Final Report

Viscon: A Solution for Motion Sickness

ME 113: Mechanical Engineering Design

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1 Project Summary

Motion sickness is a ubiquitous problem, with one 1978 study by Reason finding that around 90% of surveyed individuals had experienced some form of motion sickness in their lifetime [4]. Motion sickness is characterized by the symptoms of nausea, physical discomfort, dizziness, vertigo, and/or vomiting [9]. Not only is motion sickness unpleasant, it may also cause people to change their behavior and miss valuable opportunities to be productive or relax in a moving vehicle. With an eye towards an autonomous vehicle future, Faurecia, a multinational automotive parts manufacturer, has tasked students in ME 113 with finding a solution to motion sickness to make the experience more enjoyable and useful for the passengers. In particular, autonomous vehicles provide a unique opportunity for passengers to use their commute to be productive, as they are no longer burdened with the task of controlling the vehicle.

Unfortunately, this benefit of additional working time comes at a cost. Many individuals who experience motion sickness opt to drive because drivers almost never experience motion sickness, but autonomous vehicles eliminate drivers. As a result, we can reasonably expect the number of people susceptible to motion sickness to increase with the introduction of autonomous vehicles [8], as those protected from motion sickness by virtue of having a direct connection to the vehicle will no longer have that luxury. Sivak & Schoeottle predict that about 6% to 10% of passengers would experience frequent motion sickness in autonomous vehicles and another 6% to 12% would experience moderate or severe motion sickness at some point while riding in an autonomous vehicle [8].

Many researchers agree that a mismatch between sensed signals from the vestibular (inner ear) and visual systems is what causes motion sickness in vehicles (i.e. carsickness) [9,3]. Namely, their vestibular system registers motion, but their visual system does not. This generalizes the problem of preventing motion sickness to a problem of preventing this mismatch. Thus our task amounts to taking one of two directions: make the passenger see motion, or make them feel no motion.

This provided the background for our design objective, which is as follows:

- Create a device that mitigates motion sickness effects to allow for technology use in a moving vehicle. The device holds a tablet and rotates to help the passenger see what they are feeling, allowing the passenger to read and work without experiencing motion sickness.

Once we decided on our design objective, we began researching similar devices that had been created in the past. The three experiments that we referenced heavily in developing our designs were a 2008 study conducted by Morimoto et al. [2], a 2008 study by Kato & Kitazaki [3], and a 2012 study conducted by Wado et al [5]. The Morimoto et al. study investigated digital approaches to reducing carsickness while watching a display in a vehicle. They found that digitally rendering a screen to appear as if it rotates around a vertical axis in response to the yaw rotation of the car (Fig. 1) significantly reduced carsickness (Fig. 21, Appendix 5.2). The Kato & Kitazaki study examined a similar solution, but rotated the screen in response to the changing pitch rotation of the car. They concluded that there was no effect on carsickness from compensating according to the vehicle's pitching motion. Lastly, the Wado et al. study concluded that a passenger's active head tilt against centrifugal acceleration can reduce carsickness severity.

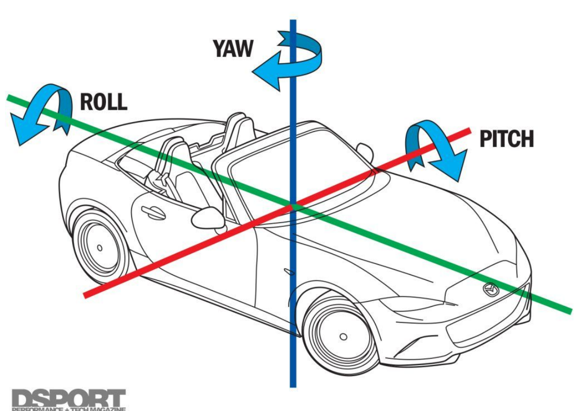


Figure 1: Car axes of rotation [10]

Based on this background research and personal interviews we have designed a device to mount an iPad or similar tablet, which is actuated to provide a visual cue of the motion of the vehicle. The rotation of the screen thus provides a sensory input to the passenger regarding the lateral acceleration of the car.

We also created this design so that it can be improved by the upcoming arrival of autonomous vehicles in two ways. First, the Inertial Measurement Unit (IMU) with which we currently measure the angular velocity of the car is likely to be unnecessary as the angular velocity data is readily available from the onboard sensors, which also increases the accuracy of the device rotation. Second, a driverless car has information about how the car is going to move before a change of direction takes place, so the screens can begin to rotate even before the car does so, which would allow the passenger to anticipate the change in direction.

It is important to note that we do not intend to cure motion sickness for all. In particular, the study by Kato & Kitazaki [3] indicated that regardless of the screen design, a passenger would still experience fewer motion sickness impacts simply by looking out the window (Fig. 21, Appendix 5.2). This led us to narrow our target audience to only those for whom working or using a device in a car is too unpleasant, and not all motion sickness sufferers, as no solution we have devised yet would be superior to simply staring at the horizon.

2 Design Summary

2.1 Design History

Our preliminary research into motion sickness posited three broad solution spaces. Careful consideration of the merits of each space led us to pursuing actuated device mounts, but there are a number of benefits to each that warrant recognition.

The first solution space we considered was wearable technologies, for which we referenced two papers. The first was a paper by Reschke on stroboscopic vision for motion sickness, and the other was a paper by Kreuger on user-worn see-through displays [6, 7]. The Reschke paper detailed the results of a study examining the impact of strobe lights flashing at a frequency of 4Hz (which is a frequency that was determined from an earlier study about motion sickness and vision reversal) and determined there is a clear benefit on motion sickness symptoms [1]. The Krueger paper examined the use of a head-up display style device worn on the head which created a virtual cross in the line of sight of the user which remained stationary relative to the horizon. This virtual cross provided a continuous reference point for the wearer and demonstrated significant positive results in testing.

The second solution space we considered was providing feedback to mimic the experience of driving. We learned through interviews that the vast majority of drivers do not experience motion sickness while actively driving, and products in this solution space would simulate the experience of driving for passengers. There are a number of potential solutions that we considered, including a cell phone holder that would move and require a user-provided restoring force correlated to moving the steering wheel, a dynamic footrest that similarly requires a restorative force from the user's feet, and an interactive joystick that a user would move to balance a pendulum that was affected by vehicular motion. This category of solutions was based upon user feedback and general knowledge of motion sickness, as we were unable to find any research supporting or disproving these methods.

Our final solution space was device mounts. As detailed above, this solution space was based on studies by Morimoto et al. [2], Kato & Kitazaki [3], and Wado et al [5]. We decided to pursue this approach after creating a table of evaluation criteria (Tab. 1, Appendix 5.1). We came to the conclusion that wearable tech was simple and easy to use, but was not mechanically interesting and did not integrate well with a vehicle. Providing feedback was novel and interesting, but did not have enough research and would force the user to actively engage with it, while also requiring the use of hands/legs. Device mounts had large body of research, were easy to use, and could be integrated directly into a vehicle.

2.2 Iteration Process

Once we decided to pursue dynamic device mounts, we began to prototype different designs in order to narrow our focus. Initially, we considered a mounting mechanism that compensated according to the yaw motion of the car (Fig. 1) by rotating around either a horizontal axis (Fig. 2a), vertical axis (Fig. 2b), or combination of both. We created initial prototypes of the horizontal axis and vertical axis designs with which we conducted preliminary testing. Our initial test focused primarily on the vertical axis prototype, which we strapped to the back of the front passenger headrest (Fig. 5). During the testing, one team member drove a 2012 Mazda3 Hatchback with two team members in the rear seat. One of the passengers manually rotated the device to correspond to the motion of the car while the other attempted to read an excerpt of a book on the device as it was rotating. From these early tests, we determined the most effective range of angles and decided to map the rotation of the device to the angular velocity of the car. We also identified several necessary changes, including pitch and height adjustability, a thinner, more compact design, and the ability of the motor to compensate for inertia.

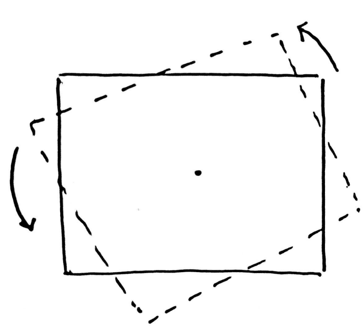


Figure 2a: Screen tilt around horizontal axis

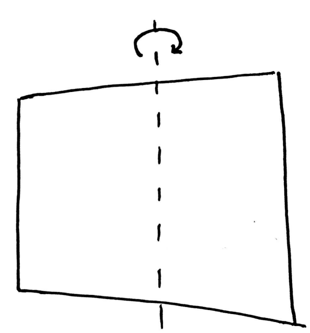


Figure 2b: Screen rotation around vertical axis

The preliminary testing also revealed to us that the two prototypes used fundamentally different methods for reducing carsickness: the vertical axis design gave passengers visual cues regarding the motion of the car while the horizontal design attempted to prompt the passenger to move in response to the motion of the car. Due to the different mechanisms each of the designs employs, we decided to focus on only the vertical axis of rotation, which was more appealing because it required less active participation from the passenger.

Having narrowed our focus to solely the vertical axis design, we were able to use our findings from the testing to refine our prototype. We built a second prototype (Fig. 3, 4, & 5) out of Duron that featured a thinner, more compact shape and a two-part axis that allowed for easier installation of the screen. The design comprised of a stationary housing around a rotating screen. The housing was designed to prevent the screen from rotating 360˚, which would be unnecessary, and instead is sufficiently large for a 30˚ rotation in either direction. This design was mounted on the back of a headrest (Fig. 5) and could be adjusted to fit any headrest size or style. We also installed a gear system and servo motor with a gear head (Fig. 4). By mating with a corresponding gear attached to the screen, the servo actuated the screen to correspond to the car's yaw angle measurements. The motor was connected to an Arduino Uno, which was also receiving inputs from an Inertial Measurement Unit (IMU). The data from the IMU was used to control the angle of rotation of the screen, which was directly related to the IMU yaw angle data.

