PACER Program
Flight Readiness Review Document
for the
Experiment HumTemP

by

Team SPARTA (Space Proximity Atmospheric Research above Tropospheric Altitudes)

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1.0 Document Purpose
This document describes the preliminary design for the humidity measurement experiment by Team SPARTA for the PACER Program. It fulfills part of the PACER Project requirements for the Flight Readiness Review (FRR) to be held July 25, 2008.

1.1. Document Scope
This FRR document specifies the scientific purpose and requirements for the Humidity Measurement experiment and provides a guideline for the development, operation and cost of this payload under the PACER Project. The document includes details of the payload design, fabrication, integration, testing, flight operation, and data analysis. In addition, project management, timelines, work breakdown, expenditures and risk management is discussed. Finally, the designs and plans presented here are preliminary and will be finalized at the time of the Flight Readiness Review (FRR).

1.2. Change Control and Update Procedures
Changes to this FRR document shall only be made after approval by designated representatives from Team SPARTA and the PACER Institution Representative. Document change requests should be sent to Team members and the PACER Institution Representative and the PACER Project.

2.0 Reference Documents


5. PACER Summer Program Critical Design Review Document for the Aerospace Balloon Imaging Testing with Accelerometer (ABITA) by The InterAmerican


3.0 Goals, Objectives, Requirements

3.1. Mission Goal
Our goal for this experiment is to better understand the complex characteristics of the atmosphere by investigating humidity, temperature and pressure within the troposphere, tropopause and lower stratosphere.

3.2. Objectives

3.2.1. Science Objectives
• Determine the relationship between pressure, humidity, and temperature within the troposphere, tropopause and stratosphere as a function of altitude.
• Compare the decrease of temperature with the change in pressure as altitude increases.
• Compare the data we obtained with data obtained from previous experiments by NOAA which collects data points every minute.
• Measure the increase in relative humidity above the tropopause.
• Calculate mixing ratio from measurements.

3.3. Technical Background and Requirements

3.3.1. Technical Objectives
• Launch a 0.5 kg payload 30km above the earth’s surface within the constraints of the budget and weight requirements.
• Construct a payload that will survive the extreme conditions of the tropopause layer of the atmosphere.
• Sensors will record data twice every minute for one second.
• Recover reliable measurements of relative humidity, temperature, and pressure in a near vacuum environment for the duration of the flight.
• Data recorded on electronics are recoverable after descent and landing.
• Compare data recorded during flight to data taken by NOAA
3.4. Science Background and Requirements

3.4.1. Science Background

What is the atmosphere? For earth, the atmosphere is a region surrounding the planet that is commonly referred to as air. This air is a mixture of 78% nitrogen, 21% oxygen, 0.9% argon, and 0.03% carbon dioxide: oxygen (O$_2$) and nitrogen (N$_2$) in the form of diatomic molecules. While there is no distinct boundary between the earth’s atmosphere and space, the atmosphere gradually thins and pressure decreases with an increasing altitude. Atmospheric pressure is the force applied to an object by the weight of the atmospheric gases above it, atmospheric pressure at sea level is $1.01 \times 10^5$ Pa or 14.7 lb/in$^2$. Within this gaseous region are layers: troposphere, stratosphere, mesosphere, and the thermosphere with thin buffer regions in between each layer seen in Figure 3-1. The troposphere begins at the earth’s surface or sea level to generally 16km above. The denser air of the troposphere contains 80% of the atmospheric mass. It is in this layer that temperatures decreasing to as low as -70°C as a function of increasing altitudes at a rate of 6.5°C/km. The troposphere is also the region where varying ranges in temperature and humidity can be observed as weather, changing atmospheric conditions. Temperature is the measure of the average kinetic energy of a system’s particles. Humidity is the water vapor content in the air. Often humidity is reported as relative humidity and given in a percentage. Relative humidity, also referred to as humidity in this paper, is the ratio of actual vapor pressure to saturation vapor pressure (the maximum moisture capacity of the air). Specific humidity is the ratio of the mass of water vapor to the total mass of air in the units of g/kg. Mixing ratio is the ratio the mass of water vapor to the mass of dry air in the units of g/kg. The specific humidity should be similar to the mixing ratio. We will calculate the mixing ratio for our flight data.

Above the troposphere, extending to 50km is the stratosphere. Ninety-nine percent of the atmospheric mass is found in the troposphere and stratosphere. Unlike the troposphere, the temperature increases with altitude, however, non-uniformly. The increase of temperature in the stratosphere is due to the ozone layer: a blanket of Oxygen (O$_3$) molecules. The ozone layer filters most of the energetic short waves, ultraviolet light, from the sun, giving off heat causing the rise in temperature of the stratosphere. In the next layer, the mesosphere temperature decreases rather uniformly, reaching temperatures as low as -90°C. This is the coldest region of the atmosphere. The mesosphere begins nearly 50km high stretching to 80km in altitude. Right above the mesosphere is the thermosphere it is heated by the sun up to temperatures reaching 1000°C. Atmospheric ballooning and satellite research has shown small traces of water vapor are found above the altitude where water will freeze. This is the essence of our investigation. We intend to launch a balloon payload that will record humidity levels, temperature and pressure levels, in order to answer questions about the increase in humidity. Water vapor, one of the greenhouse gasses is important to further understand global warming. Solar radiation of the sun passes through the atmosphere and is absorbed by the surface of the earth. This energy is then emitted back as infrared radiation. While a small
percentage of this radiation escapes into space most is trapped in by the greenhouse gases, such as water vapor, to warm the troposphere. Under ideal conditions there is a perfect balance of incoming and releasing heat back out into space that keeps the earth’s climate in the steady state. Global warming, an increase of the average temperature of the atmosphere, is attributed to an increase of greenhouse gases. The presence of and the increase of humidity in the upper atmosphere could suggest an increase in greenhouse gases. There have been many experiments conducted in an effort to understand the existence of water vapor in the upper atmosphere. The National Oceanic and Atmospheric Administration (NOAA) launch two sounding balloons a day at sites around the US. One of the reasons for experiments is to observe whether these greenhouses gases are increasing, the rate of increase, and which of the greenhouse gases are contributing. The data we will discuss was retrieved from sounding balloons launched from Ft. Worth, Texas during the summer of 2007. Figure 3-2 illustrates temperature and humidity as a function of increasing altitude. In the first 10km, the troposphere, there is a decrease in temperature. As well, there is a decrease in relative humidity with some variations due to the dynamic nature of weather. From 10km to 50km, the stratosphere, temperature increases while humidity continues to decline, but not to zero. This data indicates the presence of small amounts of water vapor present in a region of the atmosphere that is below freezing. Figure 3-3 is a plot of the mixing ratio as a function of altitude; we see an increase of water vapor above 28km. We will be launching our payload in the summer from Palestine, Texas. Therefore, we expect our data to be comparable to the atmospheric sounding data collected from NOAA’s summer data from Fort Worth, Texas for pressure, relative humidity, temperature and mixing ratio.

Figure 3-1  Temperature profile with increasing altitude
Figure 3-2  Temperature and relative humidity as a function of altitude

Figure 3-3  Mixing ratio as a function of altitude
3.4.2. Science Requirements
In order to successfully conduct this experiment, and based on some data we have obtained, we need to:

- Focus relative humidity measurements on the upper troposphere through the lower stratosphere.
- Compare our flight data to NOAA’s flight data to aid in the investigation of the troposphere, tropopause and stratosphere.
- Collect at least 360 data points containing humidity readings as low as 0% for accuracy until the payload reaches 35,000m.
- Measure temperature, relative humidity, and pressure while ascending and descending through and above the tropopause every 152m (500ft.).
- Measure pressures as low as 4 mb to gain accurate data.

3.4.3. Technical Background
Our payload is going to measure the temperature outside and inside the payload, as well as the relative humidity, and the atmospheric pressure. The pressure sensor will be located inside the payload along with an inside temperature sensor, which is on the BalloonSat. The other temperature sensor and the relative humidity sensor will have access to the outside of the payload. These sensors will need to interface with the BalloonSat and save the data into the EEPROM. Upon retrieval of the payload we will calculate the mixing ratio from the data we recorded during flight. Mixing ratio is the ratio of the mass of a variable atmospheric constituent, water vapor, to the mass of dry air with the units of grams/kilogram, given in Equation 7-7. The mixing ratio may be approximated by the specific humidity.

3.4.4. Technical Requirements

- Obtain two relative humidity data point every minutes for the duration of the flight
- Ensure that temperature and relative humidity sensor will function at -50°C. (The temperature it may encounter at the Tropopause)
- The sensors must be able to interface with the BalloonSat
- There must be enough voltage being supplied by the power source to keep the BalloonSat for at least 3 hours (This will be the approximate duration of the flight from ascension to descent).
- The payload must be able to withstand shock experienced with landing at a speed of approximately 19 km/hr.
- The power supply must be able to continue functioning at extreme temperatures.
- Internal payload must be maintained at a temperature above -20°C. In order to guarantee accurate functionality of the circuits within the parameters specified by their respective data sheets
- Sensors must accurately record the external temperature, relative humidity, and pressure.
4.0 Payload Design

Our payload is a Styrofoam hexagon that will be hollowed out. It will include additional Styrofoam within it to provide insulation. There are small openings in the hull of the payload in which the temperature and humidity sensors will be inserted in order for them to obtain accurate readings of the external conditions. There will be two vertical holes that will be lined with straws on opposite sides of the payload parallel to each other, which will allow the payload to be attached to the balloon. This keeps the strings from rubbing against the Styrofoam and wearing down its design integrity.

Incorporated within the payload will be several components. There will be the BalloonSat which will serve as our control unit and the place where our sensors will be connected. Located about the BalloonSat will be the circuit board for the pressure sensor. There will also be our power supply and insulation included inside of the box.

