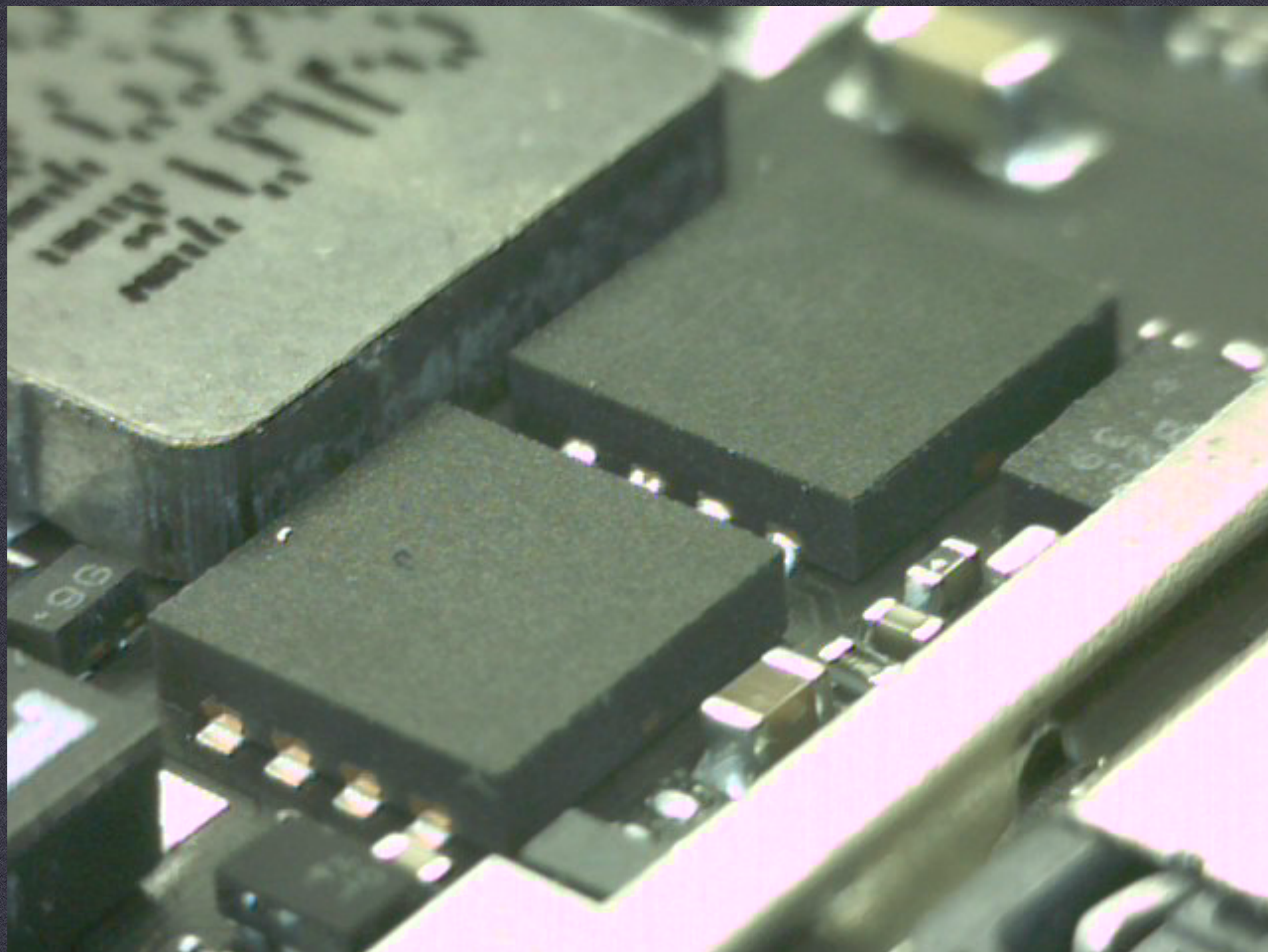
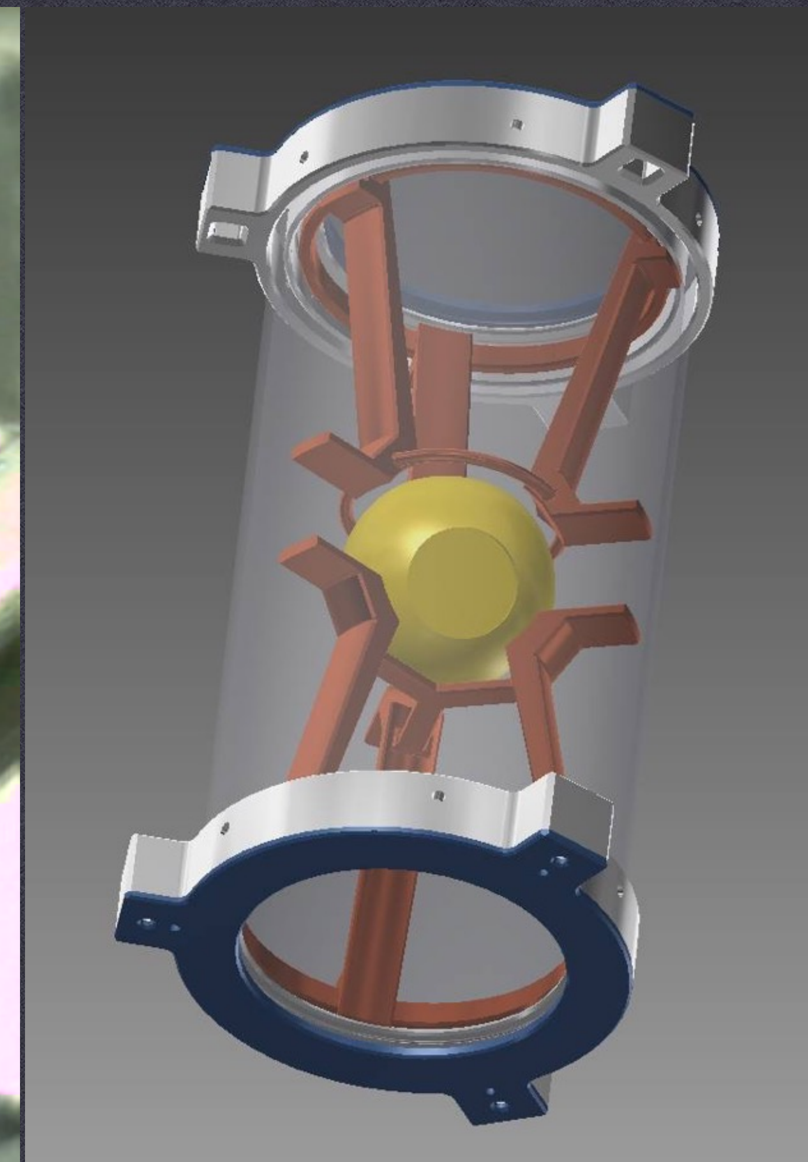



WILLIAM COOPER GILBERT

PROJECTS PRESENTATION
JET PROPULSION LABORATORY
7 JANUARY 2016

WILLIAM COOPER GILBERT
PRESENTER DESCRIPTION

Mechanical Engineering - University of Maryland

Graduating in May 2016
Minor in Nuclear Engineering
Advanced coursework in Electronics and Semi-Conductor Design

Balloon Payload Program - Space Systems Laboratory

Lab and Operations Director for BPP
Teaching Fellow for ENAE 100: Introduction to Aerospace Engineering

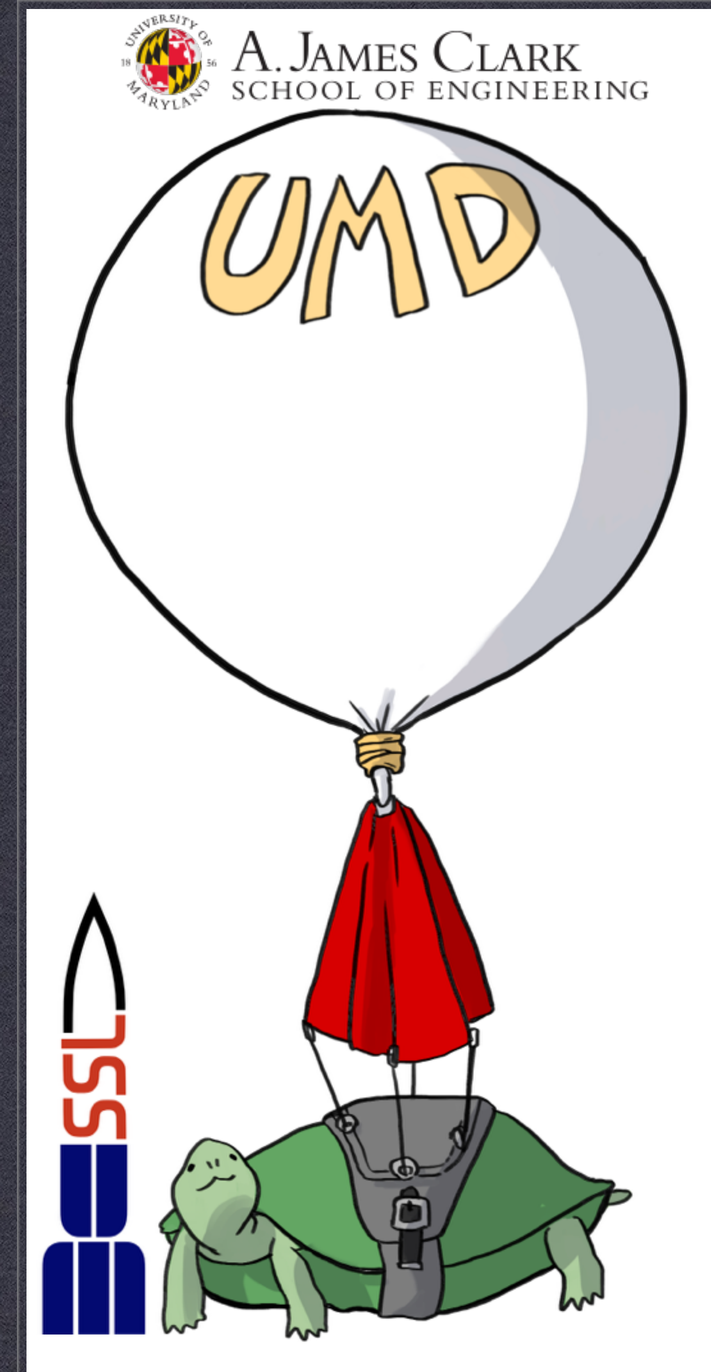
PRESENTATION OVERVIEW

BALLOON PAYLOAD PROGRAM

- PROGRAM DESCRIPTION
- PAYLOADS
  - COMMAND MODULE
    - LOW VOLTAGE PROTECTION CIRCUIT
  - SUPERSONIC
    - LED SHIFT INDICATOR CIRCUIT
  - LOOKING GLASS

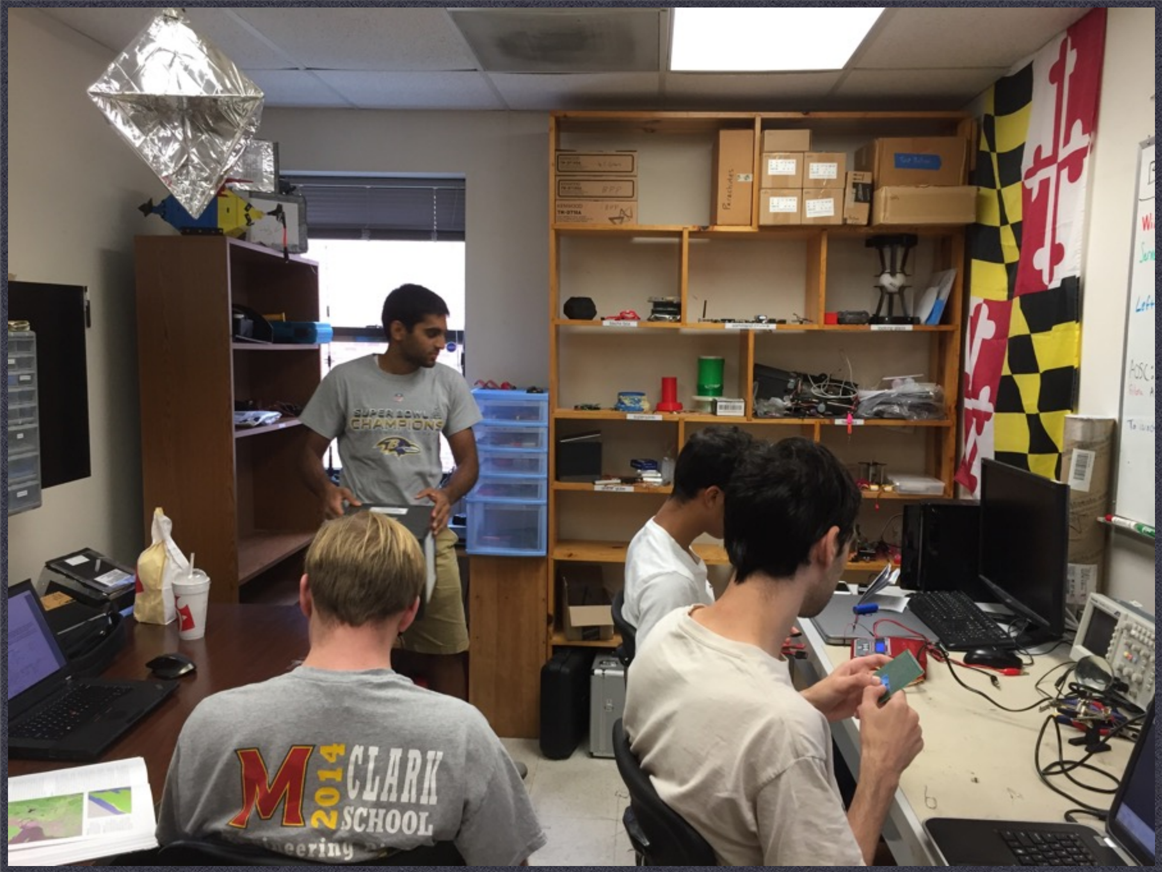
SOME ADDITIONAL PROJECTS

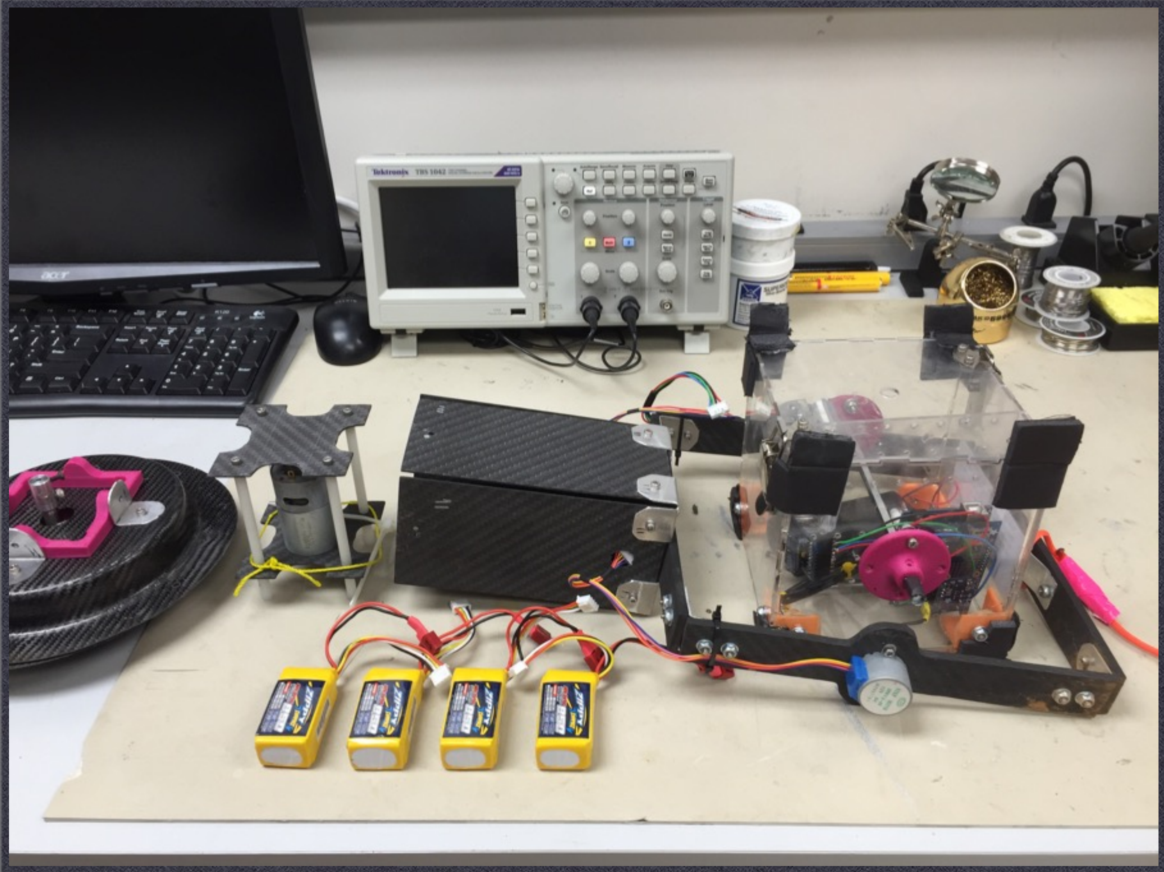
- SENSE PROGRAM, ATMOS SMT BOARDS
- APPLE IPAD MINI SEMICONDUCTOR PACKAGING ANALYSIS
- DEWALT DCF815 DESIGN ANALYSIS
- PYTHON WIFI WEATHER STATION
- INFRARED REMOTE CONTROLLED PINGPONG BALL SHOOTER



BALLOON PAYLOAD PROGRAM

BALLOON PAYLOAD PROGRAM
PROGRAM DESCRIPTION





Payload Construction

Conceptualize, design, and build payloads, systems to perform a desired function, in accordance with federal regulations [Title 14 CFR], NASA Space Grant, and Department of Aerospace Engineering requirements

- No more than 2.72kg (6lbs) per payload
- No propulsion systems

BALLOON PAYLOAD PROGRAM
PROGRAM DESCRIPTION

Payload Launch

Tie individual systems onto 20m nylon payload string with tracking module and recovery parachute, and release with 1.5kg, 4m diameter sounding balloon

