



# 2D Multilayer Thin-Films Combustion Education Model

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## **0. Introduction**

This project was conceived by Engineering students who wanted a new way to learn complicated concepts, and wanted to see more applications in class. To create a solution for this idea, our team decided to build an educational device for use in the classroom as a lecture aid. The first question we must answer is what exactly we wish to explain using this device. In a range of

concepts in the engineering curriculum, most already have obvious applications and physical examples. The exception to this includes classes like heat transfer, materials science, and organic chemistry, where most of the curriculum is focused on microscale objects. These are hard to visualize and are often the hardest for engineers to pass. For this project we chose to focus on materials science concepts because of the high amount of interesting applications and research to use as examples. Composite materials offer a useful case study for concepts learned in the classroom because of their obvious and exploitable link between their structural architecture and their material properties.

Composite materials can change in their tensile strength, shear strength, melting point, and combustion behavior simply by changing their architecture. This is the concept that we will use in our educational model. More specifically, we will show that changing the architecture of a thin film composite material (see Appendix A for a discussion of thin-films research) will change its combustion behavior. These materials represent current research and because of their high combustion temperature and quick burn time, they have applications in manufacturing, technology, and energy systems. These applications as well as their manipulatable architecture make thin-films the perfect case study for use in an educational model.

Designing such a device will allow this team to enhance the materials science classroom by offering a hands-on experience to engineering students, answering the age-old question, “why does this matter?”

## **1. Design Objectives and Constraints**

The objective of this design project is to demonstrate how the architecture of a composite material affects combustion behavior by using thin film composites as a case study. Further, our goal is to design an educational device that is safe and easy to use in the classroom, a device that easily explains the concepts we have chosen. This means we must meet the constraints of the physical design, while also writing software that accomplishes the constraints of the educational aspect.

Because of our classroom audience, the design is subject to the following constraints:

- Large enough to be clearly visible, but small enough to be portable

- Must not be subject to mechanical failure under normal use
- Must not contain any high voltages or electrical hazards
- Must not generate excessive heat
- Must be ergonomic and safe to touch
- Architecture must be easy to manipulate
- Simulation must be user-friendly
- Simulation must have a reasonable run-time
- Simulation must be easy to understand and clearly display concept

Designing around these constraints will allow us to narrow the focus of the project while also making sure to provide a useful product upon completion.

## **2. Team Organization and Project Planning**

The team is structured as follows, though a high degree of collaboration is present:

Truc Ngo - Structures/Mechanical Systems Design

Chapman Howard - Thermal/Electrical Systems & Simulation Design

To elaborate, this project contains several key sections. Building a structurally sound casing for the internal components of the device that meets the constraints of the design will be critical to producing a useful product. Truc will take on this task, designing the structure as well as analyzing the static and dynamic loads associated with general use, certifying that the device is structurally safe to operate.

There will also be many electrical components to the design associated: those associated with building the thin-film architecture as well as processing and displaying the simulation. Chapman will be responsible for this section of the project, designing the electrical systems, analyzing the thermal properties, and writing the simulation code.

There are two obvious stakeholders in the project other than the team itself: professors of materials science at Oklahoma State University (namely Dr. Jim Smay), and researchers interested in thin-films materials. Communicating with both parties will allow us to be certain we are meeting our design goals with respect to the educational aspect as well as providing an accurate representation of thin-film systems.

This project has a well-defined critical path to completion. Because the systems are relatively independent in the design phase, there is a simple way to approach project completion. See the GANTT charts attached below to validate the following assertions: Designing the electrical systems must be done prior to thermal systems since the heat generated is entirely dependent on the electrical components, sourcing the components and meeting specification required for each system must be done before designing the outer casing since the total weight of the device must be known to develop deflection calculations. A highly generalized critical path for the design phase for each team member is as follows:

**Truc:** Concept → Specify Materials/Components → Structural Design → Safety Calculations

**Chapman:** Concept → Electrical System → Thermal Calculations → Simulation Design

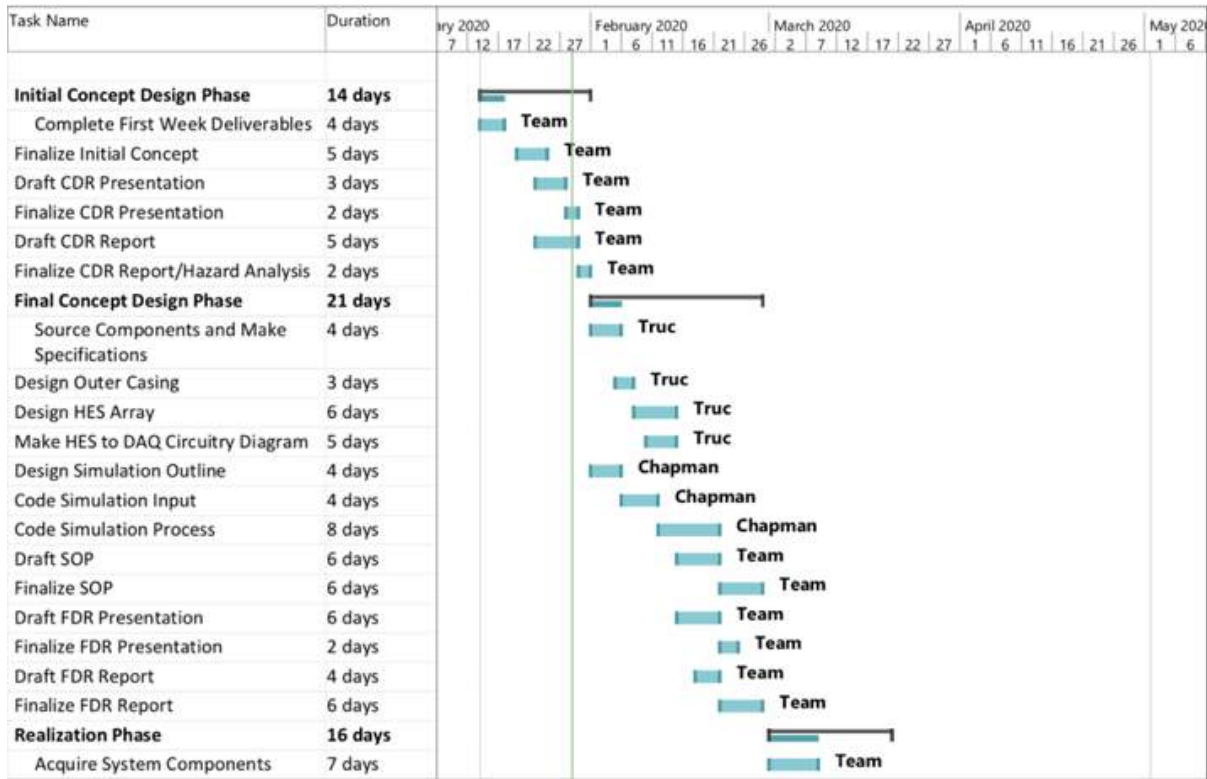


Figure 1: GANTT Chart 1





The input side will be covered in galvanized sheet metal, creating a magnetic surface for small magnets to act as the components of the array. This creates an easy way to manipulate the composite material's architectural structure. The presence of magnets in respective positions will be detected by reed switches that provide a digital reading of a magnet's location. These reed switches will be wired to an Arduino Mega board that acts as a sensor enhancement and will communicate the inputted array to the other side of the box for the visual output to be generated.

The output side of the box will act as a screen for our classroom audience to vividly see the combustion behavior. This screen will also consist of a button designed through a graphic user interface that will start the simulation following an array construction, so the visual simulation will be generated on a touch screen monitor. Connected to the touch screen monitor will be an Intel Compute Stick that acts as a miniature computer to provide a processor to the monitor and to carry the code needed to execute the simulation.

## 4. Application of Relevant Standards

### 4.1 Electrical Standards

Designing a device for use in the public classroom means that electrical standards for use with no PPE must be followed. To recap, our system will have electrical components servicing the entire device, spanning both the magnet architecture interactive side, to the touch screen simulation side. A list of the electrical components is below:

- Reed Switch Circuit Board
- Arduino Mega 2560
- Intel Compute Stick Atom
- 2x Arctic F8 Silent Case Fans
- Planar Helium PCT2235 Monitor

The **S+ IEC 61010-031 Ed. 2.0 en:2015** specifies that live voltages must be under 30v RMS, 42.4 V peak capacity, or 60 VDC in order to be classified as non-hazardous. The only live voltages in our design are found in the reed switch circuit board, and the arduino controller. To prevent the arduino controller from contacting the casing or otherwise posing a hazard, we will install an arduino brand plastic shield to cover the circuitry. We will also mitigate the risk posed by live voltages on the reed switch array by positioning the circuit board away from the other electrical components and secured as close to the magnetic back wall as possible. This will also help us since the reed switches need to be as close to the magnets as possible in order to guarantee they close as required when stimulated by the magnetic field.

Further, the live voltages on both the Arduino Mega 2560 and the reed switch circuit will be significantly less than 30v RMS. The Arduino Mega 2560 takes 5v DC power supply, and can only output a maximum of 5v through the PWM I/O ports.

All other electrical components, the compute stick, fans, and monitor, all have covered wire to prevent live voltages from posing a threat, and have been certified by their manufacturer as safe for use without PPE.

## 4.2 Thermal Standards

After understanding the electrical components in the design, we can set constraints on the amount of heat build up inside of the casing in order to maintain a safe operating temperature. The total power consumption of all of our components is dominated by the computer monitor. The monitor will pull 27W of power, while the compute stick, arduino, and reed sensor array will collectively pull less than 10W of power. To be safe in our heat calculations (see section 5.3), we use a generous safety factor and round to a total power consumption of 40W. Again, in the thermal calculations we assume that all this power is transferred into the box, where realistically the monitor would expel quite a bit of heat outward into the room.

The **ASTM C1055** specifies that safe operating temperatures for laboratory equipment must stay below 118°F. For our set-up, this is easy to achieve, as our fans maintain 15CFM in cross-flow to cool the inside of the box, which will result in a temperature rise of only 8.4°F from room temperature.

To mitigate this risk, we have chosen HDPE as our primary building material, which has an extremely low thermal conductivity ( $< 0.5 \text{ W/m-K}$ ). This allows the cooling mechanism to remove the heat from the inside of the box before a thermal gradient significant enough to heat the outside of the casing can arise. All-in-all, the machine will operate at nearly room temperature, well within the safety standards.

## 4.3 Mechanical Standards

Deflection of the assembly was calculated based on the various loads of the hardware in addition to the overall structure. The **Corrugated Polyethylene Pipe Association (CPPA)** states that an acceptable deflection for HDPE is limited to 5% of its original position. Although this

structure will not be used as a pipe, we are taking into consideration primarily the structural integrity of HDPE.

Based on the deflections at the base of the device, the calculations show to be between  $1.59 \times 10^{-4}$  in and  $2.74 \times 10^{-3}$  in. According to the design of the device, deflection should not exceed  $(5\% * 23 \text{ inches}) = 1.15$  inches and  $(5\% * 10 \text{ inches}) = 0.50$  inches respectively. This verifies that our case maintains the standard.

## 5. Design Calculations

### 5.1 Electrical Calculations

Power draw of each component:

- Monitor (27W rated)
- Arduino Mega 2560 (.5W rated)
- Intel Compute Stick (5-7W rated)
- 2x Arctic F8 Silent Case Fans (1W rated, each)
- Reed Switch array (assumed negligible, since voltage applied will be minimal, and only one row at a time for minimal time)

### 5.2 Thermal Calculations

As stated above, there will be  $\sim 35W$  generated inside the box. Rounding up to  $40W$  for a safety factor, and assuming all the heat is directed into the box, we can solve to find the necessary CFM to keep the box from heating dramatically.

$$q = mc_p \Delta T$$

$$40W = m(.24 \text{ BTU/lb} - F)\Delta T$$

$$40W (3.412 \text{ BTU/hr} - W)/(.24 \text{ BTU/lb} - F) = m\Delta T$$

$$568.7(\text{lb} - F/\text{hr})(1/.074887)\text{ft}^3/\text{lb} = v\Delta T$$

$$(7593.7)\text{ft}^3 - F/h = v\Delta T$$

*Assume 15 CFM from 1 of the selected fans*

$$\Delta T = (7593.7 / 60)\text{ft}^3 - F/m * (1/15)\text{m}/\text{ft}^3$$

$$\Delta T = 8.4^\circ F$$

### 5.3 Mechanical Calculations

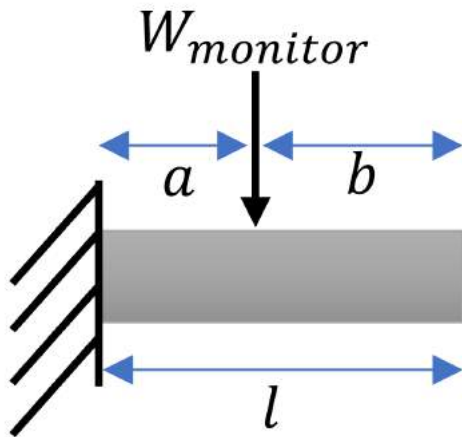
Ledge that elevates the monitor dimensions:

- $l = 1in$
- $h = 0.25in$
- $a = 0.425in$
- $b = 0.575in$
- $W_{monitor} = 7.9lbs$
- $E = 185,000psi$

$$I_x = l^3 h / 12$$

$$I_x = (1in)^3 * (0.25in) / 12$$

$$I_x = 1.333lb \cdot ft \cdot s^2$$



$$\delta_{max} = (3l - a) * W a^2 / 6EI$$

$$\theta = -W a^2 / 2EI$$

Device Base: Long Edge = 23 inches

$$\delta_{max} = (3(1in) - 0.425in) * (7.9lbs)(0.425in)^2 / 6(185,000psi)(1.333lb \cdot ft \cdot s^2)$$

$$\theta = -(7.9lbs)(0.425in)^2 / 2(185,000psi)(1.333lb \cdot ft \cdot s^2)$$

$$\theta = -0.000185^\circ$$

$$\delta_{max} = 0.000159in$$

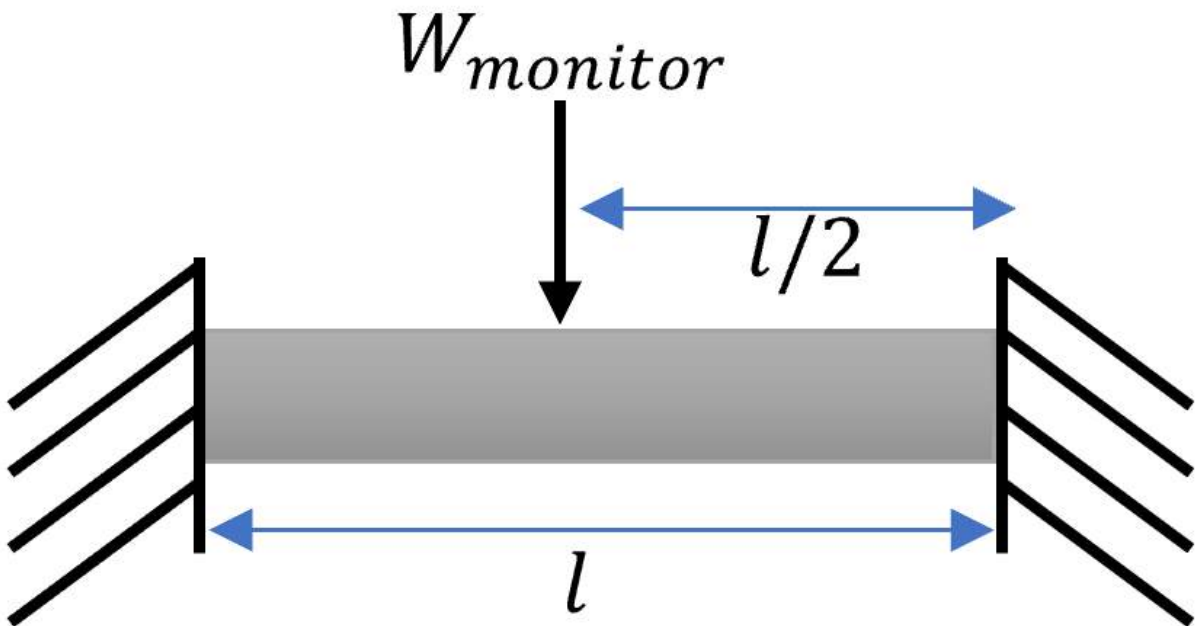
Back support that keeps the monitor upright dimensions:

- $h = 0.25in$
- $b = 4in$
- $W_{monitor} = 7.9lbs$
- $E = 185,000psi$

$$I_y = h^3b/12$$

$$I_y = (0.25in)^3 * (4in)/12$$

$$I_y = 0.005lb \cdot ft \cdot s^2$$



$$\delta_{max} = Wl^2/192EI$$

Device Base: Short Edge = 10 inches

$$\delta_{max} = (7.9lbs)(4)^2/192(185,000psi)(0.00521lb \cdot ft \cdot s^2)$$

$$\delta_{max} = 0.00274in$$

Tabulated values that contribute to the the finding of deflection on the bottom edge of the box:

**Box Dimension with Monitor Constraints**

width_OuterBox	23	in	
height_OuterBox	19	in	
width_Monitor	19.25	in	
height_Monitor	11.75	in	
depth_OuterBox	10	in	
t_HDPE	0.25	in	
$\rho_{HDPE}$	0.035	lbs/in <sup>3</sup>	
A_HDPE	431.25	in <sup>2</sup>	Magnet Side
	199.3125	in <sup>2</sup>	Monitor Side
	178.125	in <sup>2</sup>	Thin
	219.375		Top
	230		Bottom
A_Monitor	226.1875	in <sup>2</sup>	
V_HDPE	107.8125	in <sup>3</sup>	Magnet Side
	49.828125	in <sup>3</sup>	Monitor Side
	44.53125	in <sup>3</sup>	Thin
	54.84375	in <sup>3</sup>	Top
	57.5	in <sup>3</sup>	Bottom
m_Steel	4	lbs	
m_Monitor	7.9	lbs	
m_HDPE	3.7734375	lbs	Magnet Side
	1.743984375	lbs	Monitor Side
	1.55859375	lbs	Thin
	1.91953125	lbs	Top
	2.0125	lbs	Bottom
m_symmetric	8.28817375		
m_arduino	0.081571	lbs	
m_shield	0.1	lbs	
m_computer	0.132277	lbs	
m_turntable	0.05	lbs	
m_onescrew	0.00070107	lbs	
m_screws	0.070107	lbs	
m_total~	25.70559563	lbs	

**Separating the monitor and magnet sides to determine center of mass**

m\_screenside 10.76283238

m\_magnetside 7.7734375

x\_cm 4.456715665 from monitor side

x\_cm 5.543284335 from magnet side

$\sigma_{on\ turntable}$  0.111763459 psi

**Deflection Check for Bottom Side of Box**

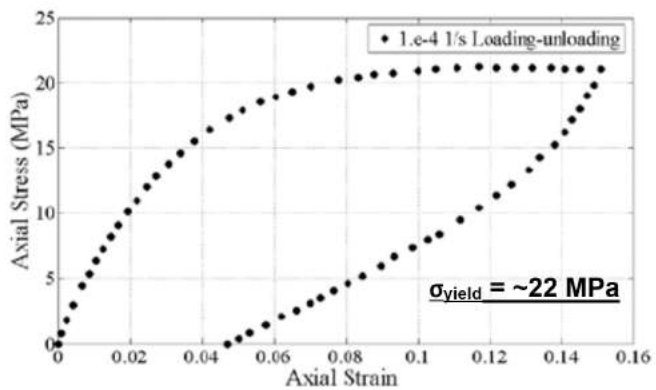
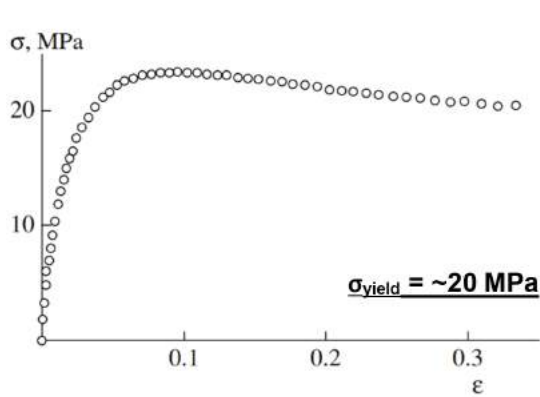
Deflection\_MaxMonitorSide 1.34678E-06 in

Deflection\_MaxMagnetSide 1.87172E-06 in

**Minimum Length/Radius of Base**

14.98039593 in

According to the plots in Figures 4 and 5, the HDPE will yield at a stress of approximately 20MPa - 22MPa, or 2900.75psi - 3190.83psi. The calculated deflection values show that the dimensions will be sufficient in stabilizing the structure.



Figures 4, 5 - Stress Strain Curves for HDPE [5][6]

## 6. Component and Material Selection and Sizing

### 6.1 Internal Components

There are two primary internal components to size for this design. It is necessary to choose an arduino control board that can handle as much resolution as possible to give the simulation as much change in architecture to display a change in combustion behavior. The largest Arduino board available has 15PWM ports, giving us a possible resolution up to 15x15 for the reed switch array. However, because the casing will be 19" tall, a 15x15 array of reed switches would take up nearly the entire back side, reducing the ergonomic appeal. We choose a 12x12 array of reed sensors to add a bit of clearance around the edges, as well as to allow us to use only one side of PWM ports on the Arduino Mega board (12 PWM ports are in series, while 3 are wired on a separate section of the board.)

Next, we have to size cooling fans for the inside of the box. Based on thermal calculation above, any standard USB computer cooling fan will work, since all have a rated volumetric flow above 10CFM. Since we have freedom to choose in this aspect of the design, we make the choice to have as quiet a fan as possible. Two Arctic F8 Silent Case Fans (rated at 15CFM with the option to blow or pull), one on either side of the box to provide cross flow, will give plenty of capacity and will make minimal noise.

### 6.2 Magnet Side

The magnetic, architecture building side of the device is integral to the educational functionality since it is the system that provides students with an interactive experience. To give this experience we have chosen to build an array of reed switches that will be activated by magnets the students place on an etched array on the back of the box. Some important design questions arise from this system: what reed switches will work? How close do the magnets need to be to the reed switches in order to activate them? Which magnets will we choose?

First, we address the questions of which reed switches to purchase. Reed switches come in two types: those that are closed and actuate open in response to a magnetic flux, and those that are open and actuate closed in response to a magnetic flux. Since we are concerned with digitizing where the students are placing the magnets, we will use reed switches that begin open and actuate closed, allowing us to see the completed circuit and tell where the activated reed switches are. Because the changing architecture is vital to our educational design, we want as much resolution as possible within our size constraints. We are also constrained by the data acquisition (Arduino Mega 2560 control board) we have access to. Since the Arduino Mega 2560 is the control board with the most powered I/O ports within our budget (15 PWM output ports), we will use it to communicate with a 12x12 array of reed switches.