Figure 4-1 Payload Design Diagram
Figure 4-2 Payload constructed
4.1. **Principle of Operation**

The payload will contain a temperature sensor, humidity sensor, and a pressure sensor. The payload will be reaching an altitude of approximately 30km rising at a speed of approximately 0.3km every minute. We will be taking temperature, humidity, and pressure readings once every 30 seconds for the duration of the flight (ascension as well as descent). Each set of data will be saved as a byte of the 8kB EEPROM. The data will be sent from the sensors as an analog signal, which will proceed to the analog to digital converter, ADC, where it will be changed into a digital signal and sent to the EEPROM to be saved. The relative humidity is capacitor sensor. A PN junction diode function as a temperature sensor and pressure sensors is a piezoresistor. They will then express these characteristics by sending analog signals or voltage outputs to the ADC which interprets these signals as actual values, which we can measure. Once the BalloonSat is recovered, the information will be taken from the EEPROM and sent into Term 232 and saved as a file. This file is opened in Excel in order to analysis the data and product graphical data. With the data we record we will calculate the mixing ratio for each point and display it as a graph.
4.2. System Design

Figure 4-3 System Design Diagram
4.2.1. Functional Components

There are six key components in our payload, as seen in Figure 4-3. The most important of these components is the BalloonSat. This functions as our control unit. Our programs are written into the BASIC Stamp and they begin to send out specific commands to all of the sensors. Our power supply is two lithium 6V batteries. The temperature sensor measures the temperature outside of the payload. Our humidity sensor functions in the same way in the respect that it is also outside of the payload taking measurements. Our pressure sensor will be inside of the payload along with an internal temperature sensor. With all of this data there must be a place to store it. Our data archive system will be the EEPROM of the BalloonSat.

4.2.2. Component Interfaces

Every aspect of the payload interfaces with one another. The payload has a bi-directional thermal and mechanical interface. There is a power interface that runs from the batteries to the BalloonSat and the various sensors being used. There will be an analog data interface going from the sensors to BalloonSat's ADC. There is a bi-directional digital data signal between the Control Sub-system (BalloonSat) and the Digital archive sub-system (EEPROM). There is a bi-directional digital signal from the Control system and the ground interface system. There is a bi-directional digital signal between the analysis and ground interface subsystem as shown in Figure 4-3.
**4.2.3. Traceability**

Table 1 Traceability Matrix

<table>
<thead>
<tr>
<th>Mission Goal:</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Our goal for this experiment is to better understand the complex characteristics of the atmosphere by investigating humidity, temperature and pressure within the troposphere, tropopause and lower stratosphere.</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>objectives</th>
<th>Requirements</th>
<th>Design Element</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine the relationship between pressure, humidity, and temperatures a function of altitude.</td>
<td>Ensure that the temperature and humidity sensor function -80°C</td>
<td>Sensors are placed outside the payload container</td>
<td></td>
</tr>
<tr>
<td>Payload survive extreme temperature and pressure conditions of the trapopause</td>
<td>Inner temp. -20°C external temp -70°C</td>
<td>Use Styrofoam and yellow monocot covering</td>
<td>External payload dimensions of 16cm x 6cm x10.5cm</td>
</tr>
<tr>
<td>Compare the data we obtained with data obtained from previous experiments by NOAA which collects data points every minute.</td>
<td>Sensors will record data once every minute for one second</td>
<td>Software sampling and recording rate of 1 data point per minute</td>
<td></td>
</tr>
<tr>
<td>Calculate absolute humidity from measurements.</td>
<td>Measure temperature, humidity, and pressure while ascending and descending through and above the tropopause every 304.80m (1000ft.).</td>
<td>Include Relative Humidity sensor</td>
<td>Equation to calculate absolute humidity given pressure, temperature and relative humidity</td>
</tr>
<tr>
<td>Measure temperature, humidity, and pressure while ascending and descending through and above the tropopause every 304.80m (1000ft.).</td>
<td>Enough voltage supplied by the power source to keep the BalloonSat for at least 3 hours</td>
<td>Power Budget</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Launch a 0.5 kg payload 30km above the earth’s surface within the constraints of the budget and weight requirements</td>
<td>Use Styrofoam for payload construction</td>
<td></td>
</tr>
</tbody>
</table>
4.3. Electrical Design

Figure 4-4 illustrates the main components of the circuit consisting of the EEPROM, BASIC Stamp, real time clock, RTC, ADC, temperature sensor located on the BalloonSAT, and three external sensors: pressure NP1200, humidity HM1500LF, and temperature diode 1N457, that will be attached to a power source. The sensors will undergo a signal conditioning, a manipulation of the analog signal so the ADC component can acknowledge and convert the input data. Some common ways to condition a signal is to filter, remove unwanted signal components, and amplify, bring the voltage up to a level readable by the ADC. Once the signal is conditioned for the ADC, it will be converted from an analog signal (voltage signature) to a corresponding digital signal and sent to the BASIC Stamp on the BalloonSAT. The BASIC Stamp sends that data to the EEPROM for storage and later retrieval. These digital signals, once retrieved will be converted to a physical quantity.

Figure 4-4 Electrical System Design
4.3.1. Sensors

Humidity Sensor HM1500LF

The relative humidity sensor shown in Figure 4-5 is a capacitive sensor with a voltage output. Inside the sensor is a capacitor whose dielectric constant is directly related to the change in relative humidity. There is a signal conditioner within the sensor that converts the dielectric change to a voltage output. The operating temperature range of this device is from -30 to 60°C.

![HM1500LF Humidity Sensor](image)

Figure 4-5  HM1500LF Humidity Sensor

Humidity Sensor Schematic

Refer to Figure 4-6. The sensor is connected to a 5V regulator located on the BalloonSAT along with a 3V reference also on the BalloonSAT. Operational amplifier U302a is used to amplify the signal and to change the DC level, so that the minimum DC level will be 0V. An amplifying factor of approximately 0.2 is required to change the 2.5mV span of the humidity sensor to the required 3V span for the ADC. The selection of the values of resistors R302, R303, R304 will determine the amount of amplification provided. The operational amplifier U302b and the potentiometer R301 are used for fine adjustment of the overall amplifying factor. The voltage regulator and amplifier will be powered by a 12V power supply.

![Humidity Schematic HM1500LF](image)

Figure 4-6  Humidity Schematic HM1500LF

Team SPARTA 15  
FRR v1.0
**Pressure Sensor NPC1210**
Within the pressure sensor is a Wheatstone bridge, Figure 4-8, the output of which is directly proportional to the pressure. This bridge has four resistors connected in a square, refer to Figure 4-8. Three of the four resistors are variable resistors of known values. The fourth is unknown. When a voltage is applied to the bridge from a to c, the electric current flowing through the bridge splits, flowing through R1 and R2 on one side, and R4 and R3 on the other side. As the pressure changes the resistor distorts causing a change in the flow of current by a process called the piezoresistive effect. As the current changes so does the voltage across the bridge. The difference of the voltage from the two sides of the bridge is directly related to the change in pressure. The operating temperature range of the pressure sensor is -40 °C to 125°C. Figure 4-7 shows the pressure sensor used in our electronics.

![Figure 4-7 NPC1210 Pressure Sensor](image)

![Figure 4-8 Wheatstone Bridge from encyclopedia of science](image)
**Pressure Sensor Schematic**

Refer to Figure 4-9. Component LM234 is a constant current source. LM234 will maintain 1.5mA through the pressure sensor by the proper selection of the resistor R105. For 1.5mA a 47Ω resistor is required. The operational amplifier U103a and U103b are used to amplify the signal and change the DC level, so that the minimum DC level will be 0 V. A gain of 30 is required to change the 100mV span of the sensor to the required 3V span for the ADC converter. The values of resistors R101 with R102 and R103 with R104 will determine the amount of amplification provided. The operational amplifier U102 is used for fine adjustments of the overall amplifying factor. The constant current source and the amplifiers will be powered by a 12V power source.

![Pressure Sensor Schematic](image)

**Figure 4-9  Pressure Sensor Schematic**

**External Temperature Sensor 1N457 (PN junction Diode)**

A PN diode, in Figure 4-10, a semi-conductor, allows current to flow through it in one direction, forward. Only a very small current is able to flow in the reverse direction, this is called the Reverse Leakage Current. When a diode is carrying a forward current there is a small voltage drop across the diode. The magnitude of this voltage drop depends on the amount of forward current and the temperature of the junction. This voltage increases as the current is increased, and decreases as the junction temperature rises. In this inverse relationship between temperature and voltage, the temperature dependence is what allows a diode to be used as a temperature sensor from very low temperature (~ -100°C) to well above room temperature (~ 100°C).
In order to be sure that the variations of the diode’s forward voltage is only caused by the temperature changes it is necessary to ensure that a constant current will flow through the diode. For a constant forward current of about 1mA the forward voltage will vary from ~500mV at +50°C to ~800mV at a temperature of -50°C. The forward voltage of the diode will vary from about 500mV to 800mV over a range of temperatures that the payload will experience (+40°C to -60°C). The ADC expects an input voltage in the range of 0V to 3V. A signal condition will be required to convert the diode’s voltage span and base to levels comparable with the ADC. The constant current source and the signal condition circuit will be powered from a 12V power supply.

![1N457/A](image)

**Figure 4-10** Diode picture from Fairchild datasheet

**Temperature Sensor Schematic**

Refer to Figure 4-11. The LM234 is the constant current source. This LM234 will maintain 1mA through the diode by the proper selection of the resistor R200. For 1mA a 68Ω resistor is required. The operational amplifier U202a is used to amplify the signal and to change the DC level, so that the minimum DC level will be 0V. An amplifying factor of 10 is required to change the 300mV span of the diode temperature sensor to the required 3V span for the ADC. The selection of the values of resistors R203 and R202 will determine the amount of amplification provided. The operational amplifier U202b and the potentiometer R201 are used for fine adjustment of the overall amplifying factor.

![Temperature Sensor Schematic](image)

**Figure 4-11** Temperature Sensor Schematic
4.3.2. Sensor Interfacing

The analog signals in the form of voltage outputs come from the sensors through the signal conditioning to the ADC. The ADC converts the analog signals to digital that goes to the BASICStamp. The BASICStamp receives these signals through channels 0, 1, 2, and 3, refer to Figure 4-12. Those signals are sent to the EEPROM to be stored for later retrieval.

Figure 4-12 Sensor and control electronics
4.3.3. Power Supply

The BASICStamp, sensor amplifiers, voltage regulators, and constant current sources (CCS) will all be directly connected to the 12V power supply. The sensors and remaining BalloonSAT components will be indirectly connected to the 12V by necessary CCS and voltage regulators of 5V. The 12V will consist of two 6V lithium batteries connected in series. A 12V source is used to account for a voltage drop due to decreasing atmospheric temperatures and the drain from the power system. There is a 3V battery backup for the RTC, see Figure 4-13.