- **No more than 5.4kg (12lbs) total**
- **Must have GPS tracking at all times**

BALLOON PAYLOAD PROGRAM
PROGRAM DESCRIPTION

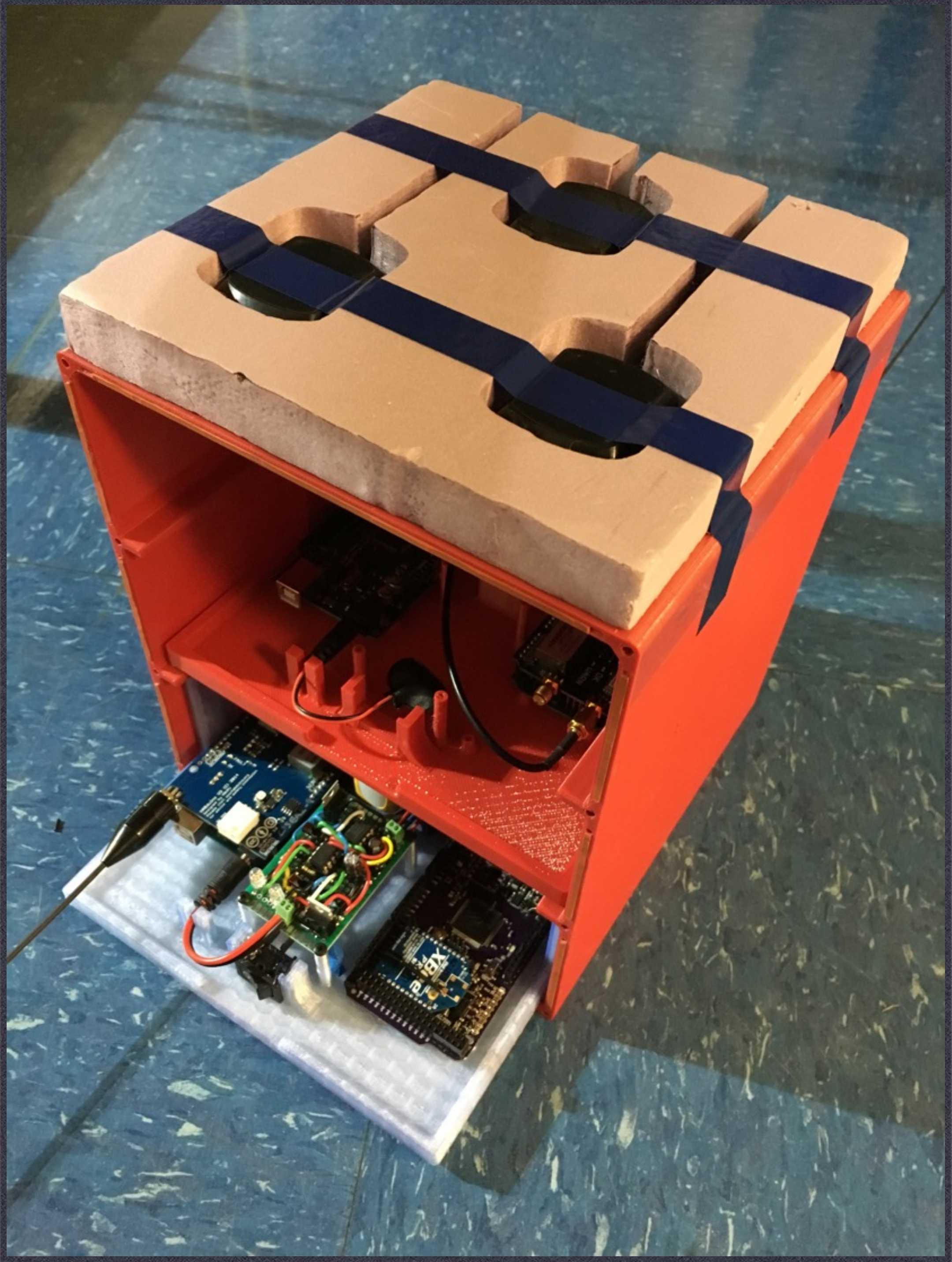

Payload Flight

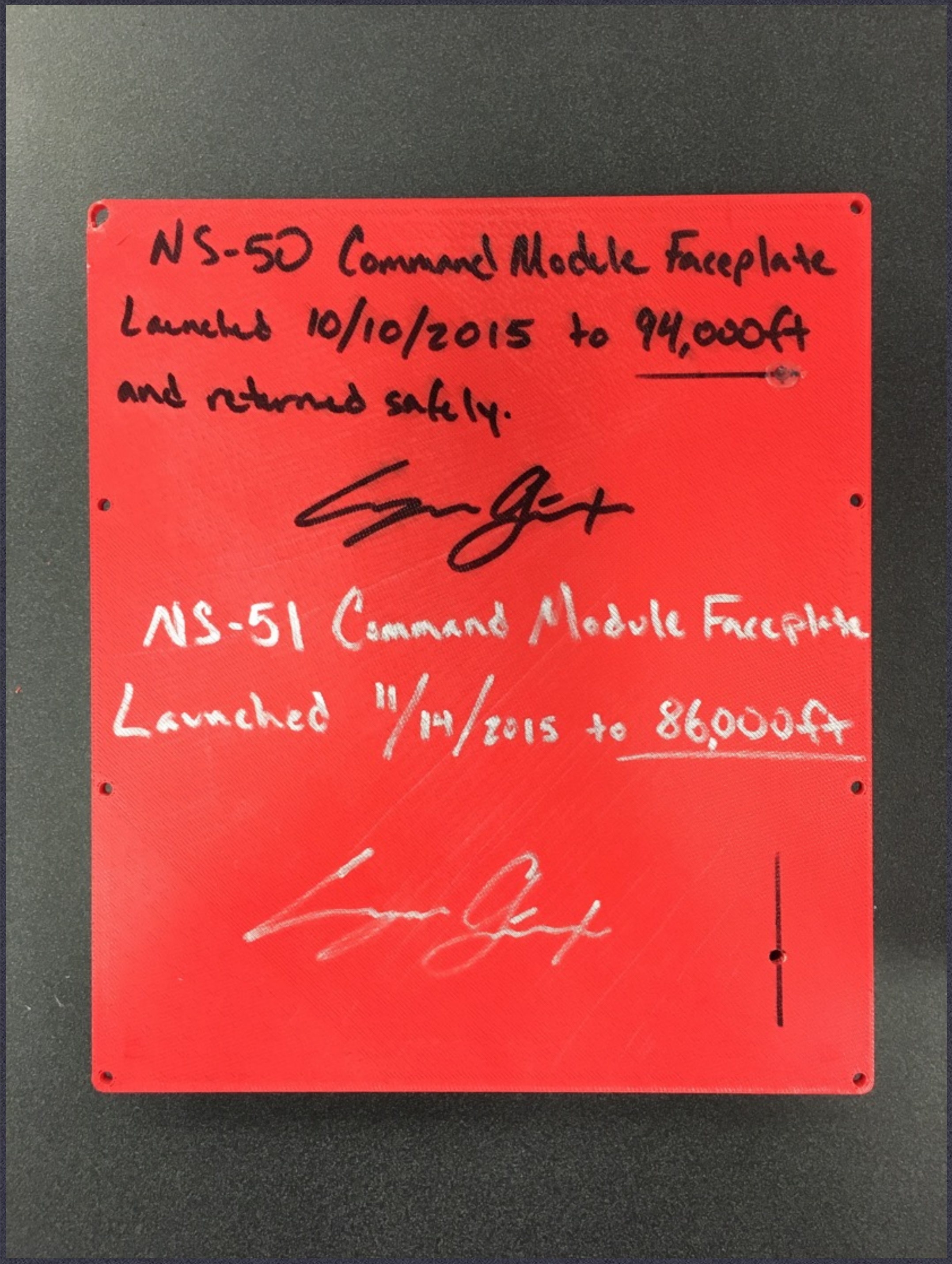
Balloon ascends to target altitude, between 25km to 35km, and bursts

- Extreme conditions during flight: -55ºC min temperature, 1kPa min pressure, 70m/s max air velocity
- APRS radio telemetry during flight, cellular-band radio telemetry during recovery (<1500m)
- Total flight time ~3 hours, total distance travelled ~110km

Altitude photo taken by TurtleNest payload at 31.4km

COMMAND MODULE





BALLOON PAYLOAD PROGRAM

COMMAND MODULE

Existing system had become impractical

- Internal hardware no longer produced
    - Frequent breakdowns
- New power supply directives
    - Rechargeable, more efficient
- Greater durability requirements
    - Time consuming to rebuild after each launch

Most Importantly, design was ad hoc, with little basis in engineering principles.

Concept Objective

To redesign the existing tracking module

- Decrease or equal existing module weight
- Increase reliability, durability, performance
- Simplify launch pad assembly, setup procedures
- Cost could be greater than previous module

Method

Apply flexible design principles, new materials, and custom hardware to create a system that can be adapted quickly and inexpensively to different launch requirements

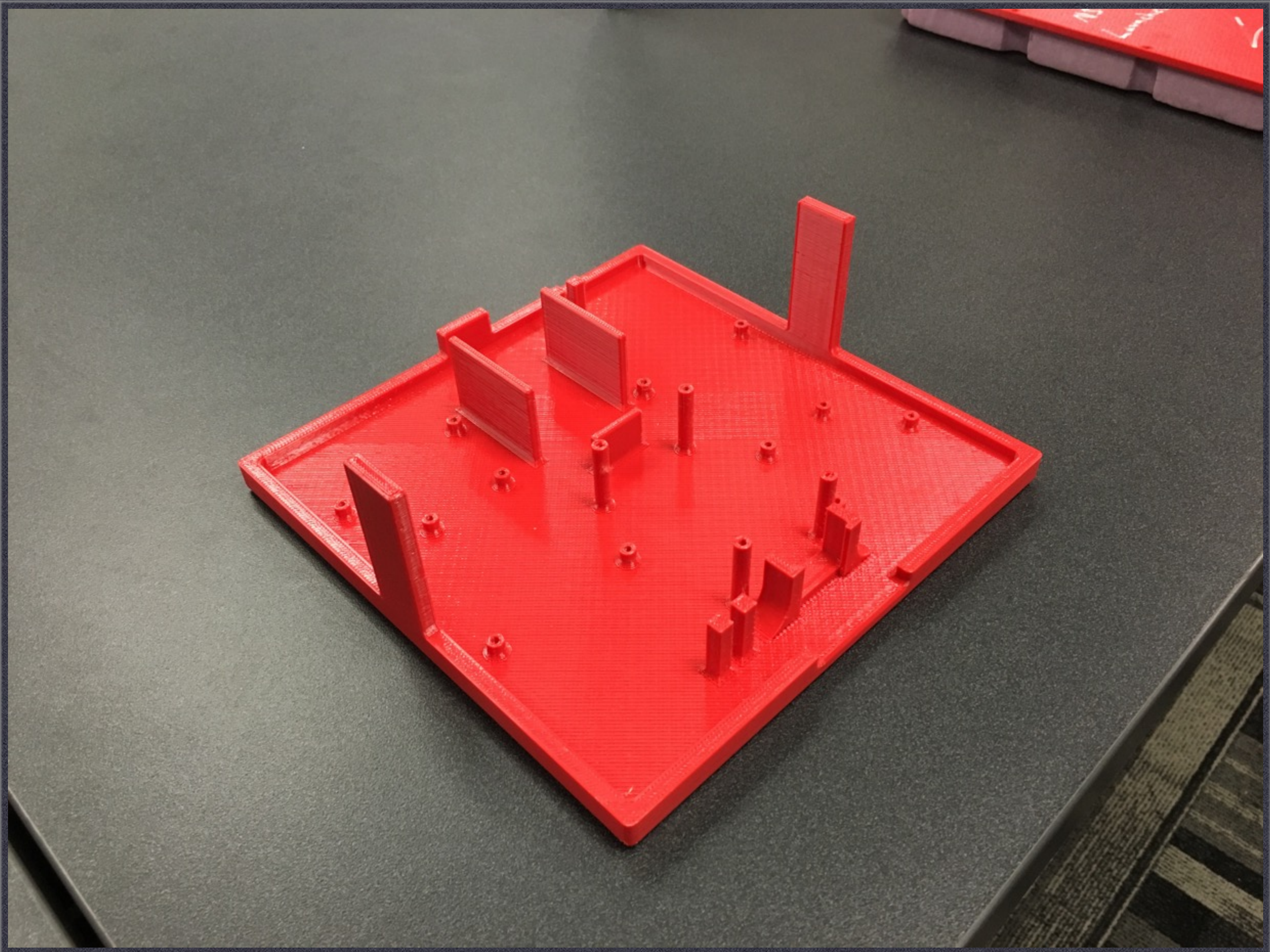
BALLOON PAYLOAD PROGRAM
COMMAND MODULE

Before Design Process

Select the highest quality components and design around them, to provide the optimal performance environment

BALLOON PAYLOAD PROGRAM
COMMAND MODULE

Flexible Design



BALLOON PAYLOAD PROGRAM
COMMAND MODULE

Flexible Design

Open plates within a shelved outer shell, stacked

- Plates allow for custom screw mounting of each component
- Custom plates for each different module configuration
  - Based off of new program template
- Multi configuration outer shell so that one shell can be used for any pair of plate designs
- Removable deformation layer
  - Double as secondary insulation

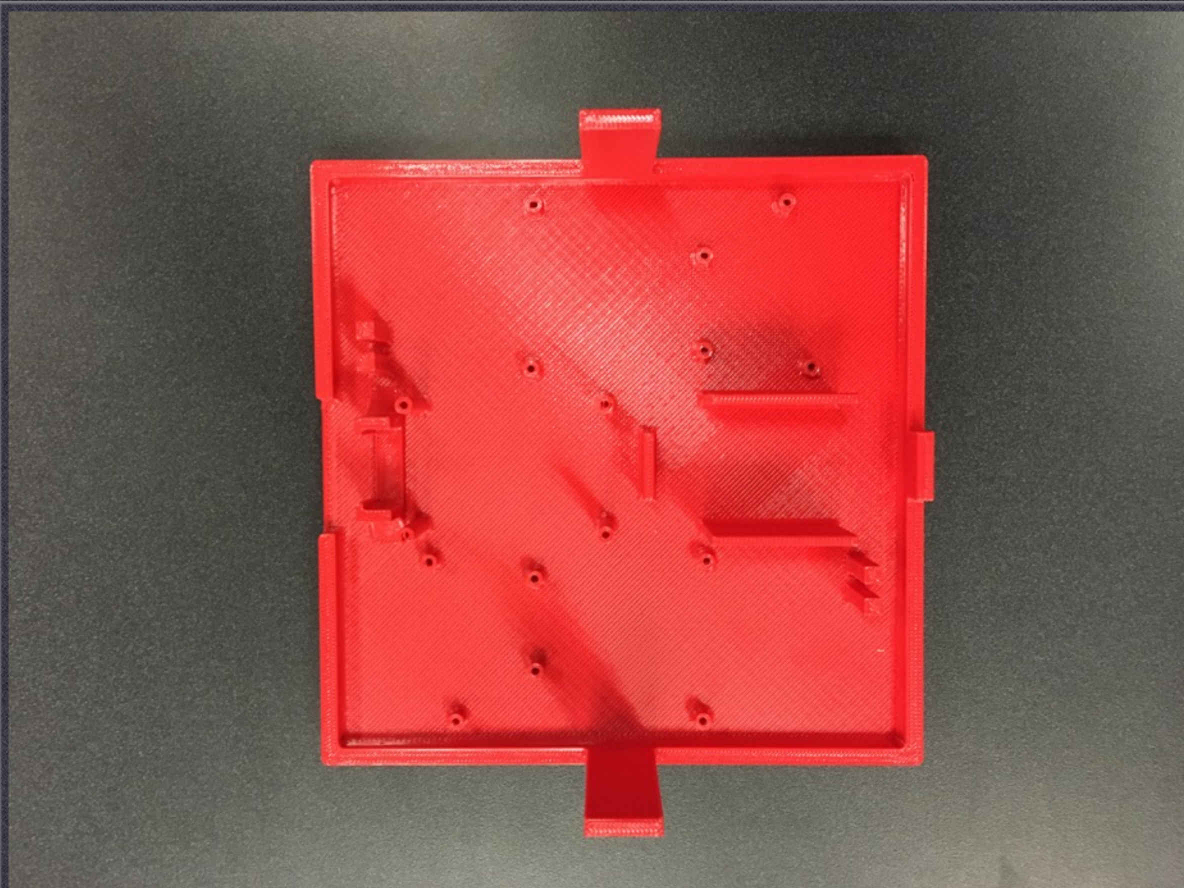
Tight tolerances in plate design (~1%) for minimal movement in horizontal and vertical within structure

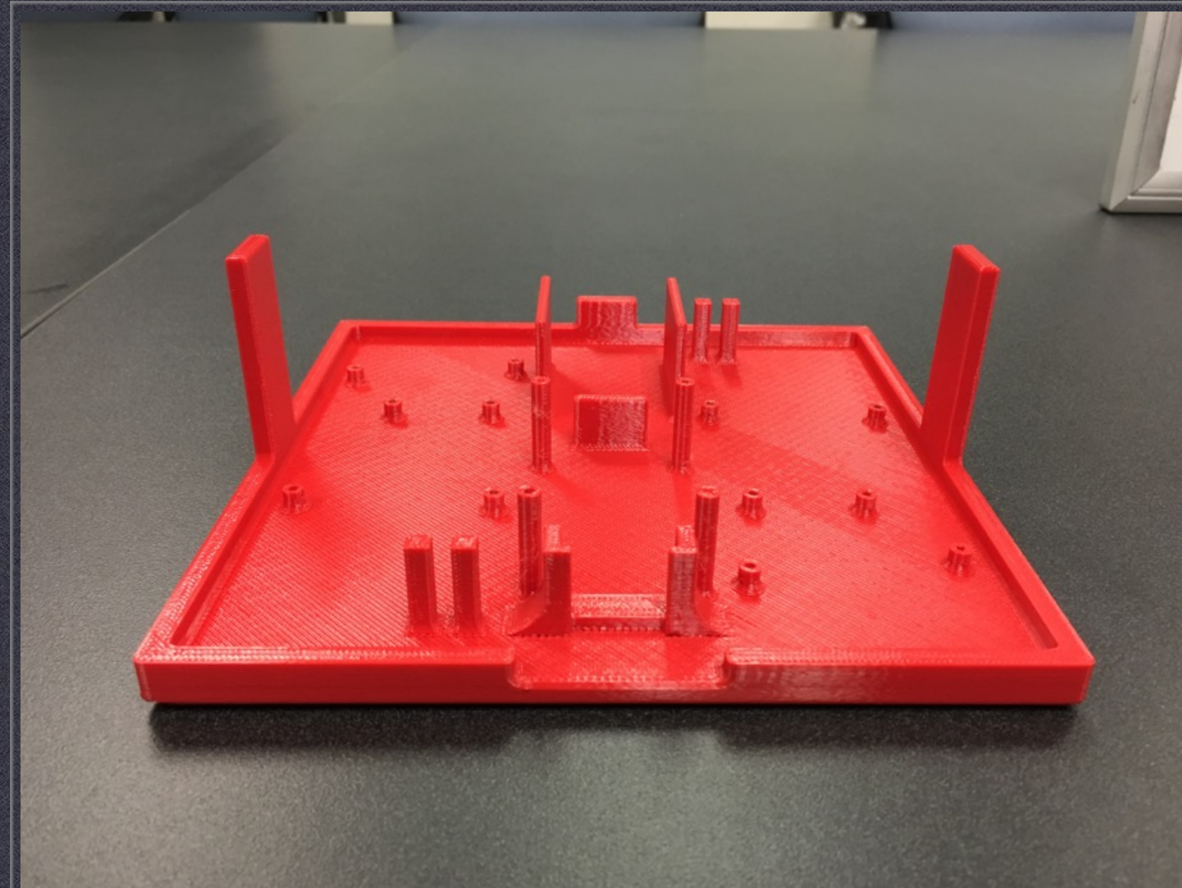
Mounting holes for electronics taken from EAGLE PCB files for exact positioning (to 0.1mm)