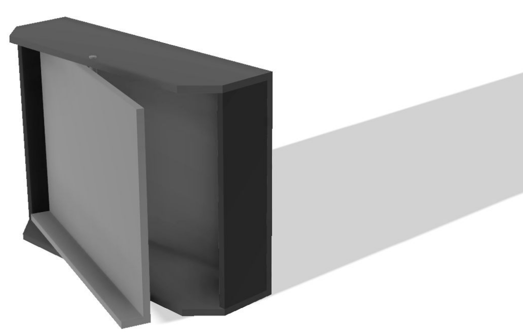


Figure 3: CAD model of the second prototype of the first design

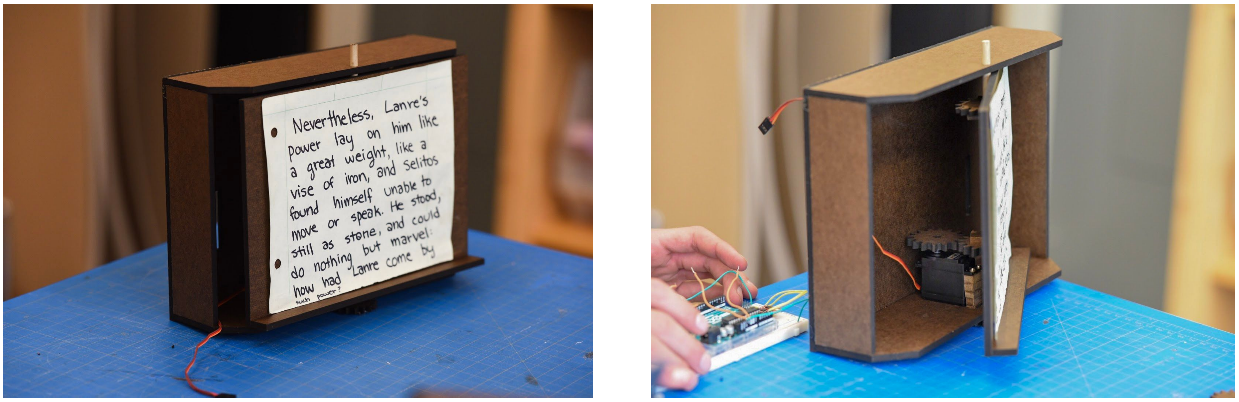


Figure 4: Second prototype of first design, showing IMU, Arduino, servo motor, and gear system

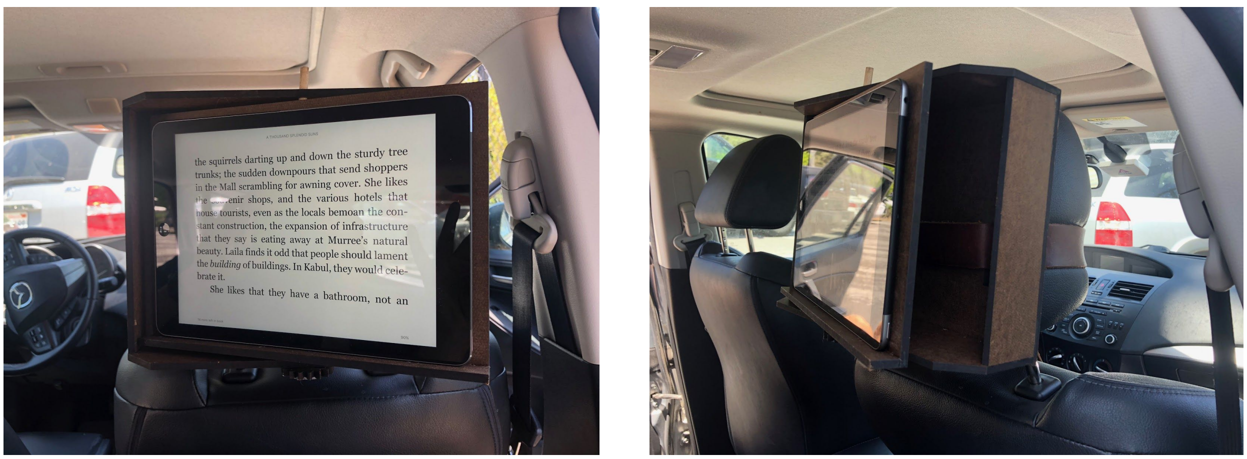


Figure 5: Second prototype of first design mounted on headrest

Through testing this second prototype, we identified several changes that we needed to make as part of our next redesign. First of all, the second design would need to be even more compact and adjustable, which would require increased mechanical robustness, through the use of tabs and ribs. Additionally, we decided to begin working with plastic, which was the material we envisioned for the final product.

These insights led to our second design (Fig. 6 and 7), which featured two separate and smaller parts: a tablet mount and servo mount, which were connected by a rod and actuated by a servo motor.

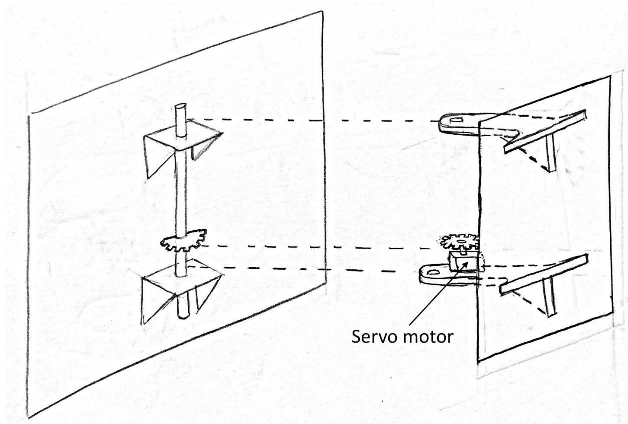


Figure 6: Second design with tablet mount (left), servo mount (right), and servo motor (labeled)

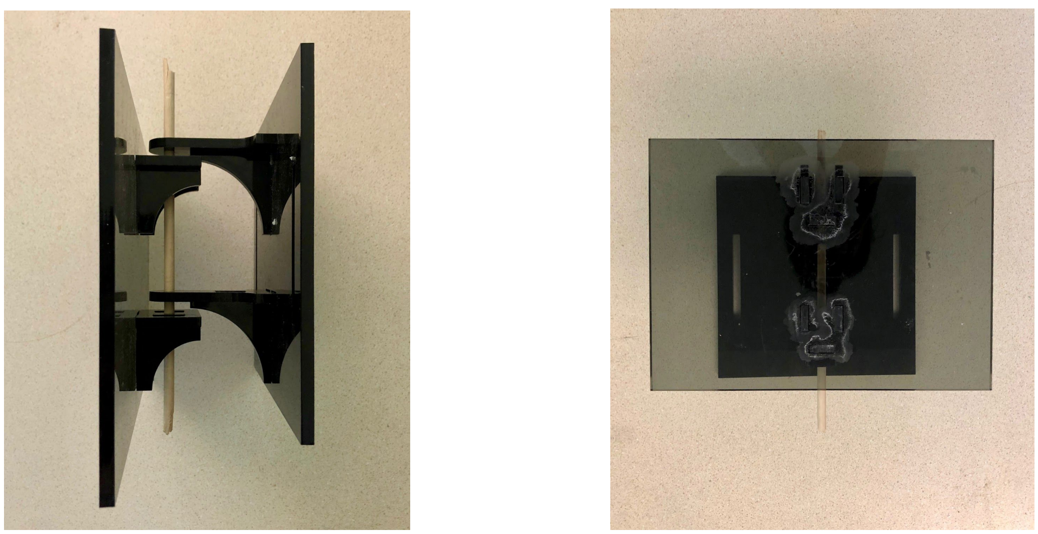


Figure 7: First prototype of second design

Figure 7 shows our first prototype of the second design, made from ¼" thick acrylic and using a ¼" wooden dowel. From this prototype, we learned that we could use thinner acrylic and make the design even more compact. Additionally, we decided to integrate our device with purchased tablet mounts. Rather than build mechanisms to attach to the headrest and tablet, we would seat our device in between two purchased mounts, one of which would attach to the headrest, and the other to the tablet (Fig. 10). Lastly, we needed to design a way for the servo to rigidly attach to the mount.

Figure 8a: Second prototype of second design

Figure 8b: Third prototype of second design

Our second prototype of our second design (Fig. 8a) was made of ⅛" acrylic and consisted of pieces that could be directly attached to two different purchased mounts. In the third prototype (Fig. 8b), we introduced a hole and supporting rib in which to seat the servo motor. For our final design (Section 2.3), we made the device even more compact so that the tablet would sit closer to the headrest, reinforced parts of the device by using ¼" acrylic, thickened the gear in order to improve gear meshing, and reduced friction in the system by replacing the wooden dowel with a $^{3}/_{16}$" brass rod, which we secured using hairpin clips.

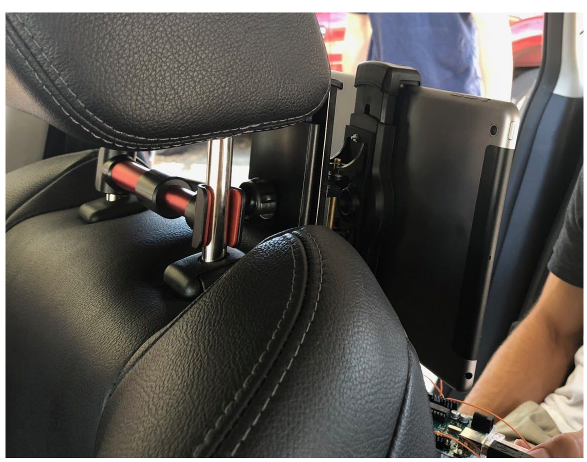


Figure 9: Device seated between two purchased mounts

While iterating our physical design, we also experimented with IMU mapping functions and location. First, we transitioned to using the angular velocity of the car, rather than the angle, to determine the rotation of the device. By matching the angle of the screen to the angular velocity of the vehicle, our device was able to provide more helpful visual cues to the passenger. Next, we collected angular velocity data from the IMU while it was placed in three different locations in the car: secured to the dashboard, mounted on the device, and secured to the steering wheel (Fig 10 and 11). It is evident that the IMU output the cleanest data while secured to the dashboard. Therefore, we decided to mount the IMU securely to the dashboard or center console while conducting participant testing.

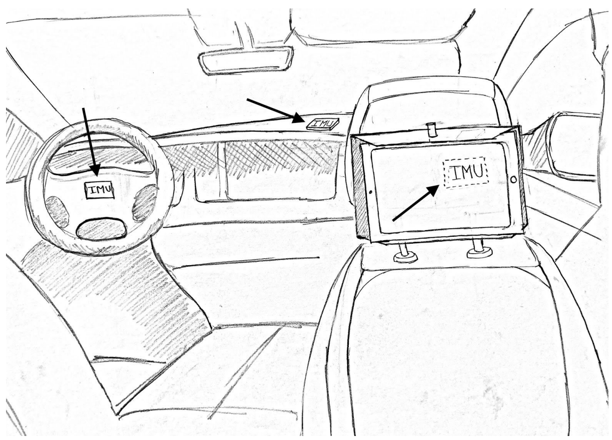


Figure 10: Some examples of considered IMU positioning: dashboard, device, and steering wheel

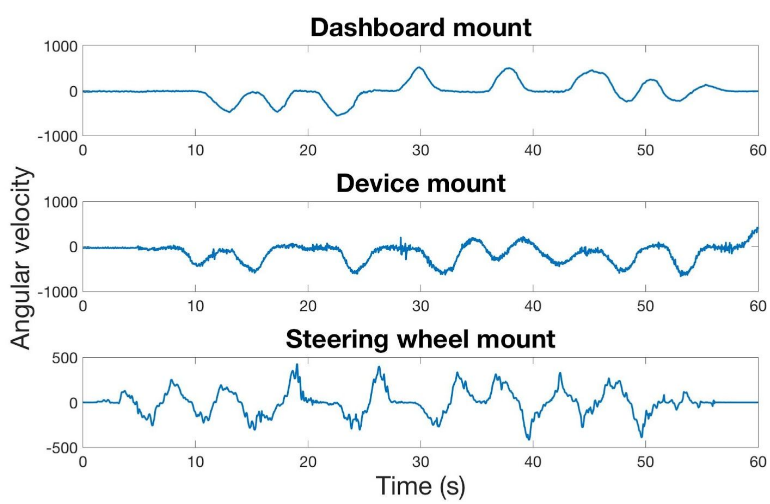


Figure 11: Angular velocity data from IMU when mounted on dashboard, device, and steering wheel

2.3 Current Design

After the two major iterations described previously, we settled on our current design which was used for user testing and demonstrated at EXPE. The design is made from laser cut acrylic and features a brass rod for rotation of the outer plate (shown in Figure 13). The pin is secured with two cotter pins to prevent slipping in the vertical direction. The two plates are in contact via a gear connected to the head of the servo motor which interacts with a half gear attached to the outer plate. This provides yaw control of the plate (and therefore the device) from the servo. The acrylic plates are attached together using acrylic cement, which is a solvent bonding agent that provides strong connections between our acrylic sheets.

