Spring | '14

Portfolio of Projects

Thomas Needham

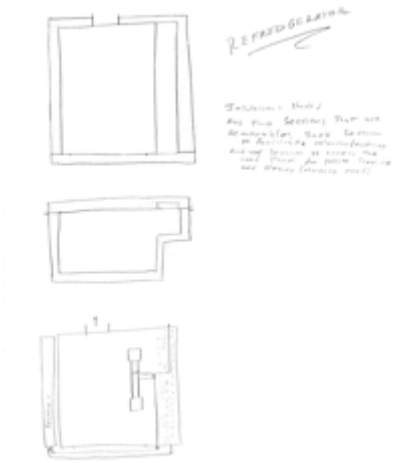
A partial representation of past projects from approximately 2010 through March of 2013.

More recent (including current) projects descriptions and designs are readily available on request, as the originals are the only copy currently.

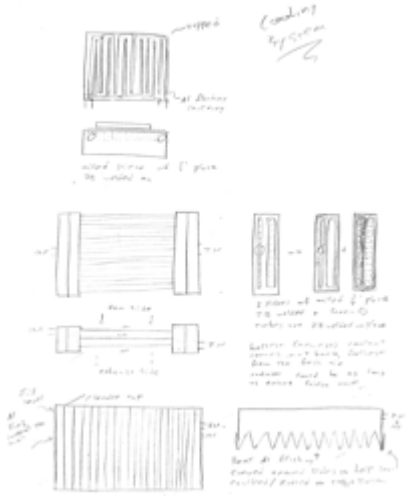
This first project is certainly the one I am most proud of. In fact, I even wrote about it in my original essays. This project also actually had a name: “The Microvendor.” I discovered microcontrollers over this past summer (2012) and conveniently also made a friend very interested in programming, Andy. Along with Mitch, my more mechanically inclined friend, we spent about 5 months planning and three weeks constructing this hilarious device. Those five months of work are what come first: every design document I could scrounge up from the shop (some, inevitably, were soaked in machine oil, burned, or otherwise illegible).

But to clarify; this was meant as a capstone project, whose prupose was to challenge myself enough to require a team. This is rather unprecedented, but served valuable. The device was meant to store food items of the user’s choice (cookies, bread dough, bacon, eggs, muffins, pizzas, etc) in a custom refridgerator. A microcontroller running a maintaince script kept the refrigerator at a constant temperature, as measured by thermistors and altered by Peltier plates (chosen for size, not efficiency). When an ‘order’ would come in, ultimately from a smartphone app, the processor would terminate refridgeration, move a dispenser tower to the tray with the desired food item, and drop it onto a conveyor belt (there were nine slots, three columns with three items each). The conveyor belt, being monitored by laser and contact senors, would travel out of the fridge unit and into the oven – also computer controlled – to be baked. Much like the fridge, the oven had thermistors and an emergency thermal cutoff to prevent fires. The computer had a database of cooking times and temperatures for specific items, and cooked the items reliably based on those figures. After cooking was complete, an exhaust fan powered on to clear the oven of hot air and cool the item to 100°F, both intended to prevent burns. Only once the item was cool, the controller would bring the conveyor back out to the receiving area to be picked up at just the time it was scheduled to be ready. Because each item had its own Teflon tray, the conveyor was free to move back to the refridgerator to awate the next order. Auxiliary systems included a manual control on the front, a bell to alert users, an emergency stop switch, liquid cooling with radiators for the Peltiers, and safety (redundancy) systems such as integral thermal cutoffs.

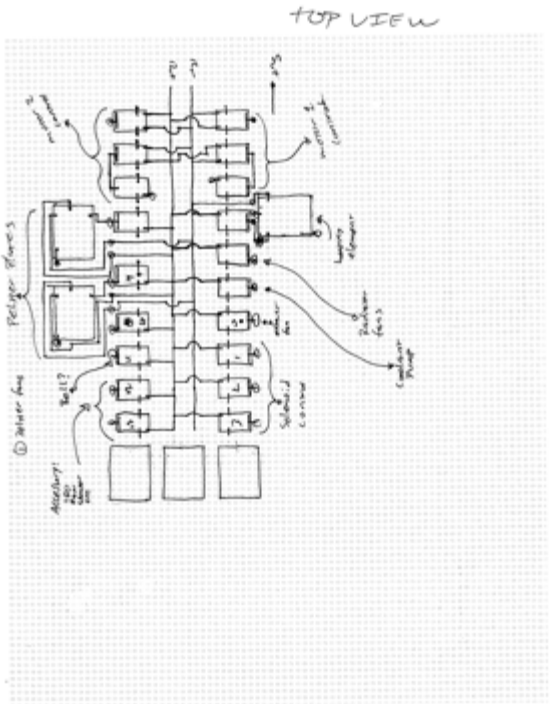
-The following are scans of a portion of the original construction schematics-



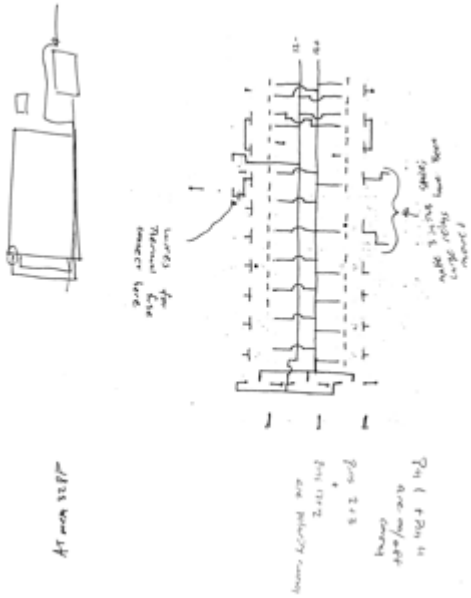
The first refrigerator layout schematic



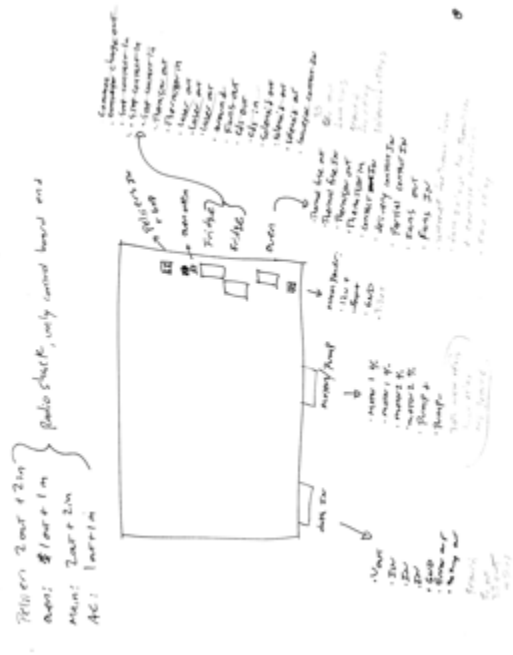
The initial design for the cooling radiator; replaced by a simpler design



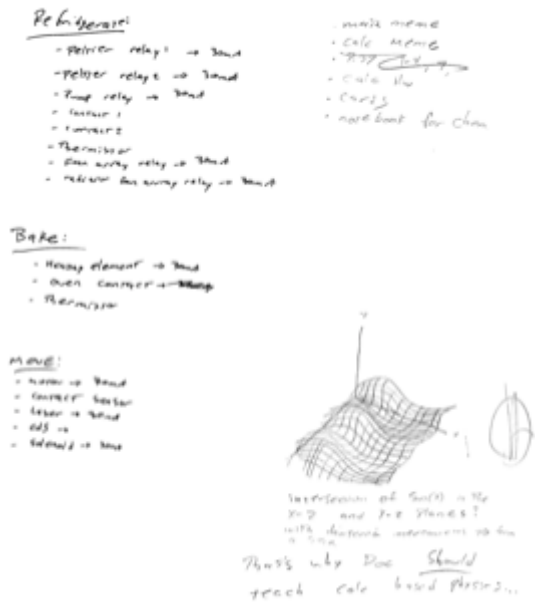
A very critical layout; the main switchboard, designed by hand prior to having PCB software



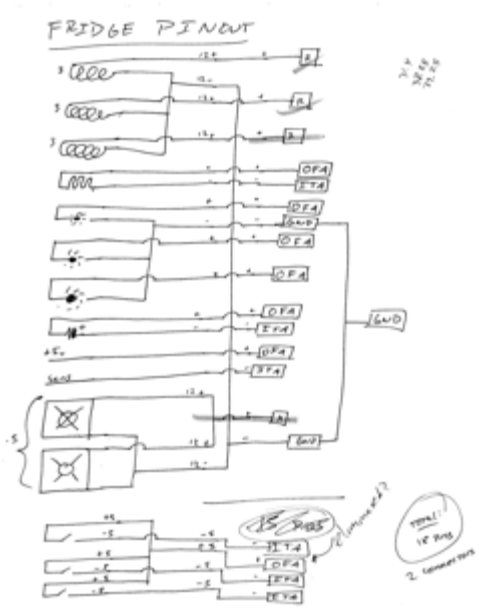
The reverse side of the previous circuit board, again done by hand, but flawless



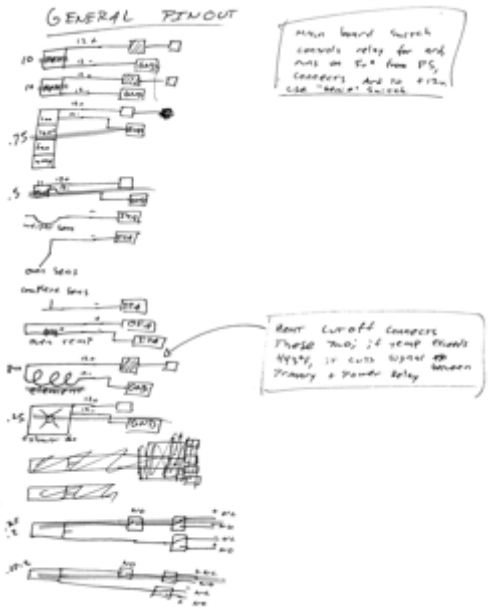
A primitive reference for pinouts of the connectors from the main computer board



A basic layout to insure no operation will overdraw the microcontroller

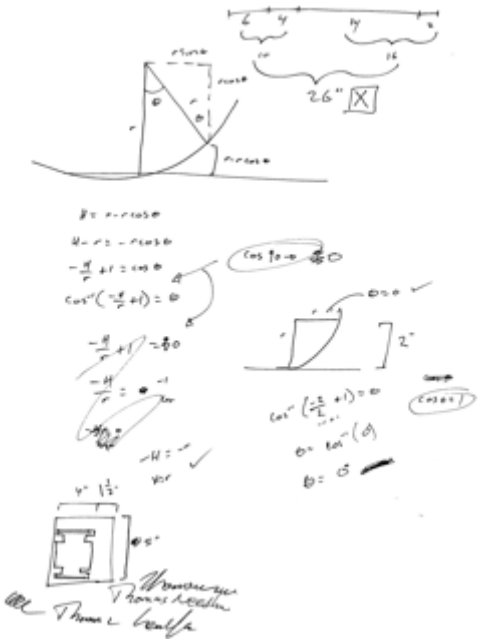


The registry of systems with I/O connections from the refrigerator

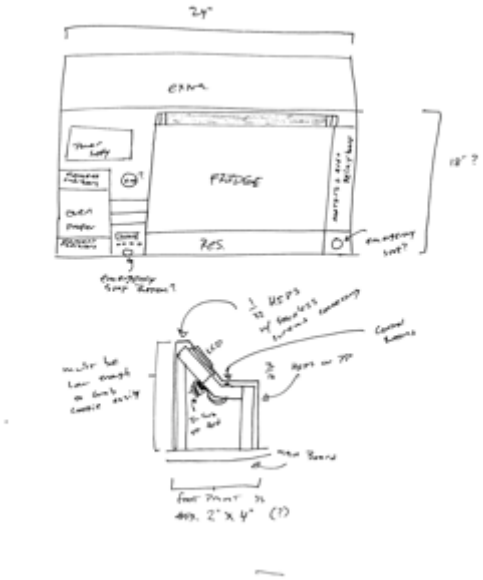


A general registry with most other I/O connections to the main controller board

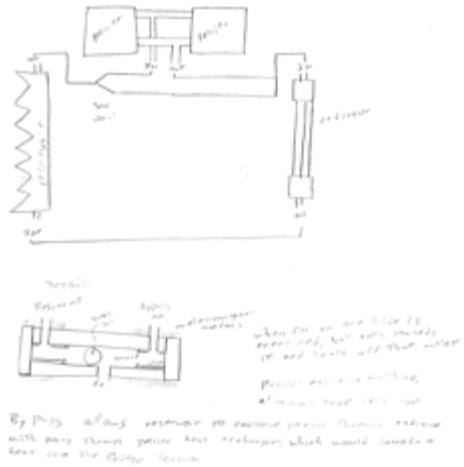
Another list of pins needed, listed for every system, including proposed multiplexing to save pins



A custom-derived formula to determine the swing height of the refrigerator door



A bird's-eye layout of the entire device; a side view of the manual control panel