Unified power system for each plate, connected to snap-in power switch

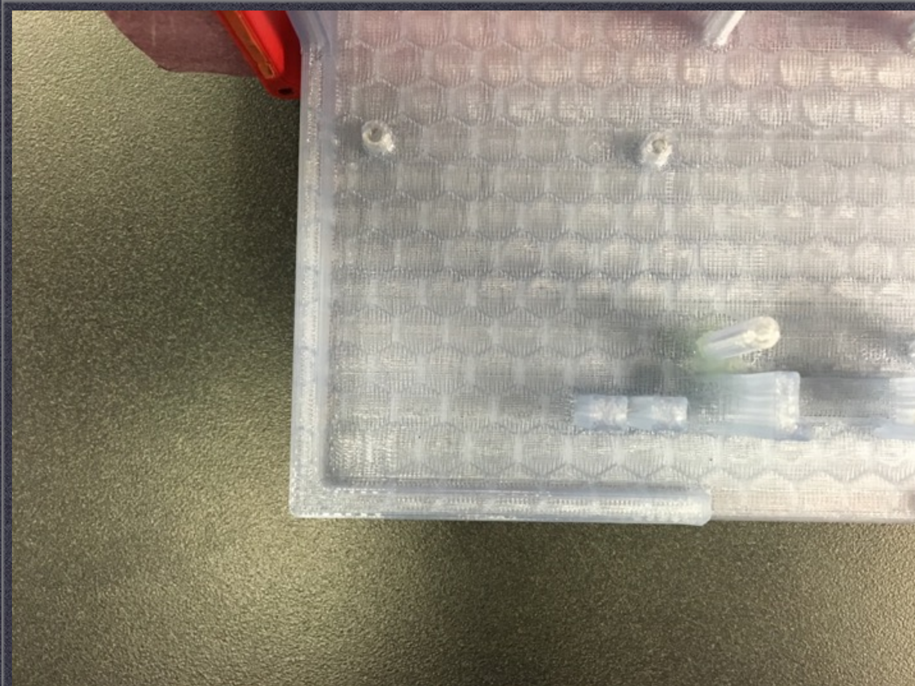
BALLOON PAYLOAD PROGRAM
COMMAND MODULE

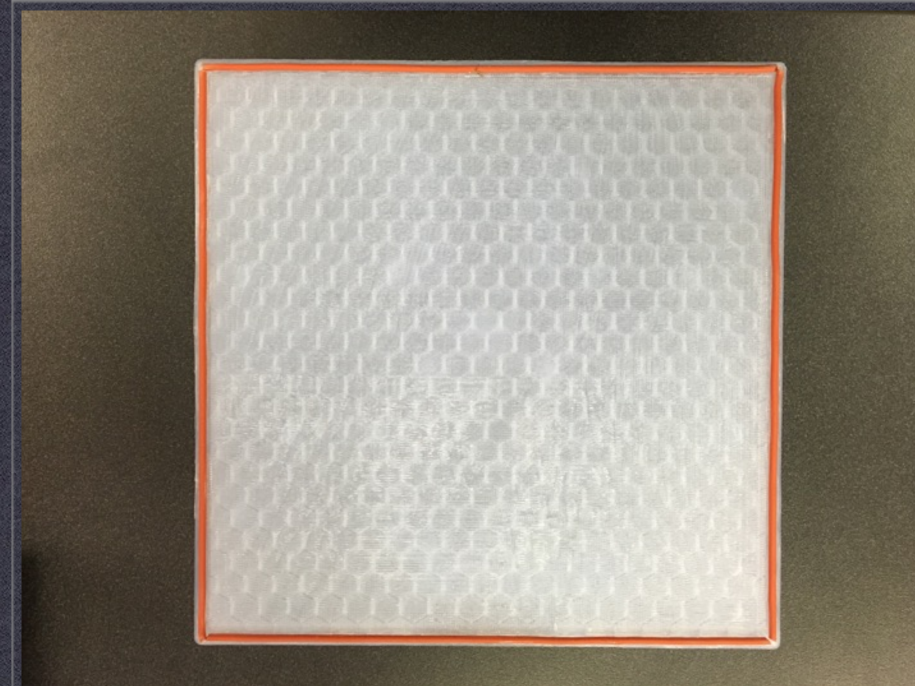
Flexible Design

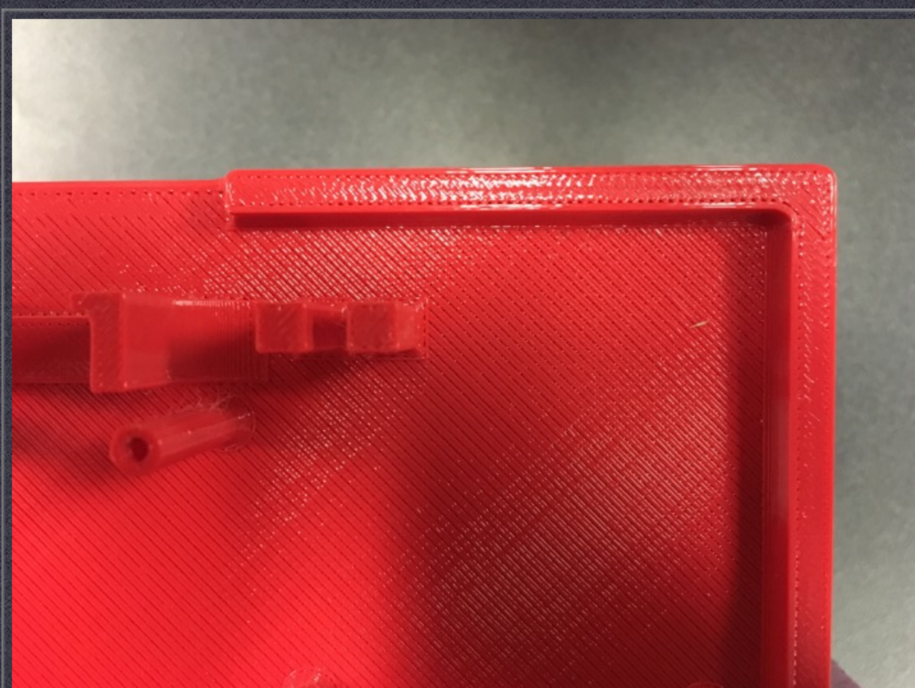




New Materials





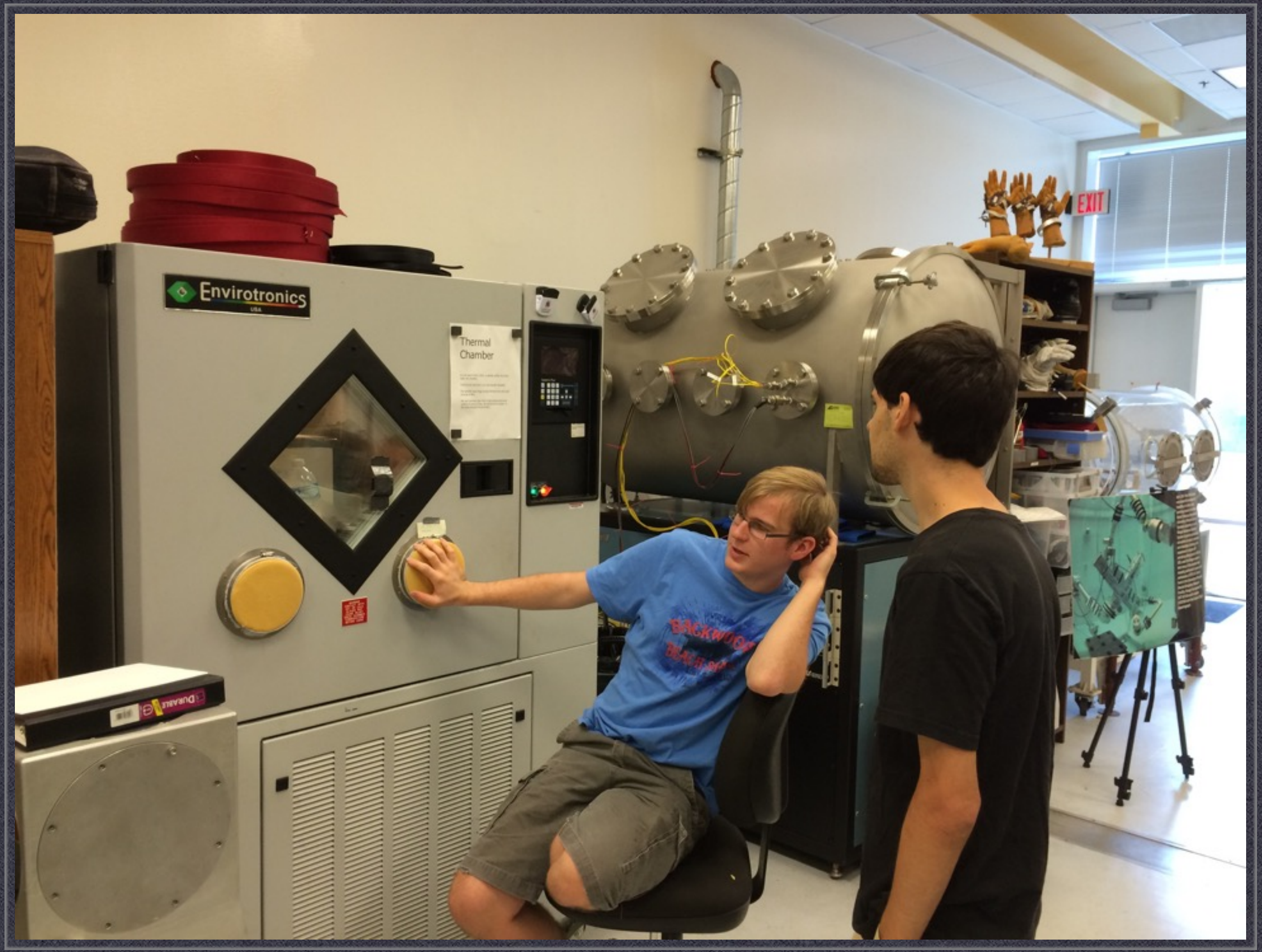


BALLOON PAYLOAD PROGRAM
COMMAND MODULE

Testing

Heat Budget for System

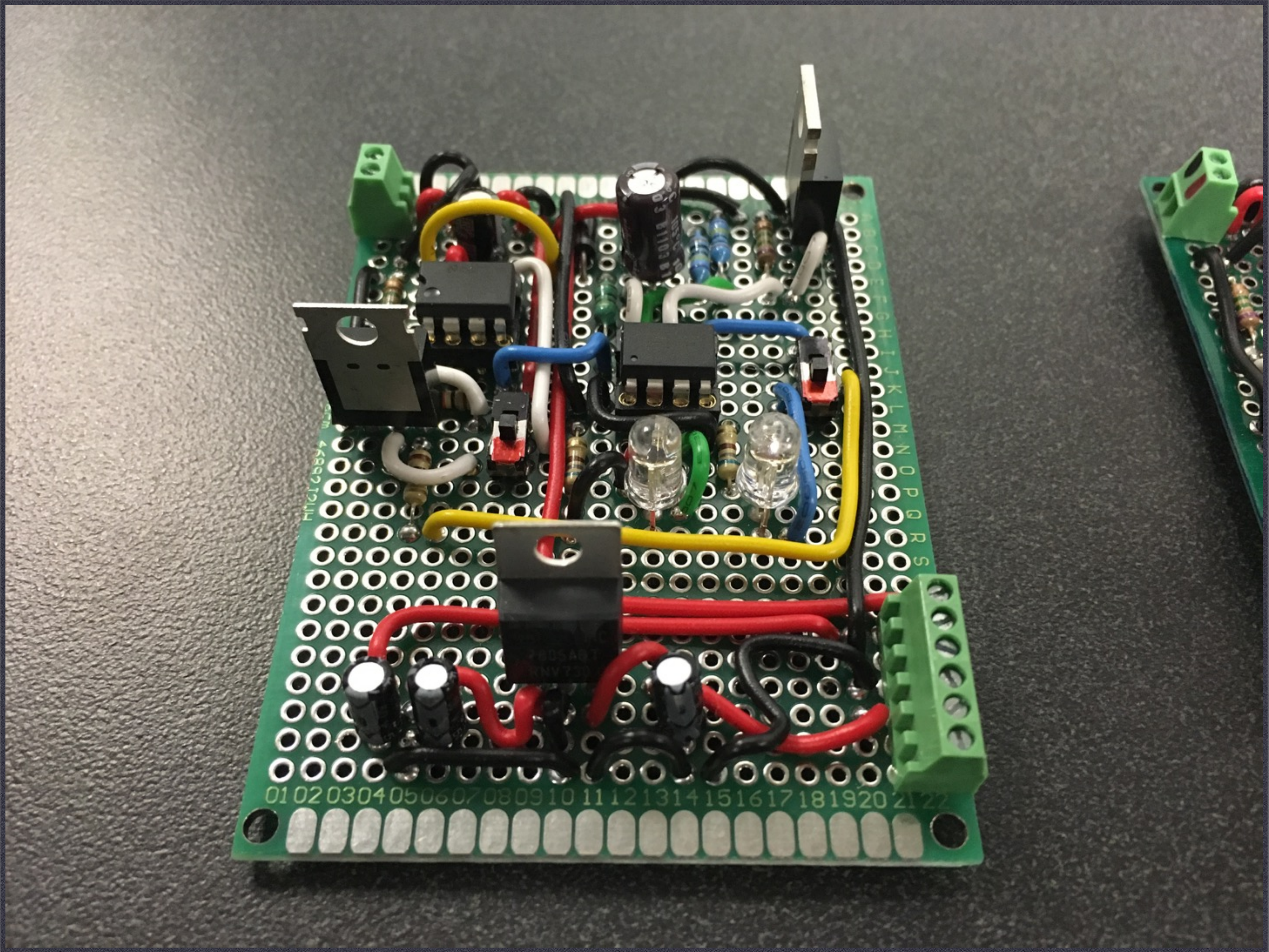
- Heat generation from electronics
  - Starting temperature not important
- Low infill reduces thermal conductivity
  - Exterior foam reduces further
- High velocity air flow would mean high convection, but insulation limits this
- Radiation not a significant factor in heat transport here



Newton's Law of Cooling and Heat Equation theoretically dictate that structure will keep electronics above 0ºC [Limit for semi-conductor reliability]

Thermal chamber testing confirms this

Custom Hardware - Low Voltage Circuit (LVC)



New battery directive

Switch to rechargeable, lightweight Lithium Polymer (LiPo) batteries

- Reduce cost by ~$1000 per year
- Wide variety of battery configurations (voltage and capacity)

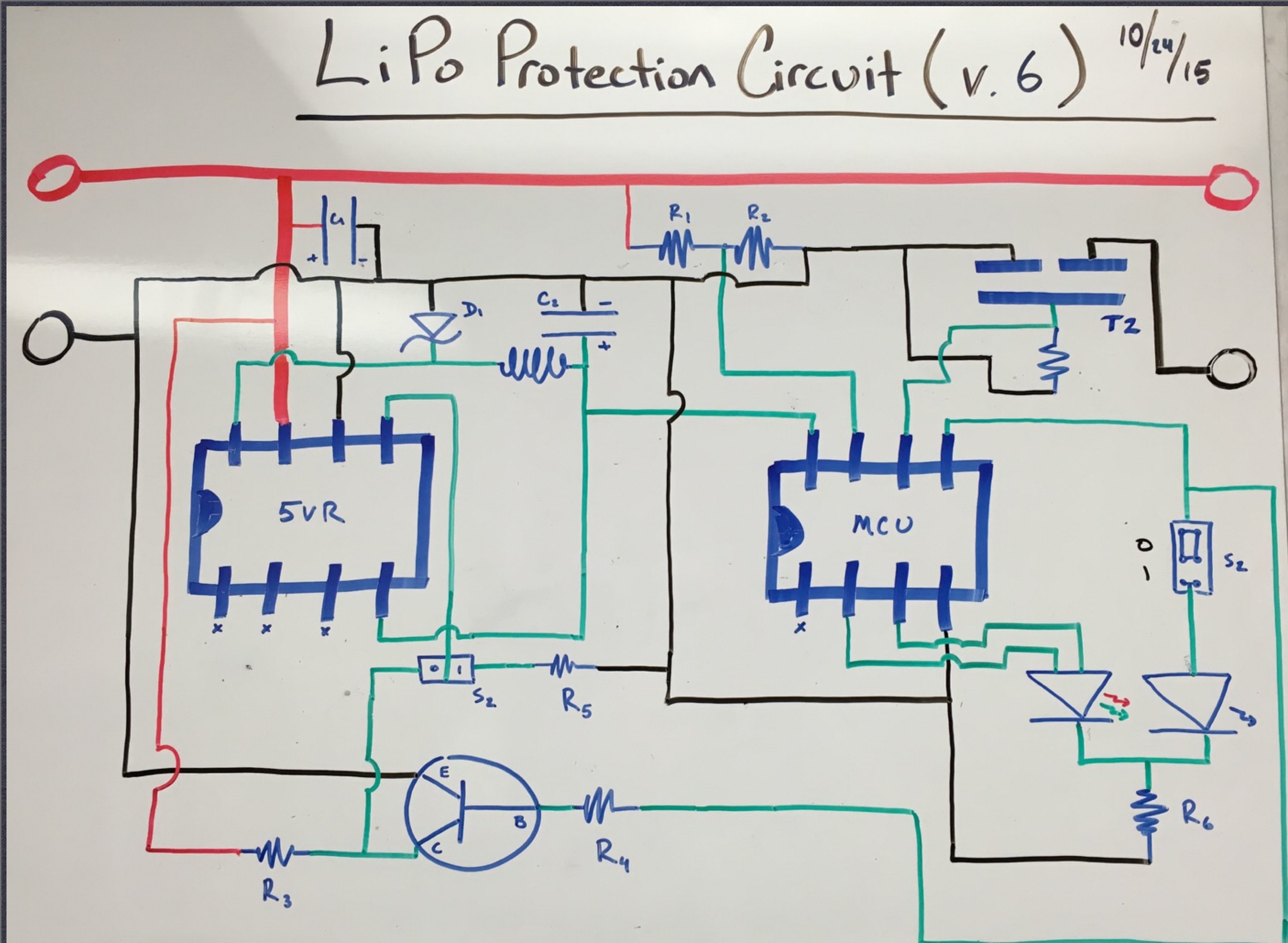
Requirements

LiPo batteries have greater needs than disposable to maintain usability

- More thermal insulation required for best performance
- Balanced charging
- Minimum 3.0v cell voltage

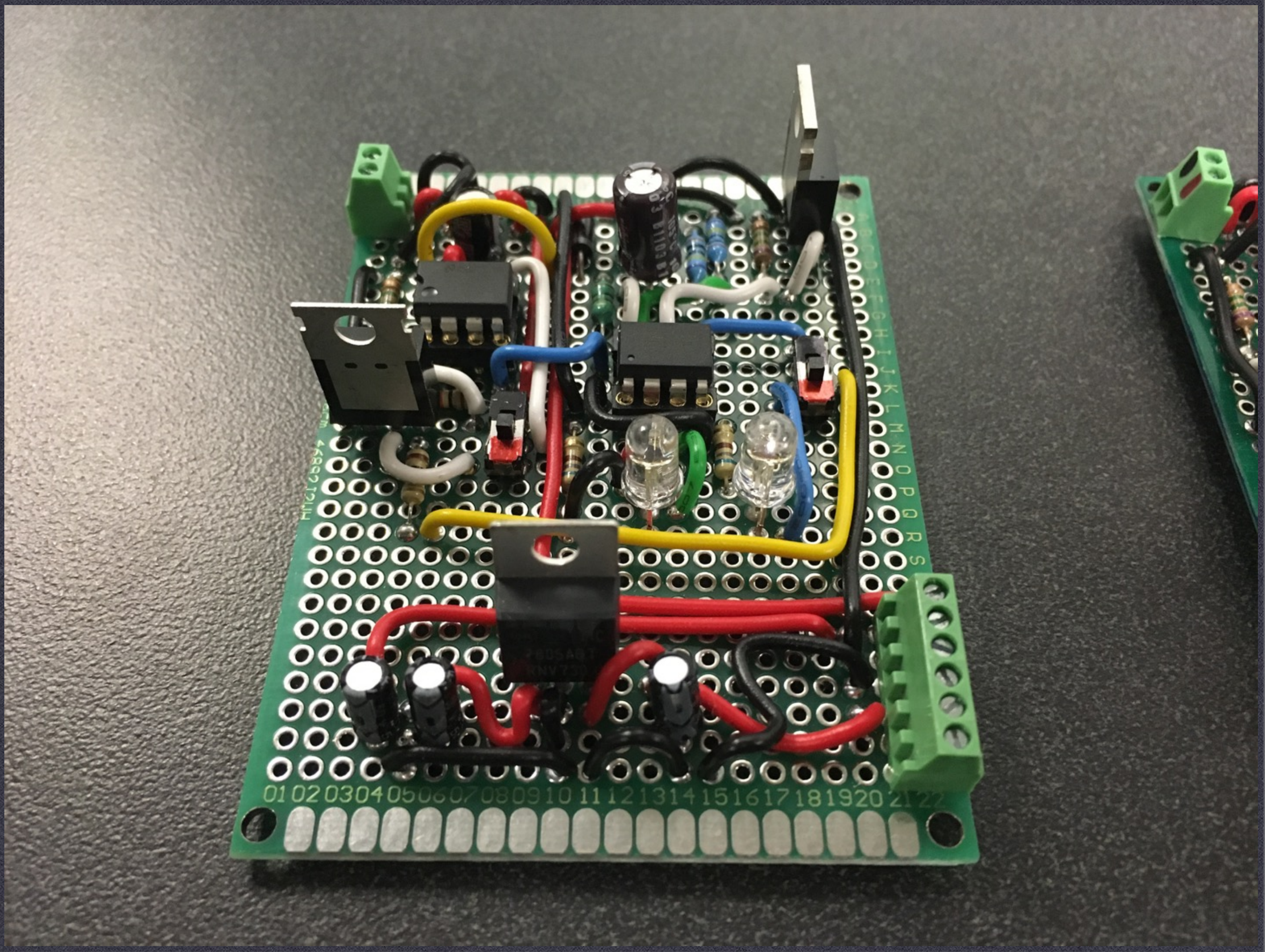
BALLOON PAYLOAD PROGRAM
COMMAND MODULE - LVC

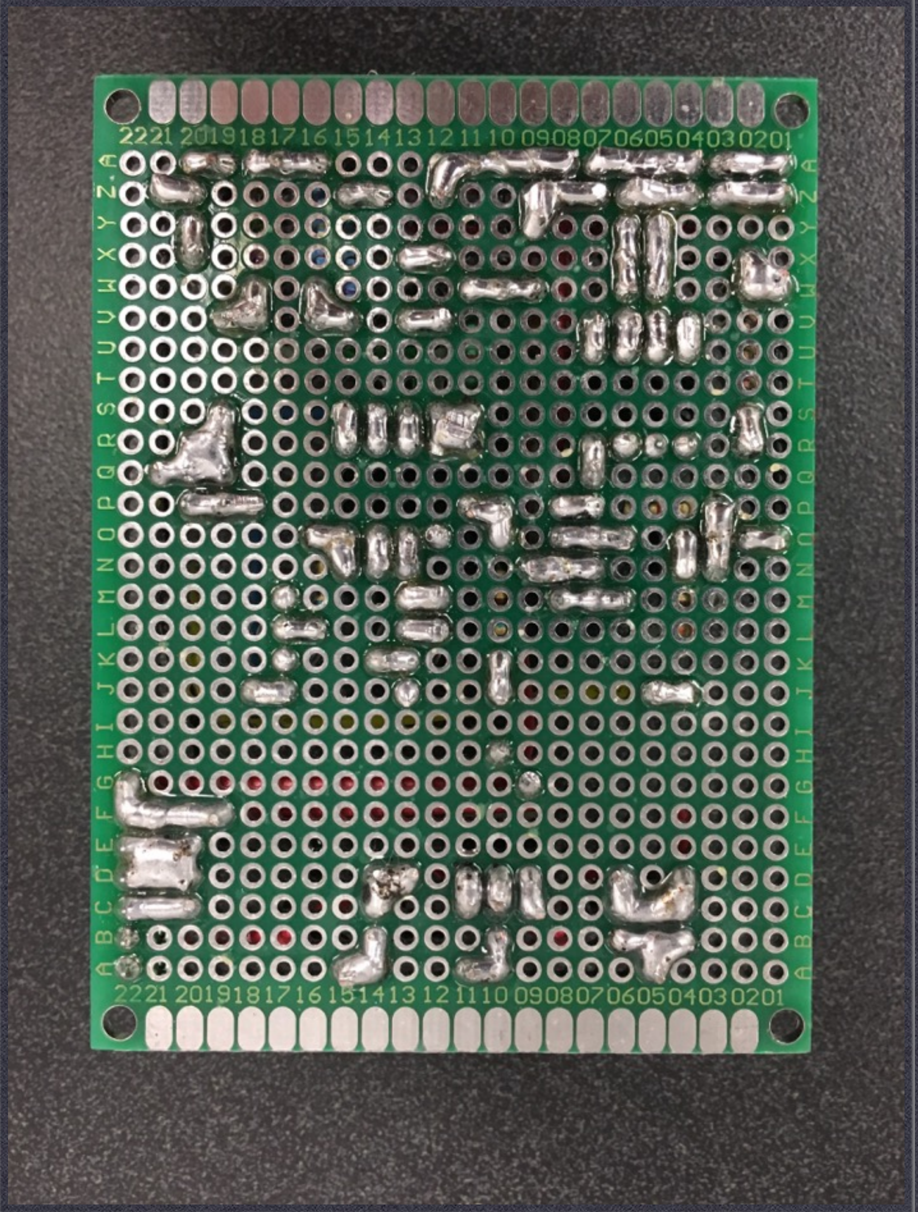
Circuit Design



BALLOON PAYLOAD PROGRAM
COMMAND MODULE - LVC

Construction





BALLOON PAYLOAD PROGRAM

COMMAND MODULE - LVC

Programming

```
}
void loop() {
  if (STARTUP == 1) {//Initialization Conditional
    digitalWrite(SLEEPSWITCH_DARLINGTON, LOW);//Start with Sleep Switch Turned Off
    digitalWrite(LOAD_NMOS, LOW);//Start with Load Turned Off
    digitalWrite(GREEN_LED, HIGH);//Set Indicators
    digitalWrite(RED_LED, HIGH);//Set Indicators
    delay(3000);
  }//
  while (STARTUP == 1) {//Startup Condition While Loop
    VOLTAGE_READ = analogRead(VOLTAGE_DIVIDER);//Read the Battery
    if (VOLTAGE_READ > UNLOADED_THRESHOLD) {//Check if Battery is Live
      BATTERY_STATUS = 1;//Call the Battery Live
      digitalWrite(SLEEPSWITCH_DARLINGTON, HIGH);//Prime Sleep Switch for Flight Mode
      digitalWrite(LOAD_NMOS, HIGH);//Turn On the Load
      digitalWrite(GREEN_LED, HIGH);//Set Indicators
      digitalWrite(RED_LED, LOW);//Set Indicators
      STARTUP = 0;//End Startup Condition
    }
    else {
      BATTERY_STATUS = 0;//Call the Battery Depleted
      digitalWrite(RED_LED, HIGH);//Set Indicators
      delay(500);
      digitalWrite(RED_LED, LOW);//Set Indicators
      delay(500);
    }
  }//Code will exit this while loop if battery is initially live
  while (STARTUP == 0) {//Operating Condition While Loop
    while (COUNTDOWN_CLOCK < 2000) {//Flight Mode before Sleep
      VOLTAGE_READ = analogRead(VOLTAGE_DIVIDER);//Read the Battery
      if ((VOLTAGE_READ > LOADED_THRESHOLD) && (BATTERY_STATUS == 1)) {//Live Battery when Loaded
        digitalWrite(LOAD_NMOS, HIGH);//Turn On the Load
        digitalWrite(GREEN_LED, HIGH);//Set Indicators
        digitalWrite(RED_LED, LOW);//Set Indicators
      }
```