![Power Supply Diagram](image)

**Figure 4-13 Power Supply Design**
4.3.4. Power Budget

The minimum current needed for the BalloonSat is 54mA. The minimum current needed for sensors is 16mA. For a 3hr flight, a minimum of 210mA-hr is needed. See Table 2. The voltage regulators require a minimum of 8V at all times. Through the HATPac experiment the two 6V lithium batteries placed in series will provide ~500mA-hr for 5 hours. The 12V power supply will be more than sufficient to supply 210mA-hr for 3 hrs.

Table 2  Power Budget

<table>
<thead>
<tr>
<th>Power Source 1</th>
<th>Current (mA)</th>
<th>Hours to Function (H)</th>
<th>Required (mA-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BalloonSAT</td>
<td>54</td>
<td>3</td>
<td>162</td>
</tr>
<tr>
<td>Pressure Sensor (Approx)</td>
<td>4</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Humidity Sensor (Approx)</td>
<td>10</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Temperature Sensor (Approx)</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>70</strong></td>
<td><strong>3</strong></td>
<td><strong>210</strong></td>
</tr>
</tbody>
</table>

4.4. Electrical Construction

In order to construct our pressure sensor we had to first create a circuit board for it, Figure 4-14. We did this by first printing the layout we had created from Express PCB. We cut a piece of Printed Circuit Board Transfer blue film approximately the size of the board (1.5in x 3in) and taped it to the printed layout. We then placed in back in the printer and re-printed the layout. We did this so the printer toner would be on top of the blue film. We then cut a piece of copper to the size of the layout. We cleaned the copper with chloroform to remove the photo-resist from it. The copper was cleaned to a shine with a piece of steel wool and wiped clean with acetone. We then taped the paper with the toner on it, face down onto the copper. Once this was done we ironed the paper onto the copper to transfer it. Once the ironing was completed we ran water between the copper and paper to remove the paper smoothly. We then examined the board for areas which needed to be touched up with polycryllic finish. We then placed the circuit-board in a mixture of peroxide and muriatic acid that was combined in a 2:1 ratio. We continued to agitate the mixture with the board in it for approximately 10-15 minutes until the etching was completed. We then rinsed
the board in water. The board was then scrubbed with the steel wool again and cleaned off with acetone.

Once this process was completed we drilled the through holed into the board. We then coated the copper side of the circuit-board to give it silver plating, which makes it easier to solder to while aiding in the prevention of oxidation of the copper. With this done we were able to solder on our surface mount components first with the aid of a Doofus which prevented the surface mount components from moving or raising up during the soldering process. Once this was done we soldered on the components that were not surface mounts, Figure 4-15 and Figure 4-16.

The humidity sensor and temperature sensor were both constructed on the prototype of the BalloonSat. They have a similar design as far as the operational amplifiers go, so we used the same layout to arrange them. We then placed the components in their respective places and soldered them. Most of the wiring was done to the bottom side of the BalloonSat to make it less cluttered. The battery was connected in series by using a capacitor as a fuse in order to prevent a fire or explosion caused by the lithium battery. There is a wire running from the positive terminal of one battery to the negative terminal of the other, which connects to the BalloonSat to supply the power, Figure 4-17.

![Pressure circuit board](image)

*Figure 4-14 Pressure circuit board*
Figure 4-15 Pressure sensor circuit board (top view)

Figure 4-16 Pressure sensor circuit board (side view)
Figure 4-17 Payload electronics
4.5. **Software Design**

4.5.1. **Data Format and Storage**

- **Outside Temperature Sensor** - 1 byte
  - Resolution: 0.6°C
  - Data will be acquired at: 2 pt./min
- **Humidity Sensor** - 1 byte
  - Resolution: 0.4 %RH
  - Data will be acquired at: 2 pt./min
- **Pressure Sensor** - 1 byte
  - Resolution: 4mb
  - Data will be acquired at: 2 pt./min
- **Inside Temperature Sensor** - 1 byte
  - Resolution: 0.5°C
  - Data will be acquired at: 2 pt./min
- **Time Stamp** - 3 bytes
  - Hour - 2 nibbles
  - Minutes - 2 nibbles
  - Seconds - 2 nibbles

- **Entire Flight Memory Usage** – 14 bytes/min. x 180 min = 2.46 kB
  - Ascent and descent: 2 data pts./min x 180min. = 360 data pts.

**Table 3 Sampling Rates and Formats**

<table>
<thead>
<tr>
<th>Byte</th>
<th>Data Stored</th>
<th>Format</th>
<th>Sampling Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hours</td>
<td>00-24 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>255 in: HEX2</td>
<td>2 pt./ min</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Minutes</td>
<td>00-59 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>255 in: HEX2</td>
<td>2 pt./ min</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Seconds</td>
<td>00-59 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>255 in: HEX2</td>
<td>2 pt./ min</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Outside Temperature</td>
<td>0-255 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>BIN</td>
<td>2 pt./ min</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Pressure</td>
<td>0-255 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>BIN</td>
<td>2 pt./ min</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Relative Humidity</td>
<td>0-255 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>BIN</td>
<td>2 pt./ min</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Inside Temperature</td>
<td>0-255 in:</td>
<td>2 pt./ min</td>
</tr>
<tr>
<td></td>
<td>BIN</td>
<td>2 pt./ min</td>
<td></td>
</tr>
</tbody>
</table>
4.5.2. Flight Software

PRE-FLIGHT

Figure 4-18, the preflight software is programmed to first prompt the user to initialize the clock. The user will then input date and time information, which will be written to the Real Time Clock. The current time stamp will be displayed to the screen. Next the EEPROM address will be initialized to zero, so that when the program starts writing data to memory, it begins writing to the first address of the EEPROM. In order to execute this task, “FF”, will be written to every address in the memory. An ‘end’ loop has been implemented so that the program will stop writing when the memory is full.
Figure 4-18 Preflight flowchart
IN-FLIGHT

Figure 4-19 and Figure 4-20, the first thing done within the flight software is the initialization of the EEPROM address to zero. Secondly, we will use the LEDs on the BalloonSat as indicators that our program is running. The program will switch on all the LEDs; then, one-by-one the LEDs will be shut off, with one-second time intervals. Next, a subroutine for a memory check has been implemented in order to prevent any overwriting of data in the case of a power outage, shown in Figure 4-21. This memory check is completed before every block of data is written to the EEPROM. Also, within this memory check, a space check is included to make sure there is enough space in the EEPROM to write the next block. After these checks are completed, the program begins writing data. Data retrieved by the sensors will be sent as analog signals to the ADC, through four different channels (channel 0= humidity, channel 1= outside temp., channel 2= pressure, channel 3= inside temp.), and will then be written to the EEPROM address by the Basic Stamp. After each piece of data is written to the EEPROM, the address will be incremented, and the channel to the ADC will be changed to the next corresponding datum that will enter the EEPROM. Next, the program will pause for 30 seconds before repeating the process. This will continue until either the batteries are disconnected or the address of the EEPROM is greater than $1FF9.
Figure 4-19 Inflight flowchart
Figure 4-20  Inflight flowchart continued
Figure 4-21 ‘Memory check’ and ‘Stop’ subroutines flowchart
POST-FLIGHT

Figure 4-22 and

Figure 4-23 the data recovery program will initialize the address of the EEPROM to the first address—zero. Initially, the hours will be read back from the EEPROM and displayed to the computer screen. Next, the address of the EEPROM is incremented. This process is done for the minutes, seconds, inside temperature, outside temperature, pressure, and relative humidity. If all of the memory is used up, an “IF THEN” statement has been implemented to ensure that the program will stop reading back data once the address is incremented to a number larger than the value of the last address of the EEPROM’s memory.
Figure 4-22 Post flight flowchart
Figure 4-23 Post flight flowchart continue
4.6. Thermal Design

To test our thermal design and determine the inside temperature and the temperature of the outer wall of the box we placed our prototype in the freezer in room 306. A HOBO on the inside of the payload recorded the internal temperature and a HOBO on the outside recorded the temperature of the freezer. We allowed the payload to stay in there for several hours to allow it to reach a steady state. By doing this we were able to produce the following graphs, Figure 4-24 and Figure 4-25.

![Figure 4-24 Payload thermal test, temperature inside payload](image-url)
It took approximately 30 minutes for the temperature inside the payload to drop from 20°C to 10°C. It took an additional 20 minutes to drop from 10°C to 0°C. It took approximately 2 hours for the payload to reach a steady state. We will only be traveling through the coldest layer of the atmosphere for approximately 8 minutes so Team SPARTA is anticipating that our payload will be able to sustain these temperatures for that amount of time.

Our payload will be in an environment where the temperatures can be as cold as 203K. In order to be sure that our circuitry will function effectively in this environment we must calculate the conductivity, \( \varepsilon \), as well as the radiation of the box. In order to calculate the thermal conductivity of the box you must use the following formula:

\[
\frac{Q}{t} = Q_c = \frac{kA(T_i - T_o)}{L}
\]

**Equation 4-1  Energy transferred due to conduction**

\( Q_c \) is the power output by the circuitry. In our case the power output is 0.6W. \( k \) is the coefficient of conductivity. For Styrofoam insulation such as the type being used for our payload the conductivity coefficient is 0.027 (W/m·K). \( A \) is the surface area of the payload which is 0.101\( m^2 \). \( T_i \) is the temperature once it has reached a steady state inside of the payload, which in our particular case was 252K. \( T_o \) is the temperature on the outer surface of the box we
are trying to calculate. \( L \) is the thickness of the box, which in our case is 0.02m thick. We calculated our thermal conductivity by solving *Equation 4-1* for \( T_0 \). See Table 4 for result.