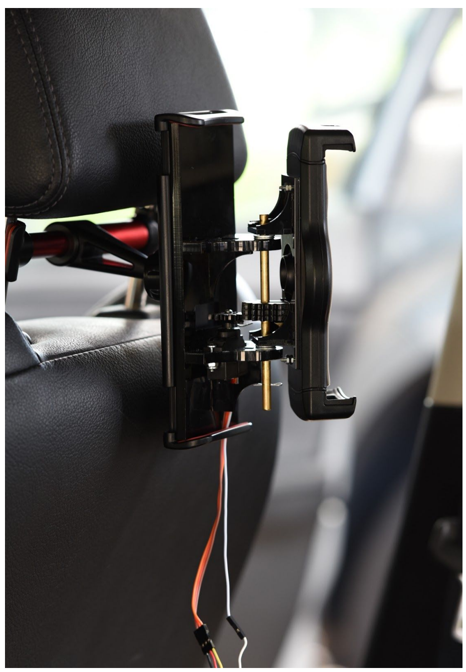


Figure 12: Current design, with gears, servo and brass rod visible

Our material choices were driven primarily by convenience and a desire to keep costs low for prototyping. Acrylic is light but also strong enough to support the device and can be cheaply laser cut for rapid prototypes without requiring specialized equipment. Acrylic also has low friction which was a key criterion for our design, because any friction would significantly impede the ability of the servo to actuate the screen position in a smooth fashion. We elected to laser cut the material because it is fairly precise and is also easily repeatable, so we could make spare parts in order to prepare for any issues that we encountered while testing our device in a vehicle.

Figure 13: Current design, carrying an iPad

We also added several small material changes for our current design to increase the robustness of the current design relative to previous iterations. We added nylon nuts to the servo mount because the bolts had a tendency to shake free from the vibration of the car, and minimizing undesirable vibration was one of our key focuses. We switched to a brass rod (from a wooden dowel) also to reduce friction and to allow the use of cotter pins to constrain it, rather than requiring a threaded rod with caps or a shoulder screw, which would have been much more difficult to assemble and disassemble for prototyping.

2.3.1 Shortcomings

Despite our many improvements and significantly smaller, lighter and more reliable design that resulted from our design iterations, there are still a number of shortcomings that we would like to fix if we had more time. These weaknesses can be split up into two main categories. Internal, which are issues relating to the device itself, and external, which are issues relating to the external environment.

Our internal issues were primarily associated with the gears and servo. We observed that our gear had a tendency to come loose from the servo during testing as the screw was not sufficiently long. We also observed significant vibration due to gear slack, which impacted both the smoothness of the rotation and the ability of the device to maintain a position through bumps in the road. This gear slack could have been improved (but likely not eliminated) through use of purchased gears, however for prototyping it was significantly easier to use laser cut gears.

A final internal issue we observed was the ease with which the servo could be back driven. This issue relates to the inertia of the screen as it moves or attempts to maintain a zero position and is shown clearly in Figures 15 and 16, which cover the IMU data for a five minute portion of a test drive. The raw data shows the input angles the Arduino is feeding to the servo, and the error is the distance the true position of the servo is from that input position. The data shows that when rotation begins the servo often overshoots the target angle as the servo is not able to resist the inertia of the screen once it is in motion. Similarly the error is nonzero even when the input is zero, because the screen is wobbling backwards and forwards due to external vibrations and the servo is incapable of resisting these vibrations. These issues could likely have been removed through use of a brushless DC motor or stepper motor, with a higher stall torque, which should greatly decrease the error between the input and true servo position.

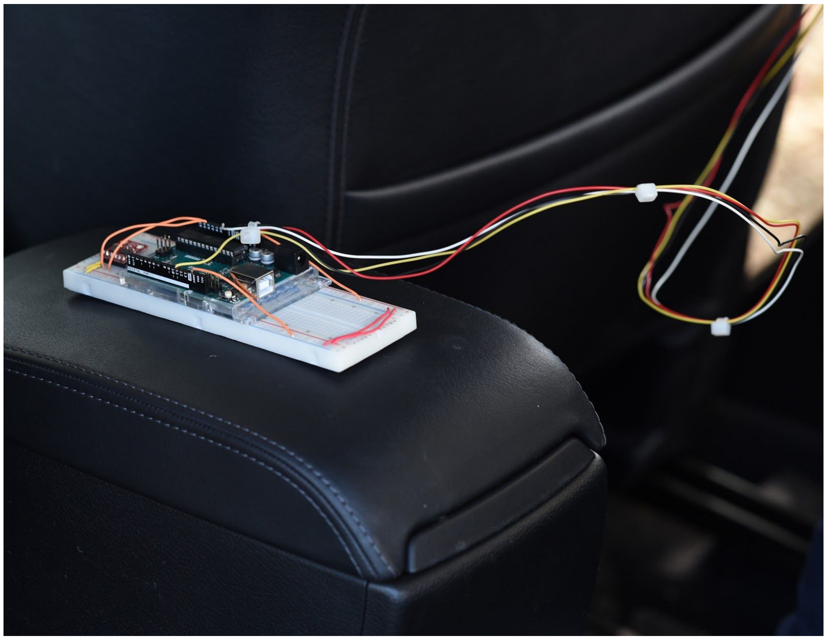


Figure 14: IMU and Arduino mounted on the armrest

We also observed a number of issues external to the device itself. We observed that the mounting with the headrest was insecure, and added additional vibration to the device. This could be fixed with a purpose-built headrest mount, as for our testing we simply modified an existing mount due to time constraints. Unfortunately our attachment had a significantly larger moment arm than the original mount, so the vibration was amplified. Similarly, the vibrations of the car itself were a significant external flaw and although we can't fix the bounciness of the car or roughness of the road, we did observe that those two variables made a significant difference to the performance and usability of the device.

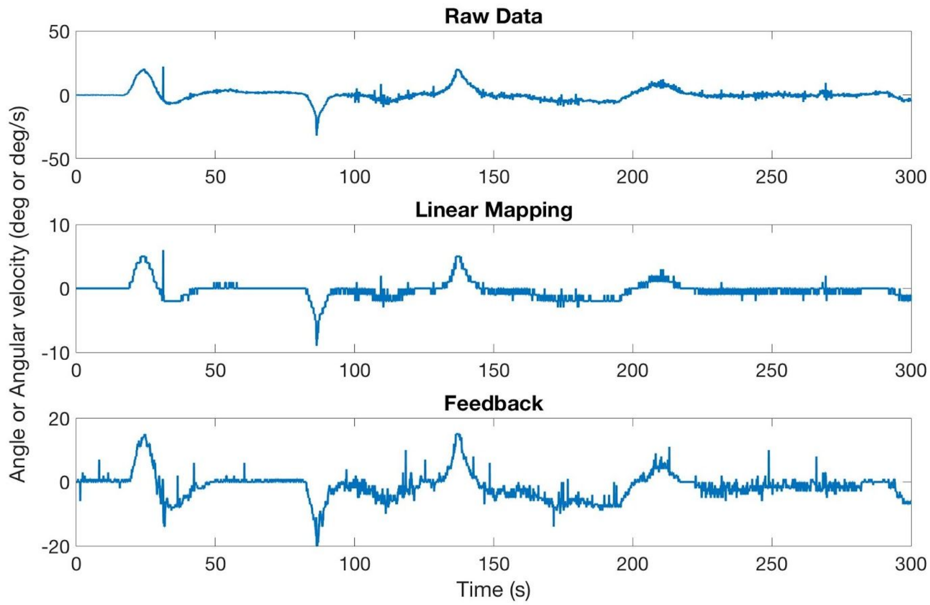


Figure 15: Comparison of raw data, linear input and servo position for a five minute drive

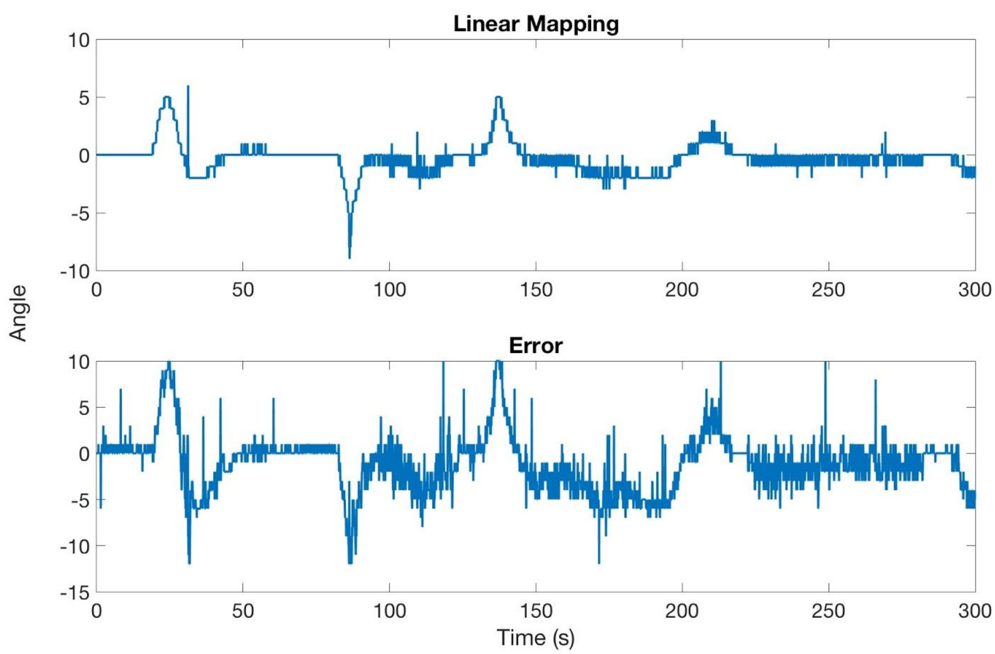


Figure 16: Comparison of mapped position and position error during a five minute drive

3 Testing and Results

3.1 Testing Procedure

In order to validate our device, we developed a standardized single-blind testing procedure. Each participant underwent two trials. One of the trials was a control trial with no device actuation, and the other trial was a test trial with full actuation. Half of the participants were randomly assigned to receive the control condition first, and half the test condition.