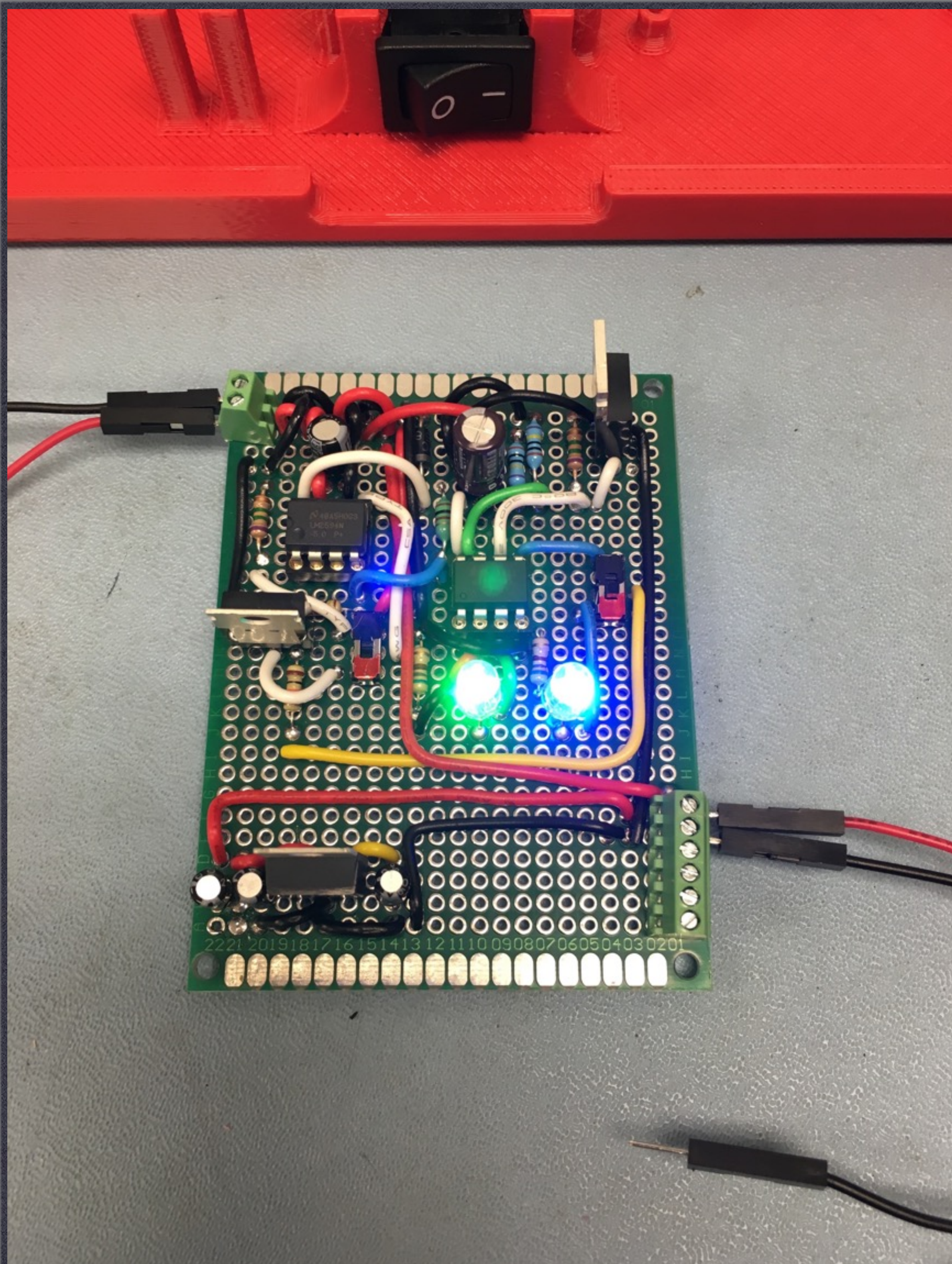
Bill of Materials

Item	Bulk Qty	Order Price	Unit Price	Qty On Board	Board Item Cost	Status	Part Number	Vendor
Small Perf	10	$3.90	$0.39	1	$0.39			Amazon
RGB LEDs	100	$7.70	$0.08	2	$0.15		B00RMBLCQ6	Amazon
N-Channel MOSFET	30	$32.92	$1.10	1	$1.10		FQP85N06	DigiKey
Darlington Pair	20	$13.20	$0.66	1	$0.66		TIP-120	DigiKey
ATtiny-85	5	$8.35	$1.67	1	$1.67		ATTINT-85-20PU	DigiKey
2-Pos Term. Blocks	30	$16.38	$0.55	1	$0.55		ED10561-ND	DigiKey
6-Pos Term. Blocks	20	$26.70	$1.34	1	$1.34		ED10565-ND	DigiKey
5v Regulator	10	$27.00	$2.70	1	$2.70		LM2594N-5.0/NOPB-ND	DigiKey
8-DIP Socket	50	$17.52	$0.35	2	$0.70		ED3031-ND	DigiKey
Slide Switch	20	$4.77	$0.24	2	$0.48		B008CZIG3I	Amazon
0.1% 1MΩ Resistors	25	$9.97	$0.40	2	$0.80		A105943CT-ND	DigiKey
5% 7.5MΩ Resistors	50	$1.44	$0.03	2	$0.06		CF14JT7M50CT-ND	DigiKey
5% General Resistors	1	$14.16	$14.16	4	$2.83	0.2	2x680Ω, 1x1kΩ, 1x10kΩ	Amazon
120uF Capacitors	10	$2.30	$0.23	1	$0.23		493-1780-ND	DigiKey
68uF Capacitors	10	$1.55	$0.16	1	$0.16		1189-2163-ND	DigiKey
100uH Inductors	10	$1.92	$0.19	1	$0.19		M10136-ND	DigiKey
Schottkey Diodes	10	$2.04	$0.20	1	$0.20		1N5817-TPCT-ND	DigiKey
Wire	1	16.00	16.00	1	$3.20	0.2	22AWG Solid Core	Amazon
				TOTAL	$17.40			

BALLOON PAYLOAD PROGRAM

COMMAND MODULE - LVC

Performance



LiPo Protection Circuit Operations Manual

Purpose

The purpose of this circuit is to prevent deep discharge of a 2S (7.4v) Lithium Polymer battery during flight operations.

Assembly Procedure

NOTE: Please following the listed steps in order, and if there are deviations from the images, consult the problem section (forthcoming).

0. Fully charge your battery, ensure it is a 2S (7.4v) LiPo. The voltage should be around 8.4v fully charged.

1. With the switch in position "O", plug battery into power switch. Ground goes directly to the board, black wire to black terminal. Power from the battery to the switch goes to the end terminal on the switch, power from switch to the battery goes to the middle terminal. There is only one end terminal on the switch.

2. With battery plugged into power switch, plug the switch into the board. Red wire to red terminal: ground coming directly from the battery, and red coming from the switch.

3. Connect the load, in many cases your Arduino, to the output terminals on the board. Red wire to red terminal, black wire to black terminal. When this step is completed, you have completed the power assembly.

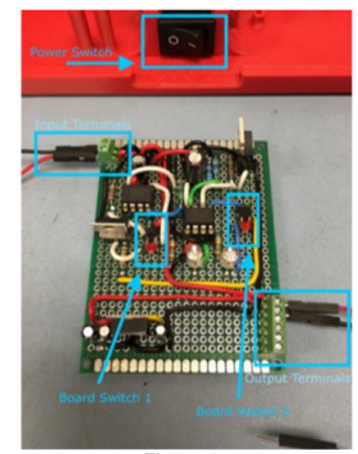


Figure 1.

Operation Procedure

NOTE: Please following the listed steps in order, and if there are deviations from the images, consult the problem section.

0. Complete the Assembly Procedure.

1. With the power switch in position "O", turn both board switched to RED.

2. Set the power switch to position "I." The board will NOT power up in this step and you will see no feedback.

3. Set the first board switch to BLACK. You should now see a GREEN LED AND a BLUE LED illuminated. Your board is now powering the load (Figure 2).

4. After you have observed an illuminated BLUE LED, set the first board switch to RED. This sets the system to flight mode.

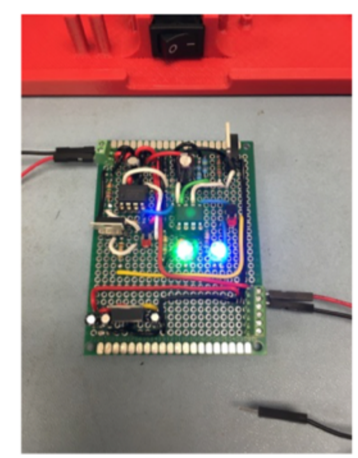
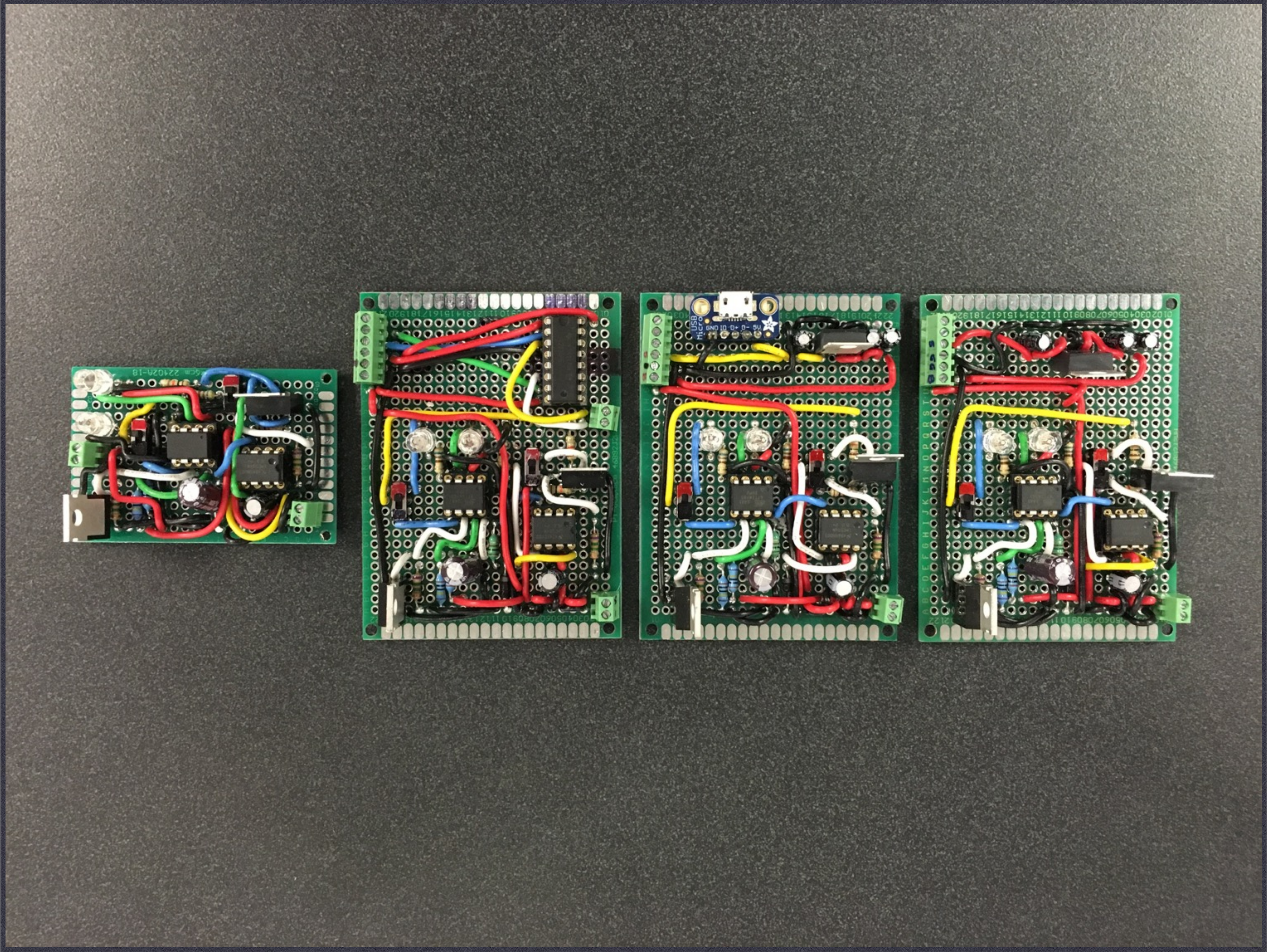


Figure 2.

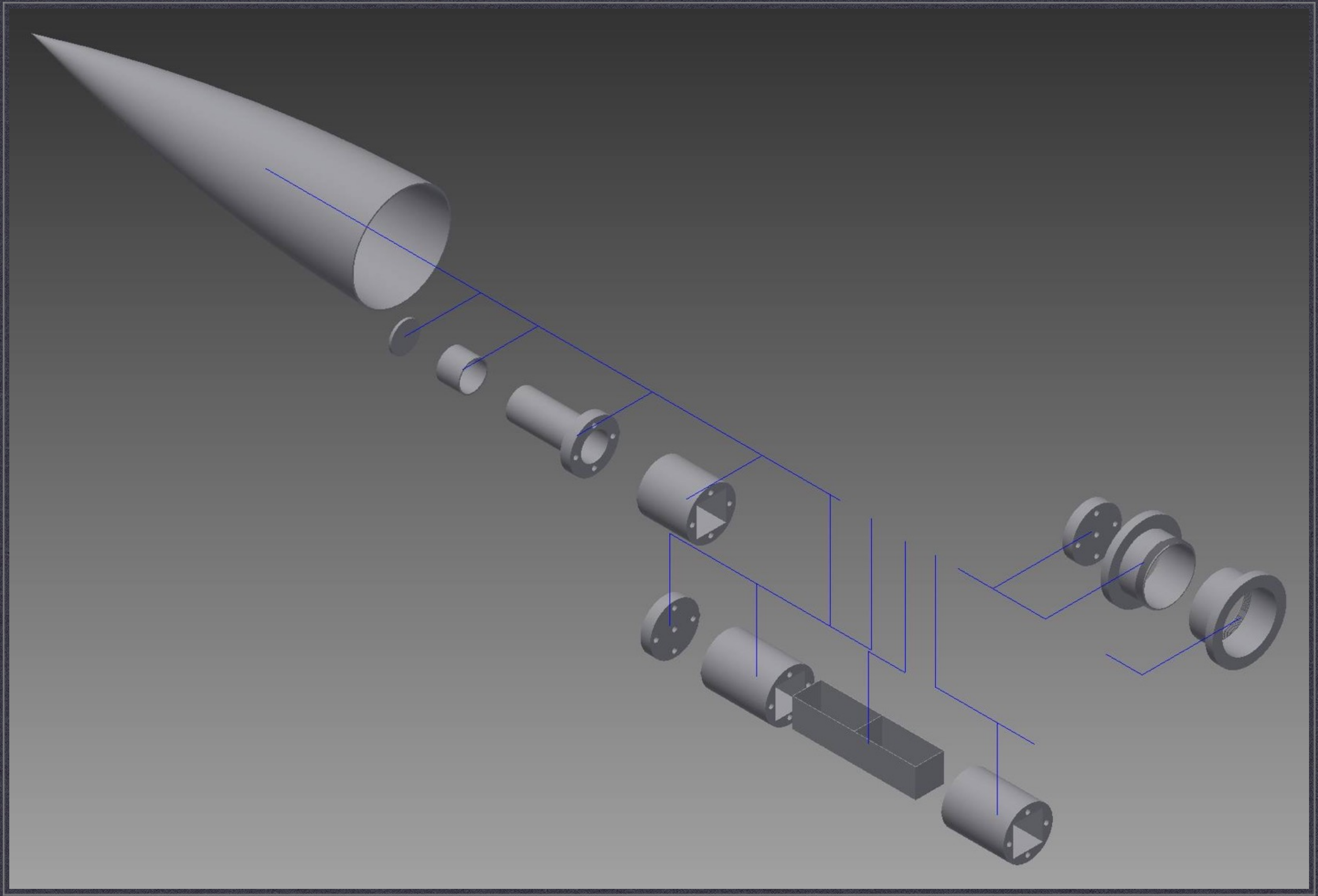
BALLOON PAYLOAD PROGRAM

COMMAND MODULE - LVC

Adoption



SUPERSONIC



BALLOON PAYLOAD PROGRAM
SUPERSONIC

Concept Objective

To develop a lightweight, inexpensive drop craft capable of surviving high velocity* free fall from the maximum balloon altitude and deploying parachutes reliably and with redundant control systems

- High velocity* here was chosen as a velocity in excess of the local speed of sound
- Drop actuation user-controllable or sensor based
- Parachute deployment user-controllable or sensor based

Purpose

- Give the program the ability to have separable payloads
- Novel challenge that requires the application of several disciplines

Method

Complex design and reliability requirements led to the decision for four stage development (simulation, subsystems, structure, complete) spread over several generations of students

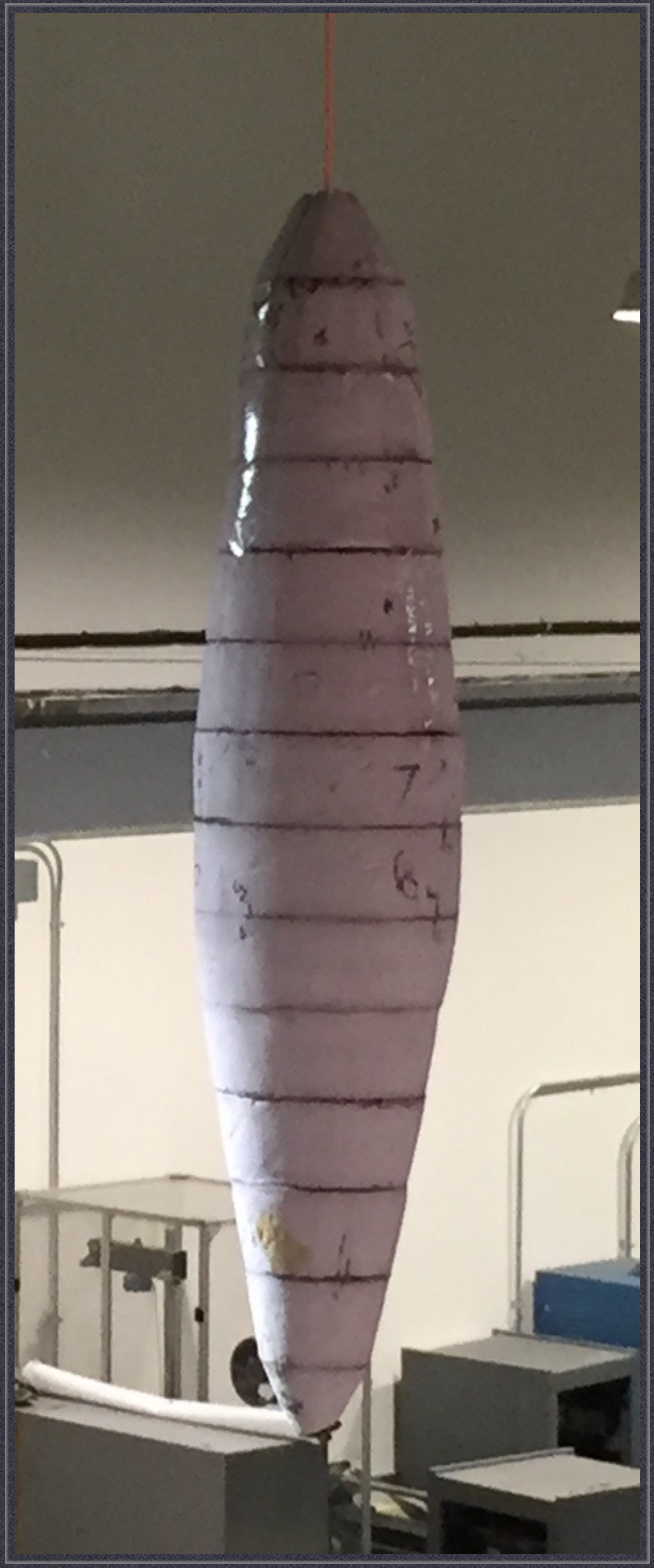
Mark I - “Pinky” - Payload Simulation

Intended to simulate maximum weight and general shape of concept during balloon flight and recovery, the latter in case of drop abort

- Foam segments held together with compression line
- Internally void except for lead shot for weight

Successfully flew on 27 September 2013

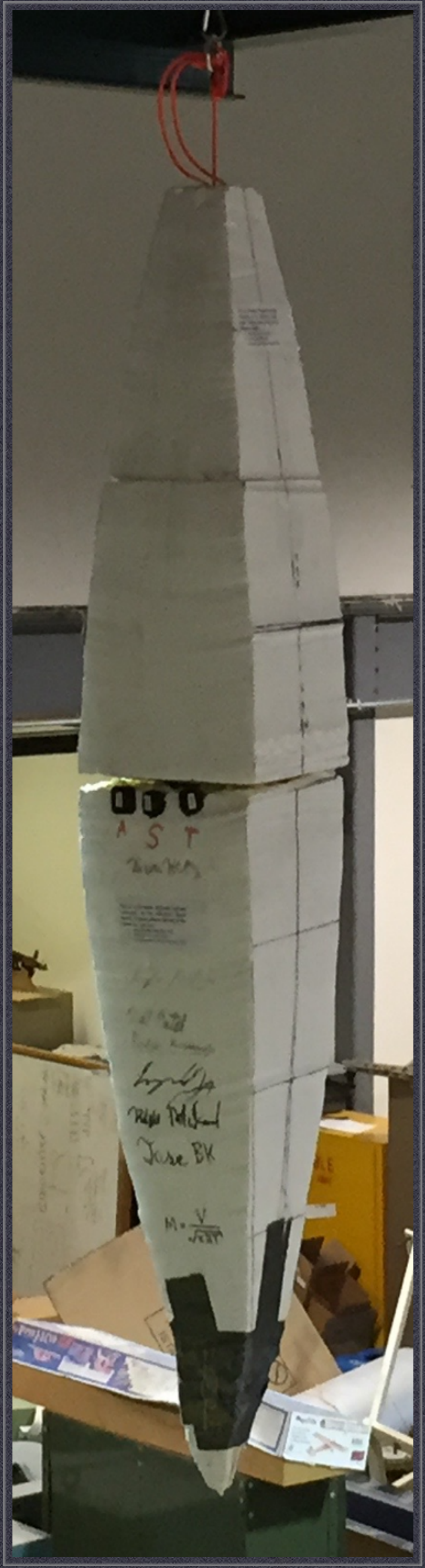
- Full GPS tracking during flight
- No observed obstruction of balloon parachute during recovery



