Julius Won, New Visions Engineering, November 11, 2023

Captions for photos will be formatted like this.

Section 0: Introduction:

This writeup is for the Engineer Your World program for New Visions Engineering. In it, I was part of a group that designed and built a pinhole camera, using it to take several photographs. This gave me practice in elements of the engineering design process.

Section 1: Purpose of the design.

The camera is supposed to be used by artists with limited manual dexterity to photograph a mural.

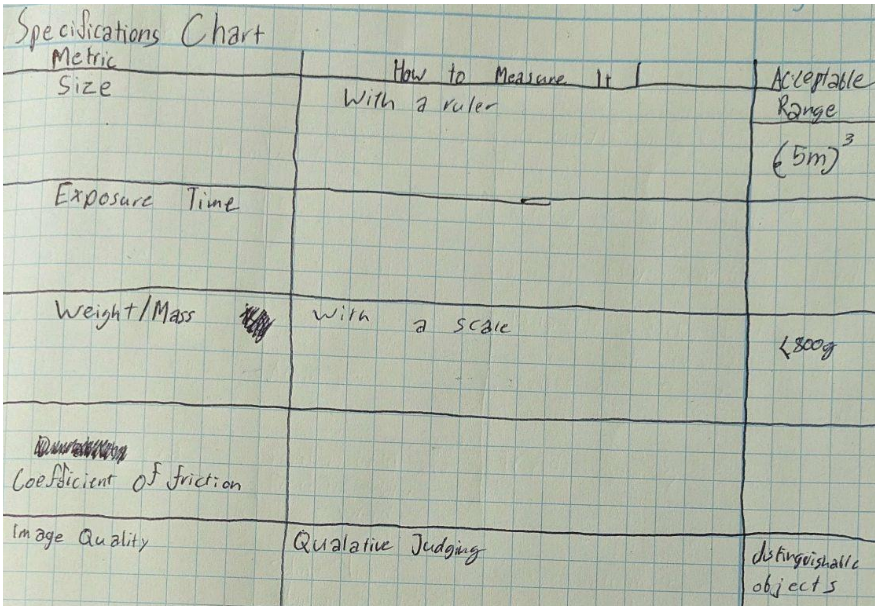
Section 2: Customer Requirements

Since the requirements were presented in such a nice format, being a video interview, it was very clear what they were from the beginning.

The requirements for the design were as follows:

- The ability to photograph a 10’x10’ mural from a maximum distance of 20’
- To be usable with minimal manual dexterity.
- To be lightweight enough to reasonably carry (<800g)

These specifications were listed simply in a chart in my engineering notebook (see below), along with the means to measure them.



Specifications Chart

Metric	How to Measure It	Acceptable Range
Size	With a ruler	$(5m)^3$
Exposure Time		
Weight/Mass	With a scale	<800g
Coefficient of friction		
Image Quality	Qualative Judging	distinguishable objects

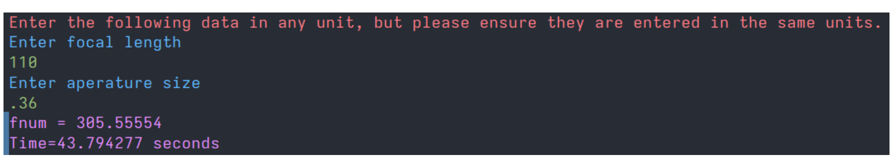
Chart of Camera Requirements

From this information, we calculated the exposure time. We did this by using known exposure times and their corresponding f-numbers. Graphing these as points and finding a line of best fit through them, it appeared to be modeled best by an exponential function. The function was:

$t=16.69e^{0.00316f}$

t is the exposure time in seconds and f is the f-stop value of the camera

Then I programmed a simple tool to speed up the process of calculating the exposure time as we refined our measurements of the variables that might affect it.