**Table 4 Data table for temperature calculation**

<table>
<thead>
<tr>
<th>Description</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy transferred by conduction</td>
<td>( Q_c )</td>
<td>0.6 W</td>
</tr>
<tr>
<td>Coefficient of conductivity</td>
<td>( k )</td>
<td>0.027 W/m·K</td>
</tr>
<tr>
<td>Area</td>
<td>( A )</td>
<td>0.101 m(^2)</td>
</tr>
<tr>
<td>Temperature inside the box</td>
<td>( T_i )</td>
<td>252K</td>
</tr>
<tr>
<td>Thickness</td>
<td>( L )</td>
<td>0.02m</td>
</tr>
<tr>
<td>Temperature outside the box (calculated)</td>
<td>( T_0 )</td>
<td>248.35K</td>
</tr>
</tbody>
</table>

Next we calculated the thermal radiation. To calculate this we must use the following equation, *Equation 4-2*:

\[
\frac{Q}{t} = Q_r = \varepsilon \sigma A (T_0^4 - T_S^4)
\]

*Equation 4-2 Energy transferred due to thermal radiation*

\( Q_r \) is the heat transferred through of radiation, when in a steady state, is equal to the power being output on the inside of the payload. \( \varepsilon \) is the emissivity of the payload which is our current unknown. \( \sigma \) is the Stefan-Boltzmann constant which is \( 5.67 \times 10^{-8} \) (W/m\(^2\)·K\(^4\)). \( T_0^4 \) is the temperature on the outside of the box, which we solved in the previous equation, raised to the fourth power. \( T_S^4 \) is the temperature of space which is generally 4K, however we tested our payload in the freezer so our \( T_S = 244.5K \) to calculate our emissivity we solved *Equation 4-2* for \( \varepsilon \), results are shown in Table 5.
Table 5  Data table for emissivity calculation

<table>
<thead>
<tr>
<th>Description</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power transferred through radiation Q</td>
<td>$Q_r$</td>
<td>0.6 W</td>
</tr>
<tr>
<td>Stefan-Boltzmann constant σ</td>
<td>$\sigma$</td>
<td>$5.67 \times 10^{-8}$ W/m²·K⁴</td>
</tr>
<tr>
<td>Area</td>
<td>$A$</td>
<td>0.101 m²</td>
</tr>
<tr>
<td>Temperature outside payload (from Table 4) $T_o$</td>
<td></td>
<td>248.3 K</td>
</tr>
<tr>
<td>Temperature of space $T_s$</td>
<td></td>
<td>144.5 K</td>
</tr>
<tr>
<td>Emissivity (calculated) $\epsilon$</td>
<td></td>
<td>0.45</td>
</tr>
</tbody>
</table>

We also calculated what the temperature on the inner and outer surface would be if it were in the tropopause where the temperature is 203K. To do this we used the conductivity, *Equation 4-1* and radiation, *Equation 4-2* formulas. To calculate the temperature on the outer wall of the payload we used *Equation 4-2*, the results are in *Table 6*.

<table>
<thead>
<tr>
<th>Description</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power transferred through radiation $Q_R$</td>
<td>$Q_R$</td>
<td>0.6 W</td>
</tr>
<tr>
<td>Stefan-Boltzmann constant $\sigma$</td>
<td>$\sigma$</td>
<td>$5.67 \times 10^{-8}$ W/m²·K⁴</td>
</tr>
<tr>
<td>Area</td>
<td>$A$</td>
<td>0.101 m²</td>
</tr>
<tr>
<td>Temperature outside of tropopause $T_S$</td>
<td>$T_S$</td>
<td>203 K</td>
</tr>
<tr>
<td>Emissivity (from Table 5) $\epsilon$</td>
<td>$\epsilon$</td>
<td>0.45</td>
</tr>
<tr>
<td>Temperature of the outer surface (calculated) $T_o$</td>
<td>$T_o$</td>
<td>210 K</td>
</tr>
</tbody>
</table>

To calculate the temperature on the inside of the payload as it passes through the 203K of the tropopause we calculated it by using *Equation 4-1*, the results are found in the *Table 7*.

<table>
<thead>
<tr>
<th>Description</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power transferred through conduction $Q_C$</td>
<td>$Q_C$</td>
<td>0.6 W</td>
</tr>
<tr>
<td>Coefficient of conductivity $k$</td>
<td>$k$</td>
<td>0.027 W/m·K</td>
</tr>
<tr>
<td>Area</td>
<td>$A$</td>
<td>0.101 m²</td>
</tr>
<tr>
<td>Thickness</td>
<td>$L$</td>
<td>0.02m</td>
</tr>
<tr>
<td>Temperature outside of payload (from Table 6) $T_o$</td>
<td>$T_o$</td>
<td>210 K</td>
</tr>
<tr>
<td>Temperature inside payload (calculated) $T_i$</td>
<td></td>
<td>214 K</td>
</tr>
</tbody>
</table>

In order to calculate the heat input from the sun as our payload ascends and descends we used the following Excel spreadsheet, *Table 8*, used on HASP and ATTIC flights and put in the proper information for the areas shaded in green.
### Table 8  Thermal table

#### LaACES Thermal

<table>
<thead>
<tr>
<th>Earth-Space Parameters</th>
<th>UNITS</th>
<th>Isun</th>
<th>1377.0</th>
<th>W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latitude</td>
<td>31</td>
<td>degrees</td>
<td></td>
</tr>
<tr>
<td>Stefan-Boltzmann</td>
<td>08 K⁻¹</td>
<td>T-float</td>
<td>210 K</td>
<td></td>
</tr>
<tr>
<td>Isun (solar constant)</td>
<td>1377 W/m²</td>
<td>Albedo</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>T-space</td>
<td>4 K</td>
<td>Day of year</td>
<td>240 day</td>
<td></td>
</tr>
<tr>
<td>Flight altitude</td>
<td>150 m</td>
<td>Hour of day</td>
<td>10.5 hr</td>
<td></td>
</tr>
<tr>
<td>Earth orbit eccentricity</td>
<td>0.01672</td>
<td>Declination angle</td>
<td>9.152442 deg</td>
<td></td>
</tr>
<tr>
<td>T-earth</td>
<td>273 K</td>
<td>Inclination angle</td>
<td>30.25859 deg</td>
<td></td>
</tr>
<tr>
<td>R-earth</td>
<td>6380000 m</td>
<td>IR Fluxmin</td>
<td>160 W/m²</td>
<td></td>
</tr>
</tbody>
</table>

| Payload Parameters | Internal Heat | 0.6 | W |
|                   | Effective Isolar | 1364.05 | W/m² |
|                   | Effective Isphere | 339.98 | W/m² |

#### Energy Balance calculations

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qsun</td>
<td>19.776 W</td>
</tr>
<tr>
<td>Qalbedo</td>
<td>17.133 W</td>
</tr>
<tr>
<td>Qpower</td>
<td>0.600 W</td>
</tr>
<tr>
<td>Q-IR</td>
<td>1.485 W</td>
</tr>
</tbody>
</table>

#### Insulation Parameters

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation absorptivity</td>
<td>0.350</td>
</tr>
<tr>
<td>Insulation thickness</td>
<td>0.020 m</td>
</tr>
<tr>
<td>Insulation emissivity</td>
<td>0.450</td>
</tr>
<tr>
<td>Insulation conductivity</td>
<td>0.027 W/mK</td>
</tr>
</tbody>
</table>

#### Area Calculations

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sphere projected area</td>
<td>4.15E⁻² m²</td>
</tr>
<tr>
<td>Total sphere surface area</td>
<td>1.66E⁻¹ m²</td>
</tr>
</tbody>
</table>

#### NOTES:

*PSL Environment Extremes*

- Solar angle based on Nominal Values (this is the PV array vertical angle)
- Insulation Outer Temp $T_i$ outer
- Insulation Inner Temp $T_i$ inner
- Kevlar Inner Temp $T_k$ inner
- Bladder Inner Temp $T_b$ inner
Below is a table with the time of day, heat input from the sun, solar angle, and the projected temperature inside the payload.

Table 9  Temperature table

<table>
<thead>
<tr>
<th>Time of day</th>
<th>$Q_{in}$ (W)</th>
<th>$\varepsilon$</th>
<th>Solar angle (deg)</th>
<th>$T_i$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30A</td>
<td>29.843</td>
<td>.45</td>
<td>23.9°</td>
<td>292.9</td>
</tr>
<tr>
<td>8:30A</td>
<td>33.575</td>
<td>.45</td>
<td>36.67°</td>
<td>299.8</td>
</tr>
<tr>
<td>9:00A</td>
<td>35.212</td>
<td>.45</td>
<td>42.87°</td>
<td>302.8</td>
</tr>
<tr>
<td>9:15A</td>
<td>35.958</td>
<td>.45</td>
<td>45.903°</td>
<td>304.1</td>
</tr>
<tr>
<td>10:30A</td>
<td>38.994</td>
<td>.45</td>
<td>59.75°</td>
<td>308.0</td>
</tr>
</tbody>
</table>

Based on the information we obtained from the table we are able to reach the conclusion that our payload will survive in the temperatures of the atmosphere while maintaining an internal temperature above 253K.

### 4.7. Mechanical Design

A Styrofoam hexagon box will be the design for the container of our payload. It will be made from Dow Styrofoam which is rigid in form and lightweight. It weighs approximately 0.25 g/in$^2$. This is beneficial when dealing with our weight budget that will be examined in a later section. Our payload will be able to withstand the different stresses it may encounter during the flight.

---

**Figure 4-26 Mechanical Design**
4.7.1. External Structure

The payload will look like a hexagon from the outside. There will be two holes in the exterior of the container to allow the temperature and humidity sensors to make accurate readings in the atmosphere. There will also be two holes running vertically in the two sides parallel to each other that will be lined with straws to allow the payload to be attached to the strings coming from the sounding balloon. To access the interior of the container there is a removable lid that will be secured down with tape.

Figure 4-27 Designed external payload structure
4.7.2. Internal Structure

Once you open the lid you will be looking at the interior of our payload that will house our power system, control system, data archive systems, etc. The insert itself contains several key components. There is a 3mm indent cut into the insert that is 9cm x 13cm. Glued into this insert is a 1mm thick piece of wood cut to fit the dimensions of 9cm x 12cm. There are four screws coming from the base of the wood that interfaces at the spots where the holes in the BalloonSat are located. There are two angle brackets located at the topmost two corners of the wood where the circuit-board for the pressure sensor is located. There is also a square protrusion on the insert where the batteries are housed and secured into place. The BalloonSat is then put into place and secured into place by nuts over the screws at ends diagonal from each other.
Figure 4-29  Internal structure

Figure 4-30  Internal structure constructed
4.7.3. Weight Budget

A Styrofoam hexagon box will be the design for the container of our payload. It will be made from Dow Styrofoam which is rigid in form and lightweight. It weighs approximately 0.25 g/in$^2$ of 2cm thick foam. This is beneficial when dealing with our weight budget that is displayed in Table 10.

