136 Min: 0	Max: 3.271E-4 Min: 0	Max: 13.87 Min: 0	Design sufficiently withstands applied loads

Table 3:10 N Static Load on Odroid XU-4.

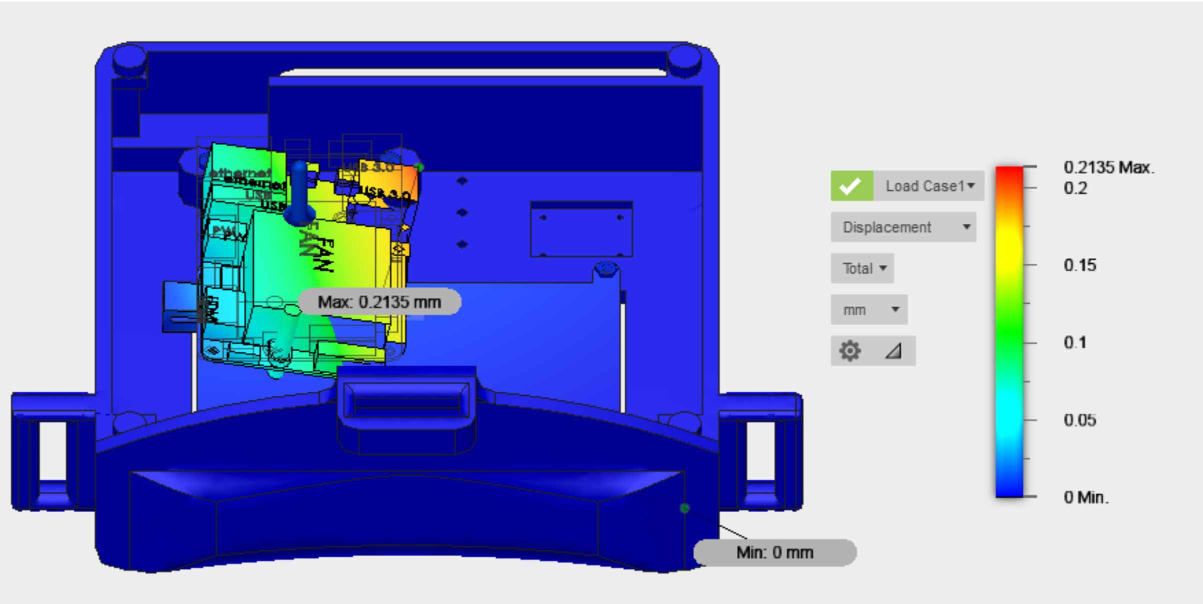

Figure 4: Displacement of Odroid-XU4, Headset V5.

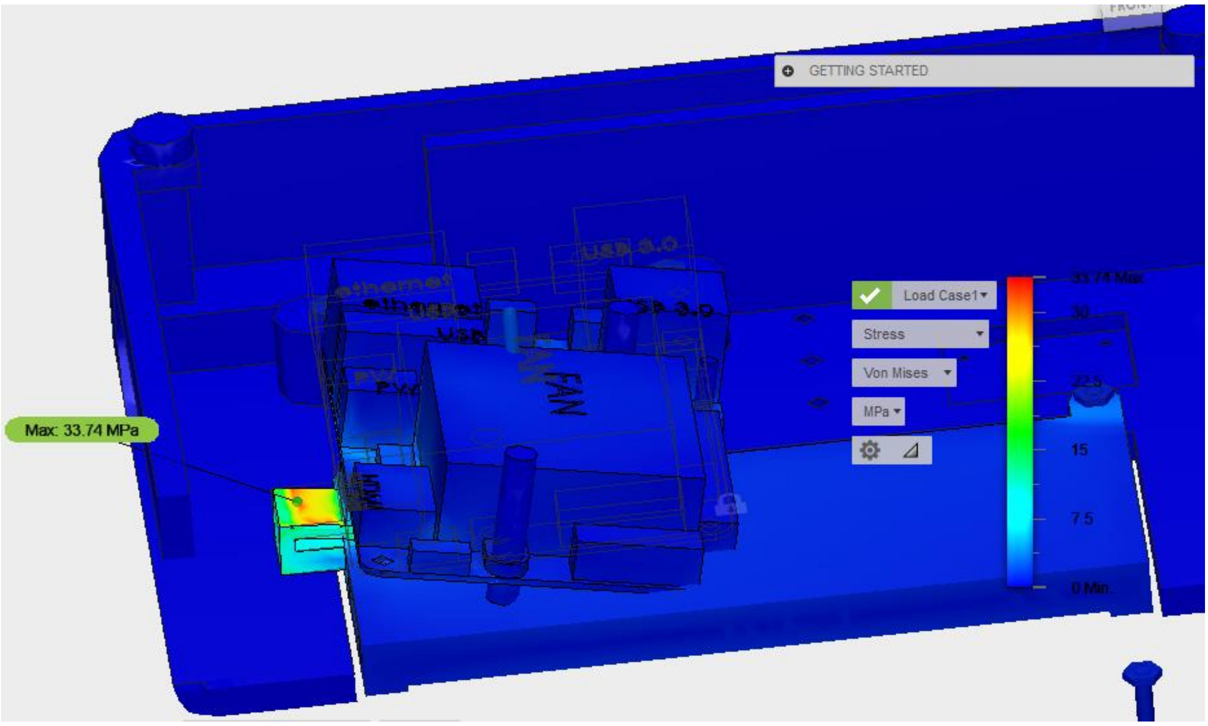

Figure 5: Location of Maximum Stress, Headset V5.

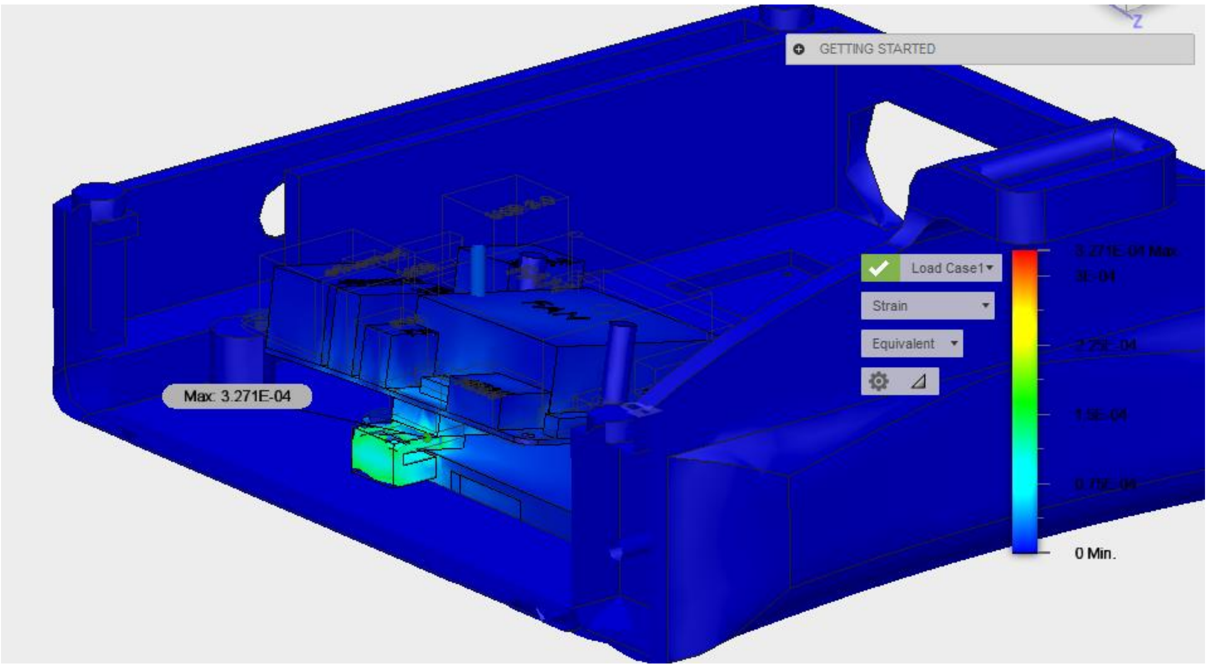

Figure 6: Strain Locations, Headset V5.

The material used to simulate the electronic hardware was silicon (Si) since most of the hardware components consist of this material [9]. Although the actual values may differ from the values from table 3 due to differences in material properties, the simulation results provide useful insight into the behavior of the parts and the critical locations.

The most important parameters are the stresses and total displacement. The table above shows the maximum stress was lowest for V1 at 5.672 MPa, and highest for V5 at 33.74 MPa. The maximum displacement was lowest for V1 at 0.0722 mm and highest for V5 at 0.2135 mm. The first two versions of the design have very low stresses and displacements because the Odroid-XU4 was directly mounted on the headset providing support at all four corners. The versions following V2 had a different setup where the Odroid-XU4 was placed on top of the screen where two corners are supported by the headset, the third corner supported by the HDMI connection and the fourth corner is overhanging with no support. The total displacement values were minimal at 10 N load but the FEA results show high stress concentration at the HDMI connection. Overall, the maximum stress (33.74 MPa) was well below the yielding stress of silicon which is 120 MPa which meets the design criteria.

2. Drop Analysis

Portable electronic devices such as the AR headset are susceptible to accidental drops. The impact forces due to the drop may cause severe functional damages to the device in the form of interconnection breakage, display damage and component/housing failure. Therefore, drop/impact protection is an important concern for the design of the headset to ensure that the design is not only functional but is also reliable.

This FEA analysis will investigate the dynamic behavior of the headset under a drop impact on a rigid floor from a height of 1 meter. For this study, it is assumed that the headset falls flat on its bottom surface. The drop test simulation will identify the maximum stresses, displacements and the critical locations after the impact. These values will help identify failure mechanisms that will aid in implementing design improvements for future iterations. A simplified model of the AR headset will be used in this study to minimize the model complexity and computation times. This analysis was carried out for only the headset V2 and V5 since V1 is like V2 and V4 is like V5 for the purpose of this FEA. Please refer to appendix V for more details of the analysis. The table below shows the summary of the results.

Version	Von Mises Stress (MPa)	Total Displacement (mm)	Equivalent Strain (mm/mm)
V2	Max: 7.85E1 Min: 0.0595	Max: 1.569 Min: 0.00977	Max: 0.005 Min: 1.55E-5
V5	Max: 1.17E2 Min: 0.1327	Max: 1.4533 Min: 0.0028	Max: 0.0069 Min: 9.097E-6

Table 4: Headset Drop Test from a Height of 1 meter

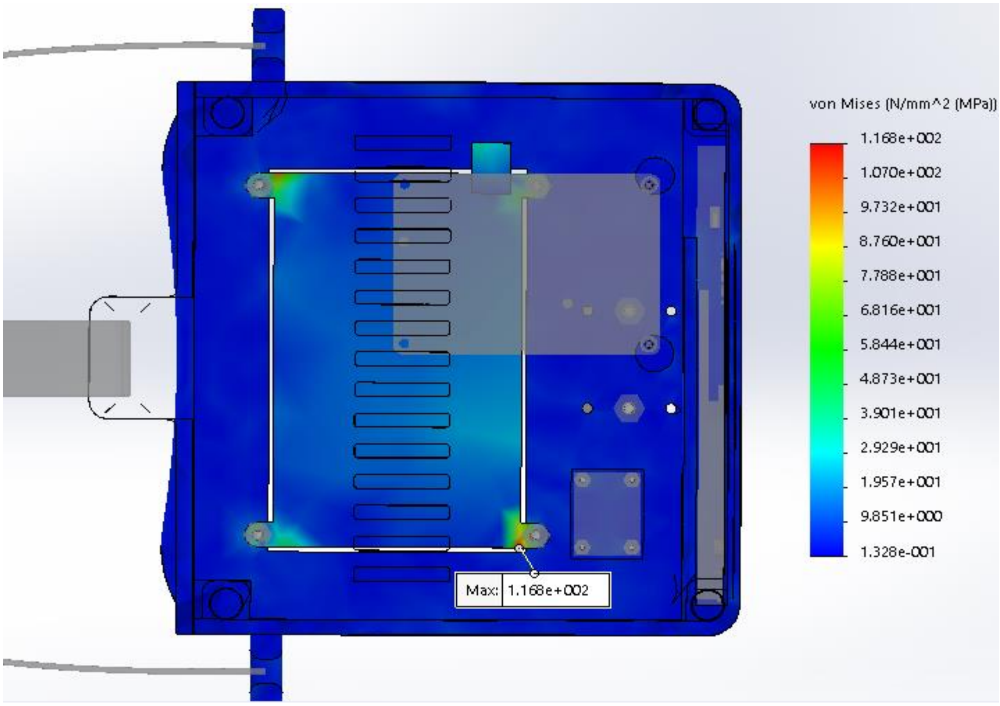

Figure 7: Von Mises Stress, Headset V5.

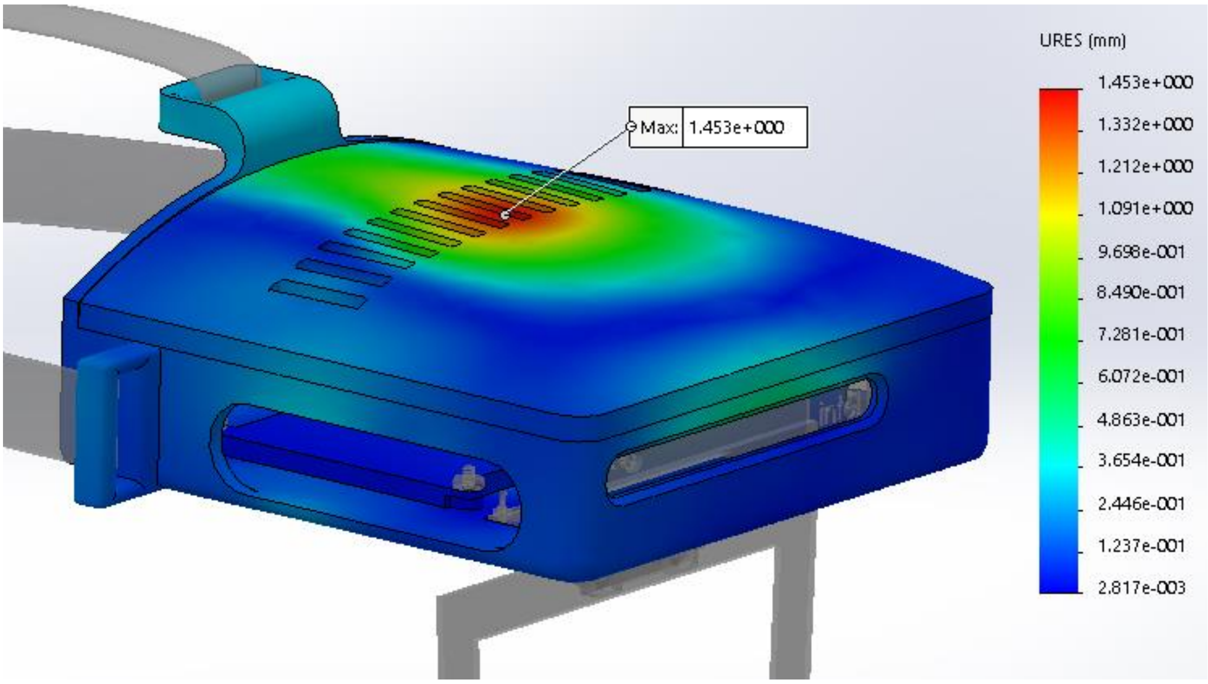

Figure 8: Displacement, Headset V5.

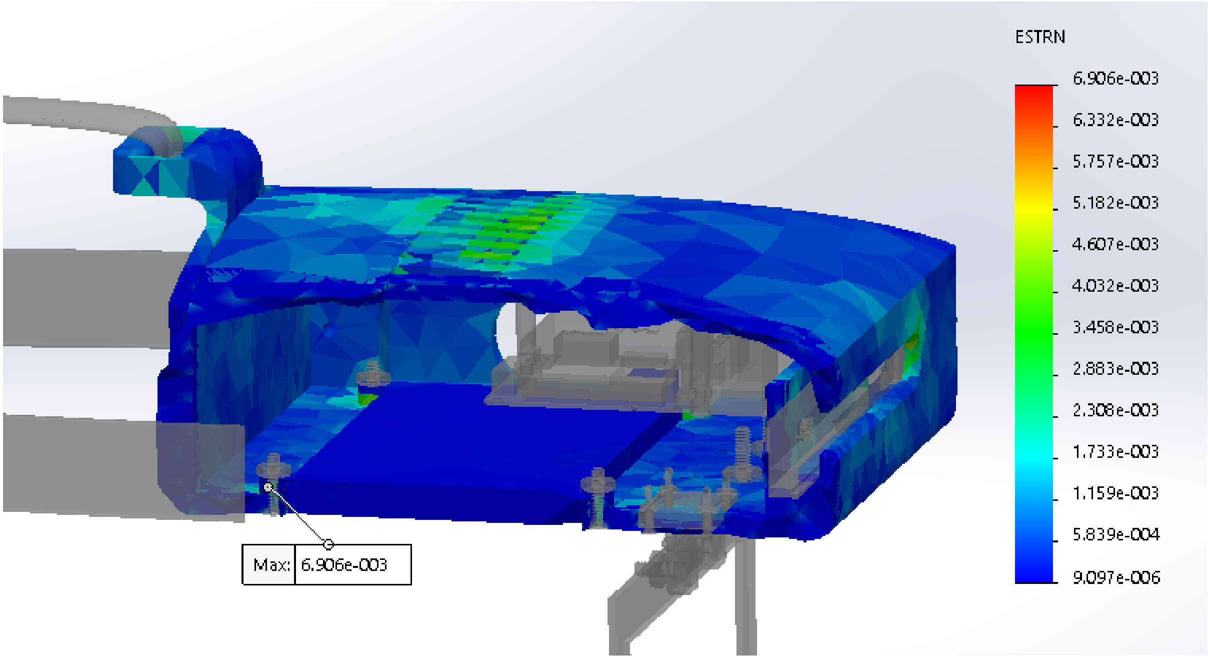

Figure 9: Strain, Headset V5.

The simulation results show that the maximum stresses and strains are located near the screen mounting holes in headset V5. The results show the maximum stresses on V2 were 78.5 MPa and the maximum stresses on V5 were 117.2 MPa. The variance in the results is due to two main reasons. First, the increase of the overall size of the headset from V2 to V5 to include all the components resulted in increase of the overall weight of the headset. Second, a new screen was used in V5. The screen used in V2 had no mounting holes and was placed on the surface supported throughout its perimeter and the simulation results assumed that the surfaces were bonded. However, the screen used in V5 was assembled using the holes provided on each corner causing stress concentrations. The values obtained from this analysis were higher than expected, this is due to the assumptions that the floor was infinitely rigid, providing no damping from the impact. Also, the model type was assumed to be linear elastic isotropic. In hindsight, a plasticity (von Mises) model would have yielded more accurate results. Nevertheless, the simulation results were very useful to locate critical locations and helped predict possible modes of failures.

3. Thermal Analysis

All electronic devices generate excess heat and thus require thermal management to improve the safety and reliability of the product. In this analysis, a thermal study will be conducted to analyze the temperature distribution of the headset under specified operating conditions. This analysis will provide useful information to determine effective ways to cool the components within the design. In this steady state analysis, PLA material was selected for the headset and top cover with thermal conductivity 0.13 W/m-K [10]. Whereas silicon was selected as a material for the screen and the Odroid-XU4 chip with thermal conductivity of 124 W/m-K. For this study, the operating temperatures of the Odroid-XU4 chip and the screen will be at 50 degrees Celsius and 35 degrees Celsius respectively. A convection coefficient of 100 W/m^{2}K will be used to estimate the heat transfer coefficient for the small fan used in the design [11]. The emissivity of the plastic surfaces will be approximately 0.95 [12]. This analysis was carried out for headset V5, please refer to appendix VI for more details of the analysis. Figures 10 and 11 below show the temperature distributions obtained from the analysis.

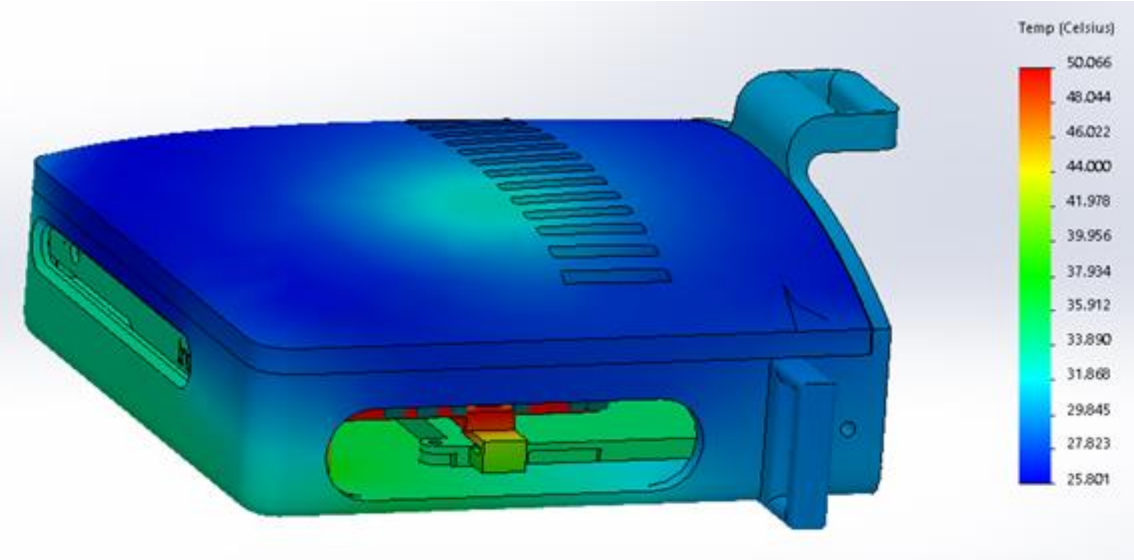

Figure 10: Temperature distribution, headset V5.

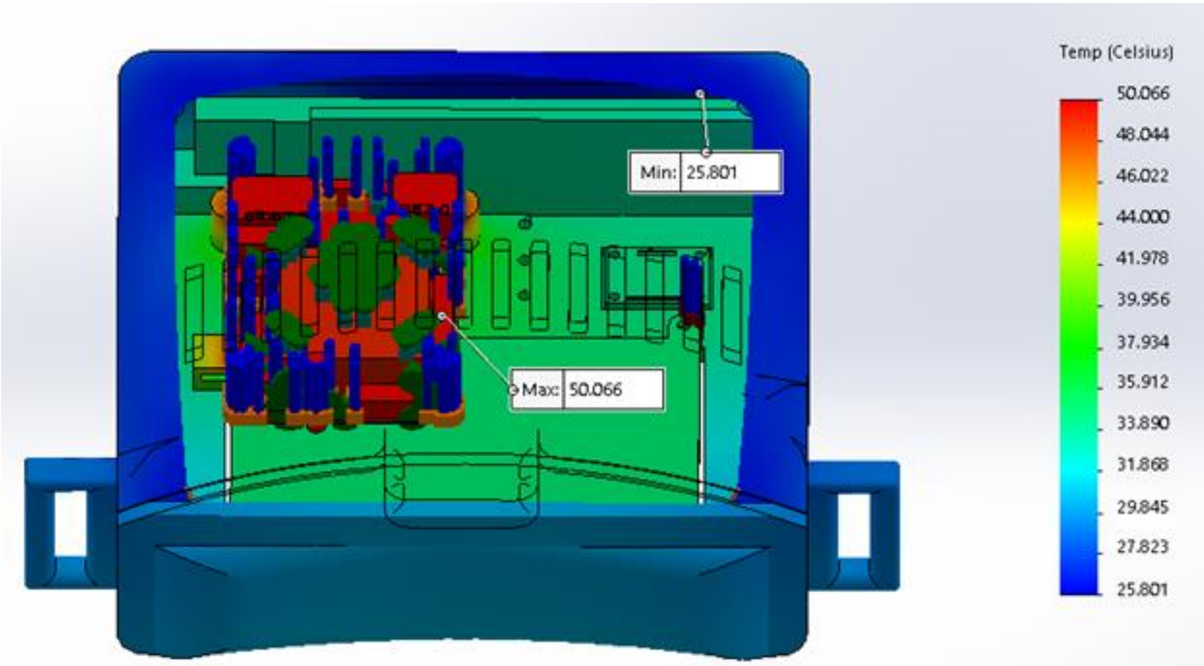

Figure 11: Section View of Temperature Distribution, Headset V5.

The temperature distributions in the figures above show that the temperature of the outer surface of the headset is close to 30 degrees Celsius. This indicates that the design provides sufficient cooling for the specified operating conditions and the headset can be safely used. The results show there is a slight increase in temperature on the top cover located directly above the Odroid-XU4. Vents were added in this location to improve heat dissipation from the system and increase air circulation inside the headset.

Test and Safety Procedures and Test Results

Safety Procedures

Any sort of product testing comes with certain safety procedures to ensure the well-being of the tester and the environment in which the test is taking place. For our augment reality headset, the impact test, drop test, steady force test, thermal test and the vibration test all originate a certain safety risk which needs to be addressed before testing can take place. To ensure that all the possible risks which may arise from testing have been addressed, a testing and safety, procedures and controls document is created and approved by the Engineer in residence. The following table provides a breakdown of the possible hazards which may arise from the different tests and the corresponding correcting action. Moreover, the safety pre-operation validation checks are listed below which need to be satisfied prior to testing.

	Name of analysis	Movement	stored energy	sharp edges	electricity	substances	radiation	physical agents	Description	Severity	Probability	Corrective or Control Action
VAL1	Steady Force Test	**No**	No	Yes	Yes	No	No	No	Danger of flying objects	Medium	Medium	Proper protective equipment worn during test. Fire extinguisher is nearby.
VAL2	Impact Test	**No**	No	Yes	Yes	No	No	No	Danger of flying objects	Medium	Medium	Proper protective equipment worn during test. Fire extinguisher is nearby.
VAL3	Drop Test	No	No	Yes	Yes	No	No	No	Danger of flying objects	Medium	High	Proper protective equipment worn during test. Fire extinguisher is nearby.
VAL4	Thermal Test	No	No	No	Yes	No	No	No	Danger of overheating and causing a fire	Medium	Low	Proper protective equipment worn during test. Fire extinguisher is nearby.
VAL5	Vibration Test	No	No	No	Yes	No	No	No	Danger of flying objects	Medium	Medium	Proper protective equipment worn during test. Fire extinguisher is nearby.

Table 5: Severity and Probability of Various Hazards for the Different Tests

PREOPERATION CHECKS FOR VAL 1, VAL 2 and VAL 3		
SAFETY		
	Name of Task	**Description**
SFT1	Test Brief	Inform everyone of the test taking place (As per standard IEC60950)
SFT2	Test Procedure	Ensure testers have reviewed standard IEC60950.
SFT3	Personal Protective Equipment	Ensure all test personnel are wearing the appropriate protective equipment (Safety Glasses)
SFT4	Projectile	Ensure a barrier is placed to limit the movement of projectiles
DEVICE INTEGRITY		
DEV1	Structural	Ensure that the AR headset is free from structural damage
DEV2	Assembly - BOM	Assembly is complete - no missing components.
INSPECTION		
INS1	Device Inspection	Engineer or Staff signature :

Table 6: Pre-operation Validation Checks for Impact, Drop and Steady Force Test

PREOPERATION CHECKS FOR VAL 4		
SAFETY		
	Name of Task	**Description**
SFT1	Test Brief	Inform everyone of the test taking place (As per standard IEC 60950)
SFT2	Test Procedure	Ensure testers have reviewed the test procedure
DEVICE INTEGRITY		
DEV1	Structural	Ensure that the AR headset is free from structural damage
DEV2	Assembly - BOM	Assembly is complete - no missing components.
DEV3	Fasteners	Ensure that the AR headset is properly fastened to the windtunnel
SYSTEM INTEGRITY		
SYS1	Temperature	Ensure thermocouples are placed inside of the AR headset
SYS2	Temperature Output Reader	Ensure that the temperature output reader is functioning properly
INSPECTION		
INS1	Device Inspection	Engineer or Staff signature :

Table 7: Pre-operation Validation Checks for the Thermal Test

PREOPERATION CHECKS FOR VAL 5		
SAFETY		
	Name of Task	**Description**
SFT1	Test Brief	Inform everyone of the test taking place
SFT2	Personal protective equipment	Ensure all test personnel are wearing the appropriate protective equipment (Safety Glasses)
DEVICE INTEGRITY		
DEV1	Structural	Ensure that the AR headset is free from structural damage
DEV2	Assembly - BOM	Assembly is complete - no missing components.
DEV3	Fasteners	Ensure that the AR headset is properly fastened to the vibration machine
SYSTEM INTEGRITY		
SYS1	Vibration	Ensure that the vibration machine is woking
SYS2	Kill Switch	Ensure that the kill switch for the vibration machine is free of obstruction and operational. TEST
INSPECTION		
INS1	Device Inspection	Engineer or Staff signature :

Table 8: Pre-operation Validation Checks for the Vibration Test

1. Steady Force Test

Objective

The objective of this experiment is to evaluate the structural and the hardware components strength of the Augmented Reality headset.

Introduction

IEC Standard 60950 is an international standard used for the safety of Information Technology Equipment [13]. Section 4.2 of this standard provides test specifications regarding Mechanical Strength for information technology equipment. Our headset meets the criteria mentioned in sections 4.2.2 and 4.2.4, and therefore, a steady force test must be performed on our headset [13].

Below the test specifications for section 4.2.2 and 4.2.4 as stated in standard IEC 60950 are found:

"4.2.2 Steady force test, 10 N

Components and parts, other than parts serving as an ENCLOSURE, are subjected to a steady force of 10 N ± 1 N [13].

4.2.4 Steady force test, 250 N

External ENCLOSURES are subjected to a steady force of 250 N ± 10 N for a period of 5 s, applied in turn to the top, bottom and sides of the ENCLOSURE fitted to the equipment, by means of a suitable test tool providing contact over a circular plane surface 30 mm in diameter. However, this test is not applied to the bottom of an ENCLOSURE of equipment having a mass of more than 18 kg [13]."

Procedures

Experiment A: Hardware Components Test

1- Remove the top cover and place the AR on the table with enclosed safety guards. Make sure to wear safety glasses.
2- Weight 1 kg of weights on the digital scale provided.
3- Power on the device and turn it off before placing the weights on the hardware.
4- Hold 5 seconds before removing the weights from the hardware.
5- Verify if the hardware components are still functioning.

Experiment B: Structural Components Test

1- Place the AR headset on the table with enclosed safety guard and wear safety glasses. Make sure the device is properly assembled.
2- Weight 25.5 kg of weights on the digital scale.
3- Put the weights on the headset and wait 5 seconds before removing them.
4- Note for any structural damages and repeat steps 1-5 for the remaining revisions.

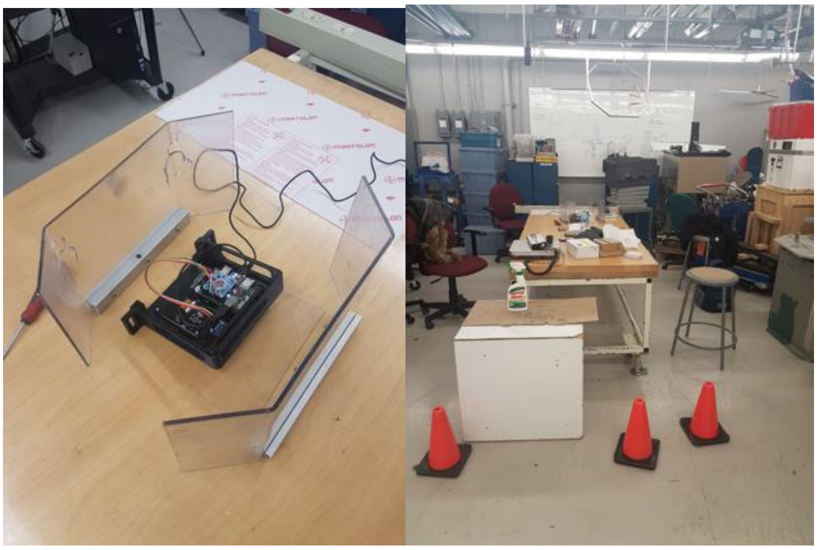

Figure 12: The Set-up

Results

Figure 13: Hardware and Outer Casing Testing Weights

Figure 14: Damaged Revision 1 Casing with load of 25.5 Kg

Revision	Weight (kg)	Force (N)	HW working/not working
4	1	9.81	Working
5			Working

Table 9: Steady Force Test on Hardware Components

Revision	Area (m^2)	Weight (kg)	Force (N)	Pressure (Pa)	Structural Damage Yes/No
1	0.0212	25.5	250.15	11799.5	Yes
2	0.0370			6760.8	No
4	0.0284			8808.1	No
5	0.0266			9404.1	No

Table 10: Steady Force Test on AR's Casing for all Printed Revisions

Discussion

After performing this experiment, we observed that the hardware components of the headset carried 1kg of weight and still functioned properly. Putting weight on the Odroid-XU4 did not affect its functionality so therefore experiment A was carried out successfully. Moving on to the second experiment, the first revision did not carry a load of 250.15 N. Cracking noises were heard when the weights were added on the headset casing. Figure 14 shows the structural damages from this experiment. The edges of the top cover suffered mostly from this experiment because of their low thickness. However, the three other revisions carried successfully the load without any damages. In addition, since revision 1 was smaller in dimension it affected the outcome of this experiment. The outer casing suffered a higher pressure of 11799.5 Pa for revision 1 because the contact area between the force applied and the outer case is smaller for as compared to the other prototypes. Hence, the outcome of this experiment is that the structural components of revision 1 failed to carry a specific steady force standardized in the industry. This experiment also demonstrated that the AR headset's dimension must be in consideration to prevent any rupture of the outer casing. Videos and additional pictures associated with this experiment can be found on the USB stick supplied with this report.

2. Impact test

Objective

The objective of the second experiment is to evaluate the toughness of PLA used for casing the AR headset and to determine the load at which failure occur.

Introduction

IEC Standard 60950 is an international standard used for the safety of Information Technology Equipment. Section 4.2 of this standard provides test specifications regarding Mechanical Strength for information technology equipment. Our headset meets the criteria mentioned in sections 4.2.5, and therefore, an impact test must be performed on our headset. Below you will find the test specification for section 4.2.5 as stated in standard IEC 60950 [13].

"4.2.5 Impact test

Except for equipment identified in 4.2.6, external surfaces of ENCLOSURES, the failure of which would give access to hazardous parts, are tested as follows [13]. A sample consisting of the complete ENCLOSURE or a portion thereof representing the largest unreinforced area, is supported in its normal position. A solid smooth steel ball, approximately 50 mm in diameter and with a mass of 500 g ± 25 g, is permitted to fall freely from rest through a vertical distance (H) of 1,3 m (see Figure 4A) onto the sample. (Vertical surfaces are exempt from this test.)

The test is not applied to the following:

- a flat panel display;
- the face of a cathode ray tube (see 4.2.8);
- the platen glass of equipment (for example, on a copying machine);

- the surface of the ENCLOSURE of STATIONARY EQUIPMENT, including EQUIPMENT FOR BUILDING IN, which is inaccessible and protected after installation”

Impact testing is performed on any prototype to determine the energy required for fracture and the energy absorbed. This test will have a great value to us because the outcome of this lab will confirm the use of PLA for the AR casing. Impact test will in all validate designs choices.

$$\frac{1}{2}mv_A^2 + mgh_A + \frac{1}{2}ks_A^2 = \frac{1}{2}mv_B^2 + mgh_B + \frac{1}{2}ks_B^2$$

Where:

- $\frac{1}{2}mv^2 = Kinetic\ Energy$
- $mgh = Potential\ Energy$
- $\frac{1}{2}ms^2 = Spring\ Energy$
- $v = velocity\ m/s$
- $m = mass\ kg$
- $h = height\ (meter)$
- $s = spring\ deflection\ (meter)$

For the impact test, the weights used start at potential energy, transforms into kinetic energy and impacts the headset with that kinetic energy. In either case there is no spring energy involved.

Procedures

1- Place the headset on the floor with enclosed safety guards. Make sure to wear safety glasses.

2- Weight 500 grams of weights on the digital scale.

3- Drop the weight on the headset top cover from 1.30 meters of height.

4- Take a picture of the headset and note down for any structural damage after the impact.

5- Repeat steps 1-4 for all the revisions. Note if 500 grams is too heavy, then drop weights incrementally to obtain failure load.