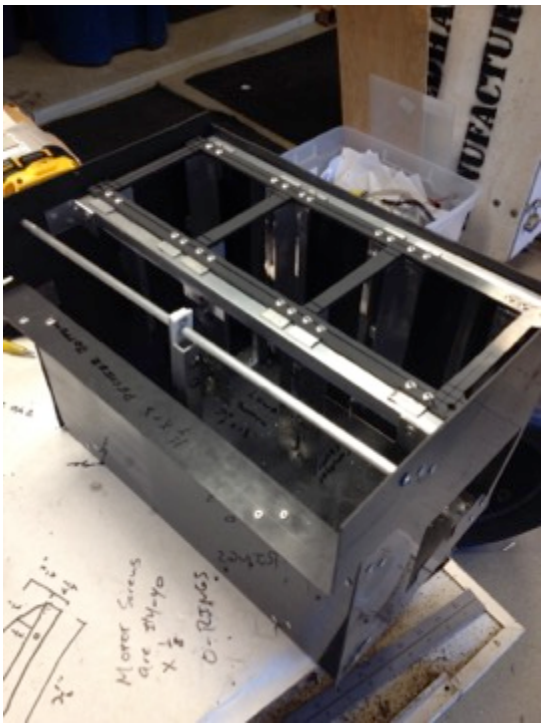


An early layout for the plumbing to cool the Peltier plates

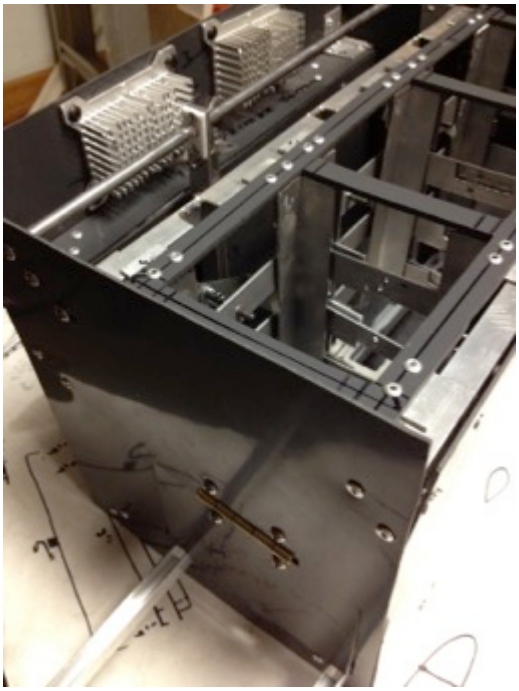
-The following images are chronological photos of construction-

The general state of construction in “The Shop”

The homemade mill most parts were hand-machined on

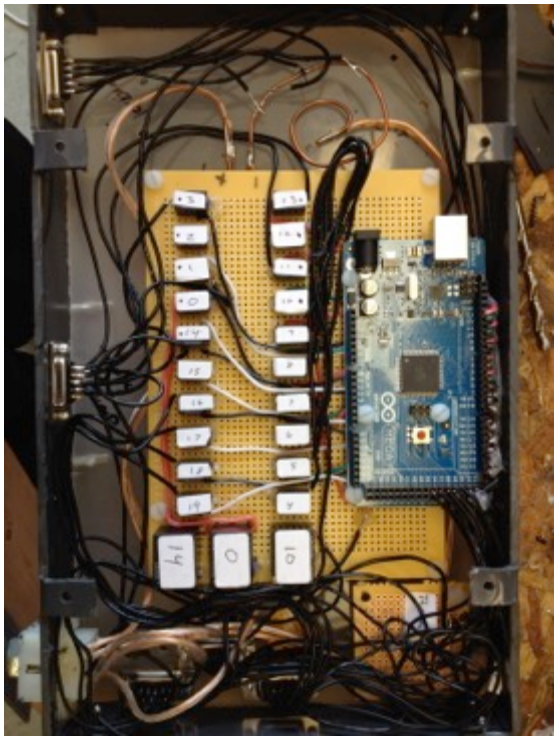


The refrigerator body and tray assembly beginning to take shape, going through fitting adjustments

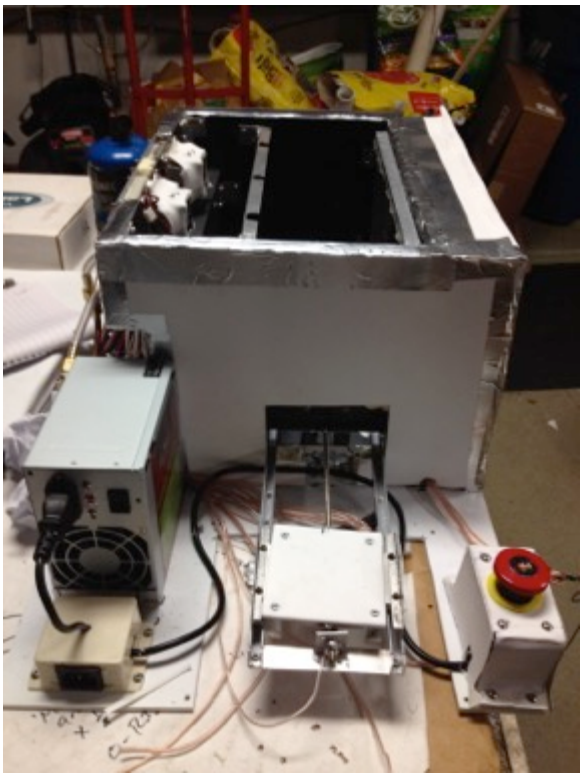


Final fitting of entry door, tray assembly, fridge walls, and trial mounting of Peltier heat sinks

Foam insulation application on refrigerator, pre-trimming

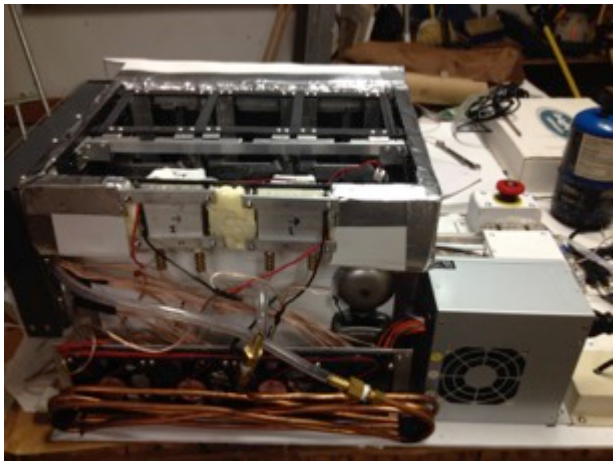


Early stage of main controller board, appx. 75% wired



Trial fitting of fridge, power supply, conveyor, and E-switch.

Reverse view showing finished, environmentally sealed controller and cooling reservoir for Peliters (left)



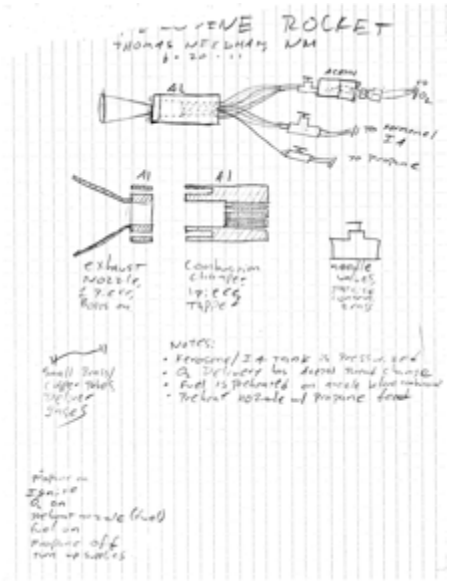
A rear view showing the power supply, cooling radiators, tray assembly, and alert bell

A top view of the oven, power supply, conveyor, manual control panel, and E-switch

A finished view of The Microvendor
- sans lid and tray assembly –
after first cookie-bake test

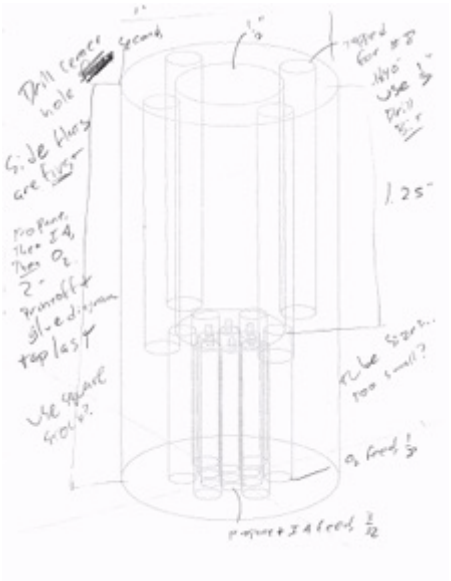
Following the Microvendor, my exploits into rocketry are my favorite projects. They come second because all too often they didn't work, or ran out of funding before they could even be started. Despite this, the massive thought required to plan it, the precision machining I would have had to do, and the incredible numbers associated with the different associations were intoxicating. So much research had to be done to design the combustion chamber that my grades noticeably dropped a few percentage points. The control systems, too, pushed me to new places; this was the first project that necessitated a microcontroller. It was the experience gained in this project's research that led me to have confidence in the Microvendor. The point of the projects (all told there were three) was, of course, to get sustained combustion in a custom chamber. Only on the third step did I have intentions of a test flight, but conveniently enough that is the one out of the price range. The first two, however, were brought into existence and did indeed sustain combustion, with truly ridiculous jets of flaming kerosene shooting all over my suburban yard.

-The following images show, chronologically, the designs and then photos of each version.-

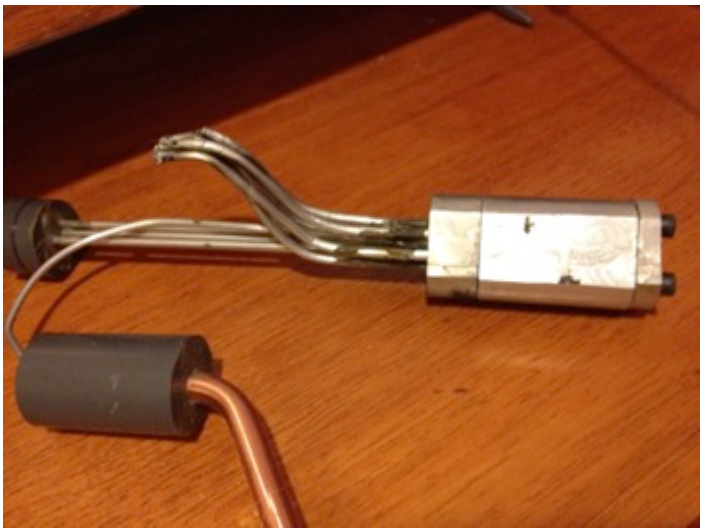


A midnight-compiled design for the first attempt for an engine, drafted in June of 2011

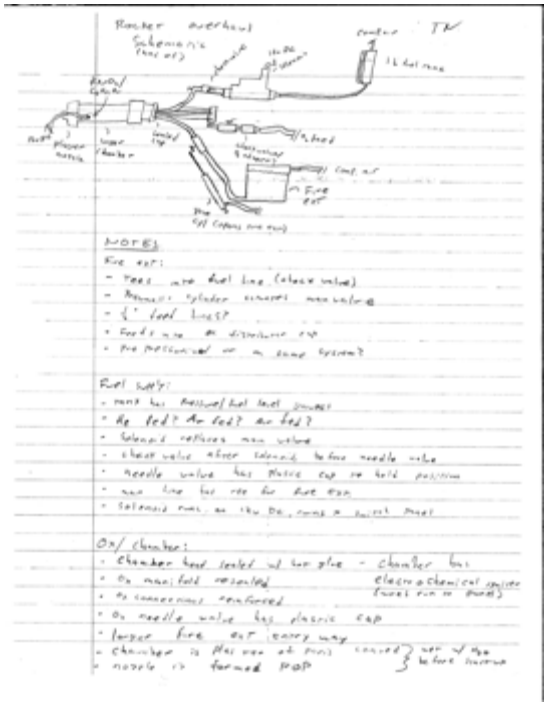
The CAD printout for the exhaust nozzle; wireframe



The wireframe printout of the chamber, with notes on drill sizes

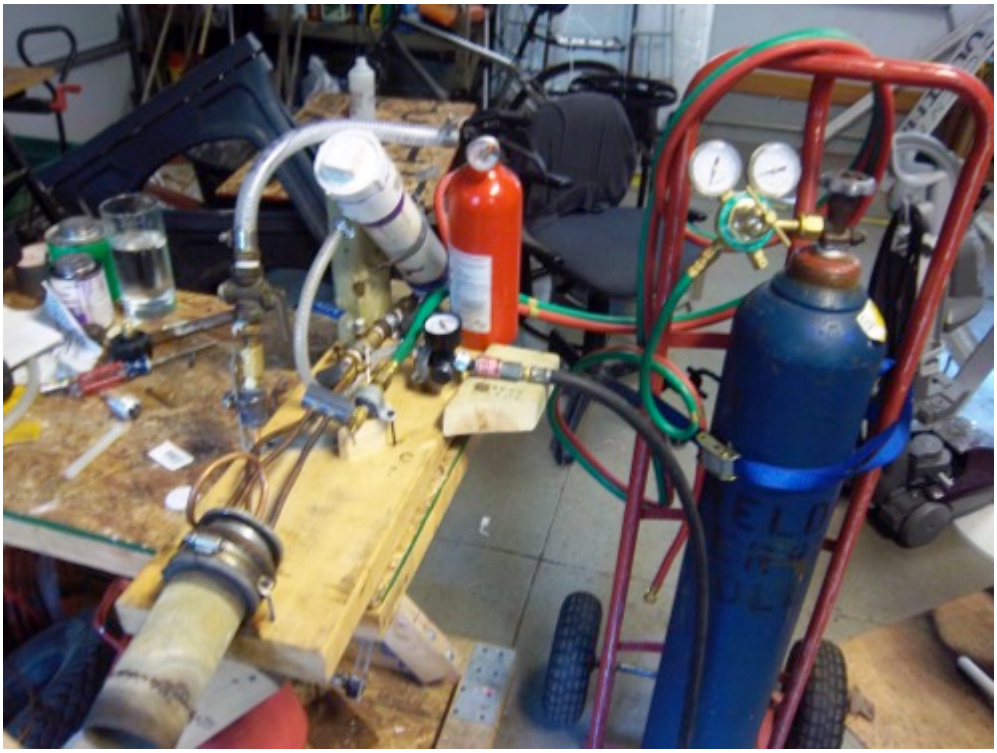


The working test assembly, shown without support/feed equipment. This version ran on isopropanol, gaseous oxygen and propane and worked quite well. The main goal was sustained combustion though, not thrust.