Participants read a passage from an iPad while they were driven on standardized route which lasted roughly 20 minutes (Appendix 5.4). The route was chosen to be windy and lightly trafficked for consistent results. Upon entering the car, they were told a standardized script and were asked to rate their motion sickness at one-minute intervals throughout the test, using a scale between one and ten. The text of the script and more information about the single-blind nature of the procedure can be found in Appendix 5.5.

Overall, we tested four participants. However, we were forced to remove our first participant due to failures in our testing procedure. We originally planned a different route, but after our first drive, we realized that the route was too short and did not contain enough curves. Thus, Participant 1 received her control trial on a different route than her test trial. Because of the disparity in testing location and duration, we did not use her trials. After all other testing was complete, we condensed and reviewed results and conducted follow-up interviews with the participants to gauge their responses to the device.

3.2 Results

3.2.1 Participant 2

Figure 17a: Participant 2 conducting test drive

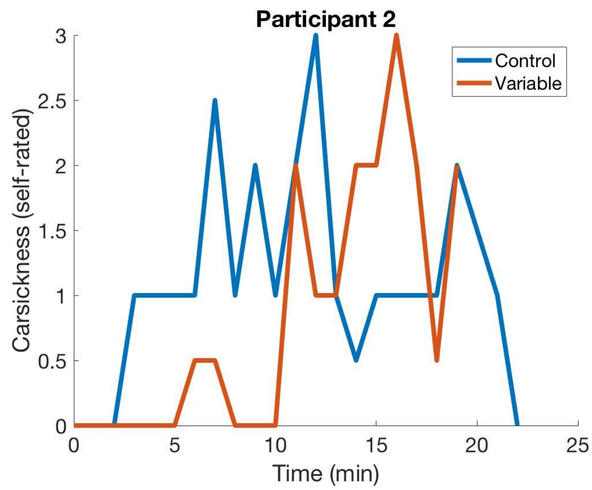


Figure 17b: Carsickness vs. time for Participant 2

Participant 2 self-reported that she normally experiences motion sickness during fast turns or unexpected movements. She found the device to be useful, although difficult to read. This may additionally have been due to the increased motion caused by a loose gear during her control trial. Her results showed that there was a small but inconclusive decrease in motion sickness during her test trial.

3.2.2 Participant 3

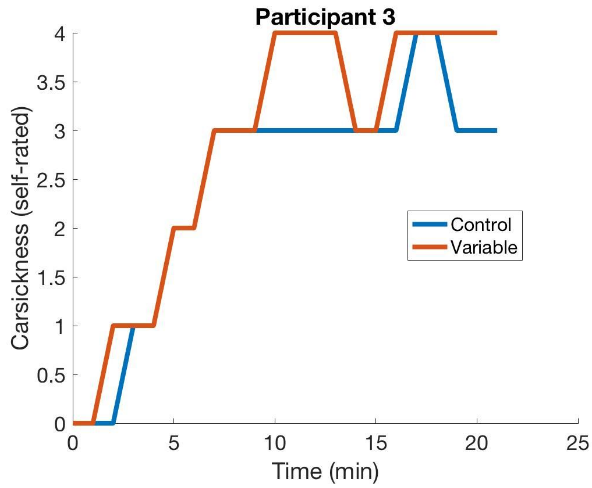


Figure 18a: Participant 3 conducting test drive

Figure 18b: Carsickness vs. time for Participant 3

Participant 3 self-reported that he normally experiences motion sickness while reading, and that the relative curvature of roads did not affect his motion sickness. He did not find the device to be useful, and attributed this to the shakiness of the screen. His results showed that there was very little change during his test trial.

3.2.3 Participant 4

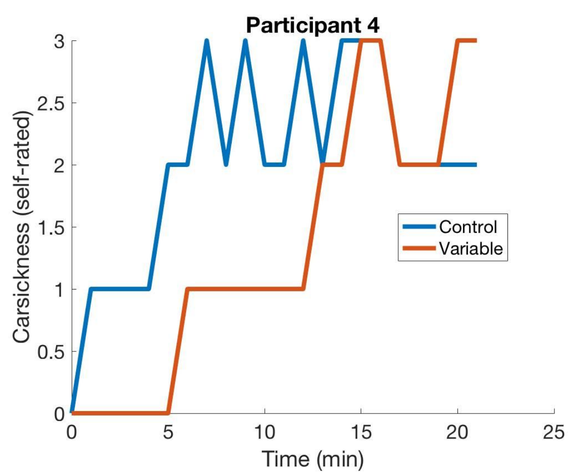


Figure 19a: Participant 4 conducting test drive

Figure 19b: Carsickness vs. time for Participant 4

Participant 4 self-reported that she normally experiences motion sickness on windy roads and with stops and starts. She found that the device was helpful, and attributed her sickness during the test trial to stopping and starting rather than lateral movement. Her results showed that there was a small decrease in motion sickness during the beginning of her test trial.

3.2.4 Average

Figure 20a: Test drive (rear view)

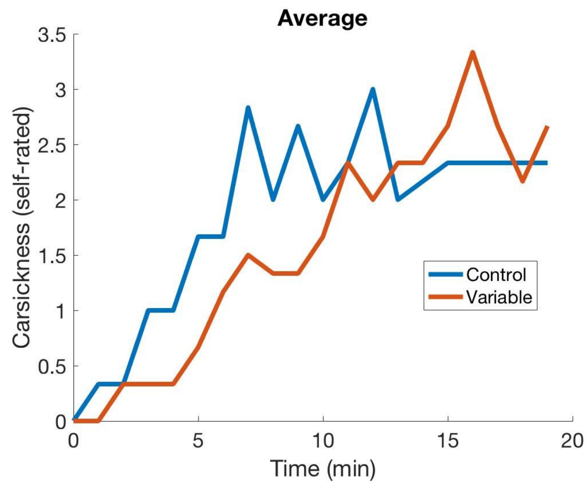


Figure 20b: Average carsickness vs. time for Participants 2, 3, and 4

The aggregate data shows a slight decrease in self-reported motion sickness during the beginning of test trials, but little change towards the end. Two participants mentioned that the shakiness of the screen was distracting. Besides this common reaction, however, responses were not consistent. Each participant focused on different aspects of the device during follow-up interviews.

3.3 Conclusions

The most important conclusion to be drawn from our testing is that more trials are required in order to establish the effectiveness of our device. This is a result of the small number of tests conducted, the inconsistencies between trials, and the inaccuracies in our device. Specifically, inaccuracies between trials were present in

Participant 1's trials because she was taken on two different routes and were present in Participant 2's trials because one of the gears was loose, which caused additional movement of the device. Additionally, the gears in our device did not mesh perfectly. Coupled with the forces caused by the weight of the iPad moving, this made the device move more than it should have, even to the extent that the screen moved slightly during the control trials.

The second conclusion to be drawn from our tests is that the relationships that participants had with the device were widely disparate. Participant 2 focused her feedback on ease of reading. Participant 3 focused on the shakiness of the device and the chosen axis of rotation. Participant 4 focused on shakiness as well as stop and start motion. This both emphasizes our conclusion that we need more participants and indicates that more customizability may be necessary.

4 Next Steps

In this section, we will describe various ways we would change our design for future iterations. The changes we list here are motivated by our own observations during testing as well as the results from our user testing and the feedback our users gave us. The changes can be summarized in four categories: motion control, sensors and data, materials, and mounting and fixturing.

4.1 Motion Control

The first task in improving our device motion control is to make it more robust. As described in the Shortcomings section of the Design Summary, our device is sensitive to a number of disturbances. First, we would use purchased gears (instead of laser cut acrylic gears) to reduce gear slack and get better meshing. We would also look to achieve more robust coupling between the motor shaft and the gear. For example, we may look at using a D-shaft or a key to fix the gear onto the motor. Finally, we would select a non-backdrivable motor or gear transmission.

These three changes would work towards ensuring that if the device mount is moved by an external disturbance, the servo motor will be able to measure the disturbance with its encoder and reject the error. These mechanical improvements serve to make it possible to focus future design work on the software side of motion control.

With enough data from user testing, we could begin to fine-tune the programmed motion of the device mount. There are two main parameters to tweak in our design: maximum amplitude of oscillation and data mapping.

For the maximum amplitude of oscillation (the maximum amount the screen can rotate), we would run experiments varying that quantity and determine the optimum for reducing motion sickness on average. Depending on variation in that data, this could also become a user defined setting (low, medium, or high) depending on preference.

For the data mapping, we would experiment with mappings between vehicle angular velocity data and device rotation other than a simple linear mapping. For example, we could try using a logarithmic or exponential mapping to emphasize a certain range of angular velocities more than others. In our final code, which is included in Appendix 5.3, we have the code written to use a exponential and square root function to map our raw data to our input values, however without a large data sample we cannot know that any sophisticated mapping would be an improvement over a straightforward linear mapping.

4.2 Sensors and Data

Improving the way we obtain and process data is important in improving the quality of the device's response to the vehicle's motion and its effectiveness in reducing motion sickness. The main priorities here are to improve the quality of data and change the source of our data.

In an autonomous vehicle, vehicle motion data is presumably readily available and high quality. With sufficient electrical and software integration into the vehicle's CPU and sensors, our device could receive data from the onboard CPU directly, eliminating the need for our device to have its own sensor and microprocessor, reducing complexity and cost but eliminating the possibility of retrofitting the device to any vehicle, autonomous or not. Still, an advantage of using an autonomous vehicle's electrical and software systems is the ability to predict the motion of the vehicle and use that prediction to eliminate the lag time between sensing and actuating. Additionally, we would experiment with using the prediction of vehicle yaw rate to preemptively rotate the device mount, giving the user an early warning that the car is about to start cornering. Once more, user testing would determine the efficacy of using motion prediction in this manner.

4.3 Materials

Material selection for the current design emphasized the ability to rapidly pivot between designs and iterate prototypes. For a finalized product, our material choices would be influenced by cost, weight, and ease of mass scale manufacturing and assembly. We anticipate that injection molded plastic would work best for our application. This choice would keep costs and weight low compared to metal and reduce the number of parts in the assembly as we could integrate the beams and supporting ribs as parts of the two main plates themselves instead of individual pieces.

4.4 Mounting and Fixturing

Experimenting with the placement of our device in the vehicle is key to improving the user experience. For future designs, we would mount the device in different parts of the vehicle, such as on the ceiling, onto the floor, or on an armrest. Additionally, we would consider a handheld version of the device for more interactive applications than reading or viewing videos.

Regardless of the final choice in mounting the device, we would prioritize designing custom components to fixture the device rigidly to its designated location in the vehicle. Using off-the-shelf iPad mounts to accelerate the pace of our prototyping process was convenient and a great choice for our design process, but they cannot be a final solution. We would need to design our own fixturing mechanisms with a comparable or better degree of adjustability to meet the requirements of individual users. The specific design of these mechanisms and components is highly dependent on the final mounting choice(s).