Table 10  Weight Budget

<table>
<thead>
<tr>
<th>Items</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box/Insulation</td>
<td>80.5g</td>
</tr>
<tr>
<td>Circuits</td>
<td>112.5g</td>
</tr>
<tr>
<td>Power &amp; Cables</td>
<td>82.1g</td>
</tr>
<tr>
<td>Insert</td>
<td>29.7g</td>
</tr>
<tr>
<td>Screws</td>
<td>1.4g</td>
</tr>
<tr>
<td>Econokoat</td>
<td>15g</td>
</tr>
<tr>
<td>Brushings &amp; Stickers</td>
<td>2.9g</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>324.1g</strong></td>
</tr>
</tbody>
</table>

5.0 Payload Development Plan

We have completed the development phase.

6.0 Payload Construction Plan

6.1. Hardware Fabrication and Testing

In order for our team to complete our objective of creating a working payload we needed to prototype and test the enclosures, circuitry, and software. All initial testing on circuitry was done on the breadboards. It was on these that we developed a way to place these components onto the BalloonSat. Our software was initially tested using potentiometers. As all of this took place the mechanical sub-system was constructed.
6.2. Integration Plan

Our payload contains five subsystems in total: power, data archive, mechanical, thermal, and sensors. In order to properly integrate these components, the mechanical subsystem must first be implemented by constructing 3-D, Styrofoam box that will physically interface with the outside environment. The thermal subsystem will be implemented through the implementation of the mechanical subsystem, which is a thermal insulator. By retaining the heat generated by the BalloonSat and other electrical components, the thermal subsystem will protect the BalloonSat from the extremely low temperatures it will experience. The pressure sensor will be placed on a separate circuit and integrated with the BalloonSat. The temperature and humidity sensor’s circuitry will be on the BalloonSat while the actual sensors will be outside the box. The data archive subsystem, or the EEPROM, is already integrated in the control subsystem. The power subsystem will physically be connected to the control and sensor subsystems and will consist of two 6V battery for a total 12V. The sensors will be physically integrated to the control subsystem. To ensure the integrity of the control, thermal, and sensor subsystems, during flight, tests will be conducted in extreme cold and low-pressure environments. These tests will also help to determine the integrity of circuits and solder joints—the mechanical subsystem.

Figure 6-1  System integration
6.3. **Software Implementation and Verification**

In order to implement the flight program, the Basic Stamp Editor programming language will be used. A main loop is needed in order to continuously record data and time stamps. To read data from the sensors, a subroutine for reading from the ADC has been implemented, as well as a subroutine for writing the data to the EEPROM; the clock time will also be written to the EEPROM using this same subroutine. “IF THEN/ELSE” statements have been created in order to perform the ‘memory space’ and ‘free address’ checks. This will prevent the flight software from writing over any data in the case of a power failure. Until the memory is full, the program will proceed in writing data and timestamps via the previous subroutines. In order to be certain that the software runs properly, we will, again, run all three programs (pre-flight, in-flight and post-flight). We will place the BalloonSat, while running the flight software, in conditions similar to what it will face in the troposphere, tropopause and lower stratosphere: temperatures approaching -70°C and pressure approaching 4mb. If the flight program runs and produces legitimate data, it will be approved for flight.

6.4. **Flight Certification Testing**

There are many conditions we may face as we travel into higher altitude. There will be a decrease in pressure, temperature, as well as a considerable amount of shock caused by turbulence and landing. These can have catastrophic effects on data if not properly accounted for and tested during payload design. In order to test if the payload will survive and function in the cold of the upper atmosphere we must test it. We can do this by placing it in a container that will be surrounded by dry ice. This will give us an idea of the payload’s functionality on an environment similar to the temperature experienced by the tropopause. In order to simulate how the payload will function in a low pressure environment like the upper atmosphere we must test it by placing it in a vacuum. This will allow us to know if it will be able to function even at low pressure. The payload must also survive the turbulence and shock of landing. To simulate this we can shake the payload and drop it from a height of approximately ten feet and see how it handles the fall.

**Vacuum Test**

The first test that team SPARTA performed was the vacuum test. We wanted to make sure that the circuits would function in a low pressure environment. To simulate this we placed the insert with the circuitry attached in a vacuum chamber. Due to the fact that the payload container was too large for the bell jar. The vacuum was pumped down to approximately 30 in. Hg at 10 in. Hg steps see *Figure 6-2*. From this test we show that the electronics will work in the low pressure environment. The pressure gauge has a accuracies of ±3%, *Figure 6-3*.
Pressure Test

Figure 6-2  Vacuum test results

Figure 6-3  Vacuum Test
Thermal Test
The next test that we performed on the payload was the thermal test. This is one of the most crucial tests that we had to do, simply because if the circuits get too cold they will cease to function. We had an internal temperature sensor as well as an external temperature sensor. The enviroment that the payload was placed in were (1) refrigerator, (2)freezer, Figure 6-5, and (3)dry ice (Co₂). The graph, Figure 6-4 shows the internal and external temperatures during the testing. The internal temperature does not goes below the 0°C. This is well above our -20°C technique requierment for the internal payload temperature. The outside temperature, however, gets down to -60 degrees after placing the payload in Co₂ for 30min. The gap in data was where we stopped taking data following the vacuum test.

Figure 6-4  Thermal test results
Figure 6-5  Thermal test, freezer environment

Shock Test
The last test that we performed was the shock test. We wanted to be sure that the payload could survive the impact of landing without damaging the EEPROM. We also wanted to make certain that nothing would come loose on impact. Once we tested this and opened the lid we saw that everything was still in its proper place, and all circuits were still functioning normally.

Figure 6-6  Shock test
7.0 **Mission Operation**

The day before launch, the preflight software must be loaded onto the BalloonSat and the Real Time Clock must be checked to make sure the correct time is being recorded. Next, the inflight software must be loaded onto the BalloonSat, and the battery pack taken out right afterwards. At least 30 minutes before flight, the new battery pack must be inserted into the payload and connected to the BalloonSat. Also, tape will need to be wrapped around the lid to ensure it is sealed well.

7.1.1. Calibrations

**1N457 Diode Temperature Sensor**

To adjust the potentiometer to set the proper gains and offset a multi-meter was used. 1N457 has an inverse relationship with temperature. For the experiment we expect to encounter temperatures at a high of around 100°C for a summer day in Palestine, Texas. At high temperatures the voltage output of the sensor needed to be close to a minimum output of 0V. The lowest temperature we expect to encounter is -70°C. At low temperatures the voltage output of the sensor needed to close to the maximum output of 3V. Based on the temperature measured, the voltages were adjusted by way of potentiometers according the specifications needed for the experiment.

To calibrate the diode temperature sensor a PASCO SF9616 multimeter with thermal couple temperature probe was used for a reference. The probe was inserted in the following environments along with the diode temperature sensor (1N457):

(1) Ethylene Glycol (C\textsubscript{2}H\textsubscript{6}O\textsubscript{2}) conditions -17.3°C and -50°C
(2) Ice and water bath 1.1°C
(3) Water at room temperature conditions 23.9°C
(4) Hot tap water conditions 38.7°C

The thermal environment produced the following counts: Refer to chart below.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>ADC counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.7</td>
<td>4</td>
</tr>
<tr>
<td>23.9</td>
<td>37</td>
</tr>
<tr>
<td>1.1</td>
<td>87</td>
</tr>
<tr>
<td>-17.3</td>
<td>127</td>
</tr>
<tr>
<td>-50.0</td>
<td>180</td>
</tr>
</tbody>
</table>
According to the data collected, Figure 7-1 a quadratic fit to the data is given by the following equation:

\[ T_i = \left( -6.517 \times 10^{-4} \right) (C^2) - (0.3764) C + 39.58 \]

where:
\[ T_i = \text{temperature measured by 1N457 diode probe, in °C} \]
\[ C = \text{analog to digital converter (ADC) counts} \]

**Equation 7-1 External temperature sensor calibration curve**

![Figure 7-1 Temperature Sensor (PN junction Diode) calibration](image)
AD780 Temperature Sensor
Sensor AD780 was calibrated to manufacturer’s specification. At 22°C the ADC output was 241 counts. Accounting for the gain adjustments for compatibility with the ADC, the mV per °C is 9.584512. We obtain that number by multiplying the manufacture’s specification of 1.9 mV/°C by the gain of 5.04448. The count per °C constant is the product of the 9.584512 mV/°C by the 255 max ADC counts per 3000 mV ADC voltage range which is .8147 counts per °C. At 22°C the relationship between temperature and ADC counts is expressed in the following equation.

\[ T_{int} = (0.8147 \times 174.3) \]

where:
- \( T_{int} \) = internal temperature as measured by AD780, in °C
- \( C \) = ADC counts

Equation 7-2  Internal temperature calibration curve

NPC1210 Pressure Sensor
To adjust the potentiometer settings gains and offset a multi-meter was used to measure the voltage output. The pressure sensor is directly related to the change in pressure. The pressure range we expect to encounter during flight is 4mb to 1014mb with a corresponding output voltage 0V to 3V respectfully. The local barometric report was used to calculate the atmospheric pressure and the corresponding voltage output.

A glass bell jar vacuum chamber with a single stage vacuum pump was used to calibrate the pressure sensors’ ADC counts to the applied pressure. The chamber was pumped down to the lowest level and then released at 2in. Hg steps. The vacuum pump gauges the amount of pressure below the current atmospheric pressure. By subtracting the value on the gauge from the actual pressure we obtain the pressure in in. Hg. 1 in. Hg is equal to 33.86 mb. For that day (Tuesday, July 22th) the actual pressure was 30.01 in. Hg. Figure 7-2, shows the connection of the pressure sensor to the vacuum pump.
The graphical relationship of ADC counts and Pressure (mb) is illustrated by the graph in Figure 7-3 with Equation 7-3.