Figure 15: The Set-up

Results

Figure 16: Revision 1 after dropping 500g from a height of 1.3 meter

Figure 17: Revision 2 after dropping 500g from a height of 1.3m

Figure 18: Revision 4 after dropping incremental weights from a height of 1.3m

Revision	Weight (g)	Height (m)	Potential Energy (J)	Structural damage to headset Yes/No
1	500	1.3	6.377	Yes
2	500		6.377	Yes
4	100		1.275	No
	200		2.551	No
	300		3.826	No
	400		5.101	No
	500		6.377	No
	600		7.652	No
	700		8.927	No
	800		10.202	No
	900		11.478	No
	1000		12.753	No

Table 11: Impact Test on AR Headset Results

Discussion

An impact test was performed to test the structural integrity of the headset if weights were dropped on it. As it can be seen from the results, the top cover of the headset was the part that failed immediately with the headset base sustaining no damage. Revisions 1 and 2 of the headset failed by sustaining major damages on the headset when a 500g weight was dropped on it. Analyzing the failure point of revision 2 further, the top cover splitted on a specific section of the print instead of a piece breaking of as it did in revision 1. This may either be due to the weight hitting the top cover on its pointed end rather than on its flat base or due to an error in the print which caused that section to have a weaker area than the rest of the top cover. For revision 4, it was decided to do an incremental weight drop on the headset from 100g to 1000g to determine specifically when the headset would fail. However, after reaching 1000g, the headset remained intact with minor indentations on the top cover. The difference between revisions 1 and 2 compared to revision 4 was the thickness of the top cover and its overall flatter design. With an increase in thickness and in infill percentage of the 3D print, it made the internal composition of revision 4 much more solid compared to the previous revisions. Moreover, revision 4 can absorb 12.753 Joules of energy without any structural damage. Videos and additional pictures associated with this experiment can be found on the USB stick supplied with this report.

3. Screen Angle Test

Objective

The objective of this experiment is to determine the angle between the HUD and the screen to get the best image projected on the HUD with respect to the outside environment.

Introduction

The objective of the HUD is to display the best quality image without changing user's field of vision. Hence, the HUD must be properly mounted on the AR device. This experiment is of great importance because the outcome will show exactly where to place the HUD and at which angle with respect to the screen.

Procedures

1- Screw the transparent HUD at 10.5 cm from the forehead edge of the headset and turn on the device.

2- Run the rotating 3D cube.

3- Move the HUD at different angles (75, 65, 55, and 45 degrees) with respect to the screen.

4- Note down the clarity of the cube projected on a scale of 1 to 5, 5 being the best quality image. Consider the outside environment as well.

5- Repeat steps above for distance 14cm and different lighting (Low, Bright, Dark)

6- Change the HUD material to opaque and repeat the experiment.

Results

HUD Material	Angle (Degree)	Distance (cm)	Lighting	Image Quality
Transparent	75	10.5	Low	1
	65	10.5	Low	1
	55	10.5	Low	4
	45	10.5	Low	4
Transparent	75	10.5	Dark	1
	65	10.5	Dark	3
	55	10.5	Dark	4
	45	10.5	Dark	5
Transparent	75	10.5	Bright	1
	65	10.5	Bright	2
	55	10.5	Bright	3

	45	10.5	Bright	4
Transparent	75	14.0	Low	1
	65	14.0	Low	1
	55	14.0	Low	2
	45	14.0	Low	2
Transparent	75	14.0	Dark	2
	65	14.0	Dark	4
	55	14.0	Dark	3
	45	14.0	Dark	3
Transparent	75	14.0	Bright	1
	65	14.0	Bright	1
	55	14.0	Bright	2
	45	14.0	Bright	1

Table 12: Image Quality when using Transparent HUD

HUD Material	Angle (Degree)	Distance (m)	Lighting	Image Quality
Opaque	75	10.5	Low	2
	65	10.5	Low	2

	55	10.5	Low	3
	45	10.5	Low	3
Opaque	75	10.5	Dark	1
	65	10.5	Dark	2
	55	10.5	Dark	1
	45	10.5	Dark	1
Opaque	75	10.5	Bright	1
	65	10.5	Bright	2
	55	10.5	Bright	3
	45	10.5	Bright	3
Opaque	75	14.0	Low	1
	65	14.0	Low	3
	55	14.0	Low	3
	45	14.0	Low	2
Opaque	75	14.0	Dark	2
	65	14.0	Dark	2
	55	14.0	Dark	2

	45	14.0	Dark	2
Opaque	75	14.0	Bright	1
	65	14.0	Bright	1
	55	14.0	Bright	2
	45	14.0	Bright	2

Table 13: Image Quality when using Opaque HUD

Discussion

After performing the experiment, the best quality image was not found to be constant because there are many factors that influence the projected image. When increasing the distance from 10.5 to 14 cm, the rotating 3D cube did not appear completely on the HUD. Therefore, decreasing the distance is far better option for having at least the entire image displayed. In addition, the image quality and the outside environment are much better seen simultaneously through the transparent HUD material than through the opaque HUD material. In general, lower angles show better outcomes than higher angles and this is independent of the lighting. From tables 12 and 13, one can also see that there is a corresponding angle for every lighting. The angle for best image displayed in the dark is different than in bright and in low lighting. Finally, this experiment was successful and very helpful because it shows the correct angle of the HUD for having the best quality image at different lighting. For our purpose, we will use the transparent material and place it 10.5 cm from the forehead edge of the headset. The angle will vary from 45 to 55 degrees depending on the lighting.

4. Thermal Test

Objective

The objective of this experiment is to determine the temperature at which the Odroid-XU4 fan turns on and the temperature of the Odroid-XU4 after extended use.

Introduction

Thermal test is useful for us because the results will clearly show the range of temperature obtained while running the device at proper rate. One method of testing the hardware heat release will be by pointing a thermal gun on the Odroid-XU4. The second method of getting temperatures data will be internally using a simple code of line. Comparing these two data we would get a proper set of temperatures.

Procedures

1- Turn on the device and display the rotating cube on the screen.

2- Point the thermal gun to the Odroid-XU4 and note down the temperature.

3- Get the maximum CPU temperature from the terminal by following the proper code.

4- Note down the temperatures for 1 hours in interval of 10 minutes.

Results

Time (minutes)	Internal Temperature (degree Celsius)	Thermal Gun Temperature (degree Celsius)
0	55	40
10	77	44
20	78	41.3
30	77	41.9

40	78	42.0
50	78	42.2
60	79	41.8

Table 14: Internal vs. Thermal Gun Temperature

Discussion

The experiment results show significant difference between the internal temperatures and the thermal gun temperatures. This difference is reasonable because the airflow reduces the temperature released from the hardware when pointing the thermal gun to collect data. Airflow at room temperature, which is between 22-24 degrees Celsius, mixes with the hot air coming out from the hardware and hence the decrease of temperature. Internal temperatures are much more accurate because they are measured directly through the central processing unit (CPU). In addition, we observed that the Odroid-XU4 fan starts to operate after 10 minutes of use. Hence why all temperatures following the 10 minutes interval are all constant. The fan makes sure that the heat release is practical and prevents hardware overheating. Finally, this experiment shows the temperature and time at which the Odroid-XU4 fan turns on. From this experiment, we also confirmed that the augmented reality headset could be use for 1 hour without overheating. We could also see that the CPU does not throttle performance while using the depth sensor and motion sensor for up to an hour of use.

5. Vibration Test

Objective

The objective of this experiment is to evaluate the integrity of the electronics assembly of the headset using vibration shaker.

Introduction

Vibration testing introduces a force with the help of a shaker to qualify product design. In our case, the AR headset includes an electronic assembly and this experiment's outcome will demonstrate if the assembly is properly mounted or needs modifications.

Procedures

1- Set-up the shaker machine referring to lab 1 of vibration lab manual (mech 375)

2- Properly assemble the device on the shaker. Make sure to tighten the screw to prevent the device from expelling during the experiment.

3- Input 5Hz on the machine and videotape the experiment. Note down any observation after the experiment.

4- Repeat the last step for different frequencies and do the same test on revision 5.

Figure 19: Vibration Shaker used to Evaluate Electronic Assembly

Results

Frequency (Hz)	Wires	Fasteners	Top Cover
5	No	No	no
10	Odroid-BNO loose	No	no
12	Loose	No	no
13.5	Loose	BNO fasteners	no
15	Loose	BNO fasteners	yes

Figure 20: Vibration Test Impact on Revision 4

Frequency (Hz)	Wires	Fasteners	Top Cover
5	No	No	No
10	No	No	No
12	No	No	No
13.5	No	No	No
15	No	No	No

Figure 21: Vibration Test Impact on Revision 5

Discussion

After performing the vibration test, we can confirm that the electronic assembly is somewhat reasonable for normal application use. The headset's hardware components of revision 4 do not come loose at low frequency of 5Hz, but they do at high frequency. However, since the device will most probably not be used in high frequency where the user would shake his head constantly, this electronic assembly is acceptable. By simple observation after each frequency test on revision 4, we notice the cables connecting the BNO to the Odroid-XU4 do come loose after 10Hz and the fasteners holding the BNO to the headset loose from 13.5z . During the experiment, we also discovered that the top cover of the headset removes completely from the revision 4 headset at a frequency of 15Hz. To fix this issue, we decided to print another revision (5) and from experimental observation we see that revision 5 resisted vibrations far better than the previous version. Videos and additional pictures associated with this experiment can be found on the USB stick supplied with this report.

6. Drop Test

Objective

The objective of the drop test is to observe what occurs to the headset after being dropped from a certain height.

Introduction

Performing a drop test on the headset provides feedback regarding the robustness of the design. Moreover, this allows the design team to observe the effects of dropping the headset on the floor, a scenario which will potentially occur during the lifetime of the headset.

IEC Standard 60950 is an international standard used for the safety of Information Technology Equipment [13]. Section 4.2 of this standard provides test specifications regarding Mechanical Strength for information technology equipment. Our headset meets the criteria mentioned in sections 4.2.6, and therefore, a Drop test must be performed on our headset [13].

"**4.2.6 Drop test**

The following equipment is subjected to a drop test:

- HAND-HELD EQUIPMENT;
- DIRECT PLUG-IN EQUIPMENT;
- TRANSPORTABLE EQUIPMENT;

Desk-top equipment having a mass of 5 kg or less that is intended for use with any one of the following:

- a cord-connected telephone handset, or
- another cord-connected hand-held accessory with an acoustic function, or
- a headset;

MOVABLE EQUIPMENT requiring lifting or handling by the USER as part of its intended use.

The height of the drop shall be:

- 750 mm ± 10 mm for desk-top equipment as described above;
- 750 mm ± 10 mm for MOVABLE EQUIPMENT as described above;
- 1 000 mm ± 10 mm for HAND -HELD EQUIPMENT , DIRECT PLUG -IN EQUIPMENT and TRANSPORTABLE EQUIPMENT."

As mentioned earlier, from basic physics we know that the conservation of energy is as follows:

$$\frac{1}{2}mv_A^2 + mgh_A + \frac{1}{2}ks_A^2 = \frac{1}{2}mv_B^2 + mgh_B + \frac{1}{2}ks_B^2$$

Where:

- $1/2mv^2 = Kinetic\ Energy$
- $mgh = Potential\ Energy$
- $1/2ms^2 = Spring\ Energy$
- $v = velocity\ m/s$
- $m = mass\ kg$
- $h = height\ (meter)$
- $s = spring\ deflection\ (meter)$

For the drop test, the headset starts off with potential energy and transforms into kinetic energy. When the headset strikes the ground, it is being hit with the stored kinetic energy.

Procedure

1. Follow the steps mentioned in the TSPCD for setup and safety.
2. Ensure there is a barrier to contain the projectiles.
3. From a height of one meter, drop the headset with all components.
4. Repeat the steps 3, two more times.
5. Record findings (Take Pictures)

Result

Figure 22: Drop Test Results

Discussion

From the above figure we observe that after dropping the headset, failures occurred on the headset. The snap fit mounts on the headset did not remain intact after it struck the ground causing the removal of the top cover from the headset. Moreover, the fastened internal components also became undone and were free floating after the headset took three impacts. Lastly, as observed in the above figure, the screen sustained some damage, but was still functional after being dropped three times.

After performing the drop tests, there are several lessons learnt. If we were to have more time during the project, we would try and find a 3D printing material that is more shock absorbent and less brittle. Furthermore, the type of fasteners used would be changed for fasteners with washers and ones that can absorb shock. Instead of using a snap fit for the top cover, a more permanent type of mount would be used. Lastly, additional padding would be added to the headset to ensure that no internal components come loose when being dropped. This test provided us with lessons learnt such as changing the 3D printed material, changing the fasteners and adding additional padding. Videos and additional pictures associated with this experiment can be found on the USB stick supplied with this report.

7. Ergonomics Test

Objective

The objective of the ergonomics test is to get the individuals input on the overall feeling of our Augmented Reality Headset.

Introduction

The overall feeling of any wearable technology varies from user to user and to get the public's perception on our headset in terms of ergonomics a survey is conducted. The survey allows the design team to get some customer feedback on the different aspects of comfortness and create design changes accordingly. The two main aspects this ergonomics test will focus on are:

1. Visibility through the heads-up display at a range of angles (from Screen Angle Test)
2. Overall comfortness when wearing the Augmented Reality Headset

<u>Procedure</u>

1. Select a fix group of users to test out the headset
2. Provide test users with the survey form
3. Help test users wear the augmented reality headset and record comments (other than the ones from survey) made from the test user

<u>Augmented Reality Headset Survey</u>

Please circle your responses.

1. How clear (quality of reflection) is the heads up display?

   1 (can't see anything)   2   3   4   5 (really clear)

2. How comfortable are the straps?

   1(not comfortable)   2   3   4   5 (very comfortable)

3. How comfortable is the augmented reality headset on your head?

   1(not comfortable)   2   3   4   5 (very comfortable)

4. How is the overall weight of the augmented reality headset?

   1(too much weight)   2   3   4   5 (perfect weight distribution)

5. How is the overall size of the augmented reality headset?

   1(too big)   2   3   4   5 (perfect size)

Results

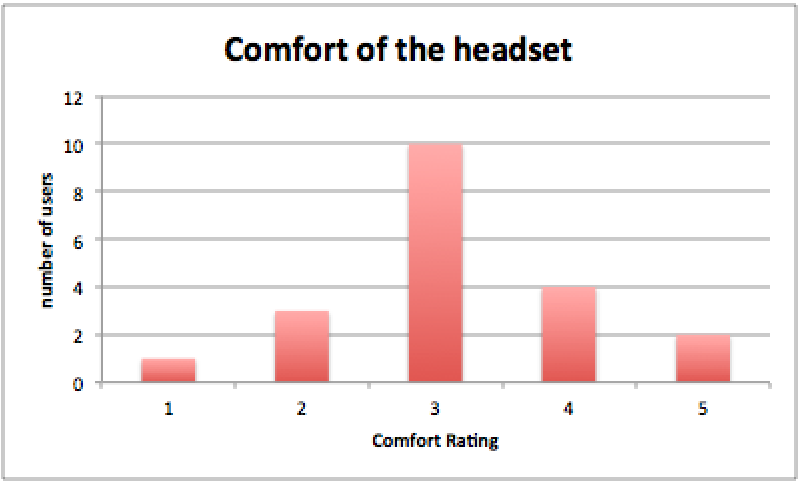

Figure 23: Comfort of the Headset by User Count

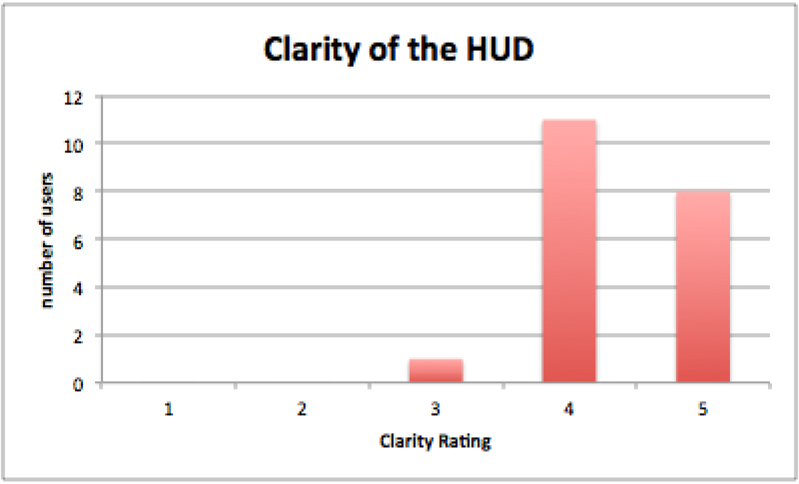

Figure 24: Clarity of the HUD by User Count

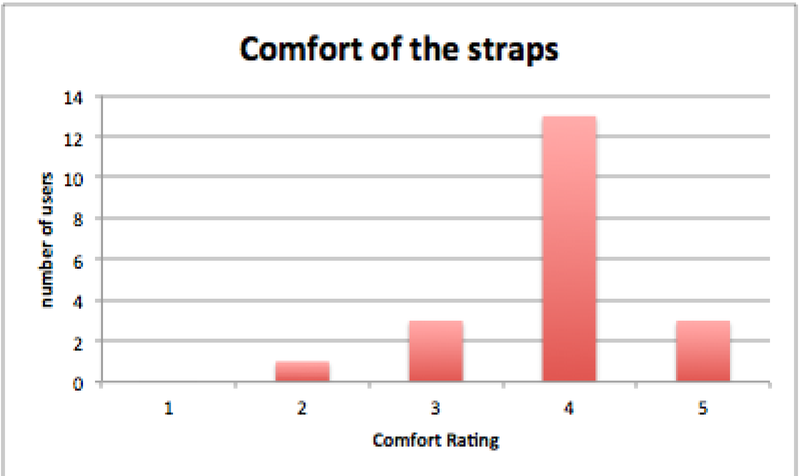

Figure 25: Comfort of the Straps by User Count

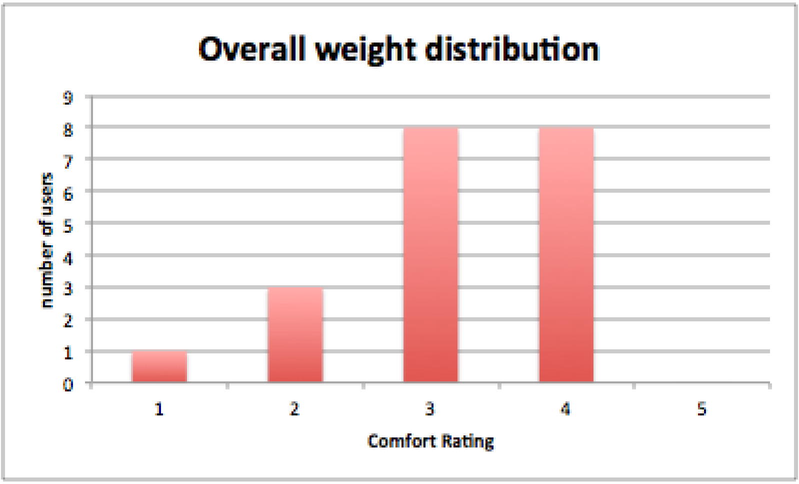

Figure 26: Overall Weight Distribution by User Count

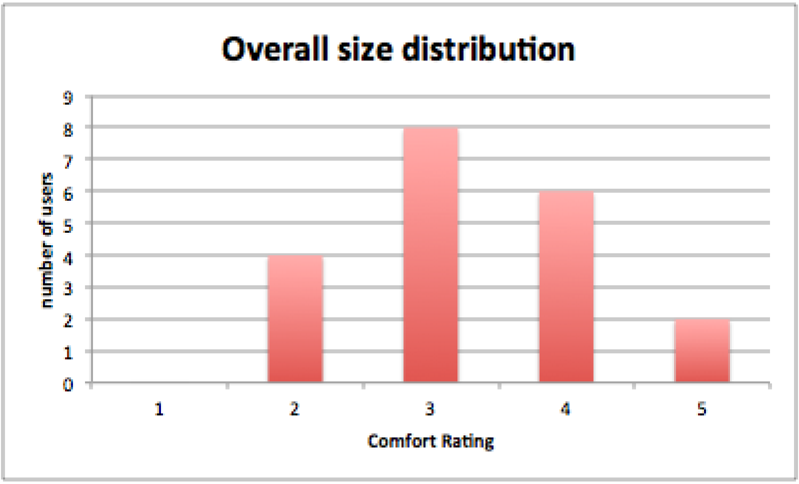

Figure 27: Overall Size Distribution by User Count

Discussion

The functionality of the headset is important but the critical aspect of it is the user experience. The overall feedback received on the image clarity of the HUD was positive. Only one user rated it a three and the rest rated it a four or five. The straps were also rated extremely high with over 70% of the users rating it a four or five. When evaluating the feedback on the comfort levels, size and weight distributions, there is a lot of room for improvement. Most of the users that tested the headset rated it a three which means they are basically on the fence. 20% of the users found that the overall weight distribution and comfort were subpar. This is something that will need to be addressed by moving around the components and adding more cushion. This feedback given from the 20-person sample size is great to help improve the headset in the area that is most important, the user experience. The focus of improving the headset will be on making it comfortable and eliminating the bad user feedback eventually. No matter how good the product is, if the experience is not user friendly, it will not be successful.

Validation of Engineering Analysis

Steady Force Test

If we analyze table 2 provided for the steady force test in the Engineering Analysis section of this report, we observe that all the different iterations sufficiently withstood the 250N applied load. While this steady force test shows that no failure occurred in a numerical simulation environment (Finite Element Analysis), it may not be the case when the actual test is performed. From the physical test, we observe that all the iterations withstood the 250N except the first iteration. The reason why failure could have occurred during testing was since the top cover was only partially printed. Additionally, some scratches were found on all iterations when the 250N load was removed from the headset. The reason why this may have occurred was because of the type of weights used. The weights used consisted of steel which easily scratches the PLA plastic material. While scratches did occur on the surface of the headset, the structural integrity was intact and therefore the finite element analysis sufficiently depicted what would occur during the steady force test.

If we analyze table 3 provided for the steady force test in the engineering analysis section of this report, we observe that the Odroid-XU4 sufficiently withstood the 10N load. In the engineering analysis the assumption was made that the Odroid-XU4 consisted of a silicone material. When the steady force test was performed on the internal components it was found that the whole headset was still working. This was validated by first making sure the headset functioned before applying the load and observing if the headset functioned after the load was applied. The headset working after the internal components were subjected to 10N validates the results obtained from finite element analysis. Ultimately, we found that the steady force analysis from FEA yielded relatively accurate results which then were validated by performing actual tests on all our revisions of the headset.

Drop Test

Examining the drop test mentioned in the engineering analysis we observe that no failures occurred in the finite element analysis. While this finite element analysis contradicts the actual drop test, there is still some important information which can be drawn out of the FEA analysis. Firstly, if we look at figure 7, we notice that the Von Mises stresses are concentrated where the screens fasteners are located. This indicates that failure would be imminent at these locations. While failure did not occur in the analysis, this was proven when the actual test took place. Moreover, examining figure 8 we note that there is a large amount of stress located at the top of the headset. This stress was displayed in the drop test as the top cover being popped out when impact took place. The reason as to why the top cover being removed was not shown in the FEA analysis was since the FEA software was not capable of producing that type of simulation. Another reason why the simulation differs from the actual drop test is due to the manufactured material being used. In simulation, we are assuming that there are no flaws (cracks) during the making of the headset. While, a 3D printed headset contains many small flaws which can easily propagate if subjected to impacts.

Thermal Test

Examining the results obtained in the thermal analysis, we notice that the operating temperatures were chosen to be 50 degrees Celsius and 35 degrees Celsius for Odroid-XU4 chip and the screen respectively. These temperatures were chosen as they are the average operating temperatures provided by the manufacturer. Using these temperatures as inputs, we could create temperature distribution images for analysis. From these images, we observe that the case itself is at 25 degrees Celsius and the inside of the headset varies from 35 degrees Celsius to 42 degrees Celsius. The results obtained from the thermal test show that the peak temperature found from the thermal gun was 44 degrees Celsius when pointed at the Odroid-XU4 and internal components. It should also be noted that the headset case remained at room temperature when the thermal test took place. The reason why some discrepancies may arise is since there are some errors when using the thermal gun (not that accurate). Moreover, some assumptions were made in the thermal analysis such as the thermal conductivity, the convection coefficient and the emissivity. Therefore, the results obtained from the thermal tests validate the results attained thermal analysis.

Hardware and Software Integration

Although our primary focus during this capstone project was to design, manufacture, test and validate an Augmented Reality headset from a Mechanical Engineering point of view, developing the software needed to simulate AR and integrating that with the hardware was still crucial and a big part of the work we did throughout the project. This section of the report briefly covers what the software does, how each part of it interacts and how it interfaces with the hardware. Minor dependencies will not be covered here.

First, Pygame is simply a toolbox of Python modules which is usually used for designing basic video games. It is free and open sourced, and we require some libraries from here to allow us to run the static rotating cube example. Next, python-smbus (system management bus) is needed as it is a subset of the I2C protocol, which we will be using to establish a connection between the Odroid- XU4 (CPU) and the BNO055 (motion sensor). To do this, we used a python port of the Adafruit BNO055 library, made specifically for that accelerometer. This Python library was created by user Ghirlekar on Github for use with a Raspberry Pi, and is named bno055-python-i2c. With a very minor tweak, depending on which bus the accelerometer is found on, this library can provide us with orientation (X-Y-Z) vectors and acceleration directly from our accelerometer. Finally, we need to access the Intel Realsense R200 (depth sensing camera) to be able to access the camera, the infra-red view and the depth view. Luckily, there is already a library made by Intel for this very purpose. Once again, it can be found on Github and is called LibRealsense, but is written entirely in C++. This is not good for our project since it is in Python. We need a wrapper for all the C++ classes and functions in LibRealsense to make them available to us in Python code. User Toinsson on Github provides us with the wrapper we need to access all the required code from the Intel library and is called PyRealsense. With LibRealSense & PyRealsense together, we can directly access a very large portion of the R200`s functionalities, the most important of which is probably the depth view. It allows us to gather data on the depth of whatever the camera is viewing as long the object is in the camera's working range. Furthermore, with the orientation of the camera/headset being detected by the BNO055, it is now possible to determine one's position with respect to objects in their surroundings, and most importantly to calculate the delta when the user moves. Greater detail on dependencies and setup/installation can be found in the Software Installation Guide below.

Software Installation Guide

Many steps must be taken to get the headset functional with respect to the software and resources which we will need. These steps will be discussed along with any problems that were encountered during the process. All necessary links and information will be included. These steps are divided into logical sections.

1. OS Ubuntu 16.04.3

The first step is to flash the appropriate operating system (OS) to the micro SD card. Ideally, the card should be of the highest speed rating possible. In our case, a class 10 micro SD card was used. The OS image can be found here:

https://wiki.odroid.com/odroid-xu4/os_images/linux/ubuntu_4.14/20171212

Once you insert the micro SD card into the Odroid-XU4 (assuming you have also connected to an HDMI display) and powered up the device, you should be greeted with the Ubuntu login page after a few seconds. The default user is “odroid” with password: odroid This should give you access to the home screen. However, an issue did occur when first trying to access the device through the odroid user.

PROBLEM:

The first few times logging in using the odroid user, the screen would go completely black after entering the password. From here, you could only remove the power cable to shut off the device and try again.

SOLUTION:

This issue was resolved by logging into the Odroid device as a guest, where you could access the desktop without an issue. Afterwards, the device was rebooted. On login, this time using the default odroid user and password, the desktop loaded without an issue.

2. Github

We will need Git to be able to download all the necessary files to get the headset operational. This includes items for the BNO055, IntelRealSense, Pyrealsense, etc. To install Git, enter the following command lines into the terminal, which can be accessed by right clicking on the home screen and selecting “Open Command Terminal”:

sudo apt-get update

That command line updates the list of applications/packages. Now enter:

sudo apt-get install git

You should now have Git on your device! Git is a software development tool used for versioning control which allows you to work cooperatively with others. To clone any given Github repository (where people commit their work), simply enter “git clone” followed by the URL of the repository you want to download. The first repo we will clone is the following:

git clone https://github.com/cbkiyanda/AR

This is the working repository for our project, which contains many examples and the working demo.

3. Running the rotating_cube.py example

The first thing we will attempt to do is run the most basic example, which simply displays a rotating cube on the screen. The example file can be found in the AR repository we previously cloned. However, we will need to install Pygame beforehand. Enter the following command line in the terminal:

sudo apt-get install python-pygame

Afterwards, we should be ready to run the example. Open a command terminal in the AR folder you previously cloned, and enter the following command:

sudo python rotating_cube.py

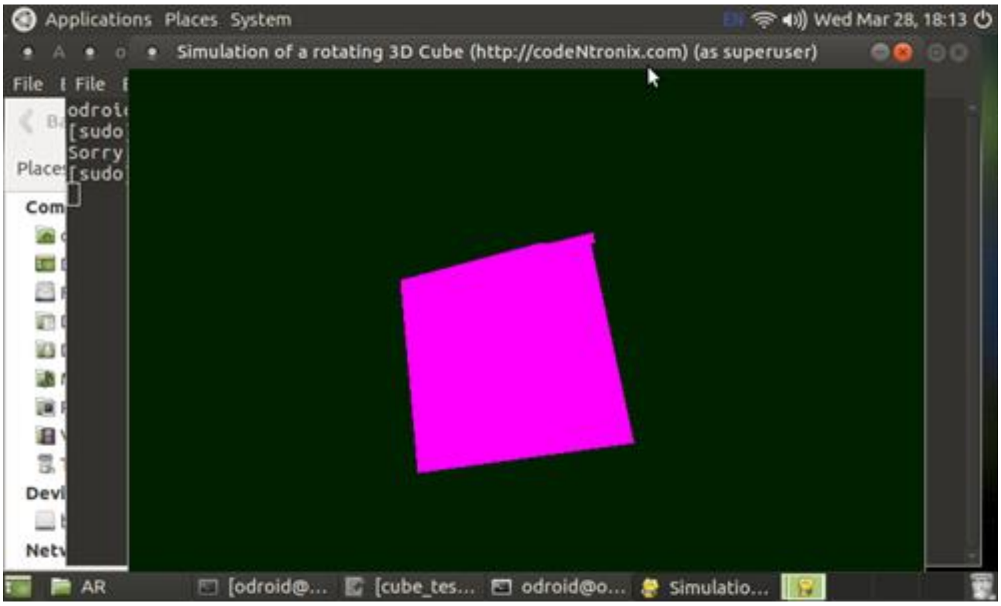

Figure 28: Simple Rotating Cube Interface

4. Adafruit BNO055 Accelerometer

First, we will need to connect the BNO055 to the Odroid-XU4. Visit the following link to view the pinouts of the BNO055:

https://learn.adafruit.com/adafruit-bno055-absolute-orientation-sensor/pinouts

We will be using the Vin, GND, SDA & SCL pins. The BNO055 requires a Vin of 3.3-5V. Visit the following link to view the pinouts for the Odroid-XU4`s 30-pin header CON10: https://wiki.odroid.com/odroid-xu4/hardware/expansion_connectors

We will be using the 5V Power, I2C_1.SDA, I2C_1.SCL & Ground pins. To make things easier, we will identify these 4 pins with their respective ordered pin numbers (Not their WiringPi GPIO number).

5V Power = 1;

I2C_1.SDA = 16;

I2C_1.SCL = 14;

Ground = 30; (we could also use pins 28 or 2)

Now, we will connect the BNO055 pins to the Odroid-XU4 in the following manner:

SCL = 14;

SDA = 16;

GND = 30;

Vin = 1;

Once we have connected both devices, we need to check that they detect each other. We will be using i2c-tools for this. We will also need python-smbus as a dependency to run the example code. Enter the following command lines in the terminal to install i2c-tools & python-smbus:

sudo apt-get install i2c-tools

sudo apt-get install python-smbus

Some information about I2C can be found here:

http://odroid.com/dokuwiki/doku.php?id=en:xu3_hardware_i2c

Now we will clone the necessary Git repo for the BNO055:

git clone https://github.com/ghirlekar/bno055-python-i2c

To see if the connection between the devices is established, enter the following command line:

sudo python i2cdetect -y 4

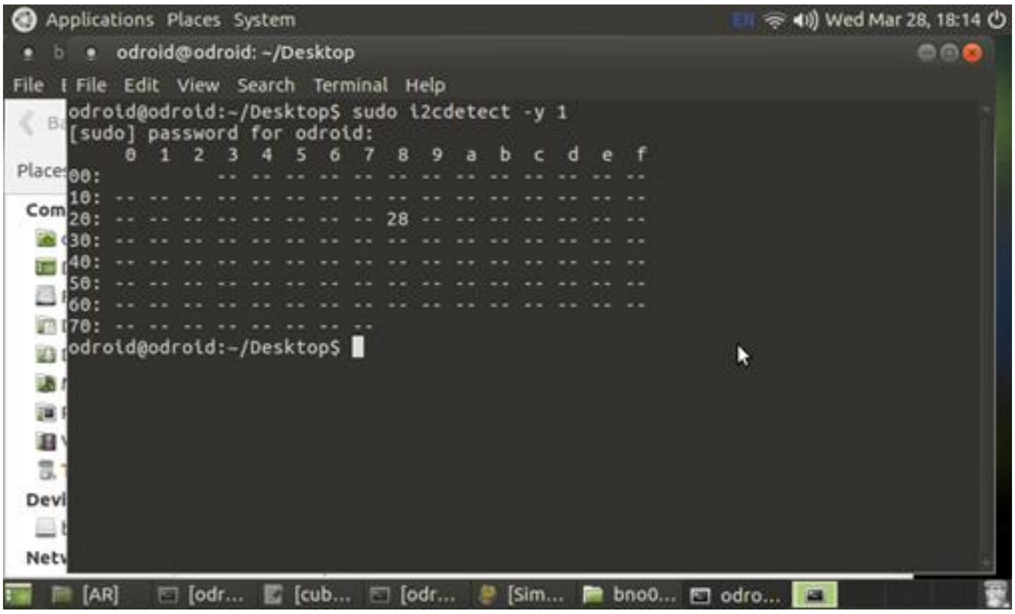

Figure 29: Detecting the BNO 055 Motion Sensor

You should see the BH1780 slave address 0x28. Now we can run the example from the repo we cloned. If everything is working properly, it should be printing out the X-Y-Z orientation vector to the screen. Go into the bno055-python-i2c folder, open a command terminal and enter:

sudo python BNO055.py

It should look something like this:

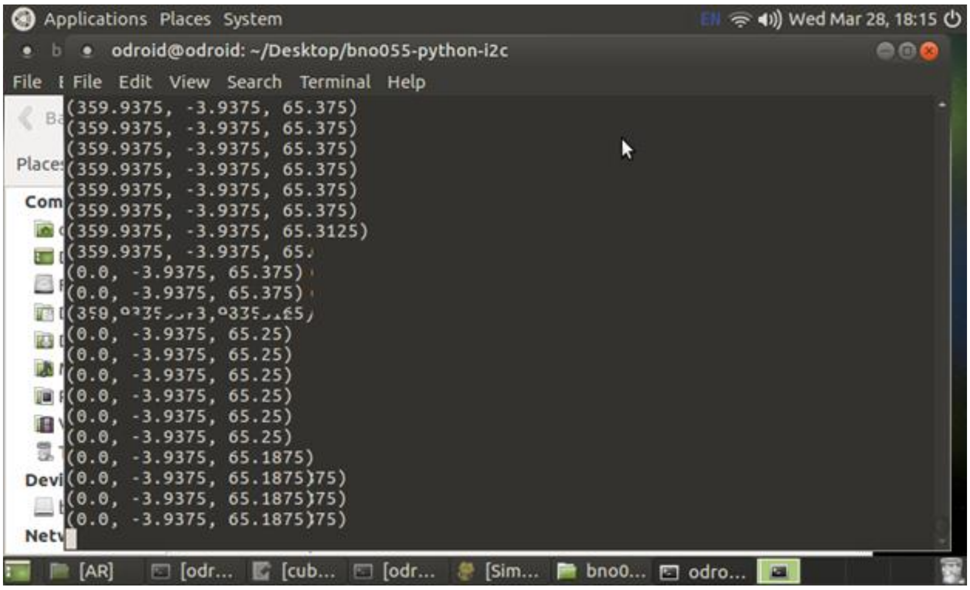

Figure 30: X-Y-Z Vector Orientation of the Headset in Real Time

5. LibRealsense

PyRealsense, which we will be using for the Intel depth sensor, requires a specific version of LibRealsense. We will need to clone that specific version, as the python wrapper has only been tested and verified with this specific version as of now. Start by cloning the entire repository, then checkout the specific tag:

git clone https://github.com/IntelRealSense/librealsense

Open a new command terminal in the librealsense folder and enter:

git checkout tags/v1.12.1

We now need to follow the installation process included in librealsense. Navigate to /doc/installation.md. This is the proper guide for linux. Alternatively, it can also be found here: https://github.com/IntelRealSense/librealsense/blob/v1.12.1/doc/installation.md

An important thing to note is that we did not perform the "sudo apt-get upgrade" command in step 1 of the guide. We also need to install cmake as we have not done that yet. Here is an even shorter summary of the steps:

sudo apt-get install libusb-1.0-0-dev pkg-config

sudo apt-get install libglfw3-dev

sudo apt-get install qtcreator

sudo apt-get install cmake

Now open a command terminal from the librealsense folder and do the following:

mkdir build

cd build

cmake .. -DBUILD_EXAMPLES:BOOL=true

make && sudo make install

Afterwards, navigate to librealsense/build/examples and double-click on cpp-capture. You should now see a normal view, a depth view, and 2 infrared views all coming from the intel camera.