5 Appendices

5.1 Evaluation Criteria

Criteria	Wearable Tech.	Feedback Loop	Dynamic Device Mounts
Supporting literature	3	1	2
Novelty	1	3	2
Likely to get indicative results with rough early prototyping	1	2	3
Able to turn on/off for those who do/don't get carsick	3	1	2
Feasibility	1	2	3
Ease of Use	3	1	2
Projected Costs	1	2	3
Total	13	12	17

Table 1: Evaluation of each design category according to criteria.

5.2 Supporting Research Figures

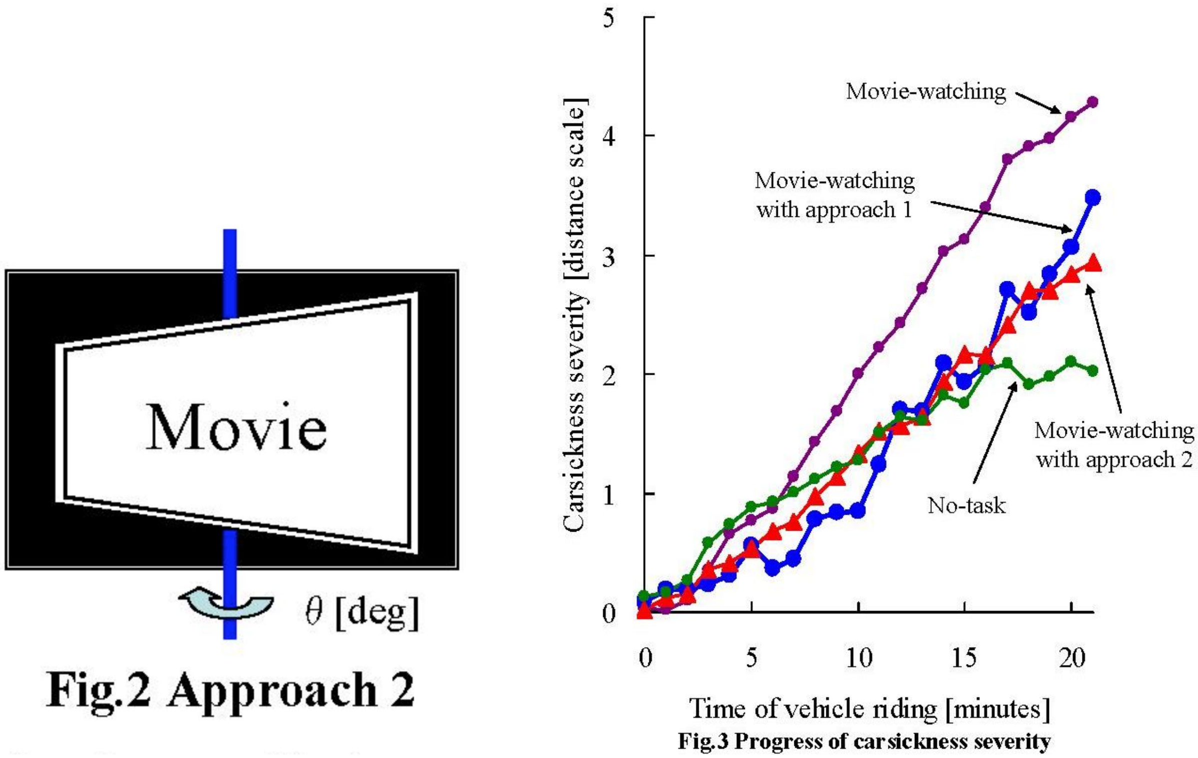


Figure 21: Figures from the Kato & Kitazaki 2008 study [3]

5.3 Arduino Code

```
#include < FreeSixIMU.h > #include < FIMU_ADXL345.h > #include < FIMU_ITG3200.h
> #include < Servo.h > #include < Wire.h >

  float values[9];
// values[0] = x
// values[1] = y
// values[2] = z
// values[3] = w(x)
// values[4] = w(y)
// values[5] = w(z)
float angles[3];

// Sets Arduino pins
int feedbackPin = A0;
int servoPin = 10;

// Set the FreeSixIMU object
FreeSixIMU sixDOF = FreeSixIMU();
char i2c_address = B1101000;
```

```
ITG3200 gyro = ITG3200();

// Sets mapping angles
int startAngle = -10;
int endAngle = 110;
int mapStart = 50;
int mapEnd = 130;

// Calibration values
int minDegrees;
int maxDegrees;
int minFeedback;
int maxFeedback;
int tolerance = 2; // max feedback measurement error

Servo myservo; // create servo object to control a servo

/*
  This function establishes the feedback values for 2 positions of the servo.
  With this information, we can interpolate feedback values for intermediate
positions
*/
void calibrate(Servo servo, int analogPin, int minPos, int maxPos) {
  // Move to the minimum position and record the feedback value
  servo.write(minPos);
  minDegrees = minPos;
  delay(2000); // make sure it has time to get there and settle
  minFeedback = analogRead(analogPin);

  // Move to the maximum position and record the feedback value
  servo.write(maxPos);
  maxDegrees = maxPos;
  delay(2000); // make sure it has time to get there and settle
  maxFeedback = analogRead(analogPin);
}

void setup() {
  Serial.begin(9600);
  Wire.begin();
  myservo.attach(servoPin);
  calibrate(myservo, feedbackPin, 20, 160); // calibrate for the 20-160 degree
range
  delay(5);
  sixDOF.init();
  delay(1000);
}

void loop() {
  sixDOF.getValues(values);
  sixDOF.getEuler(angles);

  // Reading servo position
  int feedback = analogRead(feedbackPin);
```

```
  // Linear mapping
  int linearY = map(values[5], -180, 180, startAngle, endAngle);
  myservo.write(linearY);

  // Stationary screen
  int pos = 90;
  myservo.write(pos);

  // EXPE Demo using Euler angle
  int linearY = map(angles[0], -180, 180, -130, 150);
  myservo.write(linearY);
  delay(5);
}
// Maps the raw data to a sqrt function
double sqrtMap(float value5) {
  int y = 0;
  y = sqrt(value5);
  double sqrtMap = map(value5, sqrt(startAngle), sqrt(endAngle), mapStart,
mapEnd);
  return sqrtMap;
}
// Maps the raw data to an exponential function with base 2
double expMap(float value5) {
  int y = 0;
  y = pow(2, value5);
  double expMap = map(value5, pow(2, startAngle), pow(2, endAngle), mapStart,
mapEnd);
  return expMap;
}
```

5.4 Testing Route

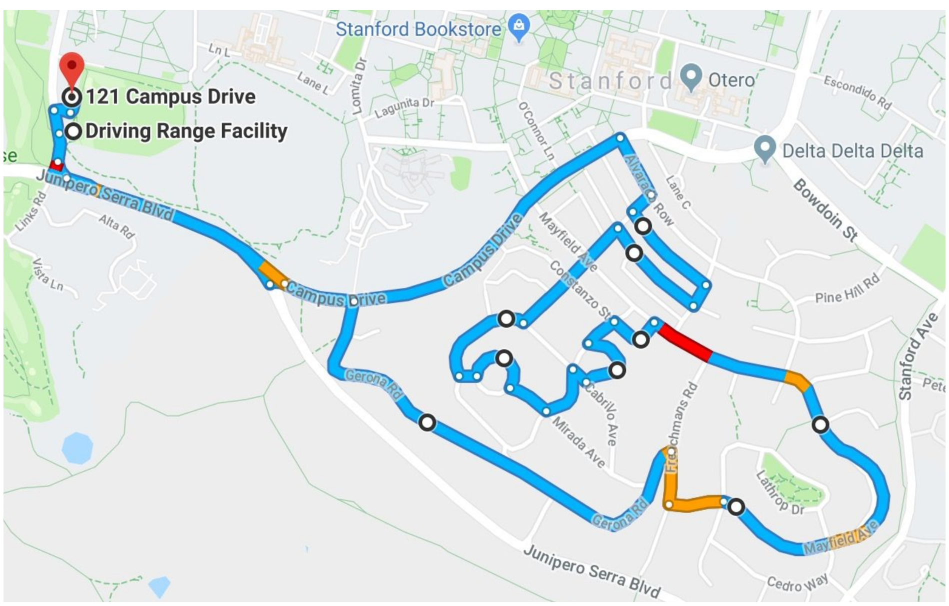


Figure 22: Test drive route

5.5 Testing Script and Roles

The testing script was as follows:
"Thank you for taking part in this study. We are testing the effects of car mounts on motion sickness, and we will have you rate the intensity of your motion sickness with the following scale: 0 is no motion sickness, 10 is throwing up or needing to stop the car, 5 is you would rather not read. Please read the text displayed on the iPad at a normal reading pace and do not look away from the iPad for long durations if you are feeling sick. If you are ever uncomfortable and wish to stop the car, please let us know and we will do so."

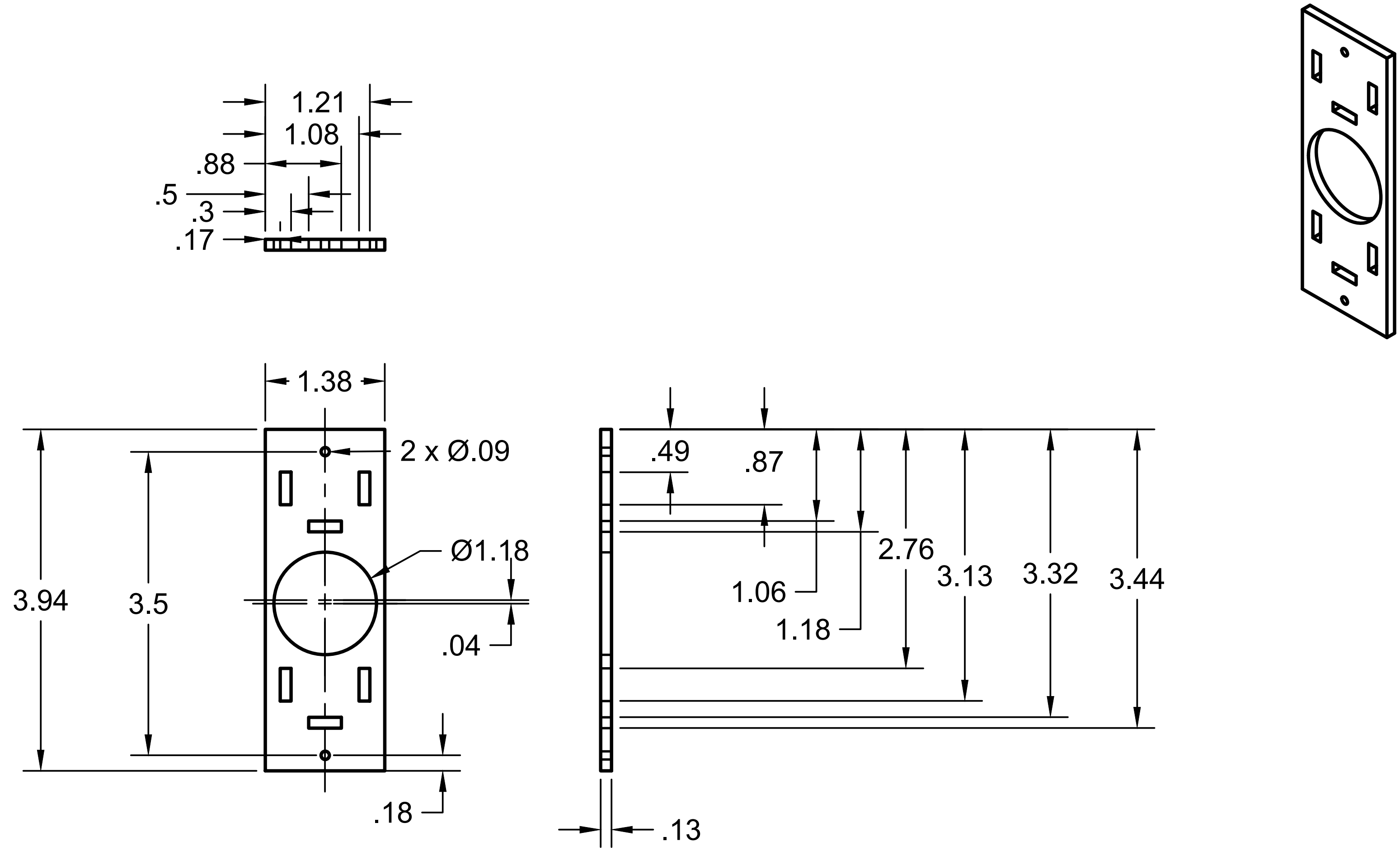
During the trials, tester A:

- Gave the prompt
- Drove the car

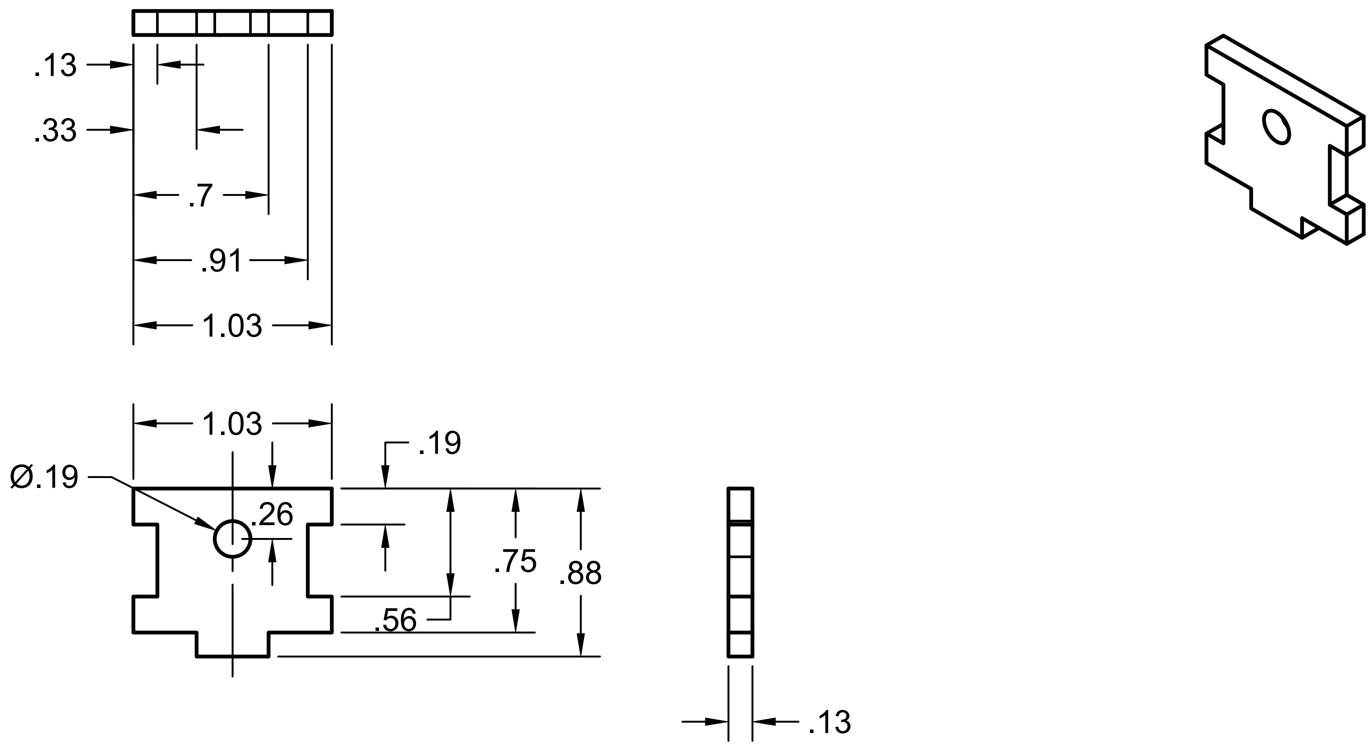
During the trials, tester B:

- Assigned the order of conditions
- Operated the device
- Requested and recorded sickness ratings from the subject

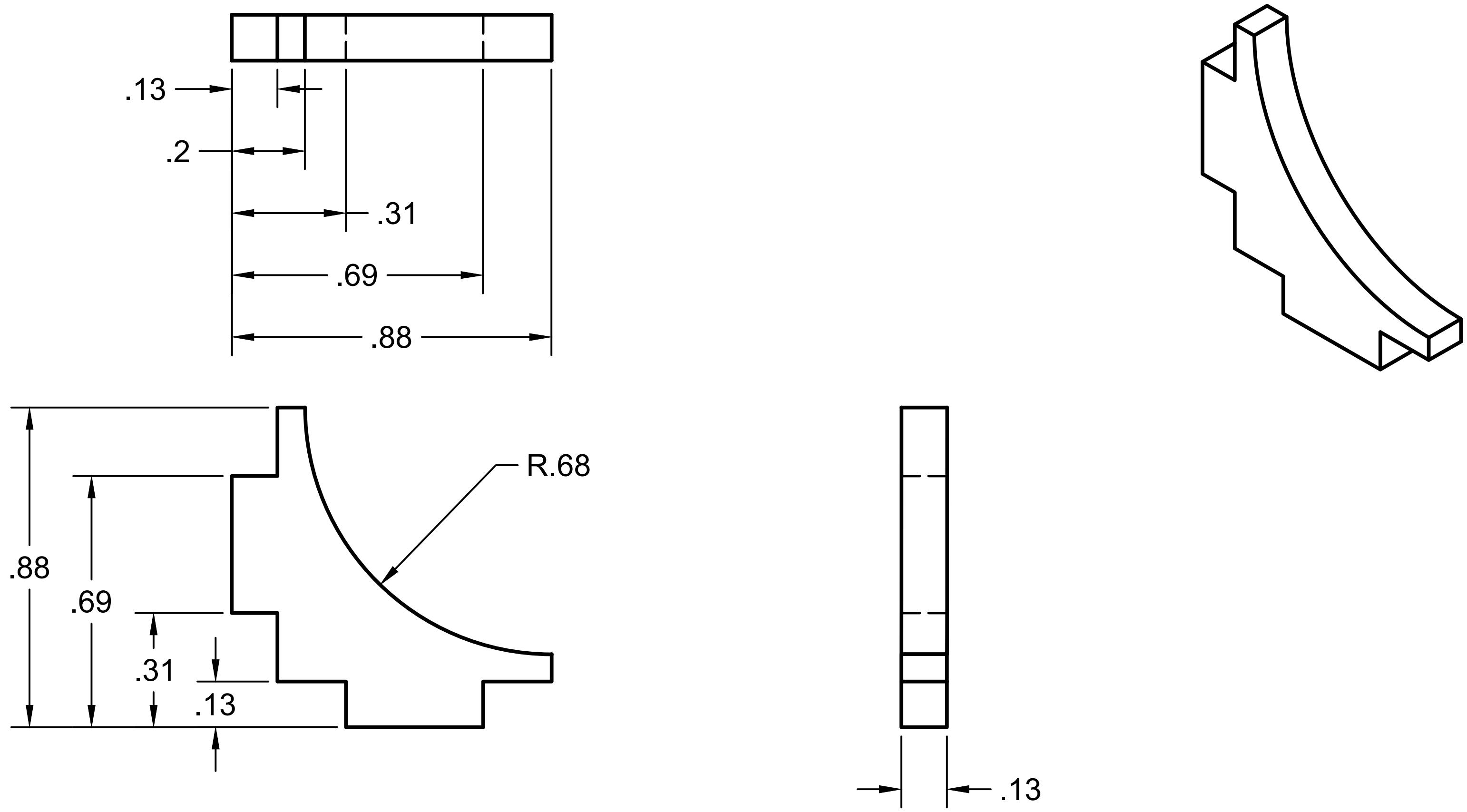
5.6 Part Drawings



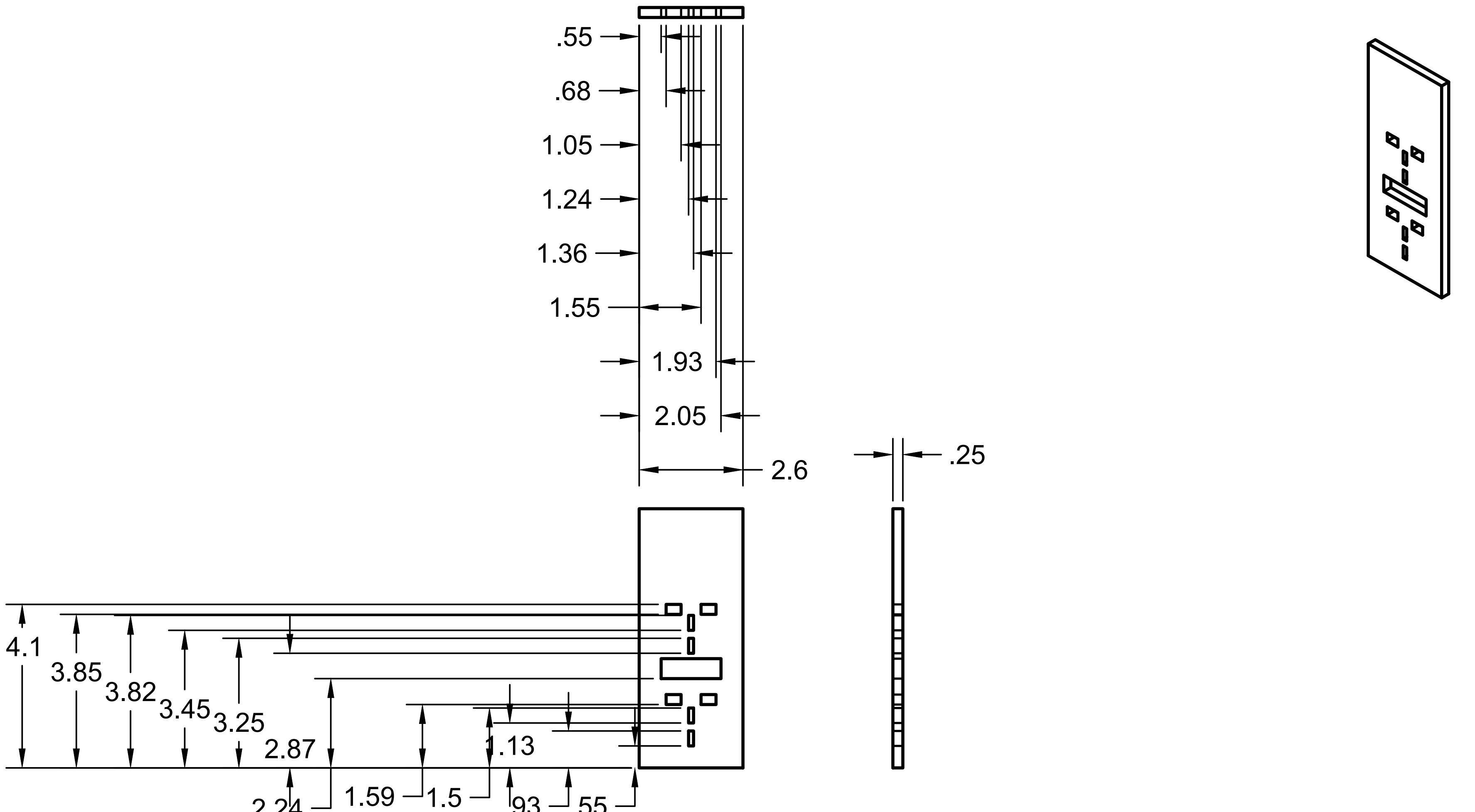
	PROJECT ME 113 TITLE Front Plate					
APPROVED	SIZE	CODE	DWG NO			REV
CHECKED	A					
DRAWN Esteban Mejia 6/11/18	SCALE 1:2		WEIGHT		SHEET 1/1	