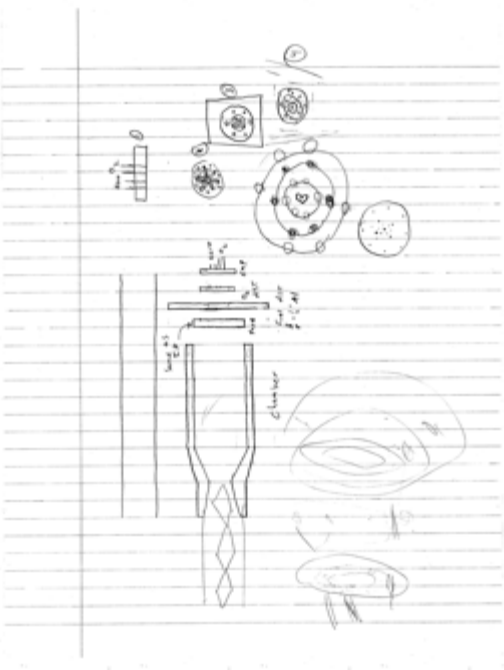


The original spec sheet for version two, complete with basic plumbing diagram

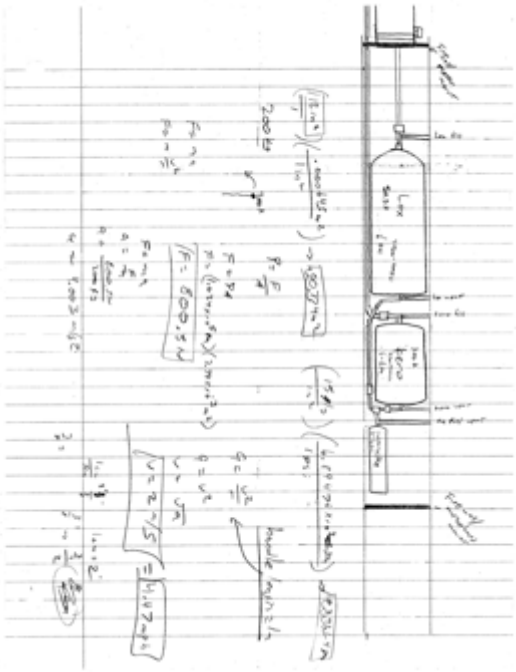
Detail of the injector unit; custom machined steel plate and Teflon seals to deliver kerosene and oxygen



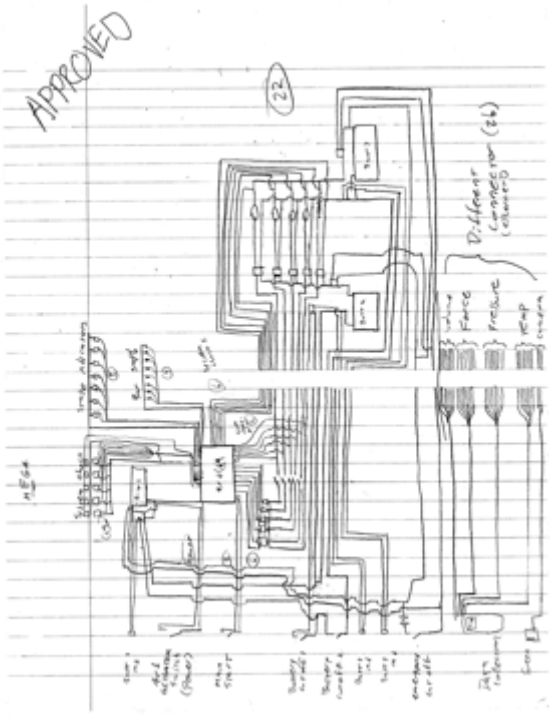
The test setup, complete with full support and feed systems and added extinguisher system. This was a very rough, industrial setup. Completed in early September, 2011



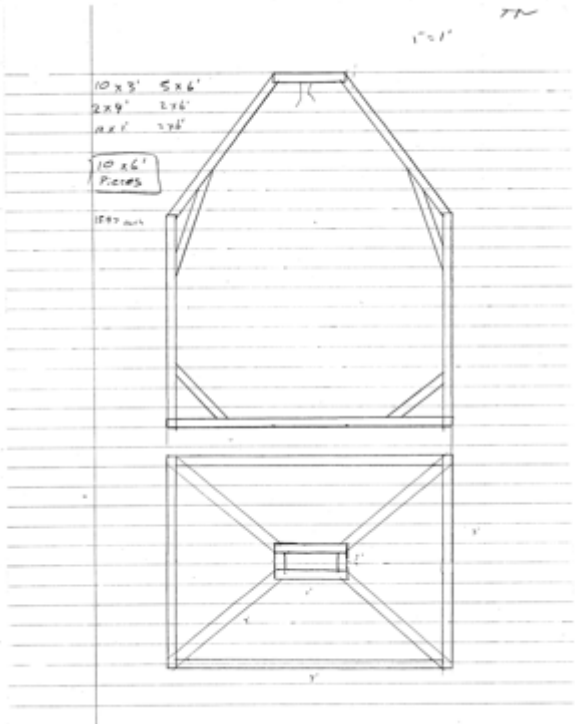
A breakdown of components for the main combustion chamber



A basic layout of all systems needed for the flight-ready vehicle



Complete wiring diagram for flight computer to test stand, complete with “approved” stamp from a friend...

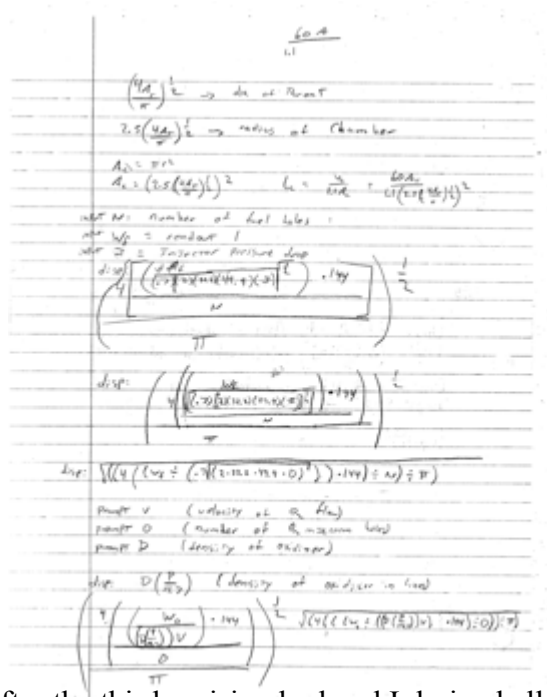


A top view and elevation of a test stand to verify the engine before flight

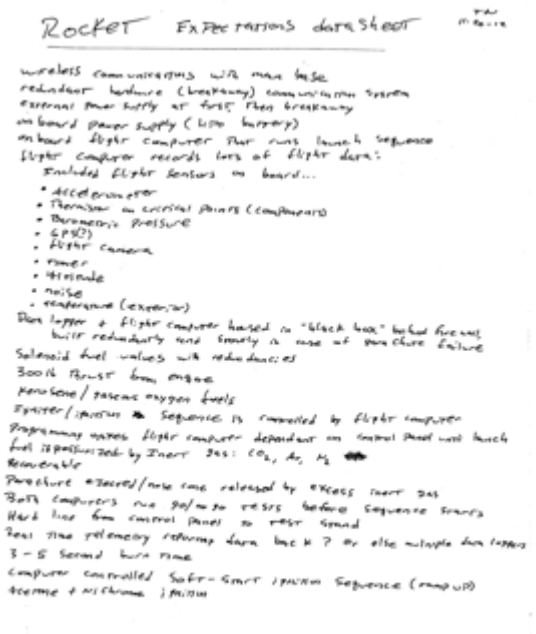
A sample page of the manual calculations for all rocket parameters

Page two of the third revision of calculations

Page three of the third revision



After the third revision by hand I derived all the formulas into simplified versions and programmed them into a TI-84 for faster calculation runs



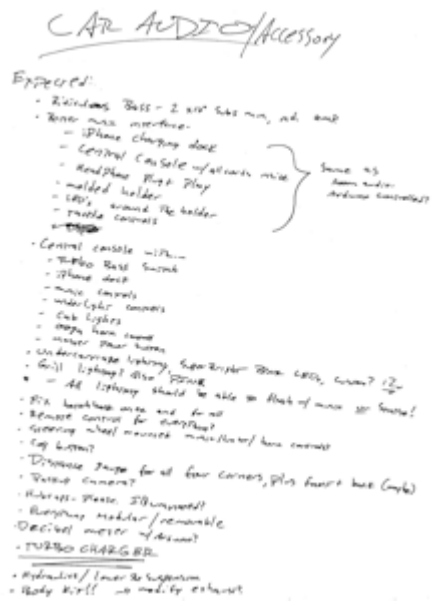
After the mechanical details were worked out with the engine, this "expectations datasheet" was drafted for the flight vehicle (a list of desired capabilities)

One of the registries of systems and components within those systems

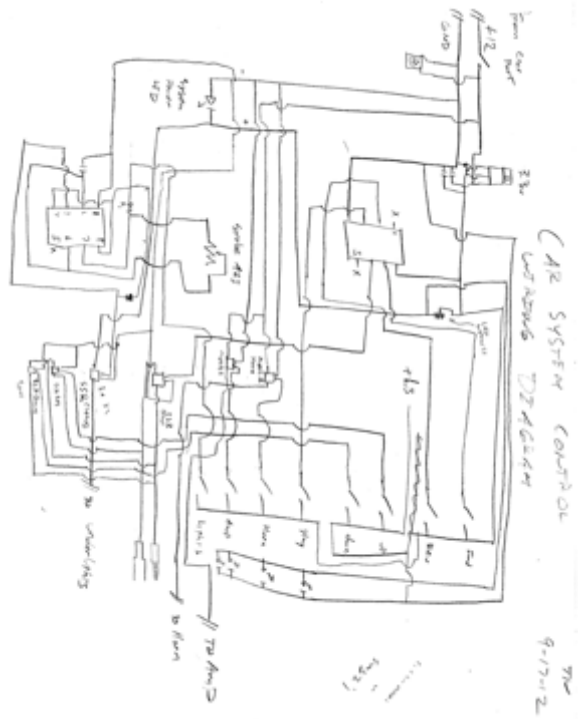
One of two component lists; every part needed for the flight vehicle.