Next, we address the problems of how close the magnets need to be to activate the reed switches and consequently which magnets we can use. This is dependent on how close we can install the circuit board to the magnetic side of the box. Based on the structural constraint of 1/4" of HDPE, and 3/80" of steel between the magnets and the reed switches, plus a 1/4" safety factor, we find a total of 13.65mm between the magnets and reed switches. Our reed switches are rated at 20 ampere turns, without knowing exact manufacturing techniques we can't know the exact conversion between ampere turns and flux in units of gauss necessary, so we use the rule of thumb of 1 ampere-turn = 1 gauss and a large safety factor of 2.5 for a total of 50 gauss necessary to activate the reed switches on our circuit board. The following formula for magnetic flux at a distance z away from the surface of a disc magnet will allow us to size our magnets:

$$B = \frac{B_r}{2} \left( \frac{D + z}{\sqrt{R^2 + (D + z)^2}} - \frac{z}{\sqrt{R^2 + z^2}} \right)$$

Figure 6: Magnetic Flux Formula

<https://www.supermagnete.de/eng/faq/How-do-you-calculate-the-magnetic-flux-density>

Where B is flux necessary in units of Gauss, B<sub>r</sub> is remanence of the magnet in units of gauss, D is thickness of the disc, R is the radius, and z is the distance from the surface of the magnet. A 5mm thick by 10mm diameter disc ferrite magnet (remanence of 3500 gauss) will have a magnetic flux of 47 gauss at the 13.65mm specified above, which is slightly less than the 50 gauss given by our safety factor of 2.5, but still suitable considering we assumed an extra 1/4" of clearance between the magnets and the reed switches.

### 6.3 Monitor Side

The selection of the monitor came with the greatest constraints since the components that we connect to the device will be powered through the monitor. The Planar® Helium™ PCT2235 monitor consists of a full HD resolution (1920x1080) LCD that has a highly responsive touch screen to compliment the graphic user interface. Since the wiring and connectors are to be all concealed inside of the box, the ports on the monitor had to be directly on the back of the device as opposed to on the sides or underneath the display. For the back of the monitor to not interfere with internal spacing, the helium computer stand is narrow and almost flush with the back back design of the Planar Helium PCT2235. The monitor is held up by a ledge of HDPE underneath it and a stripe band directly behind it. These keep the screen leveraged and stable when an applied force is exerted on the screen by a user. The screen must be elevated to also account for the usage of the cable plug-ins that will be near the lower back of the piece.

## 6.4 Structural Components

The primary material to encompass most of the device as a protective boundary to the interior wiring is marine-grade high-density polyethylene (HDPE). These sheets are more rigid than standard HDPE surfaces to reduce bending and have a much coarser texture that will reduce wear and tear over time. With its high tensile strength, durability, and low cost, we can effectively obtain and apply this material as the external packaging to our system. Since the HDPE has a lower moisture absorption rate, this material choice is suitable for its direct contact with the wires with less risk of the system short-circuiting due to moisture collection within the box.

HDPE resists the absorption of many harmful bacteria, making it reasonable to be handled among a classroom of individuals which is the intended audience. Since the internal components of the box such as the power connectors and the monitor are subject to increase in heat, the HDPE is not a thermal conductive material. Individuals who actively plan to use this device for long periods of time or plan to have the power sources running for quite a duration will still be able to touch the exterior elements of the box made of HDPE and relieve the concern of it causing burns for this will also create a barrier between the heat and the magnetic side of the assembly. As a stylistic element, the HDPE will collect far less fingerprints in comparison to materials such as metals and clear plastics.

Factors such as thermal expansion and clamp retention are critical considerations for fastener selections in applications with thermoplastics. For example, screws act as a wedge that is threaded to avoid pull-out from a material, making them an effective securance. Our assembly is subjected to temperature variants and intentional movements that risk the integrity of fasteners in conjunction with the HDPE. For plastics, to reduce the radial stress and potential hole expansion when in application, screws will need narrower thread profiles ranging from  $30^{\circ}$  to  $48^{\circ}$  as opposed to the traditional  $60^{\circ}$  threading. With this higher thread profile, there's a greater volume of material for a larger axial shear area, improving the screw's resistance to retreating from its assigned position over time.

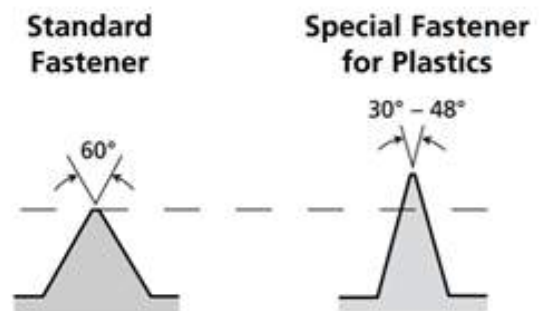


Figure 7 - Comparison between standard fasteners

We examined Young's Modulus to indicate the potential reaction of a fastener to the flexural strength of the material. According to the specification sheet for our selected sheet of marine-grade HDPE, with a flexural modulus of 185,000 psi and impressive level of ductility, we concluded on using Delta PT screws to fasten our assembled HDPE parts.

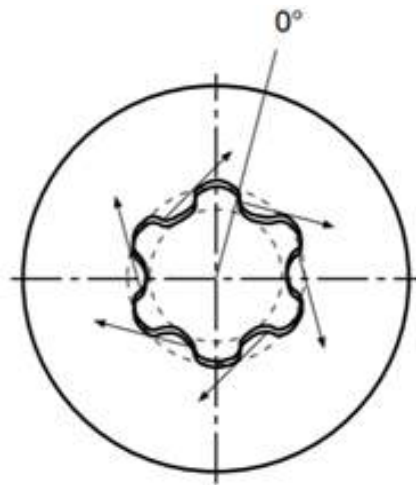


Figure 8 - Force transmission angle of 0° on

These thread-forming screws we selected have a Torx screw drive which resembles a star with circularly patterned six points. The design of Torx screw heads, in comparison to Phillips, slot, and hexagon socket drives, have been shown to decrease the tendency of a screwdriver slipping out of the screw socket due to an extraneous applied torque [4]. With the initial challenge of fastening pieces of thermoplastics together, these screw heads allow for a user who is constructing this assembly to apply extra force to the screwdriver with less damage to the members below the head since the Torx drive facilitates an appropriate amount of torque transfer for fastening the screws.

Figure 8 depicts the force transmission as 0°, and with the relatively cross section of this drive, the driving tool's torsional strength is increased. The primary usage of the Delta PT screws will be to fasten the HDPE segments to each other. In addition, they will aid in maintaining other attachments to the main structure.

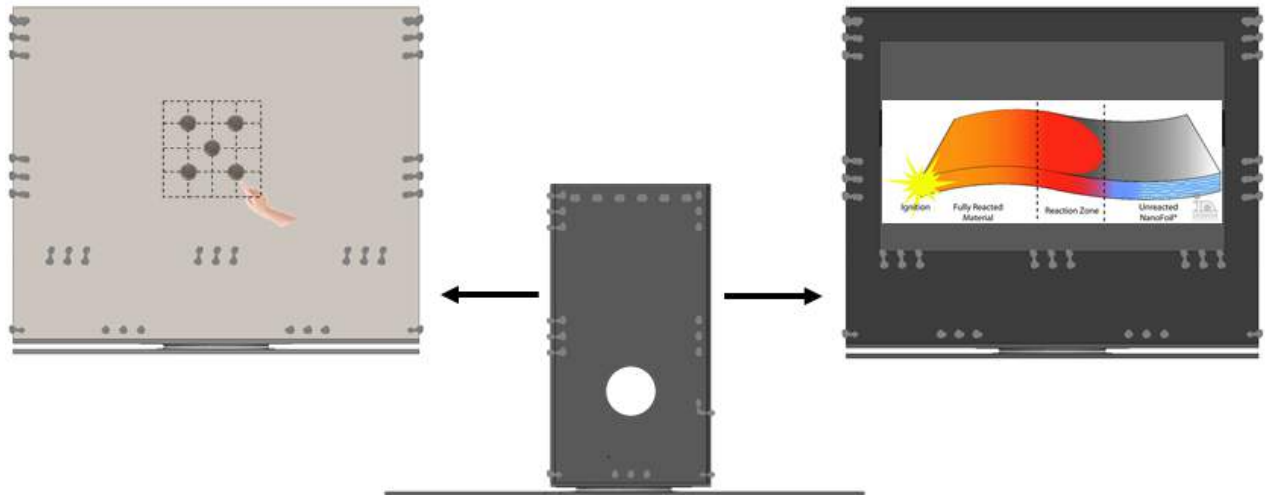
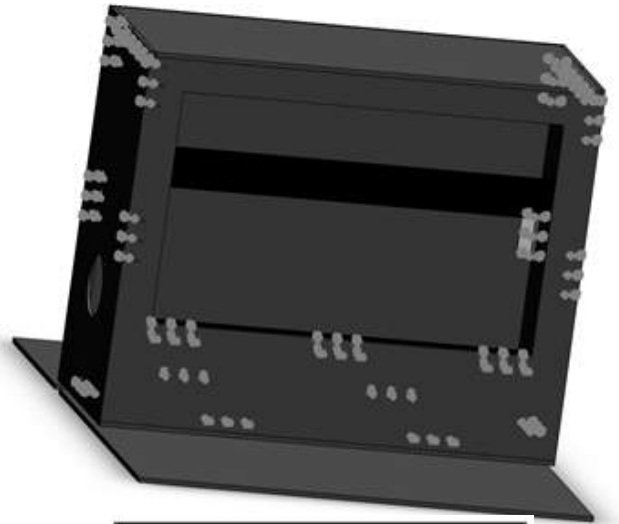
## 7. Final Design

### 7.1 Description in Relation to Concept Design

The final design will be assembled with primarily screws and corner brackets for the structure. There is enough space for placement of necessary wiring and mounting of more delicate pieces in the box. Considerations such as ventilation extrusions, organization of larger

wires, avoidance of over-bending, and connections/communications between the hardware and monitor were utilized to design this final structure.

Magnets can be placed on a board to form an array, emulating the architectural structure of composite materials. The monitor will be able to display the combustion reaction based on a code communicated to the processor. An Arduino Mega board is the sensor enhancement between the reed switches and the Intel Compute stick to transfer information to be displayed on the graphic user interface. The top lid will be able to smoothly slide on and off of the box from a roller bearing, and the base is capable of  $270^\circ$  of rotational movement about the z-axis.



## 7.2 Magnet Side

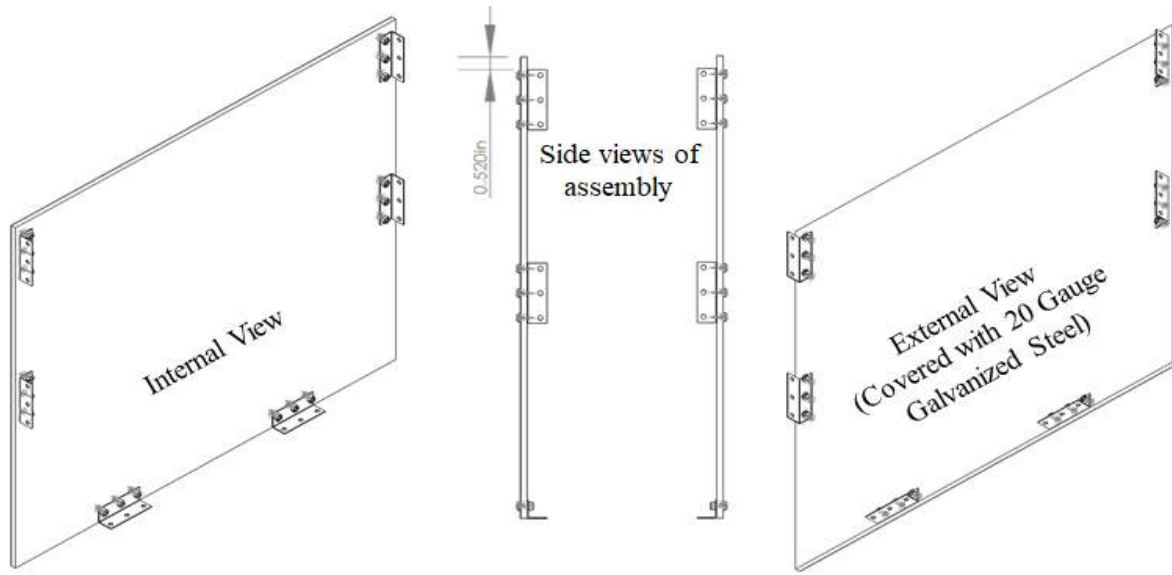


Figure 9: Simplified views of magnetic side structure

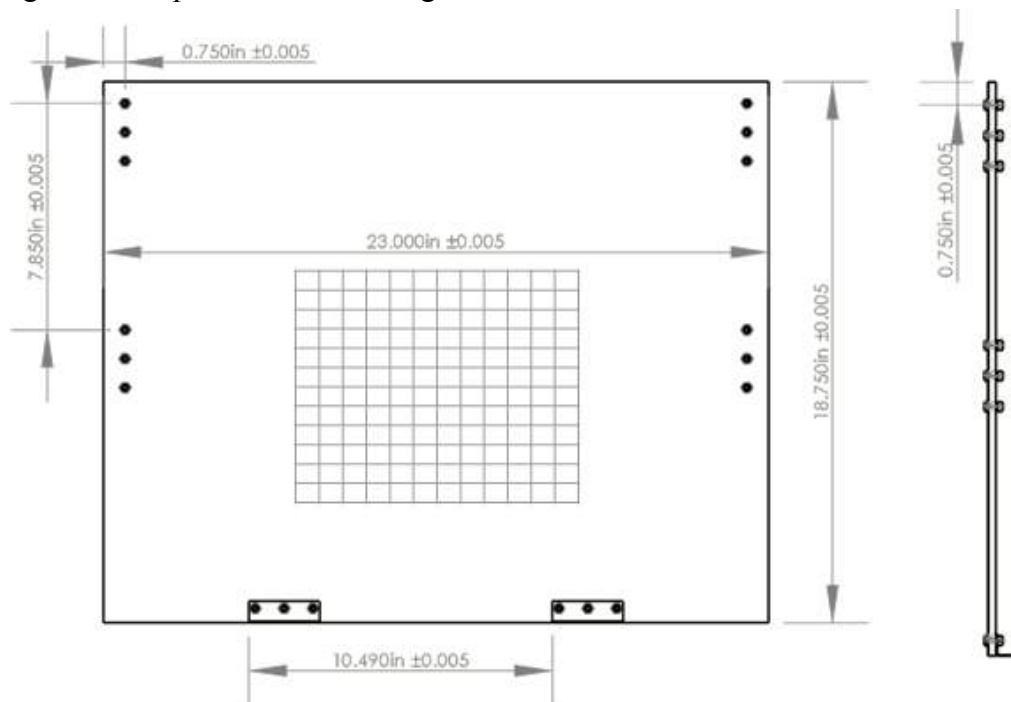


Figure 10: Detailed dimensions of the external magnetic side including locations for corner brackets (0.250in from the edge), dimensions of cutouts, and overall sizing so component

The interior design of the magnetic side will hold the reed switches wired to a custom printed circuit board that is glued directly onto the HDPE side with an Arduino board held up with epoxy and enclosed with a shield. In Figure 10, dimensions exposed to a user are defined with tolerances of the HDPE. There is an etching design done on the 20 gauge sheet metal to

provide visual constraints for where the reed switches will be located and active on the opposite surface of the side. Each square of the grid is 0.5in x 0.5in to accommodate for the size of the magnets that will be interacting with it. The magnets are 8mm (0.315in) in diameter and represent the cylinders of the thin film architecture.

### 7.3 Monitor-Holding/Display Side

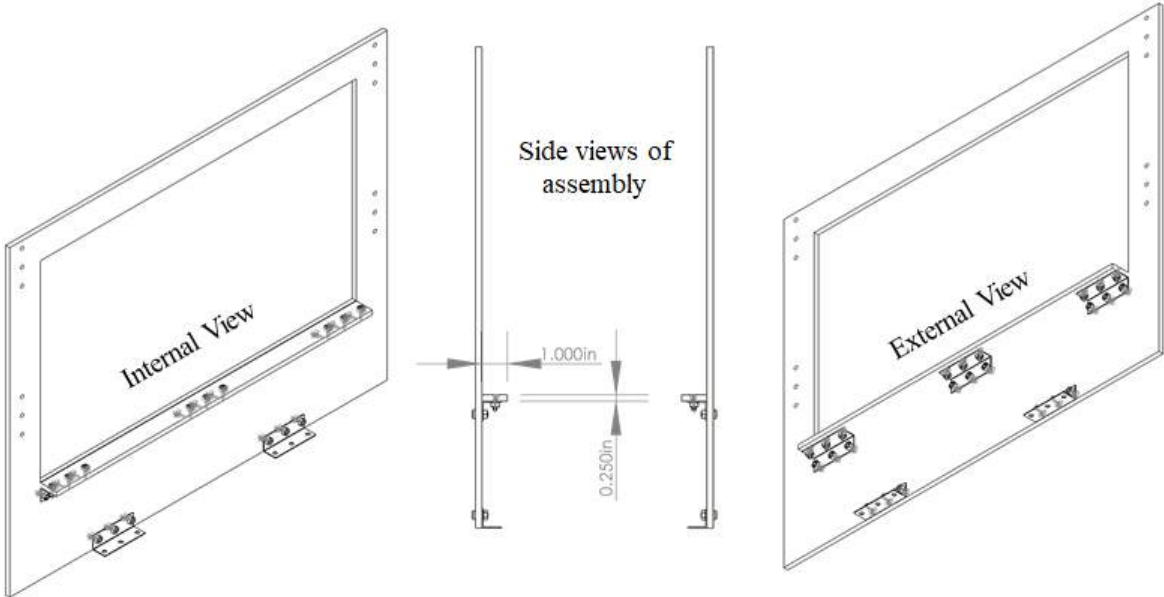
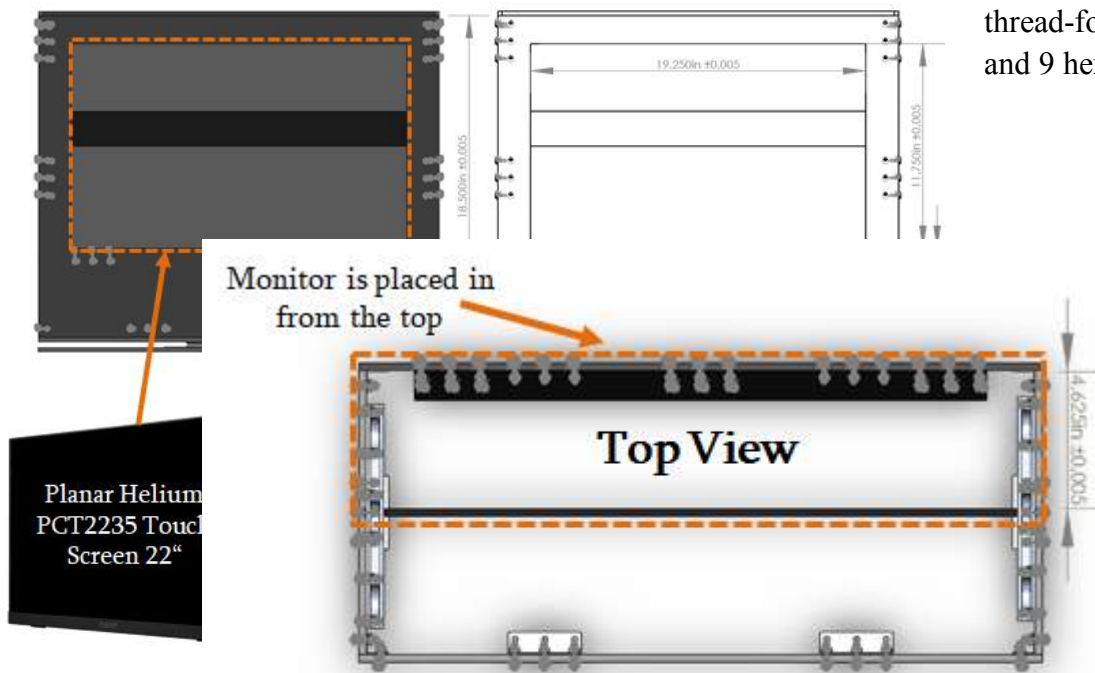


Figure 11: Detailed dimensions of the internal portion of the monitor side including locations for corner brackets, dimensions of cutouts, overall sizing of side

Figure 12: Placement of items for the monitor side

The Planar Helium Touch Screen in Figure 12 is held up by a ledge of HDPE fastened by 3 corner brackets, 9 thread-forming screws, and 9 hex nuts.



From the Top View figure, the region outline is where the monitor will be inserted during assembly. The black outlet shows the constraints for where the monitor will be held up. Further

analyses and calculations were done to confirm that the dimensions would be able to support the loading.

### 7.4 Monitor Stability: Finite Element Stress Analysis

The areas with high loads were around the monitor supports. To determine how stable these parts would be, an FEA simulation was run in Solidworks.

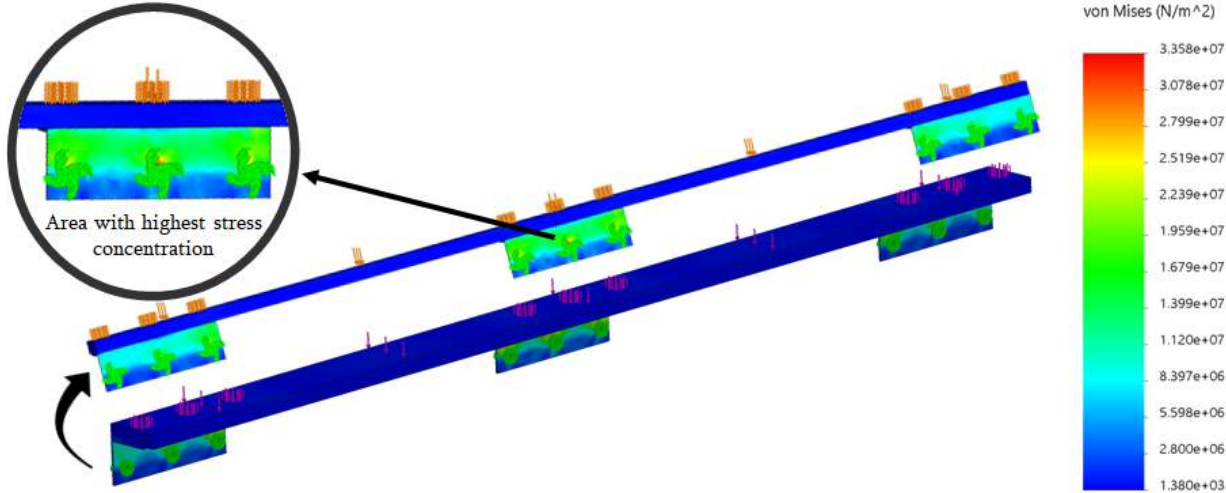




Figure 13: FEA on a ledge that leverages the monitor 5 inches above the base to account for the addition of the Intel Compute stick that will be attached from the bottom of the monitor.