Table 12  Pressure calibration data

<table>
<thead>
<tr>
<th>Counts</th>
<th>Pressure (in. Hg)</th>
<th>Pressure (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>30</td>
<td>.34</td>
</tr>
<tr>
<td>28</td>
<td>28</td>
<td>68</td>
</tr>
<tr>
<td>45</td>
<td>26</td>
<td>136</td>
</tr>
<tr>
<td>62</td>
<td>24</td>
<td>204</td>
</tr>
<tr>
<td>79</td>
<td>22</td>
<td>272</td>
</tr>
<tr>
<td>94</td>
<td>20</td>
<td>339</td>
</tr>
<tr>
<td>111</td>
<td>18</td>
<td>407</td>
</tr>
<tr>
<td>127</td>
<td>16</td>
<td>475</td>
</tr>
<tr>
<td>144</td>
<td>14</td>
<td>543</td>
</tr>
<tr>
<td>160</td>
<td>12</td>
<td>611</td>
</tr>
<tr>
<td>175</td>
<td>10</td>
<td>678</td>
</tr>
<tr>
<td>192</td>
<td>8</td>
<td>746</td>
</tr>
<tr>
<td>209</td>
<td>6</td>
<td>814</td>
</tr>
<tr>
<td>234</td>
<td>3</td>
<td>916</td>
</tr>
<tr>
<td>241</td>
<td>2</td>
<td>950</td>
</tr>
<tr>
<td>248</td>
<td>1.1</td>
<td>980</td>
</tr>
</tbody>
</table>

After the vacuum test we converted the ADC counts to pressure and noticed negative pressure readings, Figure 7-4. From this we revisited the calibration data and adjusted the slope and y-intercept to correct for the ambient atmospheric pressure and the lowest vacuum level achievable. The new linear fit is within the accuracy of the vacuum gage, Figure 7-5.
Figure 7-3  NPC1210 Pressure calibration

\[ p = 4.150 \times (ADC) + (-52.08) \]

Equation 7-3  Pressure calibration curve
Figure 7-4  Vacuum testing data

Figure 7-5  Adjustment to the pressure calibration
HM1500LF Relative Humidity Sensor

A multi-meter was used to monitor the voltage and adjust the voltage gain and offset compatibility with the ADC. The humidity sensor output is directly related to the change in humidity, the high voltage was set at a relatively high humidity taking into account space within the span for humidity at 100%. There was no resource to measure the lowest humidity we expect to encounter during flight. Based on the humidity conditions available we made adjustments for the expected output to read at near zero humidity of near 0 output voltages.

The relative humidity (RH) sensor was calibrated using an ACU Rite humidity sensor as a reference. The measurements were taken in a hallway (1) connection between physic buildings, computer room, laboratory, hallway (2) outside room 326, stairway, and outside. Relative humidity and count values were recorded in Table 13.

The best fit to the data, Figure 7-6, was a linear fit. The inconsistencies can be due to rapidly changing environmental conditions such as a slower response time of the ACU Rite sensor than the HM1520, wind, and changes in humidity from our breath or body heat.

Table 13 Relative Humidity data table

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>ADC counts</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>106</td>
<td>Hallway</td>
</tr>
<tr>
<td>43</td>
<td>120</td>
<td>Computer room</td>
</tr>
<tr>
<td>49</td>
<td>141</td>
<td>Laboratory</td>
</tr>
<tr>
<td>53</td>
<td>152</td>
<td>Hallway(2)</td>
</tr>
<tr>
<td>73</td>
<td>195</td>
<td>Stairway</td>
</tr>
<tr>
<td>87</td>
<td>251</td>
<td>Outside</td>
</tr>
</tbody>
</table>

The equation to calculate counts into relative humidity is:

\[ RH = (0.3541)C + (-1.719) \]

Equation 7-4 Humidity calibration curve
Figure 7-6  Humidity calibration curve
7.1.2. Pre-Launch Checklist

24-hrs before launch
- Remove and dispose 12V power supply
- Install real time clock backup battery (3V)
- Connect to power supply
- Load and run Pre flight Program
- Load and run In flight Program
- Place BalloonsSat and pressure circuit board in payload
- Arrange sensors

Day of launch
- Install new batteries
- Secure Payload with tape
- Launch payload

Recovery
- Remove from payload
- Connect to power source
- Load and run Post flight program
- Open Term232 save data to file
  - Save two copies of raw data
    - USB
    - Hard drive of laptop
- Data Analysis from hard drive

7.2. Flight Requirements, Operations and Recovery

During flight, the flight software will be running on the payload, which will gather data. During the tracking, altitude and position will be monitored for proper data analysis and payload recovery to occur. The highest altitude to which the payload will ascend is close to 35,000 meters, the pressure will decrease to as low as 3 mb, and the temperature will drop close to -70°C. The ascension rate is approximately 1000 ft./min (304.8m /min.). The batteries will need to provide sufficient power to the payload throughout the entirety of the flight in order to collect the data.

7.3. Data Acquisition and Analysis Plan

7.3.1. Ground Software

In order to properly retrieve the data that was collected by the flight software, the post-flight software will need to initialize the EEPROM’s address to zero and read back the raw data from the memory. The Basic Stamp Editor programming language must be used to run the post-flight software. The program Term 232 will be used to interface the data, received from the EEPROM, from Basic Stamp Editor to Microsoft Excel.
7.3.2. Data Analysis Plan

The raw data will be converted from ADC counts to physics quantities, temperature, pressure, and relative humidity, using the calibration equations, which will be developed during testing, in an Excel spreadsheet. This converted data will then be placed into Excel tables and graphs for final data analysis. We are expecting error bars on our data point on the order of 10%. We will plot temperature, pressure, relative humidity, and mixing ratio as a function of altitude.

Equation 7-5 and Equation 7-6 will be used to convert the measured relative humidity into a mixing ratio quantity, Equation 4-1. Our pressure, relative humidity, temperature and mixing ratio will then be compared to NOAA’s data for that day.

\[ RH = \frac{e}{e_s} \times 100\% \]

Equation 7-5  Relative Humidity
RH = relative humidity [\%], measured
e_s = saturation vapor pressure [mb]
e = vapor pressure [mb]

\[ e_s = P_o \times e^\frac{L(\frac{1}{T} - \frac{1}{T_o})}{R} \]

Equation 7-6  Clausius-Clapeyron Equation
T_o =273 K
L= latent heat of vaporization = 2.453x10^6 \frac{J}{kg}
P_o = vapor pressure at 273K= 6.117 mb
R= gas constant for moist air = 461 \frac{J}{kg}

\[ r = \left( \frac{0.622 \times e}{p-e} \right) \times 1000 \]

Equation 7-7  Mixing ratio equation
r= mixing ratio [\frac{g}{kg}]
p = atmospheric pressure [mb]
e = vapor pressure [mb]

8.0  Project Management

8.1. Organization and Responsibilities
<table>
<thead>
<tr>
<th>Responsibilities</th>
<th>Team Member</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team leader/Management</td>
<td>Dr. Hinton</td>
<td><a href="mailto:whinton@nsu.edu">whinton@nsu.edu</a></td>
</tr>
<tr>
<td>Mechanical Design</td>
<td>Jerod Baker</td>
<td><a href="mailto:d.j.baker@nsu.edu">d.j.baker@nsu.edu</a></td>
</tr>
<tr>
<td>Software Design</td>
<td>JP Mathis</td>
<td><a href="mailto:j.p.mathis@nsu.edu">j.p.mathis@nsu.edu</a></td>
</tr>
<tr>
<td>Electronic Design</td>
<td>Lisa Caraway</td>
<td><a href="mailto:l.a.caraway@nsu.edu">l.a.caraway@nsu.edu</a></td>
</tr>
</tbody>
</table>

### 8.2. Configuration Management Plan

When changes in mechanical, software or electronic design are needed, they will be conveyed to the team members during the team meetings. The change will be properly documented in the team notebook and in the corresponding document.

### 8.3. Interface Control

Interface control was be done through the notebook located in room 321 Nicholson Hall and the daily meetings. All changes to the software system, electrical system and payload system will be communicated at the meetings and documented in the notebook. Development sections, Electrical, Payload, Software, and Management, was divided in the notebook, current updates were be placed in the front of the divided section.

### 9.0 Master Schedule

The following section will give a general overview of the scheduling for Team SPARTA. The work breakdown structure is shown in section 9.1. Each team member was assigned a design area according to various strengths. The various milestones (PDR, CDR and FRR) are listed in section 9.3.

### 9.1. Work Breakdown Structure (WBS)

1.0 Electrical System
   1.1. Decide on type sensor
       1.1.1. Temperature
       1.1.2. Humidity
       1.1.3. Pressure
   1.2. Schematic drawing
       1.2.1. BalloonSat
       1.2.2. New Interface board
           1.2.2.1. Sensor interface design
   1.3. Power Supply
   1.4. Circuit Prototype
   1.5. Fabrication of Circuit Board

2.0 Software System
   2.1. Basic Stamp
       2.1.1. Pre flight
           2.1.1.1. Flowchart developed
2.1.1.2. Software developed
2.1.1.3. Testing
2.1.2. In flight
   2.1.2.1. Flowchart developed
   2.1.2.2. Software developed
   2.1.2.3. Testing
2.1.3. Post flight
   2.1.3.1. Flowchart developed
   2.1.3.2. Software developed
   2.1.3.3. Testing
2.2. PC
   2.2.1. Data Retrieval and Storage
   2.2.2. Conversions ADC counts to physics quantity
      2.2.2.1. Temperature
      2.2.2.2. Humidity
      2.2.2.3. Pressure
   2.2.3. Calculation Absolute Humidity
   2.2.4. Graphical representation
      2.2.4.1. Temperature vs. Altitude
      2.2.4.2. Pressure vs. Altitude
      2.2.4.3. Relative Humidity vs. Altitude
      2.2.4.4. Absolute Humidity vs. Altitude
   2.2.5. Comparison with NOAA data
3.0 Payload System
   3.1. Schematic drawing
      3.1.1. Frame construction
      3.1.2. Sensor attachment
      3.1.3. Balloon attachment
   3.2. Thermal Interface
      3.2.1. Design
      3.2.2. Construction
   3.3. Fabrication of frame
4.0 Testing
   4.1. Circuit Board Testing
   4.2. Sensor testing
   4.3. Thermal Testing
   4.4. Vacuum Testing
   4.5. Shock Testing
5.0 Documentation
   5.1. Preliminary Design Review
      5.1.1. Paper
      5.1.2. Presentation
   5.2. Critical Design Review
      5.2.1. Paper
      5.2.2. Presentation
   5.3. Flight Readiness Review
5.3.1. Paper
5.3.2. Presentation

6.0 Balloon Launch
7.0 Science Presentation

9.2. Staffing Plan

SPARTA staff

Table 15 SPARTA Staffing

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>J P Mathis</td>
<td>Software design, Testing, and Documentation</td>
</tr>
<tr>
<td>Lisa Caraway</td>
<td>Electrical design, Documentation, Testing and Equipment acquisition</td>
</tr>
<tr>
<td>Jerod Baker</td>
<td>Payload Design, Circuit Board Fabrication, Testing, and Documentation</td>
</tr>
<tr>
<td>Dr. W. Hinton</td>
<td>Management and Documentation</td>
</tr>
</tbody>
</table>
### 9.3. Timeline and Milestones

Milestones for this experiment include successfully completion of the PDR due June 30th, CDR due July 9th and the FRR due July 25th. Once these milestones are met the launch and recovery of the experimental payload will be the final milestone for this experiment.