The second component list, which together spelled out the $3000 price tag

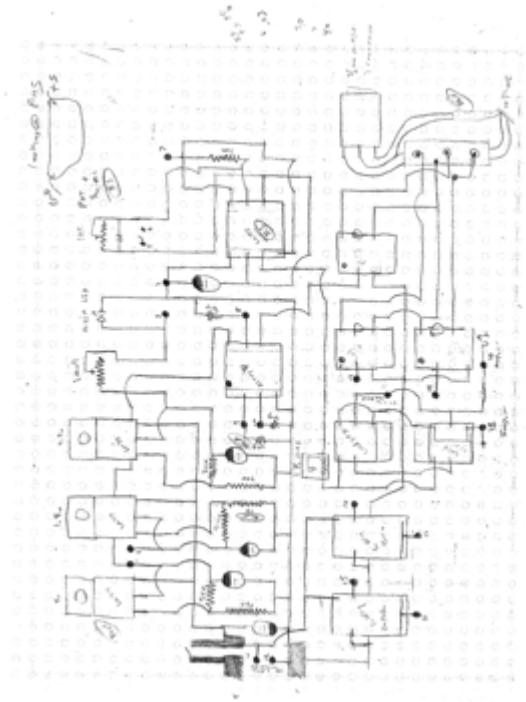
Up next in the hierarchy is one of my least practical, safe, or conventional projects. Naturally, it's the most fun. I inherited a 2005 Volkswagen Beetle, cherry red, stick shift, with flower taillights from my sister and, previously, mother. I thought I wanted our big, hulking, green F-150. Soon though, the stick shift had me hooked and I decided to stop arguing for the truck and devote my engineering efforts to "upgrading" The Bug. Ultimately this led to enhancements such as paddle shifters (to control the audio system), two 12", 1000W subwoofers, RGB LED underlights with strobe, and fresh flowers for the dashboard. The paddle shifters were machined and hewn by hand from aluminum plate, again before I had appropriate machine tools, and had two degrees of freedom each. There is a symmetric setup on the wheel for aesthetics, with each side controlling music volume and song. There were also buttons mounted below the paddles to control the lights, subwoofers, auxiliary "ooga" horn, and Siri. All these signals ran through a flexible cable from the wheel to an integrated control box housing a microcontroller assembly programmed to interpret the signals and control an iPhone through their headphone interface. A microphone was also installed to allow hands-free calling, song selection, and even texting through Siri. This project was finished, much to my dismay, a few days *after* voting took place for senior polls, of which "Best Car" was a category. It still works perfectly – and to great effect – now, and none of it has gotten me ticketed... Yet.



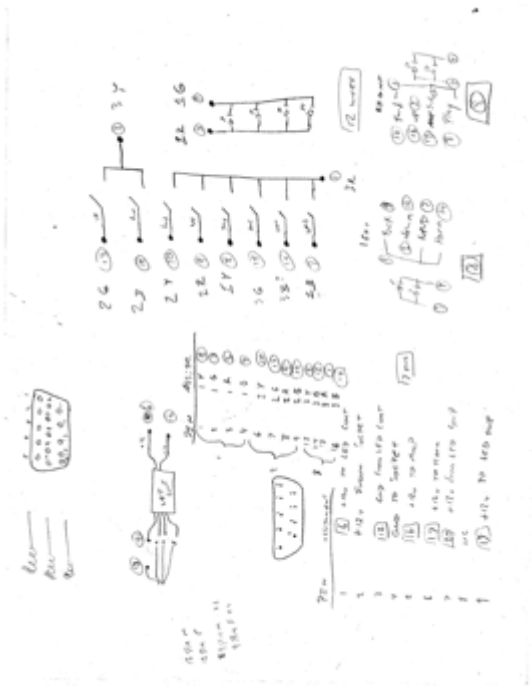
As usual, the project started out with an expectations sheet made late at night



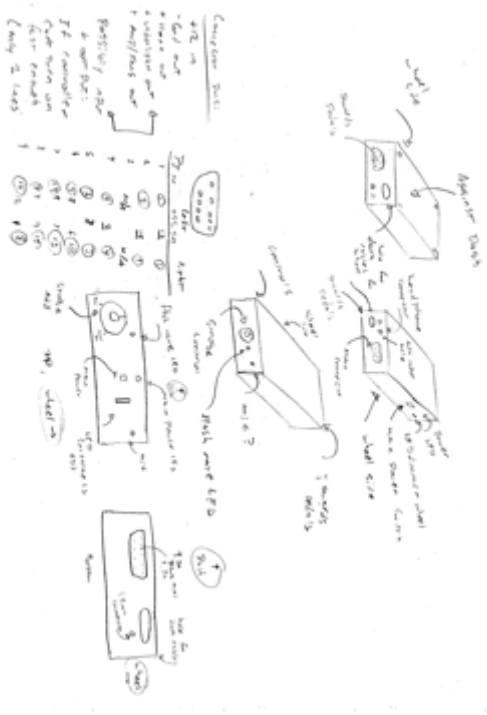
Next a basic circuit schematic was made to fulfill all (reasonable) expectations



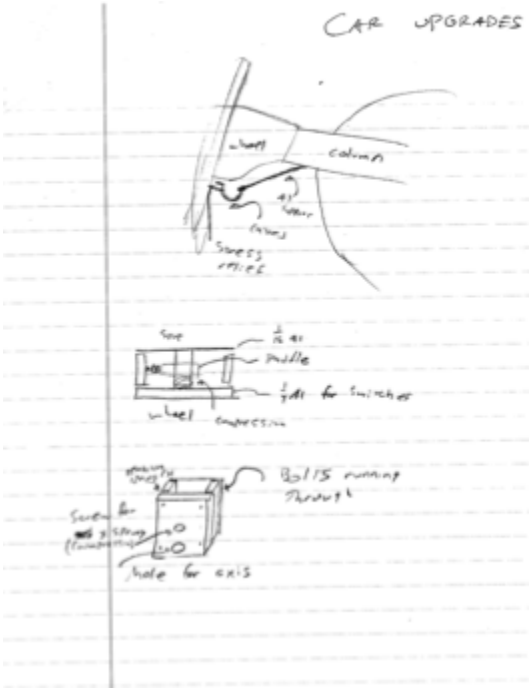
The schematic was then refined into a board, again prior to having professional CAD software



Pins on connectors out of the control box were then assigned and defined for reference



An enclosure was designed, but scrapped when extra space in the dashboard was found



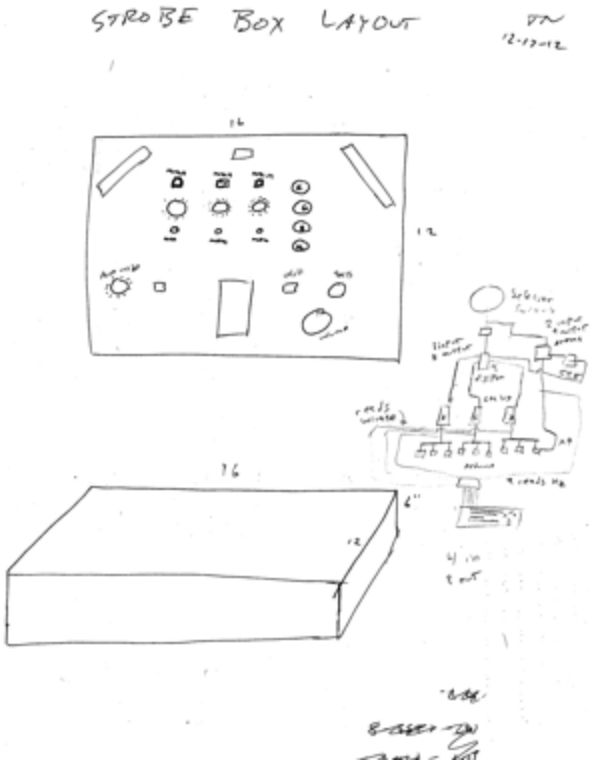
A sample of some of the mechanical documents; planning the two-way tactile paddle action

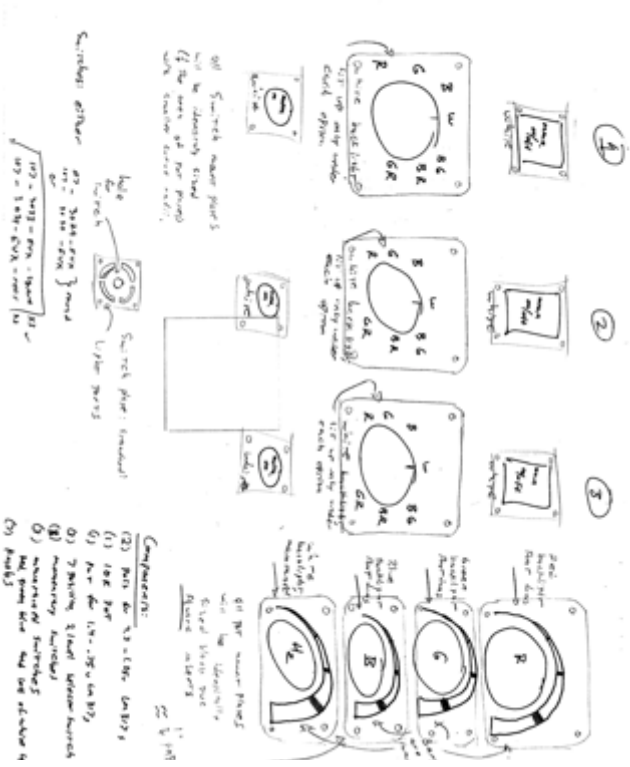
The result of all that planning
(blue illumination shows the augmentations)

Here the sandblasted aluminum paddles and
switches can be seen more clearly

Following in step with the out-there, ridiculous, seemingly useless projects is my current one. Modeled greatly after the car augmentations, it is a self-contained light show and music system combined. Unfortunately I have yet to give it a catchy name on

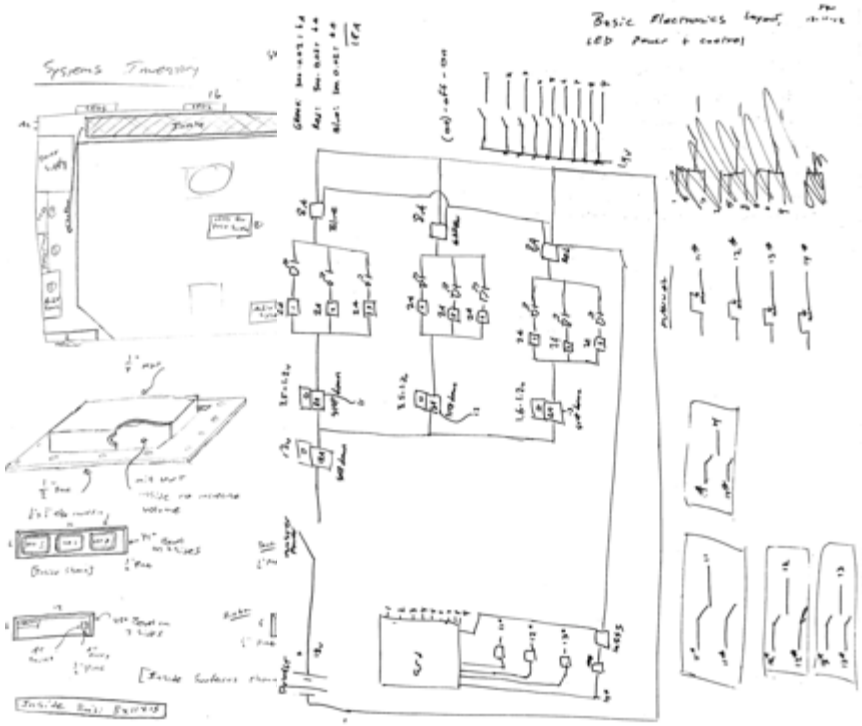
par with ‘Microvendor’, and have merely been referring to it as “the box” among peers (the whole system will be smaller than a briefcase). Compared to my car’s one, 8-pin microcontroller, however, this about two dozen. Of those, only about half are comparable to those in the Bug; the rest are 14- or 28- models, and there is even a removable, reprogrammable 100-pin package to control the lights in time with whatever song may be playing. These controllers run thermal management systems to control heat produced in converting and switching 120v AC to 3.4v DC. In addition they handle the inputs from manual controls, store preset modes, and serve as intermediates and redundancies. The former change potentiometer values to PWM signals, control digital potentiometers over serial communication, and switch LEDs around the arc of a potentiometer to designate the level of that knob. The latter are included to prevent thermal and voltage runaway, primarily to protect the 300 RGB LEDs on the front, and the microcontroller ICs within. As it is not yet finished the subsequent pictures are mainly schematics, but recently I learned how to use the Eagle suite (electronic CAD software) to better organize the many circuits constituting ‘the box.’





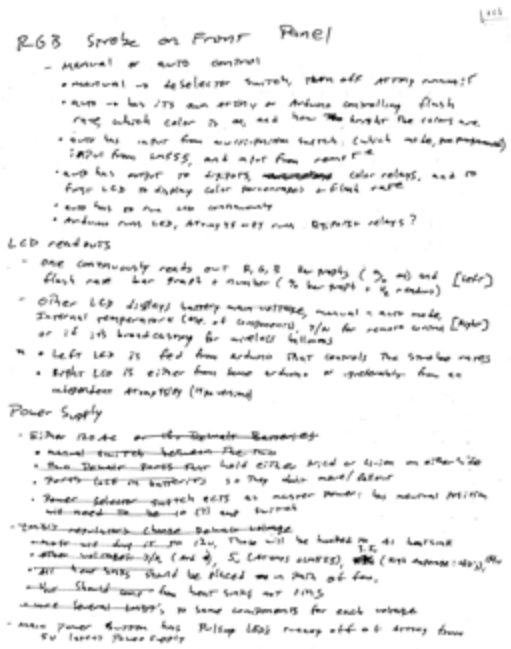
The first concept drawing of what the box would look like and the interface

A sign of what the components of the manual inputs were, intensity, strobe rate, etc.