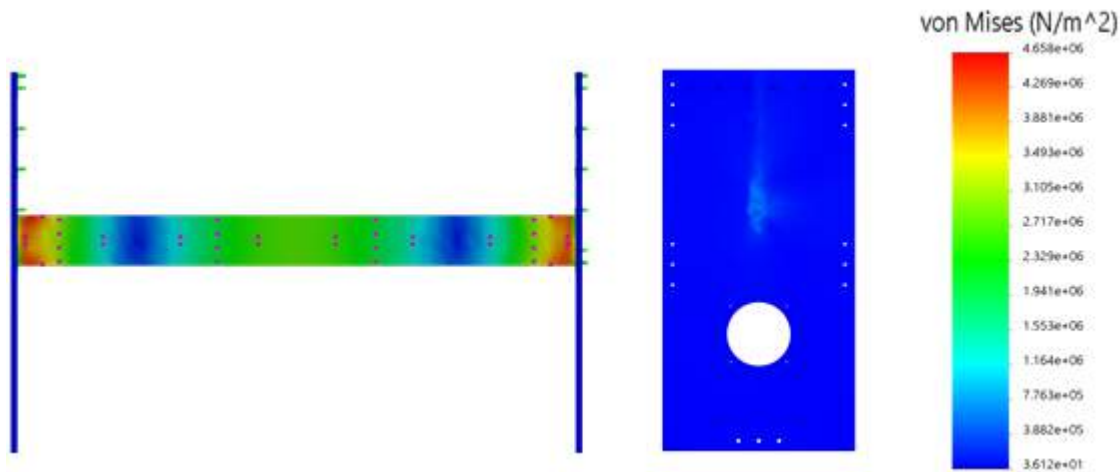


Figure 14: Stress analysis on the beam stabilizing the monitor upward and holding it upright as a user is using the touch screen.

With an applied load of 40N ( $\approx 8.8$ lbs), we observed that the 7.9lbs monitor will not not inflict too much stress on the stabilizing components. In Figure 13, the highest stress concentration area is circled and appears to be at the corner bracket. However, the stress does not exceed 33.58 MPa. From datasheets, the yield stress of the zinc-plated steel is 350 MPa (<http://www.matweb.com/search/datasheet.aspx?bassnum=MS0001&ckck=1>). Since the yielding point is much larger than the maximum stress simulated by the FEA, we can confirm that the dimensions and components are sufficient in leveraging the monitor up without failure.

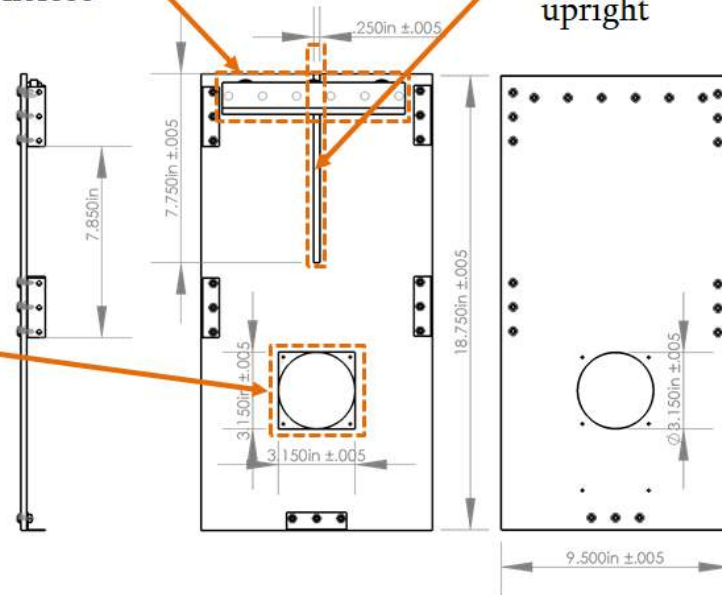
Figure 14 depicts a band that is held up by a cutout in another side of the HDPE. Since the maximum stress simulated doesn't exceed 4.658 MPa and the yield stress of HDPE from the literature is around 20 MPa, the dimensions of the structure are sufficient in stabilizing the structure without failure.

## 7.5 Short Sides

3D printed PLA bearing holder – acts as a roller for the top lid to enclose smoothly

Cut slot that holds a supportive band (2" x 22.75") to keep monitor upright

Slot cut for ventilation fans\*



The figure above outlines the function of the short sides. They are made symmetrical to facilitate and simplify the structural design. The ventilation fan will be fastened by tiny screws

supplemented. Although based on the thermal calculations only one fan is necessary to sufficiently ventilate the system, there is an addition of a second one to maintain the symmetry and to increase the chances of our success when executing the test plans.

## 7.6 Bearing Holder and Roller Device

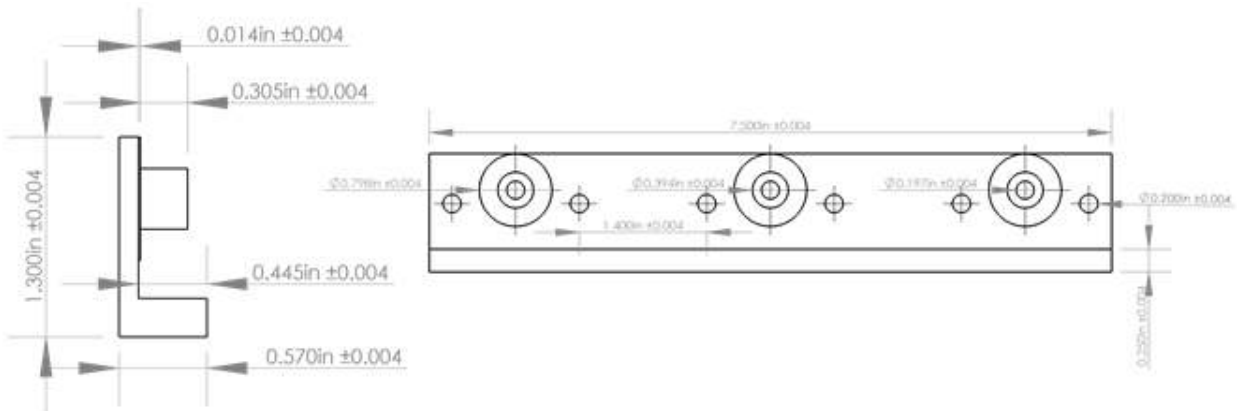


Figure 15: One side of the component - the side that will be fastened to the box assembly

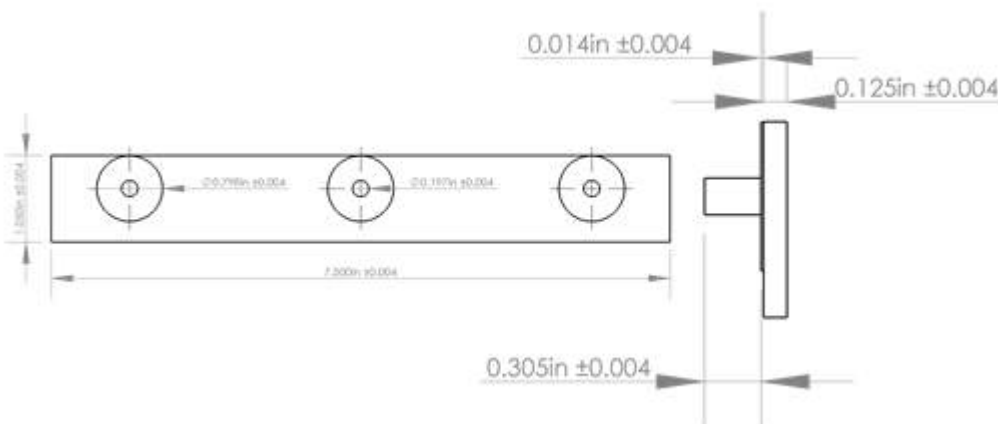
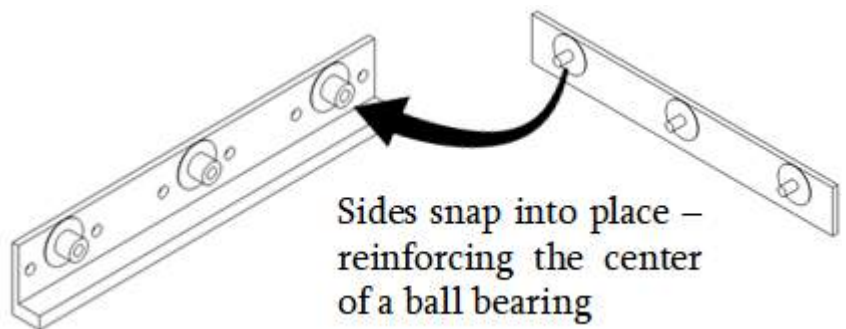


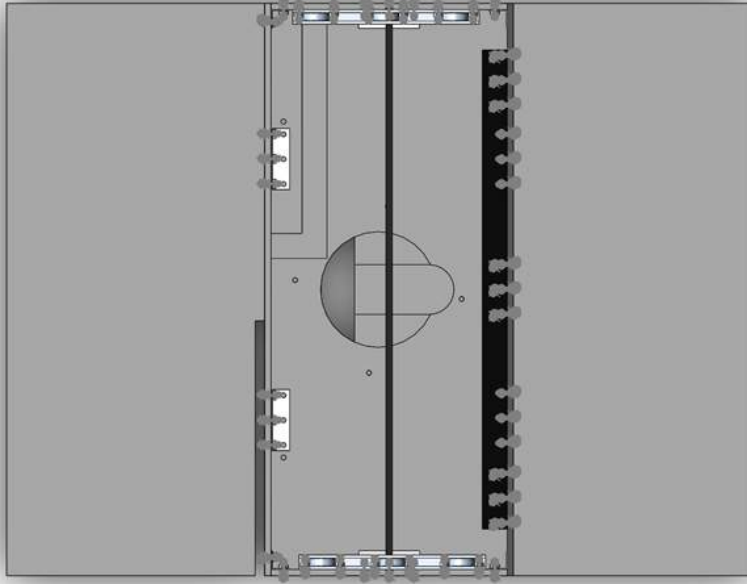
Figure 16: The side that will clamp the bearings into place

The bearing hold is 3D printed with polylactic acid and is designed with both the constraints of the short side of the box and the dimensions of a 6000-2RS double bearing taken into consideration. The tolerances in the dimensions are



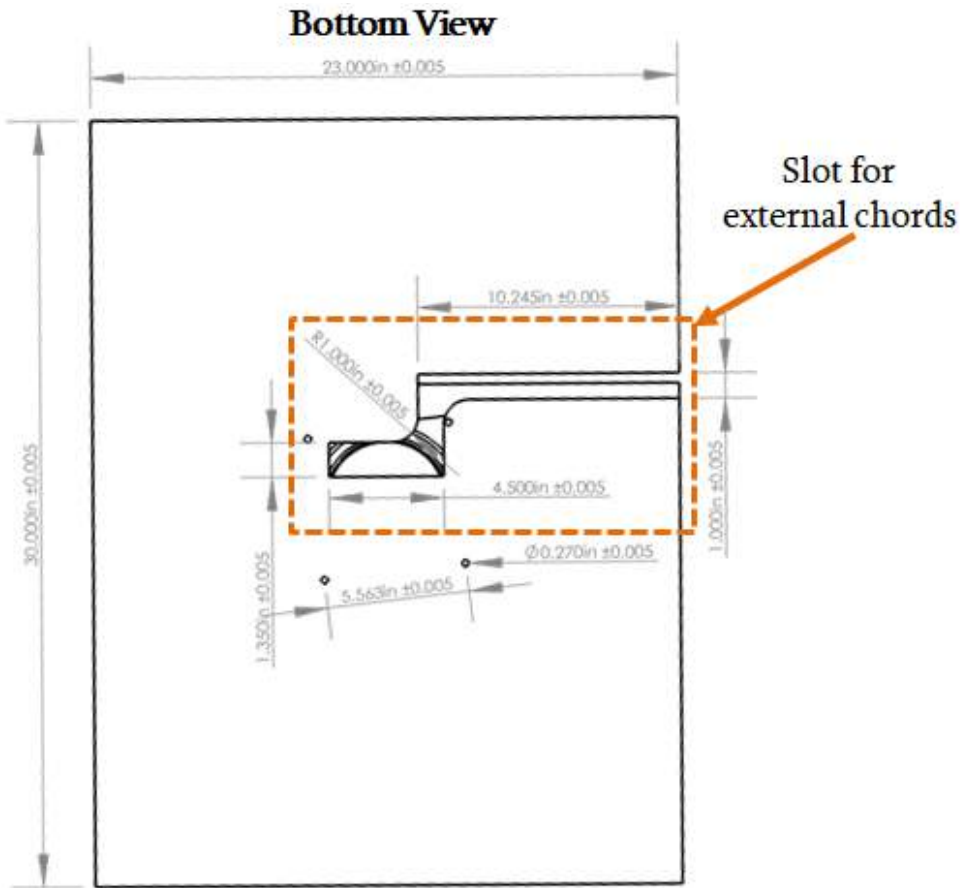
to take into consideration the PLA and calibrations in different 3D printers.

## 7.7 Base/Bottom Side



The base design is anticipated to rotate and have a designation for the external chords to be fed through and fastened. To avoid the chords wrapping around the assembly or coiling around itself, cuts have been made in the base and bottom side of the box.

With this design, the chords feeding to the outside of the box should lay flat with the surface the entire assembly is placed on.

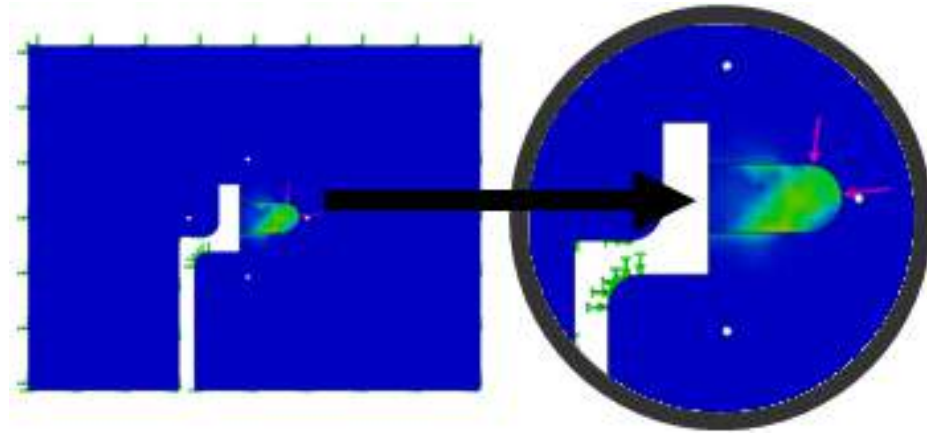


**Lubricated  
Turntable**



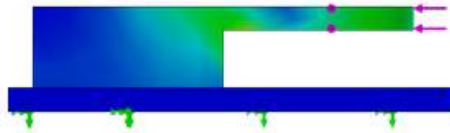
For the device to rotate, a turntable is attached between the base and bottom of the box portion of the assembly. Based on the heaviest components inside the box, the bottom of the box should not deflect surpassing standard limitations.



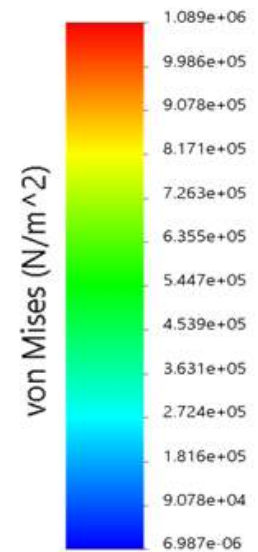
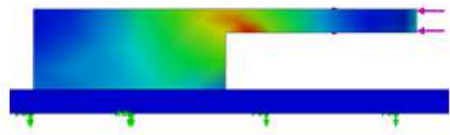


An applied force of 127N ( $\approx 28.5\text{lbs}$ ) was applied to a side in the indicator.

>> Side w/applied load

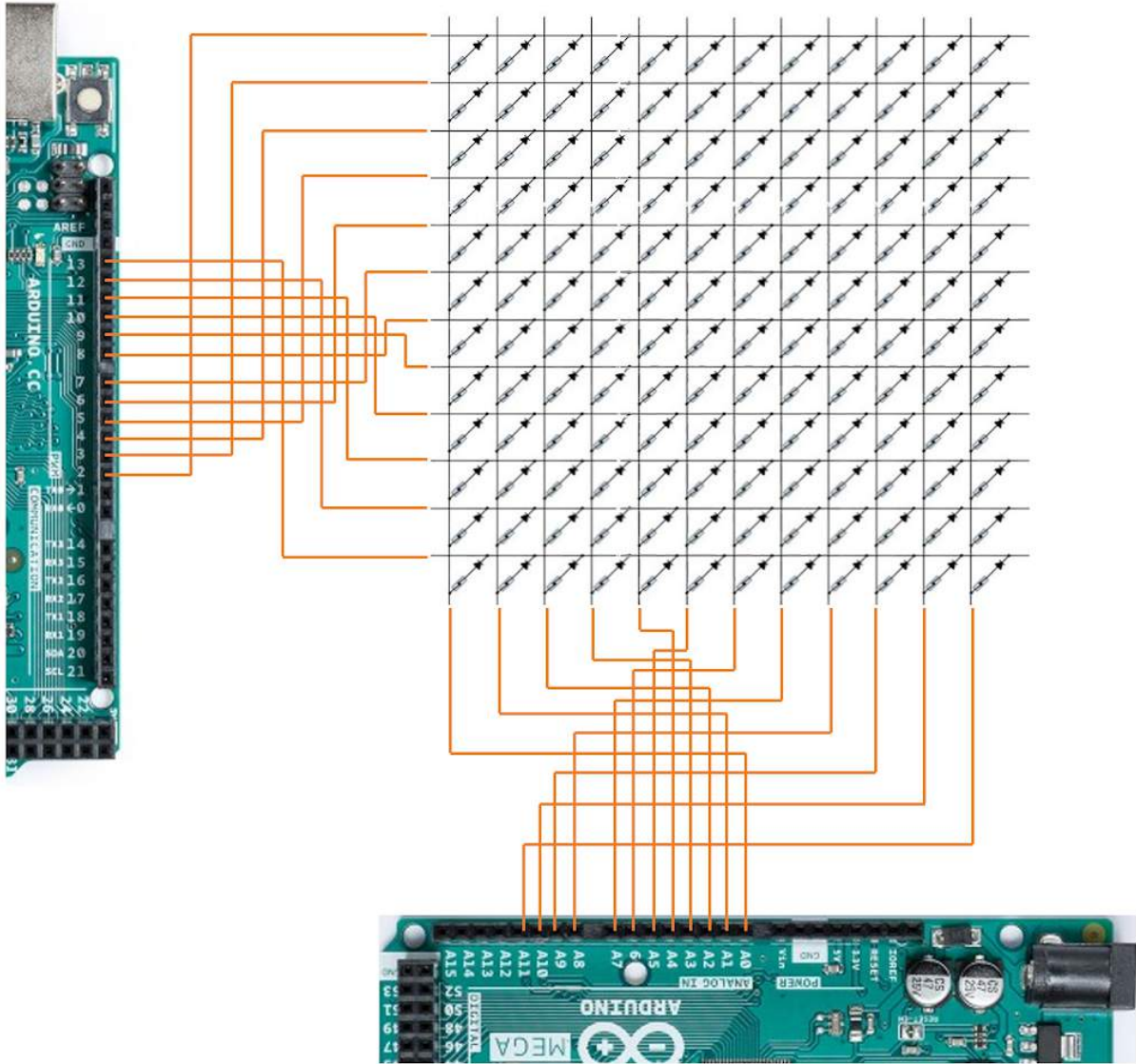


>> Opposite side



Since the maximum stress observed is 1.089 MPa, it is significantly less than the 20 MPa yield stress of HDPE. This solidifies that the design of this stopper will not fail under an even more aggressive load if a user is initially unaware of the rotation constraints.

## 7.9 Wiring Diagram







## 8. Test Plans

There are a number of systems we will need to prototype or confirm the functionality of before the device is ready to be placed in the classroom

We will need to prototype the reed witch array to confirm two things: first, that the wiring diagram and arduino logic (discussion in section 10.1) works as expected, and second that the calculations for necessary magnet distance are also correct. To accomplish this we will first make a temporary 3x3 circuit of reed switches with a breadboard, and connect the in and out leads to the Arduino like we would in our PCB. We will then run a simplified version of the Arduino code. This test will count as a success if we can successfully use magnets to turn on and off all 9 reed switches, and use the software to detect each change.

We will also need to test the compute stick's ability to supply the cooling fans with power. This will be a simple test to run: with the compute stick plugged into the computer, and the Arduino plugged into the compute stick, we will test to see if the internal circuitry can still supply enough power to the fans to run. If the fans run for 15 minutes without failure, the test will count as a success. If the test fails, we will acquire a USB power source that can plug into the wall for the fans to draw from.

We will also need to test the heat generation and removal from the internal box to ensure thermal safety. To do this, we will turn on the computer and the monitor and run the simulation program constantly for 15 minutes to see if there is any change in temperature of the inside of the box. We will make sure to keep the top hatch closed to test the worst-case scenario for heat generation. If, after 15 minutes, there is an absolute temperature change of less than 10 degrees Fahrenheit, and the temperature change in the last 5 minutes is slower than in the first 5 minutes (to ensure that the cooling system is reaching a carrying capacity) we will count the test as a success.

We will also need to confirm our deflection calculations to ensure that the full weight of the box is secured on the base and will not fail due to static or dynamic loads. To do this we will measure the static deflection and compare it against our calculations, then slowly put normal use forces (pushing and pulling the sides, picking up the bottom, and pushing on the top), to test the deflection under dynamic loading.

We will also need to test the turning speed of the base. The monitor has enough weight that its mechanical inertia will prevent it from accelerating rapidly under normal use, but we need to test that the mechanical stopper on the inside is strong enough to stop the device from spinning. The test will be counted as a success if our calculations are confirmed: the rotation stopper can safely stop the device from rotating and maintain structural stability.

Lastly, we will want to test if the device will tip over. To do this, we will position the device directly in front of a team member and have them poke to top of the device dead center, so that it does not rotate. If the device does not tip over with only one finger applying force, the test will count as a success.

See below for the 3x3 reed switch diagram for testing.