6. PyRealsense

As usual, start by cloning the necessary repositories. PyRealsense has many dependencies, and we can get one of them through git. Afterwards, install the dependencies: pyrealsense uses pycparser for extracting necessary enums and structures definitions from the librealsense API, Cython for wrapping the inlined functions in the librealsense API, and Numpy for generic data shuffling. These steps will be listed below.

git clone https://github.com/toinsson/pyrealsense

git clone https://github.com/eliben/pycparser

We now need to follow the installation process included in pyrealsense. Navigate to /docs/readme.rst. Alternatively, it can also be found here:

https://github.com/toinsson/pyrealsense/blob/master/docs/readme.rst

The guide first states many prerequisites needed for PyRealsense.

6.1 Pycparser

https://github.com/eliben/pycparser/blob/master/README.rst

Go into the pycparser folder, open a command terminal and enter:

sudo python setup.py install

Afterwards, test that the installation went correctly:

sudo python tests/all_tests.py

6. 2 Cython

http://cython.org/

Currently Cython is only available through PyPi, so we will need to install it first:

sudo apt-get install python-pip

sudo -H pip install Cyton

Installing Cython takes a while, so be patient. The message "Building wheels for collected data packages: Cython" will be displayed for a long time. This is normal.

6. 3 NumPy

Since we already have pip, it is as simple as:

pip install NumPy

6.4 Back to PyRealsense

https://github.com/toinsson/pyrealsense/blob/master/docs/readme.rst

Navigate to pyrealsense and open a command terminal. Enter:

sudo python setup.py install

Now we need to run the examples to see if we installed PyRealsense correctly. However, the examples also require dependencies of their own:

sudo apt-get install python-matplotlib

Navigate to pyrealsense/examples and enter:

sudo python show_matplotlib.py

You should get a screenshot from the R200 "plotted" in a graph if both PyRealsense & MatPlotLib are working. Finally, install OpenCV by entering the following command line:

sudo apt-get install python-opencv

Afterwards, you should have everything you need in order to run the rest of the PyRealsense examples. Feel free to run them if you wish, but we shall jump to running the chessboard example. This example attempts to gather some valid data points with respect to the X-Y-Z location of the chessboard and displays an overlaid color grid on the inner corners of the chessboard (the code is tailor made for a chessboard with 9x7 inner corners). Obviously, this implies you print out the included image of a 10x8 chessboard, as it is needed for detection.

sudo python chessboard_test_2.py

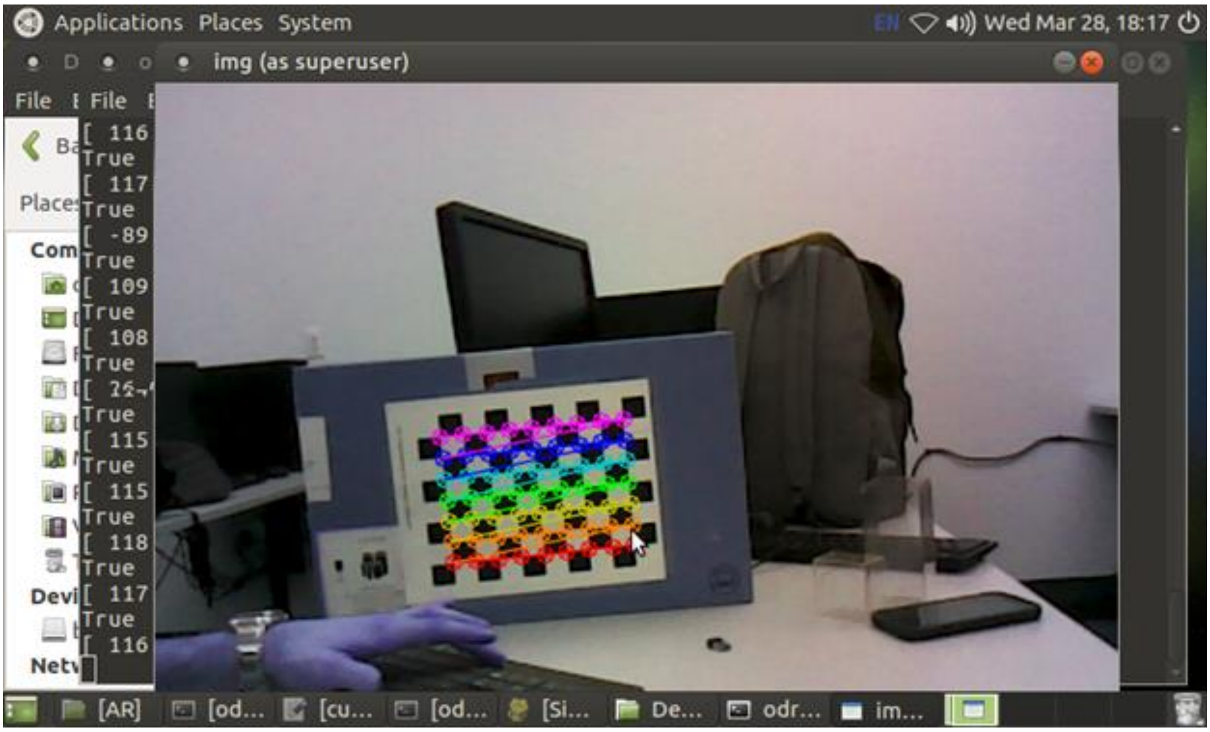

Figure 31: Integrating Intel RealSense R200 Depth Sensing Capabilities

Here is the link to the high-quality checkerboard calibration image PDF:

https://www.mrpt.org/downloads/camera-calibration-checker-board_9x7.pdf

The image also follows on the next page. Finally, our capstone presentation demo files are named as follows, feel free to play around with those too:

cube_test_bno0055_only.py (the cube example with the orientation from the BNO055) cube_test_withsensor.py (test which attempts to display the cube at the center of the chessboard along with the orientation adjustments from the BNO055, unstable)

Comprehensive Design/Validation System Diagram

Evaluation of the user needs:

1) Comfort
2) Usability
3) Experience

Initial design proposal:
A 3D printed, open source headset that is available for everyone to replicate and improve.

Research:
Evaluation of the cheaper AR headsets on the market and improve on the negative user feedback. Try to implement advanced technologies used in the more expensive AR headsets.

Detailed Design:
Refer to the drawings in the appendix. 5 iterations were made to improve the quality and functionality of the headset.

Validation of the user needs:
Through many iterations, by having people and our team try out the headset, it was easy to understand and improve the user experience.

Production/Procurement:
Intel R200 depth sensor, 5-inch screen, BNO055 motion sensor, and the Odroid-XU4 computer were purchased as core components of the design. The design was made to fit all these components in a casing to provide a great user experience.

Testing:
The following tests were performed:

1) Thermal test
2) Vibration test
3) Screen angle test
4) Steady force test
5) Impact test
6) Drop test
7) Ergonomics test

Validation:
The user experience test will be the main contributor to validate the design. The user feedback will help understand if there is a potential clientele for this sort of device. The design should be practical, ergonomic and cost efficient.

Comprehensive Cost Analysis

AR Headset Cost Analysis

Itemized Components	Purchased/Manufactured/Sponsor	Labour Hours	Cost ($)
Display			
5 in HDMI screen	Purchased		100.46
Heads Up Display	Sponsor		
Heads Up Display Hinge	Purchased		36.83
Headset			
Headset	Manufactured - External		35.5
Headband cushion and padding	Sponsor		
Headstrap	Sponsor		
Headset top cover	Manufactured - External		20.84
Sensors			
Adafruit BNO055 Orientation sensor	Purchased		63.74
Intel RealSense R200 Depth Sensor	Purchased		153.36
Processors			
Raspberry pi 3	Sponsor		
Odroid - XU4 (Heat sink + Fan incl.)	Purchased		163.02
Hardware			
Pan Head Phillips, #8-32 Thread, 1/2" LG, Zinc-Pltd Stl	Purchased		4.07
Pan Head Phillips, #8-32 Thread, 7/8" LG, Zinc-Pltd Stl	Purchased		6.46
Flat Head Phillips, #2-56 Thread, 1/2" LG, Zinc-Pltd Stl	Purchased		5.78
Flat Head Phillips, #6-32 Thread, 5/8" LG, Zinc-Pltd Stl	Purchased		4.97
Flat Head Phillips, #4-48 Thread, 3/8"LG, 18-8 SS	Purchased		18.1
#8-32 Hex Nut, Low-Strength Steel	Purchased		2.07
#2-56 Hex Nut, Low-Strength Steel	Purchased		1.26
#6-32 Hex Nut, Low-Strength Steel	Purchased		1.61
Power and Connectivity			
Odroid Wifi Module Adapter	Purchased		26.68
Four Port USB 3.0 Hub	Purchased		42.56
MicroSD 16GB USH-1	Purchased		12.64
Male 90 degree USB Connector	Purchased		8.97
90 degree 0.2m HDMI Cable	Purchased		11.38
Other			
		Total Cost ($)	720.3

Figure 32: Comprehensive Cost Analysis

Important Assembly, Operating and Maintenance Features

The casing is composed of two 3D printed modules for adjustability and for it to be open sourced (adding new components). It is assembled using bolts as fasteners to be sturdy and have removable components. The screen will also be interchangeable if ever it becomes defective and needs to be changed. It can easily be removed by disconnecting the Odroid-XU4 computer and removing four screws. Straps are mounted to the 3D printed modules to wear the headset. For operation, the Odroid-XU4 computer runs linux and that is the operating system used to portray any image on the lens. The HUD can be changed throughout the life cycle of the product simply by removing the two screws on the hinge and replacing it, if it is scratched or damaged. It is also removable because different lenses work better in different light settings. This allows the user to adjust the experience during use. A cushion was added for comfort, it will also be disposable for it to be changed throughout the life cycle of the headset.

Product Specifications

Overall dimensions of headset: 9 x 8.5 x 3.3 inches

Overall weight: 535 g

Processor

ODROID-XU4 chip

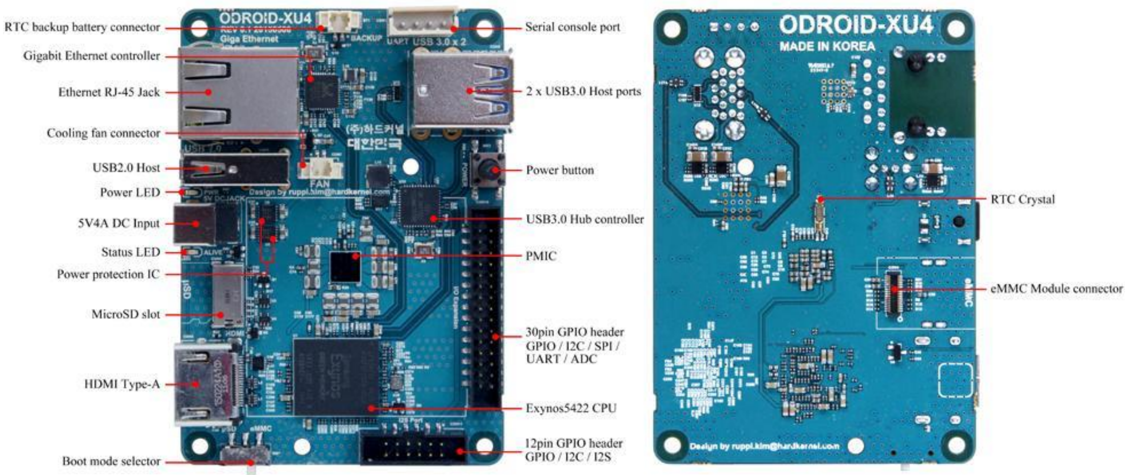

Figure 34: ODROID-XU4 board detail [14]

2 x USB 3.0	read SSD (273 MB/sec) write SSD (258 MB/sec)
Power input	4.8-5.2 V (5V/4A Power supply recommended)

Processor	Samsung Exynos5422 ARM® Cortex™-A15 Quad 2.0GHz/Cortex™-A7 Quad 1.4GHz
Size/ weight	83x58x20 mm / 38 g
WiFi	USB IEEE 802.11 ac/b/g/n 1T1R WLAN (external adapter)
Display	HDMI 1.4a
Software	Linux Kernel 4.9 LTS
Memory	2Gbyte LPDDR3 RAM PoP (750Mhz, 12GB/s memory bandwidth, 2x32bit bus)
Ethernet port	Ethernet with RJ-45 Jack

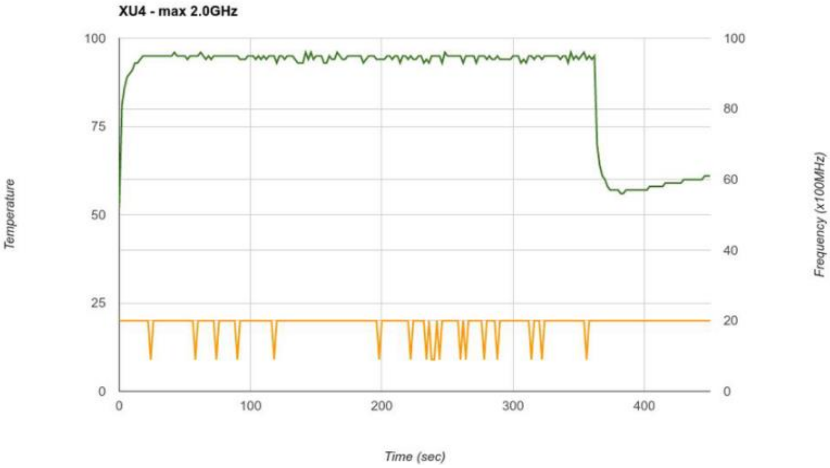

Figure 35: ODROID-XU4 operating temperature vs running time using active cooling [13]

<u>Sensors</u>

Adafruit BNO055 9-DOF sensor

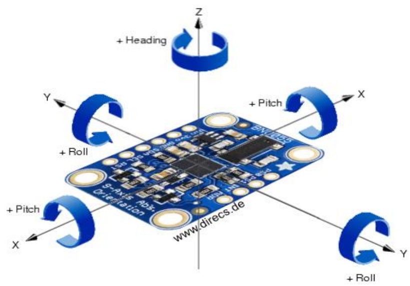

Figure 36: BNO055 axes of rotation [15]

Data output [16]:

Absolute orientation on three axis based on a 360° sphere
Angular velocity on three axis rotation speed
Acceleration vector on three axis (gravity + linear motion)
Linear acceleration vector on three axis (acceleration – gravity)
Ambient temperature in °C

Intel RealSense R200 camera

Feature	Color Camera	Infrared Cameras
Active Pixels	1920x1080 (2M)	640x480 (VGA)
Aspect Ratio	16:9	4:3
FOV (D x V x H)	77°x43°x70° (Cone)	70°x46°x59° (Cone)
Frame Rate	30FPS**	30/60FPS**
Filter Type	IR Cut Filter	IR Band Pass
Focus	Fixed	Fixed
Interface	MIPI* CSI-2, 2 Lanes	MIPI* CSI-2, 1 Lane/Camera

Figure 37: R200 camera specs [17]

Capabilities: 3D Scanning, Speech recognition, person tracking, depth enabled photo and video, hand tracking, measurement, and scene perception.

Display

HDMI Display with Multitouch by ODROID

Figure 38: ODROID-VU5 5 inch HDMI Display with Multitouch [18]

Screen Resolution	800x480 pixels
Power Consumption	500mA / 5V
Screen Dimensions	121 x 83.31 x 15mm (Including switch & Connectors)
Viewable screen size	108 x 64 mm
View Angle (Deg)	Left 70, Right 70, Up 70, Down 50
Weight	100g
Other	TFT-LCD, 5 Finger Capacitive Touch Input, Backlight On/Off Switch

Also includes:

- 6 x 3.5mm screws
- 3 x Hex nuts
- Micro USB link board

- HDMI link board
- Micro-to-Type A USB Cable (approx. 35cm)
- Micro-to-Micro USB Cable (approx. 35cm)
- TypeA-to-TypeA HDMI cable (approx. 35cm)

Optics

Clear acrylic sheet, thickness of 1/8 inch.

Optional: Semi-reflective, 1-way mirror film. (Inserted over the acrylic sheet)

Engineering Drawings

Engineering drawings for the latest revision of the headset can be found in Appendix VII and engineering drawings for older revisions can be found in the USB stick given with this report.

Gantt Chart

The final Gantt Chart can be found in Appendix VIII.

Safety and Human Impacts

Throughout the whole capstone project, significant importance was placed on the safety and ergonomics of our augmented reality headset. Starting from our design process we decided to limit the number of sharp edges and points, placing more emphasis on curves and rounded edges. In doing so, we limited the potential hazard of the user injuring themselves while operating the augmented reality headset. Furthermore, temperature testing was done on the headset for safety purposes to ensure that the headset would not overheat, catch fire and potentially burn the user. From our tests we observed that the peak temperature that the internal components reach was 42°C. While this might seem high, when the tester wore the headset it felt relatively normal.

Moreover, throughout the different design iterations, we observe that the overall size and weight has decreased. The first few iterations were larger to ensure that all the hardware would fit into the augmented reality headset. After which, when all of the hardware was placed into the headset we noticed that the overall weight of the components with the casing was strenuous on the user’s neck. Therefore, we reduced the overall size and weight of the headset without compromising the devices integrity. Additionally, we noticed that using the headset for prolonged periods of time hurt the user’s forehead where the headset rested on. In consequence, a curved feature was added to the headset where contact would be with the user’s forehead as well as soft padding to make it more comfortable.

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Appendix I: Declaration of Work

The work done by everyone is as follows:

Kostas Zoitakis: Manufacturing of components and assembly, support PM with planning/procurement, testing and design support. (14%)

Rahul Patel: Project manager, budget and planning/procurement. (14%)

Muhammad Haseb Ellahi: Manufacturing of components and assembly, testing and analysis. (14%)

Michael-Angelo Yadao: Design and engineering analysis. (15%)

Nicholas Cierson: Software (coding) and testing support. (15%)

Amir Shawwa: Design and engineering analysis. (14%)

Faraz Yunus: Testing and analysis (14%)

The team work was distributed as evenly as possible and all members supported when needed.

Signatures of the members:

Kostas Zoitakis ____
Rahul Patel ____
Muhammad Haseb Ellahi __________________________________
Michael-Angelo Yadao _____________________________________
Nicholas Cierson ____
Amir Shawwa ____
Faraz Yunus ____

Appendix II: Graduate Attributes First Lecture

Analogical Case Study

Though augmented reality is a great new innovative technology which will be a market for further development in the years to come, many issues are still present and must be approached with an ethical, legal or social view. These issues must be held into account when engineering an augmented reality device to protect the user, the service provider and the society which surrounds them.

The largest area of social and ethical problems seems to be safety relating mostly to the operator of the AR headset device, as discussed in “The Real-Life Dangers of Augmented Reality” by Eric Sabelman and Roger lam. This report discusses some negative aspects of common augmented reality applications with available devices (HoloLens, Google Glass, etc.) and compares its civilian use to that of a military fighter pilot to draw parallels of how augmented reality should be implemented properly and safely.

First, the use of augmented reality requires the user to often switch their focus from real world objects in the distance to virtual objects displayed centimeters from their face [19]. This can lead to eye strain (especially to people who already have vision problems), but most importantly longer reaction times and more distraction from the real world, especially for users who do not use augmented reality often [19]. Secondly, augmented reality usually inhibits the user’s central vision or peripheral vision, sometimes both. While virtual objects or notifications are being displayed to the user, this can often cloud his central vision. In order to limit this factor, notifications and pop-ups tend to be displayed on the sides of the screen. However, this leads to the user’s peripheral vision being impaired which can be just as bad. It allows us to gather data about the distance and speed of objects toward or away from you, which central vision does not do very well [19]. Interfering with the user’s peripheral vision can lead them to miscalculate the relative motion of objects and could lead to the user stumbling and even injuring themselves [19].

Many things can be learned from the above article which we can apply to our own augmented reality device. The first would be to always use our device in a safe location and environment, where a reduced reaction time and being more easily distracted will not have potentially harmful outcome for the user. Obviously augmented reality has many uses, but regarding our specific usage, it will not regard any high-risk locations such as streets with moving cars, high drops, or dangerous materials. In the advent of one of these factors being introduced, a second person not wearing any augmented reality device should accompany the user and serve as a spotter for any potential dangers. This type of problem is hard to deal with in an effective way as the usage is often left to the buyer of the product, so warnings should also be given about the increased risks in some sort of documentation accompanying our device to let the user know of the potential dangers. Finally, regarding the impairment of central and peripheral vision, the article mentions that this aspect was overcome in fighter pilot displays by showing the virtual items in the central vision area but having them be realistic and not simply graphics which will more easily distract the user [19]. For obvious safety reasons previously mentioned, the display of objects in peripheral vision will be limited to a strict minimum in our device to allow the user to have the best possible vision of the real world and its dangers.

Contemporary Practice

When reading through "Virtual & Augmented Reality – Understanding the race for the next computing platform" research report by Goldman Sachs, many market trends and standards are identified which are becoming important staples for the augmented reality industry and market. The aspects will be important for future augmented reality device design and will be able to provide crucial information and insight for our augmented reality project.

The most seemingly obvious market and industry trend would be that all computing is being driven towards head mounted devices, or also commonly called headsets [20]. As can be seen with already existing examples of the Microsoft HoloLens and Google Glass, the entirety of the device is worm on the user's head and allows for good mobility and motion. The device is self-contained, fully portable (which implies it being comfortable and lightweight) and does not have any exterior connections. This is the most practical way to implement and use augmented reality technology for the user and is very convenient. Furthermore, the report by Goldman Sachs also identified 9 use cases for the technology which will have the largest impact on the market. These would be military, engineering, education, video games, live events, video entertainment, healthcare, retail and real estate [20]. This would imply that the industry focus has shifted to support applications in the areas, and that augmented reality devices should be able to support functions required and many of these sectors.

Given this information, our augmented reality solution should have its place in the market. Firstly, our device is a head mounted one, which follows one of the major trends of the industry. Though as of now it needs to be plugged in to a power source (which implies the device is not mobile), it is already in our plans to make our device fully self-contained and mobile, not requiring any external connections for our final iteration. The hardest aspect of the solution to this issue will be having the power source contained in the headset and having an appropriately long usage time before needing to be plugged in to recharge. Furthermore, after seeing the markets which AR will impact the most and noticing the large number of applications for augmented reality, it would be a smart idea to not limit the functionalities of our device and have it be multi-functional. This way, it could be adapted from a video game use (for example) to an engineering use without too many complications. Finally, having the requirement that our headset be open source and easily reproducible (3D printed), this would imply that our device would be on the very low end of the price scale.

Given our expected low production cost, if our device can be made to be multipurpose and can be mobile and self-contained, we believe our final product can find its place in the augmented reality market because of the previously mentioned factors. It would be an accessible entry level device, which could then be adapted easily to new applications as the user’s uses for the headset evolve.

Appendix III: Graduate Attributes Second Lecture

Public Perceptions of Technology

Engineering View on Augmented Reality Technology in the Workplace

One of the main function of our device would be to aid engineers in research and product development by simulating in 3D, the interaction between their design and the targeted environment. Augmented reality technology would be used to superimpose the virtual information onto a part to simulate real life conditions. This is more efficient than running 2D simulations because it does not simulate the design in its entirety and does not require setups or fixtures. A potential use for our headset is to simulate the air flow around an object and analyze the data through augmented reality. In the article "Augmented Reality Projects in the Automotive and Aerospace Industries" by Holger Regenbrecht, Gregory Baratoff and Wilhelm Wilke, it explained the use of AR technology to incorporate fluid dynamics to assist in designing the interior of an airplane through an AR device [21]. With this technology, data relating to the change in pressure at different locations in the airplane was being evaluated through the AR system [21]. This application resembles the function of the headset that we designed by viewing an object from different angles and analyzing the digital information through an AR system. However, according to John Kosowatz, the issue concerning AR technology resides within its accuracy, the accuracy of virtual information being displayed into reality [22]. With inaccurate positioning system of AR technology, simulations being performed may create incorrect data since the digital information may not be properly overlaid with the physical object. This may cause the engineer to assume that the data acquired from the simulation reflects real-life situations leading the engineer to continue to the next phase of the project, thus, creating a chain of errors along the way.

Public View on Augmented Reality Technology in the Workplace

As the presence of automation is rapidly increasing in factories, it has led to the loss of many jobs. Manual routine and clerical tasks generally done by people are now being automated. This is because automation is more efficient and increases productivity in the workplace. With technologies such as these becoming widespread, the livelihoods of many people are at stake. Augmented reality may reverse this effect by giving people the opportunity to find new jobs in areas in which they do not possess the skills in [23]. This is because with the help of AR technology, a worker may be able to perform a series of tasks through the guidance of virtual instructions being displayed for the worker to follow [23]. Even if the worker has minimal knowledge in the operations, he may be able to perform them regardless by following step by step instructions. This enables people who have loss their jobs to have greater chances of employment in companies which utilizes this technology. Augmented reality is a technology which enhances efficiency in the workplace without diminishing the company's workforce.

Technology Assessment and Choice

Some changes in the design were due to non-technical factors such as aesthetics. The second iteration of the design had an overall dimension of 7.5in x 6.8in x 4in which made it bulky. The headset was large and had a box-like design making it aesthetically unattractive. This was done to ensure all hardware components and cables would properly fit in the headset, and to permit air flow within the headset to help with the cooling of the Odroid-XU4. In our final design, with the length being fixed due to the positioning of the hardware components, only the overall width and height of the headset was reduced. Additionally, a significant change in the design of the top cover was made by reducing its overall height and designing it with a sharper body rather than a box-like design. With these changes, the headset looked aesthetically more pleasing and resembled more of an AR. However, this compact design limited the air flow within the headset. To compensate for this, grills were added on the top cover and the slots on the sides of the headset were increased. Our final design looked more of a wearable headset which somewhere would wear without feeling embarrassed.

The initial design of the strap was made of velcro which enabled the user to adjust it at different lengths which best suited their preference but caused ergonomics concerns. With most of the total mass of the headset converged onto the front of the user's head, the strap configuration was not able to withstand the weight of the headset, thus, causing strain on the user's neck. To prevent this, a new strap made from an elastic material was chosen since it rests well on the user's head making it more comfortable to wear and properly levels the headset without having the user to constantly lift the device to set it correctly. Furthermore, the initial design of the back cover was flat which was uncomfortable when resting it on the user's forehead so a stick-on foam was applied. This issue was solved by merging the back cover with the headset and redesigning it with a smooth curve which rested comfortably on the user's forehead.

Another important factor is the environmental impact of the material used in 3D printing our headset. The two most popular 3D printing materials are Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA). The first revisions of our design were printed using ABS but our final design was made from PLA due to it being eco-friendly because it is made from biodegradable material [24]. By selecting this material, anyone who decide to make their very own headset using our design will know that they will not be harming the environment. As a bonus, PLA is a shinier material than ABS making it more attractive.

Appendix IV: Complete FEA Report (Steady Force Analysis)

V5 10N STATIC LOAD

Study Report

Analyzed File	V5 v8
Version	Autodesk Fusion 360 (2.0.3803)
Creation Date	2018-03-19, 18:59:31
Author	

⊟ Simulation Model 1:1

⊟ Study 2 -(10N) Static Stress

⊟ Study Properties

Study Type	Static Stress
Last Modification Date	2018-03-19, 18:43:52

⊟ Settings

⊟ General

Contact Tolerance	0.1 mm
Remove Rigid Body Modes	No

⊟ Mesh

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	No
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

⊟ Adaptive Mesh Refinement

Number of Refinement Steps	0
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	Von Mises Stress

⊟ Materials

Component	**Material**	**Safety Factor**
Headset V5 v1:1	PLA (3D Printed)	Yield Strength
Odroid XU4 v1:1	SolidWorks Materials|Silicon|67	Yield Strength
Screen V4 v1:1	SOLIDWORKS Materials|Silicon|67	Yield Strength

⊟ PLA (3D Printed)

Density	3.75E-07 kg / mm^3
Young's Modulus	3400 MPa
Poisson's Ratio	0.38
Yield Strength	13 MPa
Ultimate Tensile Strength	15 MPa
Thermal Conductivity	1.6E-04 W / (mm C)
Thermal Expansion Coefficient	8.57E-05 / C
Specific Heat	1500 J / (kg C)

⊟ SOLIDWORKS Materials|Silicon|67

Density	2.33E-06 kg / mm^3
Young's Modulus	112400 MPa
Poisson's Ratio	0.28
Yield Strength	120 MPa
Ultimate Tensile Strength	0 MPa
Thermal Conductivity	0.124 W / (mm C)
Thermal Expansion Coefficient	0 / C
Specific Heat	0 J / (kg C)

⊟ SolidWorks Materials|Silicon|67

Density	2.33E-06 kg / mm^3

Young's Modulus	112400 MPa
Poisson's Ratio	0.28
Yield Strength	120 MPa
Ultimate Tensile Strength	0 MPa
Thermal Conductivity	0.124 W / (mm C)
Thermal Expansion Coefficient	0 / C
Specific Heat	0 J / (kg C)

⊟ Contacts

⊟ Bonded

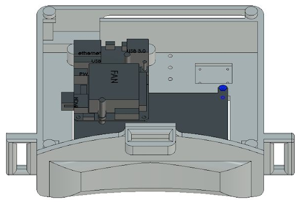
Name
[S] Bonded1 [Odroid XU4 v1:1||Screen V4 v1:1]

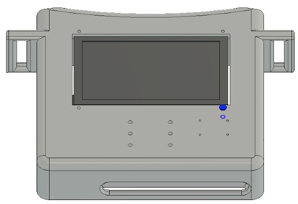
⊟ Connectors

⊟ Bolt Connector1

Type	Bolt Connector
Bolt Subtype	With Nut
Bolt Diameter	2.705 mm
Head Washer	No
Nut Washer	No
Pre-load type	Axial
Material	PLA (3D Printed)
Elastic Modulus	3400 MPa
Poisson's Ratio	0.38
Thermal Expansion Coefficient	8.57E-05 / C

⊟ Selected Entities

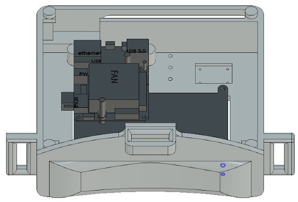


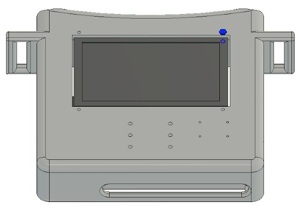


⊟ Bolt Connector2

Type	Bolt Connector
Bolt Subtype	With Nut
Bolt Diameter	2.705 mm
Head Washer	No
Nut Washer	No
Pre-load type	Axial
Material	PLA (3D Printed)
Elastic Modulus	3400 MPa
Poisson's Ratio	0.38
Thermal Expansion Coefficient	8.57E-05 / C

⊟ Selected Entities

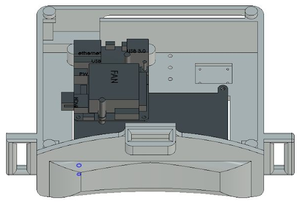


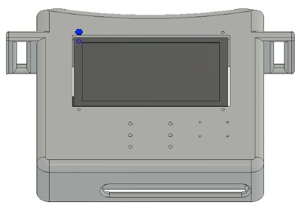


⊟ Bolt Connector3

Type	Bolt Connector
Bolt Subtype	With Nut
Bolt Diameter	2.705 mm
Head Washer	No
Nut Washer	No
Pre-load type	Axial
Material	PLA (3D Printed)
Elastic Modulus	3400 MPa
Poisson's Ratio	0.38
Thermal Expansion Coefficient	8.57E-05 / C

⊟ Selected Entities

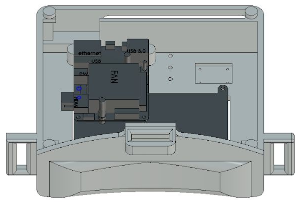


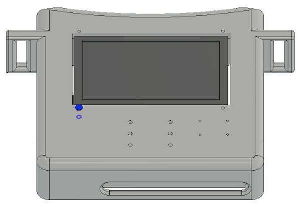


⊟ Bolt Connector4

Type	Bolt Connector
Bolt Subtype	With Nut
Bolt Diameter	2.705 mm
Head Washer	No
Nut Washer	No
Pre-load type	Axial
Material	PLA (3D Printed)
Elastic Modulus	3400 MPa
Poisson's Ratio	0.38
Thermal Expansion Coefficient	8.57E-05 / C

⊟ Selected Entities

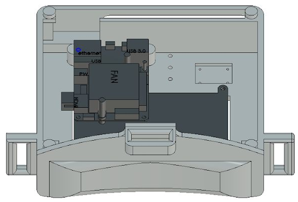


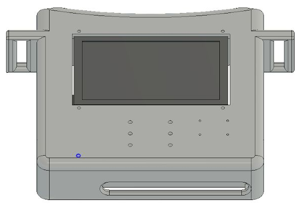


⊟ Bolt Connector5

Type	Bolt Connector
Bolt Subtype	Threaded Hole
Bolt Diameter	3.2 mm
Head Washer	No
Usable Thread Length	5 mm
Pre-load type	Axial
Material	Steel
Elastic Modulus	210000 MPa
Poisson's Ratio	0.3
Thermal Expansion Coefficient	1.2E-05 / C

⊟ Selected Entities

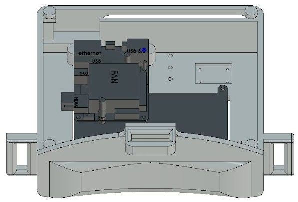


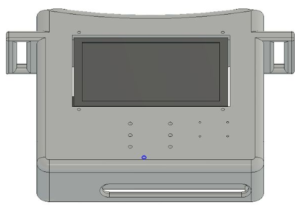


⊟ Bolt Connector6

Type	Bolt Connector
Bolt Subtype	Threaded Hole
Bolt Diameter	3.2 mm
Head Washer	No
Usable Thread Length	5 mm
Pre-load type	Axial
Material	Steel
Elastic Modulus	210000 MPa
Poisson's Ratio	0.3
Thermal Expansion Coefficient	1.2E-05 / C

⊟ Selected Entities





⊟ Mesh

Type	Nodes	Elements
Solids	55771	30876

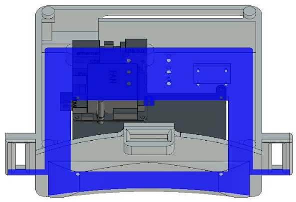
⊟ Load Case1

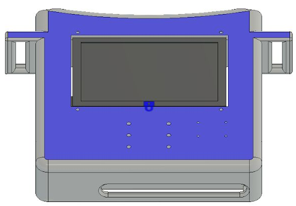
⊟ Constraints

⊟ Fixed1

Type	Fixed
Ux	Yes
Uy	Yes
Uz	Yes

⊟ Selected Entities



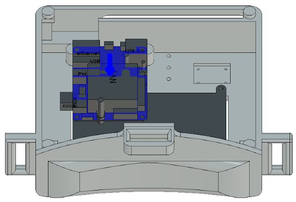


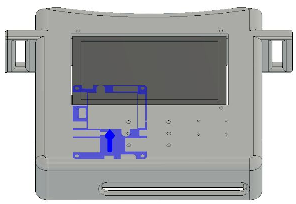
⊟ Loads

⊟ Force1

Type	Force
Magnitude	10 N
X Value	0 N
Y Value	-10 N
Z Value	-1.472E-29 N
Force Per Entity	No

⊟ Selected Entities





⊟ Results

⊟ Result Summary

Name	Minimum	Maximum
Safety Factor		
Per Body	3.557	15
Stress		
Von Mises	0 MPa	33.74 MPa
1st Principal	-8.505 MPa	38.9 MPa
3rd Principal	-32.45 MPa	6.457 MPa
Normal XX	-31.73 MPa	36.6 MPa
Normal YY	-27.34 MPa	18.19 MPa
Normal ZZ	-8.901 MPa	8.671 MPa
Shear XY	-7.553 MPa	8.13 MPa
Shear YZ	-2.846 MPa	2.399 MPa

Shear ZX	-4.579 MPa	4.341 MPa
Displacement		
Total	0 mm	0.2135 mm
X	-6.697E-04 mm	0.07142 mm
Y	-0.2076 mm	5.889E-04 mm
Z	-0.01896 mm	7.541E-04 mm
Reaction Force		
Total	0 N	1.136 N
X	-0.3298 N	0.2184 N
Y	-0.1516 N	1.135 N
Z	-0.2962 N	0.1995 N
Strain		
Equivalent	0	3.271E-04
1st Principal	-3.499E-08	3.788E-04
3rd Principal	-2.982E-04	5.553E-07
Normal XX	-2.679E-04	2.918E-04
Normal YY	-1.893E-04	1.509E-04
Normal ZZ	-7.356E-05	5.101E-05
Shear XY	-1.72E-04	1.852E-04
Shear YZ	-6.481E-05	5.464E-05
Shear ZX	-1.043E-04	9.887E-05
Contact Pressure		
Total	0 MPa	13.87 MPa
X	-4.57 MPa	5.466 MPa
Y	-5.986 MPa	12.72 MPa
Z	-0.7645 MPa	0.9387 MPa