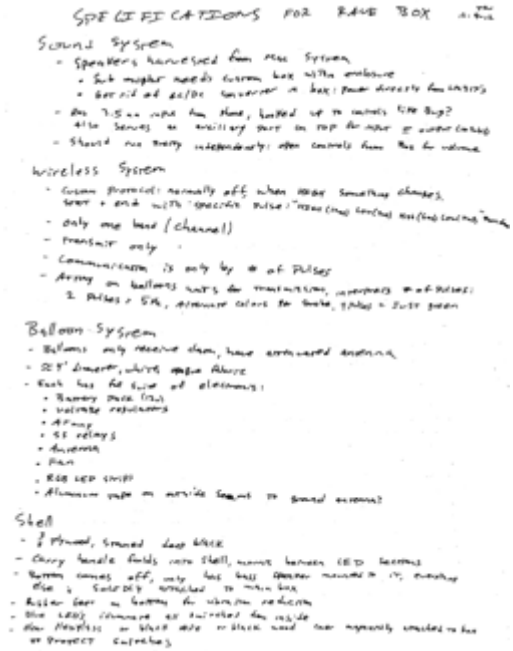


A better layout of all six sides of the box and a trimetric view, ready for CAD/CAM

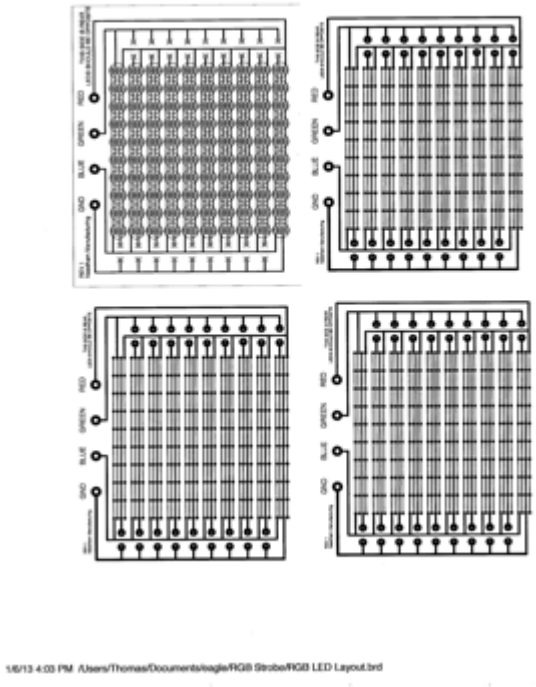
A block diagram layout of the *initial* circuitry; it has since become much more complicated



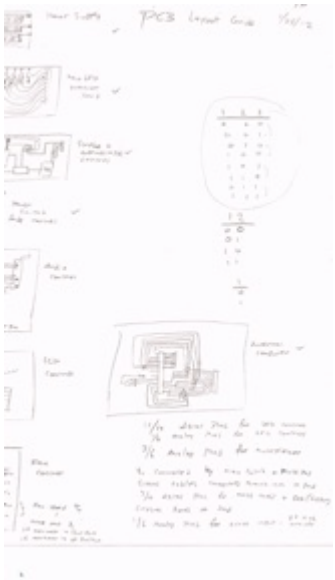
Page one of the expectations sheet, including control assignments per system



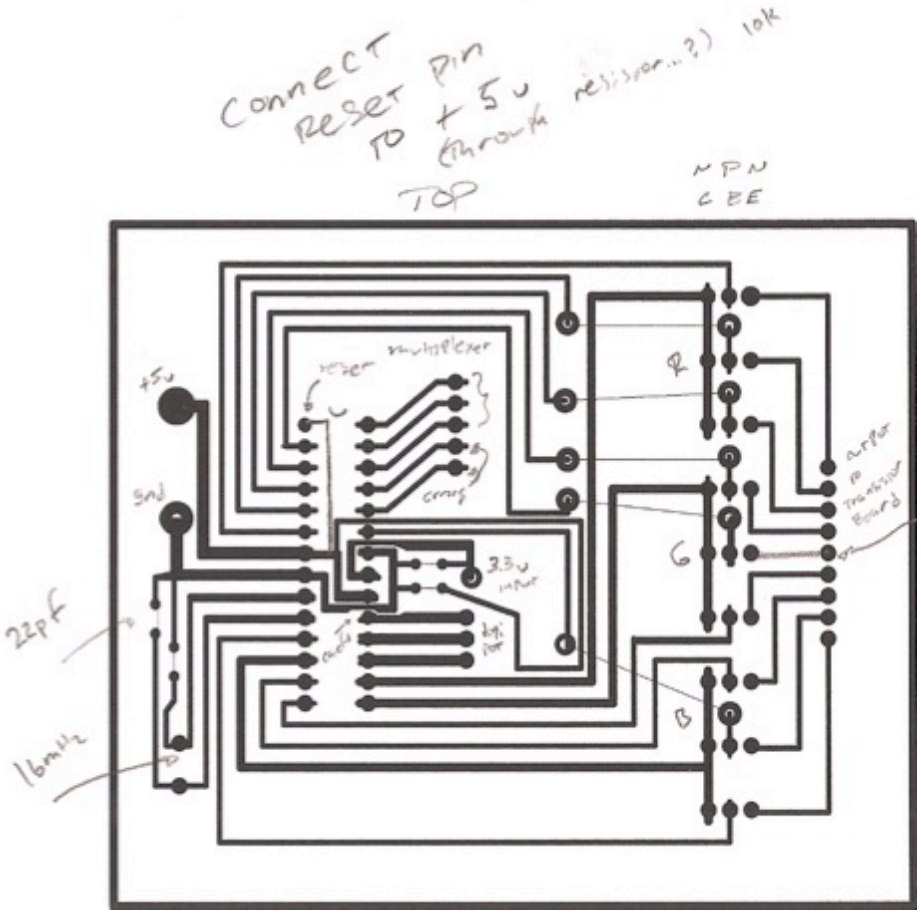
Page two of the expectations sheet, including the original plans to have illuminated balloons radio controlled by the box



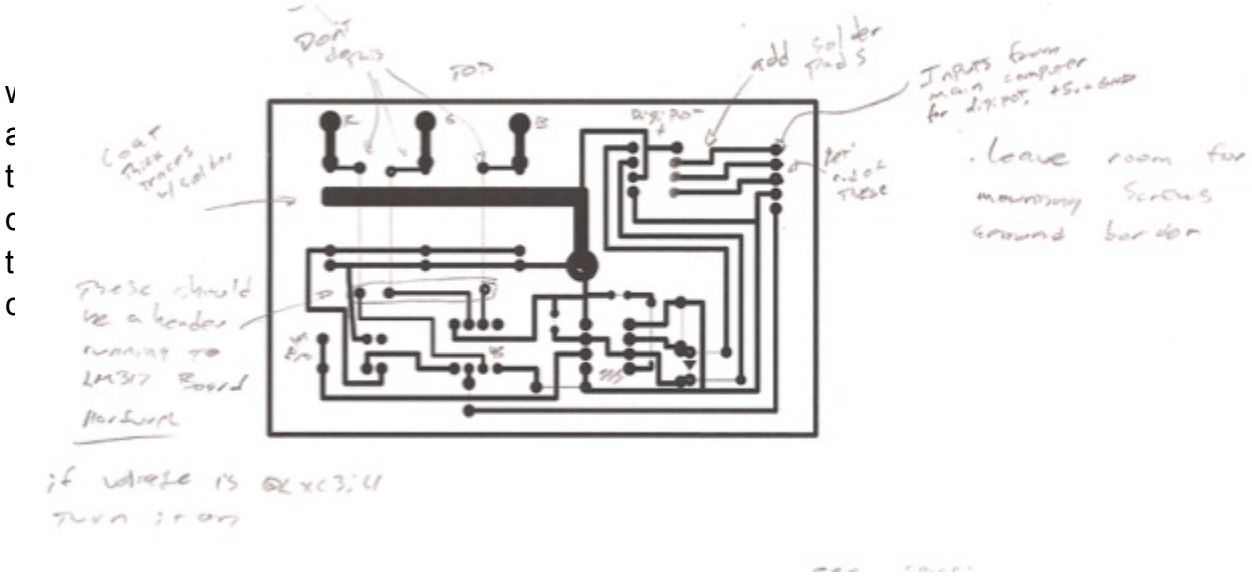
The CAD printout of the main LED boards, ready to be custom-printed on PCBs



Penciled in schematics ready to be converted to CAD PCB traces

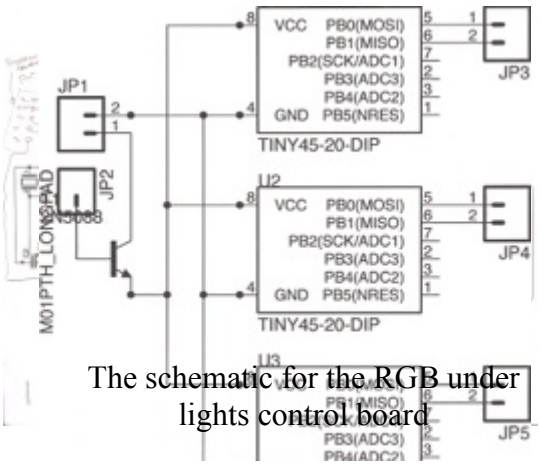


The main internal microcontroller (in charge of randomized sequences, shutting down systems in case of overload, etc.) with a portion of notes made in R2 of the board

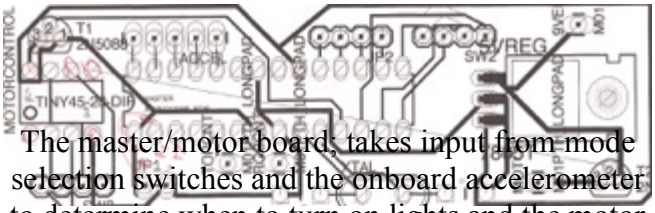


R1 of the transistor board, which switches all power to the LED arrays (~6A each). After revisions were made this board, as with all others, were printed on 1oz copper boards through photographic development

Knightrider or strobe randomly, and a RC helicopter motor, running on three times the recommended voltage. Although not as complicated as the previous light show, it still packs seven independent microcontrollers into a 4 in^3 space. As per usual, all designs were custom, all soldering done by hand, and all PCBs were homemade from CAD designs. Similarly to the last project, this is also only midway done (just today all the electronic components came in- always exciting!). Most possible images then are schematics and board views, but are far more professional than the previous hand-made designs.

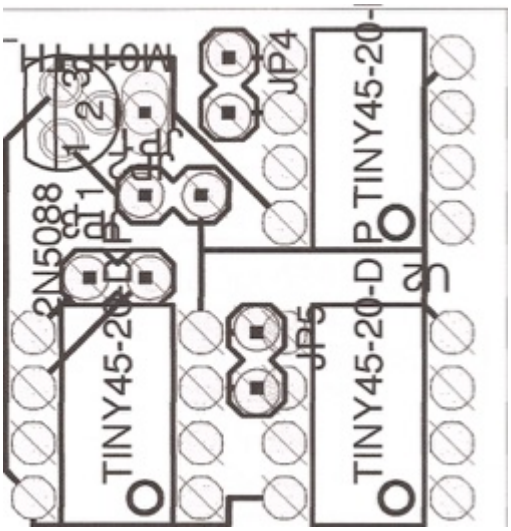


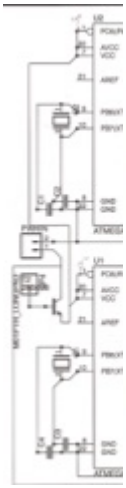
The schematic for the RGB under lights control board

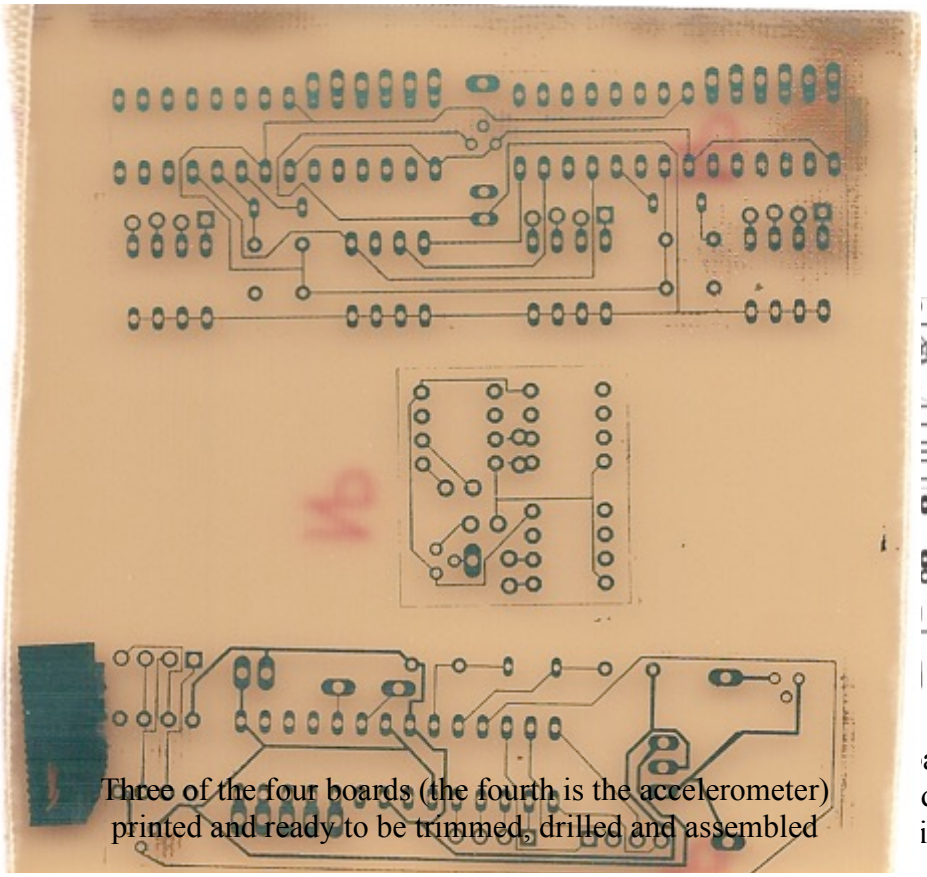


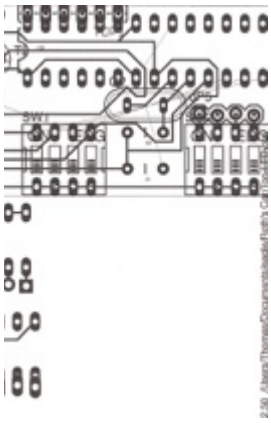
The board layout of the RGB unit; far simpler than the master unit