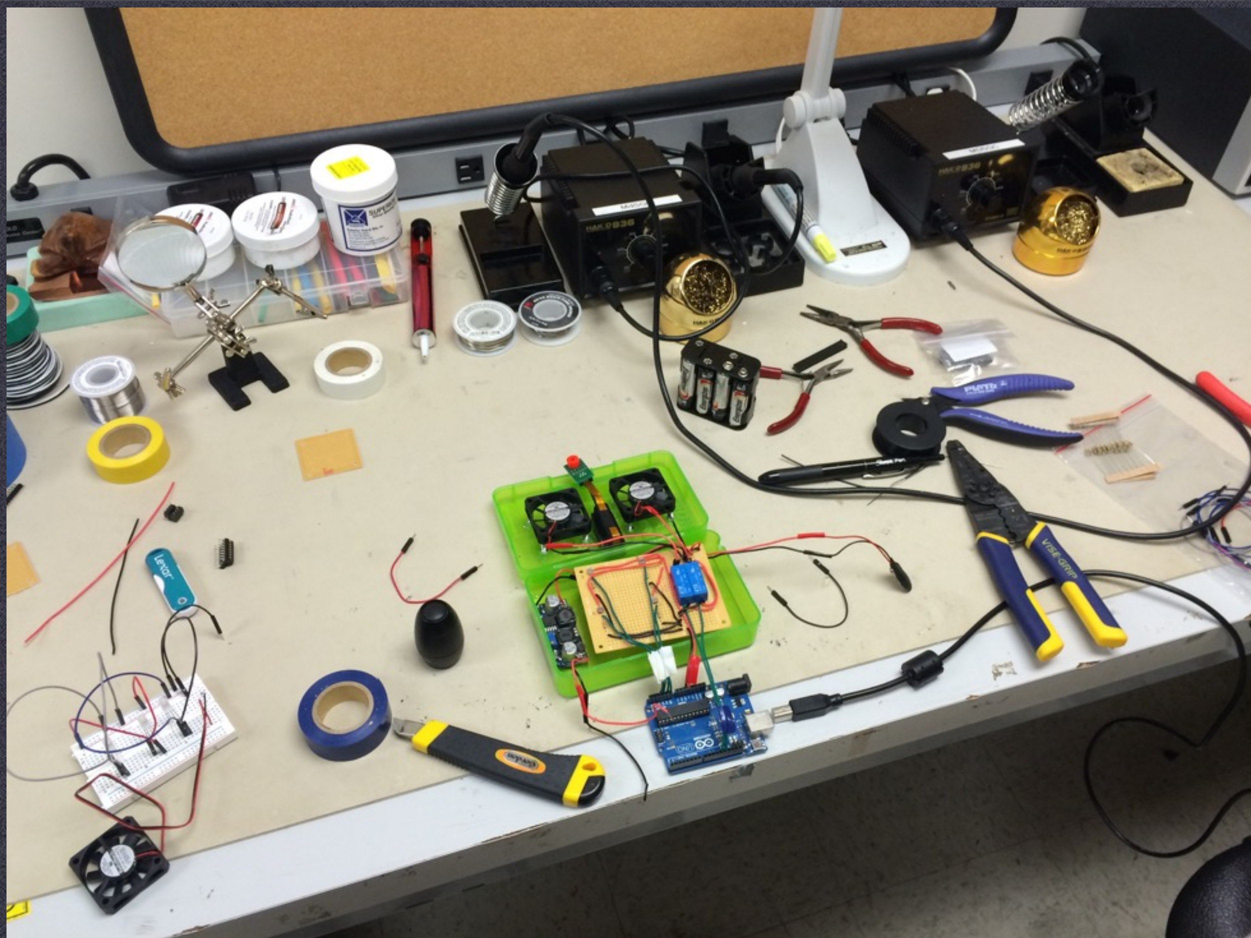
Mark II - “Heavy” - Subsystem Testing

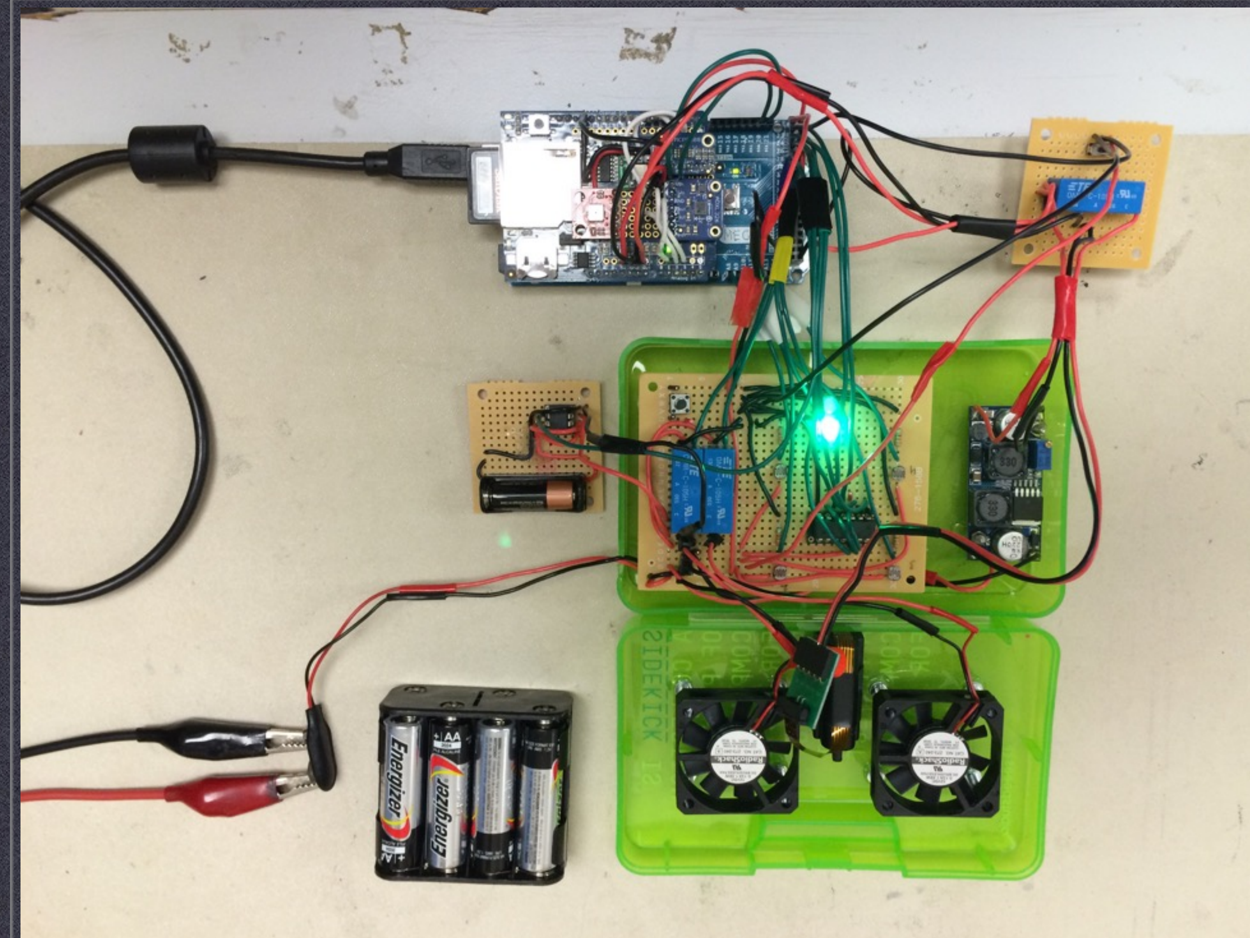
Intended as a platform for developing power regulation, actuation, sensor, and parachute subsystems, programming, internal structure.

- Dropped by static line test at 2km altitude
- Does not include parachute deployment system



BALLOON PAYLOAD PROGRAM
SUPERSONIC





Prototyping of Power Regulation, Sensors, and Actuation

- Inexpensive stand-in component used in place of expensive actuators in case of electrical short circuits
- Also used to diagnose coding errors

BALLOON PAYLOAD PROGRAM

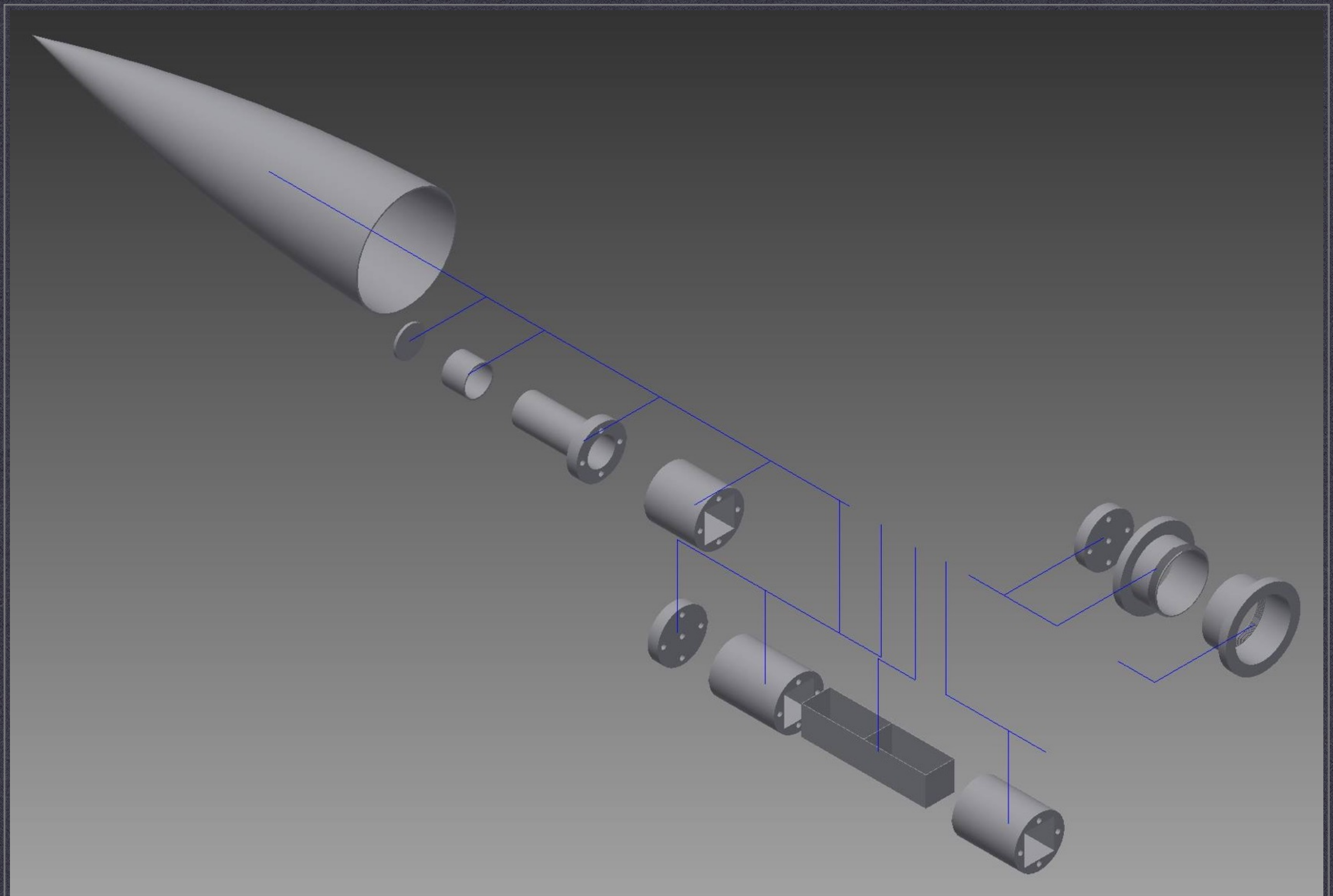
SUPERSONIC

Control Code

```
void loop(){
  Serial.print("Timer Output:   ");
  Serial.println(a);
  launch = digitalRead(4);
  if (a < 50 && dropped == false){
    if (startedup == false && locked == false && launch == false && flipped == false){
      digitalWrite(latchPin, LOW);
      shiftOut(dataPin, clockPin, MSBFIRST, B11110001);
      //  (act1-)(act1+)(act2-)(act2+)(LED-b3)(LED-b2)(LED-b1)(LED-g)
      digitalWrite(latchPin, HIGH);
      startedup = true;
      Serial.println("Started Up");
      delay(3000);
    }
    else if (startedup == true && locked == false && launch == false && flipped == false){
      digitalWrite(latchPin, LOW);
      shiftOut(dataPin, clockPin, MSBFIRST, B01010011);
      //  (act1-)(act1+)(act2-)(act2+)(LED-b3)(LED-b2)(LED-b1)(LED-g)
      digitalWrite(latchPin, HIGH);
      Serial.println("Locking...");
      delay(3000);
      digitalWrite(latchPin, LOW);
      shiftOut(dataPin, clockPin, MSBFIRST, B11110111);
      // (act1-)(act1+)(act2-)(act2+)(LED-b3)(LED-b2)(LED-b1)(LED-g)
      digitalWrite(latchPin, HIGH);
      Serial.println("Locked");
      locked = true;
      delay(3000);
    }
    else if(startedup == true && locked == true && launch == false && flipped == false){
```

BALLOON PAYLOAD PROGRAM
SUPERSONIC

Lower Structure - Exploded View



BALLOON PAYLOAD PROGRAM
SUPERSONIC

Lower structure prints

- 5% infill, 3D printed PLA plastic with hexagonal internal patterning for void space
- Nested electronics container
- Screw coupling for connection between upper and lower conical shells
- Sealed compartment for custom-cast lead weights
- Steel tie rods with nut and washer ends to hold components together

BALLOON PAYLOAD PROGRAM
SUPERSONIC

Electronics Container Test

Electrical Performance from Testing

- Minimum flight temperature was well above limit (7ºC)
- Pressure sensor accurately measured ambient conditions at altitudes of samples
  - Corroborated by exterior pressure sensors on other payloads
- GPS tracking was not as reliable as intended
  - Signal lost infrequently
  - Infrequent packet loss

Pressure determined best measurement to trigger drop and parachute deployment

GPS chip antenna replaces with larger patch antenna for better reliability

APRS radio module replaced with higher power unit
150mW to 330mW

Structural Performance from Testing

Electronics container proved durable and insulating

- Electronics container ready for Mark II

Additional Test on Overall Structure

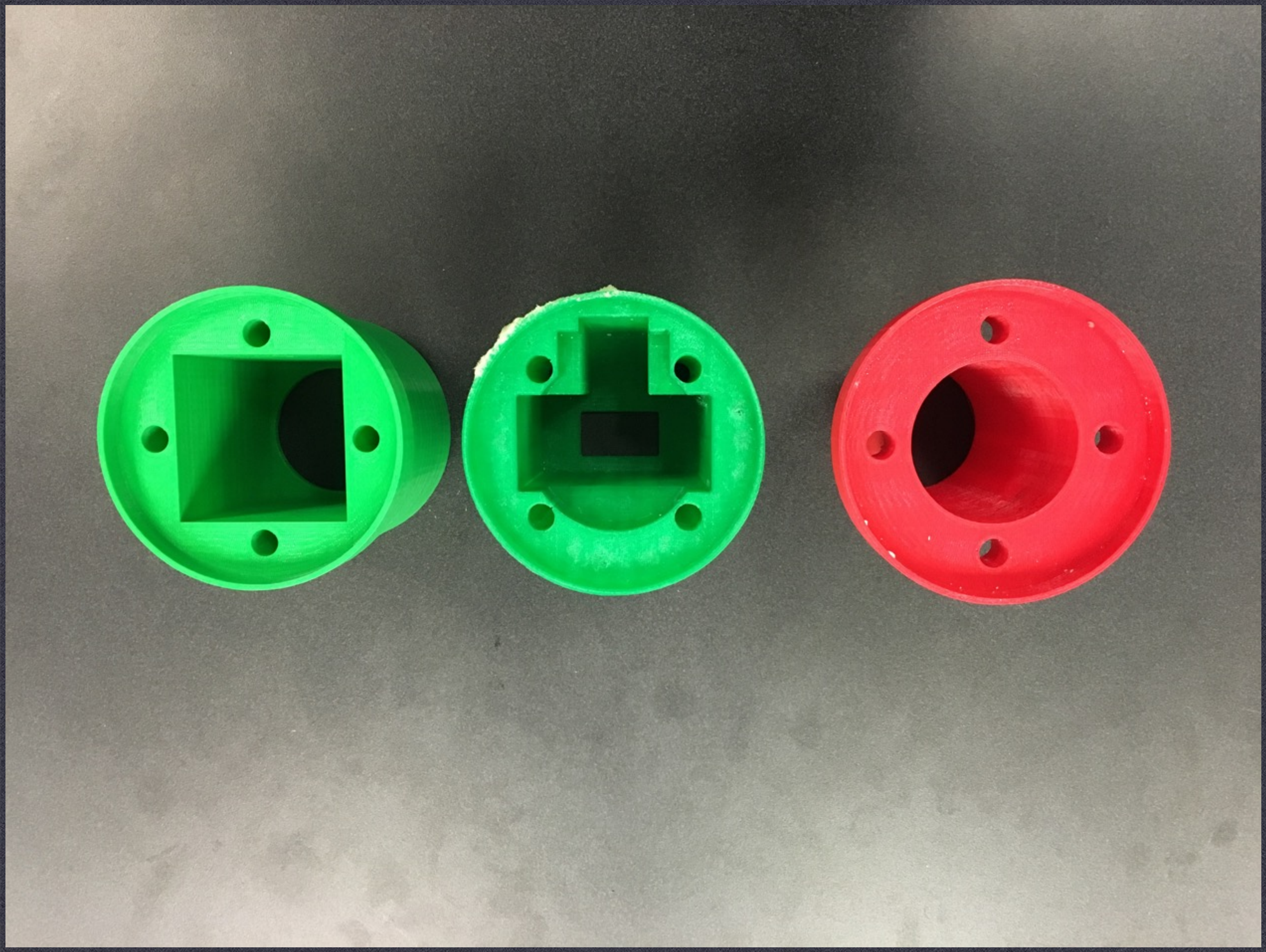
All printed structural components assembled into module, tied in to parachute system, dropped from tall parking garage

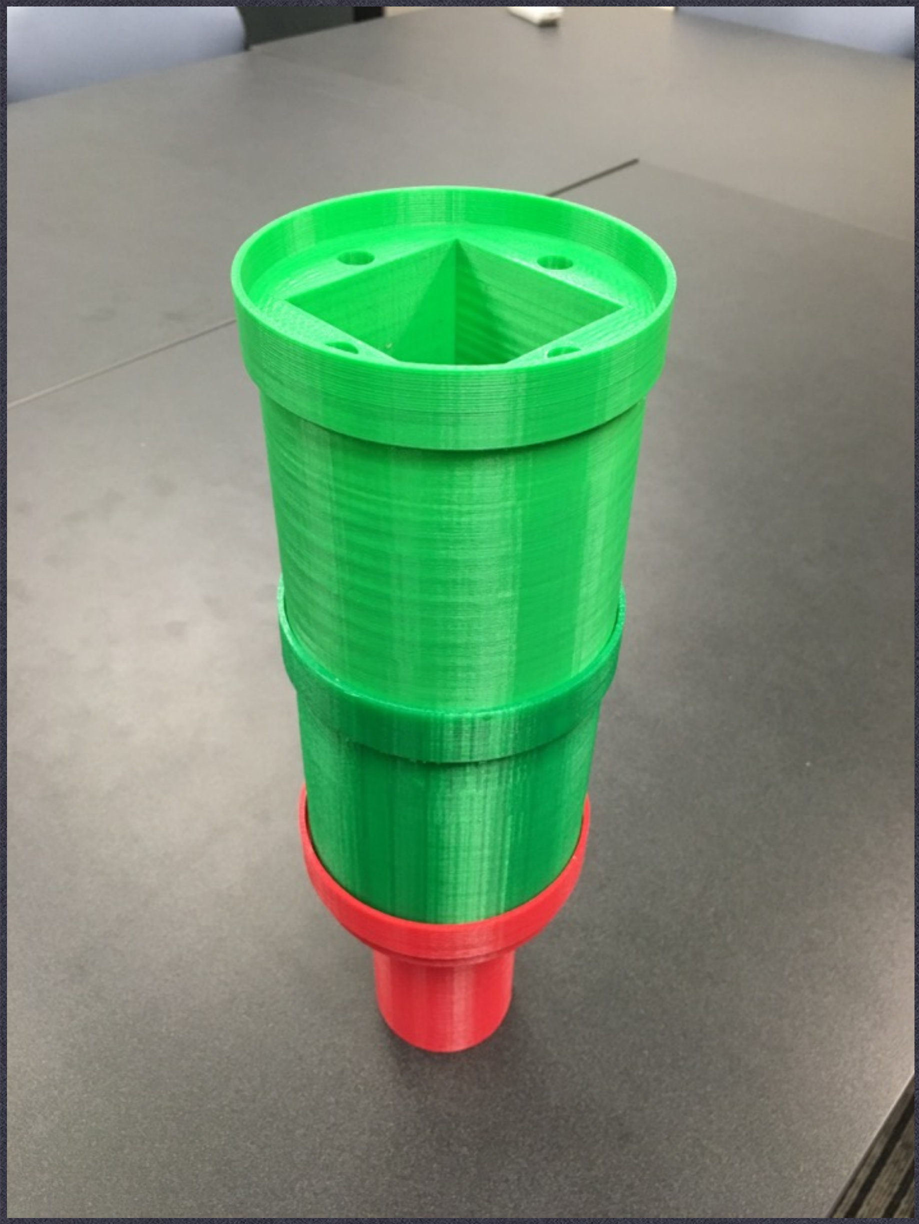
- Parachutes opened as expected
- Strong gust of wind blew module laterally into parking garage
    - Fractured several components
    - Damaged components reprinted with increase in infill percentage
    - Modification to add collar around component couplings
    - Screw coupling redesigned to allow for actuator mounting