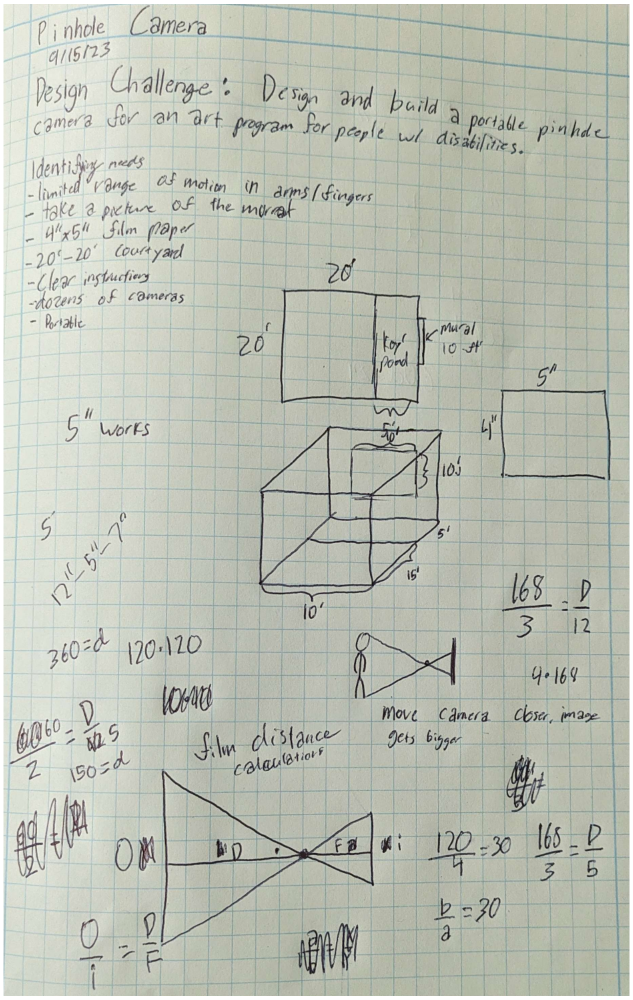
```
Enter the following data in any unit, but please ensure they are entered in the same units.
Enter focal length
110
Enter aperature size
.36
fnum = 305.55554
Time=43.794277 seconds
```

```csharp
using System;
namespace MyApp // Note: actual namespace depends on the project name.
{
    internal class Program{
        static void Main(string[] args){
            float focalLength=0;
            float aperaturesize=0;
            float fnum;
            float time;
            Console.ForegroundColor=ConsoleColor.Red;
            Console.WriteLine("Enter the following data in any consistent unit.");
            Console.ForegroundColor=ConsoleColor.Blue;
            Console.WriteLine("Enter focal length");
            Console.ForegroundColor=ConsoleColor.DarkGreen;
            try{
                focalLength=float.Parse(Console.ReadLine());
            }catch(FormatException){
                Console.WriteLine("Enter a real number");
                Main(new string[0]);
            }
            Console.ForegroundColor=ConsoleColor.Blue;
            Console.WriteLine("Enter aperature size");
            Console.ForegroundColor=ConsoleColor.DarkGreen;
            try{
            aperaturesize=float.Parse(Console.ReadLine());
            }catch(FormatException){
                Console.WriteLine("Enter a real number");
                Main(new string[0]);
            }
            Console.ForegroundColor=ConsoleColor.Magenta;
            fnum=(float)focalLength/(float)aperaturesize;
            Console.WriteLine("fnum = "+fnum.ToString());
            time=(float)16.6878*(float)Math.Pow((float)Math.E,(float)0.00315761*(float)fnum);
            Console.WriteLine("Time="+time+" seconds");
        }
    }
}
```

Code for Camera Exposure Time Calculator

The other restriction that we had to take into consideration was the ability of the camera to photograph the 10 ft x 10 ft area. We knew that the ratio between the height of the frame and the distance to the mural must be equal to the ratio between the height of the film and the focal length (distance from the pinhole to the camera), and so were able to simply solve for the maximum length of the camera, which works out to be 8”.