The master/motor board, takes input from mode selection switches and the onboard accelerometer to determine when to turn on lights and the motor







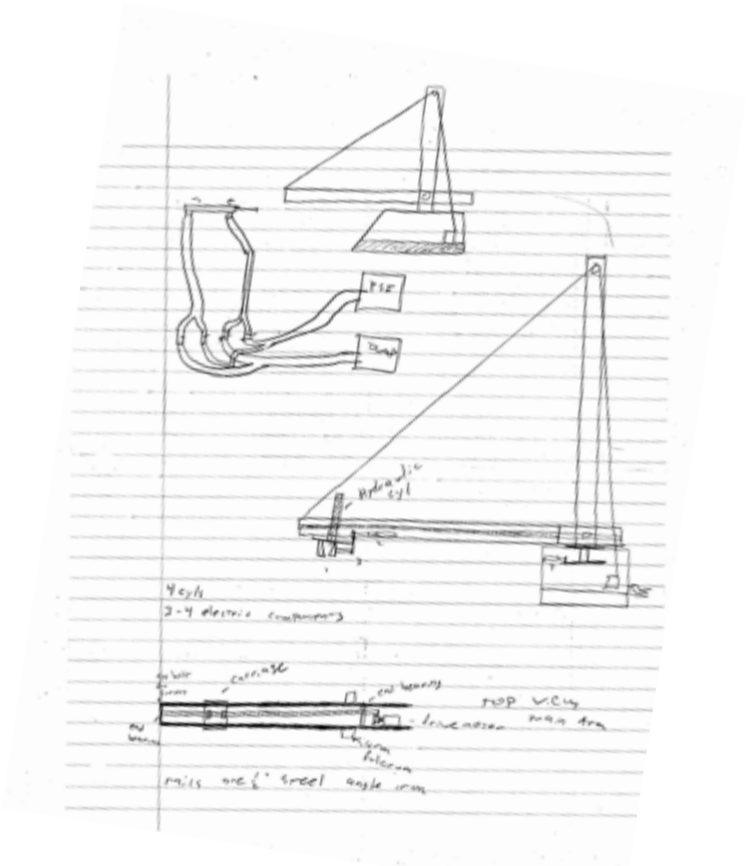


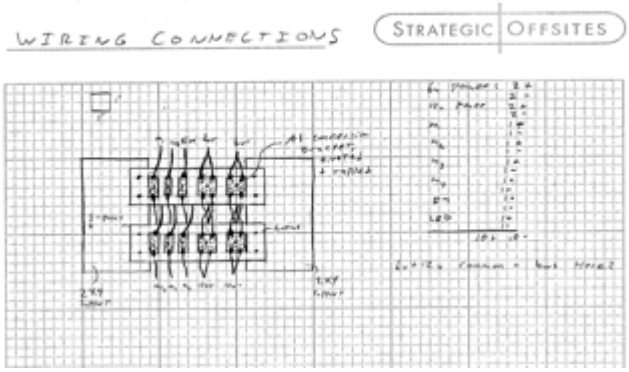
The top LI ... ard; one with
DIP switch ... d one exclusively
of operatic ... ing

Three of the four boards (the fourth is the accelerometer) printed and ready to be trimmed, drilled and assembled

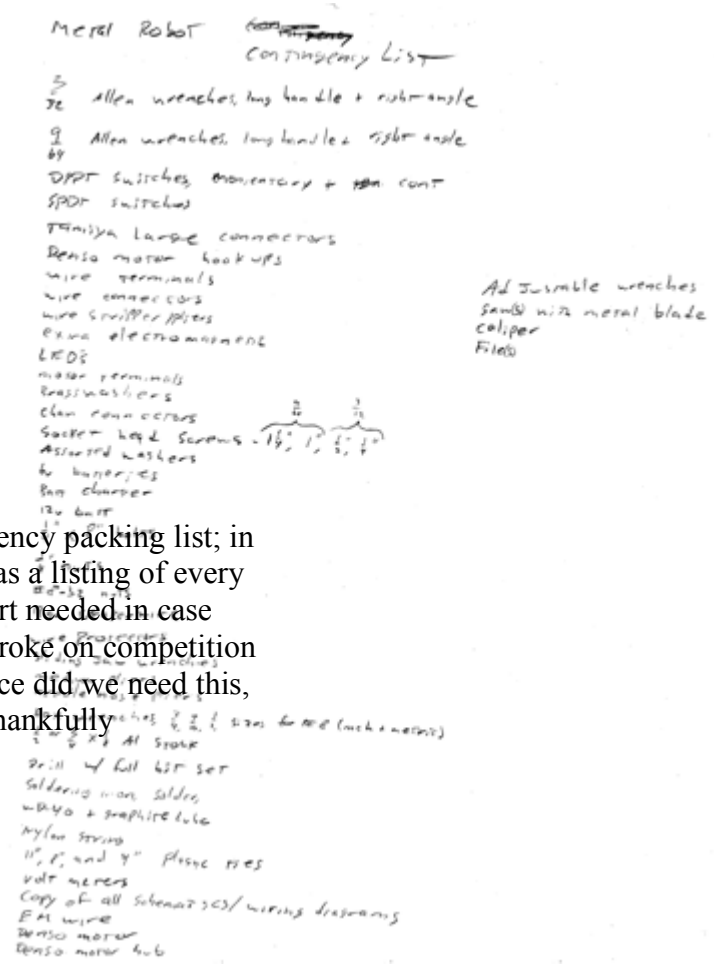
This is rather the end of the big budget, just-for-fun projects that I enjoy so much. The next project to be described, while just as fun and over the top as the others, *had* to be made for my school's Science Olympiad team. Somehow they realized I enjoy technical challenges and mechanisms... Regardless, the robotic arm that resulted will live in infamy in school history for many seasons to come; there was a rule made post-season to prevent the team using it again. Where others had modified kits of plastic, this was a three-foot towering metal beast. It ran off of power window motors from the local FIRST robotics team, which were powered by, naturally, a car battery. The control panel ended up being a podium capable of wheeling around all 100 pounds of the contraption, and was wired with heavy gauge stranded copper off of bus bars to prevent any electrical fires- I don't think many others had to worry about that. Admittedly it was not

the best design for the task at hand (delicate manipulation) but certainly had the power to still place quite well at competitions. It is now retired in storage, awaiting its inevitable scrapping for parts as so often happens to latent projects. Those are good motors, and would serve well in automatic door openers, curtain closers, and all sorts of things. Of special note: where the last two projects introduced me to electronic CAD, this was the first to put me in touch with me electronics supplier, Mouser. Since then my datasheet-reading proficiency has increased exponentially. The robot was used last season, and so was completed just after Christmas of 2011.





The wiring connections between the control panel and umbilical cable; made removable to protect control during bus rides



The contingency packing list; in reality is was a listing of every single part needed in case something broke on competition day. Not once did we need this, thankfully

-The competition rules mandated we have paperwork for the robot, below is a sampling-

Sylvania Northview Team _____ Operating Description

Device Reactions to Input;

- 6v main switch: 6v +/- buses are energized
- 12v main switch: 12v +/- buses are energized
- M1 primary switch: arm actuates up/down, correlating with action of switch
- M1 voltage control: M1 switches either 6v or 12v, depending on contact of switch
- M2 switch: the base of the arm will rotate left/right, correlating with action of switch
- M3 primary switch: the shuttle will move in/out, correlating with action of switch
- M3 voltage control: M3 switches either 6v or 12v, depending on contact of switch
- M4 switch: the end effector opens/closes, correlating with action of switch
- EM switch: the electromagnet is/isn't energized, correlating with action of switch

Tentative Plan of Movement

1. Energize both buses
2. Switch M1 volt control to 12v
3. Actuate M1 down to horizontal position
4. Switch M1 volt control to 6v
5. Rotate base over west-most battery on north side of Arm Square (M2)
6. Lower arm (M1) to height that EM touches target battery
7. Energize EM
8. Raise arm (M1) to lift battery above nails/other batteries
9. Rotate arm back to due north position (M2)
10. Extend arm (M3, with M3 volt control on 6v) to position EM over north goal box
11. De-energize EM
12. Retract arm to starting position,
13. Repeat processes {6-12} with remaining 3 batteries
14. After all batteries are deposited, repeat {6-12} with 5 ferromagnetic nails on north edge

If time allows;

15. Rotate base (M2) to east edge of Arm Square over the north-most PVC segment
16. Fully open end effector (EE) (M4)
17. Lower arm (M1) such that the lowest parts of the EE are on the competition surface
18. Close EE to grip PVC (M4)
19. Raise arm (M1)
20. Rotate base so that arm is in line with east goal box (M2)
21. Extend shuttle to point directly over goal box (M3)
22. Fully open EE (M4)
23. Retract shuttle (M3)
24. Rotate base to next PVC segment (M2)
25. Repeat {17-24} until all 5 segments are deposited OR time is called

The "Operating Description" telling how each part moved and how we planned to move it

Sylvania Northview Team _____ Robotic Arm Component List

Electrified Components;

Window motors (x3)
Ebay.com/ First Robotics
12v max voltage, 467.5g
6v/12v power supply from battery bank (depending on application)

Right angle gear motor
Ebay.com/ First Robotics
12v max voltage, _____g
12v power supply from battery bank

Electromagnet wire
Amazon.com
30 AWG, ~3 amp max current flow (@12v)
6v power supply from battery bank

Speaker wire
Menards
18AWG, stranded, double run
6/12v (depending on application)

Tamiya connectors (x5)
Amazon.com
Large type, male on robot, red/black polarity
6/12v (depending on application)

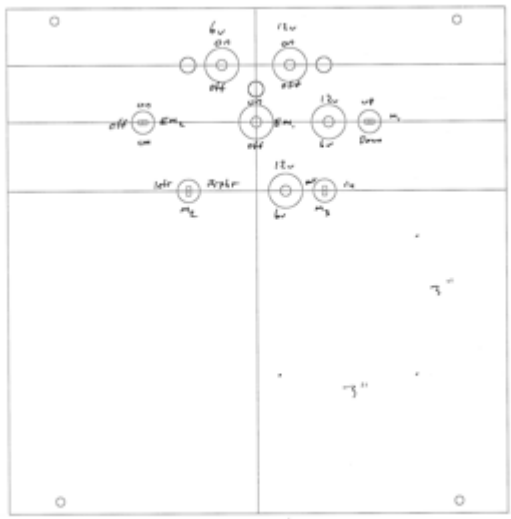
Mechanical (non-electrified) Components;

Right angle linear motion screw drive
Ebay.com/ First Robotics
2.25" screw length, 1:1 gear reduction
Energized by right angle gear motor

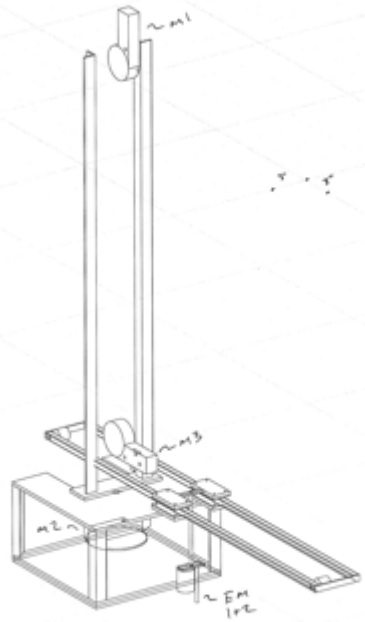
Spline-Woodruff key adapter (x3)
Ebay.com/First Robotics
6 point spline, 5/8" shaft diameter, 44g
Energized by window motors

Bike gears (x2)
The Bike Route (donation)
appx. 3:1 reduction, _____/_____ teeth

Page one (of three) of the parts list, which also required submitting details of every part