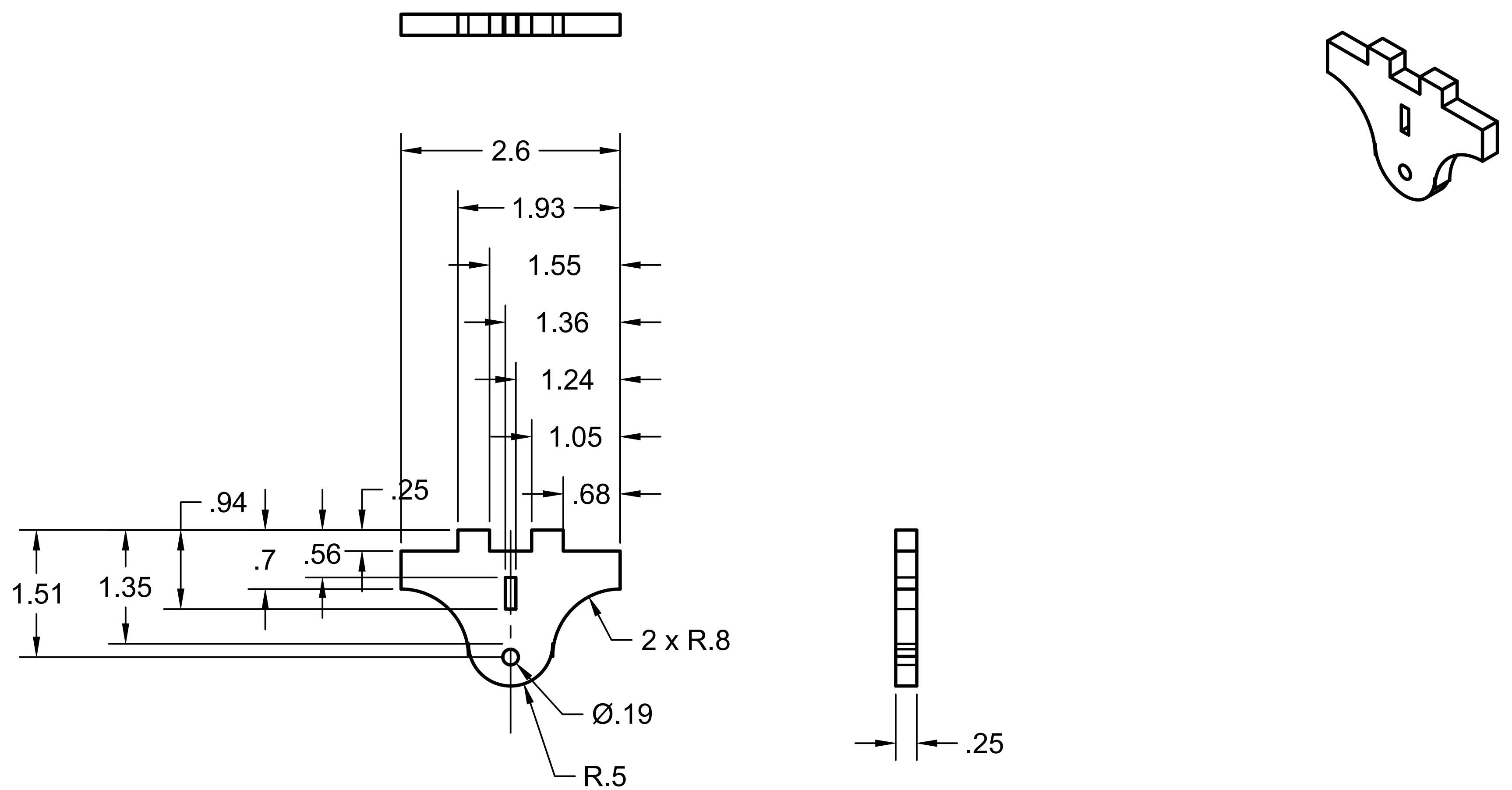
PROJECT ME 113				
TITLE Bearing				
APPROVED	SIZE A	CODE	DWG NO	REV
CHECKED				
DRAWN Esteban Mejia 6/11/18	SCALE 1:1	WEIGHT	SHEET 1/1	



PROJECT: ME 113			
TITLE: Bearing Rib			
APPROVED	SIZE: A	CODE	DWG NO	REV
CHECKED				
DRAWN: Esteban Mejia 6/10/18	SCALE: 2:1	WEIGHT	SHEET: 1/1

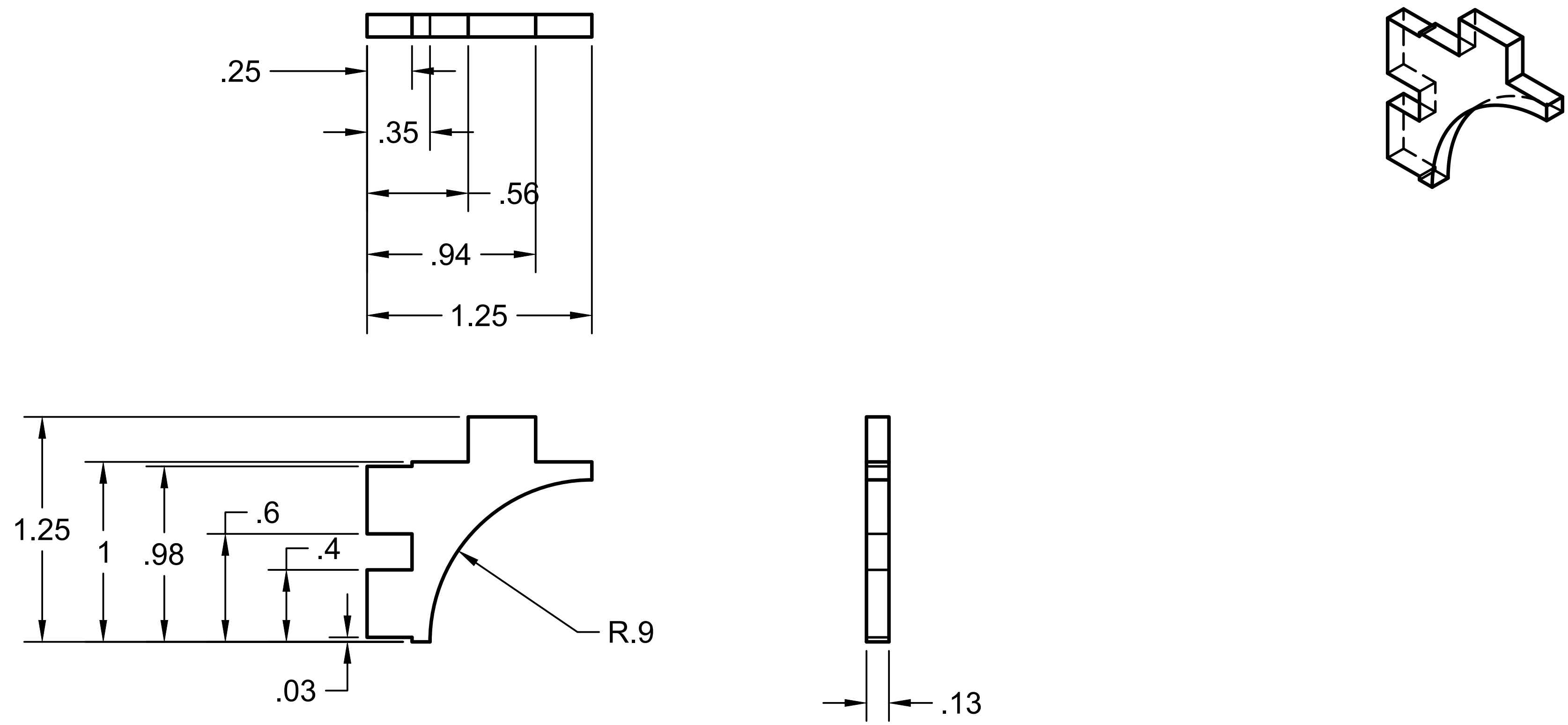


	PROJECT ME 113			
	TITLE Back Plate			
APPROVED	SIZE A	CODE	DWG NO	REV
CHECKED				
DRAWN Esteban Mejia 6/11/18	SCALE 1:4	WEIGHT	SHEET 1/1	