BALLOON PAYLOAD PROGRAM

SUPERSONIC

Modified Component Reprints

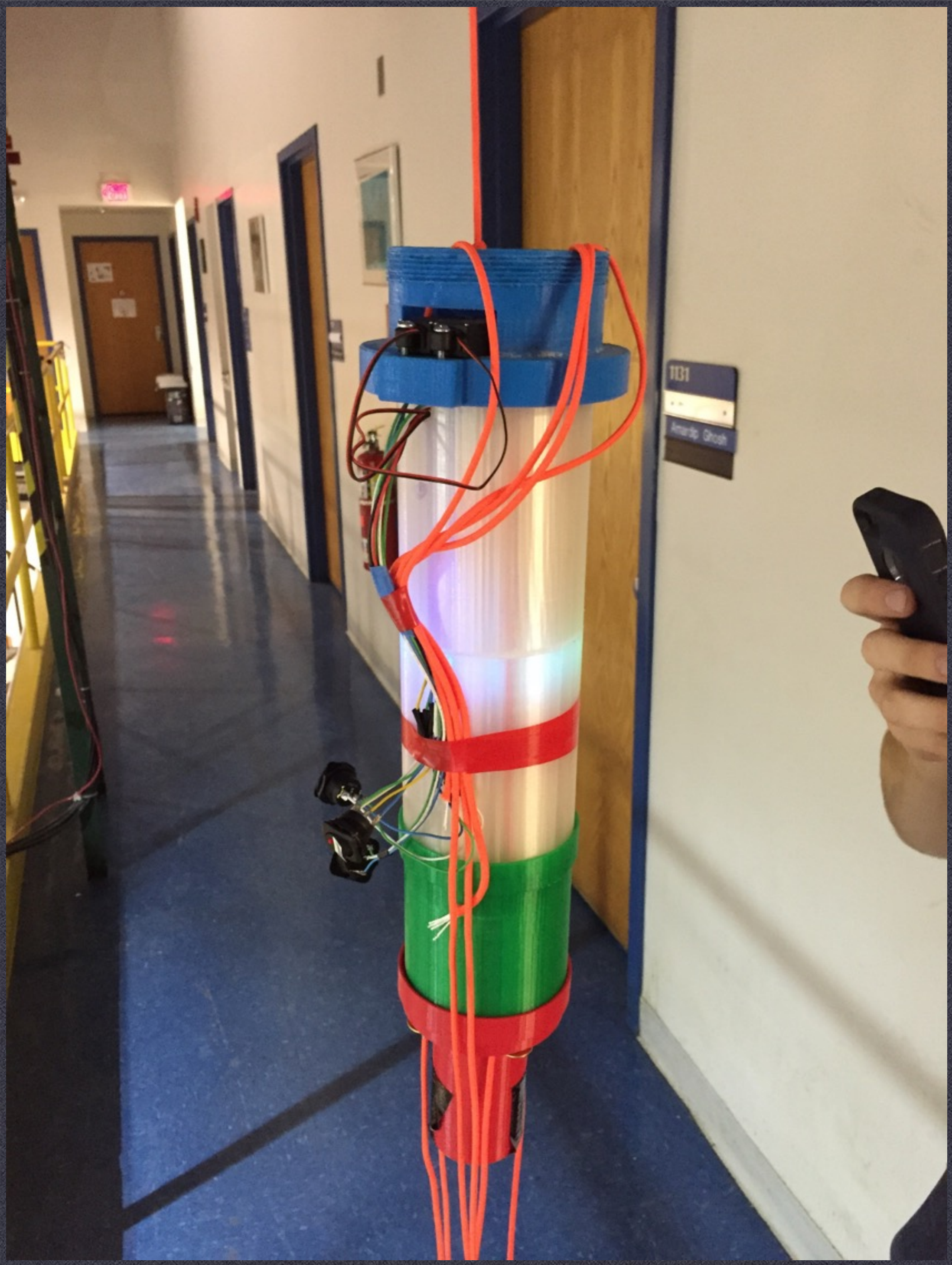




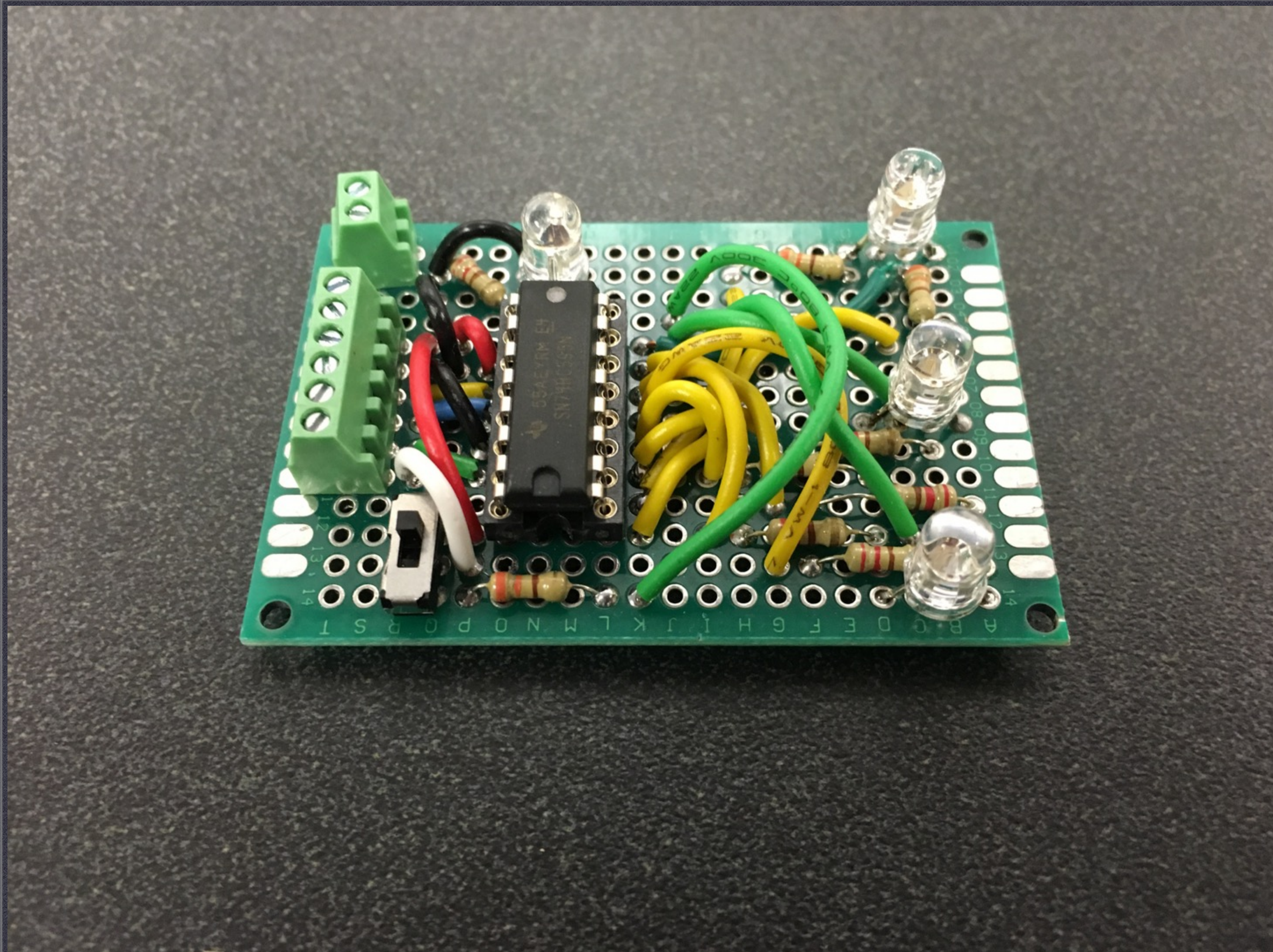
Modified Component Reprints

BALLOON PAYLOAD PROGRAM
SUPERSONIC

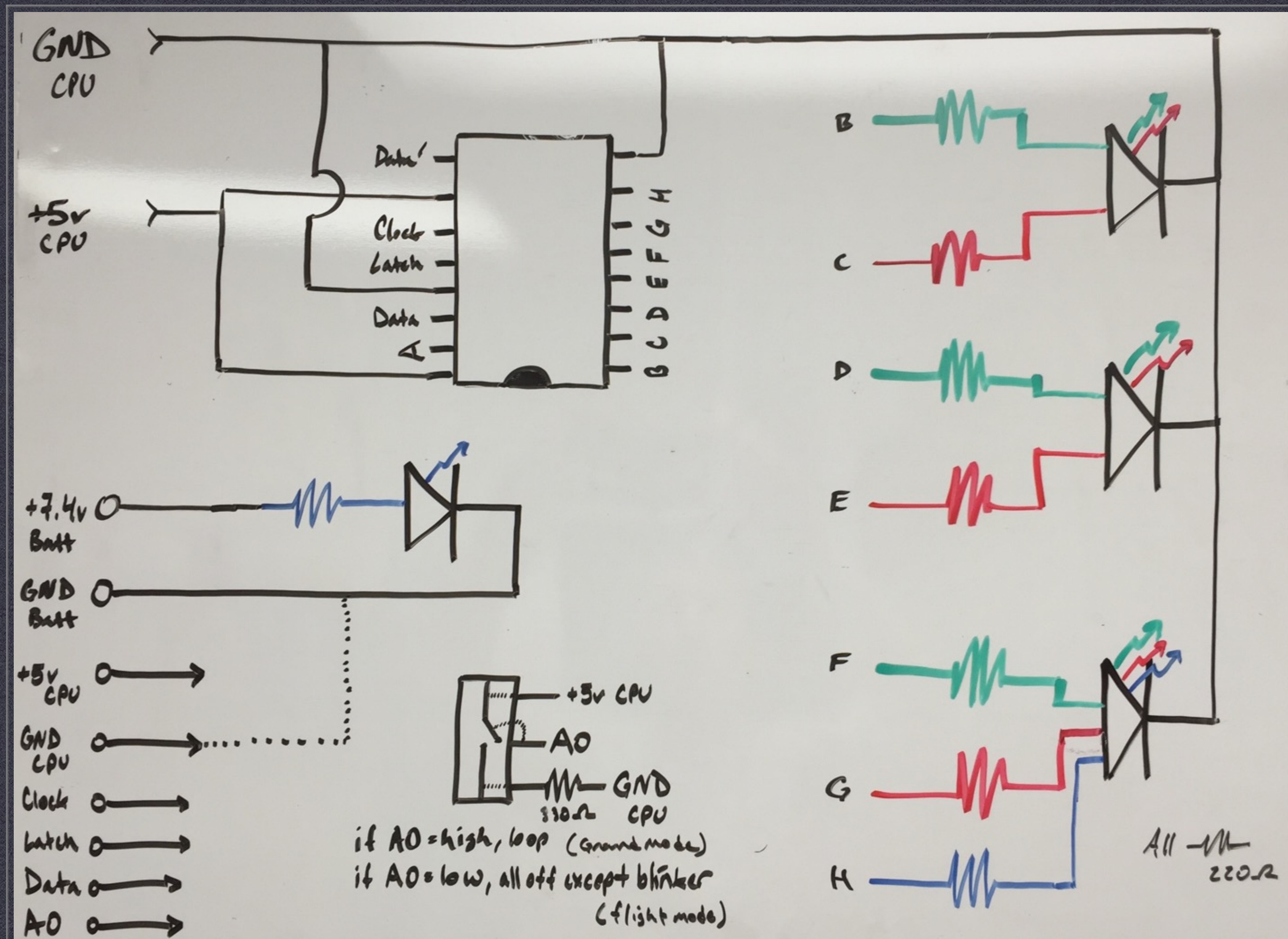
Fully Assembled Internal Components - Mark II



Custom Hardware - LED Status Indicator

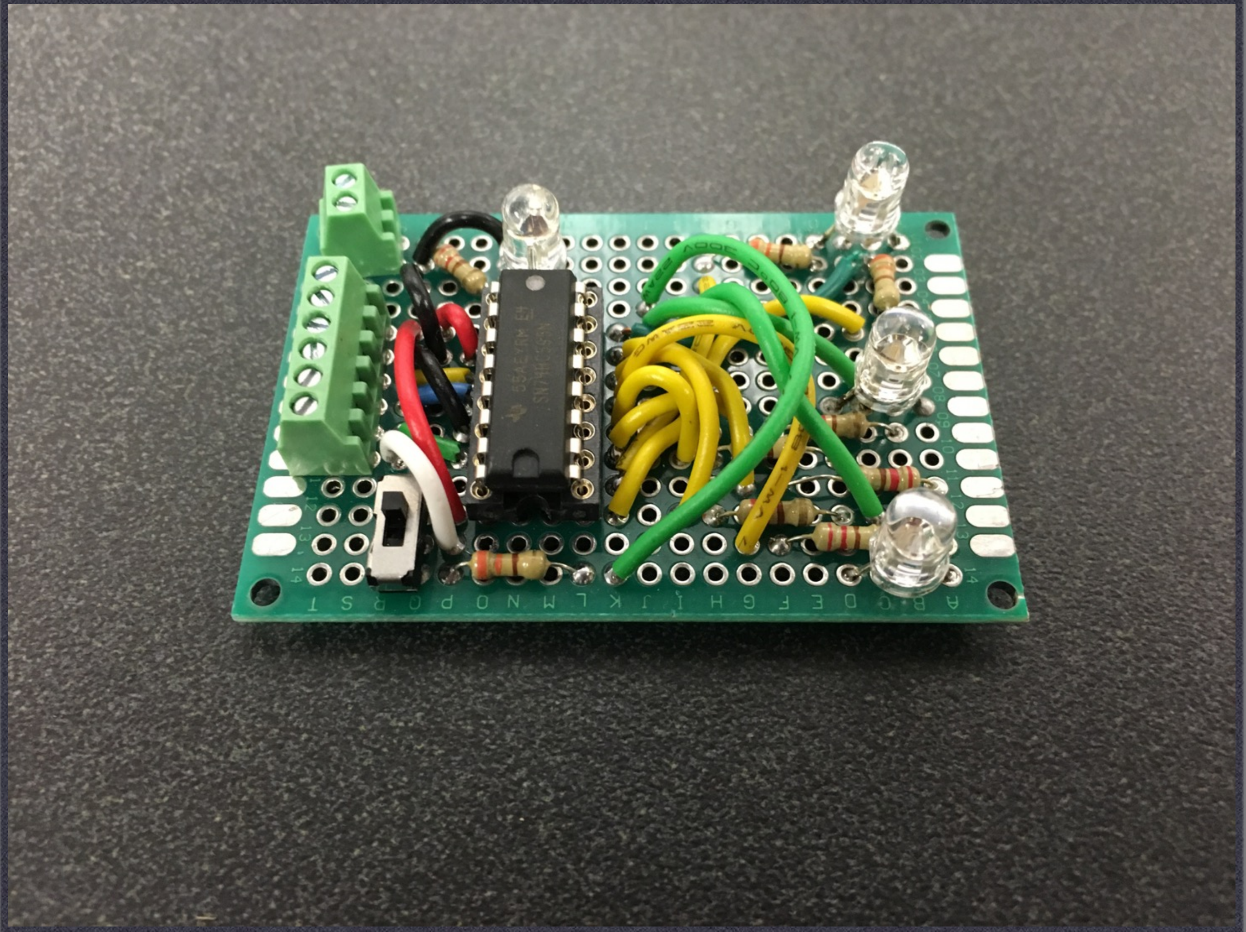


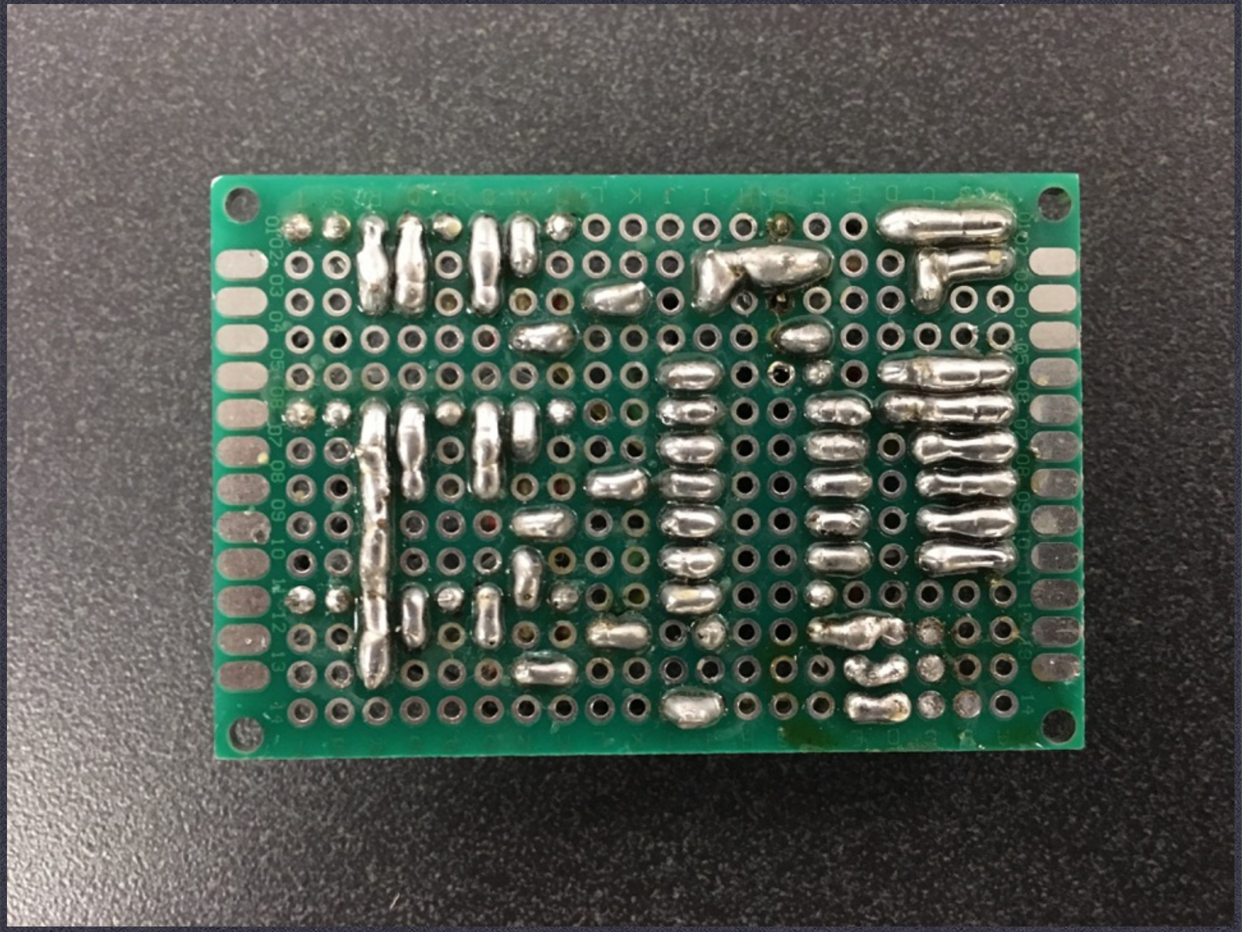
Circuit Design



BALLOON PAYLOAD PROGRAM
SUPERSONIC - LED STATUS INDICATOR

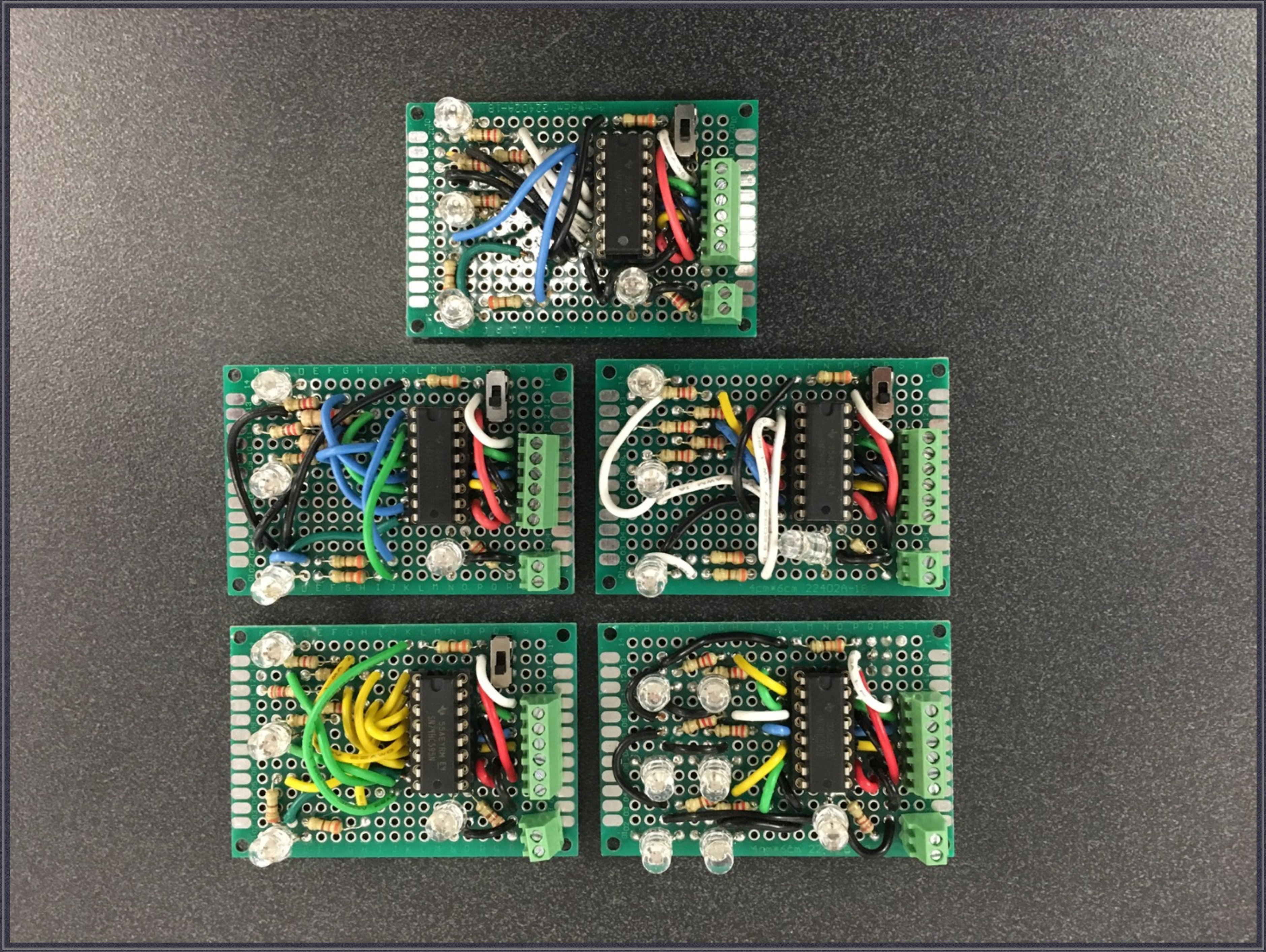
Construction





BALLOON PAYLOAD PROGRAM
SUPERSONIC - LED STATUS INDICATOR

Adoption



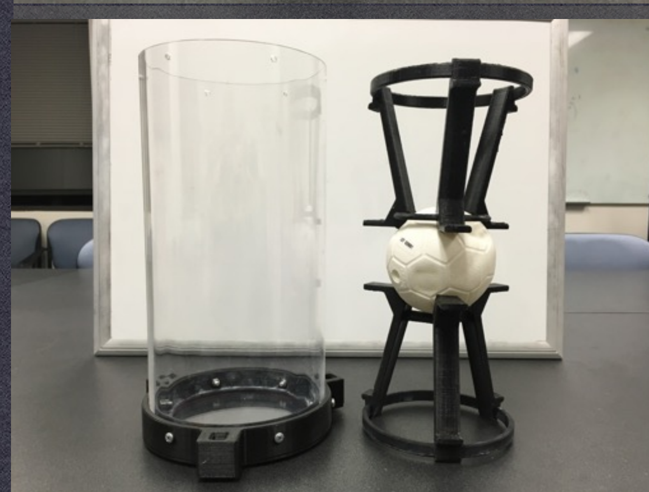
2km Static Line Drop Test Recovery

Next Phase of Project - Mark III “TBD”