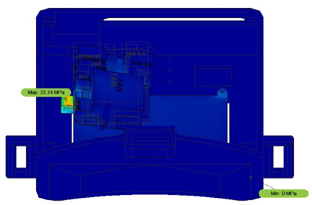
⊟ Reaction Forces

Constraint Name	**Reaction Force**		**Reaction Moment**	
	Magnitude	**Component (X,Y,Z)**	**Magnitude**	**Component (X,Y,Z)**
Fixed1	10.05 N	3.685E-08 N	367.5 N mm	192.3 N mm
		10.05 N		-1.424E-05 N mm
		-2.194E-07 N		-313.2 N mm

⊟ Stress

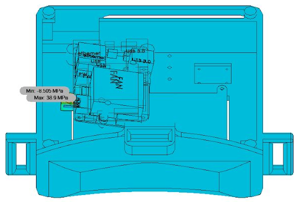
⊟ Von Mises

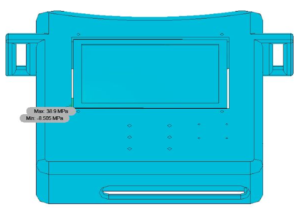
[MPa] 0 33.74



⊟ 1st Principal

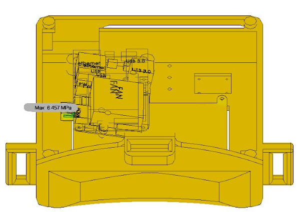
[MPa] -8.51 38.9

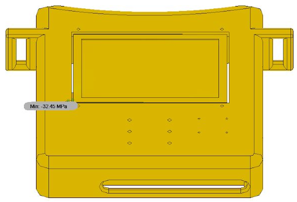




⊟ 3rd Principal

[MPa] -32.45 6.46

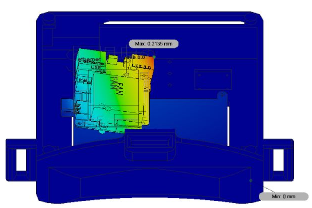




Displacement

Total

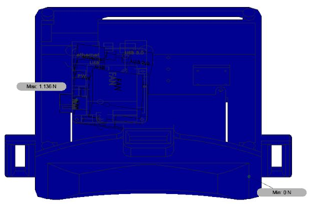
[mm] 0 0.2135

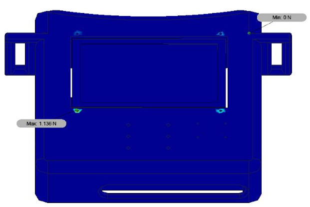


Reaction Force

⊟ Total

[N] 0 1.136

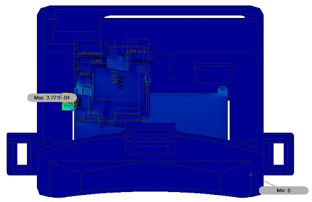




⊟ Strain

⊟ Equivalent

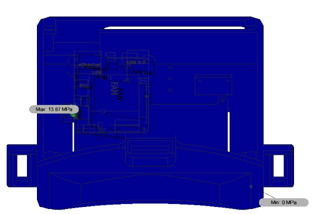
0 3.271E-04

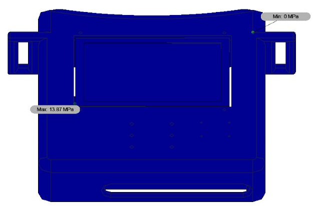


⊟ Contact Pressure

⊟ Total

[MPa] 0 13.87




Min: 0 MPa
Max: 13.87 MPa

V5 250N STATIC LOAD

Study Report

Analyzed File	V5 v5
Version	Autodesk Fusion 360 (2.0.3803)
Creation Date	2018-03-18, 20:34:34
Author	

⊟ Simulation Model 1:1

⊟ Study 1 -(250N) Static Stress

⊟ Study Properties

Study Type	Static Stress
Last Modification Date	2018-03-18, 20:27:09

⊟ Settings

⊟ General

Contact Tolerance	0.1 mm
Remove Rigid Body Modes	No

⊟ Mesh

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	Yes
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

⊟ Adaptive Mesh Refinement

Number of Refinement Steps	0
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	Von Mises Stress

⊟ Materials

Component	Material	Safety Factor
Headset V5 v1:1	PLA (3D Printed)	Yield Strength
Top Cover V5 v1:1	PLA (3D Printed)	Yield Strength

⊟ PLA (3D Printed)

Density	3.75E-07 kg / mm^3
Young's Modulus	3400 MPa
Poisson's Ratio	0.38
Yield Strength	13 MPa
Ultimate Tensile Strength	15 MPa
Thermal Conductivity	1.6E-04 W / (mm C)
Thermal Expansion Coefficient	8.57E-05 / C
Specific Heat	1500 J / (kg C)

⊟ Contacts

⊟ Bonded

Name
[S] Bonded1 [Headset V5 v1:1||Top Cover V5 v1:1]
[S] Bonded2 [Headset V5 v1:1||Top Cover V5 v1:1]

⊟ Mesh

Type	Nodes	Elements
Solids	43425	23187

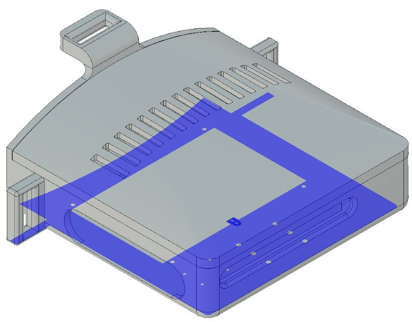
⊟ Load Case1

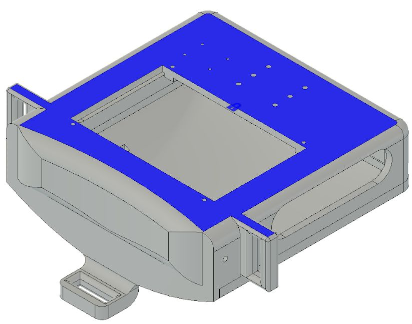
⊟ Constraints

⊟ Fixed1

Type	Fixed
Ux	Yes
Uy	Yes
Uz	Yes

⊟ Selected Entities



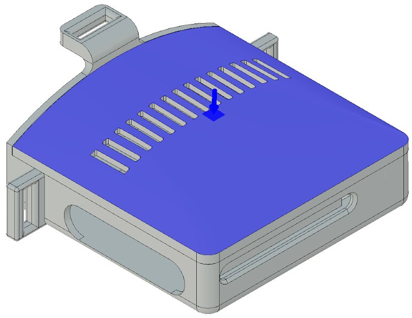


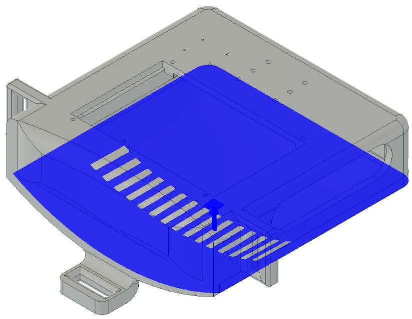
⊟ Loads

⊟ Pressure1

Type	Pressure
Magnitude	0.008304 MPa

⊟ Selected Entities





⊟ Results

⊟ Result Summary

Name	Minimum	Maximum
Safety Factor		
Per Body	3.551	15
Stress		
Von Mises	7.998E-07 MPa	3.661 MPa
1st Principal	-0.9877 MPa	5.662 MPa
3rd Principal	-4.158 MPa	1.81 MPa
Normal XX	-3.145 MPa	4.414 MPa
Normal YY	-3.941 MPa	4.095 MPa
Normal ZZ	-2.2 MPa	2.439 MPa
Shear XY	-1.878 MPa	1.748 MPa
Shear YZ	-0.6424 MPa	0.8271 MPa

Shear ZX	-1.264 MPa	1.222 MPa
Displacement		
Total	0 mm	0.2114 mm
X	-0.04344 mm	0.04941 mm
Y	-0.2098 mm	0.009054 mm
Z	-0.04114 mm	0.0295 mm
Reaction Force		
Total	0 N	15.85 N
X	-6.009 N	6.938 N
Y	-5.835 N	15.21 N
Z	-4.091 N	2.114 N
Strain		
Equivalent	3.275E-10	0.001942
1st Principal	2.152E-10	0.001863
3rd Principal	-0.001511	-2.12E-10
Normal XX	-7.849E-04	6.984E-04
Normal YY	-8.563E-04	7.048E-04
Normal ZZ	-5.23E-04	3.86E-04
Shear XY	-0.001524	0.001419
Shear YZ	-5.215E-04	6.714E-04
Shear ZX	-0.001026	9.92E-04
Contact Pressure		
Total	0 MPa	4.295 MPa
X	-1.29 MPa	1.314 MPa
Y	-4.095 MPa	3.941 MPa
Z	-0.3589 MPa	0.3432 MPa

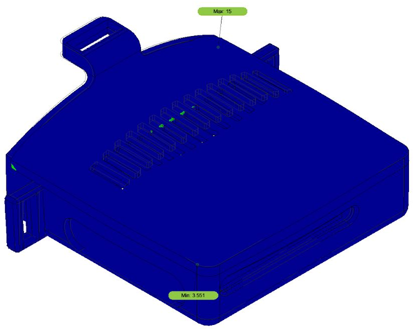
⊟ Reaction Forces

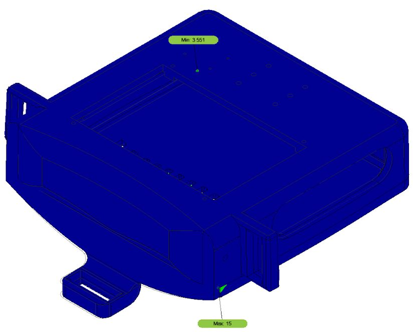
Constraint Name	**Reaction Force**		**Reaction Moment**	
	Magnitude	**Component (X,Y,Z)**	**Magnitude**	**Component (X,Y,Z)**
Fixed1	236 N	0.1898 N	2577 N mm	-2573 N mm
		234.9 N		46.1 N mm
		-22.75 N		134.5 N mm

⊟ Safety Factor

⊟ Per Body

0 8

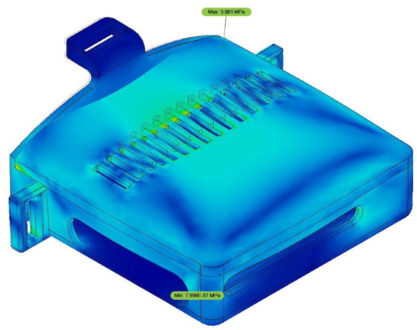


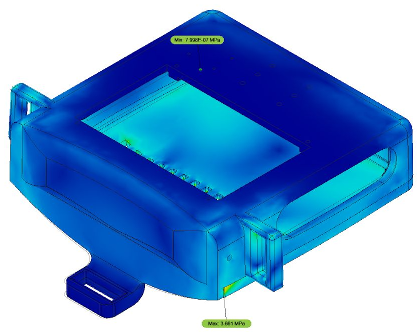


⊟ Stress

⊟ Von Mises

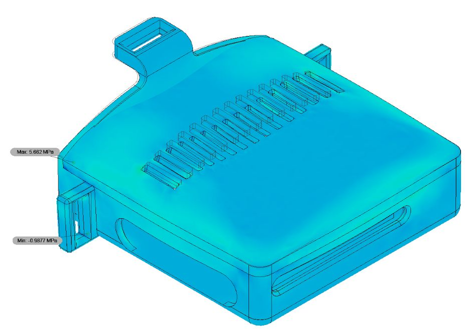
[MPa] 0 3.661

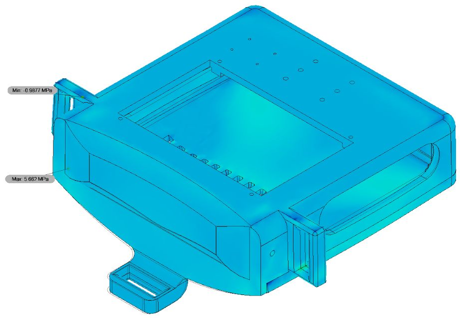




⊟ 1st Principal

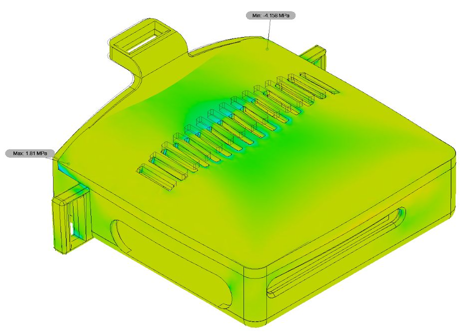
[MPa] -0.988 5.662

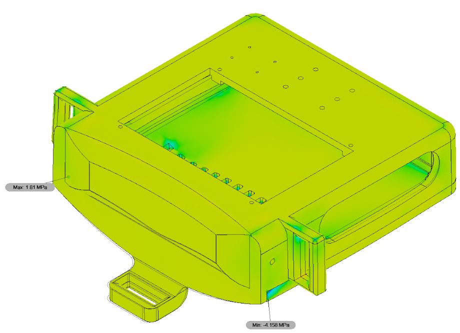




⊟ 3rd Principal

[MPa] -4.158 1.81

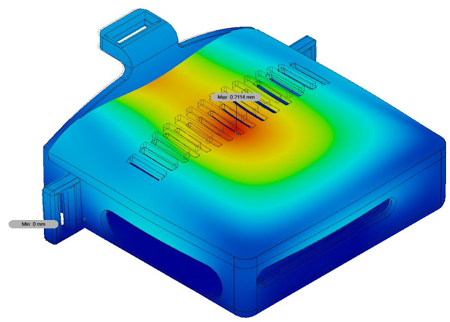


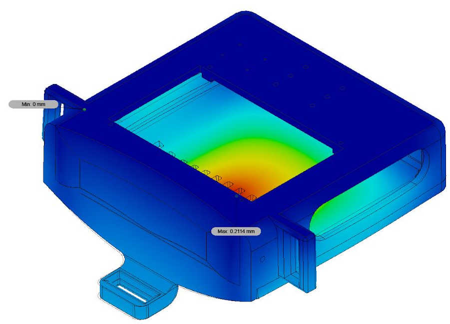


⊟ Displacement

⊟ Total

[mm] 0 0.2114

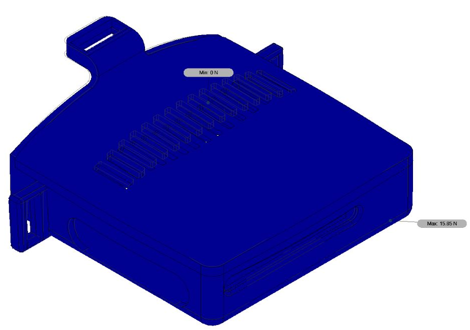


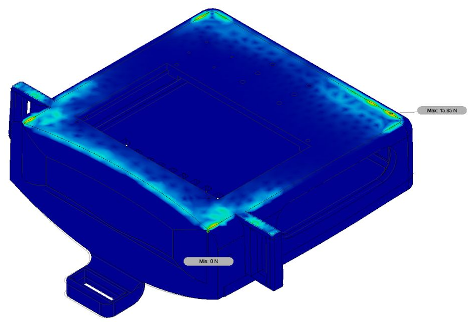


⊟ Reaction Force

⊟ Total

[N] 0 15.85

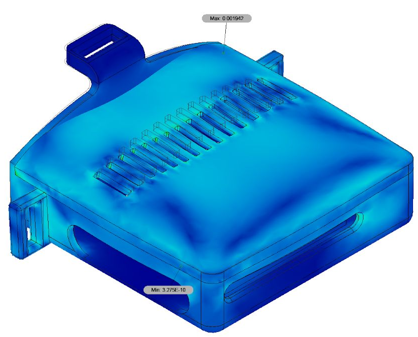


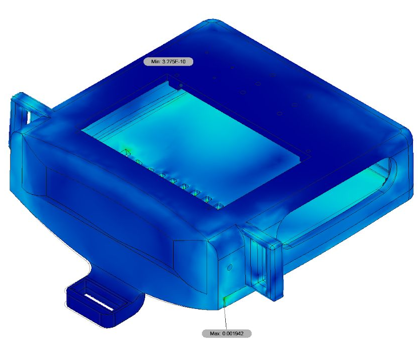


⊟ Strain

⊟ Equivalent

0 [color scale] 0.001942

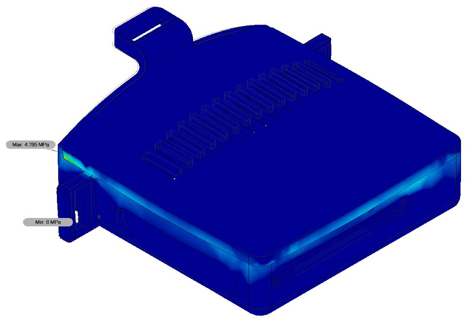


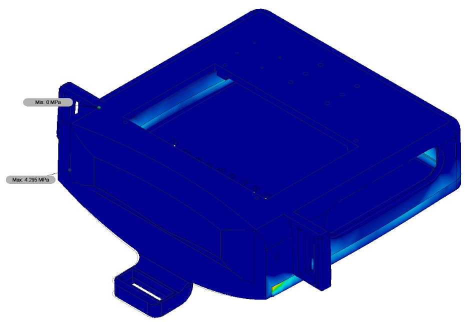


⊟ Contact Pressure

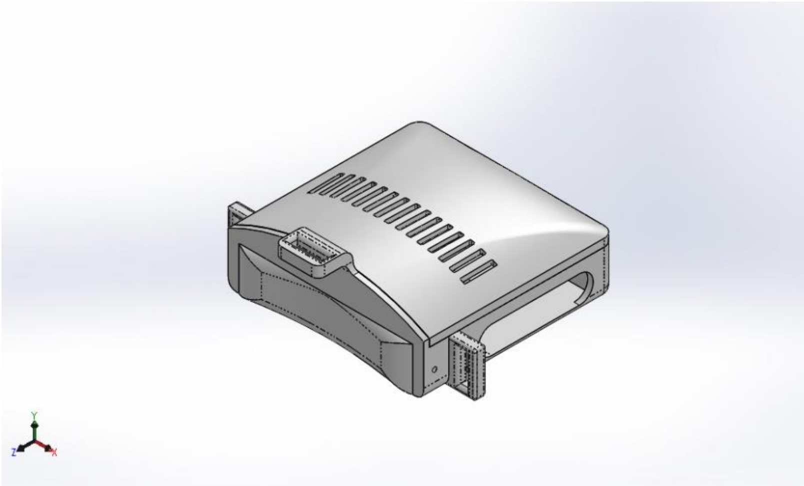
⊟ Total

[MPa] 0 4.295





Appendix V: Complete FEA Report (Drop Analysis)



Simulation of Assembly V5

Date: Tuesday, March 20, 2018
Designer: Solidworks
Study name: Drop Test 1
Analysis type: Drop Test

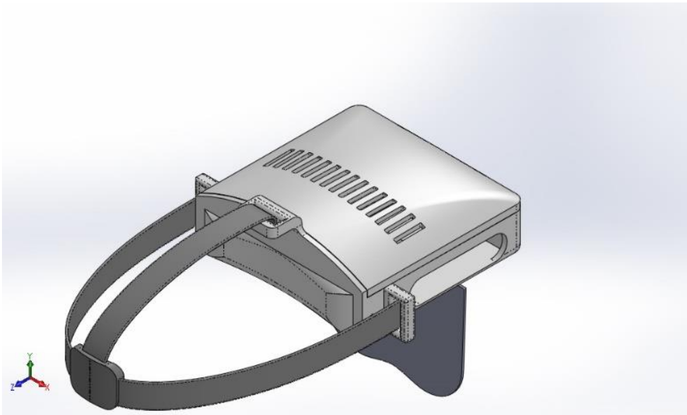
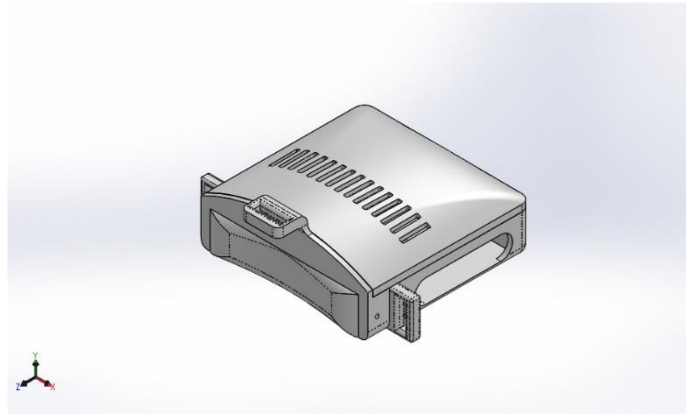
Table of Contents

Description 1
Assumptions 2
Model Information 2
Study Properties 4
Units 4
Material Properties 5
Contact Information 6
Mesh information 7
Study Results 9
Conclusion 11

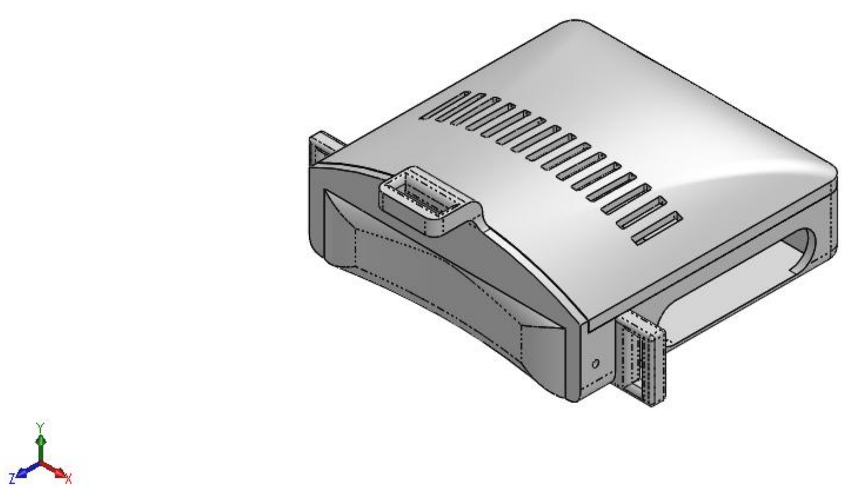
Description

No Data

Assumptions

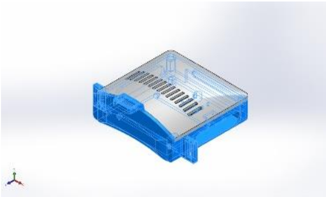
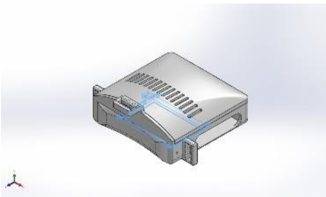
	
Original Model	Model Analyzed

Model Information



Model name: Assembly V5
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**

Fillet42 	Solid Body	**Mass:0.0930418 kg** **Volume:0.000297734 m^3** **Density:312.5 kg/m^3** **Weight:0.91181 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V5\Headset V5.SLDPRT** Mar 20 19:58:34 2018
Boss-Extrude7 	Solid Body	**Mass:0.183091 kg** **Volume:7.85796e-005 m^3** **Density:2330 kg/m^3** **Weight:1.79429 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V4\Screen V4.SLDPRT** Mar 17 00:05:53 2018
Cut-Extrude3 	Solid Body	**Mass:0.0413043 kg** **Volume:0.000132173 m^3** **Density:312.501 kg/m^3** **Weight:0.404782 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V5\Top Cover V5.SLDPRT** Mar 20 00:49:03 2018

Study Properties

Study name	Drop Test 1
Analysis type	Drop Test
Mesh type	Solid Mesh
Large displacement	On
Result folder	SOLIDWORKS document (C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V5\FEA)

Setup Information

Type	Drop height
Drop Height from Centroid	1 m
Gravity	9.81 m/s^2
Gravity Reference	Top Plane
Friction Coefficient	0
Target Stiffness	Rigid target
Critical Damping Ratio	0

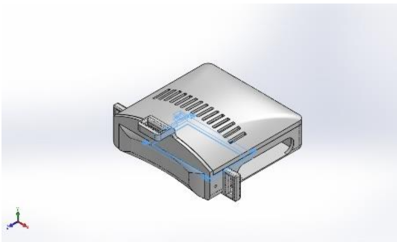
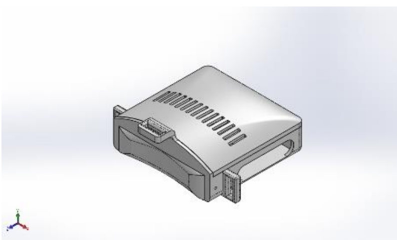
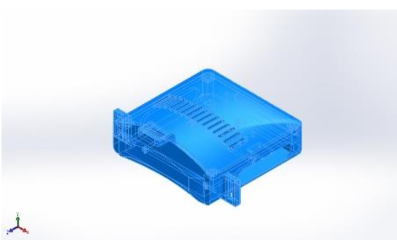
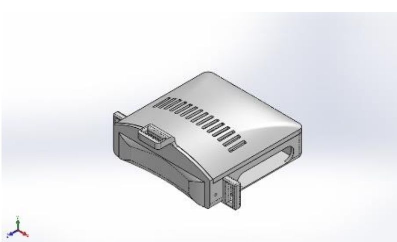
Result Options

Solution Time After Impact	296.3 microsec
Save Results Starting From	0 microsec
No. of Plots	25
No. of Graph Steps Per Plot	20
Number of vertex	0

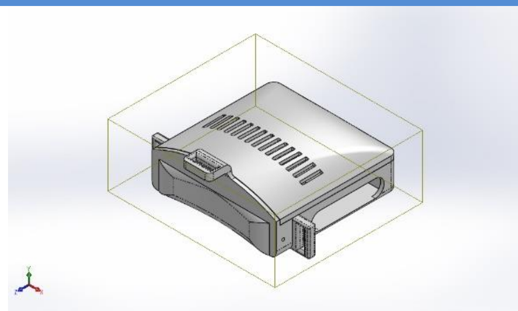
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	**Name:** Silicon **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 1.2e+008 N/m^2 **Elastic modulus:** 1.124e+011 N/m^2 **Poisson's ratio:** 0.28 **Mass density:** 2330 kg/m^3 **Shear modulus:** 4.9e+010 N/m^2	SolidBody 1(Boss-Extrude7)(Screen V4-1)
Curve Data:N/A		
	**Name:** Acrylic (Medium-high impact) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 4.5e+007 N/m^2 **Tensile strength:** 7.3e+007 N/m^2 **Elastic modulus:** 3e+009 N/m^2 **Poisson's ratio:** 0.35 **Mass density:** 1200 kg/m^3 **Shear modulus:** 8.9e+008 N/m^2 **Thermal expansion coefficient:** 5.2e-005 /Kelvin	SolidBody 1(Fillet42)(Headset V5-1), SolidBody 1(Cut-Extrude3)(Top Cover V5-2)
Curve Data:N/A		
	**Name:** PLA (3D Printed) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 1.3e+007 N/m^2 **Tensile strength:** 1.5e+007 N/m^2 **Elastic modulus:** 3.4e+009 N/m^2 **Poisson's ratio:** 0.38 **Mass density:** 312.5 kg/m^3	<Material_ComponentList1/>
Curve Data:N/A		
	**Name:** ABS **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Tensile strength:** 3e+007 N/m^2 **Elastic modulus:** 2e+009 N/m^2 **Poisson's ratio:** 0.394 **Mass density:** 1020 kg/m^3 **Shear modulus:** 3.189e+008 N/m^2	<Material_ComponentList1/>
Curve Data:N/A		

Contact Information

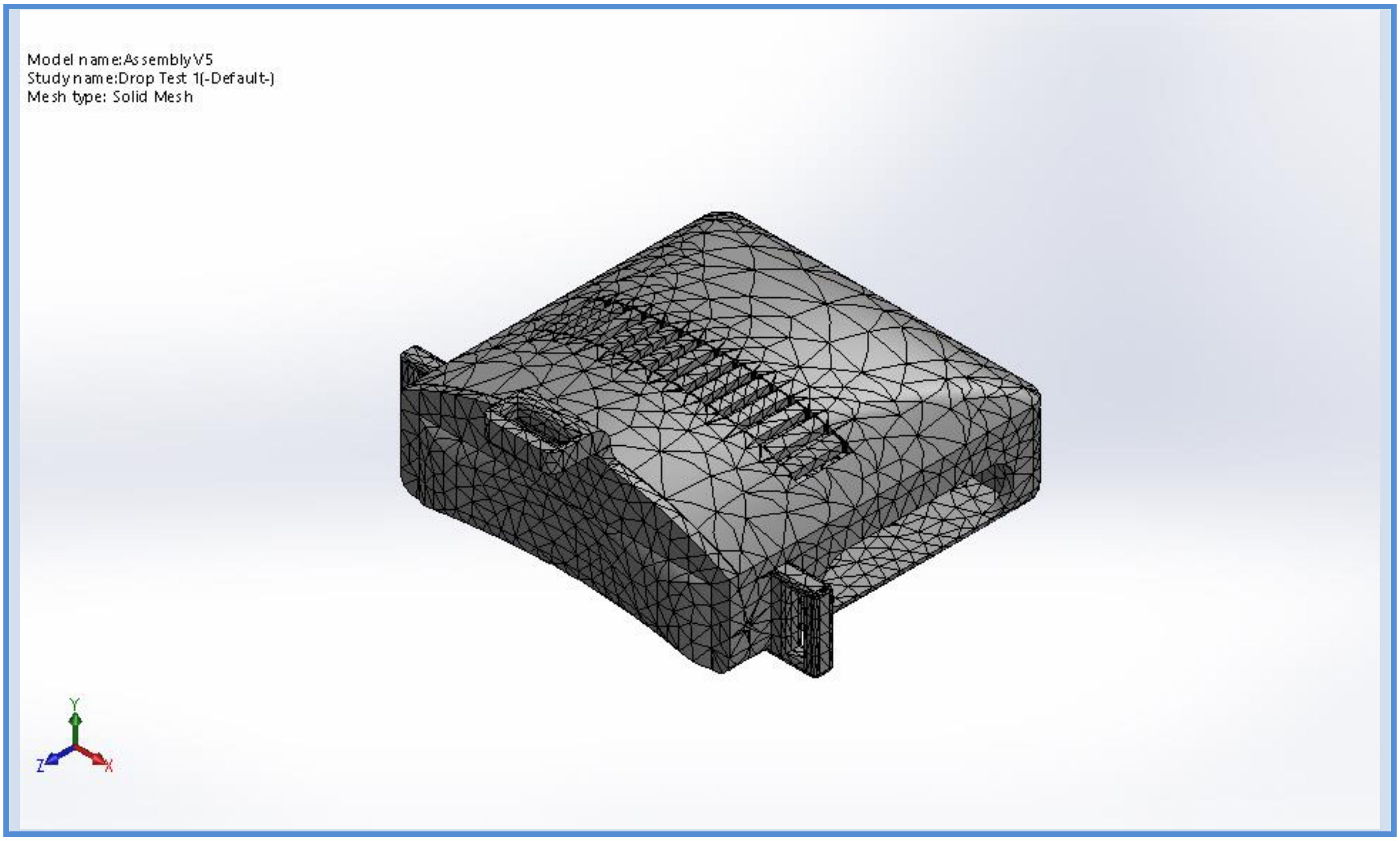
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Mesh information

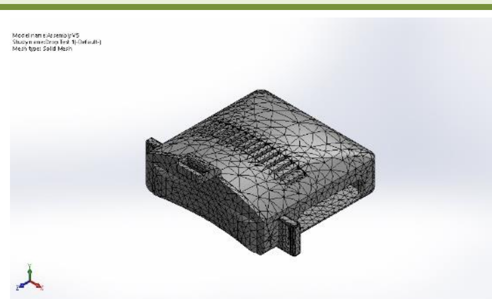
Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points
Maximum element size	36.5991 mm
Minimum element size	7.31982 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh information - Details

Total Nodes	24823
Total Elements	28336
Maximum Aspect Ratio	40.277
% of elements with Aspect Ratio < 3	66.5
% of elements with Aspect Ratio > 10	2.71
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:04
Computer name:	LENOVO-PC

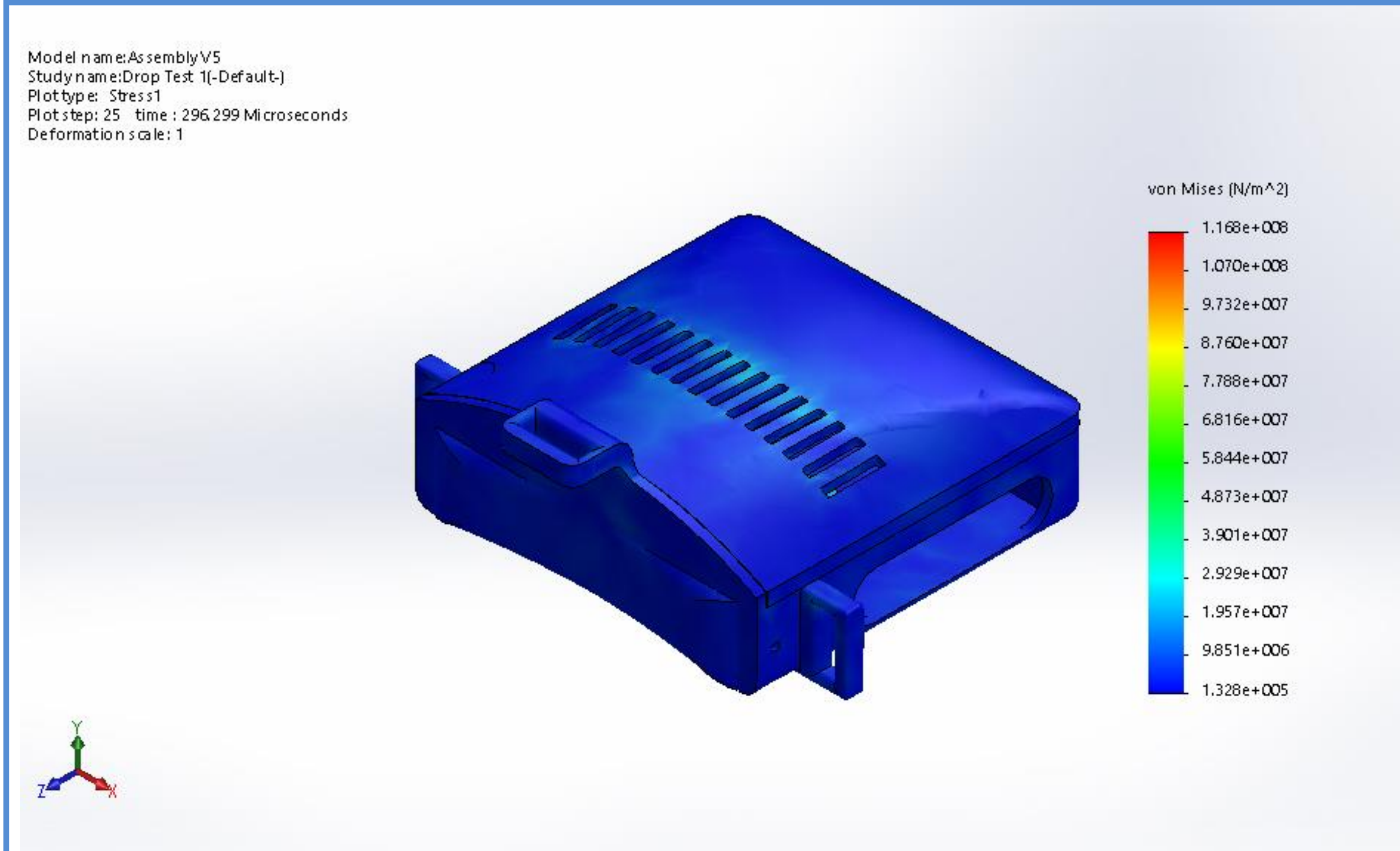


Mesh Control Information:

Mesh Control Name	Mesh Control Image	Mesh Control Details
Control-1		**Entities:** 1 Solid Body (s) **Units:** mm **Size:** 6.67924 **Ratio:** 1.5