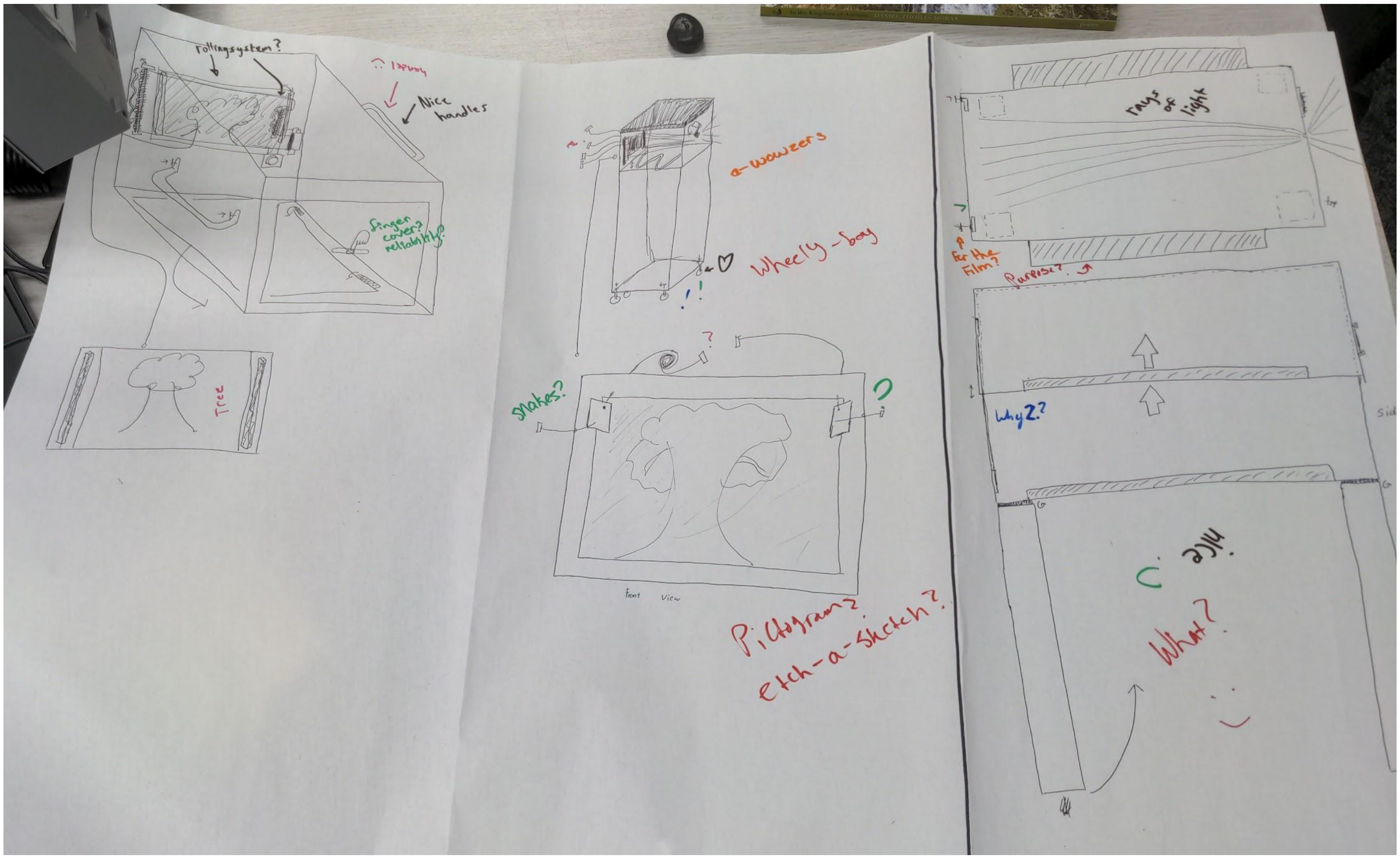
Unfortunately, as will be discussed in section four, incorrect measurements were used in the technical sketches, specifically with the focal length of the camera. While the correct measurements had been made, we moved to the technical sketch with calculations that assumed the width of the film to be 5” rather than the correct 4”. This led to a hasty deconstruction, modification, and reconstruction of the camera, and while it didn’t become a large issue this time, it is clearly a weak point in our design process. Since getting the calculations right is such a basic part of design, we definitely should have double-checked everything before moving on to the technical sketches. That being said, while mistakes happen to a certain extent, they can be corrected, and for future building, I will be sure to measure twice.