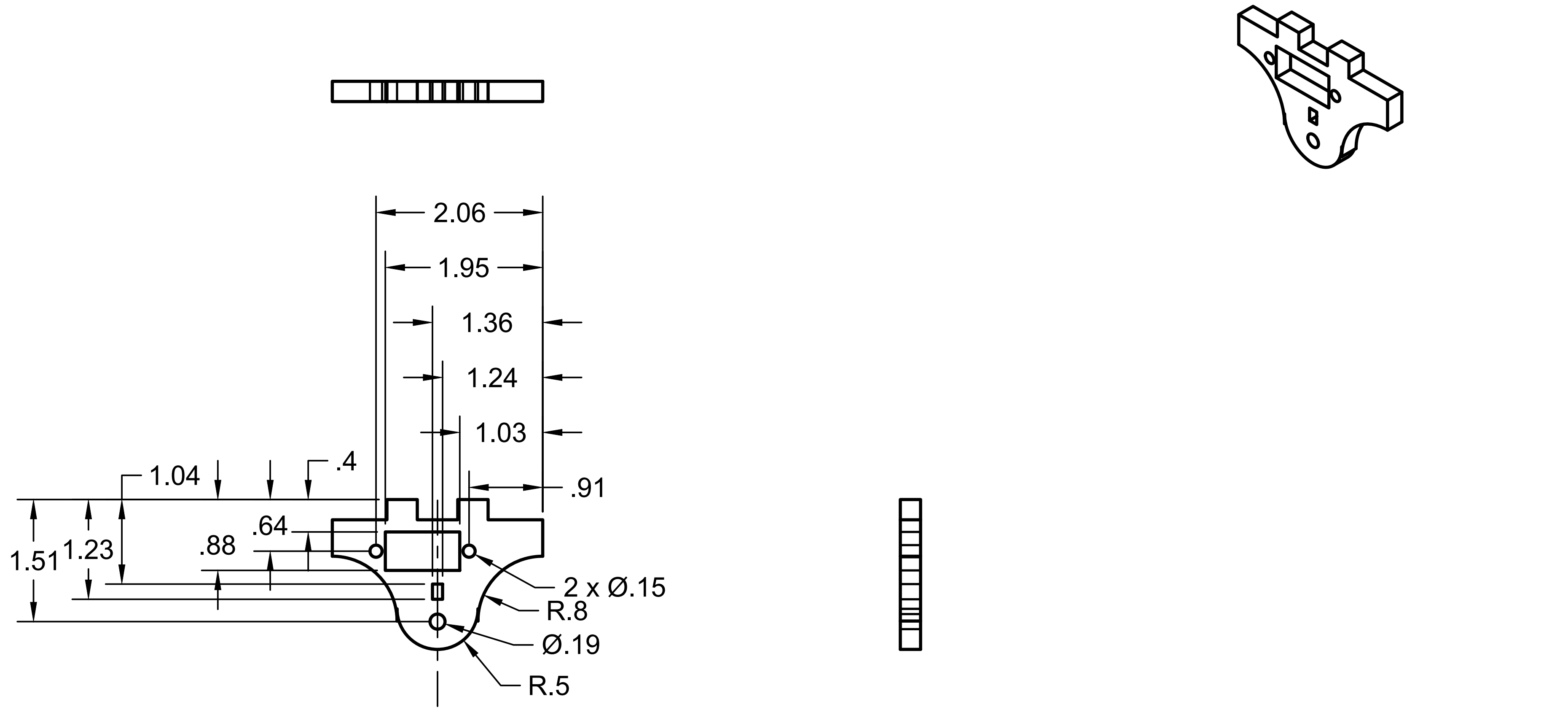


PROJECT	ME 113
TITLE	Beam

APPROVED		SIZE A	CODE	DWG NO	REV
CHECKED					
DRAWN Esteban Mejia 6/11/18		SCALE 1:2	WEIGHT	SHEET 1/1	

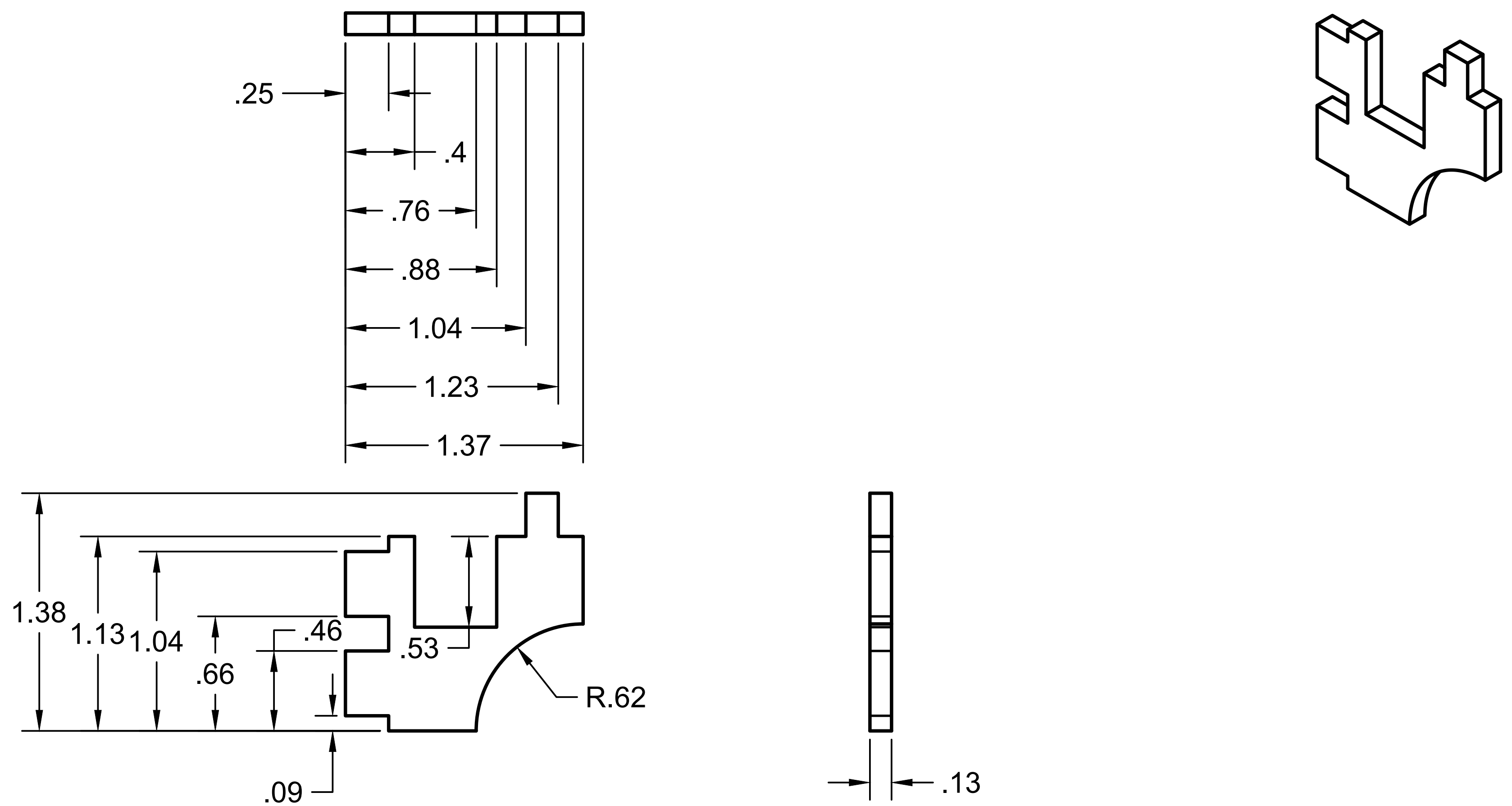


PROJECT ME 113				
TITLE Beam Rib				
APPROVED	SIZE A	CODE	DWG NO	REV
CHECKED				
DRAWN Esteban Mejia 6/11/18	SCALE 1:1	WEIGHT	SHEET 1/1	

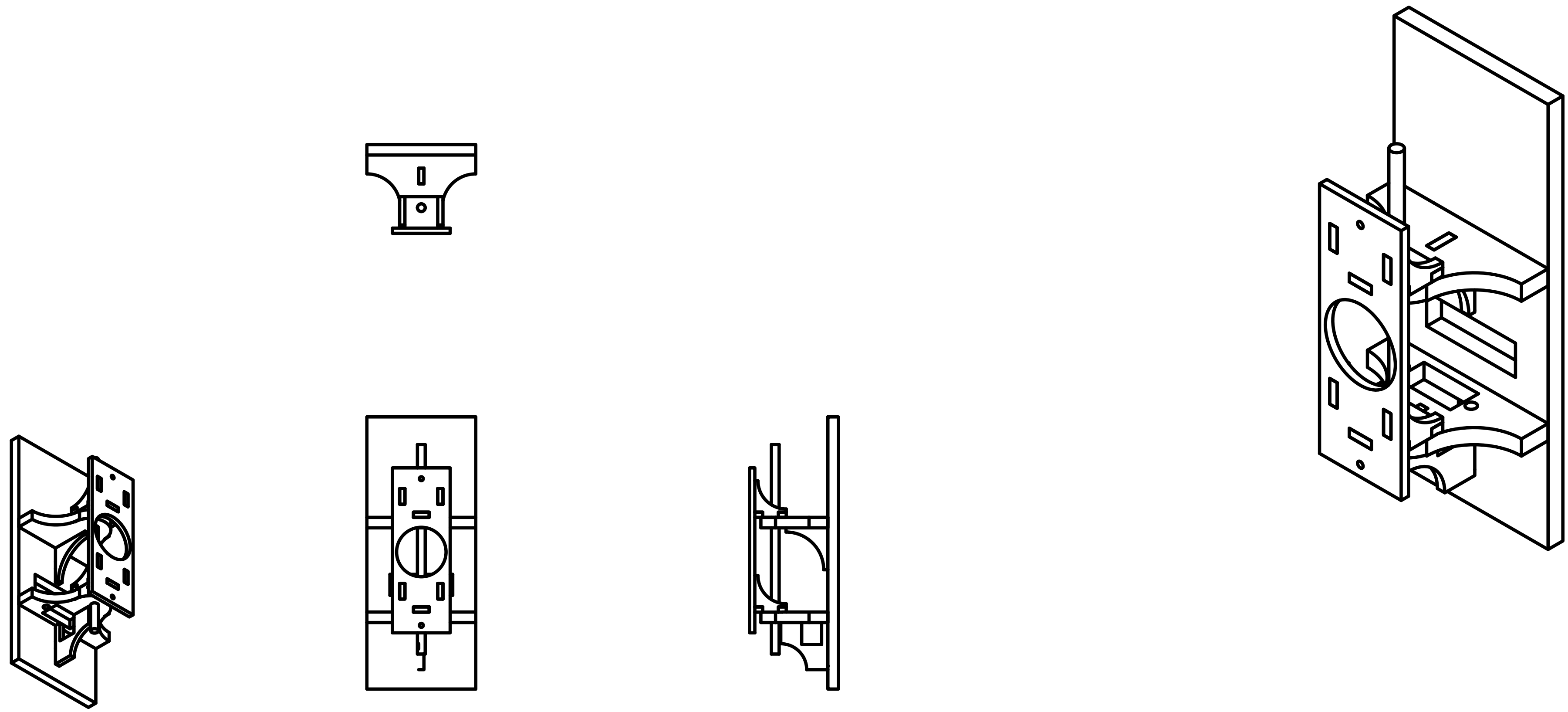


Exterior dimensions defined by Beam drawing

PROJECT	ME 113			
TITLE	Servo Beam			
APPROVED		SIZE A	CODE	DWG NO	REV
CHECKED				
DRAWN Esteban Mejia 6/11/18		SCALE 1:2	WEIGHT	SHEET 1/1



PROJECT	ME 113			
TITLE	Servo Rib			
APPROVED		SIZE A	CODE	DWG NO	REV
CHECKED				
DRAWN Esteban Mejia 6/11/18		SCALE 1:1	WEIGHT	SHEET 1/1



PROJECT	ME 113 - Viscon			
TITLE	Assembly			
APPROVED		SIZE A	CODE	DWG NO	REV
CHECKED				
DRAWN Esteban Mejia 6/10/18	SCALE 1:4	WEIGHT	SHEET 1/1	

6 References

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