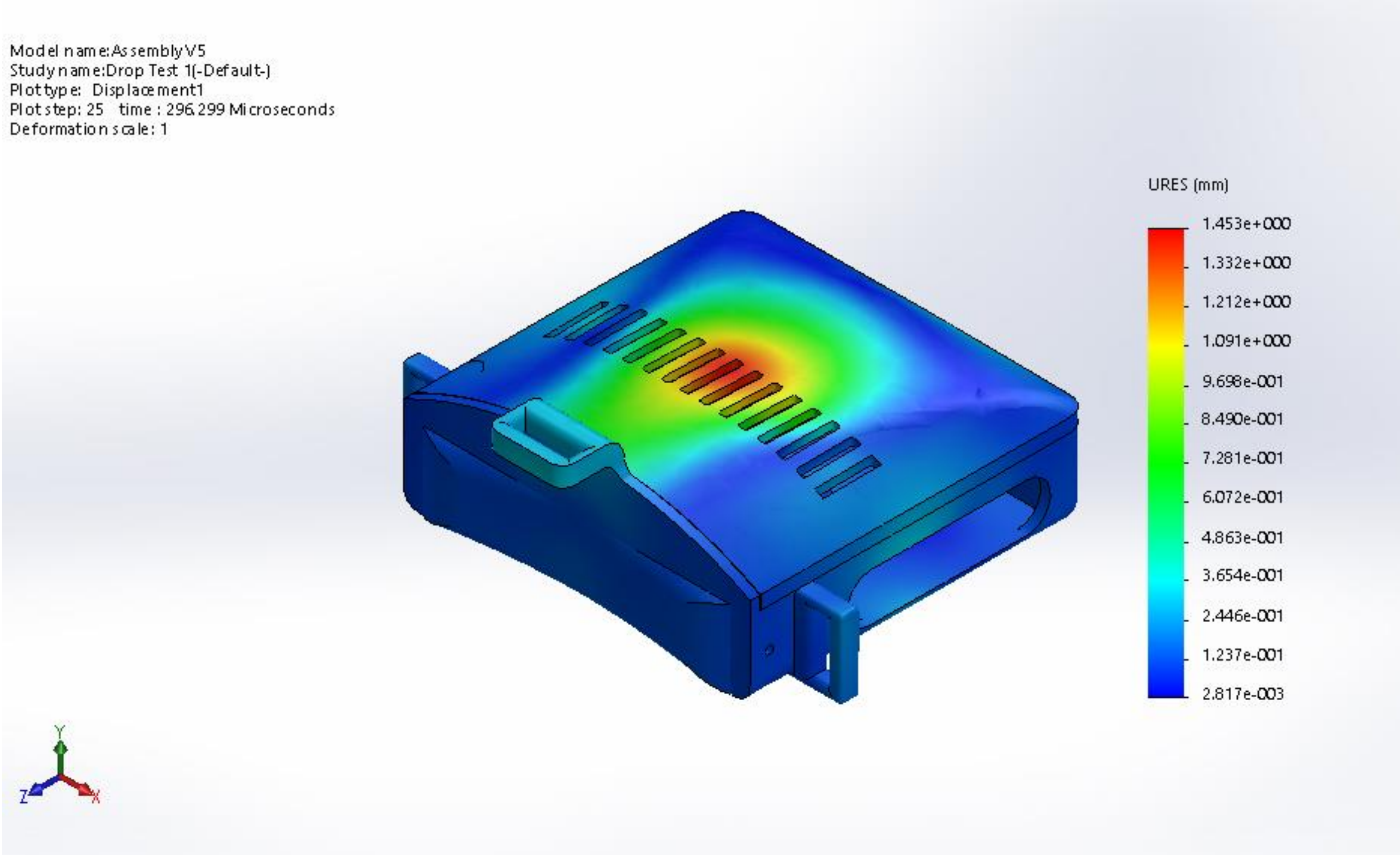
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	132755 N/m^2 Node: 16131	1.16756e+008 N/m^2 Node: 17329



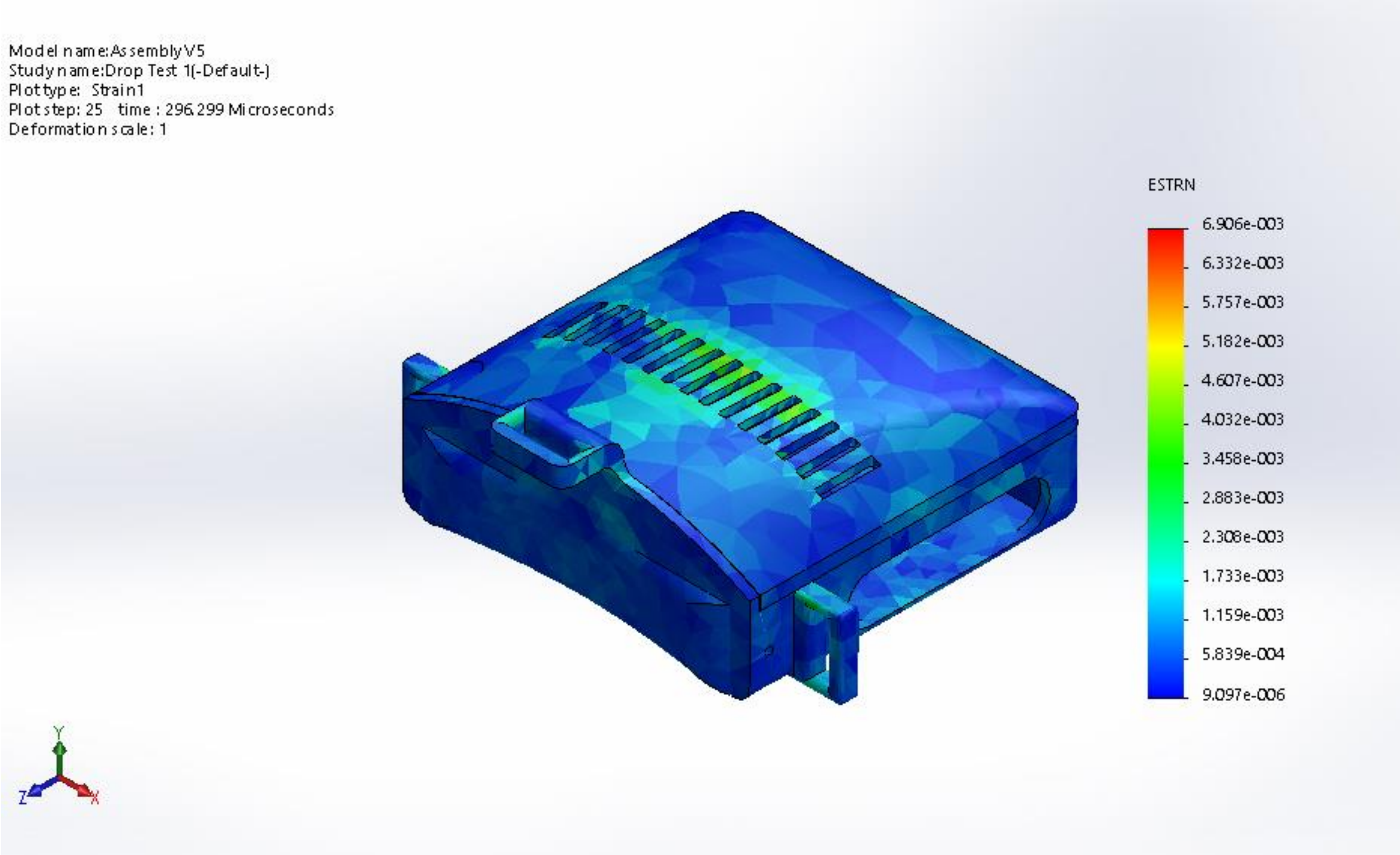
Assembly V5-Drop Test 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.00281657 mm Node: 17792	1.45334 mm Node: 20353



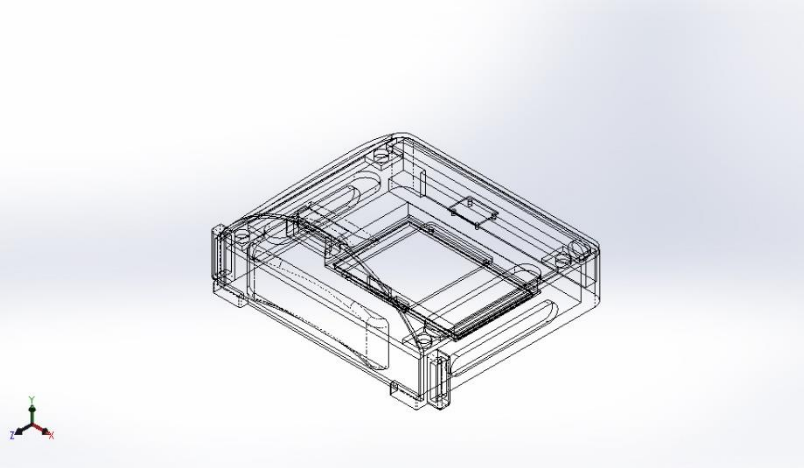
Assembly V5-Drop Test 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	9.0974e-006 Element: 9277	0.00690635 Element: 4481



Assembly V5-Drop Test 1-Strain-Strain1

Conclusion



Simulation of AssemblyV2

Date: Tuesday, March 20, 2018
Designer: Solidworks
Study name: Drop Test 1
Analysis type: Drop Test

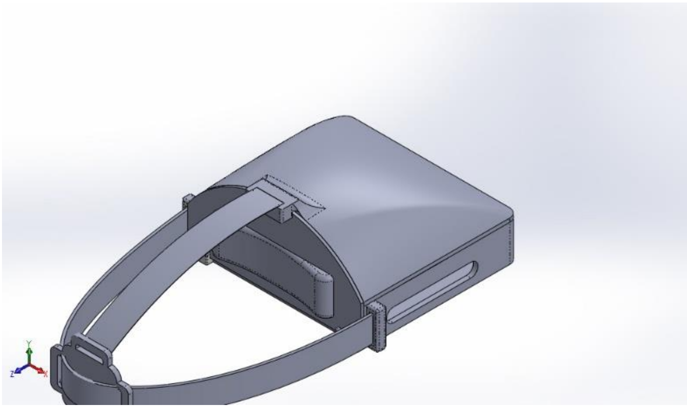
Table of Contents

Description 1
Assumptions 2
Model Information 2
Study Properties 4
Units 4
Material Properties 5
Contact Information 5
Mesh information 6
Study Results 8
Conclusion 10

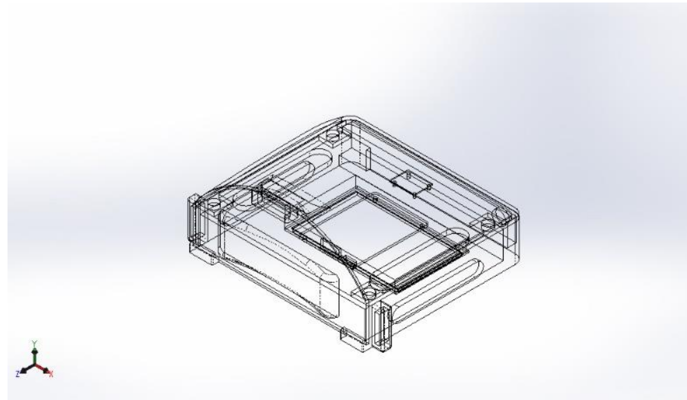
Description

No Data

Assumptions

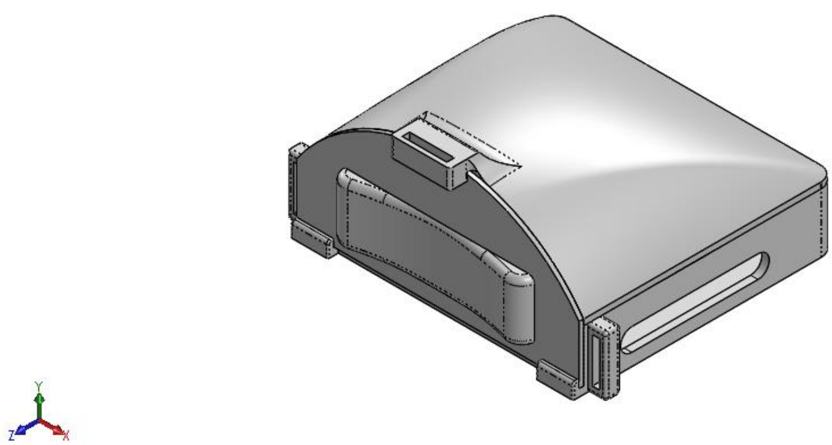


Original Model



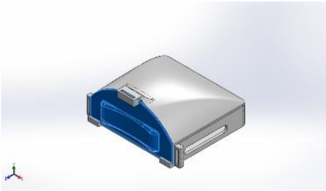
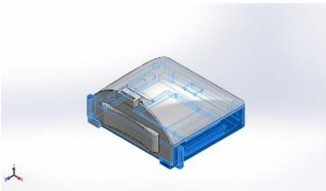
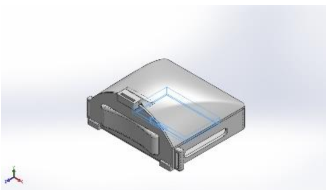
Model Analyzed

Model Information



Model name: AssemblyV2
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified

Fillet2 	Solid Body	**Mass:0.0197607 kg Volume:6.32342e-005 m^3 Density:312.5 kg/m^3 Weight:0.193655 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V2\Back Cover V2.SLDPRT** Nov 05 15:02:13 2017
Cut-Extrude26 	Solid Body	**Mass:0.107369 kg Volume:0.000343581 m^3 Density:312.5 kg/m^3 Weight:1.05222 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V2\Headset V2.SLDPRT** Mar 18 04:01:54 2018
Cut-Extrude2 	Solid Body	**Mass:0.265968 kg Volume:0.000114149 m^3 Density:2330 kg/m^3 Weight:2.60649 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V2\Headset parts V2\Screen v3.SLDPRT** Nov 03 13:40:01 2017
Fillet10 	Solid Body	**Mass:0.0421456 kg Volume:0.000134866 m^3 Density:312.499 kg/m^3 Weight:0.413027 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V2\Top Cover V2.SLDPRT** Mar 18 04:01:53 2018

Study Properties

Study name	Drop Test 1
Analysis type	Drop Test
Mesh type	Solid Mesh
Large displacement	On
Result folder	SOLIDWORKS document (C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V2\FEA)

Setup Information

Type	Drop height
Drop Height from Centroid	1 m
Gravity	9.81 m/s^2
Gravity Reference	Top Plane
Friction Coefficient	0
Target Stiffness	Rigid target
Critical Damping Ratio	0

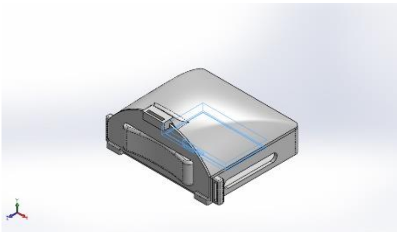
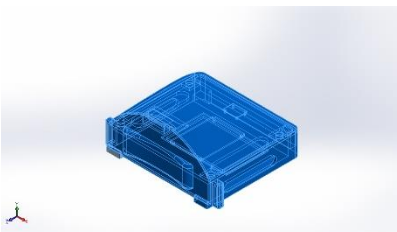
Result Options

Solution Time After Impact	273.1 microsec
Save Results Starting From	0 microsec
No. of Plots	25
No. of Graph Steps Per Plot	20
Number of vertex	0

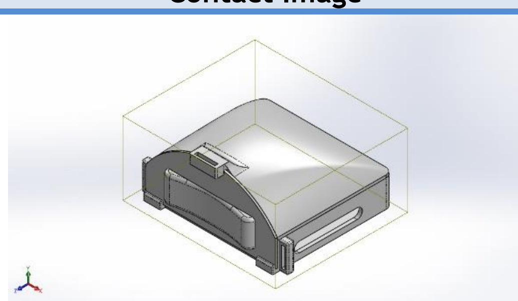
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	**Name:** Silicon **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 1.2e+008 N/m^2 **Elastic modulus:** 1.124e+011 N/m^2 **Poisson's ratio:** 0.28 **Mass density:** 2330 kg/m^3 **Shear modulus:** 4.9e+010 N/m^2	SolidBody 1(Cut-Extrude2)(Screen v3-1)
Curve Data:N/A		
	**Name:** PLA (3D Printed) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 1.3e+007 N/m^2 **Tensile strength:** 1.5e+007 N/m^2 **Elastic modulus:** 3.4e+009 N/m^2 **Poisson's ratio:** 0.38 **Mass density:** 312.5 kg/m^3	SolidBody 1(Fillet2)(Back Cover V2-2), SolidBody 5(Cut-Extrude26)(Headset V2-1), SolidBody 8(Fillet10)(Top Cover V2-1)
Curve Data:N/A		

Contact Information

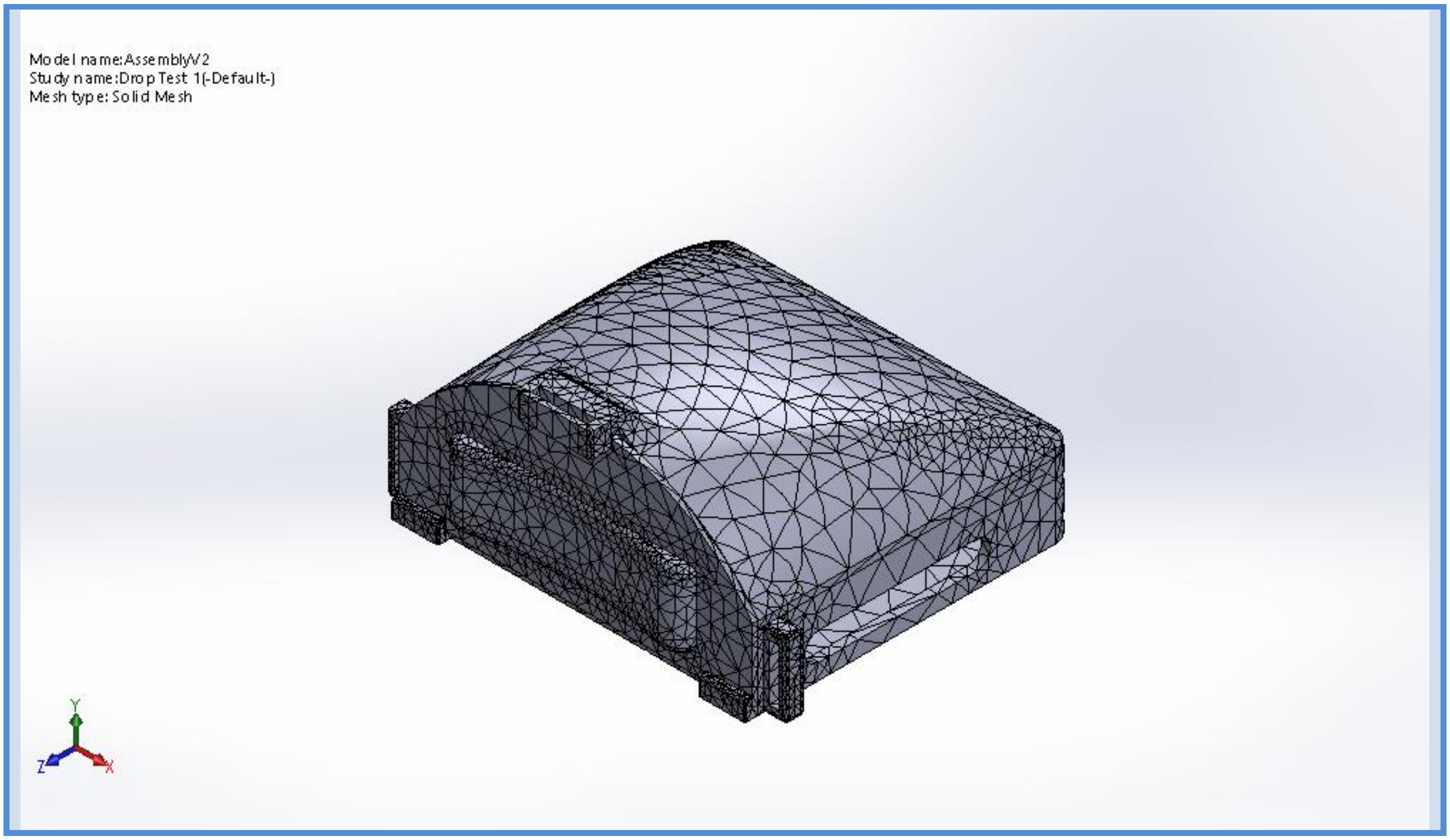
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points
Maximum element size	17.5261 mm
Minimum element size	3.50522 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

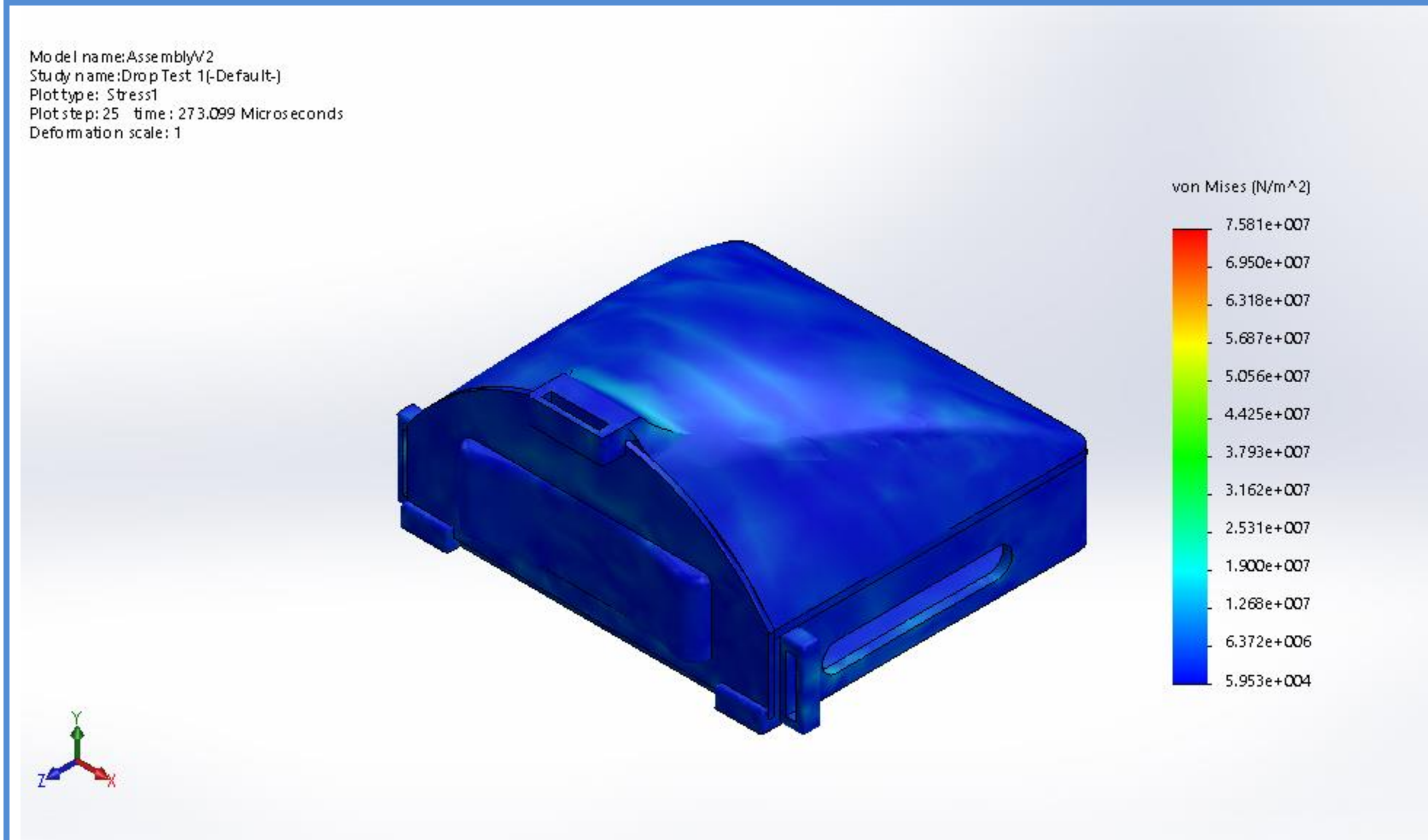
Mesh information - Details

Total Nodes	28975
Total Elements	33335
Maximum Aspect Ratio	58.739
% of elements with Aspect Ratio < 3	63.6
% of elements with Aspect Ratio > 10	2.67
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:05
Computer name:	LENOVO-PC


Model name:AssemblyV2
Study name:Drop Test 1(-Default-)
Mesh type: Solid Mesh
Y
Z
X

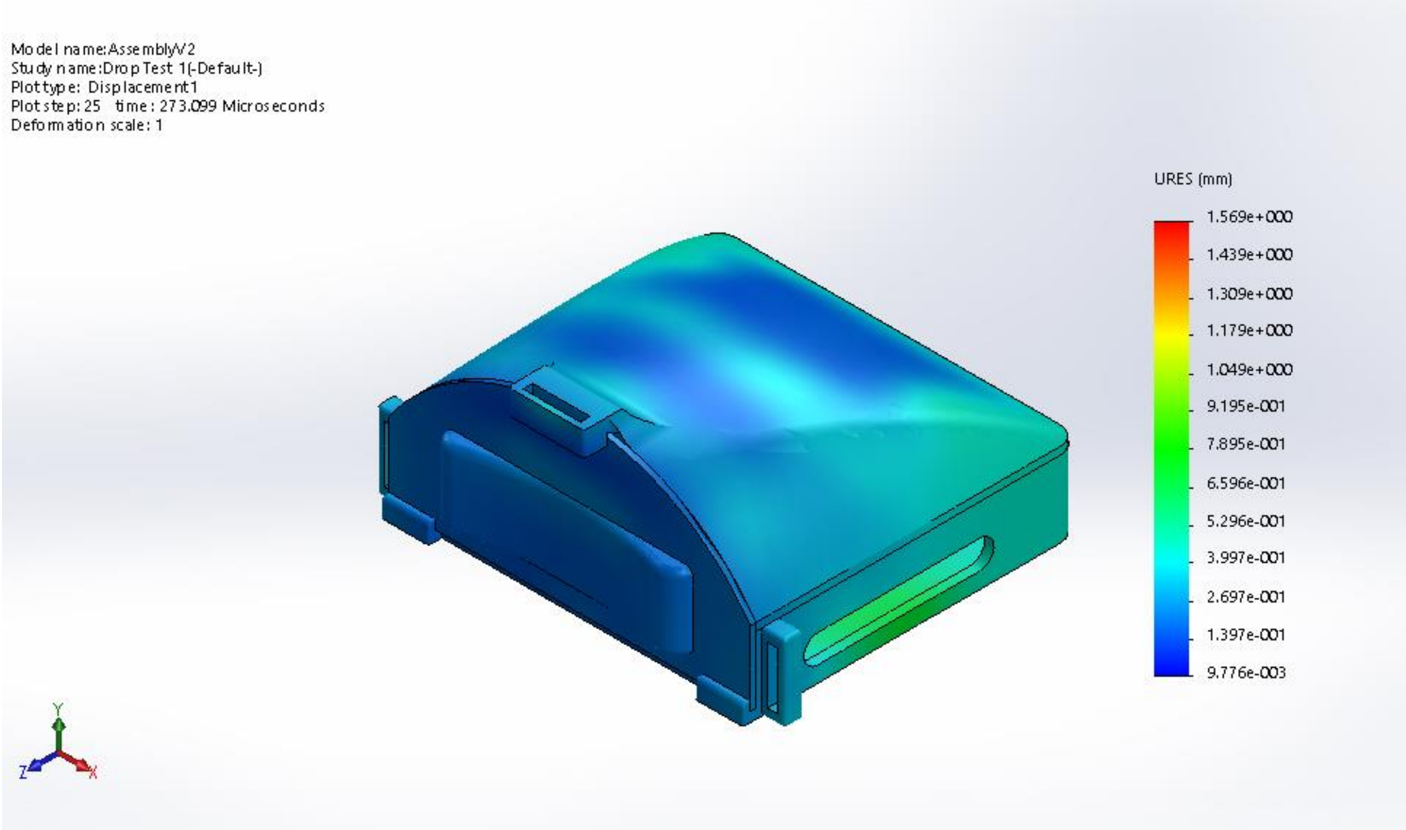
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	59534.8 N/m^2 Node: 20924	7.58101e+007 N/m^2 Node: 19981



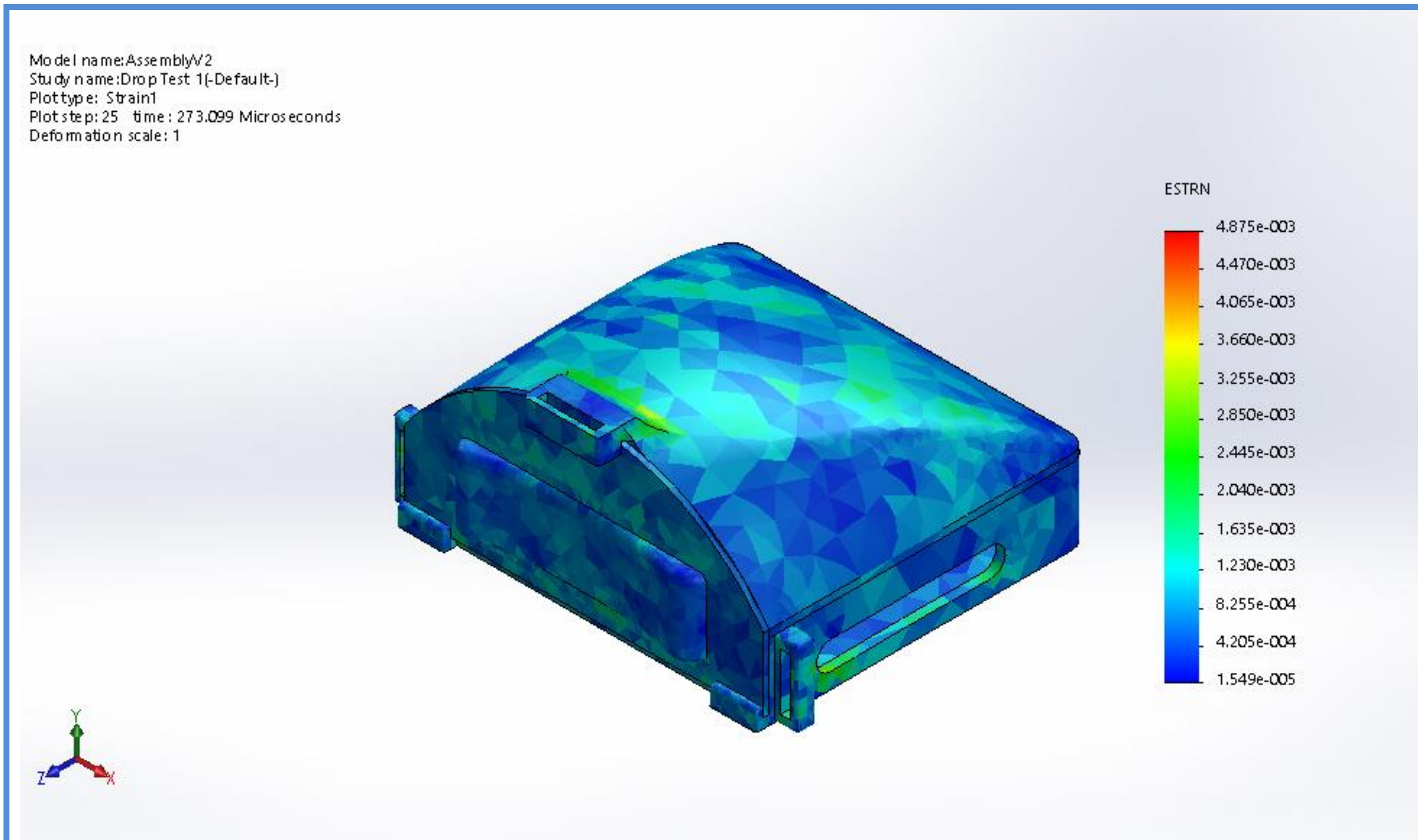
AssemblyV2-Drop Test 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.00977578 mm Node: 16372	1.56928 mm Node: 14333



AssemblyV2-Drop Test 1-Displacement-Displacement1

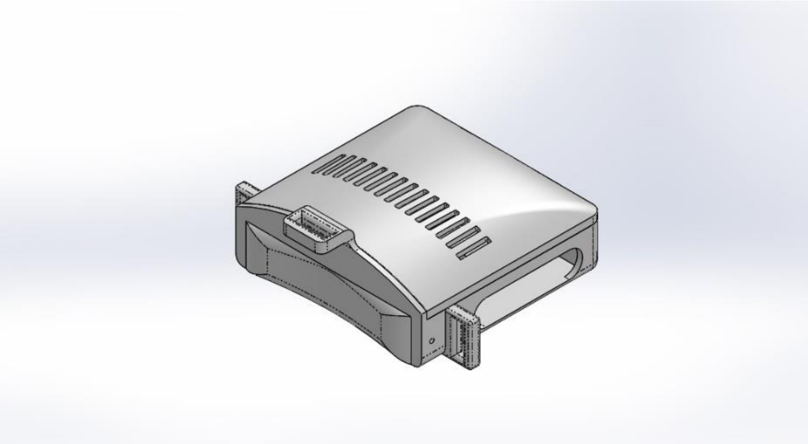
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.54883e-005 Element: 10328	0.00487539 Element: 5205



AssemblyV2-Drop Test 1-Strain-Strain1

Conclusion

Appendix VI: Complete FEA Report (Thermal Analysis)



Simulation of Assembly V5

Date: Thursday, March 29, 2018
Designer: Solidworks
Study name: Thermal 1
Analysis type: Thermal(Steady state)

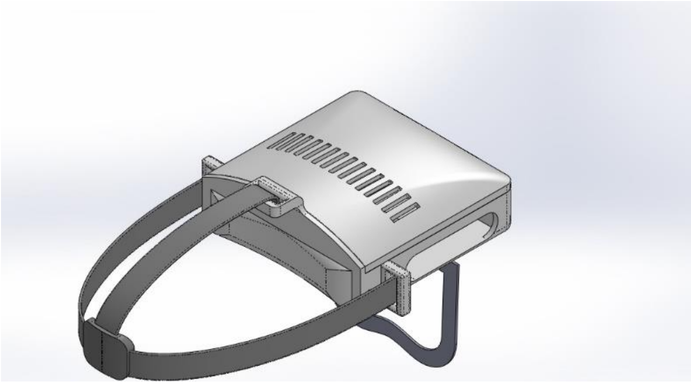
Table of Contents

Description 1
Assumptions 2
Model Information 3
Study Properties 5
Units 5
Material Properties 6
Thermal Loads 7
Contact Information 8
Mesh information 9
Sensor Details ... **Error! Bookmark not defined.**
Study Results 10

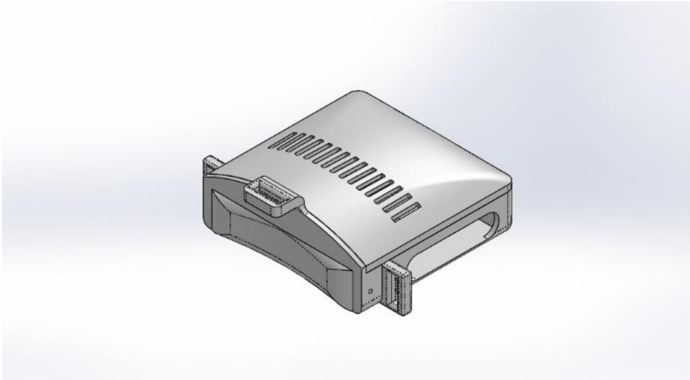
Description

Thermal Analysis

Assumptions

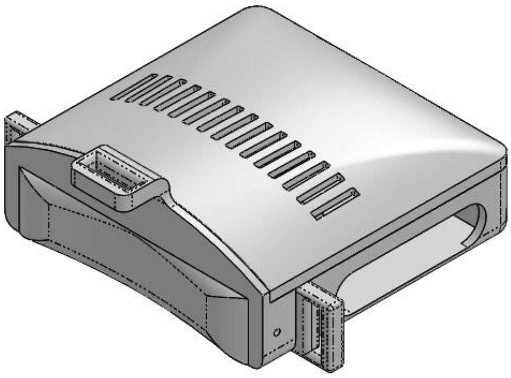


Original Model



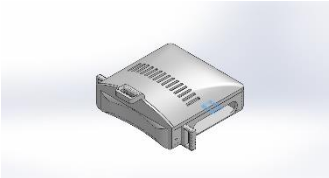
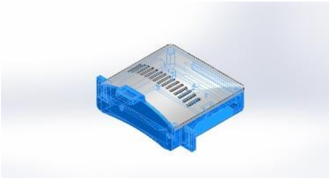
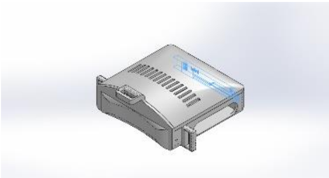
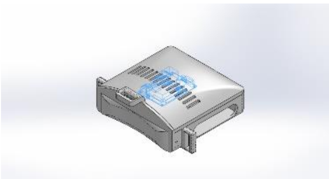
Model Analyzed