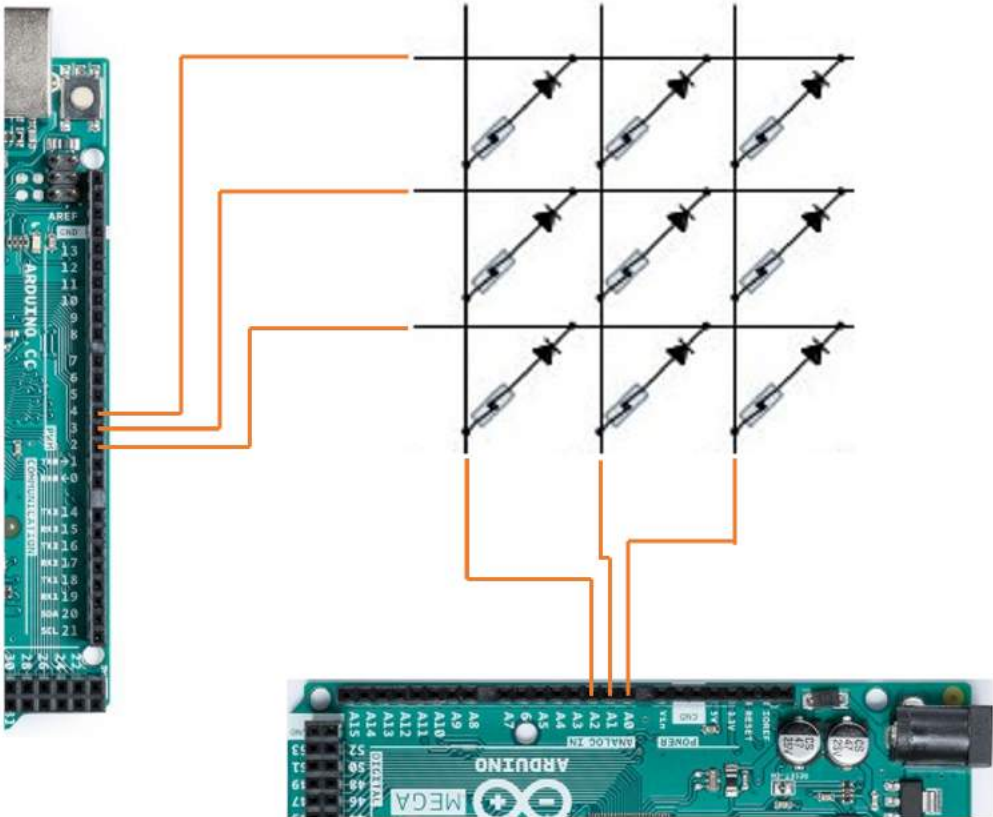


Figure 17: Wiring Diagram

## 9. Measurement Devices and Sensors

Though we are not using any devices for live data feedback into the system, we are using a reed sensor array to measure the placement of the magnets on the back board. Based on our design choice of a 12x12 reed switch array, and the physical constraints of the composite we are simulating, we will only be using 36 magnets. This means there are a total of  $144 \text{ choose } 36 = 1.12 * 10^{34}$  possible combinations of magnets on the back board, which, even ruling out combinations with magnets directly next to each other, is still enough freedom to create many different architectures.

We chose to use reed switches because we only need to know where the magnets are placed. This means that using N/O (normally open) reed switches, when a magnet closes the leads inside the switch, it will complete a circuit to the next column.

The reed switches do not measure or output a signal, they are only there to complete the circuit. The only uncertainty present in the use of the reed switches is the ability of the magnets to produce a B field strong enough to trip the switch. However, we have done calculations above (see section 4.1) to ensure that the magnets will be strong enough to trip these reed switches rated at 20 Ampere Turns.

The only possible material interaction with the reed switches would be the galvanized sheet metal on the back of the magnet side of the board possibly altering the magnetic field produced. However, the sheet metal is only 3/80 of an inch thick and the distance from each magnet to the reed switch is well within our 1/4" safety factor.

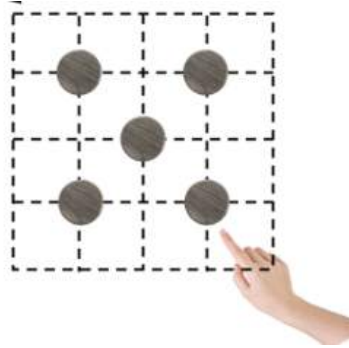


Figure 18: Wiring Diagram

## 10. Simulation and User Interface

## 10.1 - Input/Arduino Communication

The simulation will take as input an array of 1's and 0's that signify where the magnets are placed on the galvanized sheet metal. For example, the following array of magnets:



Would be translated through the Arduino control system into the following array of 1's and 0's:

```
0  0  0  0  0
0  1  0  1  0
0  0  1  0  0
0  1  0  1  0
0  0  0  0  0
```

Now we have two questions to answer. How does the Arduino write this code and translate it to the python simulation and how does the simulation take this array and translate it into a graph of aluminum cylinders in a platinum shell?

First, the Arduino Mega 2560 has 15 PWM ports, and we will use 12 of them to connect to the rows of the reed switch circuit, and connect the columns of the reed switch circuit to the IN pins (A0-A11) on the Arduino (see wiring diagram below.) This will allow us to run a small voltage through each row, and check which columns light up. See the following pseudocode for a more detailed explanation:

```
For i in rows
    write(HIGH) to row_i
    For j in cols
```

If col\_j = True

Add (i,j) to ReedSwitchesOn

To better follow the pseudocode, see the wiring diagram below:



Figure 19: Wiring Diagram

Next, we want to answer how the simulation takes an array like the following

0	0	0	0	0
0	1	0	1	0
0	0	1	0	0

```

0    1    0    1    0
0    0    0    0    0

```

And translates it into a graph of aluminum cylinders. The algorithm is relatively simple: use a resolution factor to set the amount of grid points between each point in the upper array (preset to 1 for a sizing of 1 grid points per nanometer), then find the array points that have integer values, then find the integer values that are 1, and for each value of 1, set any grid point in a certain radius to the concentration that represents aluminum. The following is summarized in the pseudocode:

```

Input array1s0s

Define x = array(0,length(array)+2, step = 1/res*40)

Define y = array(0,length(array[0])+2, step = 1/res*40)

Define Z = array(length(y),length(x), initialize vals to -1)

For i in length(x)
    For j in length(y)
        If x[i] and y[j] are ints and array1s0s[i][j] = 1
            Set all points in a 50nm zone from Z[i][j] to 1

```

In the last step there is also a function to find the premix concentration if the radius is between 48 and 50 nanometers. The reason why the circles have radius 49nm will be covered in the next section.

## 10.2 - Graphing/Physics Processing

The graphing the simulation is done through the pcolormesh library of python, which takes a set of grid points and assigns a color value to them based on a specified colormap. An example graph is given below.



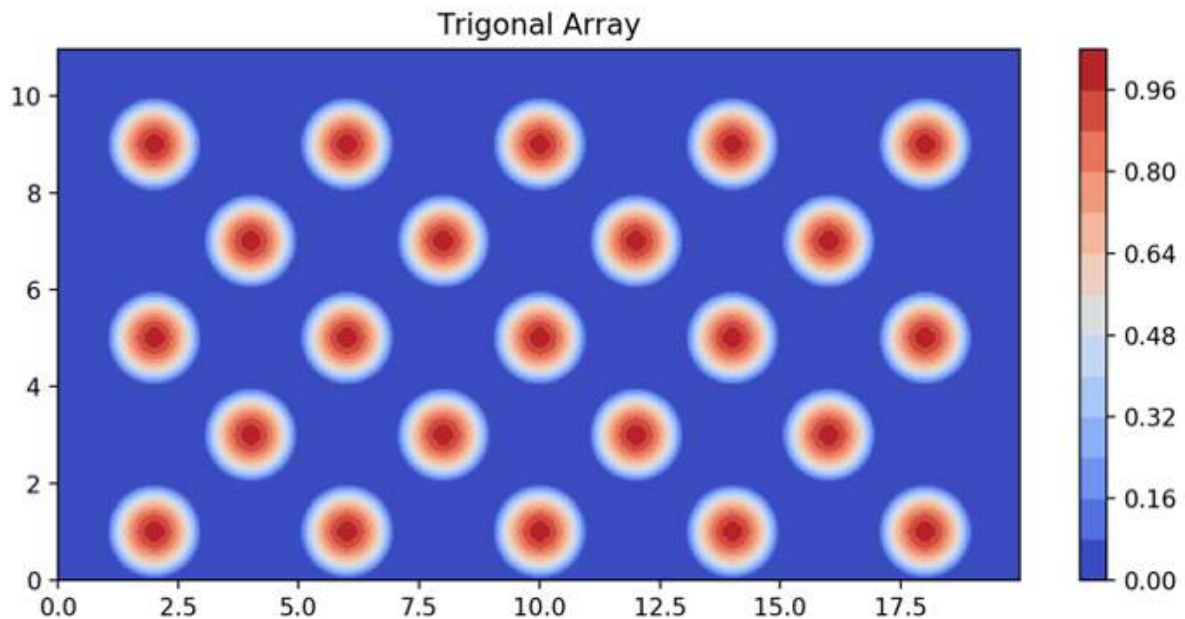


Figure 20: Example Array

Here we are looking at the concentration as it varies from 1.0 (pure aluminum) to 0.0 (pure platinum). This library is helpful because it has an image processing routine (`imshow`) that can bypass recreating a new color mesh each time one has to regraph. This is exceptionally useful for our simulation since we will have to regraph many many times.

To begin to assimilate the physics of the system into the simulation, we must first guarantee that the array is equimolar in distribution, since the velocity calculations in section 10.3 depend on physical constants from an equimolar system. To ensure this, we compute the molar density of aluminum and the molar density of platinum to find the ratio of area we'll need in the graph to guarantee an equimolar distribution. We find that aluminum is roughly  $10 \text{ mol/cm}^3$  and platinum is  $9 \text{ mol/cm}^3$ , and given that the system is symmetric in the Z direction, this means the graph should have an area breakdown of 10/19 aluminum of 9/19 platinum.

Now we find the total area of the graph. Assuming that the distance between adjacent circles in the above diagram is  $40 \text{ nm}$ , then we get that the total graph will be  $26 \times 14 \times 40 \text{ nm} \times 40 \text{ nm} = 520,000 \text{ nm}^2$ . Unlike the graph above, we have calculated for the  $12 \times 12$  array that 36 magnets will be sufficient to create an architecture, so we find that we need  $520,000 \text{ nm}^2 \times (10/19 \text{ Al fraction}) \times (1/36) = 7602 \text{ nm}^2$  per aluminum circle. This equates to a radius of  $49 \text{ nm}$ .

See the following graph for a representation of the 1:1 equimolar distribution:

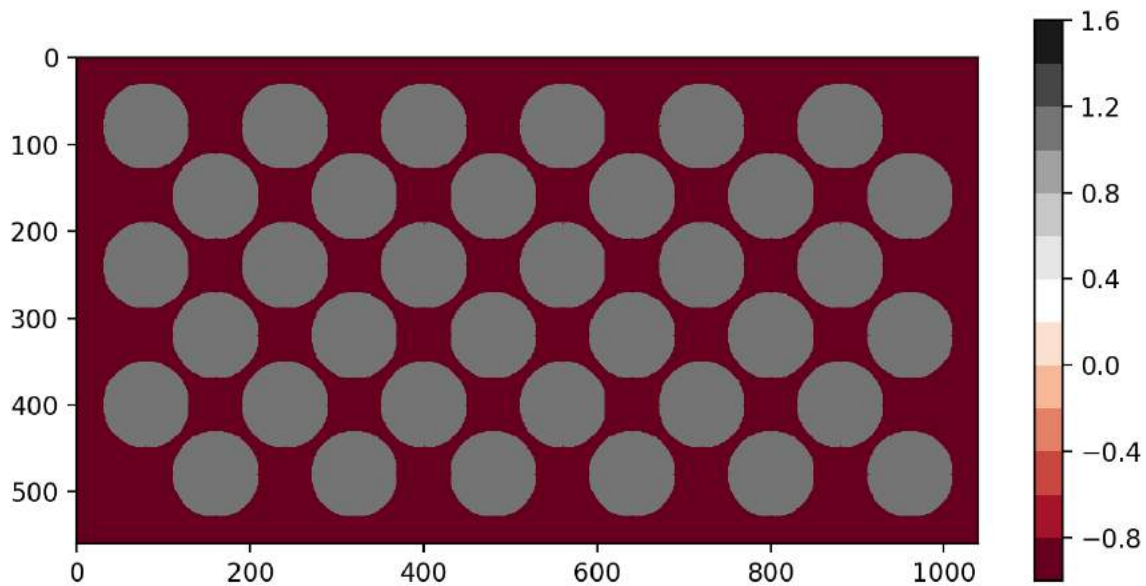


Figure 21: Equimolar Array

### 10.3 - Velocity Equations

Though the physics of the composite material are encoded into the simulation a bit using the graphing algorithm specified above, the heaviest link between the simulation and the real world function is the development of velocity equations for the propagating flame. This is the only reason why having a simulation run on a micro-computer is possible. Previously, to analyze the combustion of these systems, a full thermodynamic FEA was necessary to account for the heat generated and spread throughout the reaction. With the development of velocity equations

for the 1D case in Mann [8], the door was opened to using these analytical solutions to the partial differential equations that govern the reaction and heat flow. We'll give an explanation as to how these velocity equations are solved.

To begin understanding how the reactants arranged in a 2D array will respond when ignited, it is useful to return to a foundational study in the study of one dimensional arrays. The study [8] by Mann et al. gives an in detail derivation of the foundational math behind the reactions of foils like that in Figure 26 Appendix A. We follow this derivation in detail to become familiar enough to derive the equation for two dimensions. Our ultimate goal will be to derive an equation for the velocity of flame propagation for the 2D arrays.

Below is the equation quoted from [8].

$$v_x^2 = \left( \sum_{n=odd} \frac{k_n^2}{\alpha_n^2} \right)^{-1} \frac{4\lambda^2 RT_f^2 A}{E(T_{f0} - T_0)} \exp(-E/RT_f)$$

The derivation follows three basic steps. First it is necessary to evaluate Fick's law of diffusion in one dimension and rewrite the equation in a separable form, since the concentration is a function of position and time. Instrumental in the derivation is understanding which variables in Fick's equation will be negligible. After finding the separable form the two parts of the partial differential equation become two ordinary differential equations that can be solved using known techniques. One is fundamental, the other is in the form of a regular Sturm-Louisville problem. The solution clearly has two parts. One Fourier series that represents solving for the wave case of the propagating flame, and the exponential piece that represents solving for the heat transfer.

We'll begin with the basic treatment of Fick's law in two dimensions:

$$\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} + v_y \frac{\partial C}{\partial y} = \left( \frac{\partial}{\partial x}, \frac{\partial}{\partial y} \right) \left( D \frac{\partial C}{\partial x} + D \frac{\partial C}{\partial y} \right)$$

Where the function D is defined as:

$$D = \lambda A \exp\left(\frac{E}{RT_x}\right)$$

Then we assume that the time derivatives go to zero in the steady-state solution, and that the mixed partials are negligible to get the follow simplified equation:

$$v_x \frac{\partial C}{\partial x} - \frac{\partial D}{\partial x} \frac{\partial C}{\partial x} = D \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right)$$

Then, like Mann does in the paper, we make the substitution to the progress variable F, which gives us the following useful substitutions:

$$\begin{aligned} \frac{\partial F}{\partial x} &= \exp\left(\frac{-E}{RT_x}\right) = \frac{D}{\lambda A} \\ \frac{\partial C}{\partial x} &= \frac{\partial F}{\partial x} \frac{\partial C}{\partial F} = \frac{D}{\lambda A} \frac{\partial C}{\partial F} \\ \frac{\partial^2 C}{\partial x^2} &= \frac{\partial}{\partial x} \frac{\partial C}{\partial x} = \frac{\partial}{\partial x} \left( \frac{D}{\lambda A} \frac{\partial C}{\partial F} \right) = \frac{D}{\lambda^2 A^2} \frac{\partial D}{\partial F} + \frac{D}{\lambda A} \frac{\partial^2 C}{\partial F \partial x} \\ \Rightarrow \frac{\partial^2 C}{\partial x^2} &= \frac{D}{\lambda^2 A^2} \frac{\partial D}{\partial F} + \frac{D^2}{\lambda^2 A^2} \frac{\partial^2 C}{\partial F^2} \\ \frac{\partial D}{\partial x} &= \frac{\partial F}{\partial x} \frac{\partial D}{\partial F} = \frac{D}{\lambda A} \frac{\partial D}{\partial F} \end{aligned}$$

This makes the PDE separable in the form:

$$\frac{v_x}{\lambda A} \frac{\partial C}{\partial F} - \frac{D}{\lambda A} \frac{\partial D}{\partial F} \frac{\partial C}{\partial F} - 2 \frac{D}{\lambda^2 A^2} \frac{\partial D}{\partial F} \frac{\partial C}{\partial F} - \frac{D^2}{\lambda^2 A^2} \frac{\partial^2 C}{\partial F^2} = \frac{\partial^2 C}{\partial y^2}$$

Now we make another simplifying assumption like the Mann derivation, taking the flame properties everywhere else besides the flame front to be negligible, meaning that the partial of F with respect to F will go to zero, giving:

$$\frac{v_x}{\lambda A} \frac{\partial C}{\partial F} - \frac{D}{\lambda A} \frac{\partial D}{\partial F} \frac{\partial C}{\partial F} - 2 \frac{D}{\lambda^2 A^2} \frac{\partial D}{\partial F} \frac{\partial C}{\partial F} - \frac{D^2}{\lambda^2 A^2} \frac{\partial^2 C}{\partial F^2} = \frac{\partial^2 C}{\partial y^2} = -\alpha^2 M(F) N(y)$$

$$\Rightarrow \frac{v_x}{\lambda A} \frac{\partial M(F)}{\partial F} - \frac{D}{\lambda A} \frac{\partial D}{\partial F} \frac{\partial M(F)}{\partial F} - 2 \frac{D}{\lambda^2 A^2} \frac{\partial D}{\partial F} \frac{\partial M(F)}{\partial F} - \frac{D^2}{\lambda^2 A^2} \frac{\partial^2 M(F)}{\partial F^2} = -\alpha^2 M(F)$$

Which, though incredibly complicated, can be solved in mathematica if we simply define the following constants:

$$\beta = \lambda A$$

$$\gamma = \frac{2D + \beta D - v_x \beta}{D^2}$$

$$\omega = \frac{D^2(4\beta^2 \alpha^2) + (2D + D\beta - v_x \beta)^2}{D^4}$$

Giving our final solution to Fick's law for this system as:

$$M(F)C(y) = \sum_{n=odd} k_n \sin(\alpha_n y) \left[ \exp\left(\frac{F}{2}(-\gamma + \sqrt{\omega})\right) + \exp\left(\frac{F}{2}(-\gamma - \sqrt{\omega})\right) \right]$$

Now we adjoin a simplified version of Fourier's law of heat transfer for this system (solved in [8]) and solve to find the velocity of the self-propagating wavefront:

$$\frac{\partial F}{\partial x} = -\frac{v_x E}{c_p \rho \lambda R T_f^2} \int_0^F \Delta_x(C) dF$$

Finally, we can do some algebra to rearrange and solve for  $v_x$  to get:

$$v_x = \frac{\exp(E/RT_f) \frac{2\lambda RT_f^2}{E(T_{f0} - T_0)}}{\sum_{n=odd} k_n^2 \left( \frac{-1}{-\gamma + \sqrt{\omega}} + \frac{-1}{-\gamma - \sqrt{\omega}} + \frac{-2}{-\gamma} \right)}$$

Which is tough to solve since  $v_x$  appear on both sides of the equation, but can be reduced to the following cubic equation:

$$c_3 v_x^3 + c_2 v_x^2 + c_1 v_x + c_0$$

$$c_3 = -(1/2) \sum \frac{k_n^2}{\alpha_n^2}$$

$$c_2 = \sum \frac{k_n^2}{\alpha_n^2} \left( 4D + \frac{2D}{\beta} \right)$$

$$c_1 = -(1/2) \sum \frac{k_n^2}{\alpha_n^2} \left( \frac{D^2}{2} + \frac{2D^2}{\beta} \right) + \sum k_n^2 D^2 - a\beta$$

$$c_0 = 2aD + a\beta D$$

$$a = \exp\left(\frac{-E}{RT_f}\right) \frac{2\lambda RT_f^2}{E(T_{f0} - T_0)}$$

## 10.4 - Simulation Algorithm

The simulation runs on a while loop that iterates a time step after each successive pass. The basic algorithm is actually rather simple. Since the composite material is approximated by a grid, with one node at each grid point, we simply need to use the velocity equation to find the time required for the flame to pass from one grid point to the next. The simulation runs like this: While the flame front is still active, find every node on the flame front that has neighbors that are unreacted. If a node has no unreacted neighbors, remove it from the flame front. If it does have neighbors, see if the flame front node has had its velocities calculated yet, if not, do so, then go through the list of the neighbors and see if they've had their ignition time set yet. If the ignition

time from this node is sooner than the ignition time that is set, then reset the ignition time to the lower value. Increment the time step and redraw the graph every 50 time steps. In Pseudocode:

```
While length(flameFront) > 0
    For node in flameFront
        checkNeighbors(node)
        If no neighbors remove node from flameFront
        Else, for every neighbor do
            If t_ignition == timestep
                Ignite neighbor, add to flameFront
            If not flameFront node has velocityvalues
                Calculate velocity values
            For each neighbor
                If node.t_ig > new t_ignition
                    Use velocity vals to set t_ignition
    Timestep ++
    If timestep % 50 == 0
        Redraw graph
```

## 10.5 - User Interface

The user interface for the simulation is designed to be simple and easy to understand. When the program is started, the following screen will appear:

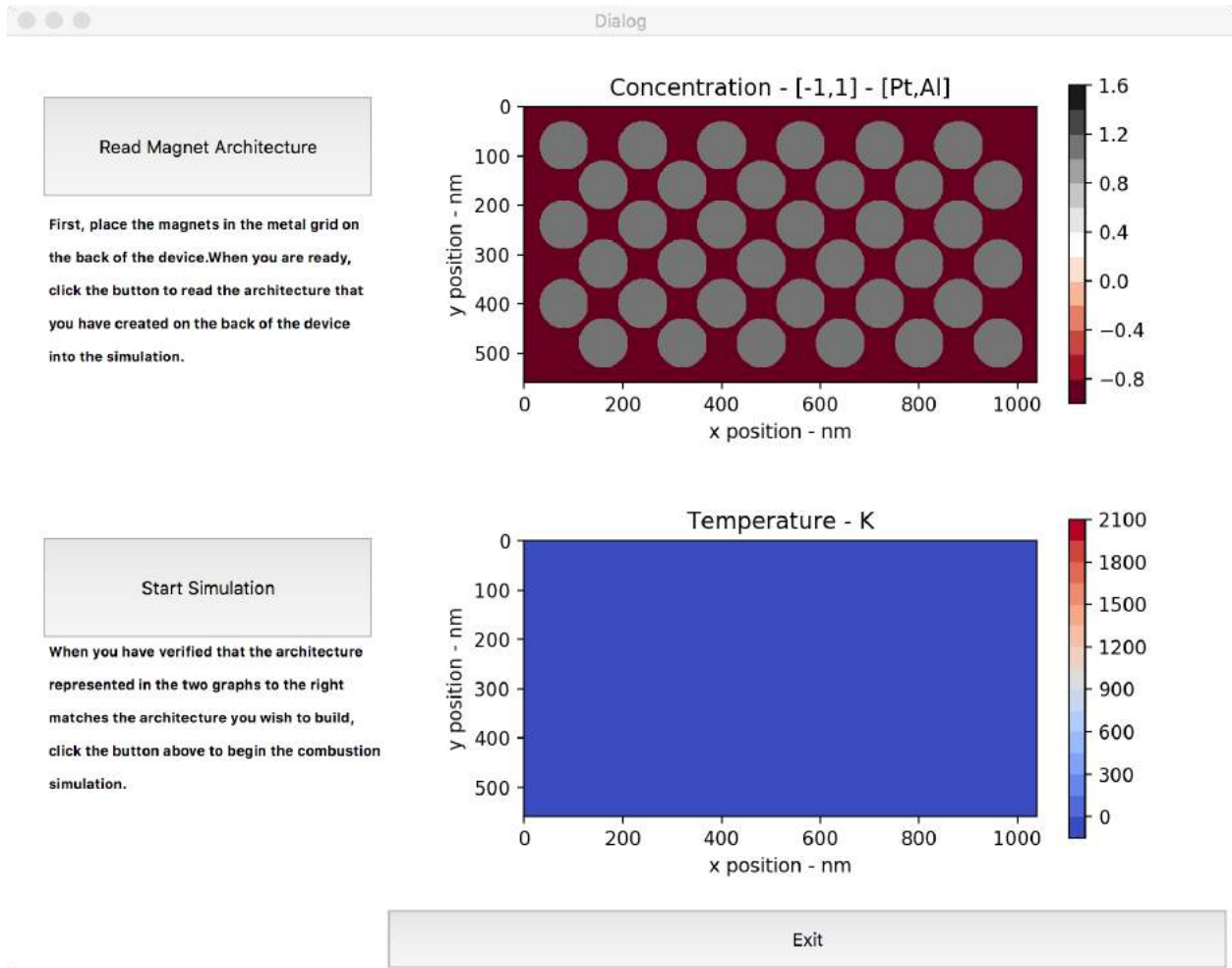


Figure 22: User Interface

The available actions are to read the magnet architecture, begin the simulation, or exit the userform. When the read magnet architecture button is clicked, it will direct the arduino to run the reed switch detection routine, then read the output textfile from the arduino and convert it to a graph like the one seen above.