Calculations for depth of camera and notes on required dimensions.

Section 3: Idea Generation

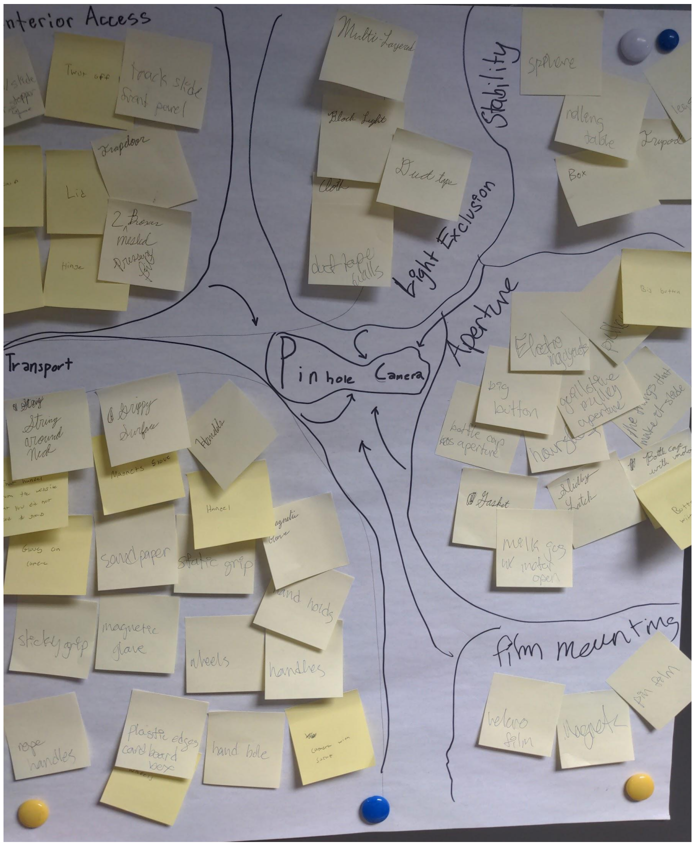
The first ideas I generated were on a c-sketch (below) in conjunction with the rest of my group. The c-sketch gathered any design ideas that had a chance of making it into the final camera. The goal of this for me was to end up taking parts from different sketches my group produced and combining different parts into the camera design while taking into account the feedback of classmates who reviewed mine.