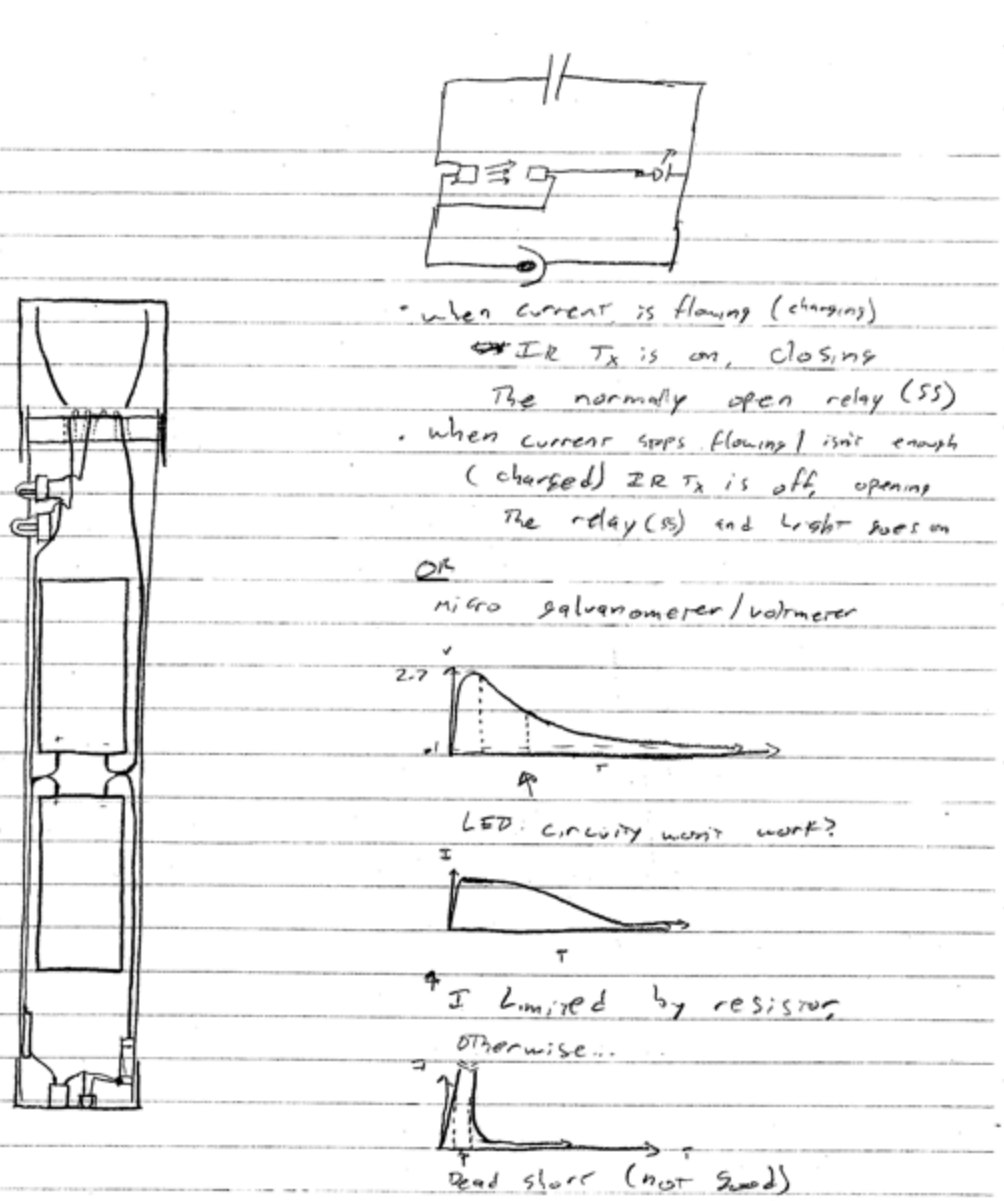
The CAD file required as technical drawings of the control panel



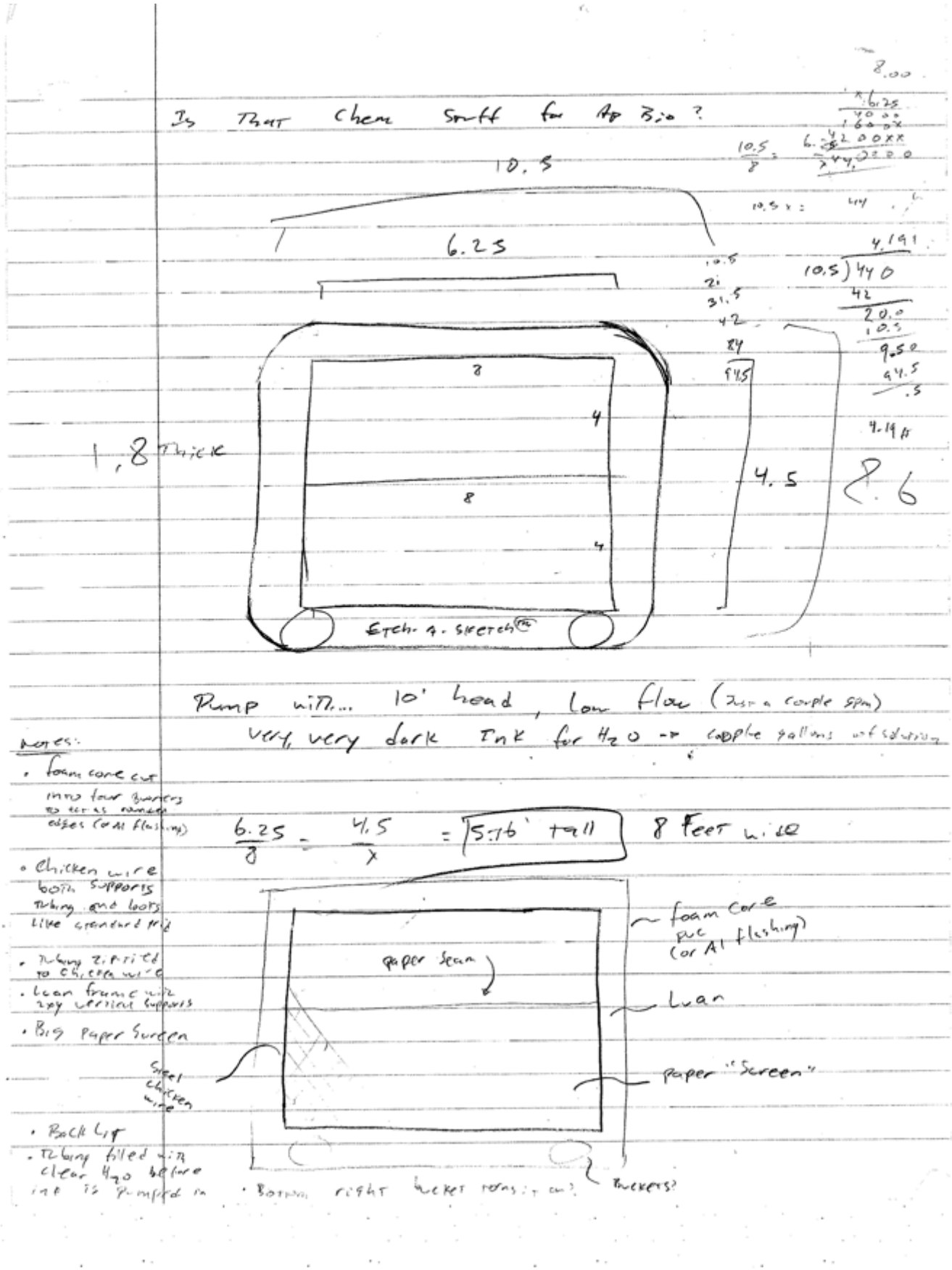
A trimetric CAD view of the robot; all components were steel, welded, drilled or otherwise machined custom

Beyond these projects are the ones from the early days of my engineering career, if it could even be called that back then. Looking through my files to compile this portfolio of sorts caused flashbacks and plenty of embarrassment. A few notables are included here as foils to the comparitively elaborate projects I have done in the past few years. In general they either didn't meet their original specifications or didn't make it to the production stage, but either way they were invaluable. These show the progression from idealistic young doodler to more realistic tinkerer sentient of the bounds of his own skills and of budgetary restrictions. Oh the things could've been done if all the materials were available and cheap…

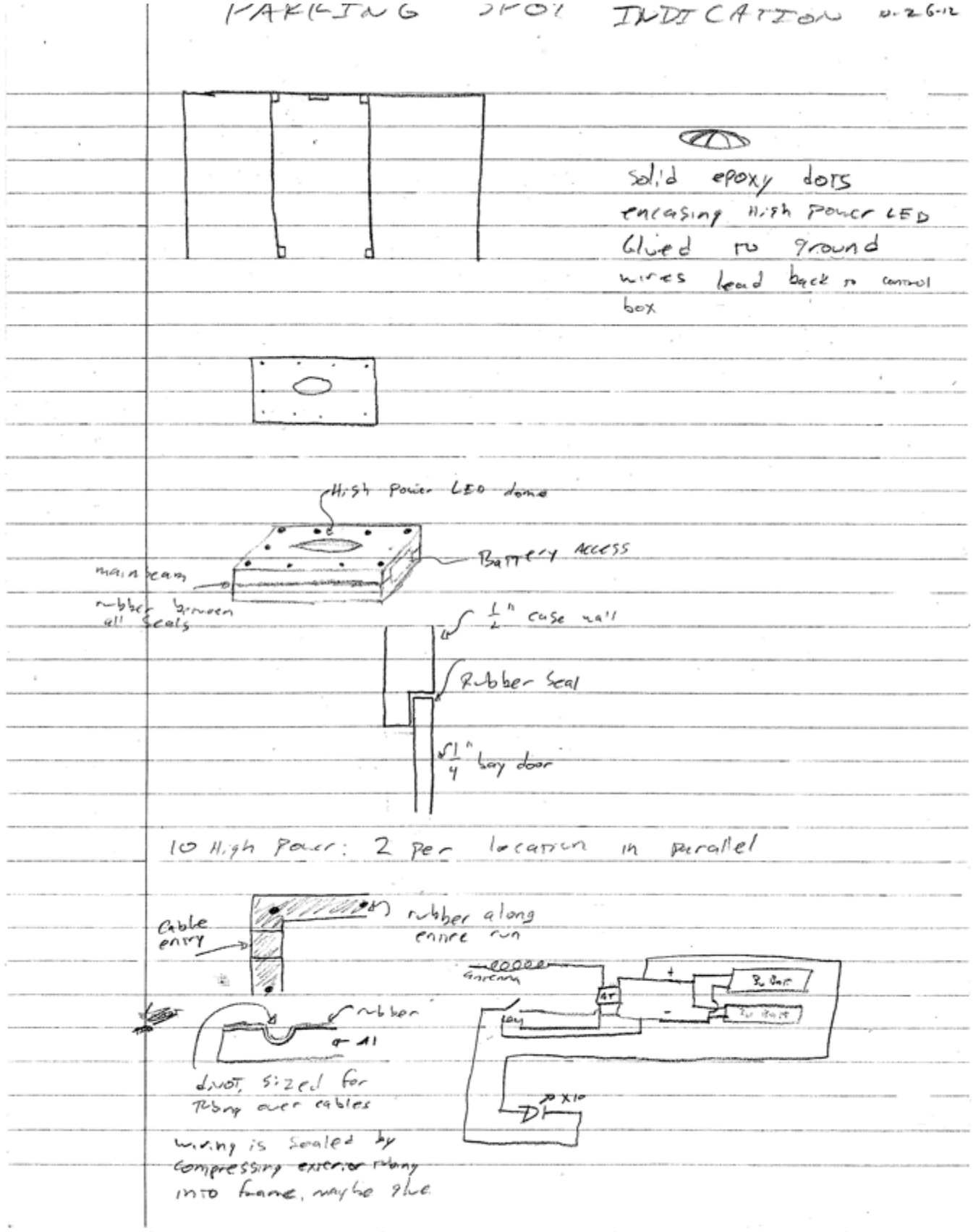
Rather than going into as much detail as before, and largely because I only started keeping detailed records around 2010, these descriptions will be truncated and most likely only include one picture.