When the start simulation button is clicked, the python code will begin the simulation while loop as specified in the section above. Then the graph will begin to update in the following fashion:



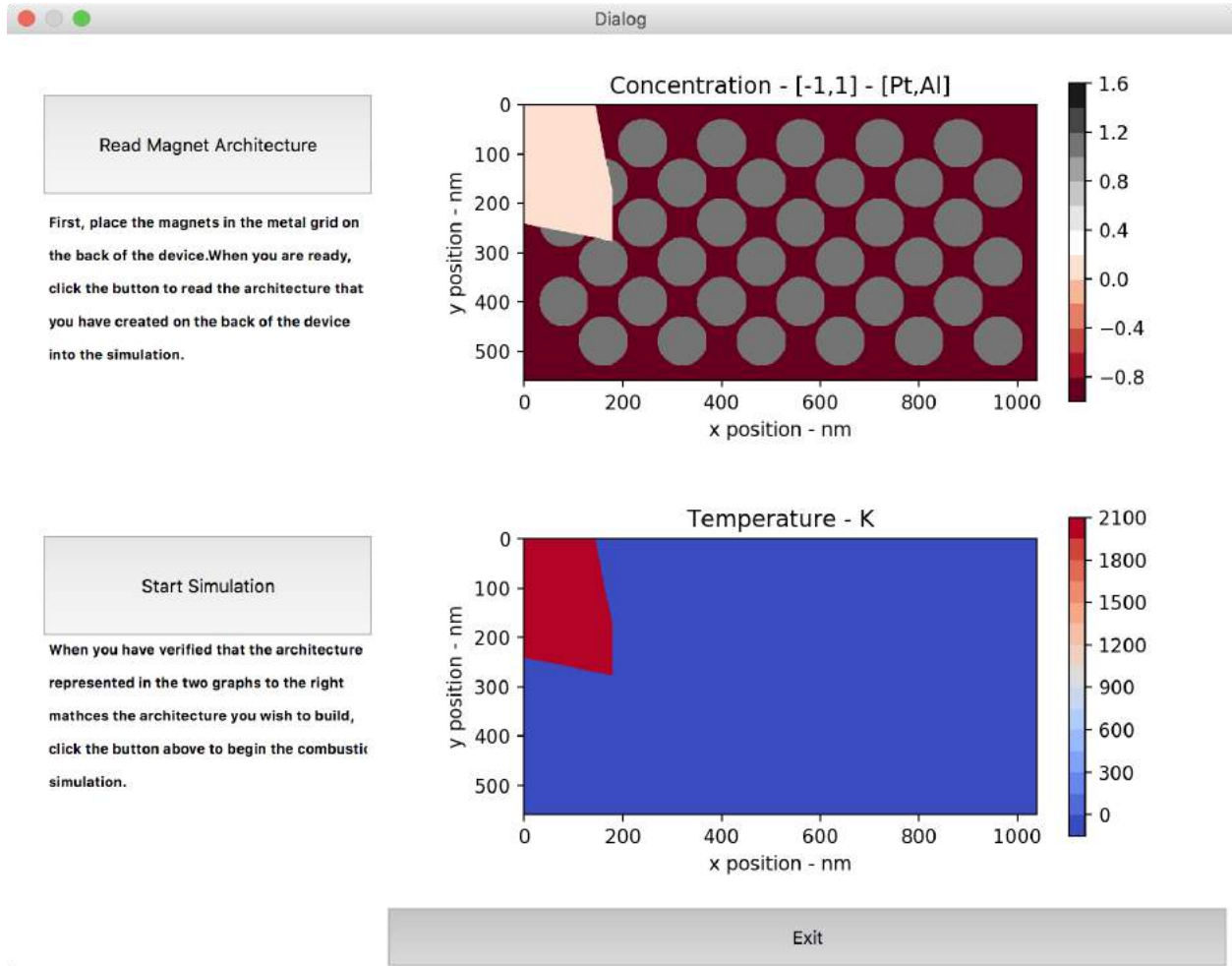


Figure 23: Simulation progress

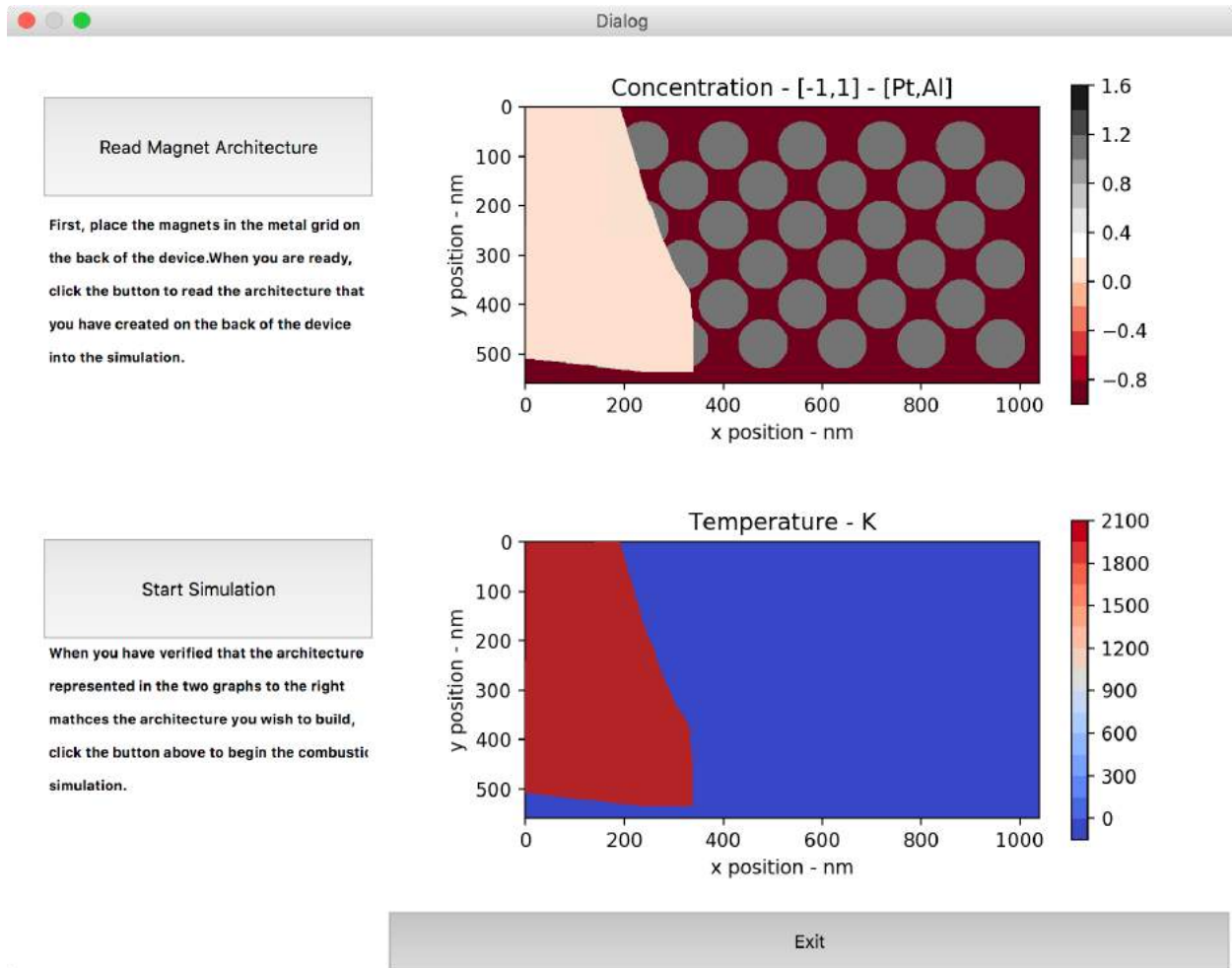


Figure 24: Simulation progress

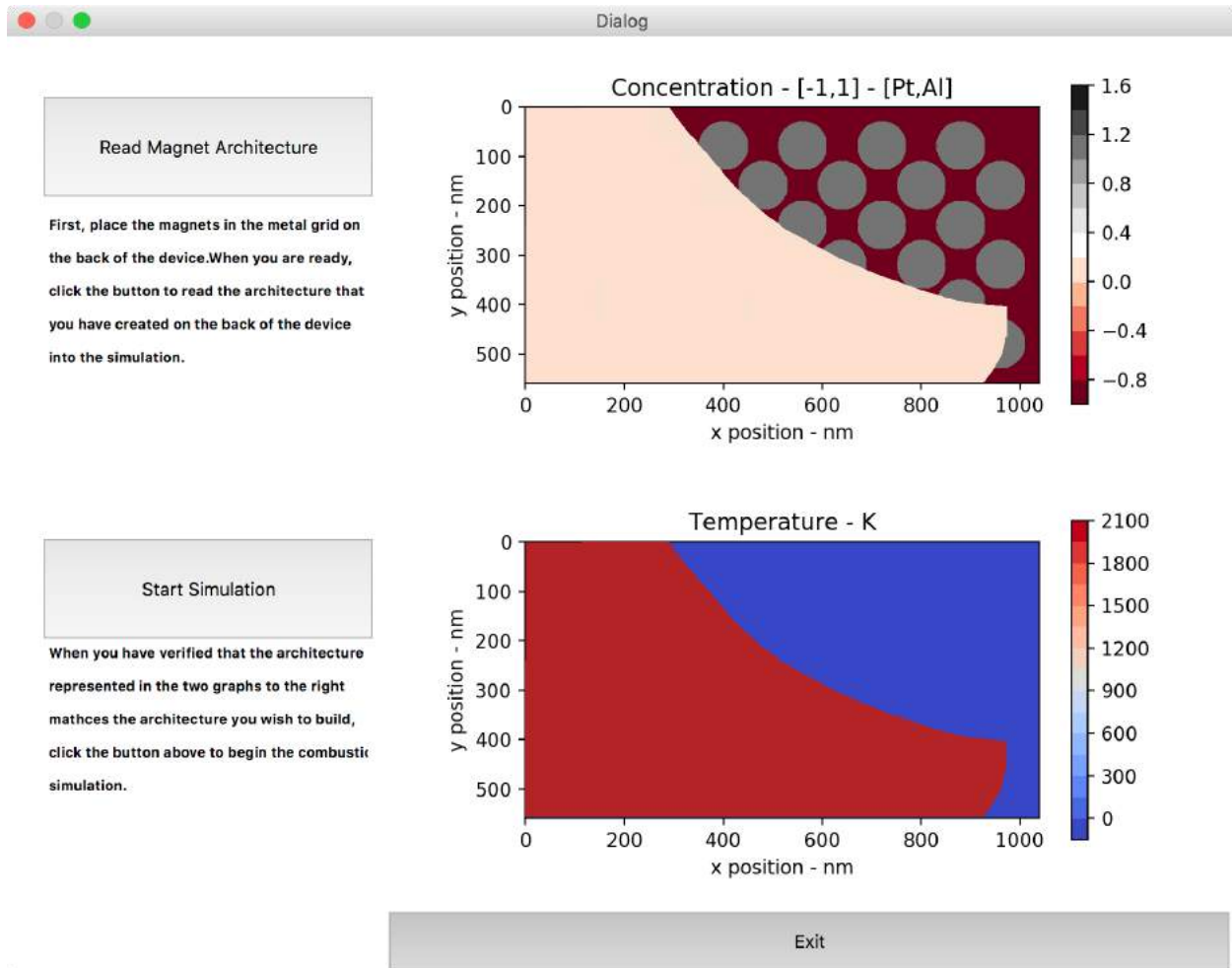


Figure 25: Simulation progress

When the simulation is finished, a pop-up box will appear at the top of the screen asking if you wish to reset the graphs or exit the program. Clicking the reset graphs button will direct you back to the original start up page as seen above, and clicking the exit button will stop the program.

Further improvements on the simulation would be to add more customization options for the simulation, including setting the resolution of the graph in a pop up box when clicking the read magnet architecture buttons.

# 11. Educational Activity

## 1. OVERVIEW:

From Csíkszentmihályi [1], Flow is the psychological state one reaches when engaging in an autotelic (self-rewarding) activity, which leads to the highest degree of immersion and engagement in learning activities. From this research we extracted four key aspects to any engaging learning activity.

1. Awaken Enthusiasm
2. Focus Attention
3. Direct Experience
4. Shared Inspiration

This educational activity guide will walk you through an engaging lesson targeted at sophomore level engineering students taking an introductory materials science class. Simply follow sections 2-5 in order, with the educational device present for the direct experience. The powerpoint slides including questions and discussion guidelines for sections 3 and 5 are included in the documentation package: PP1 and PP2 respectively.

This activity will work best if you have read through the following sections beforehand and are familiar with the goals of each section, as well as the concept of Flow from Csíkszentmihályi, M. (1996), listed in the references.

## 2. AWAKEN ENTHUSIASM:

An overview of the Awaken Enthusiasm section: In order for a student to enter the autotelic state, it is necessary for them to have an intrinsic desire to participate in the activity. We must begin by creating this desire by giving them an activity that is high-energy and fun, and then we will use the next section to transfer that energy and desire into a more focused state. This will allow us to create an atmosphere where students are not only excited, but also motivated to learn about our specific topic. Again, the important part of this section is that students are **energetic and having fun**, so that we may use that energy in the next section.

An outline of the Awaken Enthusiasm section: in this section, students will play a favorite game of the young engineer. They will make a tower of marshmallows and dry spaghetti noodles as tall as they can in only five minutes. This will illustrate the importance of architecture in the behavior of a system. You will need the following supplies:

- ½ lb of spaghetti noodles per 5 person group
- Small bag of marshmallows per 5 person group
- Small wood/plastic square per 5 person group
- 1/2lb bag of pennies per 5 person group

The objective of the game is as follows. When the timer starts, the students will have 5 minutes to build a structure as tall, and as strong as they can utilizing only raw spaghetti noodles and small marshmallows. Normally the tallest structure wins, however, since we are dealing with sophomore engineering students, they will have the added challenge of supporting a load of two rolls of pennies (.25kg) at the top of their structure. This way we can see that though some architectures may share certain qualities (height, or symmetry pattern) they may still behave differently when tested by an external stimulus. The section time outline is as follows:

- Split students into groups of 5 (1-2 minutes)
- Race to build the structure (5 minutes)
- Test structures at the front of class (8-9 minutes)

After testing the structures at the front of class, pick a few winners, then move on to **section 3: Focus Attention**.

### 3. FOCUS ATTENTION:

An overview of the Focus Attention section: after the students have been engaged in a high-energy, fun activity in the previous section, they are ready to take that desire and apply it to the specific concept that we will be working with. We must give them enough information to satisfy their desire, but in such a way that still leaves them curious and searching for more. In order to maintain and heighten their autotelic state, we must engage them in a critical discussion that leads down a path toward a culminating direct experience in the next section. The important part of this section is to **use the energy from before** to transition into a more academic atmosphere.

An outline of the Focus attention section: in this section, students will discuss with their group why they chose to design their tower the way they did, engage in a class discussion about what the best architectures were from the previous activity, and the professor will tie this into composite materials and ultimately into the field of multilayer thin films to transition into the direct experience. You will need the following supplies:

- Best towers from last section at front of class
- Powerpoint slides for nano-composites (PP1)

Begin by recapping the previous exercise, and making some observations about why some towers were successful, and why some were not. Then give the students the opportunity to talk about their own designs in their groups for about a minute. After that, you will engage the class in discussion to come up with an idea for the perfect marshmallow tower. This will be the transition into composite materials. “Just like we can discuss how to build a better marshmallow tower, scientists can discuss how to build better composite materials.” Then give a brief introduction to nano-composite materials, and focus on multilayer thin films (**PP1 in Package**) . Draw connections between each step of the marshmallow tower building, brainstorming, experimentation, failures, applications, to thin films. End with “So let’s do a small version of what we’re talking about. Let’s build a thin-film composite, and let’s see how it behaves.” Follow this time outline:

- Make observations about winning towers (2 minutes)
- Groups reflect on their tower design (1 minute)
- Class designs the perfect marshmallow tower (2 minutes)
- Connect to real science (3 minutes)
- Introduction to composites/thin films (5 minutes)
- Introduce Direct Experience (2 minutes)

### 4. DIRECT EXPERIENCE:

An overview of the Direct Experience section: With good teaching skills, after the previous two sections, the students should be at the peak of their desire to learn. They should be in a fully

autotelic state and be craving a hands-on experience to satisfy their curiosity about the subject they were just introduced to. That is what we will give them now. At this point, the energy from the initial activity should have been transformed into genuine curiosity and interest in the subject. The direct experience will harness this interest and give students a way to fully experiment with it. The important part of this section is that **students apply the concepts** to a physical model and **analyze their direct experience** in order to satisfy their desire to learn.

An outline of the Direct Experience section: students will now build their own architecture for a 2D thin-film multilayer, just like they built their own architecture for the marshmallow tower. Two of the winning groups will be able to come to the front, draw an architecture, and then load it into the simulation, which should be displayed via HDMI to the entire class. The class will guess how the wave will spread, watch the first simulation, then make a prediction about how the second architecture will perform, then watch that simulation. Afterwards the professor will highlight the difference between the two architectures, and make some conjectures about why they might have behaved differently. For this section you will need the following supplies:

- Educational Device, ready to function & display to projector
- Powerpoint slide with video of wave propagation in 1D

As stated in the outline, begin by asking two of the winning groups to come forward, and draw a 2D architecture of cylinders on a piece of paper. Then pick one group to go first, and use the magnets to input the architecture into the simulation. Discuss with the class their predictions, process the simulation, discuss the results, then repeat with the second group. Then recap with the class what happened in the simulation, and why the two architectures may have behaved differently. Follow this time outline:

- Two winning groups come forward and draw their architectures (2 mins)
- Group 1 loads into simulation, predictions & discussion (5 mins)
- Group 2 loads into simulation, predictions & discussion (5 mins)
- Recap with class (3 mins)

## 5. SHARED INSPIRATION:

An overview of the Shared Inspiration section: this should feel like the falling action and conclusion to a good story. We have learned, discussed, and analyzed a new topic, and now to get the best out of the autotelic state and to reinforce what they have learned, we must recap the experiences and lessons, and tie them into a more global picture. The important thing to remember about this section is to **solidify the students' understanding by connecting to a wider perspective**.

An outline of the Shared Inspiration section: students will need to remember what they did, why they did it, what they should take away from it, and why it should be important to them. First, we will recall how even the incredibly complex, innovative composite materials obey the same basic idea as the marshmallow tower: architecture affects behavior. Then we will encourage the students, asking what made them qualified to make a good marshmallow tower, then tell them that the qualifications for making a good composite material are harder to acquire, but just as easy to apply. They need to understand that they are already good engineers, they understand the small scale process, they just need more practice and more study to apply the small scale process to large-scale projects. You will need the following supplies:

- Powerpoint Slides for recap and application **(PP2)**

As stated in the outline, begin by discussing with the students, following the guidelines above. Then make the connection from sophomore engineering student to Ph.D groundbreaking scientist. Then end with an application of composite materials (such as nano-welding) that allows them to make tiny systems work together to produce a functional large-scale system. Follow this time outline:

- Discuss the 3 whys (5 minutes)
- Discuss the connection between tower and composite (3 minutes)
- Connect the sophomore engineer and Ph.D scientist (2 minutes)
- Discuss large-scale projects made possible by basic ideas (5 minutes)



## **6. CONCLUSION:**

Feel free to edit any part of the activity you wish to satisfy your class requirements, and please consult the user manual for the 2D Combust Simulation Educational Device. Reading up on the concept of Flow Learning would greatly behoove any professor or TA following this educational activity. The paper is linked below. Remember that the basic idea of this activity and Flow in general is to get your students into a psychological state where paying attention and participating in the class activity is self-rewarding and leaves them inspired and curious about what they just learned. It is a scientifically verified way to give students a better learning experience.

## **REFERENCES:**

[1] Csíkszentmihályi, M. (1996). *Flow and the psychology of discovery and invention*. New York: Harper Collins. Chicago

# **12. User Manual**

## **1. Introduction**

## 1.1. System Organization/Environment

This device will initiate a new way for engineering students to learn and see more applications of complicated concepts. As an educational model, it will serve as a hands-on unit for engineering students to approach complex variations of a thin film composite material's architecture and observe a corresponding combustion reaction. Since research on thin films is evolving with their incredible combustion behavior, their applications in various industries and laboratories have gained an interest.

On a side with galvanized sheet metal, an individual will be able to manipulate an array with magnets, producing an architectural structure for the composite material. On the side with the monitor, a graphic user interface will have widgets that allow the simulation to begin and produce the combustion behavior.

The educational model is intended for classroom and laboratory usage. With a 22'' screen display, it can reach a large audience, ideal for presentations. Despite the larger screen, the design is compact for long-term storage with minimal maintenance.