Collaborative Sketch of Camera

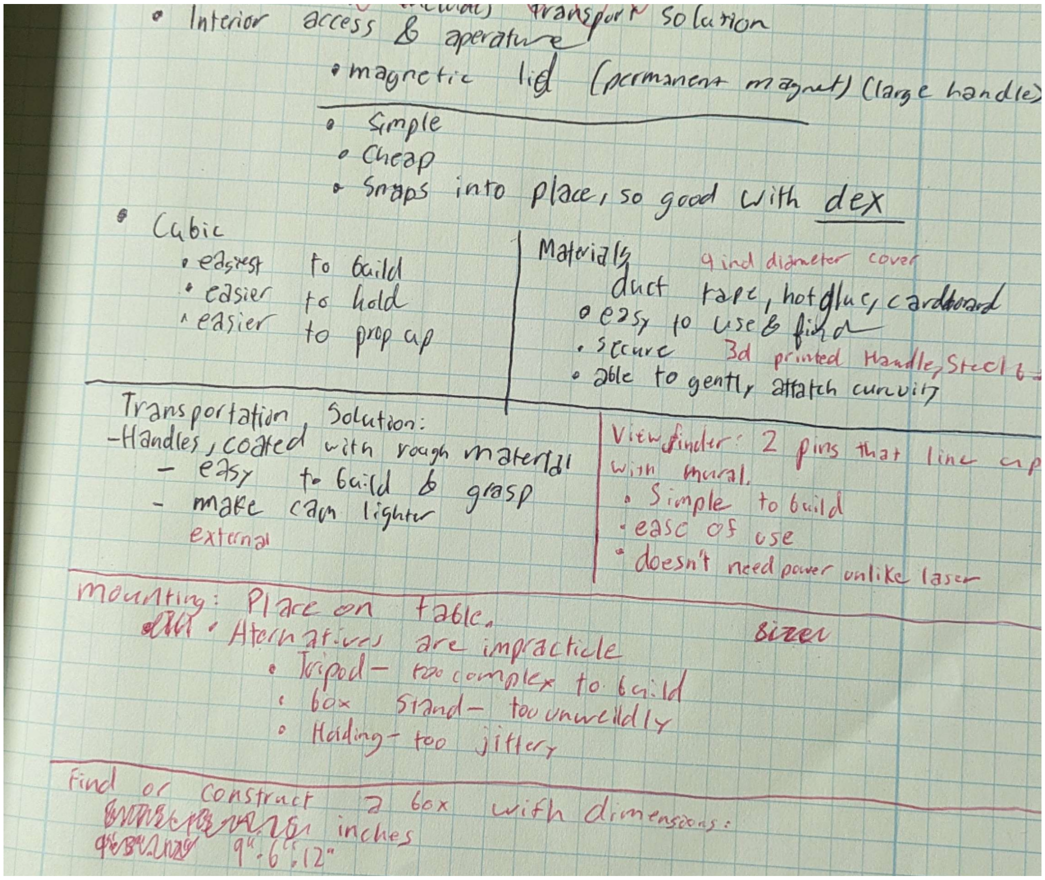
Directly after c-sketching, we moved to brainstorming, which pulled the ideas from the c-sketch into problem-specific solutions. For each concept, there were many competing concepts to fulfill the same role. The camera aperture, for example, had many different proposed solutions for a lid, including a laptop privacy switch, a motorized version of a milk carton screw-on cap, and an electromagnet that could be magnetized and demagnetized to release the lid. The film was proposed to be pinned to the wall, or velcroed.

By mind-mapping, we sorted these solutions into the problems that they solved, thus allowing us to eliminate all but one solution for each need of the camera. We found six categories of solutions: Film mounting, transportation, light exclusion, stability, interior access, and aperture control.



Mind Map

This still left us with the task of selecting one solution for each category. To do this, we laid out the advantages and disadvantages of each of the options, but mainly focused on a few characteristics, those being: a) How completely they fulfilled their function, b) How practical they would be to construct, and c) how easily they could break. This gave us a description of how each component would fill its role. Then we simply chose the concept that fulfilled these categories best and worked on ways to combine them.



... transport solution
- Interior access & aperature
  - magnetic lid (permanent magnet) (large handle)
  - Simple
  - Cheap
  - Snaps into place, so good with dex
- Cubic
  - easiest to build
  - easier to hold
  - easier to prop up

Materials 9 ind diameter cover
duct tape, hot glue, cardboard
- easy to use & find
- secure 3d printed Handle, Steel ...
- able to gently attach circuitry

Transportation Solution:
- Handles, coated with rough material
  - easy to build & grasp
  - make cam lighter

external

Viewfinder: 2 pins that line up with mural.
- Simple to build
- ease of use
- doesn't need power unlike laser

mounting: Place on table.