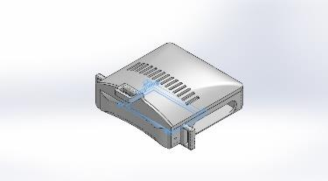
Model Information



Model name: Assembly V5
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude2 	Solid Body	Mass:0.00495064 kg Volume:2.12474e-006 m^3 Density:2330 kg/m^3 Weight:0.0485163 N	C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V3\Adafruit BNO055 motion sensor v2.SLDPRT Mar 17 00:06:37 2018
Fillet42 	Solid Body	Mass:0.0930418 kg Volume:0.000297734 m^3 Density:312.5 kg/m^3 Weight:0.91181 N	C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V5\Headset V5.SLDPRT Mar 20 19:58:34 2018
Cut-Extrude11 	Solid Body	Mass:0.049033 kg Volume:2.10442e-005 m^3 Density:2330 kg/m^3 Weight:0.480524 N	C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V3\Intel real sense camera R200.SLDPRT Mar 18 04:01:41 2018
Cut-Extrude7 	Solid Body	Mass:0.110083 kg Volume:4.72461e-005 m^3 Density:2330 kg/m^3 Weight:1.07882 N	C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V3\Odroid XU4.SLDPRT Mar 17 00:09:37 2018
Boss-Extrude7	Solid Body	Mass:0.183091 kg Volume:7.85796e-005 m^3 Density:2330 kg/m^3 Weight:1.79429 N	C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V4\Screen V4.SLDPRT Mar 17 00:05:53 2018

			
Cut-Extrude3 	Solid Body	**Mass:0.0413043 kg Volume:0.000132173 m^3 Density:312.501 kg/m^3 Weight:0.404782 N**	**C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V5\Top Cover V5.SLDPRT** Mar 20 00:49:03 2018

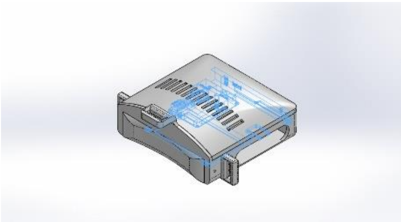
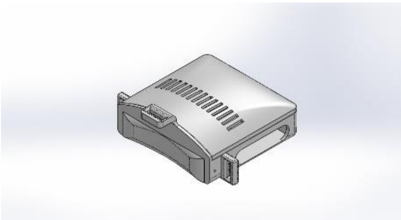
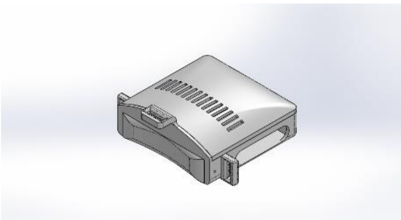
Study Properties

Study name	Thermal 1
Analysis type	Thermal(Steady state)
Mesh type	Solid Mesh
Solver type	FFEPlus
Solution type	Steady state
Contact resistance defined?	No
Result folder	SOLIDWORKS document (C:\Users\Amir Shawwa\Desktop\W18\MECH 490\MECH 490\ARHeadset\CADS\AR V5\FEA)

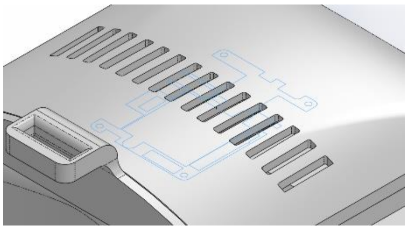
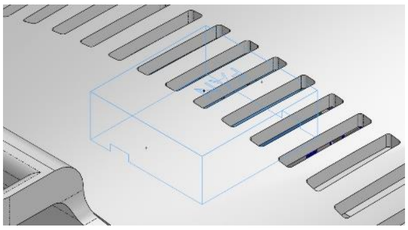
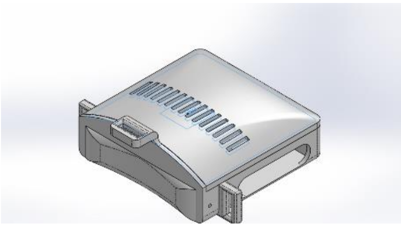
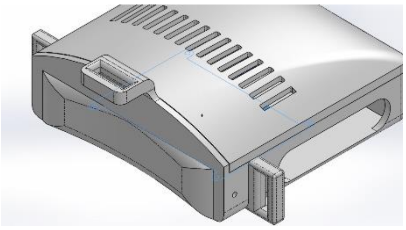
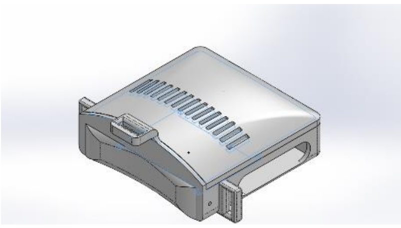
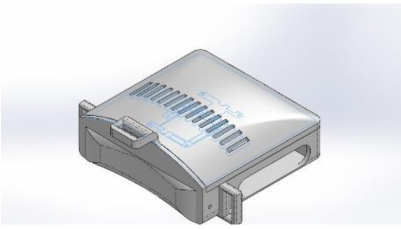
Units

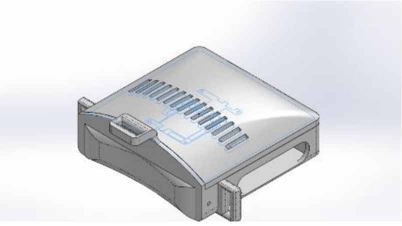
Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

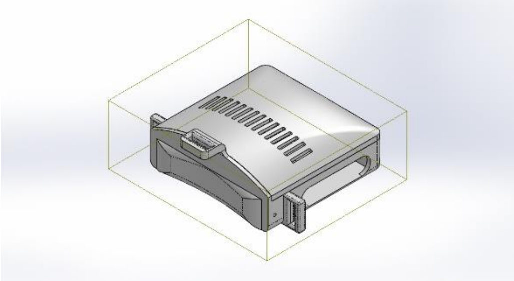
Model Reference	Properties	Components
	**Name:** Silicon **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 124 W/(m.K) **Mass density:** 2330 kg/m^3	SolidBody 1(Cut-Extrude2)(Adafruit BNO055 motion sensor v2-1), SolidBody 1(Cut-Extrude11)(Intel real sense camera R200-1), SolidBody 1(Cut-Extrude7)(Odroid XU4-1), SolidBody 1(Boss-Extrude7)(Screen V4-1)
Curve Data:N/A		
	**Name:** Acrylic (Medium-high impact) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.21 W/(m.K) **Specific heat:** 1500 J/(kg.K) **Mass density:** 1200 kg/m^3	SolidBody 1(Fillet42)(Headset V5-1), SolidBody 1(Cut-Extrude3)(Top Cover V5-2)
Curve Data:N/A		
	**Name:** PLA (3D Printed) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.13 W/(m.K) **Specific heat:** 1800 J/(kg.K) **Mass density:** 312.5 kg/m^3	<Material_ComponentList1/>
Curve Data:N/A		
	**Name:** ABS **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.2256 W/(m.K) **Specific heat:** 1386 J/(kg.K) **Mass density:** 1020 kg/m^3	<Material_ComponentList1/>
Curve Data:N/A		

Thermal Loads

Load name	Load Image	Load Details
Temperature-1		**Entities:** 1 face(s) **Temperature:** 50 Celsius
Convection-1		**Entities:** 5 face(s) **Convection Coefficient:** 100 W/(m^2.K) **Time variation:** Off **Temperature variation:** Off **Bulk Ambient Temperature:** 298.15 Kelvin **Time variation:** Off
Radiation-1		**Entities:** 2 face(s) **Radiation Type:** Surface to surface **Open system:** On **Ambient Temperature:** 25 Celsius **Emissivity:** 0.95
Temperature-3		**Entities:** 1 face(s) **Temperature:** 35 Celsius
Radiation-2		**Entities:** 2 face(s) **Radiation Type:** Surface to surface **Open system:** On **Ambient Temperature:** 25 Celsius **Emissivity:** 0.95
Radiation-3		**Entities:** 2 face(s) **Radiation Type:** Surface to ambient **Ambient Temperature:** 25 Celsius **Emissivity:** 0.95 **View Factor:** 0.5

Radiation-4		**Entities:** 2 face(s) **Radiation Type:** Surface to ambient **Ambient Temperature:** 25 Celsius **Emissivity:** 0.95 **View Factor:** 0.5

Contact Information

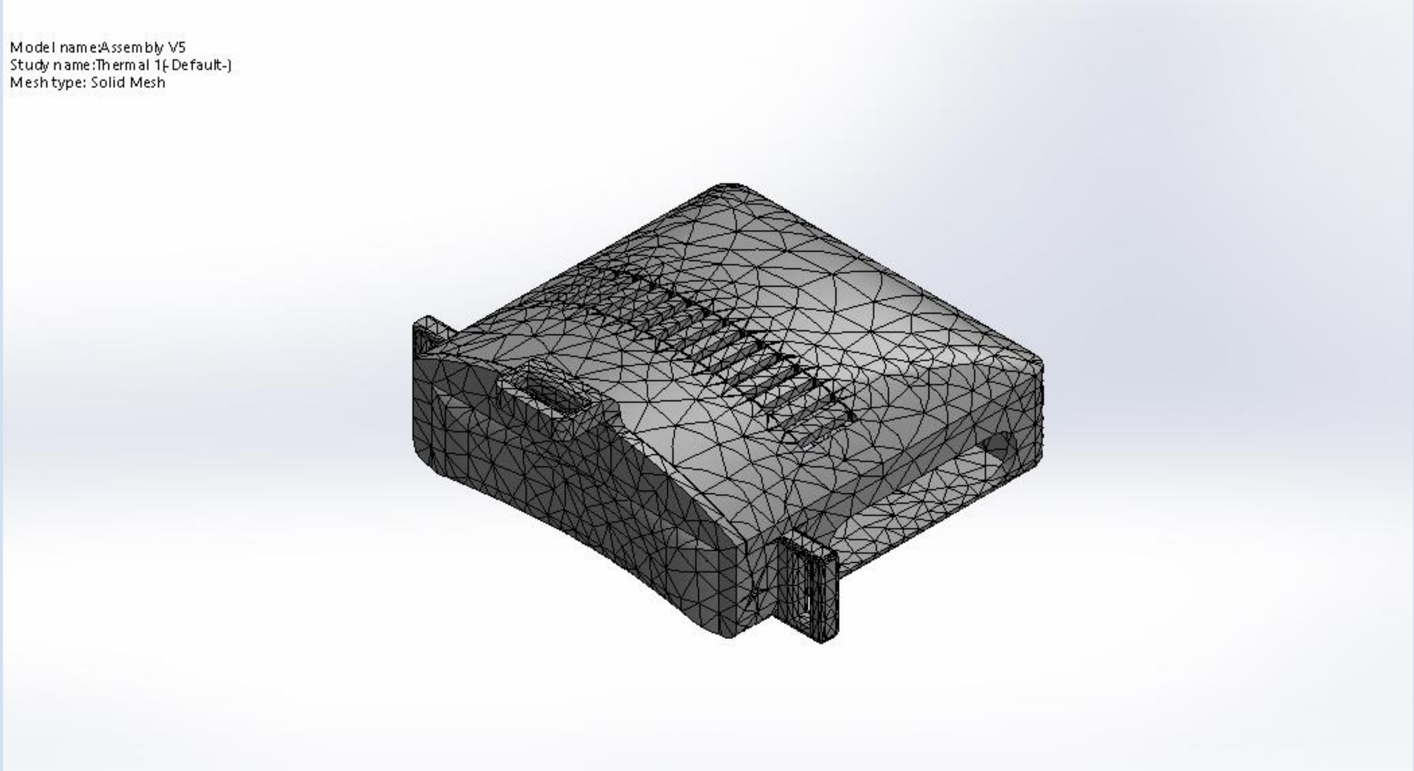
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points
Maximum element size	32.7399 mm
Minimum element size	6.54799 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

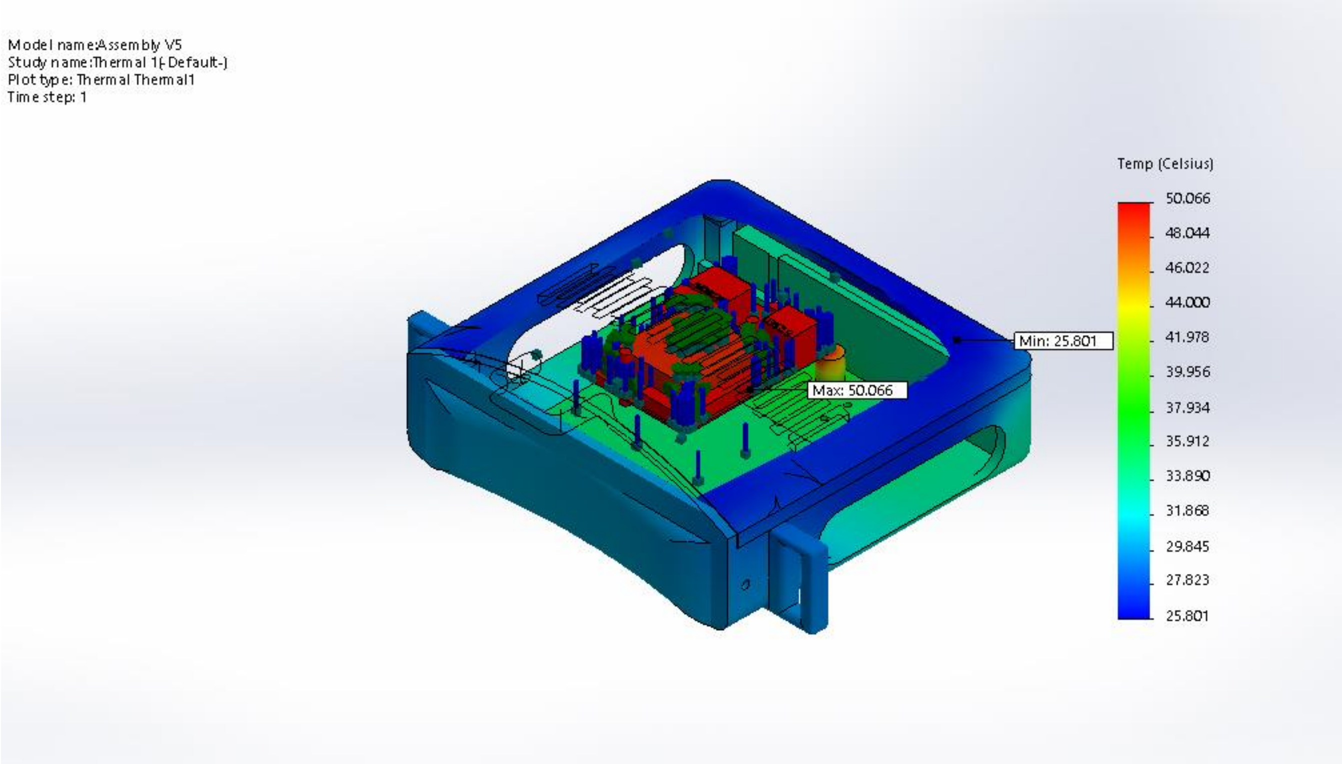
Mesh information - Details

Total Nodes	39572
Total Elements	20741
Maximum Aspect Ratio	122.17
% of elements with Aspect Ratio < 3	51.4
% of elements with Aspect Ratio > 10	5.29
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:07
Computer name:	LENOVO-PC



Study Results

Name	Type	Min	Max
Thermal1	TEMP: Temperature	25.8012 Celsius Node: 34039	50.0664 Celsius Node: 21463



Assembly V5-Thermal 1-Thermal-Thermal1

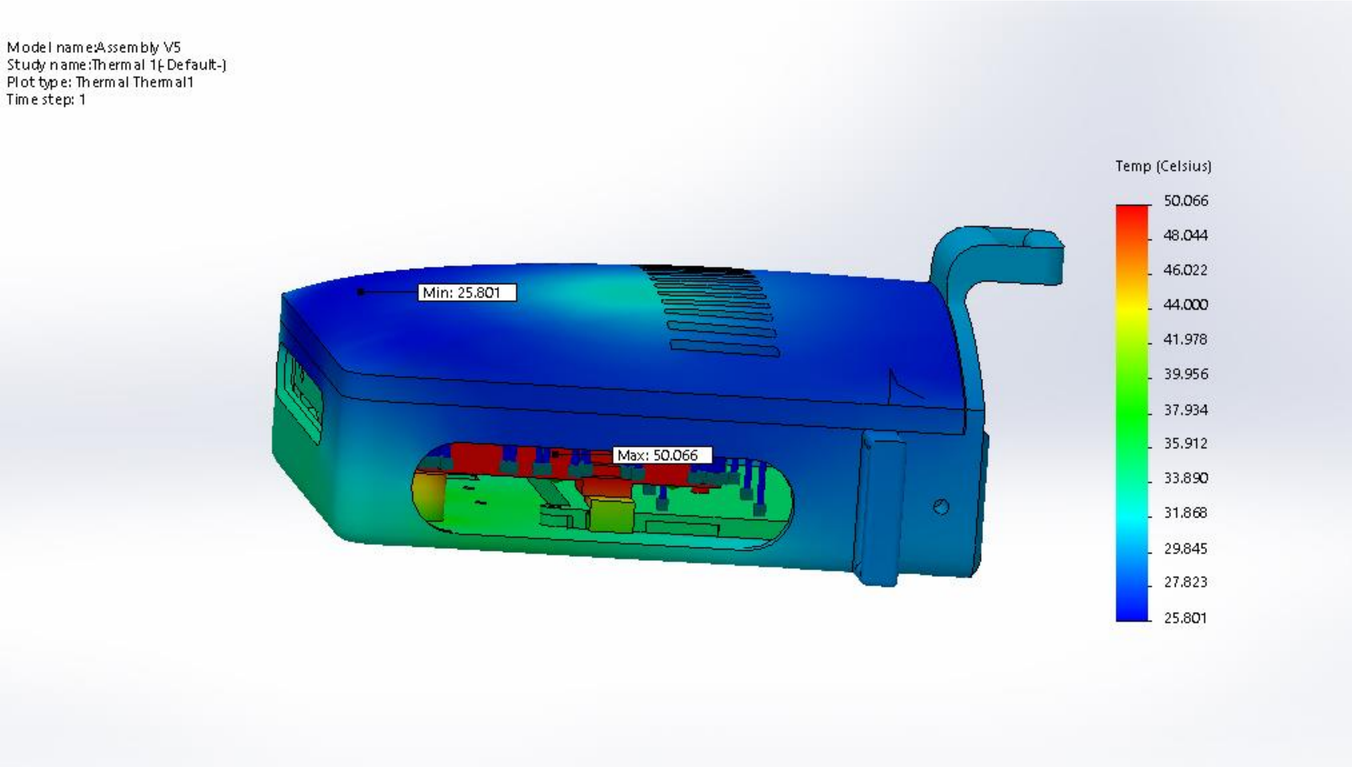


Image-1

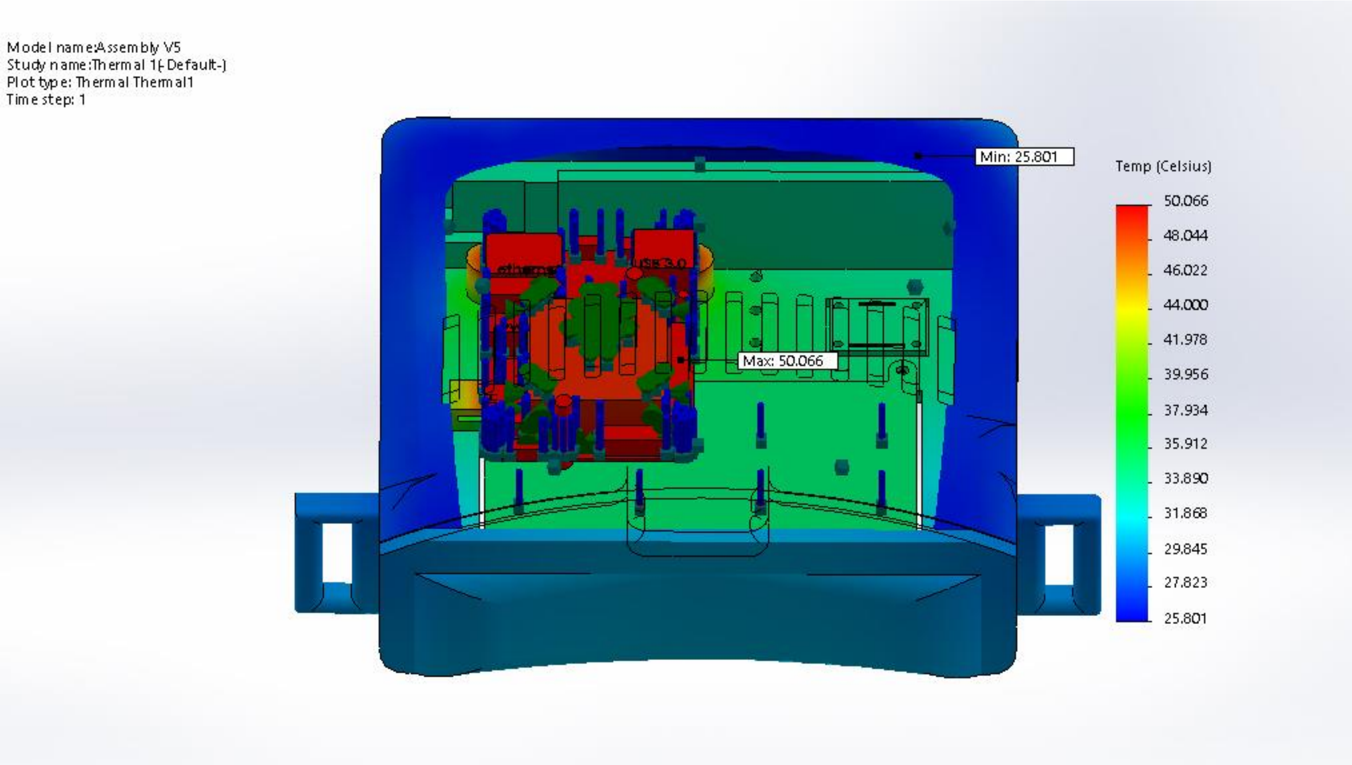
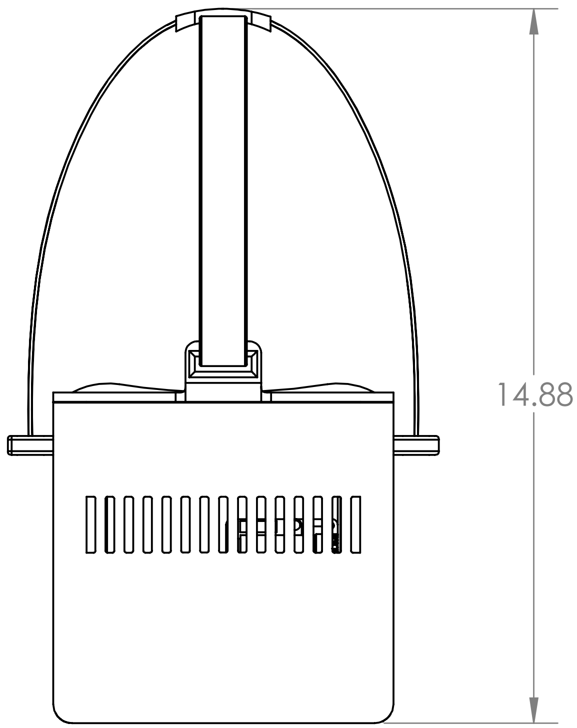
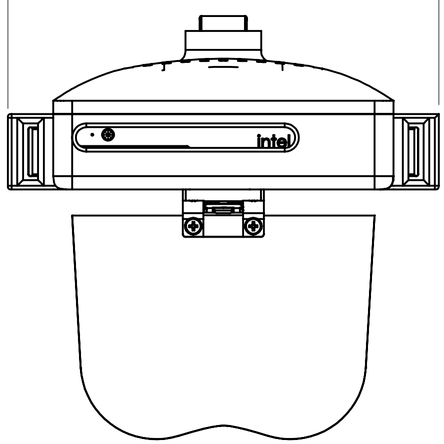
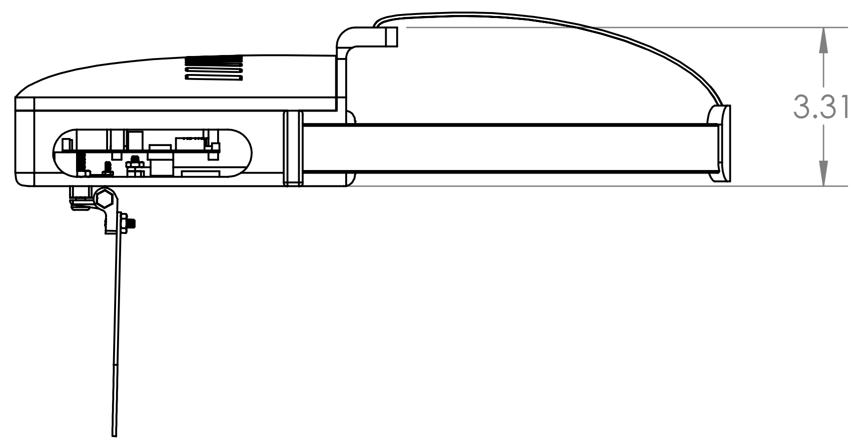


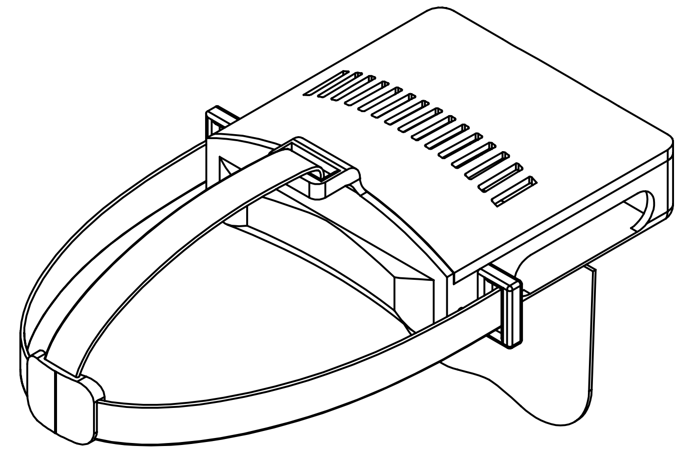
Image-2

Appendix VII: Engineering Drawings (Revision 5)



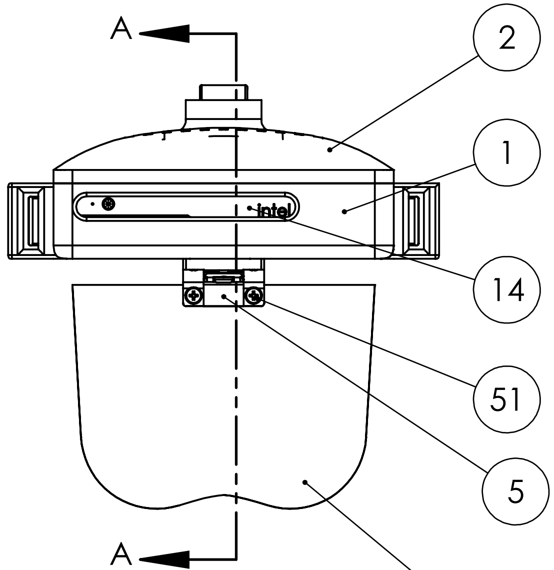


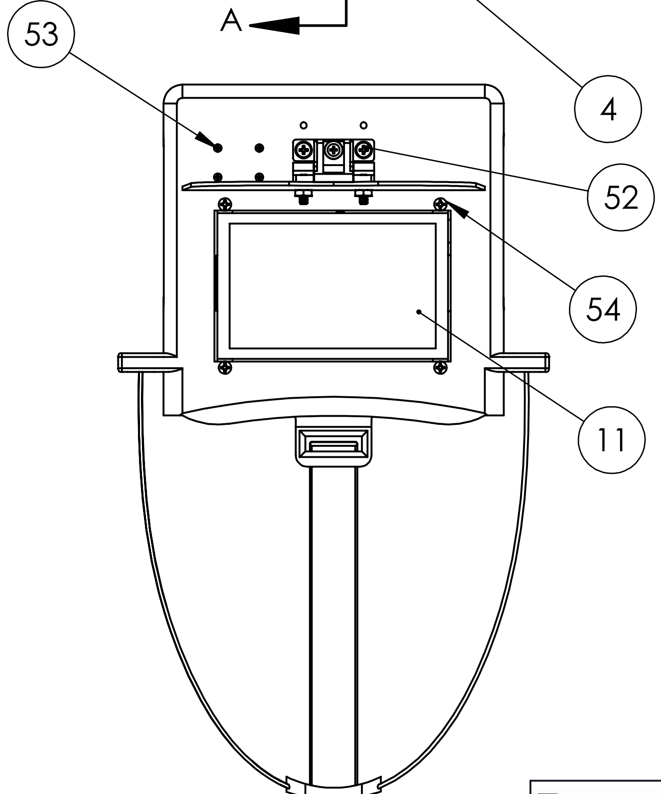


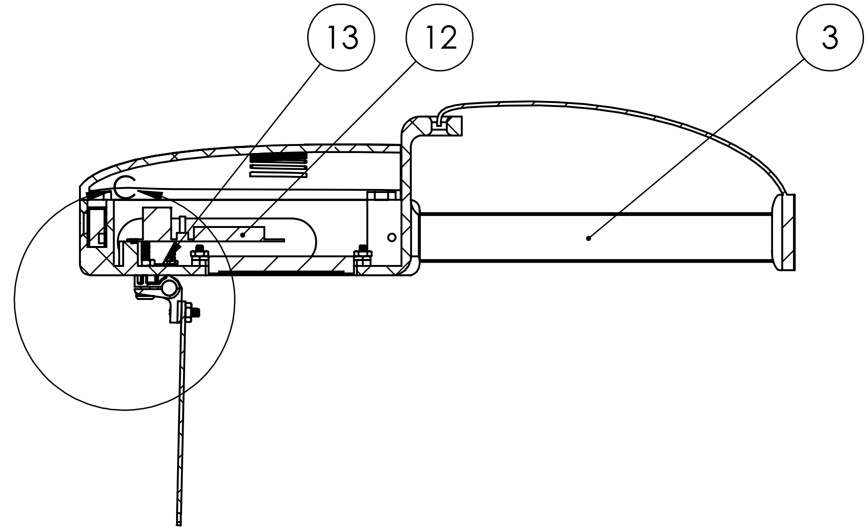


ISOMETRIC VIEW
SCALE: NONE
FOR REFERENCE ONLY

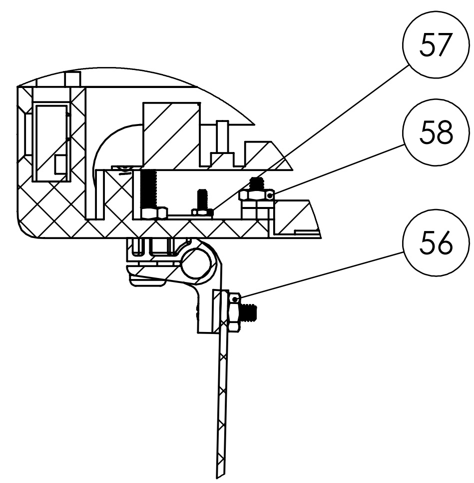
Concordia University	MATERIAL **VARIES**		UNLESS OTHERWISE SPECIFIED: SURFACE ROUGHNESS √ ; TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°	TITLE **ASSEMBLY**
	FINISH			
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **A. SHAWWA**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED	A SIZE	DATE **3/19/2018** USED ON **MECH 490**
	DRAFTER **M. A. YADAO**	APPROVED **R. PATEL**	SCALE **1:4**	SHEET **1 /12** DWG NO. **11809301** REV NO. **05**







SECTION A-A
SCALE 1 : 4

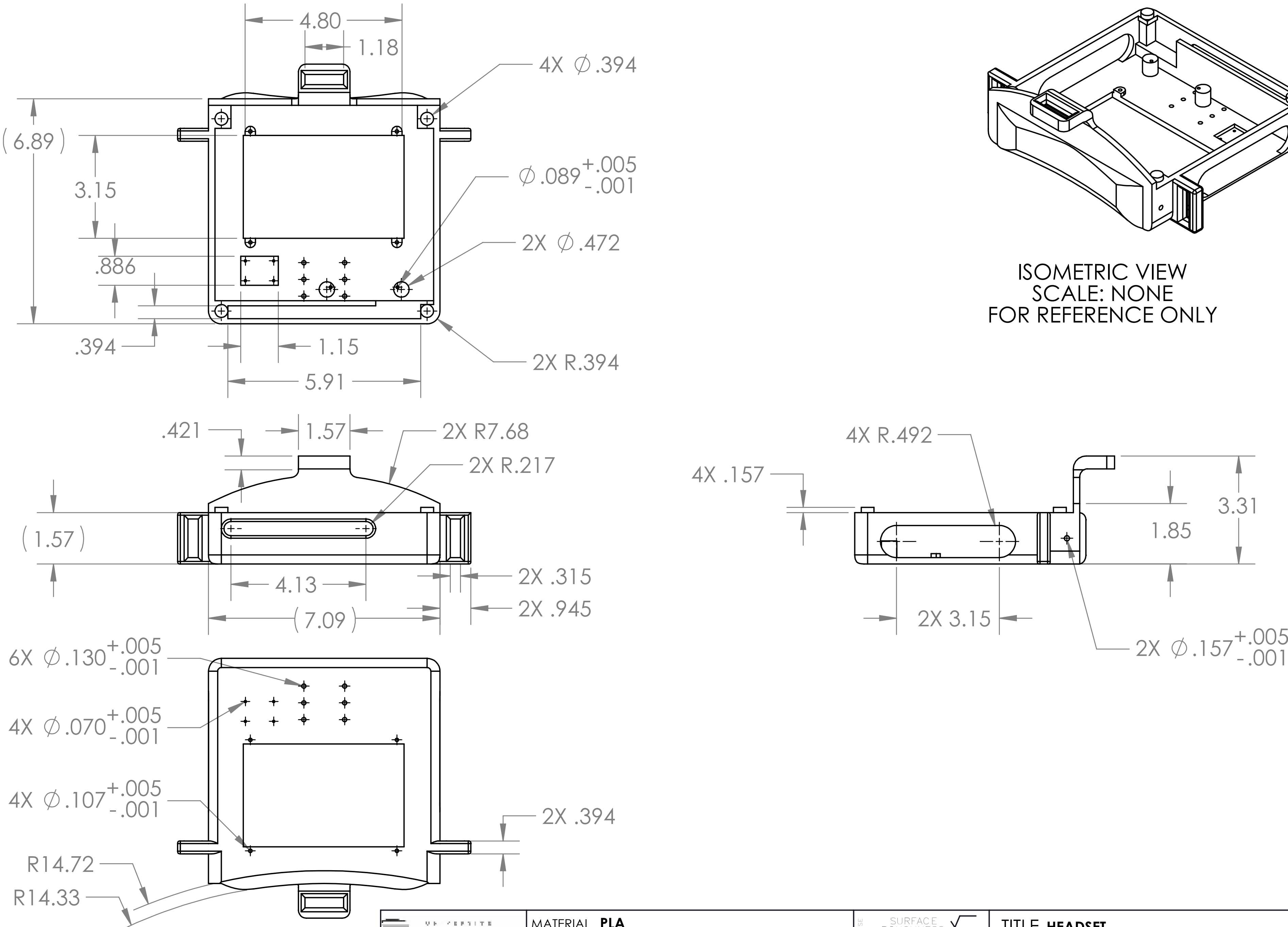


DETAIL C
SCALE 1 : 2

Concordia	MATERIAL **VARIES**		SURFACE ROUGHNESS	TITLE **ASSEMBLY - SECTIONS**	
	FINISH		UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1 .X ± .05 .XX ± .005 .XXX ± .002 ANGLE ± .5°		
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **A. SHAWWA**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED		A SIZE	DATE **3/19/2018** USED ON **MECH 490**
	DRAFTER **M. A. YADAO**	APPROVED **R. PATEL**	SCALE **1:4**	SHEET **2 /12**	DWG NO. **11809302** REV NO. **05**