## 2. Step by Step Instructions for Assembling the System

### 2.1. Simplified List of Materials

- ¼'' High Density Polyethylene Sheets
  - 23'' x 18.75''
    - Side A (Metal Side)
  - 23'' x 18.5'' with Opening
    - Side B (Monitor Side)
  - 22.5 x 9.75''
    - Side C (Top)
  - 23'' x 10''
    - Side D (Bottom)
  - 9.5'' x 18.75''
    - Side E1
    - Side E2
  - 30'' x 23''
    - Side F (Base)
  - L-Shape
    - Side G (Stopper)
  - Filleted L-Shape
    - Side H (Lever)
  - 1'' x 19.25''
    - Side I (Shelf Ledge)
  - 22.75'' x 2''
    - Side J (Band)
- Arduino Board
- Arduino Shield
- 20 Gauge Steel Sheet
- Intel Compute Stick
- HDPE Adhesive
- Monitor
- Turntable Bearing
- Hex Nut x 100
- Thread-Forming Screws x 100
- Corner Brace x 16
- 6000-2RS Bearings x 10
- Bearing Holder x 2
- Bearing Gripper x 2
- Ceramic Magnets x 180
- Ventilation Fans x 2
- Ventilation Fan Adapters x 2
- Reed Switches x 150
- Jumper Wires x 2

## 2.2. External Structure

1. Position the sheet metal on Side A. The holes along the perimeter will line up on both of the pieces.
2. Line up a corner bracket with a set of 3 holes. One of the sides of the corner bracket should lay flat on the HDPE side with its other side facing the edge of Side A.
3. With a thread forming screw, feed it through one of the holes lined up with the metal sheet, HDPE, and corner bracket. The bottom of the screw head should lay flat on the sheet metal.
4. Use a hex nut to fasten the other side of the screw.
5. Repeat steps 3 and 4 with the remainder of the openings for the corner bracket.
6. Repeat steps 2-5 for the rest of the Side A.
7. Obtain Side I. On the side with the countersunk extrusions, feed thread-forming screws through each hole.
8. On the other side of Side I, line up corner brackets with each set of three holes. Have the end of the corner bracket lined up with the edge of the long side edge of Side I.
9. Fasten the corner brackets with hex nuts in each screw.
10. Line the free edge of corner brackets on Side I with the edge directly beneath the opening on Side B.
11. Feed screws through the holes with the head laying flat against the side opposite to the corner brackets. The thread forming screw should be in contact with the HDPE of side B.
12. Fasten the other end of the screw with hex nuts.
13. Along the perimeter of Side B, repeat steps 2, 3, 4, and 5 for the remaining sets of holes.
14. With Sides E1 and E2, attach the ventilation fans to each interior with screws and nuts.
15. With the bearing holders, prop a bearing on each cylinder.
16. Fasten the bearing holders to the top short edge of Side E1.
17. Take the other bearing holder to attach to Side E2.
18. Take the bearing gripper to snap into each of the bearing holders. This will keep the bearings attached.
19. Fasten Sides E1 and E2 to Side A, lining up the holes with the corner brackets. With the thread-forming screws and hex nuts, feed them into each hold that lines up.
20. Fasten Side B to Sides E1 and E2.
21. Fasten the current assembly to Side D, lining Side D to the bottom.
22. Attach the turntable to Side D with four thread-forming screws.
23. Glue Side G to align each of its smallest sides (in surface area) to sides in the base (Side D) of the box assembly.
24. Attach Side F to the turntable, lining up the holes to fasten with the thread-forming screws.
25. With Side H, glue the base rectangle to the circular opening in the turntable, from the top.
26. Allow a minimum of 24 hours to ensure the epoxy is secured.

## 2.3. Wiring

For electrical assembly, make sure you have the following parts to work with:

- Reed Switch Circuit Board
- 24 Male-Male Jumper Wire, 28AWG
- Arduino MEGA 2560
- USB-A to USB-B cable
- Intel Compute Stick + Power Cord
- Planar Helium PCT2235 Monitor + Power Cord
- Final HDPE Sheet 22.75"x2"

With your materials in front of you, and having followed the previous instructions for assembling the structural frame of the device, you are now ready for the electrical assembly. Follow these steps:

1. Prop the machine on its side so that side A is parallel to the floor. Lay the Reed Switch Circuit Board on side A, using measurements to ensure it is perfectly centered. Use a white marker to mark the position of the circuit board and remove the board from inside the casing.
2. Where the corners of the circuit board were, use 120-grit sandpaper to rough the surface of the HDPE. Then, put a generous but safe amount of adhesive in each corner and carefully press the circuit board back into its centered position on the adhesive. Let dry overnight on a level surface.
3. When adhesive has dried, turn the device over so it is now level with side B parallel to the floor.
4. Carefully slide the monitor bottom-first, with the screen facing out, through the track on side B. Be careful! The monitor is not secure yet.
5. Carefully plug the intel compute stick and the monitor power cord into the monitor.
6. Plug in the intel compute stick power cord.
7. Making sure to keep both cords going toward the bottom of the device, slide the HDPE 22.75"x2" sheet into the extrusions directly behind the monitor to secure it. Both power cords should safely go out the bottom of the rotating base now.
8. Making sure to keep the power cords in the cord slot of the base, stand the device up on the base. Be careful! The base rotates.
9. Now secure the device so that side E1 is parallel to the ground.
10. Using the same steps we used for gluing the circuit board to side A, secure the arduino board to the top half of the inside wall of side E1, and let the glue dry overnight.
11. Plug the USB-B into the arduino and the USB-A into the intel compute stick.
12. Using the Male-Male jumper wires, with the bottom row being R0, secure each row pin of the Reed Switch circuit board to Arduino pin D(R+2). Example: R0 → D2, R5 → D7, R11 (final row) → D13.
13. Using the Male-Male jumper wires, with the rightmost column being C0, secure each column pin of the Reed Switch circuit board to Arduino pin D(C+54). Example: C0 → D54, C5 → D59, C11 (final column) → D65.
14. The system is now ready to be plugged in and turned on.

## **2.4. Transportation of the System**

With less than 30lbs to support, two people can lift and balance this device when transporting. When moving and placing the device anywhere, it must lay flat on its base. Avoid angling or leveraging the device on its sides that can alter the internal wiring and structural integrity.

1. Locate the short sides of the box. Place your fingers at these sides, especially the corners to support the weight.
2. Make sure your partner has a firm grip on their edge of the box.
3. Have either you or your partner stabilize the box from rotating about the turntable.
4. Carefully lift the entire system and transport it to your cool and dry location.
5. Find a flat surface to place the system on. Slowly lower the device to the desired location.

## **2.5. Storing the System**

Keep the device in a cool, maintained, and dry environment when operating or when in storage. A temperature level between 60°F-75°F is the ideal room to store this device and its components. In increasingly higher temperatures above 75°F can cause the electrical components to fail, especially when the device is off and the ventilation fans are not running. The system does not need to be disassembled to store.

# **3. Starting and Stopping the System**

## **3.1. Setup System**

1. Plug in the two power cords. Turn on the compute stick and the monitor and the Arduino board.
2. When the computer has booted-up, double tap the 2D\_SIM\_EXECUTE file on the desktop to begin the simulation software.
3. When the GUI has launched, use the maintenance manual to make sure that the reed switch array is functioning properly using the “Read Magnet Architecture” button on the GUI.
4. Place the magnets on the lattice engraved in side A, and follow the educational activity.

## **3.2. Stopping and Suspending the system**

1. There is no data to be saved in this program. If you wish to save the results of the simulation, it is possible to download screen-recording software and record the window the simulation is running in.

2. When you are through with the educational activity, simply hit the “Exit” button on the simulation to close the simulation. Then power-off windows as normal.
3. Open the top hatch of the device and carefully turn off the Arduino, turn off the compute stick, and turn off the monitor.
4. Unplug both power cords.
5. Follow the decommissioning guide from here on steps for storage.

## 13. Standard Operating Procedure

### OKLAHOMA STATE UNIVERSITY NCL STANDARD OPERATING PROCEDURE

This document is for use by the Project Team to develop a Standard Operating Procedure (SOP) and sent to the NCL Safety Review Board. **The completed SOP should be shared with all the members of the team.** The SOP should be revised whenever a significant change to the location or scope of work occurs. The NCL Safety Review Board (SRB) is available to assist in completion or review of the SOP. For questions, please call (405) 744-5915 or email [ceatncl@okstate.edu](mailto:ceatncl@okstate.edu). Submit the completed SOP to the NCL SRB by emailing an electronic copy to [ceatncl@okstate.edu](mailto:ceatncl@okstate.edu) with the subject heading: SOP\_<Team/Group name>. Save the file name in the following format (<team/group name>\_<date-of-submission> Ex: ImpactTester\_2018-01-31). Please allow at least two business days for approval or requested revisions. Hand written documents will not be approved.

**The following SOP generally follows under:**

	SOP is for a general lab operation/process that could apply to several chemicals
X	SOP is for a specific protocol/experiment/procedure
	SOP is for a specific chemical or class of chemicals with similar hazards

**Section I.**

Project Title:	2D Mutlilayer Thin Films Educational Model		
Principal Investigator/Project Manager:	Dr. Aurelie Azoug	Department:	MAE
Email:	azoug@okstate.edu	Phone:	405-744-5900
Project Duration:	Spring Semester 2020		

**Location of Fabrication/Testing** Include room number(s) as appropriate

CEAT North Labs		UAFS	
ATRC		Richmond Hills	
Other	ENDEAVOR		

OSU Contact Person:	Dr. Azoug	Phone:	405-744-5900
Local (Field) Contact Person:	Dr. Brad Rowland	Phone:	405-744-9689

**Group/Project Members** (Attach separate sheet of paper if necessary)

Name	Email	Leader	Member
Truc Ngo	Tructn@okstate.edu	X	
Chapman Howard	Chapman.howard@okstate.edu	X	

**Section II.**

**Procedure Overview:** Provide a brief description of the project and/or procedure.  
 (Attach separate sheet of paper if necessary)



**The goal of the project is to provide an example of real world applications of concepts learned in ENSC 3313: Materials Science. Team member Chapman Howard had the chance to study multimetal thin-films during his internship at Sandia National Laboratories in Summer 2019. During this internship he realized that thin films were a good case study for materials science concepts such as the relationship between composite architecture and material properties. Thin films also serve as an example of what materials scientists are studying today. Chapman continued this study on campus in Fall 2019 by deriving a set of closed form solutions to the governing differential equations for heat transfer and molecular diffusion in the thin film materials. Using these equations, this project aims to give students the opportunity to "build" their own thin film composite, then see how the architecture they constructed affects how the material behaves when ignited.**

**To accomplish this, the team will construct a device that students can interact with to build the architecture of the thin film material, then use a computer simulation to view how that architecture will burn. The device will look like a thick briefcase that has a touchscreen on one side, and a magnetic board on the other. Students will use the magnetic board to place circular magnets in the desired architecture, and use the touchscreen to start and view the simulation. An internal circuit will read the position of the magnets on the back side and relay it to the computer as the architecture input to the simulation.**

**They key aspects of this project are that the magnets are ergonomic and easy to use, the internal circuit accurately reads the position of the magnets, and that the simulation is both quick and has a user-friendly GUI.**

### **Section III.**

**Hazards Inherent to the Project (Check all that Apply)**

<p>Extreme Temperature</p> <p>Electrical Hazard &gt; 50 volts or high current</p> <p>Noise Generated &gt; 85 dBA</p> <p>Sharp Edges</p> <p>Flying Debris or Impact</p> <p>Pressure Vessel/Compressed Gas</p> <p>Bungee Cables/Elastic Energy Storage</p> <p>Fire Hazards (open flame, welding, cutting)</p> <p>Handling Hazardous Materials</p> <p>Dusts/Other Particulate Hazards</p> <p>Work in Confined Space (natural or man-made)</p> <p>Falling Objects</p> <p>Trenching/Excavating</p> <p>Explosion</p>	<p>Heights (roofs, lifts, towers, catwalks, etc.)</p> <p>Potential for Oxygen Deficiency or Other Atmospheric Hazard (i.e. gas, vapor)</p> <p>Storage of Hazardous Materials on site</p> <p>Lithium Batteries</p> <p>Transportation of Hazardous Materials</p> <p>Other:</p> <p><b>Equipment Used</b></p> <p>Golf Cart/ATV</p> <p>Forklift</p> <p>Tractor</p> <p>Other</p>
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**Health and Safety Information:** Briefly describe the hazards associated with the materials or equipment used during the procedure. (Attach separate sheet of paper if necessary)

A major component of this design is to ensure that the device is ergonomic and safe to use. Having any major safety concerns associated with use would constitute a design failure.

**Section IV.**

<p><b>Personal Protective Equipment or Clothing Required:</b> All activities require basic protection including appropriate clothing, hand protection, safety shoes/boots, and eye protection. Any additional PPE requirements based on the hazards identified as part of minimizing risk of exposure, injury or illness. (Check all that Apply)</p>		
<p>Face Shields/Safety Glasses Hearing Protection Hard Hat Gloves Fall Protection</p>	<p>Respirator Type: Cartridge/Filter Type: N95 Particulate Mask Portable Eye Wash</p>	<p>Emergency Shower Extraction Equipment (Confined Space) Other:</p>
<p><b>Safety Training Required</b></p>		
<p>Advanced First Aid</p>	<p>Confined Space</p>	
<p>CPR</p>	<p>Laser Safety</p>	
<p>Emergency Action and Preparedness</p>	<p>Forklift/Other Heavy Equipment</p>	
<p>Project Specific Hazard Communication</p>	<p>N95 Particulate Mask Disclaimer</p>	
<p>Compressed Gasses</p>	<p>Respiratory Protections</p>	

HotWorks (Welding, Torch/Plasma Cutting)	Fire Extinguisher
Ladder	Other:

## Section V.

**Method Procedures:** Give a step-by-step instruction for the procedure. (Attach separate sheet of paper if necessary)

step 0: Carefully place the device firmly on a flat surface with the computer screen facing you, making sure not to tangle power cords

step 1: Plug in the power cords either to a wall outlet, or a grounded surge protector

step 2: Carefully slide out the hatch on the top of the device

step 3: Find the power button on the bottom of the monitor, and press it

step 4: Find the power button on the bottom of the compute stick and press it

step 5: Wait for the system to turn out (at least 2 minutes)

step 6: Pull the mouse out of the inside of the device

step 7: use the mouse to unlock Windows on the computer

step 8: click on "2D simulation.py" on the desktop

step 9: spin the device 180 degrees, carefully. If you feel resistance, spin the other direction

step 10: use the magnets to build your architecture, being sure to only place one magnet per grid point

step 11: when you are finished building the architecture continue to step 12

step 12: Spin the device 180 degrees in place, so that you are now looking at the touchscreen side.

step 13: In the top right of the screen, press the button that says "Read magnet architecture"

step 14: Wait for computer to display "Finishing reading architecture!", and it will display the architecture on screen

step 15: In the bottom right of the screen press the button that says "Start simulation"

step 16: you will see a pop-up box with several options. First find the heading titled "Where do you want to ignite?" and select one of the options below.

step 17: Find the slider bar titled "Number of grid points per nanometer" and slide it to the right for a slower but more accurate simulation, or to the left for a faster but less accurate simulation

step 18: At the top right of the dialogue box push the button that reads "Start Simulation!"

step 19: patiently wait as the simulation runs, you will know the simulation is finished when the words "Simulation finished!" appear at the top of the screen

step 20: At the bottom of the screen you will see two options: "Run another simulation" and "Quit Program"

Step 21: If you click "Run another simulation", spin the device around 180 degrees and return to step 0

Step 22: If you click "Quit program" then wait for the program to exit, then unplug the device

Step 23: Open the top flap, and return the power cord to the inside

Step 24: Close the top flap, and store the magnets somewhere safe

Step 25: Store the device and the magnets somewhere safe

## Section VI.

**Waste Disposal Procedure:** Give a step-by-step instruction for the procedure (if applicable). (Attach separate sheet of paper if necessary)

## Section VII.

**First Aid Procedures:** Give a step-by-step instruction for the procedure. (Attach separate sheet of paper if necessary) This section should also contain the address and location(s) that the SOP will be used.

**All incidents require that as soon as possible the Instructor of Record and Profession Staff over lab be notified.**

Location: Address and room location (Example: 1724 West Tyler, Northside of the building in HighBay)

Location of Nearest Hard Phone Line: EN 110

Nearest Location of a solid Cell phone signal: Directly outline EN 108

Emergencies:

- One person is assigned to stay with the injured personal
- One person should be assigned to call 911, this person will stay on the phone and state the following
  - o Location of the accident (This should include building and room)
  - o Type of injury
- One person should be assigned to escort the emergency response crew to the location

Specialized First Aid Procedures as related to this project:

## Section VIII.

**Spill/Release Containment, Decontamination, and Clean-up Procedures:** Give a step-by-step instruction for the procedure (if applicable). (Attach separate sheet of paper if necessary)

## Section IX.

**Approvals Required:** Describe any special approvals required before conducting this work such as approval by Principal Investigator or lab supervisor before beginning work (if applicable). (Attach separate sheet of paper if necessary)

**Section X.**

**Designated Area/Communications:** (For work involving particularly hazardous dangers, identify the area where the work will be conducted and to where it will be confined; identify any communication that will be done to assure others know the hazards and location of this work.) (if applicable). (Attach separate sheet of paper if necessary)

**Section XI.**



**Piping, Wiring, and Instrumentation diagram:** (This should include a detailed schematic illustrations of the functional relationship of piping, instrumentation and system equipment components)



Attached below is the wiring diagram for the 12x12 array of reed switches into the Arduino control board.

Once the SRB has approved the document, all team members will be required to electronically sign the document below.

By signing below, I certify that I have read the Standard Operating Plan (SOP) and agree that all listed participants and I will abide by the SOP and adhere to all OSU policies and procedures as well as any local policies, procedures or guidelines.

PI  
Signature: \_\_\_\_\_

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Participants:

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**Section XII.**

**Attachment Section:**

## **14. Maintenance Manual**

### **General Maintenance Guidelines:**

The 2D Multilayer Combustion Simulation Educational Tool should be inspected for maintenance every time it is used. Before use and before all transportation, all internal components should be inspected to be sure they are tight-fitting and stable. The device should be kept clean and dust-free internally and externally. The turntable base should be properly lubricated with WD-40, and the front monitor should be clean. Proper maintenance for the device constitutes regular, diligent cleanliness and screw tightening.

## **Planar Helium PCT2235 Monitor:** [PCT2235](#)

The Planar Helium PCT2235 Monitor comes with a user-manual referenced above. For the purposes of this educational device, one should follow the instructions of the above manual: keep the monitor dust free, and inspect regularly for loose screws.

## **Arctic F8 Silent Fans**

The Arctic F8 Silent Fans do not come with a manufacturer specified maintenance plan. For the purposes of the educational device, one should keep the fans clean and free of dust or debris to ensure they can properly cool the inside of the device. Do not attempt to repair the electrical components of the fans by yourself. Always consult a licensed electrical technician for service.

## **Reed Switch Array Circuit Board:**

The Reed Switch Circuit Board is a custom constructed part for this educational device. It is important to ensure the circuit board securely fastened as close to the wall as possible in order for it to work correctly. The adhesive keeping the circuit board secure should be inspected prior to any educational activity, as well as checking the functionality of the magnetic sensor array should be tested with software in the following manner:

Boot up the software as normal. Place one magnet on the board and click “Read Magnet Architecture” on the simulation GUI. If the simulation correctly reads the position of the magnet, proceed to a 2x2 array, then a 4x4 array, then an 8x8 array, then a 12x12 array of magnets to ensure the board and the software is functioning appropriately.

Be sure to keep the circuit board dry, and free of dust and debris.

**HDPE Casing:** [Care & Maintenance Manual](#)

The above link is a reference to the name-brand version of the HDPE used for this device. It specifies that one should be careful not to stain the HDPE, and to brush only lightly when cleaning. For the purposes of this machine, the casing should need minimal maintenance, except screw tightening, covered in the corner braces section.

## **Turntable:**

For the device to function properly, spray WD-40 lubricant into the gap between the two rotating plates twice per year, except in cases of consistent and regular use, when you should lubricate more consistently. Just as with all other components of the device, all screws mounting the turntable to the HDPE casing should be tightened before each use.

**Arduino:** [Arduino MEGA 2560](#)

The Arduino board has no manufacturer specified maintenance plan. For the purposes of this educational device, the board should be dusted before each use, and kept free from any debris. Before each use, the Arduino should be inspected to ensure the adhesive has not worn off and the board is not in danger of becoming loose. If the adhesive has worn off and the board is loose, carefully remove the rest of the board from the adhesive, remove the adhesive from the HDPE, and re-glue the board to the inside of the casing.

**Compute Stick:** [Intel Compute Stick](#)

The component has the manufacturer specified user-guide linked above for reference. For maintenance, keep the device free from dust and debris, and follow the manufacturer instructions (also given in the user manual) for powering on and off. Keep the device from overheating, but make sure it stays plugged into the monitor.

**Corner Braces:**

There is no manufacturer specified maintenance manual for this product. Before each use, make sure that each of the 16 corner braces are inspected, and the screws in each are tightened using a T25 screwdriver.

Make sure to tighten the screws before and after each transportation of the device. Always transport the device right-side up.

## 15. Decommissioning Guide

## **INSTRUCTIONS FOR DECOMMISSIONING:**

\_\_\_\_\_To begin, make sure the device is unplugged, all components have powered off, and all components inside the device have returned to room temperature through normal free-standing convection.

Next, gather the magnets. Place them in a cloth bag for storage, and set aside for the time being. After all the magnets have been removed from the back of the device and are out of the way, you may proceed.

Now make sure that all the internal components are clean, dry, and have maintained their structural integrity. If any internal component looks loose or like it has failed in some way, consult the maintenance manual for instructions on how to repair the part before storage. If all parts are dry, clean, and in working condition, then proceed.

Find the power cord that is exiting the base of the machine. Unplug the power cord from the wall, and unplug all internal components from power. Keep the compute stick plugged in to the monitor, and keep the two fans and the arduino board plugged into the compute stick. Wrap up the power cord, and put in the cloth bag with magnets. If the cord does not fit in the bag, securely wrap the cord together and place it inside of the device.

You should now put all components inside the device, and slide the top lid shut. Everything should be secure on the inside of the device, and the device should remain right-side up at all times. Store the device somewhere dry and cool for long periods of time, making sure to follow the instructions in the maintenance manual on how often to clean the machine. Regular dusting is recommended.

Leave the device in the cool dry storage until needed, making sure to follow the instructions in the User Manual on how to assemble and boot up the machine.