size

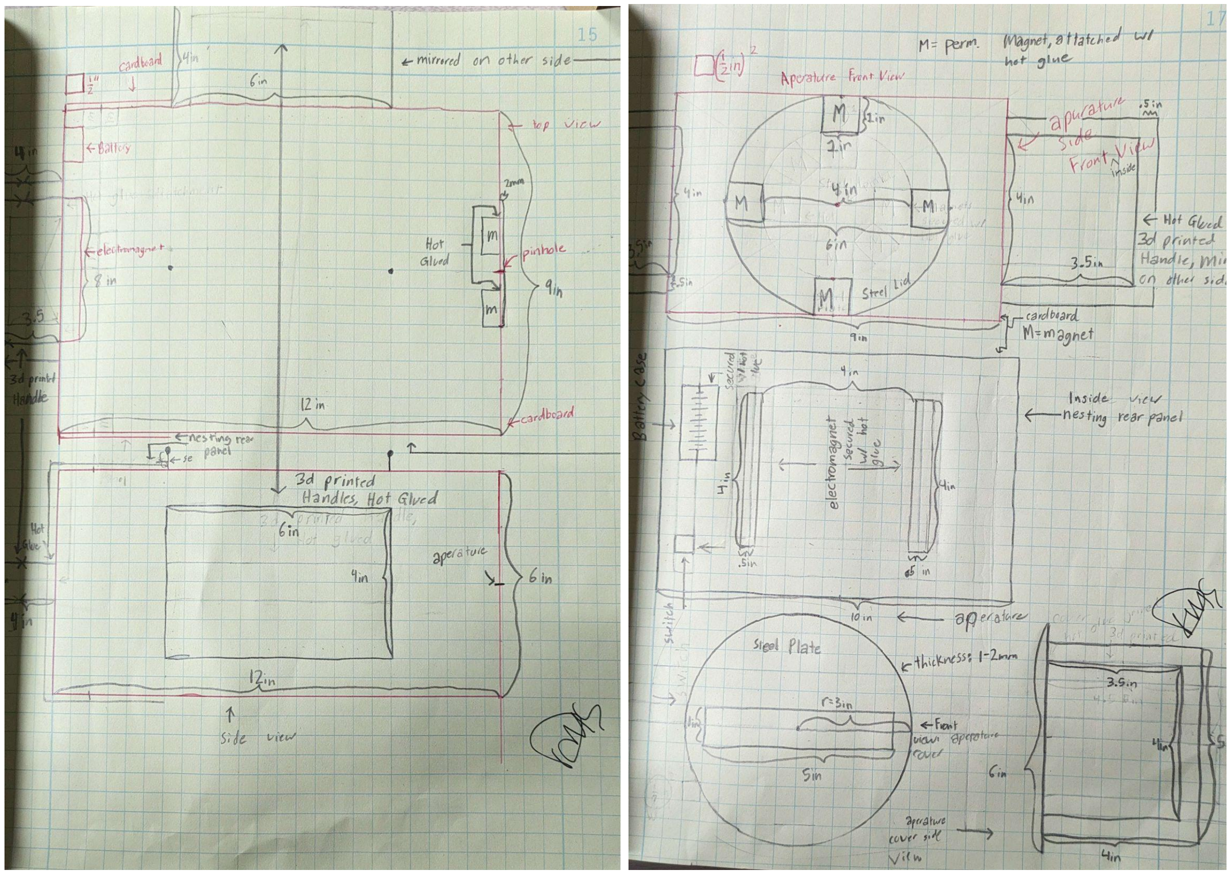
- Alternatives are impractical
  - Tripod - too complex to build
  - box stand - too unwieldly
  - Holding - too jittery

Find or construct a box with dimensions:
inches
9"·6"·12"

Design Choice Justification from Engineering Notebook

The approach to design selection worked. It justified our choices along multiple axes and led to a camera that was sturdy and functional while simple in design. It did come with drawbacks, however, chiefly the fact that all the components were largely looked at in a vacuum. This led to an incongruous design, such as 3D-printed handles on a cardboard frame, but since the camera had few moving parts, this didn’t cause problems besides visual inconsistency and minor difficulty attaching components. Besides this, I think our design process took full advantage of the variety of designs produced by the c-sketches across the team. This is a big reason why the camera was successful.