- Development of parachute deployment subsystem
- Implementation of active radio control [Neel Patel & Nick Rossomando]
- Research into velocity measuring methods [Steve Lentine]
- Aerodynamic shell [Neel Patel]

Expected Launch June 2016

LOOKING GLASS



BALLOON PAYLOAD PROGRAM
LOOKING GLASS

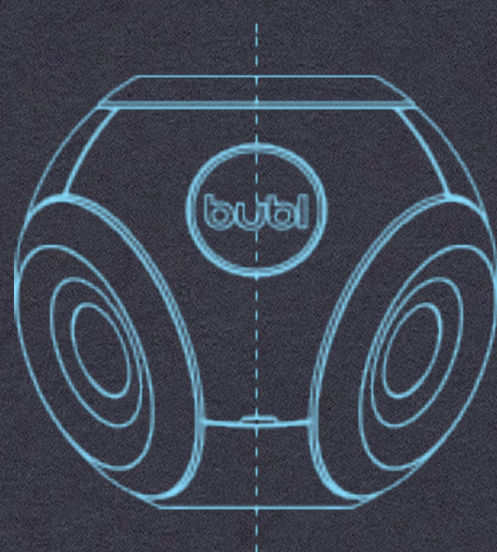
Concept Objective

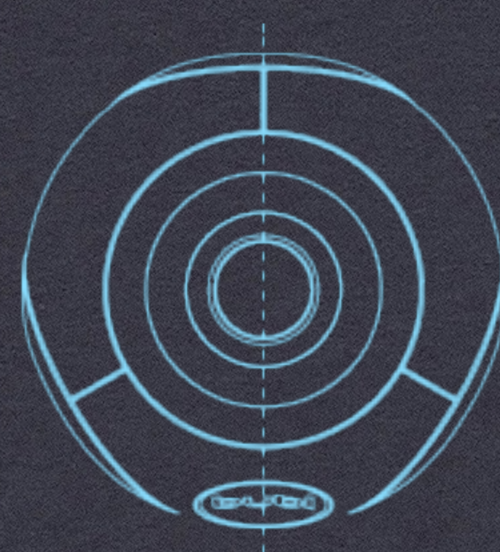
To build a container to house a prototype version of the Bublcam 360º camera, on loan from Bubl inc., during flight and return it safely.

- Transparent structure for camera view
- Rigid structure to withstand recovery
- Video captured compatible with OculusRift

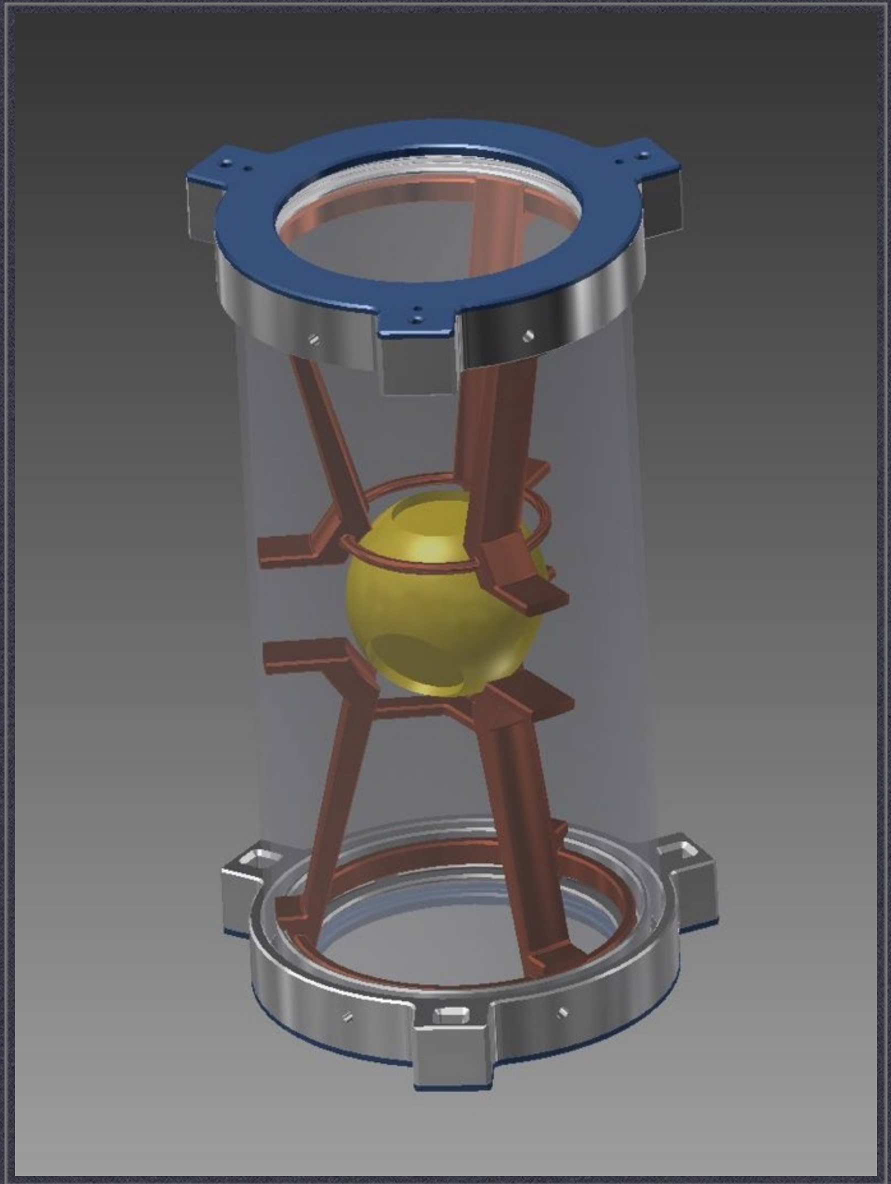
Method

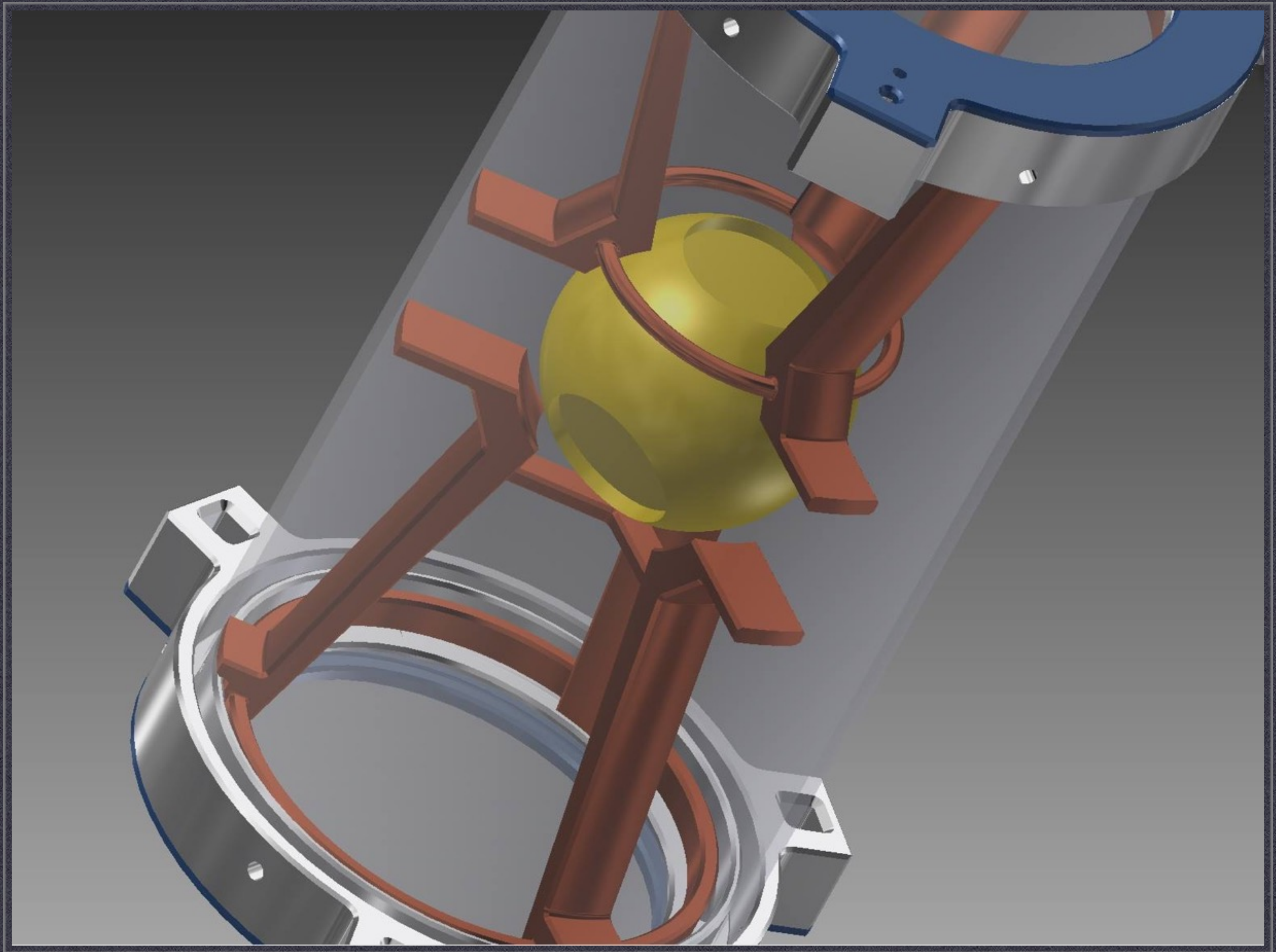
Single purpose 3D printed compression structure within acrylic cylinder and segmented 3D printed end caps





Design Model





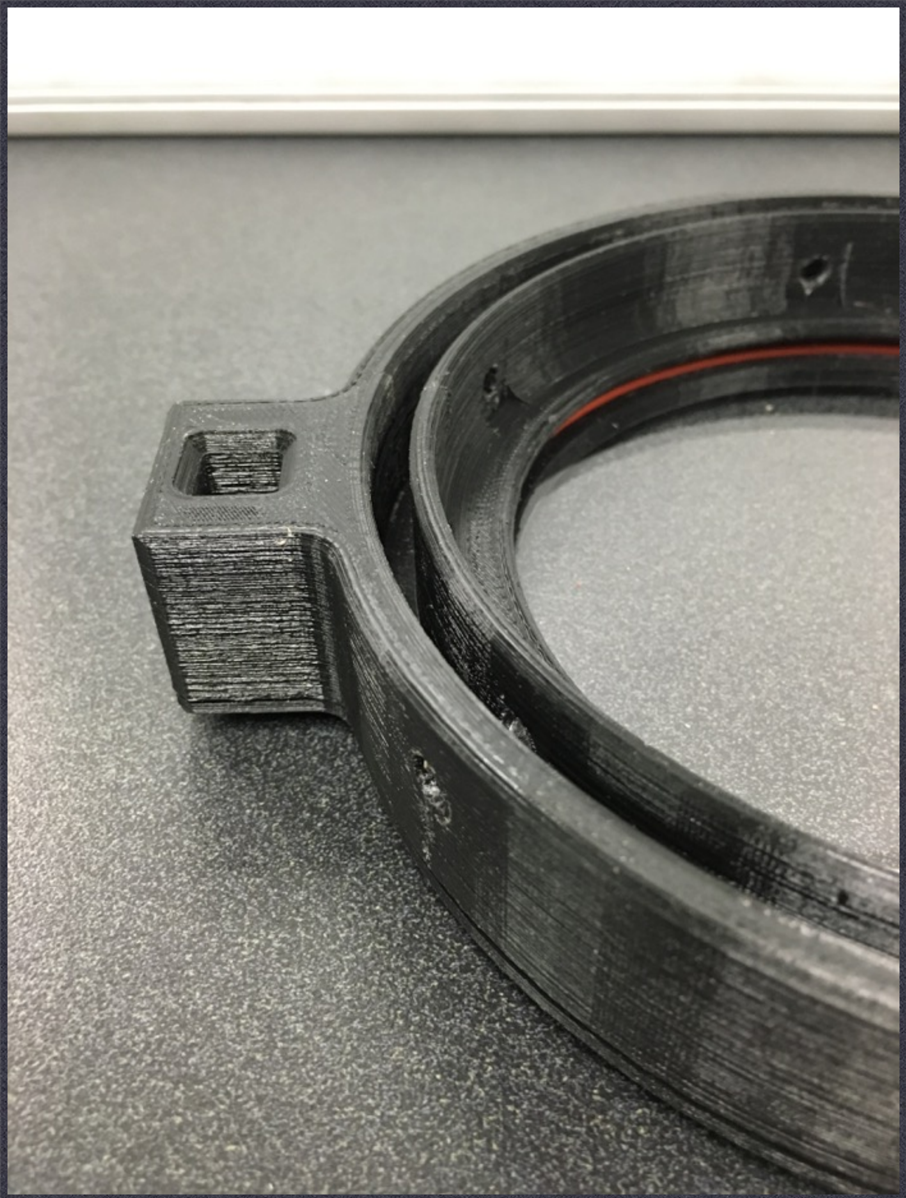
Printed Structure

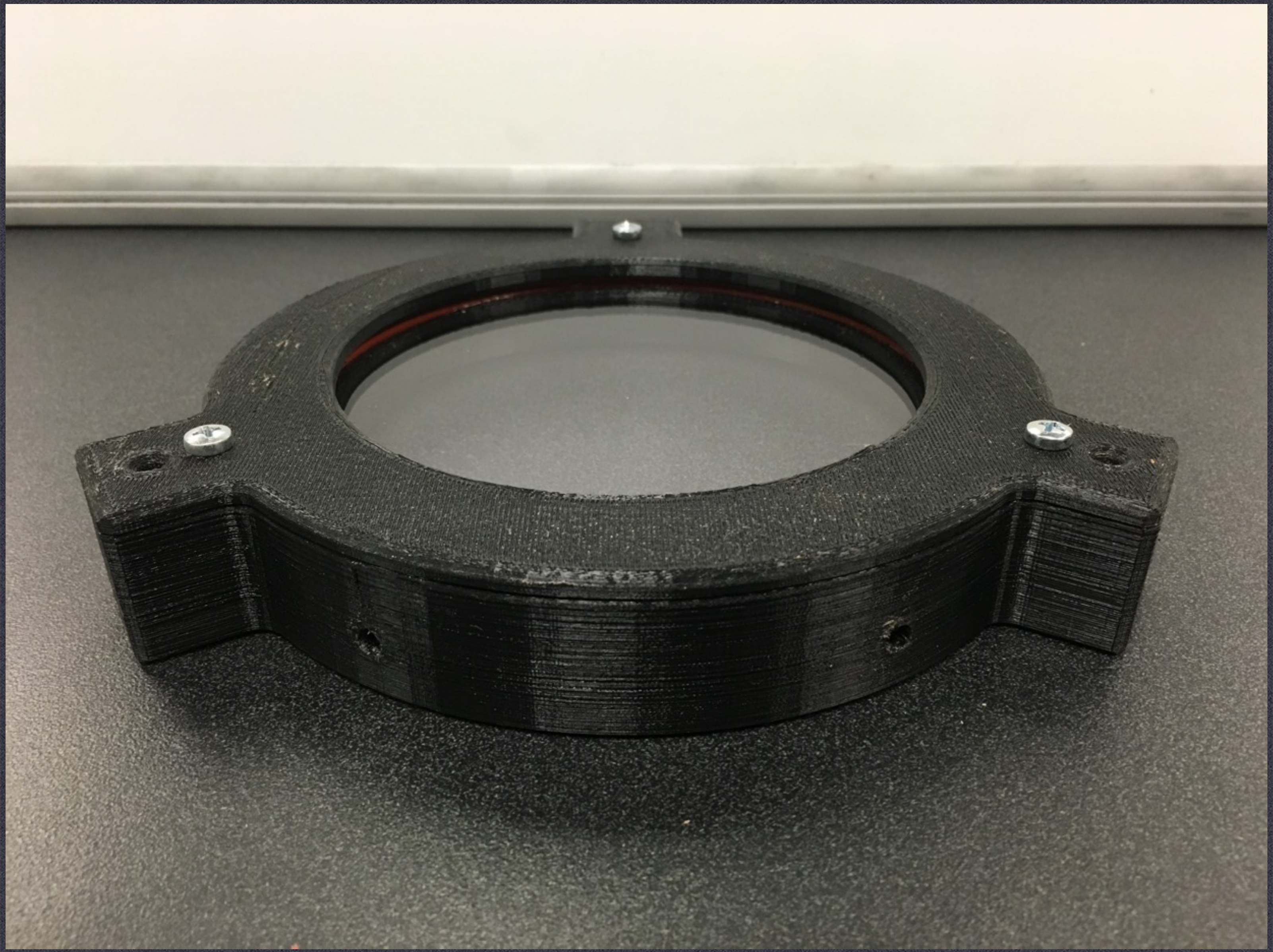
Internal Structure Components

Internal Structure Components

BALLOON PAYLOAD PROGRAM
LOOKING GLASS

End Cap Components





Pre-Launch Condition

Post-Launch Condition

Launch Image from 2500m

Structure Performance

- Acrylic received minor scratches from impact, no fractures
- 3D printed end caps in tact, no damage
- Internal structure in tact, remained in compression during flight, no damage

Camera Performance

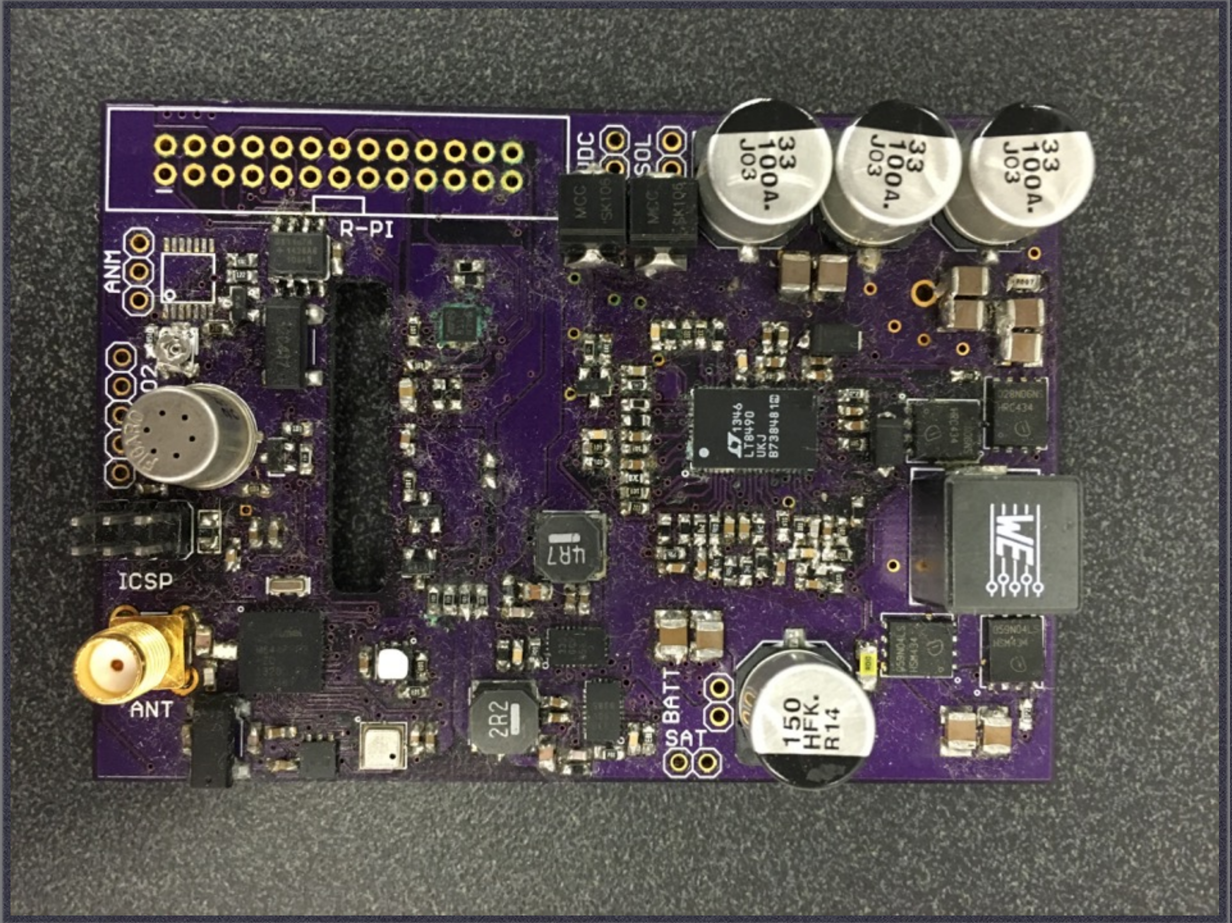
- Camera survived impact, no damage
- Glitch in software switched from video to camera mode
- Pictures to 3000m, then battery life exceeded
- Poor resolution camera, low battery capacity