## **16. Cost Estimate**

### 15.1 Cost of Materials







<a href="https://www.mcmaster.com/6031k17">https://www.mcmaster.com/6031k17</a>			
Thread-Forming Screws for Thin Plastic	\$8.56	4	\$34.24
<a href="https://www.mcmaster.com/96817a640">https://www.mcmaster.com/96817a640</a>			
Hex Nut (Pack)	\$1.76	1	\$1.76
<a href="https://www.mcmaster.com/90592a095">https://www.mcmaster.com/90592a095</a>			
<b>Other</b>			
Corner Brace (4 Pack)	\$3.28	4	\$13.12
<a href="https://www.lowes.com/pd/National-Hardware-4-Pack-2-5-in-Zinc-Corner-Brace/1000201731">https://www.lowes.com/pd/National-Hardware-4-Pack-2-5-in-Zinc-Corner-Brace/1000201731</a>			
20 Gauge Steel Sheet (w/shipping)	\$11.48	1	\$38.70
Adds weight to opposite side of the monitor to improve balance in the center of mass			
<a href="https://www.metalsdepot.com/steel-products/steel-sheet">https://www.metalsdepot.com/steel-products/steel-sheet</a>			
Arduino Board	\$38.50	1	\$38.50
<a href="https://store.arduino.cc/usa/mega-2560-r3">https://store.arduino.cc/usa/mega-2560-r3</a>			
Intel Compute Stick	\$150.00	1	\$150.00
Intel Atom® processor will allow it to run the simulation			

<https://www.intel.com/content/www/us/en/products/boards-kits/compute-stick/stk1aw32sc.html>

HDPE Adhesive with shipping	\$11.04	1	\$11.04
Shear Strength = 3770psi			
<a href="https://www.homedepot.com/p/J-B-Weld-0-85-oz-PlasticBonder-Black-Adhesive-50139/308472914?mtc=Shopping-B-F_D24-G-D24-Multi-Multi-NA-Feed-SMART-NA-NA-All_Paint_Smart&amp;cm_mmc=Shopping-B-F_D24-G-D24-Multi-Multi-NA-Feed-SMART-NA-NA-All_Paint_Smart-71700000048001153-58700004793621602-92700041080546167&amp;gclid=Cj0KCQjw9ZzzBRCKARIsANwXaeKSIpaHq_bpbPZ-MI2EzJDHJkRQaRWP_YsIP7gMLikZk4zg1IVIVmQaArumEALw_wcB&amp;gclsrc=aw.ds">https://www.homedepot.com/p/J-B-Weld-0-85-oz-PlasticBonder-Black-Adhesive-50139/308472914?mtc=Shopping-B-F_D24-G-D24-Multi-Multi-NA-Feed-SMART-NA-NA-All_Paint_Smart&amp;cm_mmc=Shopping-B-F_D24-G-D24-Multi-Multi-NA-Feed-SMART-NA-NA-All_Paint_Smart-71700000048001153-58700004793621602-92700041080546167&amp;gclid=Cj0KCQjw9ZzzBRCKARIsANwXaeKSIpaHq_bpbPZ-MI2EzJDHJkRQaRWP_YsIP7gMLikZk4zg1IVIVmQaArumEALw_wcB&amp;gclsrc=aw.ds</a>			
		<b>Total</b>	<b>\$822.67</b>

Including other factors (i.e. shipping, tax) for the total cost of materials: ≈\$900

### 15.2 Total Cost Estimate Summary

Hours	Week	Engineering & Marketing Labor Rate	Total
Chapman			
12	10	\$75/hr	\$9000
Truc			
12	10	\$75/hr	\$9000

Total cost for labor = \$18000

**\$900** [*Cost of Materials*]  
**+\$18000** [*Engineering & Marketing Labor*]  
**\$18900**

## References:

- [1] Arnemann, M. (2012). Energy Efficiency of Refrigeration Systems. International Refrigeration and Air Conditioning Conference. Accessible via <http://docs.lib.purdue.edu/iracc/1356/>.
- [2] (2015). Stanley Engineered Fastening. Accessible via [https://www.stanleyengineeredfastening.com/-/media/web/sef/resources/docs/other/threaded\\_fasteners\\_for\\_plastics.ashx](https://www.stanleyengineeredfastening.com/-/media/web/sef/resources/docs/other/threaded_fasteners_for_plastics.ashx)
- [3] (2019). Direct assembly into metals using thread forming screws. Accessible via [www.bossard.com](http://www.bossard.com)
- [4] U.S. Patent 3,584,667, Bernard F Reiland, "Coupling arrangement and tools for same", filed 1967-03-21
- [5] Patlazhan, S.A., *et al.* (2008). Stress-Strain Behavior of High-Density Polyethylene below the Yield Point: Effect of Unloading Rate.
- [6] Düşünceli, Necmi & Aydemir, Bulent & Terzi, Niyazi. (2010). Cyclic Behavior of High Density Polyethylene (HDPE). AIP Conference Proceedings. 1255. 10.1063/1.3455664.
- [7] *Ignition and self-propagating reactions in Al/Pt multilayers of varying design* D. P. Adams, R. V. Reeves, M. J. Abere, C. Sobczak, C. D. Yarrington, M. A. Rodriguez, and P. G. Kotula.
- [8] A. B. Mann, A. J. Gavens, M. E. Reiss, D. Van Heerden, G. Bao, and T. P. Weihs. *Modeling and characterizing the propagation velocity of exothermic reactions in multilayer foils*. Journal of Applied Physics 82, 1178 (1997)
- [9] Suleiman, Muhannad Taher. (2002). The Structural Performance of Flexible Pipes.



Figure 27: 2D Array

The 1D case is easily understood. Since there is only one direction in which the metals vary, the only variable to be manipulated is how far apart the bilayers are. The graph below from a paper by Adams, Reeves, Abere et al. [7] displays how manipulating the geometry (changing the bilayer thickness) has a direct measurable effect on the combustion behavior of the sample.

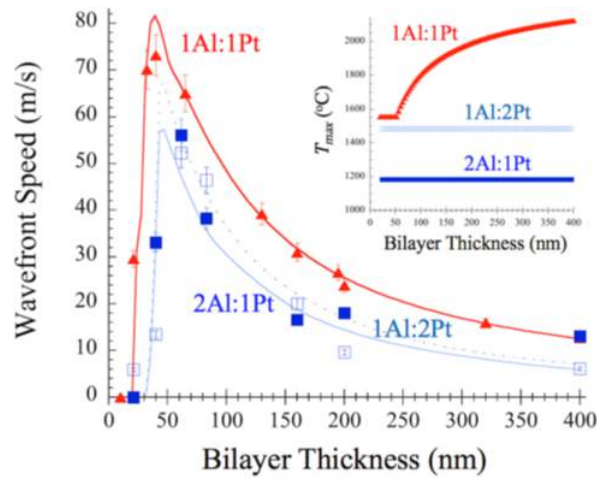


Figure 28: Velocity Graph

However, as discussed in the velocity calculations in section 10.3, the math becomes much more complicated when moving to two dimensions. Since this hypothesis that 2D arrays might burn more quickly has little evidence to support it, and given the time and material cost of running the experiments, a necessary simulation, like the one present in this project, would be of great use for scientists looking to validate their assumptions.

## B. Simulation Code

The code for the GUI processing, graphing, and simulation algorithm is below:

```

1 import numpy as np
2 import sys
3 import time
4 import _2D_Multilayer_Simulation
5 import cubic as cb
6
7 import sys
8
9 from PyQt5.QtWidgets import QApplication, QMainWindow, QMenu, QVBoxLayout, QSizePolicy, QMessageBox, QWidget, QPushButton
10 from PyQt5.QtGui import QIcon
11
12 from matplotlib.backends.backend_qt5agg import FigureCanvasQTAgg as FigureCanvas
13 from matplotlib.figure import Figure
14 import matplotlib.pyplot as plt
15 from matplotlib.colors import BoundaryNorm
16 from matplotlib.ticker import MaxNLocator
17
18 import random
19
20 from PyQt5.QtWidgets import QDialog, QApplication
21 from PyQt5.QtWidgets import QFileDialog, QMessageBox
22 from PyQt5.QtGui import QCursor
23 from PyQt5.QtCore import Qt
24
25 from OpenGL.GL import *
26 from OpenGL.GLU import *
27 from OpenGL.GLUT import *
28
29
30 from opengl import Ui_Dialog
31
32 #Create the Main GUI Window
33 class main_window(QDialog):
34     def __init__(self):
35         super(main_window,self).__init__()
36
37         #Set up the standard UI Dialog
38         self.ui = Ui_Dialog()
39         self.ui.setupUi(self)
40
41         #Make the two PlotCanvases for Graphing
42         m = PlotCanvas(self, width=8, height=4,num = 1)
43         m.move(725,265)
44         self.m = m

```

```

n = PlotCanvas(self, width=8, height=4,num = 2)
n.move(-25,265)
self.n = n

#Assign the buttons and show the form
self.assign_widgets()
self.show()

def assign_widgets(self):
    # heavily customized!
    self.ui.exit.clicked.connect(self.ExitApp)
    self.ui.startsim.clicked.connect(self.runsim)
    self.ui.readmagnets.clicked.connect(self.drawfirst)

def ExitApp(self):
    self.close()
    sys.exit(app.exec_())

def redraw(self):
    #Every time the graphs need to be redrawn
    #Change the concentration/temperature data
    #Then redraw the figure and signal the UI to update
    self.n.im.set_data(self.n.Z)
    self.n.figure.canvas.draw()
    self.m.im.set_data(self.m.Z)
    self.m.figure.canvas.draw()
    app.processEvents()

def drawfirst(self):
    #The initial drawing on the two canvases
    self.n.plot()
    self.m.plot()
    self.n.figure.canvas.draw()
    self.m.figure.canvas.draw()

def runsim(self):
    #First step in the simulation is to creat the grid , then ignite at a corner
    mesh = _2D_Multilayer_Simulation.meshArray(self.n.X,self.n.Y,self.n.Z)

```

```

89     _2D_Multilayer_Simulation.ignite(mesh,self.n.z,self.m.z)
90     self.redraw()
91
92     #this will create the initial flameFront array
93     def initFire(mesh):
94         fireArray = []
95         for i in range(len(mesh)):
96             for j in range(len(mesh[0])):
97                 if mesh[i][j].onFire:
98                     fireArray.append(mesh[i][j])
99
100        return fireArray
101
102        #This method takes a node in flameFront and determines if any
103        #of its neighbors are still unreacted
104        def Neighbors(mesh,node):
105            i,j = node.coords
106
107            neighbors = []
108            neighborsdir = []
109
110            #need to check all 8 cases
111            if not mesh[i-1][j].onFire and i-1 > 0:
112                neighbors.append(mesh[i-1][j])
113                neighborsdir.append("down")
114
115            if not mesh[i-1][j-1].onFire and i-1 > 0 and j-1 > 0:
116                neighbors.append(mesh[i-1][j-1])
117                neighborsdir.append("downl")
118
119            if not mesh[i-1][j+1].onFire and i-1 > 0 and j+1 < len(mesh[0]):
120                neighbors.append(mesh[i-1][j+1])
121                neighborsdir.append("downr")
122
123            if not mesh[i+1][j-1].onFire and i+1 < len(mesh) and j-1 > 0:
124                neighbors.append(mesh[i+1][j-1])
125                neighborsdir.append("upl")
126
127            if not mesh[i+1][j+1].onFire and i+1 < len(mesh) and j+1 < len(mesh[0]):
128                neighbors.append(mesh[i+1][j+1])
129                neighborsdir.append("upr")
130
131            if not mesh[i+1][j].onFire and i+1 < len(mesh):
132                neighbors.append(mesh[i+1][j])
133                neighborsdir.append("up")

```



```

133         neighborsdir.append("up")
134
135         if not mesh[i][j+1].onFire and j+1 < len(mesh[0]):
136             neighbors.append(mesh[i][j+1])
137             neighborsdir.append("right")
138
139         if not mesh[i][j-1].onFire and j-1 > 0:
140             neighbors.append(mesh[i][j-1])
141             neighborsdir.append("left")
142
143         return neighbors,neighborsdir
144
145
146     #create the initial flameFront array
147     flameFront = initFire(mesh)
148
149
150     #The simulation runs in a while loop, with timestep set to 1/300 nanoSeconds
151     #Every time step all the nodes in flameFront are checked for neighbors
152     #The velocity for each node in the flameFront into each neighbor is calculated
153     #only once, then the t_ignition for the neighbor node is set using (timestep/velocity)
154     #At each timestep the neighbors are checked to see if they should be ignited
155     #rinse and repeat until there are no more nodes on the flameFront
156     tstep = 0
157     while len(flameFront) > 0:
158
159         #check every node in flameFront for neighbors
160         for i in range(len(flameFront)):
161             if i == len(flameFront): break
162             node = flameFront[i]
163             a,b = Neighbors(mesh,node)
164
165             #if a node has no neighbors, remove it from flameFront
166             if not a:
167                 flameFront.pop(i)
168
169             #if a node has neighbors, check to see if they should be ignited
170             #if time to be ignited, then add to flameFront
171             else:
172                 for node in a:
173                     k,j = node.coords
174                     if node.tig == tstep:
175                         node.onFire = True
176                         self.n.Z[k][j] = 0

```

```

177         self.m.Z[k][j] = 2000
178         flameFront.append(node)
179
180         #if the node doesn't have its velocities calculated yet, do that
181         if not node.nodevels:
182             node.nodevels = cb._2D_Cubic(flameFront[i].coords,self.n.X,self.n.Y,self.n.Z)
183
184         #for each neighbor, try and set its t_ignition, but only if
185         #the new t_ignition is sooner than the old one
186
187         for l in range(len(a)):
188             if b[l] == "up":
189                 v = timestep+np.around(300.0/node.nodevels[0])
190                 if v < a[l].tig: a[l].tig = v
191             if b[l] == "upr":
192                 v = timestep+np.around(300.0/node.nodevels[3])
193                 if v < a[l].tig: a[l].tig = v
194             if b[l] == "upl":
195                 v = timestep+np.around(300.0/node.nodevels[1])
196                 if v < a[l].tig: a[l].tig = v
197             if b[l] == "left":
198                 v = timestep+np.around(300.0/node.nodevels[2])
199                 if v < a[l].tig: a[l].tig = v
200             if b[l] == "right":
201                 v = timestep+np.around(300.0/node.nodevels[2])
202                 if v < a[l].tig: a[l].tig = v
203             if b[l] == "down":
204                 v = timestep+np.around(300.0/node.nodevels[0])
205                 if v < a[l].tig: a[l].tig = v
206             if b[l] == "downl":
207                 v = timestep+np.around(300.0/node.nodevels[3])
208                 if v < a[l].tig: a[l].tig = v
209             if b[l] == "downr":
210                 v = timestep+np.around(300.0/node.nodevels[1])
211                 if v < a[l].tig: a[l].tig = v
212         timestep += 1
213
214         #redraw every 50/300 nanoseconds
215         if timestep % 50 == 0: self.redraw()
216
217         print("finished")
218
219
220

```

```

221
222
223
224
225
226
227
228
229
230 class PlotCanvas(FigureCanvas):
231
232     def __init__(self, parent=None, width=5, height=4, dpi=100, num = 0):
233
234         #make the figure to graph with
235         fig = Figure(figsize=(width, height), dpi=dpi)
236         self.axes = fig.add_subplot(111)
237         self.num = num
238         self.Z = []
239
240         FigureCanvas.__init__(self, fig)
241         self.setParent(parent)
242
243         FigureCanvas.setSizePolicy(self,
244             QSizePolicy.Expanding,
245             QSizePolicy.Expanding)
246         FigureCanvas.updateGeometry(self)
247
248         #For the temperature graph
249         if self.num == 1:
250
251             array = _2D_Multilayer_Simulation.makeArray()
252             X,Y,Z = _2D_Multilayer_Simulation.makeConcentration(1,array)
253             self.array = array
254             self.X = X
255             self.Y = Y
256             self.Z = Z
257
258         #for the concentration graph
259         if self.num == 2:
260
261             array = _2D_Multilayer_Simulation.makeArray2()
262             X,Y,Z = _2D_Multilayer_Simulation.makeConcentration(1,array)
263             self.array = array
264             self.X = X

```

```

258     #for the concentration graph
259     if self.num == 2:
260
261         array = _2D_Multilayer_Simulation.makeArray2()
262         X,Y,Z = _2D_Multilayer_Simulation.makeConcentration(1,array)
263         self.array = array
264         self.X = X
265         self.Y = Y
266         self.Z = Z
267
268
269     def plot(self):
270
271         #for the temperature graph
272         if self.num == 1:
273
274             levels = MaxNLocator(nbins=15).tick_values(self.Z.min(), 2000)
275             cmap = plt.get_cmap('coolwarm')
276
277
278         #for the concentration graph
279         if self.num == 2:
280             levels = MaxNLocator(nbins=15).tick_values(self.Z.min(), 1.5)
281             cmap = plt.get_cmap('RdGy')
282         #for both graphs, generate a pcolormesh image to plot with
283         #then draw it
284         norm = BoundaryNorm(levels, ncolors=cmap.N, clip=True)
285         ax0 = self.figure.add_subplot(111)
286         im = ax0.imshow(self.Z, cmap=cmap, norm=norm)
287         self.figure.colorbar(im, ax=ax0)
288         ax0.set_title('')
289         self.im = im
290         plt.draw()
291
292
293     #UI equivalent of the main() method
294     if __name__ == "__main__":
295         app = QApplication.instance()
296         if not app:
297             app = QApplication(sys.argv)
298         app.aboutToQuit.connect(app.deleteLater)
299         main_win = main_window()
300         sys.exit(app.exec_())
301

```

**The code for initializing the arrays and creating the Nodes is below:**

```

1 import matplotlib
2 import matplotlib.pyplot as plt
3 from matplotlib.colors import BoundaryNorm
4 from matplotlib.ticker import MaxNLocator
5 import numpy as np
6
7 def makeConcentration(resolution, array):
8
9     #the code to create the 2nm intermixing layer
10    def falloff(i,j,Z):
11
12        #in a 50x50 square around the center of a cylinder
13        #if more than 48 nm away from center, start mixing
14        for row in range(-50*resolution,50*resolution-1):
15            for col in range(-50*resolution,50*resolution-1):
16                dist = np.sqrt(row**2+col**2)
17                if dist > 48 and dist < 50:
18                    dist = dist - 48
19                    val = 2*((resolution**2 - dist**2)/resolution**2)**2-1
20                    Z[j+col][i+row] = val
21                if dist < 48: Z[j+col][i+row] = 1
22
23
24
25
26
27
28
29    #create the outer arrays for graphing
30    x = np.arange(0,26,step = 1.0/(resolution*40))
31    y = np.arange(0,14,step = 1.0/(resolution*40))
32
33    #make them into a meshgrid for pcolormesh
34    X,Y = np.meshgrid(x,y)
35    Z = np.ones((len(y),len(x)),dtype = float)
36    #initialize concentration as -1 to fit Mann's criteria
37    Z = Z*(-1)
38
39    #Find the center of the circles in the array, then change the
40    #concentration of the Z meshgrid to match the cylinder
41    for i in range(len(x)):
42        for j in range(len(y)):
43            if int(x[i]) == x[i] and int(y[j]) == y[j]:
44                if x[i] < 25 and y[j] < 13:

```

```

45         if array[int(y[j])][int(x[i])] == 1:
46             falloff(40+i,40+j,Z)
47
48     return X,Y,Z
49
50
51     #initialize the temperature array to 300K
52 def makeArray():
53     array = np.zeros((13,25), dtype = int)
54     for i in range(12):
55         for j in range(24):
56             array[i][j] = 300
57
58     return array
59
60     #initialize the concentration array with a staggered lattice
61 def makeArray2():
62     array = np.zeros((13,25), dtype = int)
63
64     for i in range(12):
65         for j in range(24):
66             if j%4 == 1 and i%4 == 1:
67                 array[i][j] = 1
68             if j%4 == 3 and i > 0 and i%4 == 3:
69                 array[i][j] = 1
70     return array
71
72     #create a class for the ArrayNode object that can store all the necessary information
73     #for the simulation and velocity calculations
74 class ArrayNode():
75     def __init__(self, conc = 0, coords = (0,0), onFire = False, hasNeighbors = True, tig = 1e7,nodevels = []):
76         self.rbility = conc
77         self.onFire = onFire
78         self.hasNeighbors = hasNeighbors
79         self.coords = coords
80         self.tig = tig
81         self.nodevels = nodevels
82
83     #take the arrays and create a grid of nodes
84 def meshArray(X,Y,Z):
85     #make a node at every grid point with collected data
86     xlen = int(len(Z))
87     ylen = int(len(Z[0]))
88     mesh = np.empty((xlen,ylen), dtype = ArrayNode)

```

```

"""If the Arduino were actually connected we would run the following
meshpoints = []
start_time = time.time()

while (time.time()-start_time) < 3.0:
    data = arduino.readline()[:-2] #the last bit gets rid of the new-line cha
    if data:
        meshpoints.append(data)

array = np.zeros((13,25), dtype = int)

for tuple in meshpoints
    array[tuple[0]][tuple[1]] == 1
"""

```

```

57
58     return array
59
60     #initialize the concentration array with a staggered lattice
61 def makeArray2():
62     array = np.zeros((13,25), dtype = int)
63
64     for i in range(12):
65         for j in range(24):
66             if j%4 == 1 and i%4 == 1:
67                 array[i][j] = 1
68             if j%4 == 3 and i > 0 and i%4 == 3:
69                 array[i][j] = 1
70     return array
71
72     #create a class for the ArrayNode object that can store all the necessary information
73     #for the simulation and velocity calculations
74 class ArrayNode():
75     def __init__(self, conc = 0, coords = (0,0), onFire = False, hasNeighbors = True, tig = 1e7,nodevels = []):
76         self.rbility = conc
77         self.onFire = onFire
78         self.hasNeighbors = hasNeighbors
79         self.coords = coords
80         self.tig = tig
81         self.nodevels = nodevels
82
83     #take the arrays and create a grid of nodes
84 def meshArray(X,Y,Z):
85     #make a node at every grid point with collected data
86     xlen = int(len(Z))
87     ylen = int(len(Z[0]))
88     mesh = np.empty((xlen,ylen), dtype = ArrayNode)
89     for i in range(xlen):
90         for j in range(ylen):
91             mesh[i][j] = ArrayNode(coords = (i,j), conc = Z[i][j])
92     return mesh
93
94     #initialize a corner to be ignited
95 def ignite(mesh,Z1,Z2):
96     for i in range(100):
97         mesh[i][0].onFire = True
98         Z1[i][0] = 0
99         Z2[i][0] = 2000
00