<table>
<thead>
<tr>
<th>Table 16 General Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBS</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>5.1</td>
</tr>
<tr>
<td>5.2</td>
</tr>
<tr>
<td>5.3</td>
</tr>
<tr>
<td>5.3.1</td>
</tr>
<tr>
<td>5.3.2</td>
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<tr>
<td>5.4</td>
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<td>6</td>
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<table>
<thead>
<tr>
<th>Table 17 Electrical System Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBS</td>
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<tr>
<td>-----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
</tr>
<tr>
<td>1.2</td>
</tr>
<tr>
<td>1.2.1</td>
</tr>
<tr>
<td>1.2.2</td>
</tr>
<tr>
<td>1.2.2.1</td>
</tr>
<tr>
<td>1.3</td>
</tr>
<tr>
<td>1.4</td>
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<td>1.5</td>
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<td>1.6</td>
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<tr>
<td>WBS</td>
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</tr>
<tr>
<td>2</td>
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<tr>
<td>2.1</td>
</tr>
<tr>
<td>2.1.1</td>
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<tr>
<td>2.1.1.1</td>
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<tr>
<td>2.1.1.2</td>
</tr>
<tr>
<td>2.1.1.3</td>
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<td>2.1.2</td>
</tr>
<tr>
<td>2.1.2.1</td>
</tr>
<tr>
<td>2.1.2.2</td>
</tr>
<tr>
<td>2.1.2.3</td>
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<tr>
<td>2.1.3</td>
</tr>
<tr>
<td>2.1.3.1</td>
</tr>
<tr>
<td>2.1.3.2</td>
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<tr>
<td>2.1.3.3</td>
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<td>2.2</td>
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<tr>
<td>2.2.1</td>
</tr>
<tr>
<td>2.2.2</td>
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<tr>
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<td>2.2.2.2</td>
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<td>2.2.4.4</td>
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<tr>
<td>2.2.5</td>
</tr>
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</table>
### Table 19  Payload System Timeline

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Jun 22, '08</th>
<th>Jun 29, '08</th>
<th>Jul 6, '08</th>
<th>Jul 13, '08</th>
<th>Jul 20, '08</th>
<th>Jul 27, '08</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBS 3 Payload System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3.1 Schematic drawing</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.1 Frame construction</td>
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<td></td>
<td>100%</td>
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<td></td>
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</tr>
<tr>
<td>3.1.2 Sensor attachment</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3 Balloon attachment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2 Thermal Interface</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3.2.1 Design</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3.2.2 Prototype payload</td>
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<td></td>
</tr>
<tr>
<td>3.4 Fabrication of frame</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Table 20  System Testing Timeline

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Jun 22, '08</th>
<th>Jun 29, '08</th>
<th>Jul 6, '08</th>
<th>Jul 13, '08</th>
<th>Jul 20, '08</th>
<th>Jul 27, '08</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBS 4 System Testing</td>
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<td></td>
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<tr>
<td>4.1 Circuit Board Testing</td>
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<td></td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2 Sensor testing</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.3 Vacuum testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.4 Thermal testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4.5 Shock Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
10.0 Master Budget

10.1 Expenditure Plan

10.2 Material Acquisition Plan

All items necessary for the payload construction have been purchased and received. The allotted budget was $500.00 and the total expenditure for this experiment was $186.29, comfortably under budget, see Table 21.

Table 21 Material Acquisition

<table>
<thead>
<tr>
<th>Item</th>
<th>Acquisition</th>
<th>Cost</th>
<th>Lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>Purchase(4)</td>
<td>$20.00</td>
<td>received</td>
</tr>
<tr>
<td>Sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (IM457 temp sensor diode)</td>
<td>Purchase (5)</td>
<td>$1.00</td>
<td>received</td>
</tr>
<tr>
<td>Pressure (IC 1210 015A psi)</td>
<td>Existing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity (HM1500LF)</td>
<td>Purchase (1)</td>
<td>$45.06</td>
<td>received</td>
</tr>
<tr>
<td>Humidity (HIH4000)</td>
<td>Purchase (1)</td>
<td>$26.24</td>
<td>received</td>
</tr>
<tr>
<td>Humidity (HM1520)</td>
<td>Purchase(1)</td>
<td>$89.99</td>
<td>received</td>
</tr>
<tr>
<td>Styrofoam (2cm thick)</td>
<td>Existing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BalloonSat</td>
<td>Existing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$186.29</strong></td>
<td></td>
</tr>
</tbody>
</table>

11.0 Risk Management and Contingency

Table 22, is a list of the risk associated with the design, development and fabrication of the HumTemP experiment. Along with the list of risk we also developed a contingency plan to mitigate the risk and assigned a person responsible for these areas. From the risk management table we were able to assign a likely hood of the risk occurring and the impact of the risk if it occurred. Table 23 graphs the severity of the risk and allows us to focus on the more severe and likely risk. Team SPARTA has of to date not incurred any of the high impact risk.

Table 22 Risk Management

<table>
<thead>
<tr>
<th>Risk</th>
<th>Contingency Plan</th>
<th>Likely hood</th>
<th>Impact</th>
<th>Personnel Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload falls apart mid flight</td>
<td>Document the shock test results to ensure structural integrity</td>
<td>2</td>
<td>5</td>
<td>Jerod</td>
</tr>
<tr>
<td>Payload dropped preflight</td>
<td>Document the shock test results to ensure structural integrity</td>
<td>2</td>
<td>1</td>
<td>Jerod</td>
</tr>
<tr>
<td>Payload broken after fabrication but before flight</td>
<td>Handle carefully</td>
<td>2</td>
<td>4</td>
<td>Jerod</td>
</tr>
<tr>
<td>Component fails during flight</td>
<td>Testing of all electric components</td>
<td>3</td>
<td>5</td>
<td>Jerod</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------</td>
<td>---</td>
<td>---</td>
<td>------</td>
</tr>
<tr>
<td>Component fails before flight (before testing)</td>
<td>Testing of all electric components</td>
<td>3</td>
<td>3</td>
<td>Jerod</td>
</tr>
<tr>
<td>Component fails before flight (after testing)</td>
<td>Test electrical components after receipt</td>
<td>2</td>
<td>2</td>
<td>Jerod</td>
</tr>
<tr>
<td>Drop sensitive component during fabrication</td>
<td>Work in a “clean” environment</td>
<td>5</td>
<td>3</td>
<td>Lisa</td>
</tr>
<tr>
<td>BalloonSat destroyed (magic smoke)</td>
<td>Bread board prototype circuit</td>
<td>3</td>
<td>3</td>
<td>Jerod</td>
</tr>
<tr>
<td>Bad Solder joint during fabrication</td>
<td>Joints inspected by second person and the circuit testing to assure working circuit board</td>
<td>4</td>
<td>4</td>
<td>Jerod/Lisa</td>
</tr>
<tr>
<td>Not installing battery for launch</td>
<td>Designate battery installer</td>
<td>3</td>
<td>5</td>
<td>Lisa</td>
</tr>
</tbody>
</table>

**Software**

| Forget to take computer/program to Palestine, TX | Make a check list before packing to leave for Palestine, TX | 3 | 5 | JP |

**Thermal**

| Sensor freeze during flight | Document results of thermal testing to ensure that sensor will function within temperature range | 2 | 4 | Jerod/Lisa |
| Circuit board freeze during flight | Document results of thermal testing to ensure that sensor will function within temperature range | 2 | 4 | Jerod/Lisa |

**General**

| Wrong sensor order | Check order before sent | 2 | 4 | Lisa |
| Payload not recovered | Transferring Risk | 3 | 5 | |
| Exceed weight budget | Develop weight budget with 20% contingency | 2 | 5 | Jerod |
| Exceed financial budget | Develop equipment budget with 20% contingency | 1 | 5 | Jerod |
| Undocumented change | Daily meetings and hardcopy of system work placed in notebook | 5 | 4 | Team |
### Table 23 Risk Severity Matrix

<table>
<thead>
<tr>
<th>Likely Impact</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>Drop sensitive component during fabrication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>Bad Solder joint during fabrication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>BalloonSat destroyed Component fails before testing</td>
<td></td>
<td>Not installing new battery for launch</td>
</tr>
<tr>
<td>2</td>
<td>Payload dropped preflight</td>
<td>Component fails before flight (after testing)</td>
<td>Sensor freeze or Circuit board freeze during flight</td>
<td>Payload broken after fabrication but before flight Wrong sensor order</td>
<td>Payload falls apart mid flight Exceed weight budget</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Exceed financial budget</td>
</tr>
</tbody>
</table>