Section 4: Build Process and Environmental Obstacles

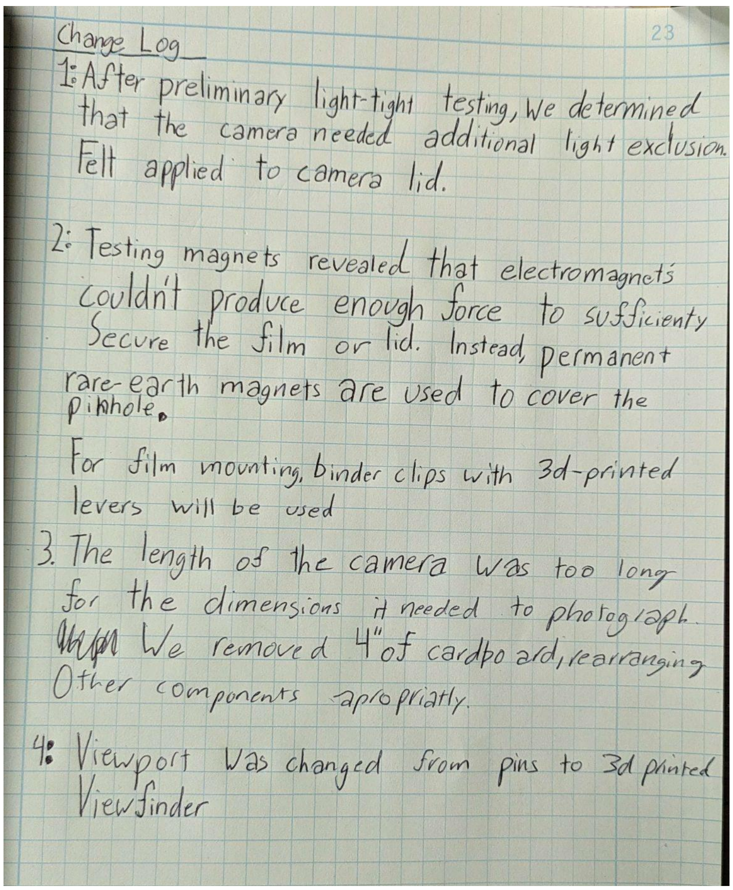


Dimensioned Technical Sketches of the Camera

The first problem was apparent as soon as the camera box was made; the light-tight tests revealed that the film cover had insufficient light exclusion. This was rectified by adding felt padding to the entire cover. After this inclusion, light-tight testing revealed smaller light leaks due to insufficient glue, which were easily patched.

The second problem became apparent after light-tight testing when building the electromagnet to hold the film in place. I wrapped an electromagnet and tested it with a power supply. There were two reasons it was clearly not a functional solution. The first was that the energy from a reasonable number of AA or AAA batteries wasn’t sufficient to hold the film in place. This was tested before the camera was assembled. The second was that the electromagnets would stay magnetized for some time after power was cut to them, thus eliminating all the benefits. In place of the electromagnet, we attached binder clips to hold the film, and 3D-printed handles to make them suitable for use with limited dexterity.

Towards the end of the project, after pictures were taken, we found that the dimensions of the camera needed to be corrected. The camera was unable to meet the requirements, specifically requiring a 30’ distance from the target to capture a 10’ x 10’ area. The focal length was 12” instead of the minimum 8”.Looking back to the original notes from the beginning of the project, the calculations for the minimum focal length of the box were made, but it appears that they were looked over in the technical sketches and construction, as the height of the film was assumed to be 5” rather than the correct 4”. Fortunately, the design could be compacted to exactly the right length without changing the shape of the handles or lid. This let us simply cut out 4” of cardboard and move the handles and viewfinders to their new positions.