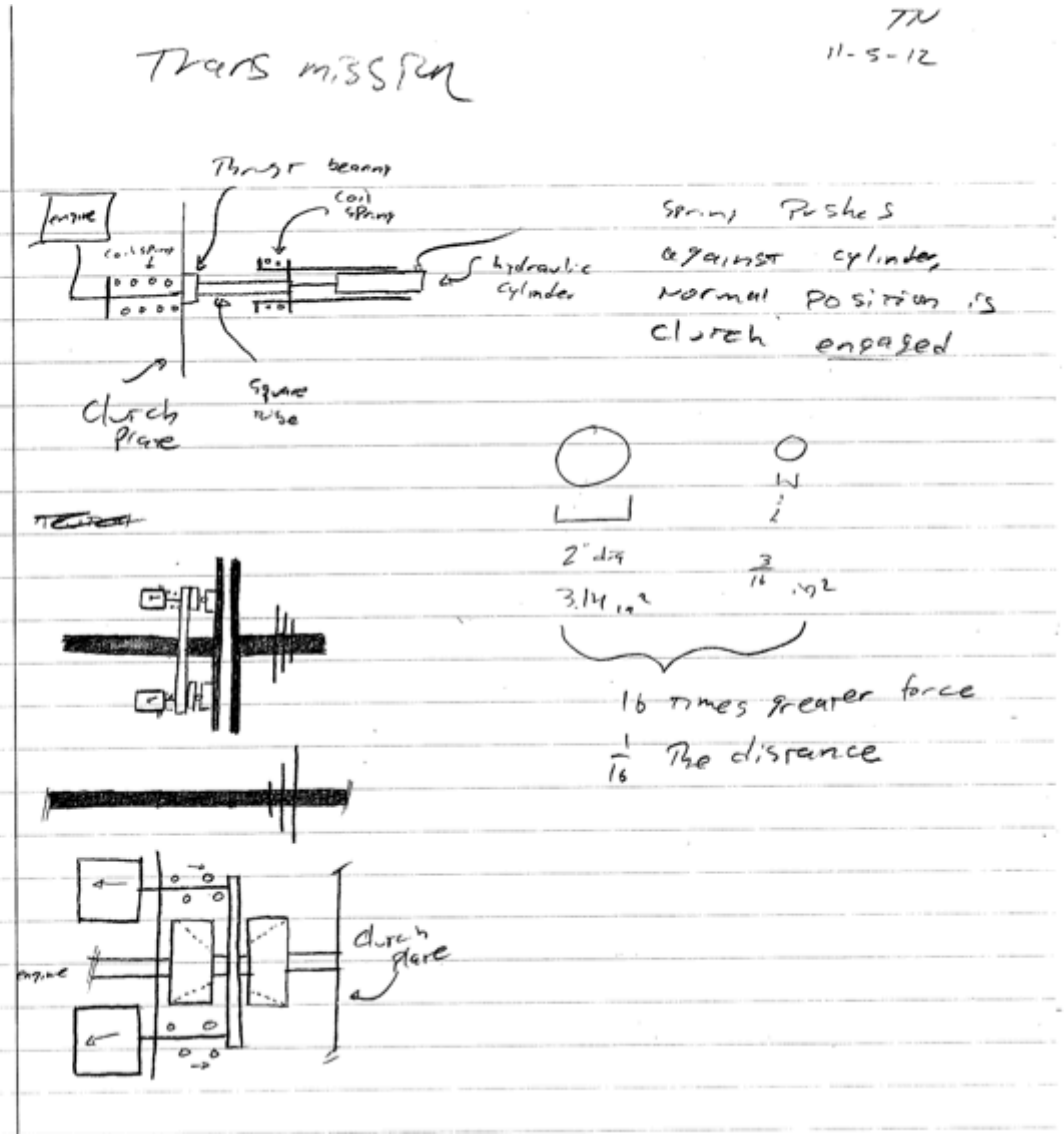
An early design for a capacitor-powered flashlight as a gift for my father. This was eventually made, but the soldering of surface-mount LEDs was problematic, at best.



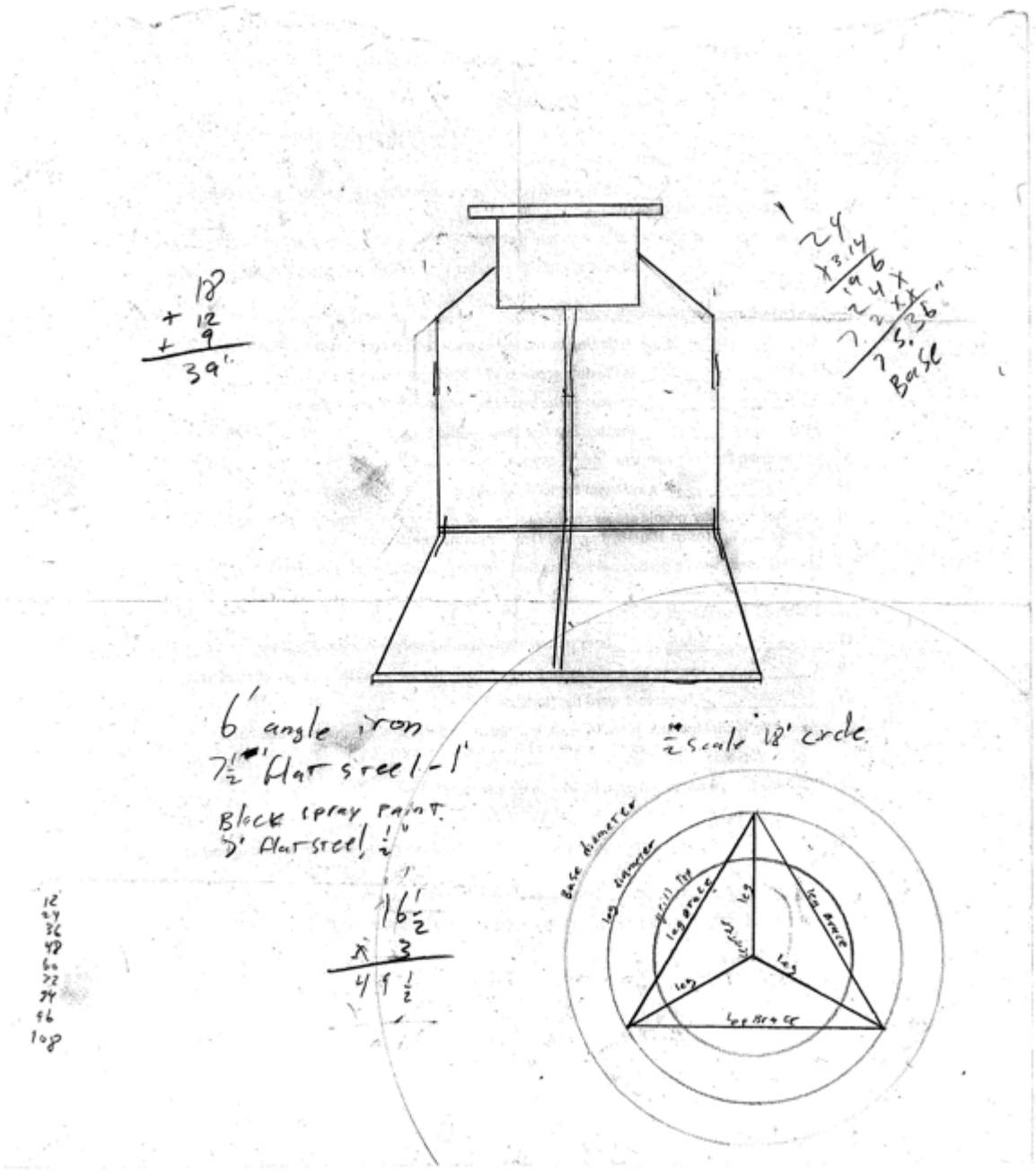
This was also actually made; it is an eight-foot tall replica of an Etch-A-Sketch for a Toy Story themed school dance. In addition to all the right features, it also had moving ink behind it and an RGB LED heart in the center that lit up and changed color. It was very well received and inspired me to plan bigger for this upcoming dance.



Unfortunately this never made it past conception. Because the parking lot at our school is so poorly lit in the morning, the winter months make it especially hard to tell whose parking spot is whose. This would have placed five sets of high power LEDs around my spot, to be turned on by a radio transmitter on my car that was controlled by the same in-car computer. This was ready to go until a friend reminded me that the snowplows coming through would have destroyed the system.



This little doodle, made in the middle of AP calculus one day, was just a thought exercise on whether I could come up with a workable transmission/clutch assembly for the amazing go kart I one day hope to make. Naturally this wasn't ever fabricated due to lack of purpose. But it was an excellent thought process, especially since I drive a stick shift.

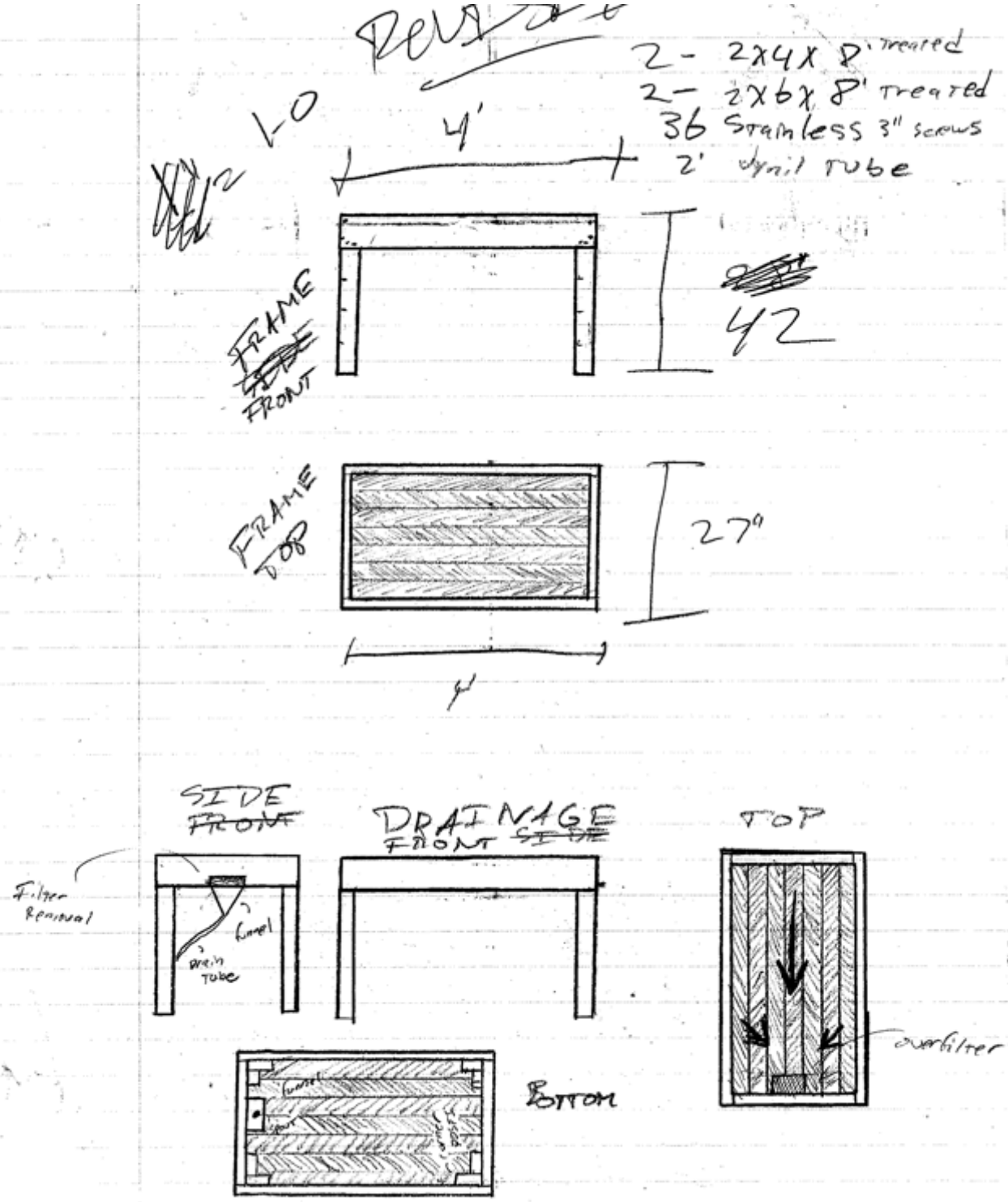


My father loves BD's Mongolian grill. After my technical skills had advanced a bit, and after I convinced him we "need" a welder, he asked me to make him a better wok. This was the result, in continuous use since my freshman year. The drafting too was surprising good for that long ago, and so it earned a spot in this section, as it was a bit simplistic to show off before.

ZIP LINE

- 250' 3/16" cable @ Andersons
- 8 ~~hooks~~ Clamps for Tree hoops
- 6 clamps for main line
- 6 Thimbles 3/16
- 10 black reinforced Tubing
- 2 (more) 1/2" Pulleys
- ?
- 7 small screw carabeners
- 2 large screw carabeners
- 1 can rust resistant black spray paint
- 1 old tire w/out rim
- come along, rented (hopefully)

One of my first large scale projects was a 200’ zip line from one end of our yard to the other. In the winter of 2009-’10 I got cabin fever, and my relief was to spend a month or so putting together a zip line from one end of my yard to the other. It is still great fun to this day: for special occasions I pull it out of storage and throw it up for my friends to scare their parents with. The real fun of it though was the leaps forward in physics and engineering it required. Here was something I would take my life on, not just another strobe light. And, being one of my first, I knew very little about industrial suppliers and procedures for cable handling/hardware.


2- 2x4x 8' treated
2- 2x6x 8' treated
36 Stainless 3" screws
2' drain tube
4'
1-0
FRAME
FRONT
42
FRAME
TOP
27"
4'
SIDE
FRONT
DRAINAGE
FRONT
TOP
Filter Removal
Gravel
drain tube
overfilter
BOTTOM

This was a project contracted by my mother that practically went to commercial production (by my standards). I made one, and she loved it, so I made two more- all of which she promptly flaunted to neighbors, who then wanted one. If not immediately apparent, they are raised flower beds/planters large enough to even accommodate tomato plants. They have held well up for three years now.