### 12.0 Glossary

- **PACER**  Physics and Aerospace Catalyst Experiences in Research
- **CDR**  Critical Design Review
- **FRR**  Flight Readiness Review
- **PDR**  Preliminary Design Review
- **TBD**  To be determined
- **TBS**  To be supplied
- **WBS**  Work breakdown structure
- **RH**  Relative Humidity
- **NOAA**  National Oceanic and Atmospheric Administration
- **ADC**  Analog to Digital Converter
- **RTC**  Real Time Clock
- **DC**  Direct Current
Appendix 1

PREFLIGHT SOURCE CODE

' {$STAMP BS2p}
' {$PBASIC 2.5}

value VAR Byte
adcBits VAR Byte
mux VAR Byte
CS PIN 15
CLK PIN 14
DataOutput PIN 13
SDA PIN 8
SCL PIN SDA+1
addr VAR Word

C_SEC CON 0
C_MINUTE CON 1
C_HOUR CON 2
C_DATE CON 3
C_MONTH CON 4
C_DAY CON 5
C_YEAR CON 6
CONTROL CON 7

rtc PIN 10
sdat PIN 11
sclk PIN 12
array VAR Byt(7)

'DATA for SETTING the real time clock
ADR VAR Byte
VAL VAR Byte

DEBUG CR, "year: "
DEBUGIN HEX2 array(6)
DEBUG CR, "day: "
DEBUGIN HEX2 array(5)
DEBUG CR, "month: "
DEBUGIN HEX2 array(4)
DEBUG CR, "date: "
DEBUGIN HEX2 array(3)
DEBUG CR, "hours: "
DEBUGIN HEX2 array(2)
DEBUG CR, "minutes: "
DEBUGIN HEX2 array(1)
DEBUG CR, "seconds: "
DEBUGIN HEX2 array(0)
'date/mo/yr hr:min:sec day
DEBUG CR, HEX2 array(3), "/", HEX2 array(4), "/", HEX2 array(6), ", ", HEX2 array(2), ":", HEX2 array(1), ":", HEX2 array(0), CR
DEBUG "Today is the ", HEX2 array(5), "st/nd/rd/th day of the week."

main1:
LOW rtc
LOW sclk
HIGH rtc 'bring/RST high while sclk is low

SHIFTOUT sdat,sclk,LSBFIRST,[$80|(CONTROL<<1)\8]
SHIFTOUT sdat,sclk,LSBFIRST,[$00\8]

LOW rtc 'bring/RST low to terminate
'now write time and date, one byte at a time
FOR ADR =0 TO 6
VAL = array(ADR)
GOSUB _PUT_TIME 'and write it to clock
NEXT

'set the write protect bit
LOW rtc
LOW sclk
HIGH rtc 'bring/RST high while sclk is low
SHIFTOUT sdat,sclk,LSBFIRST,[$80|(CONTROL<<1)\8]
SHIFTOUT sdat,sclk,LSBFIRST,[$80\8] ' 1 in most sign bit

LOW rtc 'bring/RST low to terminate

FOR addr=$0 TO $1fff
   value = $FF
   GOSUB Write_To_EEPROM
   IF (addr >$1fff)THEN GOSUB stop_
   DEBUG "highaddress: ",HEX2 addr.HIGHBYTE, " lowaddress: ",HEX2 addr.LOWBYTE, CR
   NEXT
STOP
stop_:
   DEBUG "DONE!!"
STOP
_PUT_TIME:
  LOW rtc
  LOW sclk
  HIGH rtc 'bring/RST high while sclk is low
  SHIFTOUT sdat,sclk,LSBFIRST,[$80|(ADR<<1)|8]'command byte
  SHIFTOUT sdat,sclk,LSBFIRST,[VAL|8]
  LOW rtc 'terminate the sequence
RETURN

Write_To_EEPROM:
  I2COUT SDA, $A0, addr.HIGHBYTE\addr.LOWBYTE, [value]
  PAUSE 10
RETURN
Appendix 2

INFLIGHT SOURCE CODE

' {\$STAMP BS2p}
' {\$PBASIC 2.5}

'VARIABLE DECLARATIONS
ADR VAR Byte      'real time clock register address
VAL VAR Byte      'rtc data I/O
hrs VAR Byte      'temporary storage for hours
mns VAR Byte      'temporary storage for minutes
sec VAR Byte      'temporary storage for seconds
value VAR Byte    'data I/O to the EEPROM
adcBits VAR Byte  'input data from the ADC
result VAR Byte   'variable used for reading EEPROM
mux VAR Byte      'channel address for the ADC
idx VAR Nib       'address index
addrx VAR Word    'psuedoaddress for checking data
ok_write VAR Bit  'flag
addr VAR Word     'address for the EEPROM

'CONSTANTS
C_SEC CON 0
C_MINUTE CON 1
C_HOUR CON 2
C_DATE CON 3
C_MONTH CON 4
C_DAY CON 5
C_YEAR CON 6      'address for the 'hours' register

'PINS
rtc PIN 10        'chip enable for rtc, active HIGH
sdat PIN 11       'bidirectional I/O bit for rtc
sclk PIN 12       'synchronous clock for the rtc
CS PIN 15         'chip select for ADC, active LOW
CLK PIN 14        'synchronous clock for the ADC
DataOutput PIN 13 'I/O data line for the ADC
SDA PIN 8         'I/O for EEPROM
SCL PIN SDA+1     'synchronous clock for EEPROM

'INITIALIZATIONS
addr=0
addrx=0

'Indicators
HIGH 4
HIGH 5
HIGH 6
HIGH 7
PAUSE 1000
LOW 7
PAUSE 1000
LOW 6
PAUSE 1000
LOW 5
PAUSE 1000
LOW 4

'Data Acquisition and Space Check
Data_check:
  GOSUB Mem_check
  IF (ok_write = 1) THEN GOTO Write_
  addr=addr+7
GOTO Data_check

'Writing loop
Write_
  GOSUB Get_time     'GO TO GET_DATE_TIME SUB-ROUTINE
  DEBUG CR
  'mux=12,ch0 mux=14,ch1 mux=13,ch2
  mux=15,ch3
  mux=15
  GOSUB ADC_Data      'GO TO ADC_DATA SUB-ROUTINE
  value=adcBits
  GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-ROUTINE
  addr=addr+1

  mux=14
  GOSUB ADC_Data       'GO TO ADC_DATA SUB-ROUTINE
  value=adcBits
  GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-ROUTINE
  addr=addr+1

  mux=13
  GOSUB ADC_Data       'GO TO ADC_DATA SUB-ROUTINE
  value=adcBits
  GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-ROUTINE
  addr=addr+1

  mux=12
  GOSUB ADC_Data       'GO TO ADC_DATA SUB-ROUTINE
value=adcBits
GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-Routine
addr=addr+1

IF (addr > $1FF9) THEN GOTO stop_
PAUSE 30000
GOTO Data_check

''''''''''Subroutines''''''''''
Mem_check:
IF (addr > $1FF9) THEN GOTO stop_
ok_write = 1
FOR idx=0 TO 6
addrx=addr+idx
I2CIN SDA, $A1, addrx.HIGHBYTE\ addrx.LOWBYTE, [STR result\1]
IF (result <> $FF) THEN ok_write=0
NEXT
RETURN

Get_time:
ADR = C_DATE
GOSUB GET_TIME

ADR = C_MONTH
GOSUB GET_TIME

ADR = C_YEAR
GOSUB GET_TIME

ADR = C_HOUR
GOSUB GET_TIME
value=VAL
GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-Routine
addr=addr+1

ADR = C_MINUTE
GOSUB GET_TIME
value=VAL
GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-Routine
addr=addr+1

ADR = C_SEC
GOSUB GET_TIME
DEBUG HEX2 VAL
value=VAL
GOSUB Write_To_EEPROM 'GO TO WRITE_TO_EEPROM SUB-Routine
addr=addr+1
RETURN

!important : get time:
  LOW rtc
  LOW sclk
  HIGH rtc 'bring/RST high while sclk is low
  SHIFTOUT sdat,sclk,LSBFIRST,[$81|(ADR<<1)|8]'command byte
  SHIFTIN sdat,sclk,LSBPRE,[VAL|8]
  LOW rtc
RETURN

stop_:
  GOTO stop_
RETURN

ADC_Data:
  HIGH CS
  LOW CS
  LOW CLK
  'command to start conversion
  SHIFTOUT DataOutput, CLK, MSBFIRST, [mux|4]
  'Reads the resulting value
  SHIFTIN DataOutput, CLK, MSBPOST, [adcBits|8]
RETURN

Write_To_EEPROM:
  I2COUT SDA, $A0, addr.HIGHBYTE\addr.LOWBYTE, [value]
  PAUSE 10
RETURN
Appendix 3

POSTFLIGHT SOURCE CODE

' {$STAMP BS2p}
' {$PBASIC 2.5}

SDA PIN 8 ' EEPROM read variables AND CONSTANTS
SCL PIN SDA+1
addr VAR Word
result VAR Byte
insidetemp VAR Byte
outsidetemp VAR Byte
pressure VAR Byte
humidity VAR Byte
hrs VAR Byte
mns VAR Byte
sec VAR Byte

addr=0

'main loop
DO
  GOSUB Read_From_EEPROM
  hrs=result
  DEBUG HEX2 hrs,":"
  addr=addr+1
  GOSUB Read_From_EEPROM
  mns=result
  DEBUG HEX2 mns,":"
  addr=addr+1
  GOSUB Read_From_EEPROM
  sec=result
  DEBUG HEX2 sec," "
  addr=addr+1
  GOSUB Read_From_EEPROM
  insidetemp=result
  DEBUG DEC3 insidetemp," " 'ch3
  addr=addr+1
  GOSUB Read_From_EEPROM
  outsidetemp=result
  DEBUG DEC3 outsidetemp," " 'ch1
  addr=addr+1
  GOSUB Read_From_EEPROM
  pressure=result
  DEBUG DEC3 pressure," " 'ch2
  addr=addr+1
GOSUB Read_From_EEPROM
humidity=result
DEBUG DEC3 humidity, CR 'ch0
addr=addr+1

DEBUG CR
IF (addr > $1FFF) THEN GOSUB end_loop
LOOP
end_loop:
    DEBUG "DONE!"
STOP

Read_From_EEPROM:
    I2CIN SDA, $A1, addr.HIGHBYTE\ addr.LOWBYTE, [STR result\1]RETURN