ITEM NO.	DESCRIPTION	PART NUMBER	MNF/OEM/SPL	QTY.
1	HEADSET	11809001	EXTERNAL - 3D HUBS	1
2	TOP COVER	11809002	EXTERNAL - 3D HUBS	1
3	HEAD STRAP	11809005	STUDENT - AMIR SHAWWA	1
4	HEADS-UP DISPLAY	11809006	STUDENT - KOSTAS ZOITAKIS	1
5	ADJUSTABLE-FRICTION HINGE	1791A440	MCMASTER	1
11	SCREEN	11809011	AMAZON	1
12	ODROID XU4	0007A	AMERIDROID.COM	1
13	ADAFRUIT BNO055 MOTION SENSOR	ADA2472	ADAFRUIT	1
14	INTEL REALSENSE CAMERA R200	MM#939143	INTEL REALSENSE	1
51	PAN HEAD PHILLIPS [#8-32 x 1/2" LG]	90272A194	MCMASTER	2
52	PAN HEAD PHILLIPS [#8-32 x 7/8" LG]	90272A198	MCMASTER	2
53	FLAT HEAD PHILLIPS [#2-56 x 1/2" LG]	90273A070	MCMASTER	4
54	FLAT HEAD PHILLIPS [#6-32 x 5/8" LG]	90273A150	MCMASTER	4
55	FLAT HEAD PHILLIPS [#4-48 x 3/8" LG]	91771A742	MCMASTER	2
56	HEX NUT [#8-32]	90480A009	MCMASTER	4
57	HEX NUT [#2-56]	90480A003	MCMASTER	4
58	HEX NUT [#6-32]	90480A007	MCMASTER	4

Concordia University	MATERIAL		SURFACE ROUGHNESS / UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°	TITLE BOM
	FINISH			
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **A. SHAWWA**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED	A SIZE	DATE **3/19/2018** USED ON **MECH 490**
	DRAFTER **M. A. YADAO**	APPROVED **R. PATEL**	SCALE **1:8**	SHEET **3 /12** DWG NO. **11809303** REV NO. **05**



Concordia University

PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY

MATERIAL **PLA**

FINISH **CLEAN**

DESIGNER **A. SHAWWA**

ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED

DRAFTER **M. A. YADAO**

APPROVED **R. PATEL**

UNLESS OTHERWISE SPECIFIED

SURFACE ROUGHNESS √

TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°

SCALE **1:4**

TITLE **HEADSET**

A SIZE

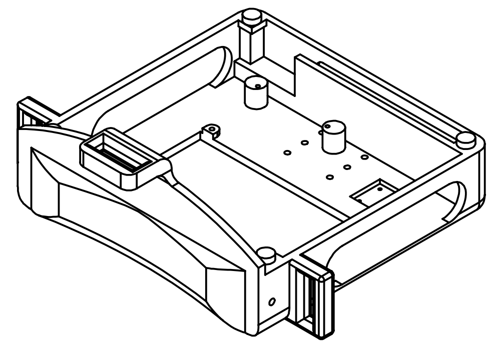
DATE **3/19/2018**

USED ON **MECH 490**

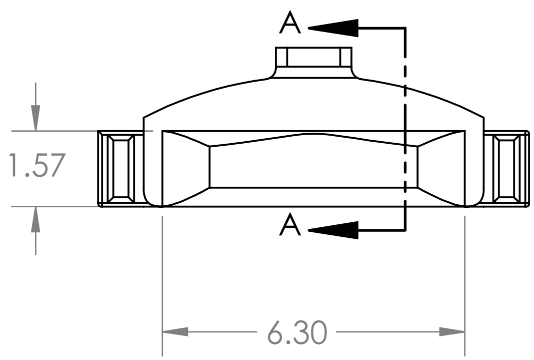
SHEET **4 /12**

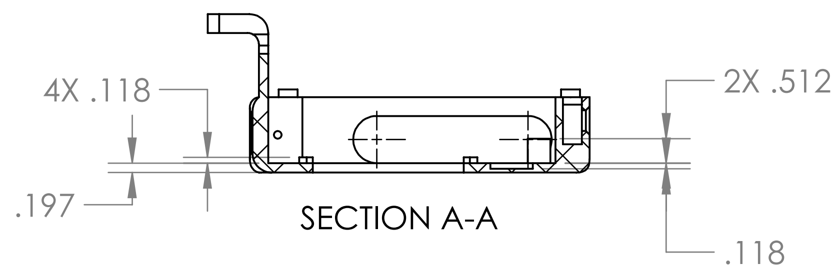
DWG NO. **11809001**

REV NO. **05**



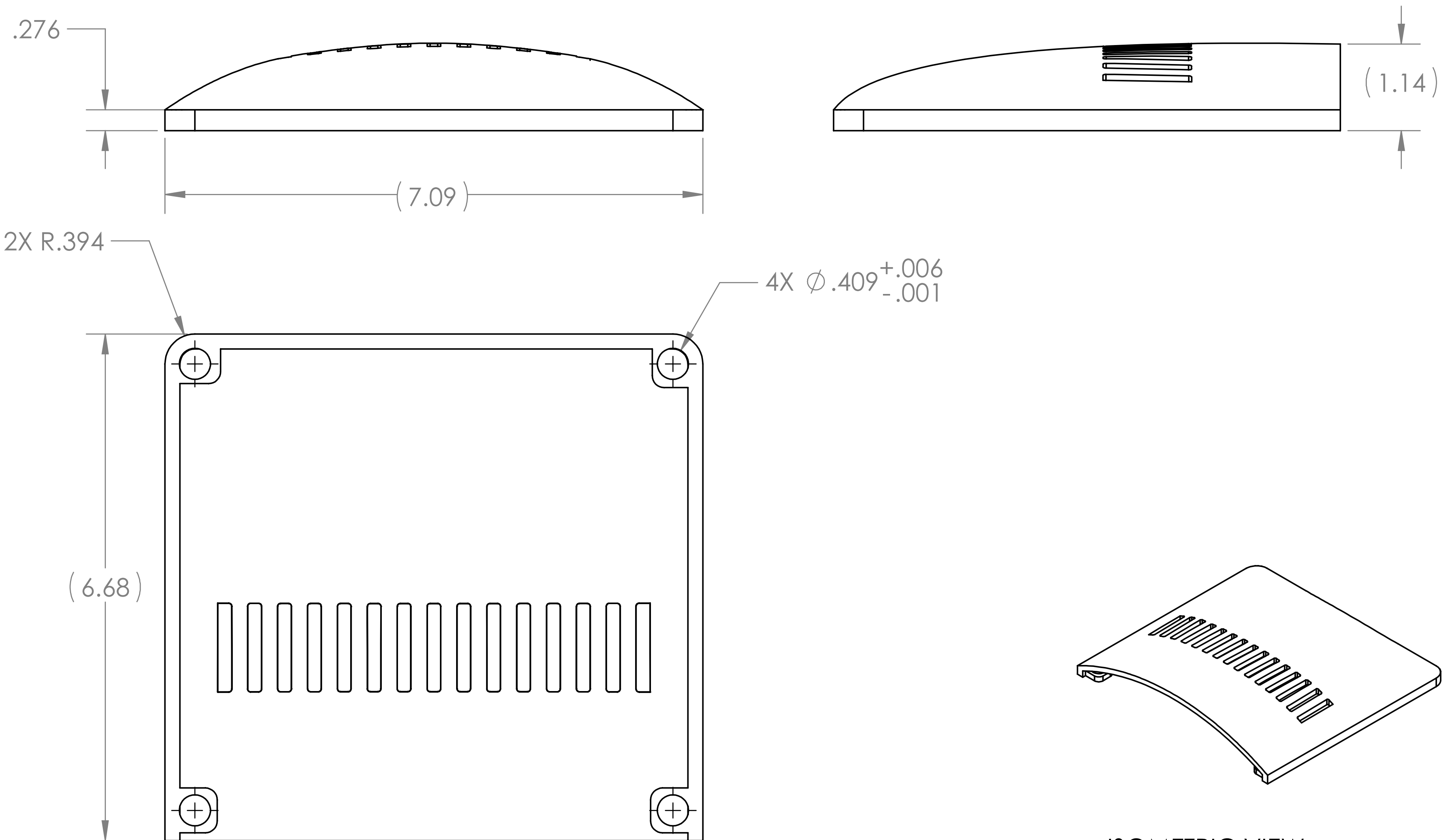
ISOMETRIC VIEW
SCALE: NONE
FOR REFERENCE ONLY





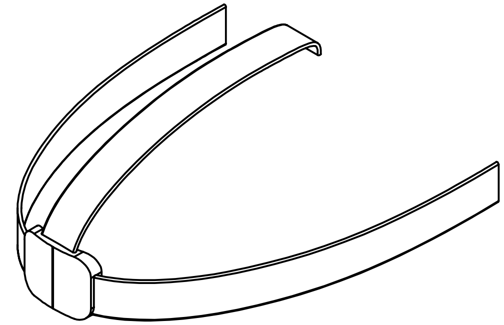
SECTION A-A

Concordia University	MATERIAL PLA		SURFACE ROUGHNESS	TITLE HEADSET
	FINISH CLEAN		TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5° (UNLESS OTHERWISE SPECIFIED)	
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER A. SHAWWA	ALL DIMENSIONS IN INCHES UNLESS OTHERWISE SPECIFIED		A SIZE · DATE 3/19/2018 · USED ON MECH 490
	DRAFTER M. A. YADAO	APPROVED R. PATEL	SCALE 1:4	SHEET 5 /12 · DWG NO. 11809001 · REV NO. 05



ISOMETRIC VIEW
SCALE: NONE
FOR REFERENCE ONLY

Concordia University	MATERIAL **PLA**		SURFACE ROUGHNESS √	TITLE **TOP COVER**	
	FINISH **CLEAN**		UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°		
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **A. SHAWWA**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED		A SIZE	DATE **3/19/2018**	USED ON **MECH 490**
	DRAFTER **M. A. YADAO**	APPROVED **R. PATEL**	SCALE **1:2**	SHEET **6 /12**	DWG NO. **11809002**	REV NO. **05**



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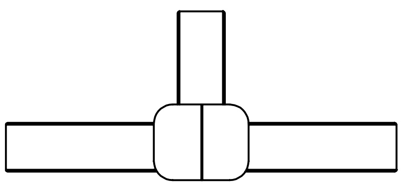
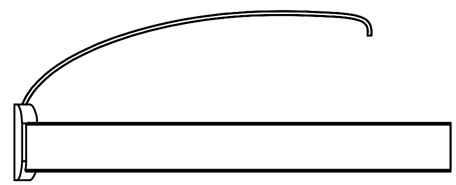
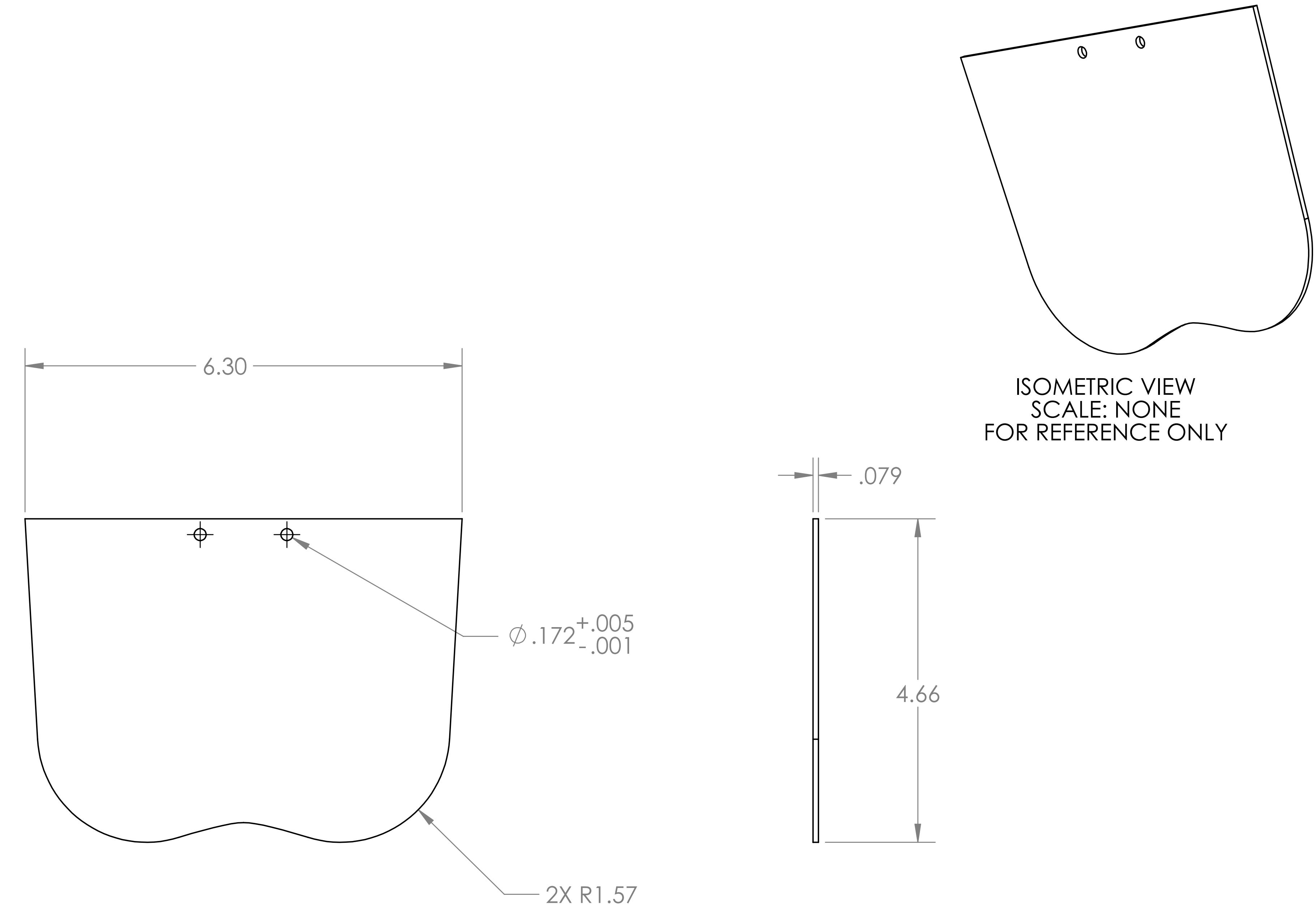
FOR REFERENCE ONLY

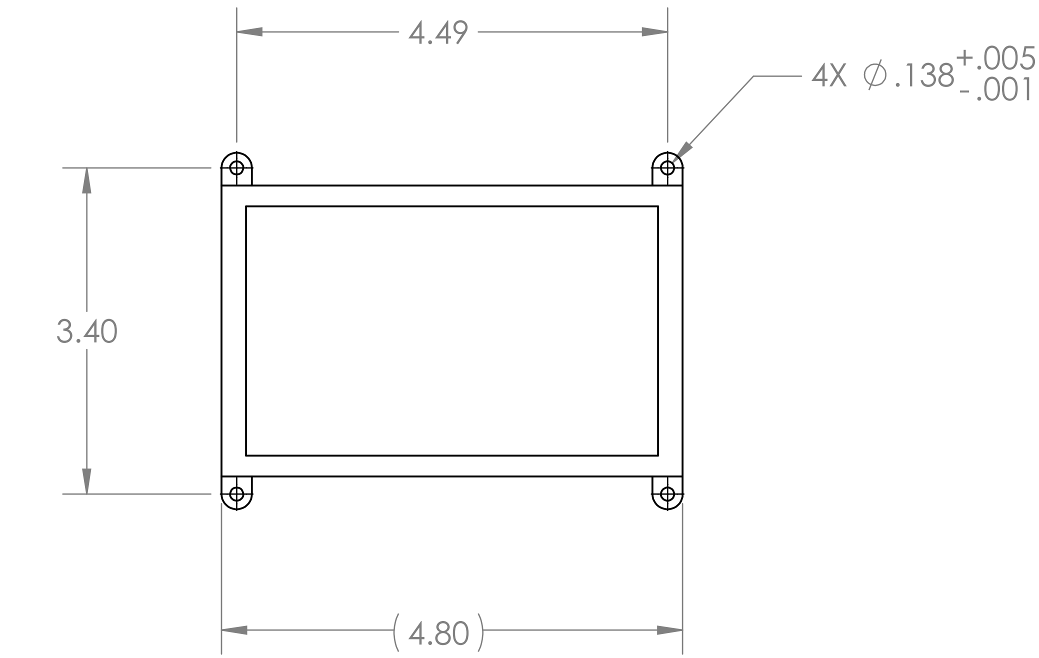


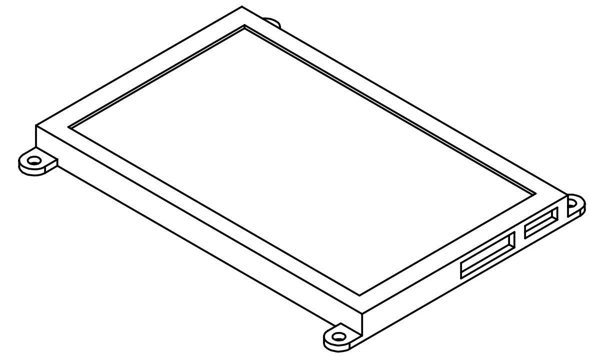


MATERIAL **STRETCHABLE FABRIC**
FINISH
DESIGNER **A. SHAWWA**
ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED
DRAFTER **M. A. YADAO**
APPROVED **R. PATEL**
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
TOLERANCES X ± .1
.X ± .05
.XX ± .005
.XXX ± .002
ANGLE ± .5°
SCALE **1:4**
TITLE **HEAD STRAP**
A SIZE
DATE **3/19/2018**
USED ON **MECH 490**
SHEET **7 /12**
DWG NO. **11809005**
REV NO. **02**

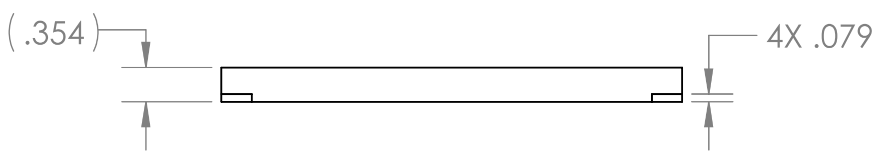


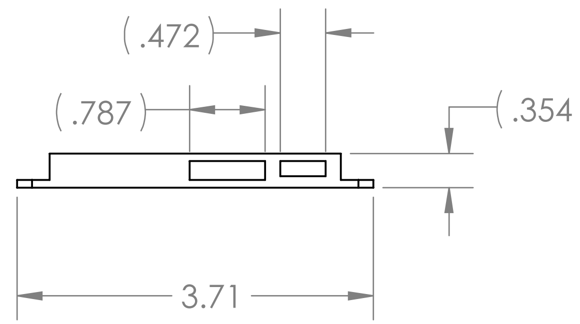
Concordia University	MATERIAL **ACRYLIC**		SURFACE ROUGHNESS √	TITLE **HEADS UP DISPLAY**	
	FINISH		UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°		
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **A. SHAWWA**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED		A SIZE	DATE **3/19/2018** USED ON **MECH 490**
	DRAFTER **M. A. YADAO**	APPROVED **R. PATEL**	SCALE **1:2**	SHEET **8 /12**	DWG NO. **11809006** REV NO. **02**



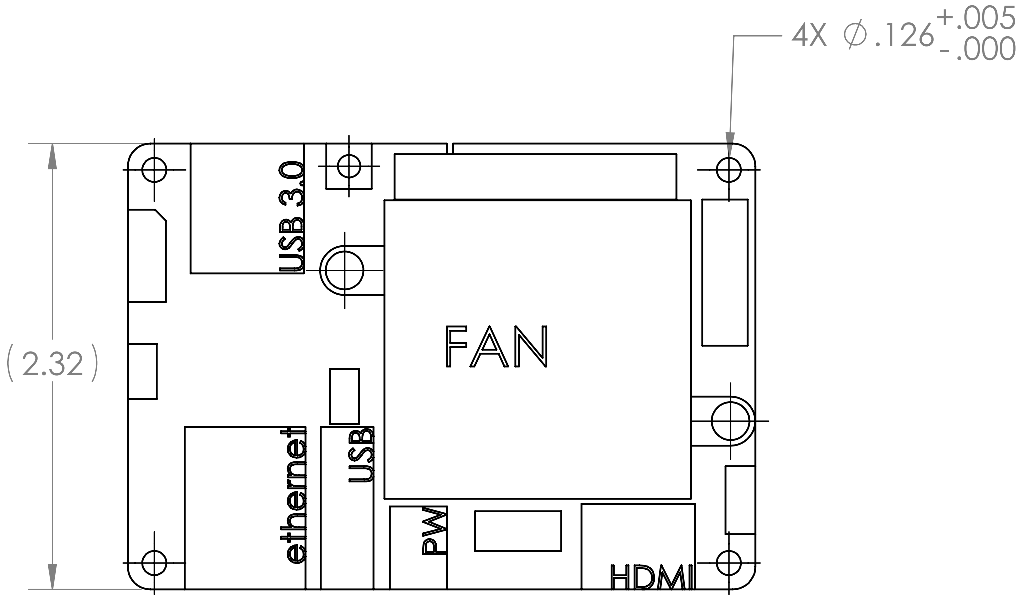


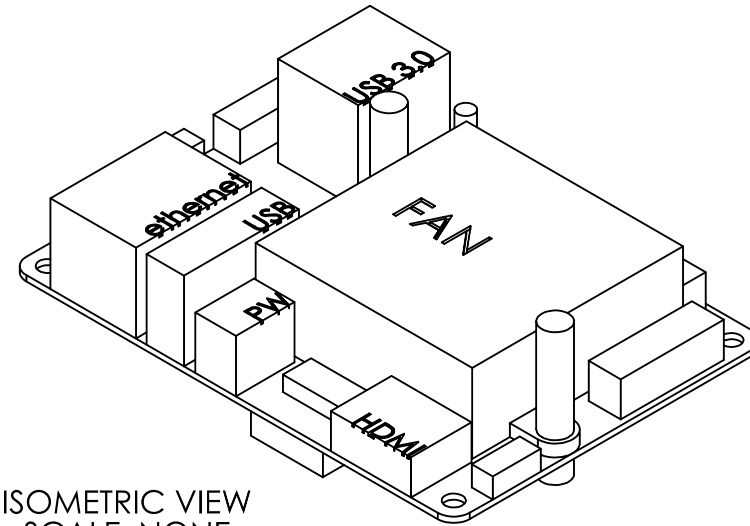
ISOMETRIC VIEW
SCALE: NONE
FOR REFERENCE ONLY



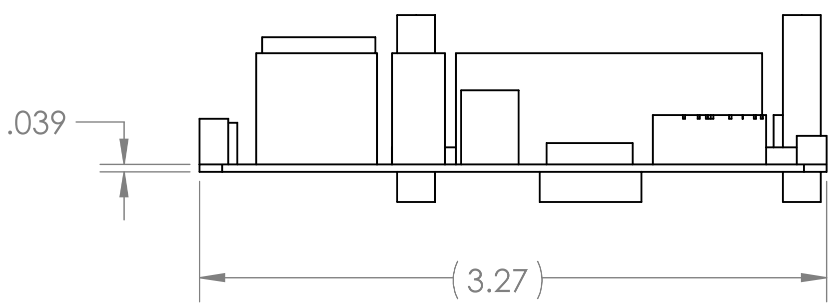


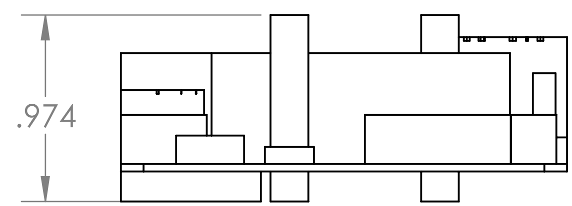
Concordia University	MATERIAL **ABS**		SURFACE ROUGHNESS / UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°	TITLE **SCREEN**
	FINISH **CLEAN**			
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **A. SHAWWA**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED	A SIZE	DATE **3/19/2018** USED ON **MECH 490**
	DRAFTER **M. A. YADAO**	APPROVED **R. PATEL**	SCALE **1:2**	SHEET **9 /12** DWG NO. **11809011** REV NO. **04**



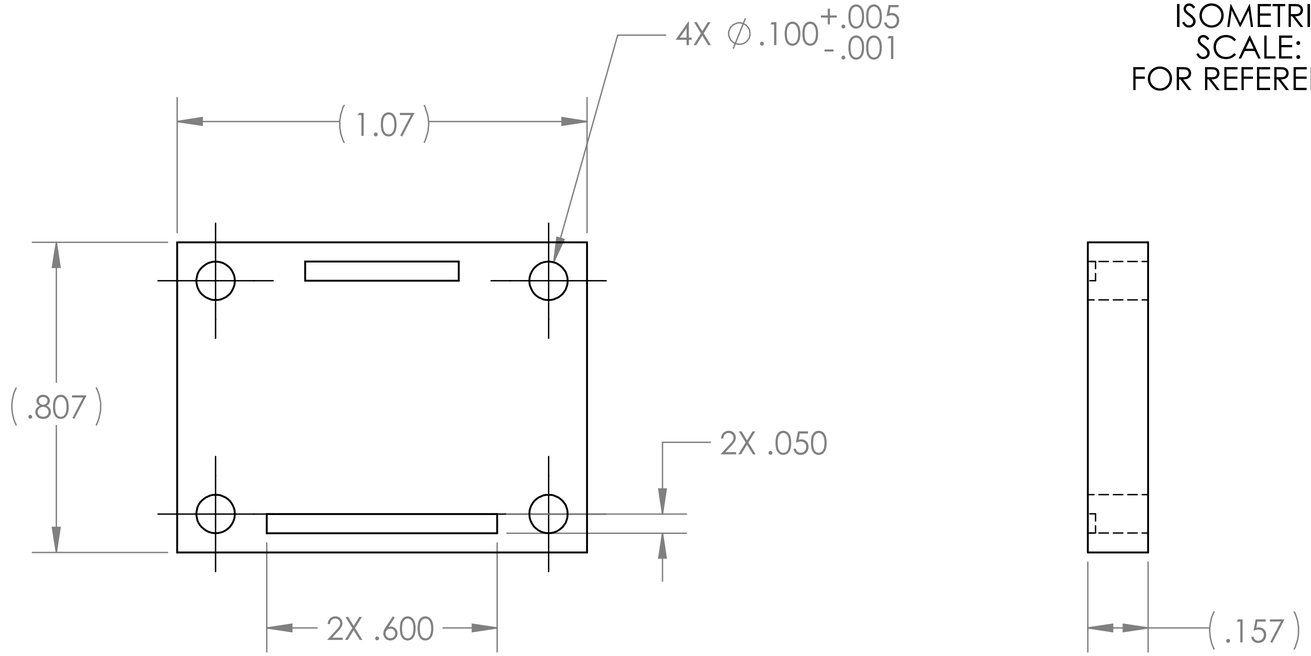


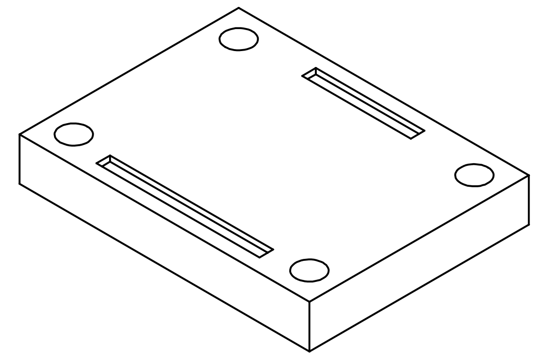
ISOMETRIC VIEW
SCALE: NONE
FOR REFERENCE ONLY





Concordia University	MATERIAL VARIES	SURFACE ROUGHNESS √	TITLE **ODROID XU4**
	FINISH VARIES	UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°	
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **ONLINE** / ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED		A SIZE / DATE **3/19/2018** / USED ON **MECH 490**
	DRAFTER **ONLINE** / APPROVED **ONLINE**	SCALE **1:1**	SHEET **10/12** / DWG NO. **0007A** / REV NO. **04**





ISOMETRIC VIEW
SCALE: NONE
FOR REFERENCE ONLY

Concordia

PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY

MATERIAL **VARIES**

FINISH **VARIES**

DESIGNER **ONLINE**

DRAFTER **ONLINE**

ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED

APPROVED **ONLINE**

UNLESS OTHERWISE SPECIFIED

SURFACE ROUGHNESS

TOLERANCES X ± .1
.X ± .05
.XX ± .005
.XXX ± .002
ANGLE ± .5°

SCALE **2:1**

TITLE **ADAFRUIT BNO055 MOTION SENSOR**

A SIZE

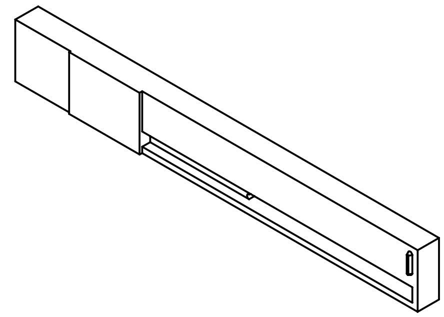
DATE **3/19/2018**

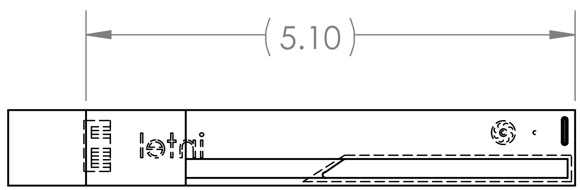
USED ON **MECH 490**

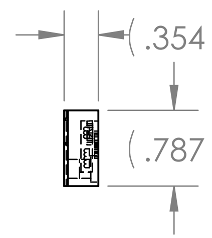
SHEET **11/12**

DWG NO. **ADA2472**

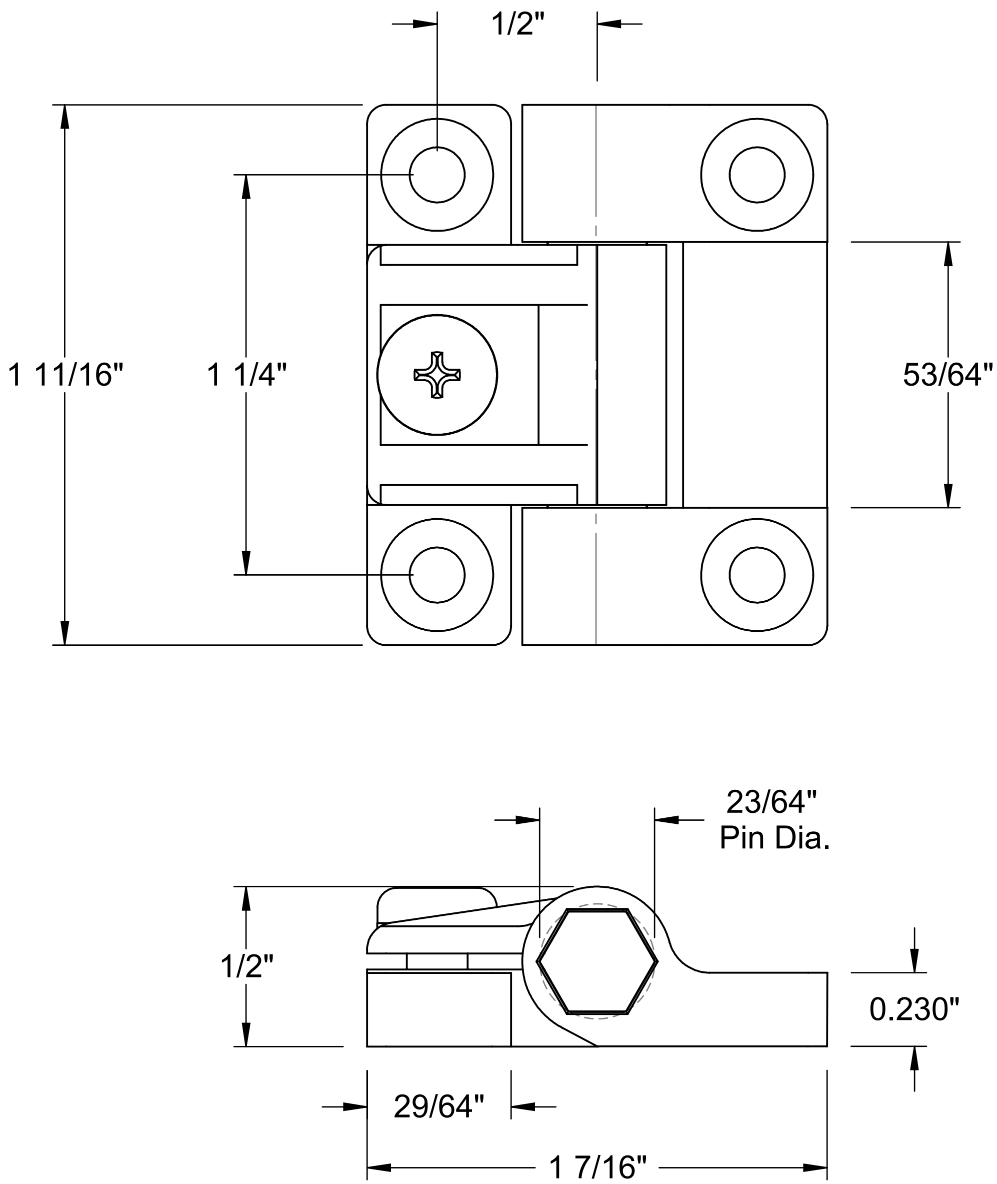
REV NO. **04**

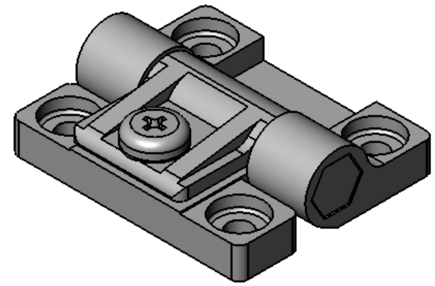






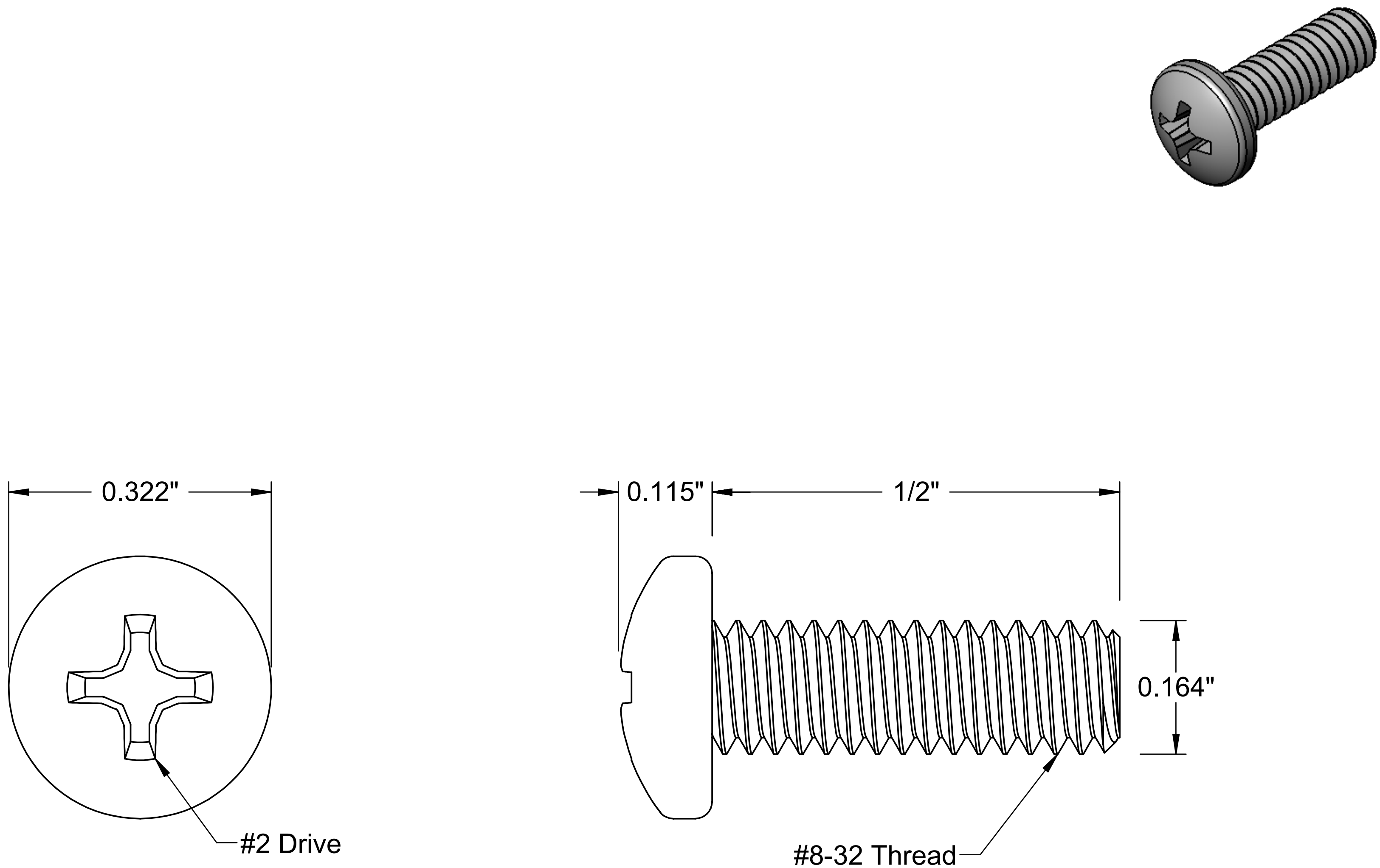
Concordia UNIVERSITY	MATERIAL VARIES		SURFACE ROUGHNESS	TITLE **INTEL REALSENSE CAMERA R200**
	FINISH VARIES		UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1, .X ± .05, .XX ± .005, .XXX ± .002, ANGLE ± .5°	
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **ONLINE**	ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED		A SIZE · DATE **3/19/2018** · USED ON **MECH 490**
	DRAFTER **ONLINE**	APPROVED **ONLINE**	SCALE **1:2**	SHEET **12/12** · DWG NO. **MM#939143** · REV NO. **04**



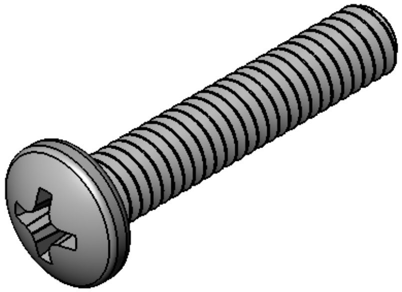


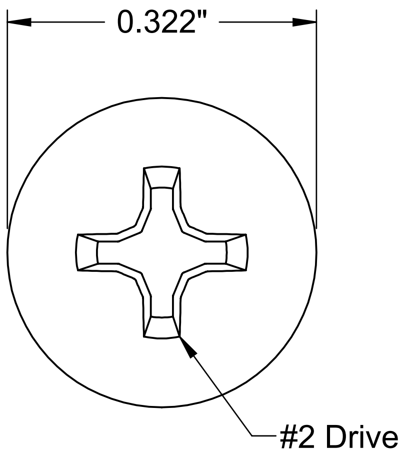
Hinge uses #8 screws.