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Change Log

1: After preliminary light-tight testing, we determined that the camera needed additional light exclusion. Felt applied to camera lid.

2: Testing magnets revealed that electromagnets couldn't produce enough force to sufficienty secure the film or lid. Instead, permanent rare-earth magnets are used to cover the pinhole.

For film mounting, binder clips with 3d-printed levers will be used

3. The length of the camera was too long for the dimensions it needed to photograph. We removed 4" of cardboard, rearranging other components apropriatly.

4: Viewport was changed from pins to 3d printed viewfinder

Changelog from Engineering Notebook

After this, the camera was fully assembled and ready for the first photograph. Using the exposure time calculator I programmed, we inputted the information about our camera and took a photo with the exposure time it calculated. It was overexposed to the point of being unusable, and we decided to lower the exposure time by 30 seconds. After trying again with no success, we moved to a shadowy courtyard and tried there, using the original exposure time calculations, which led to the first good photos. During the first two unsuccessful photos, the camera was pointed into the sun, and I believe this was the cause of the overexposure. This realization led to no physical modification to the camera, but the rest of the photos were taken correctly afterward. I photographed a range of different contrasts and distances, and we were satisfied with the camera, deeming it complete.

The completed camera differed in only the ways mentioned above from the technical sketch; it ended up within all the restrictions after it had to be cut down to size, and the rest of the changes fully fixed their problems. The levered binder clips to hold the film ended up being successful, as we were able to operate it easily wearing oven mitts, and the handles made it very easy to transport while being very durable.

Photo from the camera of two meter sticks placed 10’ apart, simulating the 10’ mural.

Section 5: Documentation and Communicating Results

Providing documentation for the camera was important to simulate the real-world publishing of results. While this particular project is just a school project, in the real world, a project that isn’t properly communicated to others will never be able to be produced. It also cannot be revised or commented on by outside eyes. This would make it much less useful and usable. I believe that learning how to communicate ideas and creations in this manner is essential to my engineering education.

In building instructions to reproduce the camera, the end product differed only slightly from those of the original technical sketch, but in a few key ways, with those being the recalculated focal distance, felt-lined film mount, and newer viewfinders. Since our design was, in my opinion, fairly simple, instructions were easy to write.

Certain sections of the documentation were especially critical, as they were places that were easy to mess up or required extra precision. These sections included the pinhole itself, the viewfinders, and the film mounting. While I think these areas were the most important to have clear documentation for, we strove to have the entire documentation be easy to understand and straightforward.

Section 6: Lessons Learned and Moving Forward

This project has been a wonderful learning experience and quite fun. While it is true that we had some initial poor planning and some later setbacks, I believe that we were able to think on our feet and solve them. We produced a unique camera and I've certainly realized a few things about engineering, and it was satisfying to see a completed project work well.

Working in a group for this was certainly an interesting time. We distributed the workload by having teammates take charge of different aspects of construction that suited them best, such as one person 3D printing the handles, one person constructing the cardboard frame, and myself constructing the metal and magnetic parts. While everyone contributed to the idea generation phase the same way, different perspectives and styles became blended in the construction/building phase. You can see this in the variety of materials used, and while it led to a mildly inconsistent appearance, each person contributed good quality work, and we were able to connect all the sections well. However, to do it again, I would ahead of time agree on a common design language. If not purely for aesthetics, on a more complex design, consistency across the product would allow components to be more easily designed to work together.

As mentioned before, a glaring problem appeared in the middle of the project, that being the incorrect focal distance talked about in section 4. We were able to adapt and fix the problem, and our original design had left plenty of space in case of mistakes, making it all the easier. That being said, it is much better to not have the problem in the first place, and for future projects, I intend to put much more time into the first blueprints before their construction, and be more rigorous in proofreading the initial plan.

I intend to improve for my next project, and I feel that this one has uncovered weaknesses that I ought to cover. I'll think thoroughly through the design before building and work with a harmonious design language next time.