```

The code for velocity calculations is below:

```
1 import numpy as np
2 import _2D_Multilayer_Simulation as td
3 import time
4 def _2D_Cubic(pos,X,Y,Z):
5     delta = 40 #nm
6     i,j = pos
7
8     def kn(n):
9         #Different for -90, -45, 0, 45 , 90
10        concvalues45 = []
11        concvalues0 = []
12        concvaluesn45 = []
13        concvaluesn90 = []
14
15        for l in range(-2*delta,2*delta):
16            if i+l > 0 and j+l > 0 and i+l < 560 and j+l < 1040:
17                concvalues45.append(Z[i+l][j+l]*np.sin(an(n)*Y[i+l][j+l]))
18            k45 = 1.0/(2*delta) * np.trapz(concvalues45)
19
20        for l in range(-2*delta,2*delta):
21            if i+l > 0 and i+l < 560:
22                concvalues0.append(Z[i+l][j]*np.sin(an(n)*Y[i+l][j]*X[i+l][j]))
23            k0 = 1.0/(2*delta) * np.trapz(concvalues0)
24
25        for l in range(-2*delta,2*delta):
26            if i-l > 0 and j+l > 0 and i-l < 560 and j+l < 1040:
27                concvaluesn45.append(Z[i-l][j+l]*np.sin(an(n)*(Y[i-l][j+l]*X[i-l][j+l])))
28            kn45 = 1.0/(2*delta) * np.trapz(concvaluesn45)
29
30        for l in range(-2*delta,2*delta):
31            if j+l > 0 and j+l < 1040:
32                concvaluesn90.append(Z[i][j+l]*np.sin(an(n)*X[i][j+l]))
33            kn90 = 1.0/(2*delta) * np.trapz(concvaluesn90)
34
35        return kn90,kn45,k0,k45
36
37    def an(n):
38        return (n*np.pi)/(2*delta)
39
40
41    sumkoan90 = 0
42    sumkoan45 = 0
43    sumkoap0 = 0
44    sumkoap45 = 0
45    sumk0 = 0
```



```

45 sumkn90 = 0
46 sumkn45 = 0
47 sumkp0 = 0
48 sumkp45 = 0
49
50 for i in [1]:
51     n90,n45,p0,p45 = kn(i)
52     a = an(i)
53     sumkoan90 += (n90**2)/(a**2)
54     sumkoan45 += (n45**2)/(a**2)
55     sumkoap0 += (p0**2)/(a**2)
56     sumkoap45 += (p45**2)/(a**2)
57     sumkn90 += n90**2
58     sumkn45 += n45**2
59     sumkp0 += p0**2
60     sumkp45 += p45**2
61
62
63
64
65 a = np.exp(-51000/(8.314*2000))*(2*2.8e-6*8.314*2000**2)/(51000*2099)
66 D = 3.2e-6
67 beta = .2*2.8e-6
68
69 #c3 = -sumkoa/2
70 #c2 = sumkoa*(D+2/beta)
71 #c1 = -sumkoa * ((D**2)/2 + 2*(D**2 / beta)) + sumk * D**2 - a*beta
72 #c0 = 2*a*D + a*beta*D
73 c3 = -sumkoan90/2.0
74 c2 = sumkoan90*(4*D+2.0*D/beta)
75 c1 = -sumkoan90 * ((D**2.0)/2 + 2*(D**2 / beta**2)) + sumkn90 * D**2 - a*beta
76 c0 = 2.0*a*D + a*beta*D
77 roots = np.roots([c3,c2,c1,c0])
78
79 greatestn90 = 0
80
81 for root in roots:
82     if root > greatestn90: greatestn90 = root
83
84
85 c3 = -sumkoan45/2.0
86 c2 = sumkoan45*(4*D+2.0*D/beta)
87 c1 = -sumkoan45 * ((D**2.0)/2 + 2*(D**2 / beta**2)) + sumkn45 * D**2 - a*beta
88 c0 = 2.0*a*D + a*beta*D
89 roots = np.roots([c3,c2,c1,c0])

```

```

83
84
85     c3 = -sumkoan45/2.0
86     c2 = sumkoan45*(4*D+2.0*D/beta)
87     c1 = -sumkoan45 * ((D**2.0)/2 + 2*(D**2 / beta**2)) + sumkn45 * D**2 - a*beta
88     c0 = 2.0*a*D + a*beta*D
89     roots = np.roots([c3,c2,c1,c0])
90
91     greatestn45 = 0
92
93     for root in roots:
94         if root > greatestn45: greatestn45 = root
95
96     c3 = -sumkoap0/2.0
97     c2 = sumkoap0*(4*D+2.0*D/beta)
98     c1 = -sumkoap0 * ((D**2.0)/2 + 2*(D**2 / beta**2)) + sumkp0 * D**2 - a*beta
99     c0 = 2.0*a*D + a*beta*D
100    roots = np.roots([c3,c2,c1,c0])
101
102    greatestp0 = 0
103
104    for root in roots:
105        if root > greatestp0: greatestp0 = root
106
107    c3 = -sumkoap45/2.0
108    c2 = sumkoap45*(4*D+2.0*D/beta)
109    c1 = -sumkoap45 * ((D**2.0)/2 + 2*(D**2 / beta**2)) + sumkp45 * D**2 - a*beta
110    c0 = 2.0*a*D + a*beta*D
111    roots = np.roots([c3,c2,c1,c0])
112
113    greatestp45 = 0
114
115    for root in roots:
116        if root > greatestp45: greatestp45 = root
117
118    return greatestn90,greatestn45,greatestp0,greatestp45
119
120    #array = td.makeArray2()
121    #X,Y,Z = td.makeConcentration(1,array)
122    #pos = (20,20)
123
124    #start_time = time.time()
125    #vels = _2D_Cubic(pos,X,Y,Z)
126

```

## The code for GUI initialization is below:

```
1 # -*- coding: utf-8 -*-
2
3 # Form implementation generated from reading ui file '/Users/chap/Documents/2D5im/Simulation 0Pengl.ui'
4 #
5 # Created by: PyQt5 UI code generator 5.14.1
6 #
7 # WARNING! All changes made in this file will be lost!
8
9
10 from PyQt5 import QtCore, QtGui, QtWidgets
11
12
13 class UI_Dialog(object):
14     def setUpUi(self, Dialog):
15         Dialog.setObjectName("Dialog")
16         Dialog.resize(1440, 771)
17         self.exit = QtWidgets.QPushButton(Dialog)
18         self.exit.setGeometry(QtCore.QRect(1310, 720, 113, 32))
19         self.exit.setObjectName("exit")
20         self.label = QtWidgets.QLabel(Dialog)
21         self.label.setGeometry(QtCore.QRect(930, 230, 261, 31))
22         self.label.setObjectName("label")
23         self.label_2 = QtWidgets.QLabel(Dialog)
24         self.label_2.setGeometry(QtCore.QRect(240, 230, 331, 31))
25         self.label_2.setObjectName("label_2")
26         self.readmagnets = QtWidgets.QPushButton(Dialog)
27         self.readmagnets.setGeometry(QtCore.QRect(40, 20, 201, 81))
28         self.readmagnets.setObjectName("readmagnets")
29         self.startsim = QtWidgets.QPushButton(Dialog)
30         self.startsim.setGeometry(QtCore.QRect(1160, 20, 221, 81))
31         self.startsim.setObjectName("startsim")
32
33         self.retranslateUi(Dialog)
34         QtCore.QMetaObject.connectSlotsByName(Dialog)
35
36     def retranslateUi(self, Dialog):
37         _translate = QtCore.QCoreApplication.translate
38         Dialog.setWindowTitle(_translate("Dialog", "Dialog"))
39         self.exit.setText(_translate("Dialog", "Exit"))
40         self.label.setText(_translate("Dialog", "<html><head/><body><span style='font-size:24pt; font-weight:600;'>Graph of Temperature</span></p></body></html>"))
41         self.label_2.setText(_translate("Dialog", "<html><head/><body><span style='font-size:24pt; font-weight:600;'>Graph of Concentration</span></p></body></html>"))
42         self.readmagnets.setText(_translate("Dialog", "Read Magnet Architecture"))
43         self.startsim.setText(_translate("Dialog", "Start Simulation"))
44
```

## **C. Educational Activity Powerpoints**

### **PP1 Focus Attention**



# 2D Multilayer Thin-Films Combustion Educational Activity: PP1

MAE 4344

Team Members: Truc Ngo, Chapman Howard  
Project Mentor/Champion: Dr. Aurelie Azoug



## Focus Attention

---

### Two Winning Towers at Front of Class:

(3 minutes)

Class Discussion:

- What did the winners do differently?
- Are their towers taller?
- What repeating units do they have?

Spend 1 minute reflecting on your design as a group



## Focus Attention

---

### What's the perfect tower?

(2 minutes)

Class Discussion:

- What should the base look like?
- How tall should it be?
- What kind of repeating units should it have?
- How do you know this will make a better design?



## Focus Attention

---

### How does this connect?

(3 minutes)

Just like we can compete and discuss how to build a better marshmallow tower, scientists discuss and compete to build better composite materials.

Composite material: Made up of two or more materials and has characteristics different than the original two materials.





## Focus Attention

### How does this connect?

(3 minutes)

- Reinforced concrete in bridges



[https://www.researchgate.net/figure/Typical-concrete-bridge-deck-deterioration-and-damage-rebar-corrosion-left\\_fig1\\_281897822](https://www.researchgate.net/figure/Typical-concrete-bridge-deck-deterioration-and-damage-rebar-corrosion-left_fig1_281897822)

- Fiberglass in boats



<https://www.aliexpress.com/item/4000025294031.html>

- Metal composites in new technology (GaAs semiconductor)



<https://compoundsemiconductor.net/article/94567/GaAs-The-Logical-Successor-To-CMOS>



## Focus Attention

---

### Thin-Film Composites?

(5 minutes)

Special class of metal composites:

**Reactive multilayer thin films** are heterogeneous solids that can be stimulated by an external source to release stored chemical energy in a sudden outpouring of light, heat, and sound. [1]

- What are some technological uses for light, heat, and sound?



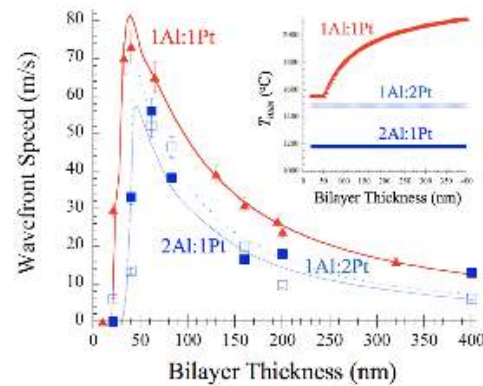
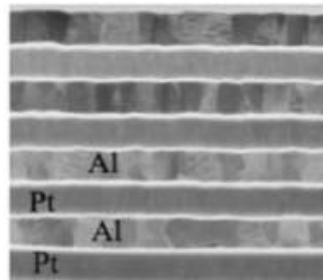
## Focus Attention

### Thin-Film Composites?

(5 minutes)

Thin-Film with one dimension of symmetry:

Look at graph! The speed of combustion changes with layer size.



TEM image of Al/Pt multilayer [2] Flame Velocity vs. Bilayer Thickness [2]



## Focus Attention

---

### Thin-Film Composites?

(5 minutes)

Think of the parallels between designing towers and thin-films:

- Tower had height/load goal, Thin-films have temperature or speed goal
- Who used any experimentation to build their towers?  
Much experimentation goes into building Thin-Films.
- How many towers failed to make it to the test?  
A popular area of research for thin-films is failure.

Mostly true for composites in general.



## Focus Attention

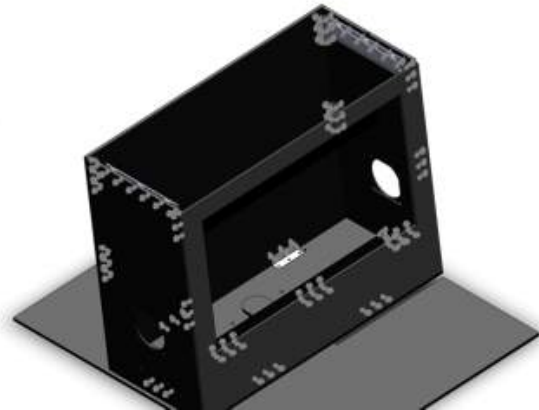
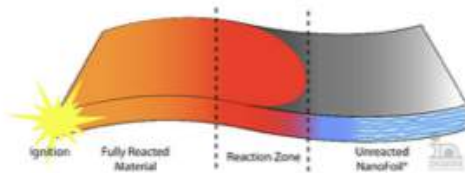
### Introduce Direct Experience

(2 minutes)

Now we get to make up a test!

We have a device that will:

- Take a customizable architecture
- Simulate the combustion behavior



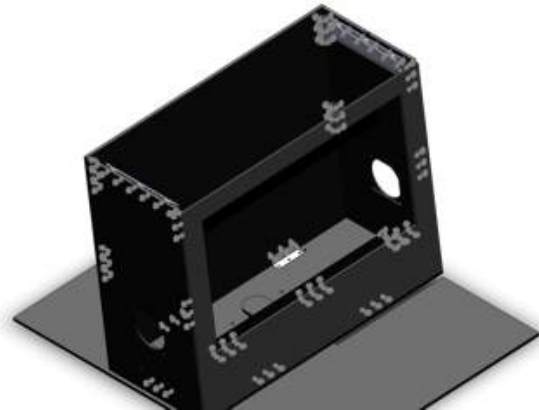
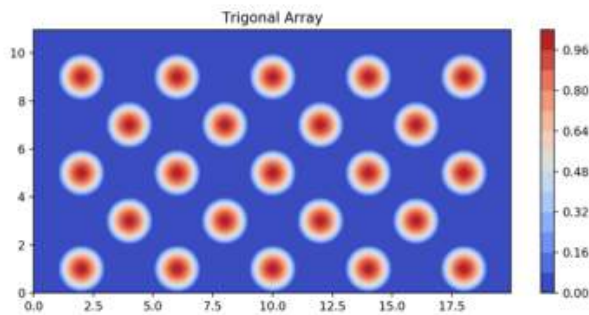


# Direct Experience

## Preparation

(2 minutes)

Two winning teams come forward, draw a symmetry of circles in the plane, example:





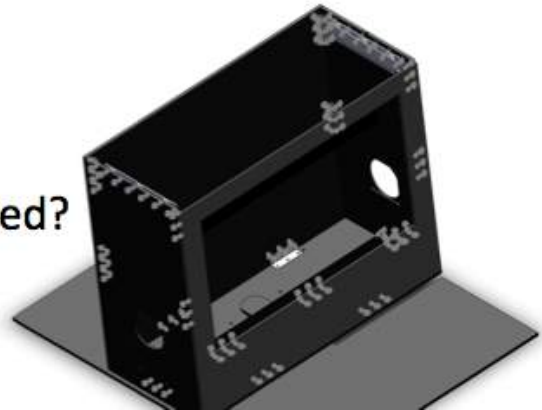
## Direct Experience

---

### Repeat

(5 minutes x 2)

- Use magnets to load symmetry into simulation
- How do you think the system will behave?
- Run Simulation
- Were you right?
- What was different?
- Why might that have happened?



### PP2 Share Inspiration



# 2D Multilayer Thin-Films Combustion Educational Activity: PP2

MAE 4344

Team Members: Truc Ngo, Chapman Howard  
Project Mentor/Champion: Dr. Aurelie Azoug





## Share Inspiration

---

### The Three W's

(5 minutes)

Remember

- What did we do?
  - Why did we do it?
  - Why should it be important to you?
-



## Share Inspiration

---

### The Three W's

(5 minutes)

What did we do?

- Class answer?
  - Built marshmallow towers → Architecture
  - Learned why some architectures were better
  - Applied it to composite materials
  - Learned about thin-film composites
  - Simulated thin-film composite behavior
-



## Share Inspiration

---

### The Three W's

(5 minutes)

Why did we do it?

- Class answer?
  - Complex composite materials obey the same principles as cutting edge thin-films
  - Small system with a big concept behind it
  - Many real life applications depend on this concept
-



## Share Inspiration

---

### The Three W's

(5 minutes)

Why should it be important to you?

- Class answer?
  - You proved you're already good engineers with the marshmallow towers
  - You just need practice and more study to apply this process to complicated systems
  - You now have more insight into why composites behave the way they do
-



## Share Inspiration

---

### Tower → Thin-Film

(3 minutes)

How is the tower connected to the Thin-Film?

- Class answer?
  - Architecture affects behavior. Somebody tell me how, in both cases.
  - How did we approach building a perfect tower? What would that look like if we were building a perfect thin-film?
-



## Share Inspiration

---

### Sophomore Engineer → Professional Scientist

(2 minutes)

What skills did you use today?

- Brainstorm
- Experiment
- Reflect
- Iterate

What skills do you not have yet?

- Experience
  - Specialized knowledge
-



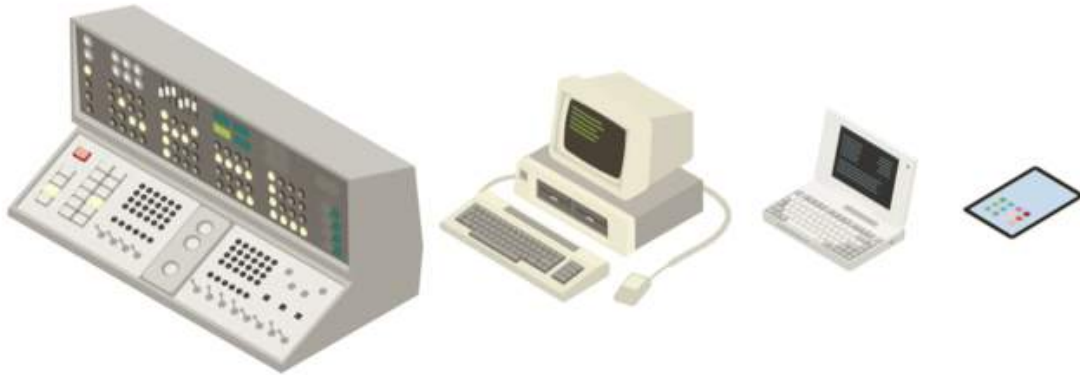
## Share Inspiration

---

### Large Scale Projects

(5 minutes)

What have people done with this knowledge?



<https://learn.g2.com/history-of-computers>

How were composite materials present in this design?

---



# Share Inspiration

---

## Large Scale Projects

(5 minutes)

What have people done with this knowledge?



[https://www.flickr.com/photos/ganda\\_stw/3227645432](https://www.flickr.com/photos/ganda_stw/3227645432)



<http://compositesmanufacturingmagazine.com/2014/10/building-bigger-boats-with-fiberglass-vacuum-infusion/>

How were composite materials present in this design?

---





# Share Inspiration

---

## Large Scale Projects

(5 minutes)

What have people done with this knowledge?



<https://imgur.com/gallery/cv2lh>



[http://www.highestbridges.com/wiki/index.php?title=Reiicanjiang\\_Railway\\_Bridge\\_Shuibai](http://www.highestbridges.com/wiki/index.php?title=Reiicanjiang_Railway_Bridge_Shuibai)

How were composite materials present in this design?

---



## Share Inspiration

---

End

You can design structures and devices just as groundbreaking! You just have to put in the time.

## D. ABET Criteria Report

### ABET Student Outcome Self-Evaluations

In designing your project, how did you demonstrate your competency in each of the 7 ABET Student Outcomes (SO#) listed below? Include a paragraph answer for each of the 7 student outcomes.

**SO1: Students demonstrated the ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.**

For student outcome number one, we had to make several design decisions that all affected each other. Choosing the materials to build each component meant weighing possible modes of failure. To analyze this we used static and dynamic analyses to choose a material that would not fail, but did not add unwanted weight or other aspects to the design. We had to use aspects of computer science to write the simulation, differential equations to analyse the materials, and thermodynamics to analyze the heat flow. Our wealth of classroom experience gave us many tools to use for this project.

**SO2: Students demonstrated the ability to apply the engineering design process to produce solutions that meet specified needs with consideration for public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.**

We initiated our design project with defining a primary desired audience. With that in mind, we were able to take into consideration a context for where our project would be applied to. Since we focused our audience to be engineering students in an introductory materials science course and understood the primary user of our device being a teaching expert, we outlined the codes and standards for various components of our construction. For example, we wanted users to be able to manipulate a device to see hands-on a combustion reaction. With this in mind, the device must have a partition between the electrical components and the environment. Voltages were also kept below 30 volts for safe laboratory usage. Our material selection of high-density polyethylene (HDPE) accounts for the many people in a lecture hall that would interact with this device since HDPE is generally a germ-resistant material. HDPE is also a durable, light weight, and low-cost material. With these qualities, we are able to make a more compact model for long-term storage. To accommodate for the larger range of individuals viewing the device, we also wanted to provide a bigger screen to allow a greater resolution and for a single larger audience to view.

**SO3: Students demonstrated the ability to communicate effectively with a range of audiences.**

During this project we have had to present our ideas, solutions, and designs on a casual level to our fellow teammates, and on a more formal level to our project champion and point of contact at Sandia National Laboratories. We have had to communicate using multiple mediums: email, phone-calls, face-to-face, PowerPoint presentations, and video calls. Without using these

mediums effectively, the design process could not have progressed as essential stakeholders would have been left out.

**SO4: Students demonstrated the ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.**

Certain parts of this project involved communicating with a representative at Sandia National Laboratories, a government-run lab with strict rules about the spread of information. Care had to be taken to respect the professional culture at Sandia. To engineer a successful device, we had to make judgements on how much information the device would give to its users, and if the device could be a threat to information security. We had to weigh the expense of each component, as we were operating on a limited budget, and we had to make sure the device was free of any operational hazards because of its intended use in the classroom. We certified each part of the design met these requirements before moving forward with the project.

**SO5: Students demonstrated the ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives.**

In a team setting, we established specific roles for each member, constructing a large gantt chart for desired milestones and smaller schedules to outline smaller goals that maintained our accountability to such strict deadlines. At meetings, all ideas were considered and discussed in correlation to the design goals of the project, working together to assure that we all understood the project goals and outcomes. We had to learn and respect everyone's work ethic and be accommodating to everyone's individual schedule while also supplying sufficient time to meet as a group to execute elements of the project. Since we did not designate a team leader, it was crucial for us all to step up and initiate various tasks and to plan executions. We had to trust that the other member understood the concepts and respect decisions mutually agreed upon that would produce a better outcome.

**SO6: Students demonstrated the ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.**

An important part of this design project was to incorporate a thorough test plan to run after fabrication of the device. Designing tests and experiments to acquire data about the heat generation of the inside of the device, the operational speed of the computer, the performance of the reed switch array, and the physical stability of the device were paramount to the project's success. Necessary codes and standards guided our definitions of acceptable values for each test. Defining in precise terms the successes of each design test required us to use our experiences analyzing data in the classroom setting and apply it to a novel situation.

**SO7: Students demonstrated the ability to acquire and apply new knowledge as needed, using appropriate learning strategies.**

Before our first meeting, we read over published articles of our topic to have a better understanding of what we wanted our device to demonstrate. To make an educational model, one of our first steps had to be the competency in our topic. We met to discuss how the recent literature corresponded with our previous courses and how we wanted to relay that information to others. We scheduled meetings with professors to discuss their experiences on topics that we were unfamiliar with and further researched those elements per their recommendations. We checked out textbooks from the library to review concepts that refreshed our background in the calculations for our build, and we did research to expand on our knowledge of the formulas we already knew and were able to further justify our decisions in the selection of the materials and design.