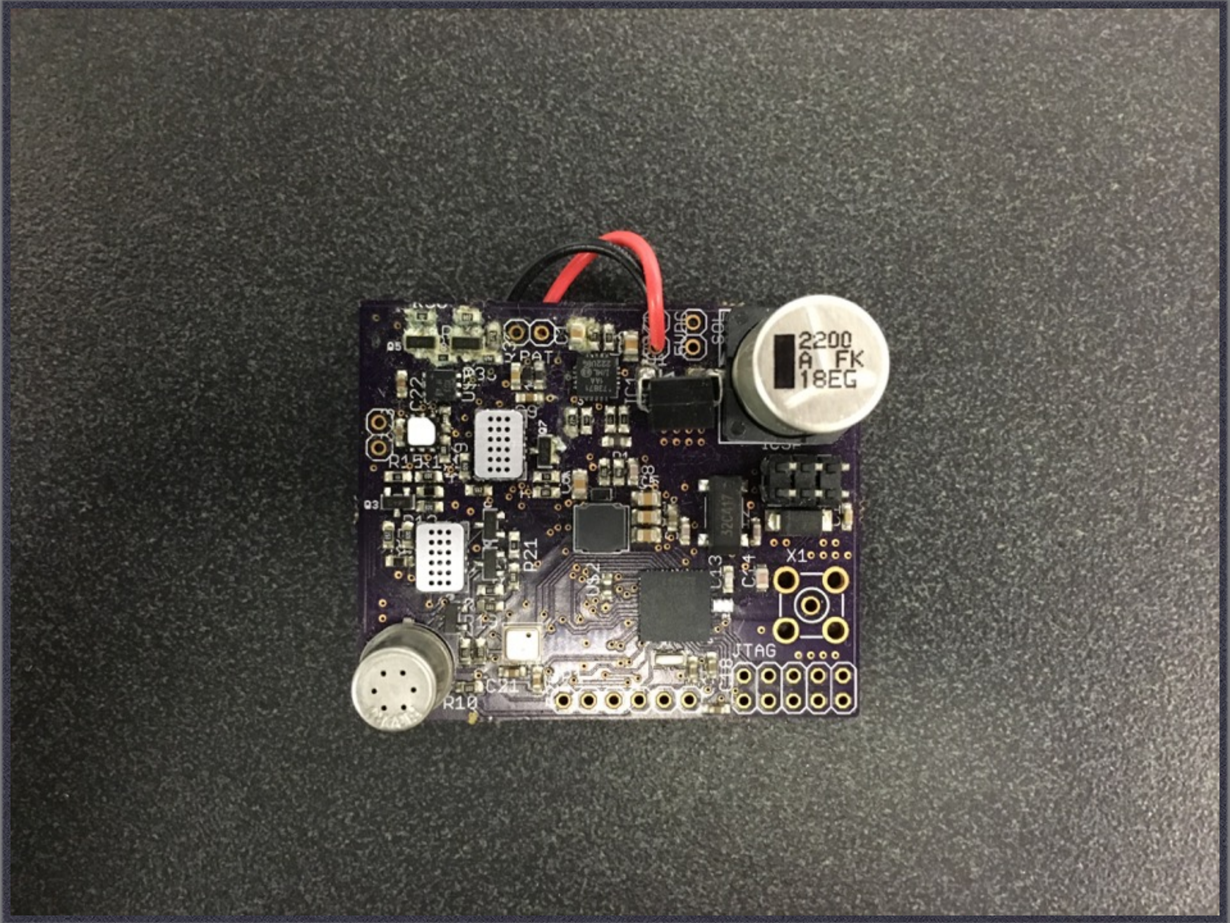
SOME ADDITIONAL PROJECTS
SENSE PROGRAM, ATMOS SMT BOARDS

Project Objective

To develop a network of high-accuracy sensor stations to monitor weather, air pollution, greenhouse gases for under $500 per station using embedded systems design

- **Current high-accuracy options are too expensive [~$100,000]**
- **Low-accuracy stations are widespread but lack sensitivity**



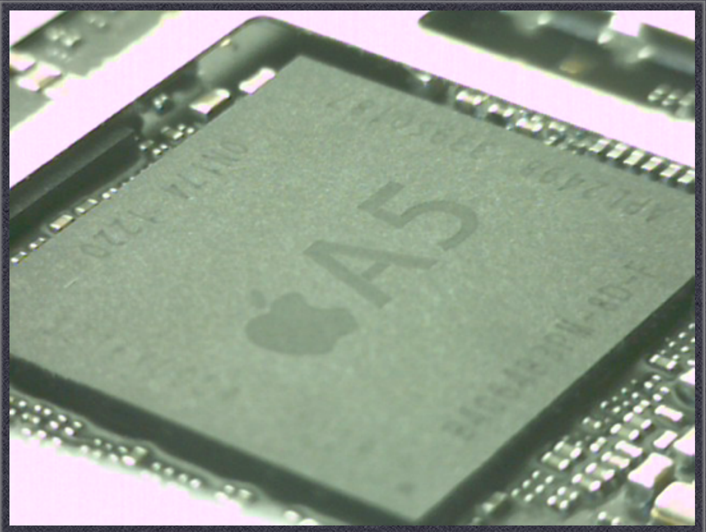


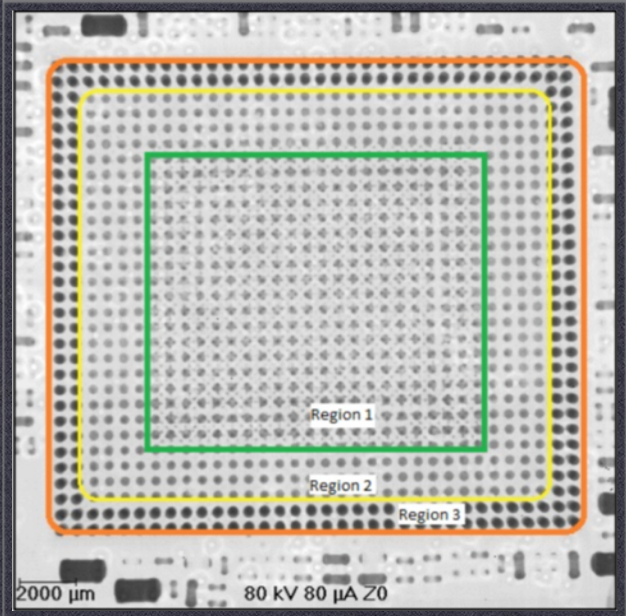
SOME ADDITIONAL PROJECTS
APPLE IPAD MINI SEMICONDUCTOR PACKAGING ANALYSIS

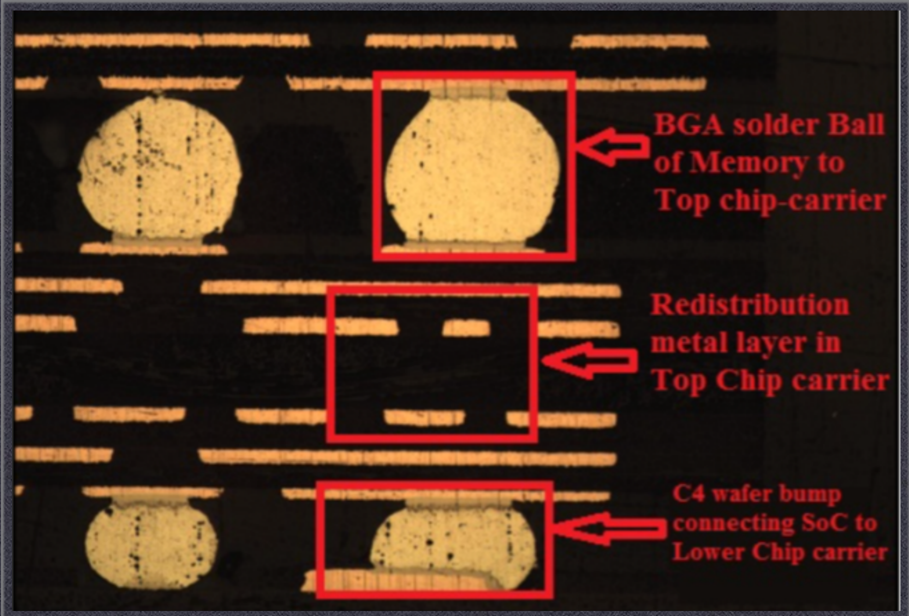
Project Objective

Disassemble and examine Apple iPad Mini [1st generation, WiFi+GSM] circuit board to study semiconductor packaging technologies used by industry leader to analyze current state of the art

- **Focus on A5 System-on-Chip using X-Ray Imaging and encapsulated cross-sectioning**





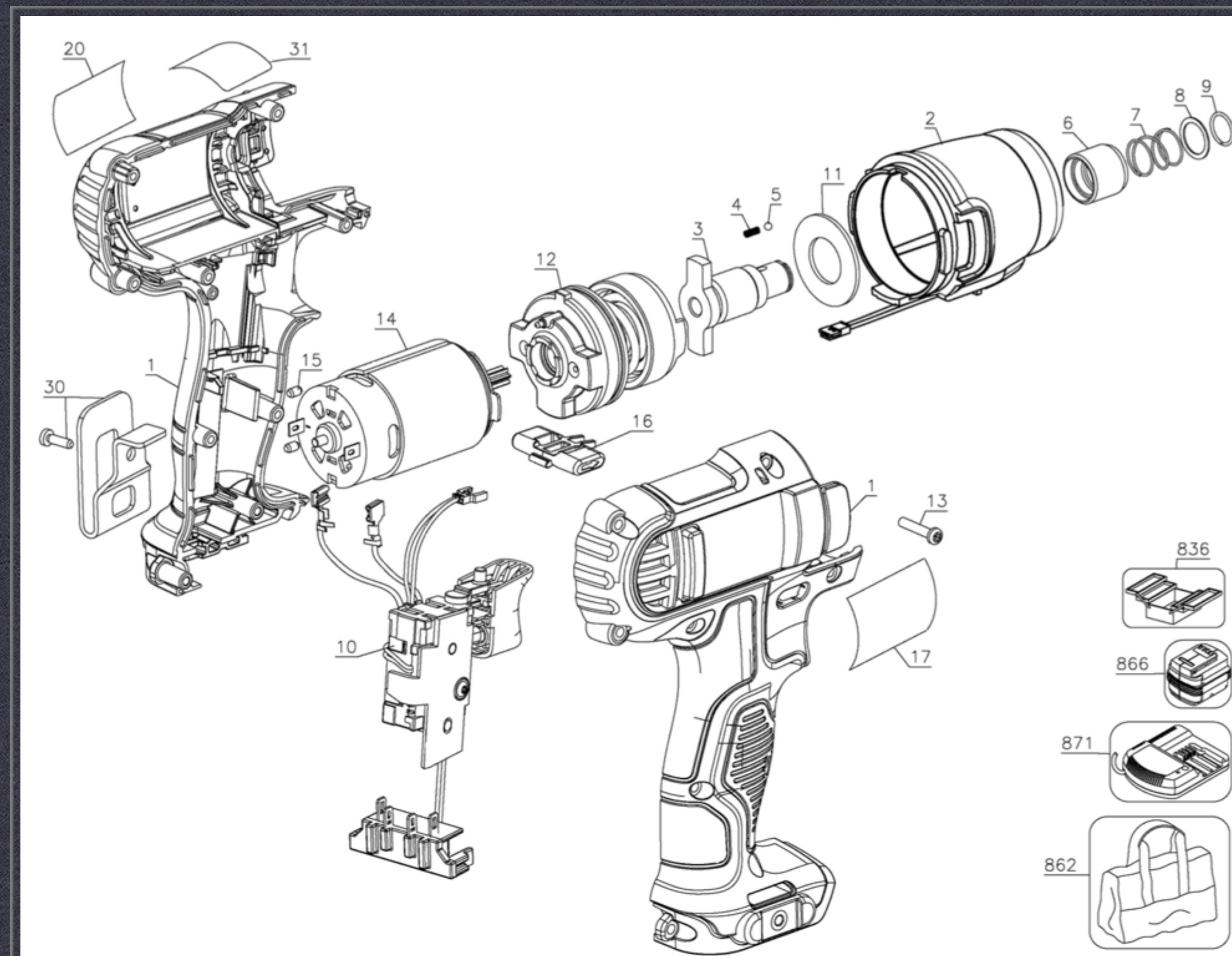


SOME ADDITIONAL PROJECTS
DEWALT DCF815 DESIGN ANALYSIS

Project Objective

To disassemble a DeWalt impact driver, study the tool subsystems with respect to their physical, thermal, electrical, stack-up, and DFM characteristics, and design tool improvements

- **Detailed analysis of each component within each subsystem, and the manufacturing process the produced that component**
- **Presented tool improvements to the design team at DeWalt that created the DCF815 and a panel of professors and instructors, in a setting similar to a PDR, for review and discussion**

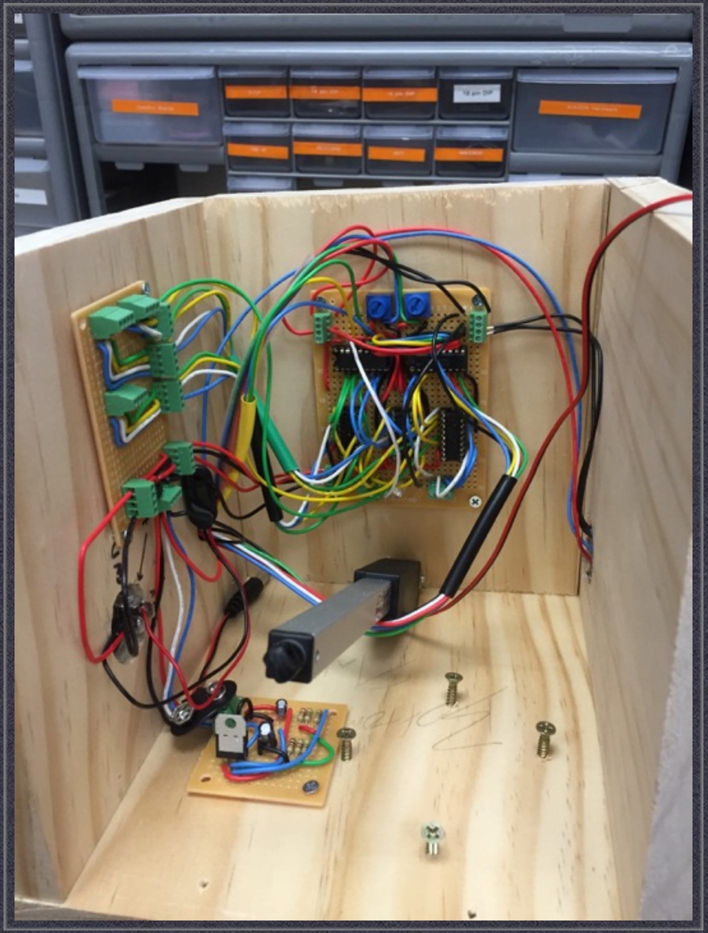


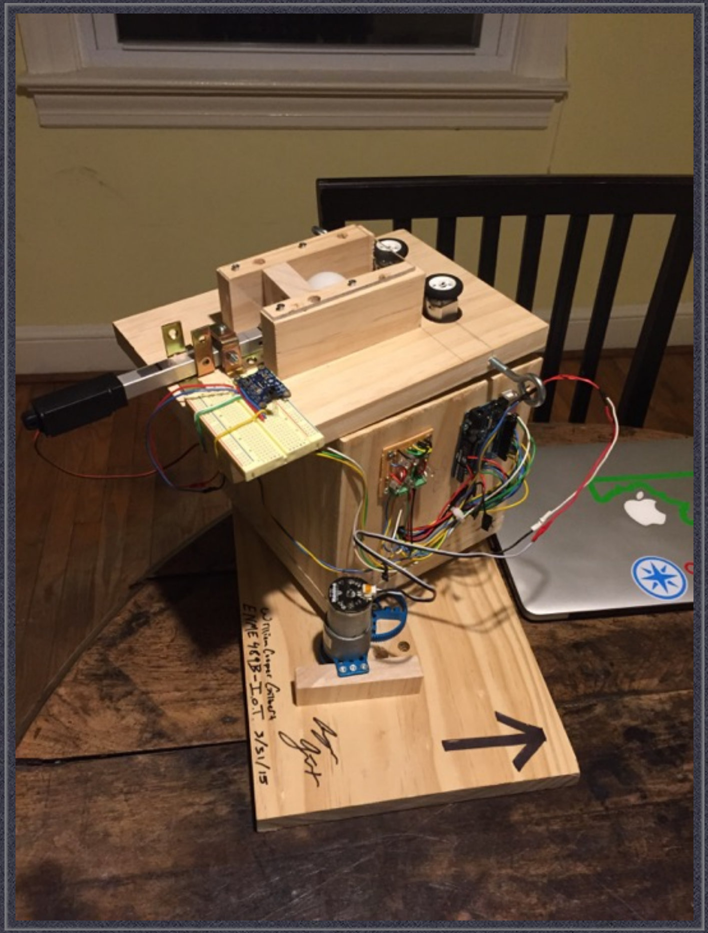
SOME ADDITIONAL PROJECTS
INFRARED REMOTE CONTROLLED PINGPONG BALL TURRET

Project Objective

Using predetermined motors, build a system that demonstrates full range of motion and can fire a pingpong ball with accuracy at multiple targets using infrared user control

- System records and stores IR signals for each command in setup mode for recall during firing mode
- Programmed in C++, uses 9 DOF IMU to determine relative position of firing platform in space
- Custom power regulation and redistribution circuits

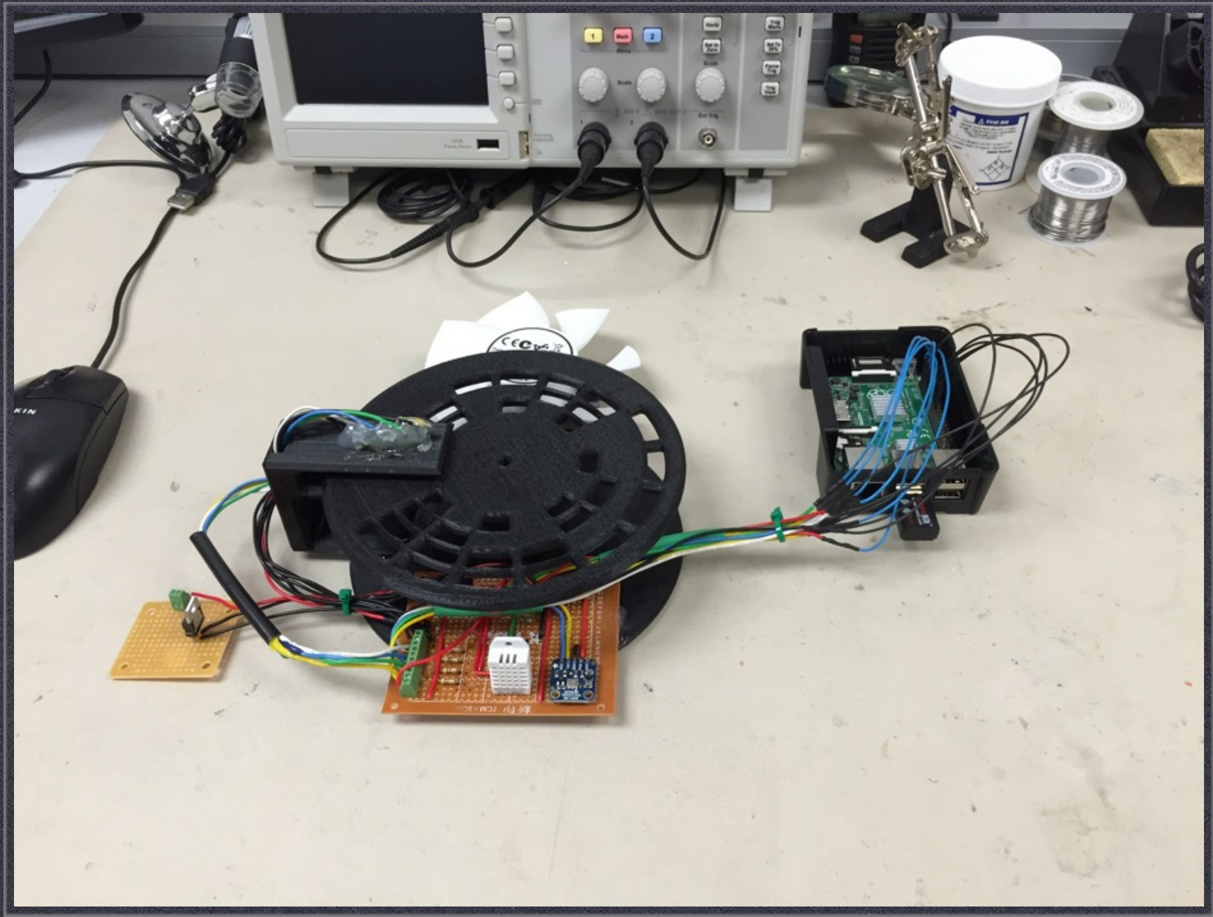




Project Objective

To build an autonomous weather station, programmed in Python and using Raspberry Pi as a processor and Apache server, measuring temperature, pressure, humidity, windspeed, and wind direction

- Optical encoder using LEDs and photo-resistors with 3D printed encoder disk for 22.5º resolution wind direction
- Instantaneous measurements available from web address call, time range measurements sent to database [ThingSpeak] at 1Hz, available with HTML file



Q & A