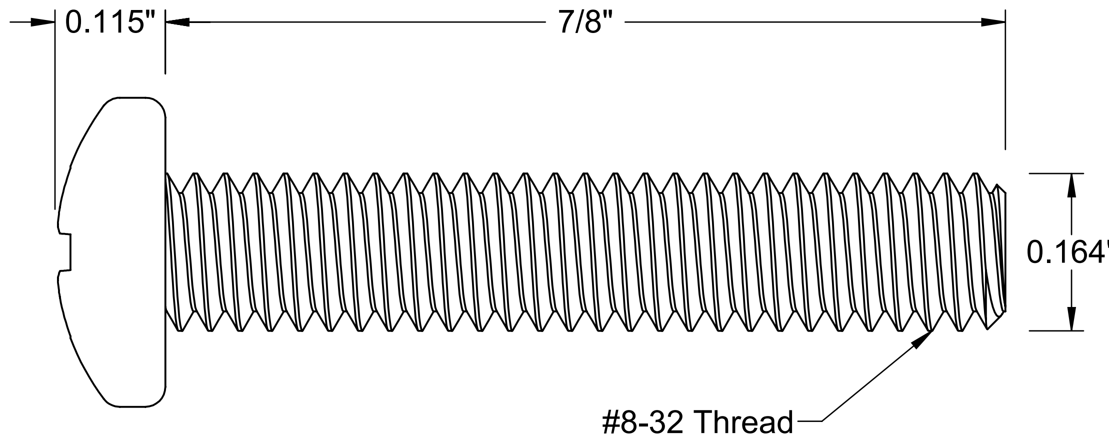
McMASTER-CARR® CAD	PART NUMBER	1791A44
http://www.mcmaster.com © 2013 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Adjustable-Friction Hinge	



McMASTER-CARR® CAD	PART NUMBER	90272A194
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	







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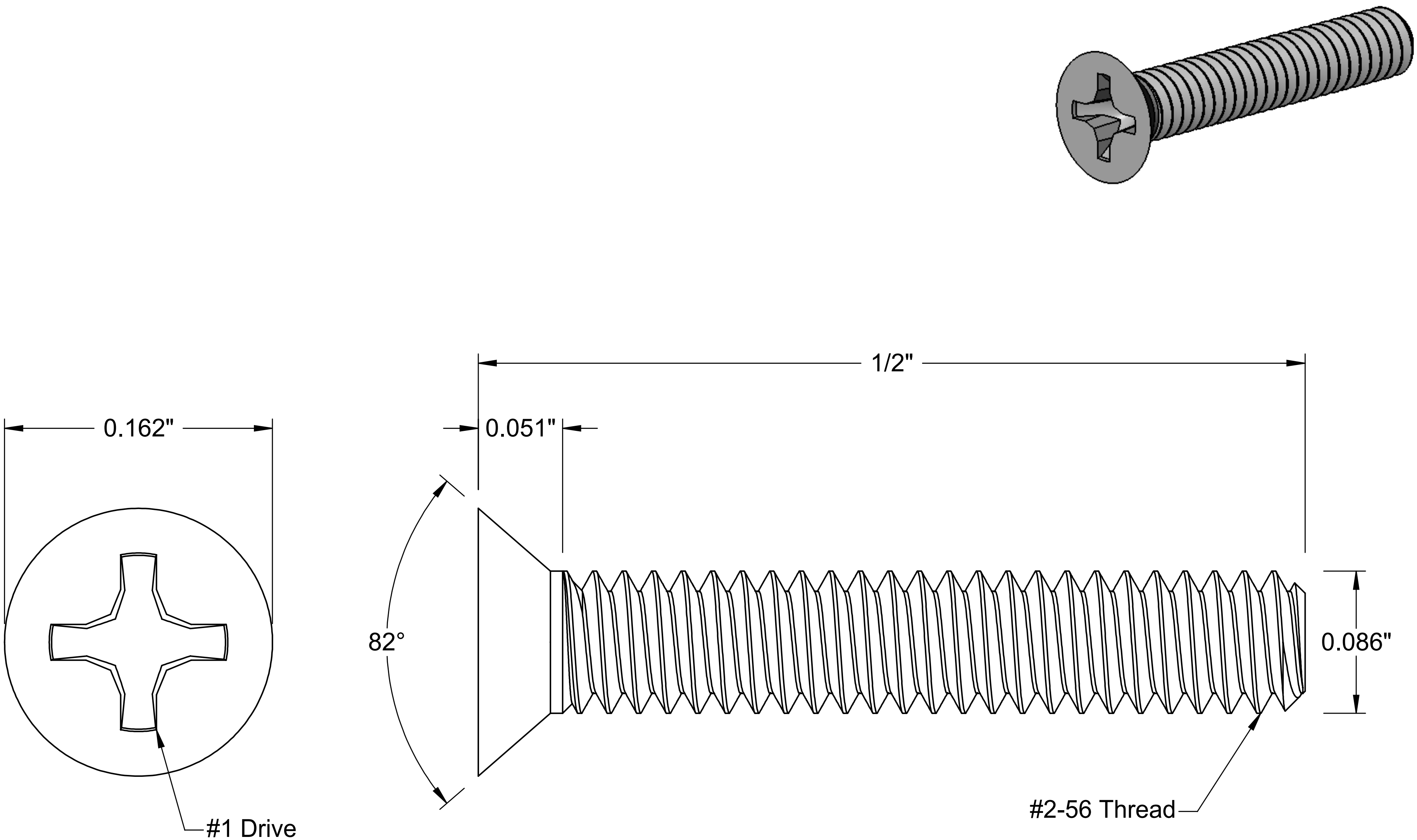
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	



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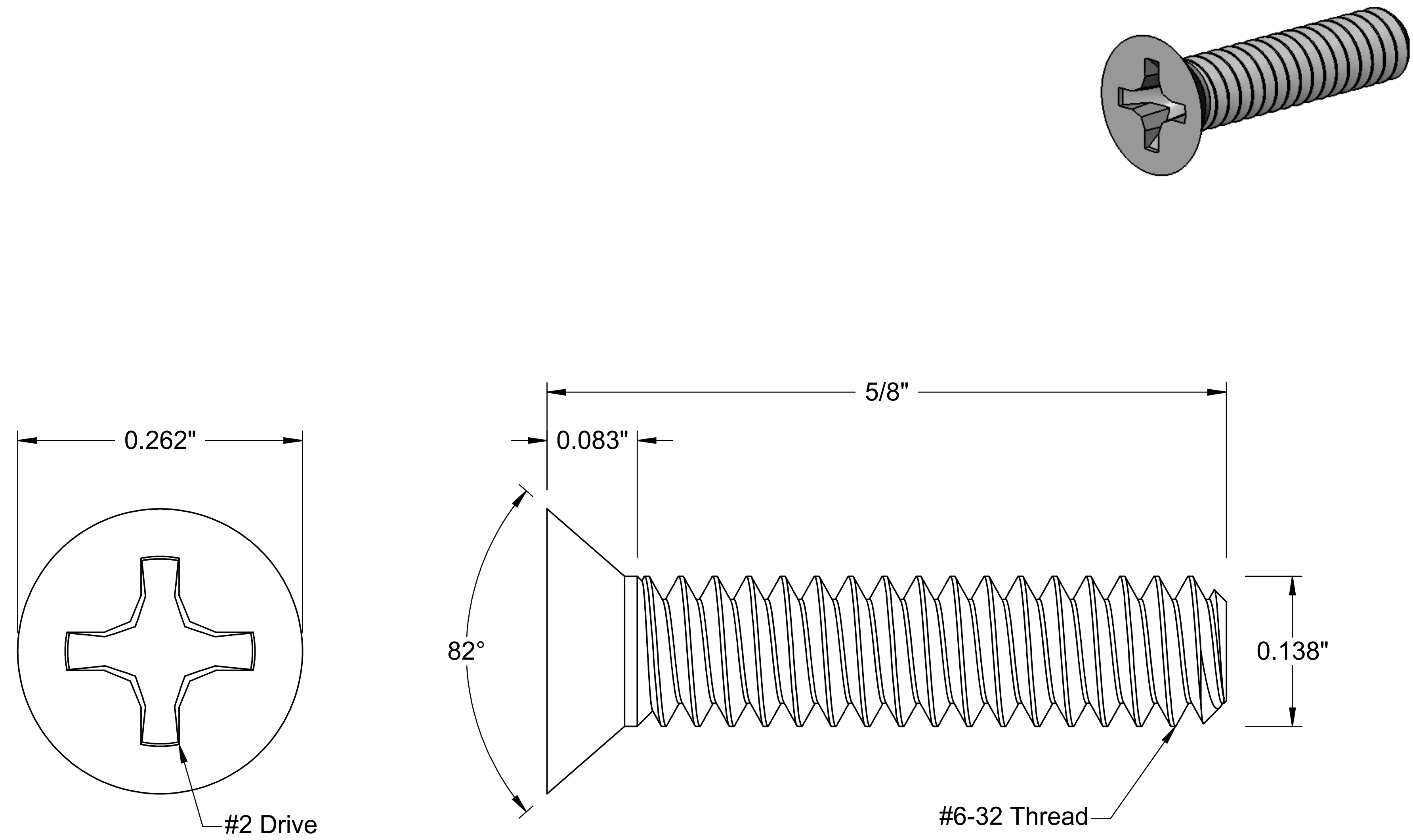
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Flat Head Phillips Machine Screw	



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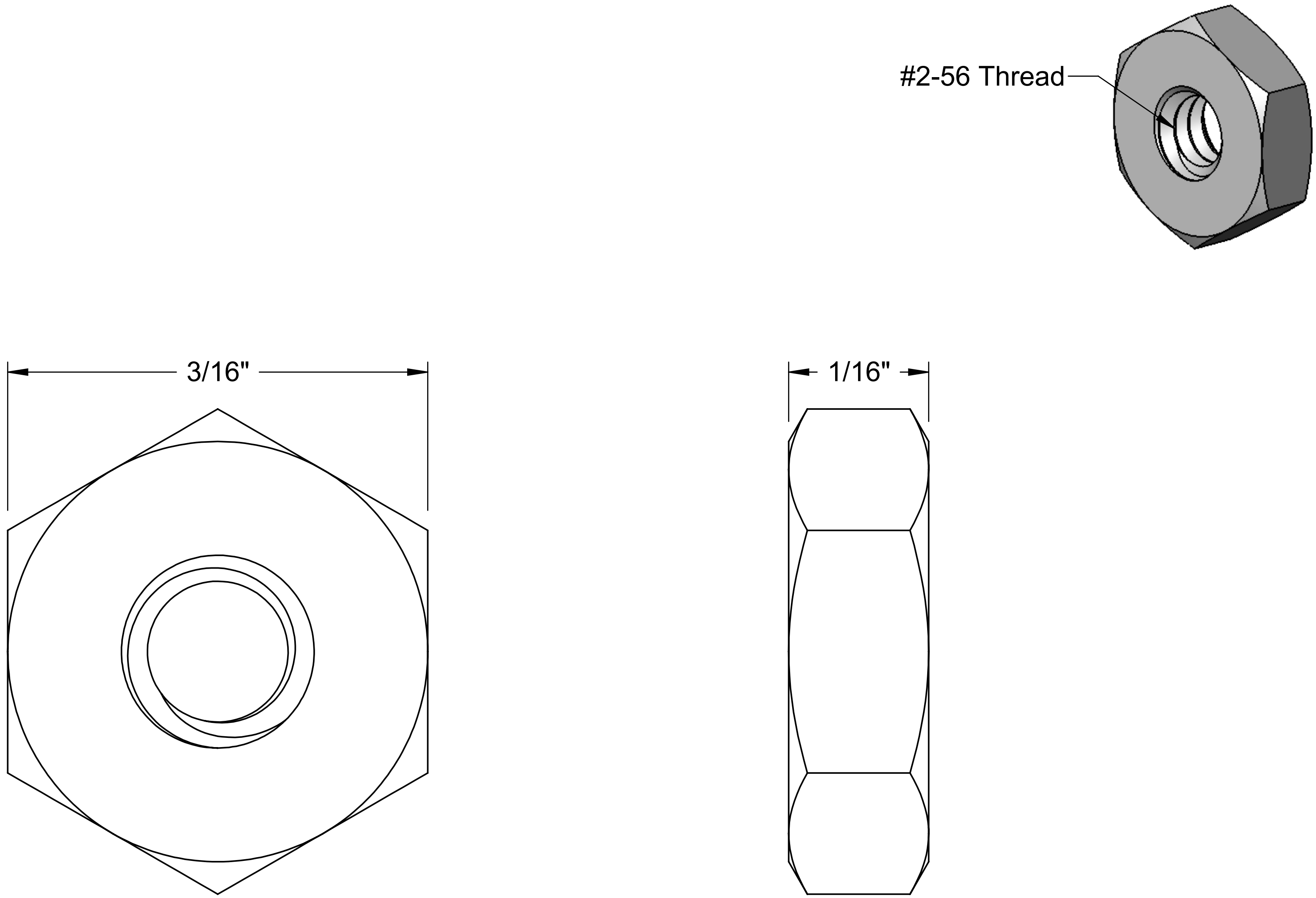
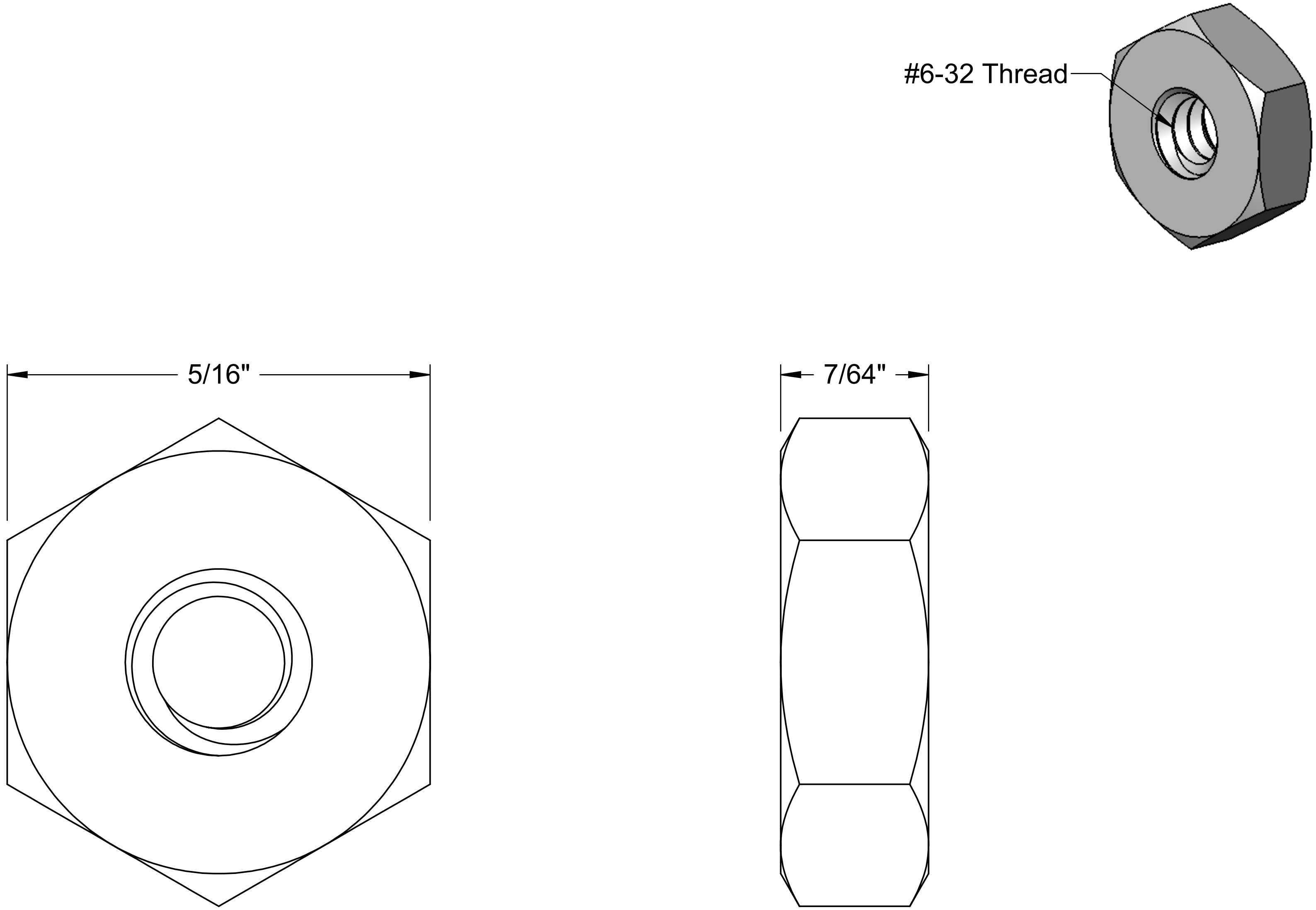
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Flat Head Phillips Machine Screw



McMASTER-CARR® CAD	PART NUMBER	90480A003
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company	Hex Nut	
Information in this drawing is provided for reference only.		



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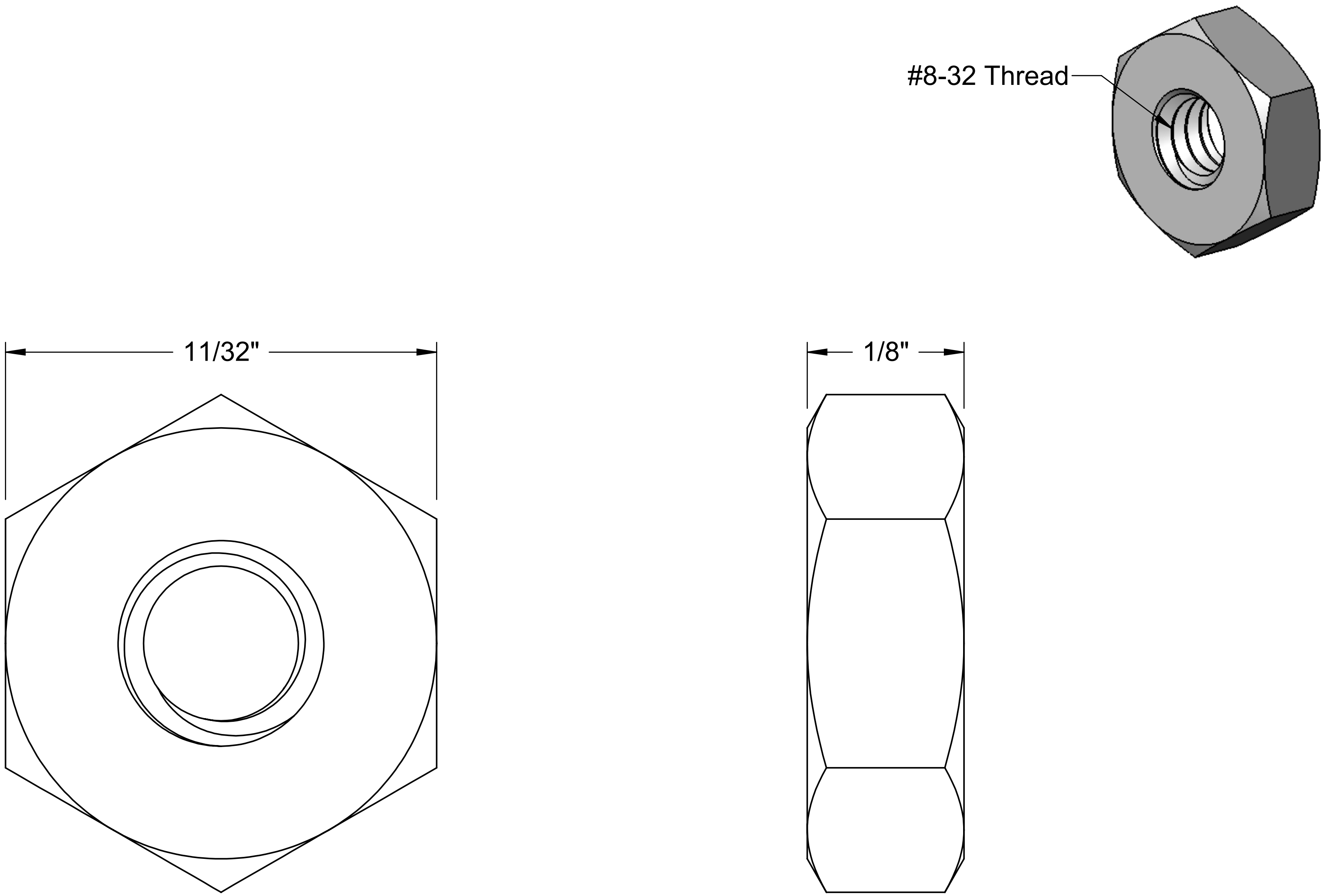
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Hex Nut



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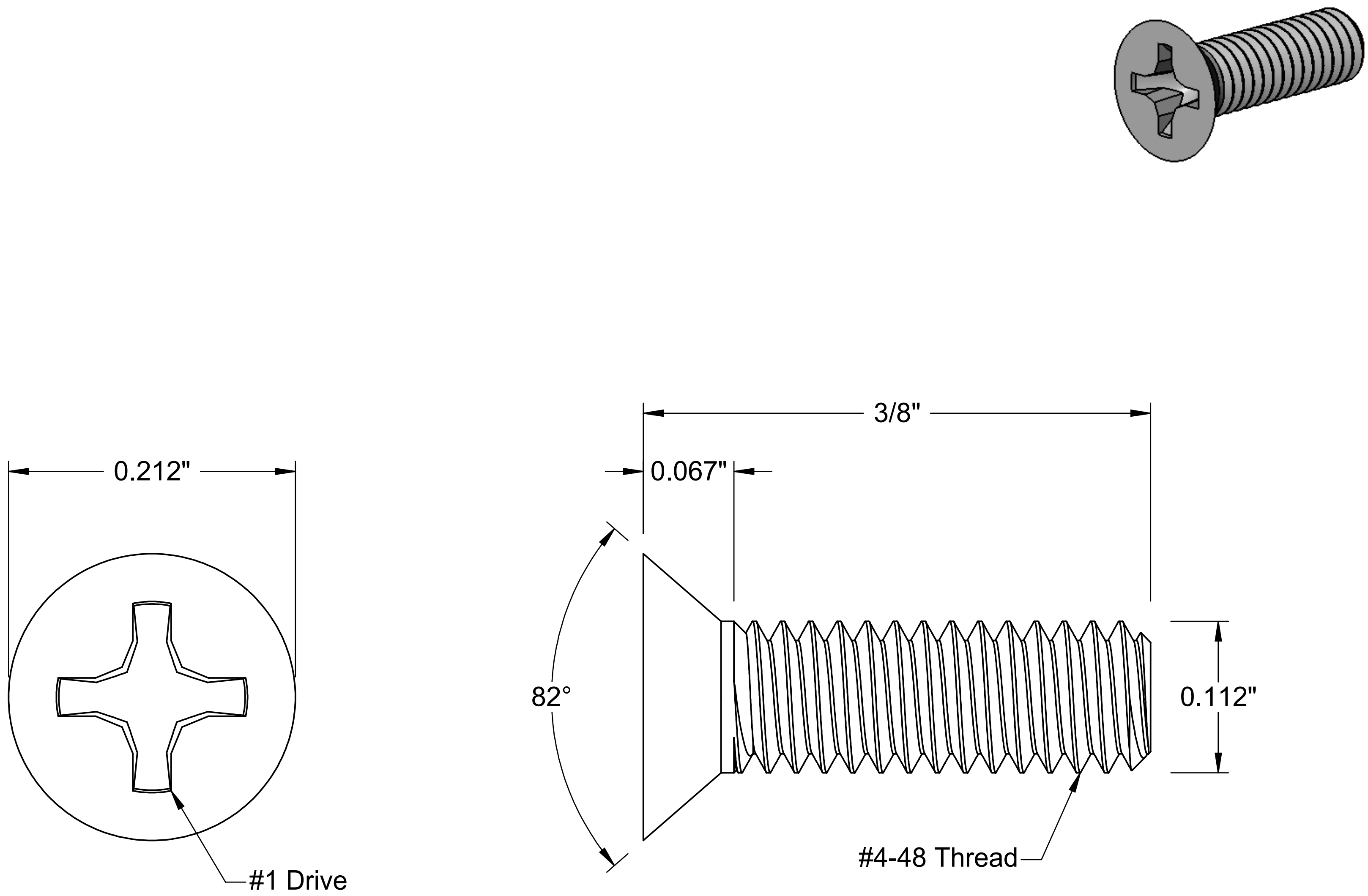
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Hex Nut	



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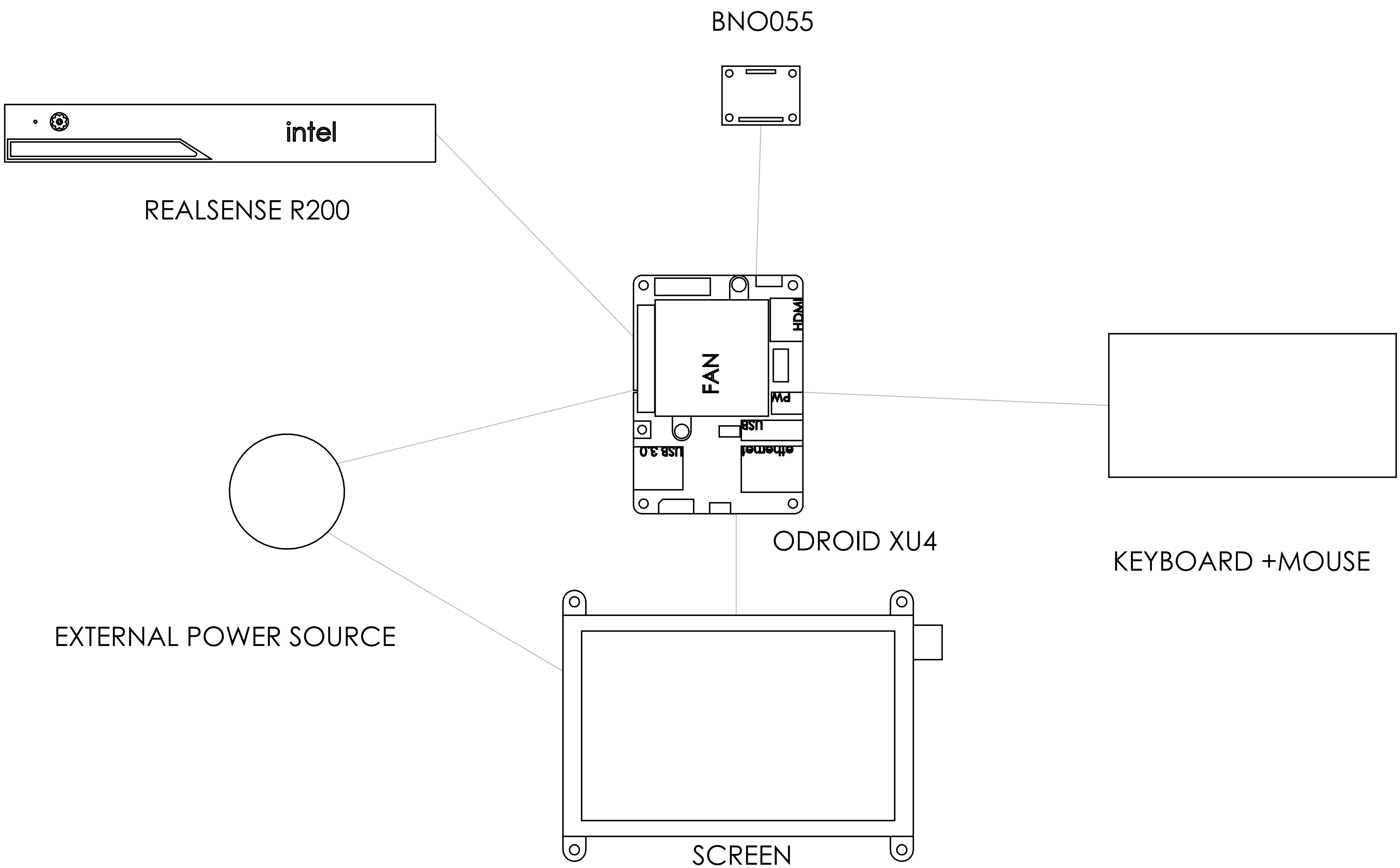
http://www.mcmaster.com Information in this drawing is provided for reference only.	Flat Head Phillips Machine Screw	



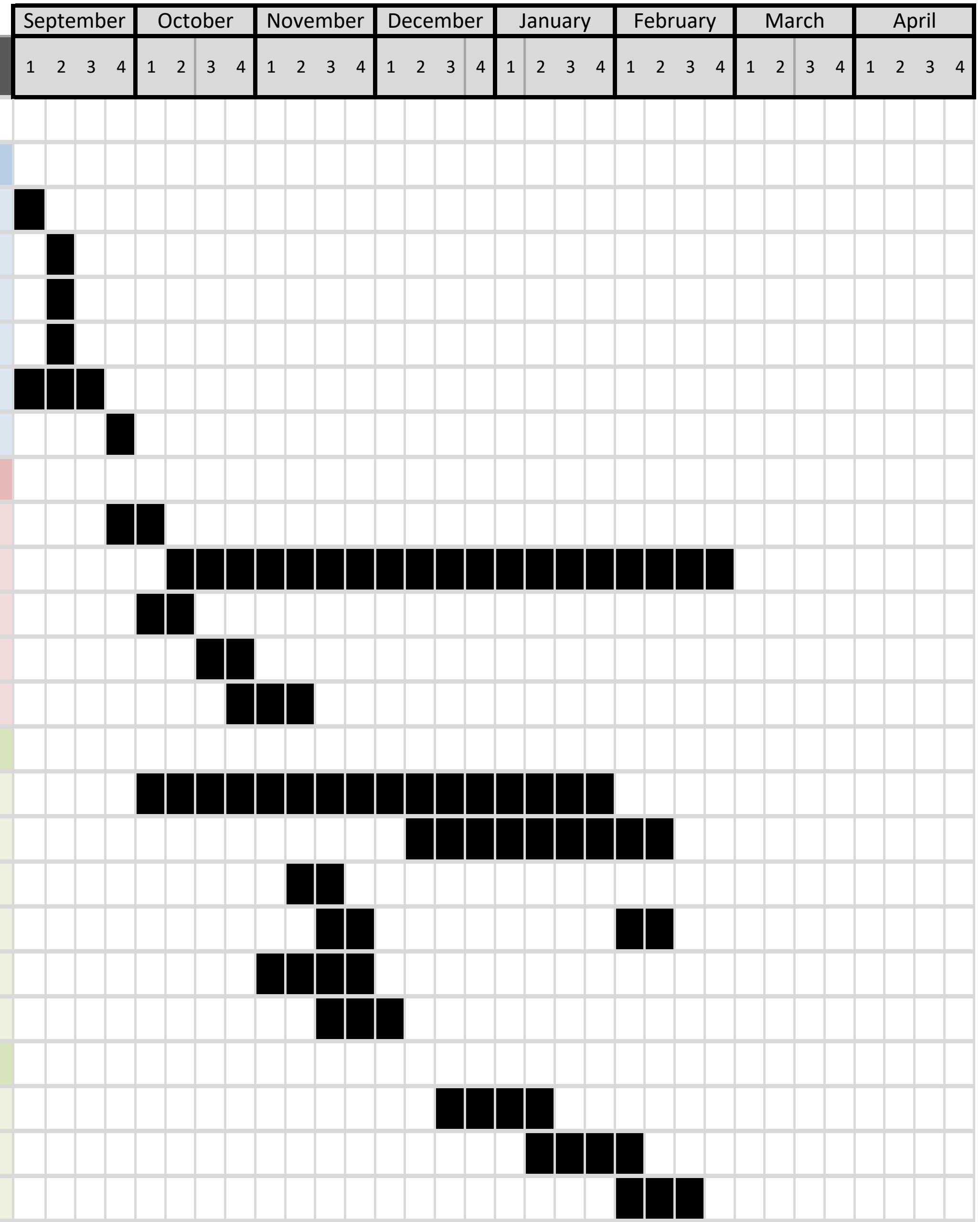
Concordia	MATERIAL -	SURFACE ROUGHNESS √63	TITLE **SYSTEM DIAGRAM**
	FINISH -	UNLESS OTHERWISE SPECIFIED TOLERANCES X ± .1 .X ± .05 .XX ± .005 .XXX ± .002 ANGLE ± .5°	
PROPRIETARY INFORMATION NOT TO BE RELEASED WITHOUT WRITTEN AUTHORIZATION FROM CONCORDIA UNIVERSITY	DESIGNER **TEAM** — ALL DIMENSIONS IN **INCHES** UNLESS OTHERWISE SPECIFIED		A SIZE — DATE **3/30/2018** — USED ON **MECH 490**
	DRAFTER **TEAM** — APPROVED **TEAM**	SCALE **-**	SHEET **1 / 1** — DWG NO. **1** — REV NO. **2**

Appendix VIII: Gantt Chart

AUGMENTED REALITY HEADSET

TEAM 9

TASK	ASSIGNED TO
Preliminary Design Ideas, Brainstorming and Planning	
Project Choice	All
Project Planning and Deadline Setting	Rahul
Initial Capstone Professor Meeting	All
Setting Design Criterias and Scope of Project	Rahul
Letter of Intent/Team Engineering	All
Audit 1	All
Conceptual Design	
Initial Design (V1)	Amir
Updating Design Revisions (V2-5)	Amir, Michael
Design Proposal and Feasibility Study	All
Audit 2	All
FFF Completion	All
Manufacturing, Sourcing and Assembly	
3D Printing Revisions 1-5	Haseb
Component Sourcing	Kostas
Audit 3	All
Audit 4 Package	Rahul
Midterm Progress Report + Pres	All
Final Manufacturing Drawing	All
Hardware/Software Integration	
BNO055 Integration	Nicholas
Libreal Sense Integration	Nicholas
Pyreal Sense Integration	Nicholas



		September				October				November				December				January				February				March				April			
TASK	**ASSIGNED TO**	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Coding Demos	Nicholas																						■	■	■	■	■	■	■				
Debugging	Nicholas																	■	■	■	■	■	■	■	■	■	■	■	■				
Testing and Engineering Analysis (FEA)																																	
TSPCD	Faraz, Rahul																			■	■	■	■	■	■	■							
Steady force and Impact Test	Haseb, Faraz																							■	■	■							
Thermal and Vibration Test	Michael, Haseb																									■	■						
Screen Angle Test	Michael, Haseb																										■	■					
Drop Test	Kostas																										■	■					
FEA Engineering Analysis (Structural, Drop, Thermal)	Amir, Rahul																					■	■	■	■	■	■	■	■				
Final Project Documentation and Presentation																																	
Prototype Demonstration Preparation	All																		■	■	■	■	■										
Audit 5 Preparation	All																					■	■	■									
Workbook and Doc Control	All					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Final Capstone Report	All																									■	■	■	■	■			
Poster Session Preperation	All																										■	■	■	■			

Appendix IX: Augmented Reality Headset Pictures