High-Altitude Balloon Curriculum and Hands-On Sensors for Effective Student Learning in Astronomy and STEM

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Students create and fly experiments up to 30 km altitude using a low-cost balloon High-Altitude Research Platform (HARP) greatly advance understanding in introductory astronomy, general education, and advanced classes in engineering, physics, and meteorology. In order to effectively utilize this capability various class and lab formats have been implemented. We typically use four to five lab periods for the HARP program where students research their team project first in concept, second design with some building, third complete fabrication and calibration, and finally launch, data analysis and presentation. Usually students will have a creative experiment (can fail) and a Basic experiment (often works). Learning objectives include the scientific method, data analysis, understanding the environment, interpretation of data, and team presentation. Various curriculum plans and syllabi will be compared with some assessment results. Remote sensing above 98% of the uncharted atmosphere (NearSpace) using cameras, intensifiers, IR and UV sensors provide access to the heavens and large regions of the earth below. *Insitu* and limb atmospheric gas measurements, near-space stratosphere measurements/microbes, and cosmic rays engage students in areas from planetary atmospheres, exo-origins research, and to supernova acceleration. The HARP program provides an engaging laboratory, gives challenging STEM field experiences, reaches students from diverse backgrounds, encourages collaboration among science faculty, and provides quantitative assessment of the learning outcomes. Over a 10-year period Taylor University has successfully launched and recovered over 275 HARP systems. The many launches in a short period of time allowed the payload bus design to evolve toward increased performance, reliability, standardization, simplicity, and modularity for low-cost launch services.

I. Introduction

High–altitude balloon launches provide low-cost access to near space and give general education and upper level students the opportunity to experience firsthand the excitement of real science in a relatively unexplored region of the stratosphere. Small balloons achieve heights of 30 km and can carry payloads up to 4 kgs without needing special FAA waivers. The flight passes through the troposphere, tropopause, most of the ozone layer, and up through 98-99% of the atmosphere (see Figure1). A balloon travels for about 2-6 hours and covers a horizontal distance of 0 to over 200 km (see figure 2 map). To date we have launched over 280 balloons and have recovered over 99% due to the reliable and redundant GPS flight transceiver system, the ideal launch conditions in Indiana, and motivated student recovery teams.

Fig. 1. Video camera frame of student twin balloon ascending while also showing the atmosphere, the curved limb-of- the- earth, and black heavens.

Typically, an introductory astronomy 101 class with 120 students will fly their instruments on a single balloon. Students fly many types of low-cost Basic sensors: Temperature, pressure, humidity, visible light, solar cells, video cameras, UV and IR sensors, spectrometers, Geiger counters, accelerometers, gas sensors, wind sensors, and field sensors. In our 101 curriculum 5-6 students are grouped together to develop two types of experiment packages. The group must choose one or more Basic sensors (ensures good data) and also develop a Creative group experiment. Example creative experiments include recording sound with altitude, imaging cockroach survivability, studying greenhouse gas heating in soda bottles, and many other ideas. Student groups develop and build their payload during two labs (2hr/lab), launch and

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collect data for one lab, and plot and interpret data for presentation in the fourth lab.

II. Balloon Experiment Objectives

The use of balloons for real projects significantly invigorates and expedites development and teamwork, teaches problem solving and instructor mentoring, drives schedule and creativity, uncovers unexpected problems, permits end-to-end testing, gives a real environmental check (significant thermal vacuum and freefall vibration test), and forces completion and validation of the flight and ground station software. Figure 3 illustrates some of the program operational logistics.

Fig. 2. Flight paths of over 200 launches in Indiana over the past 10 years

Specifically, the HARP balloon experiment helps students 1) learn the Scientific Method (hypothesis, test, observe, analyze, interpret, predict, repeat, document), 2) learn some hand-on technical skills (design, soldering, fabrication, electronics, assembly, and team work, 3) learn engineering principles (heat transfer, sensors, GPS, communication links, optics, remote imaging, and data processing), 4) learn atmospheric variables (pressure, temperature, wind, troposphere, stratosphere, humidity, windows, and others), 5) obtain physics knowledge (fundamental equations, radiation, acceleration, Archimedes principle, etc.), 6) apply data analysis skills (using Excel, handling noisy data, plotting profiles, creating log plots, and applying different plot formats), and 7) documentation (Wiki, team report, presentation, and resume). The objective is for students to have fun, efficiently learn, value science, improve in STEM, and advance in critical thinking skills.

III. Astronomy 101 and Engineering ENP252 Balloon Lab Curriculum Examples

To better understand the curriculum requirements a four week lab example is given in Appendix 1. Astronomy student are meeting the earth science general education requirement and span from freshman to seniors. During our concentrated January Term we usually fill the class at 72 students. Two sophomore engineering classes have used balloon labs as part of their ABET project and learning experience: ENP 252 Principles of Engineering and ENP 331 Introduction to Electronics. A balloon lab example is given in Appendix 2.

IV. Conclusions and Student Assessment and Evaluations

There are many ways to effectively inspire students to learn and enjoy science while becoming aware of the scientific method and improve their critical thinking and STEM skills. Some student assessment on our programs is given by Voss et al. 2011. Overall students give high marks and assessment data shows significant growth when care is given to the teaching pedagogy.

V. Acknowledgements

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VI. References

Voss, H. D., Jeff Dailey, and Steve J. Snyder, High-Altitude Balloon Launches and Hands-On Sensors for Effective Student Learning in Astronomy and STEM, *Voss*, Earth and Space Science: Making Connections in Education and Public Outreach, ASP Conference Series, Vol. CS-443, p340, ©2011, Editor Jenson: ISBN 978-1-58381-766-7.

VII. Appendix 1

LAB 10-13: High-Altitude Balloon Project Example

Purpose

The main purpose of this lab is to introduce you to the scientific method, and provide you with the tools that you need to design, execute, and analyze your own experiment. As a result, the lab includes both an organized (Basic) experiment and one that is deliberately vague (Team Innovative experiment). You will be graded on your individual and team's understanding and implementation of the scientific method within the constraints of the project and on the overall lab write-up. The balloon, with your experiments, will hopefully make it to over 98% of the earth's atmosphere at 30 km altitude to the region called Near Space.

Definitions:

<u>Basic Experiment</u>: Each lab team will develop a simple sensor array (Plug and Play) that will measure some basic properties of the atmosphere and may include: Temperature sensors, humidity sensor, pressure sensors, solar sensors, UV sensors, IR Sensor, CO2 sensor, video camera, magnetic sensor, Geiger counter, accelerometer sensor, GPS wind speed, and other sensors.

You will also need to calibrate your sensor and decide physical location and pointing direction. For example for a temperature sensor you should measure the voltage coming out of the sensor when it is at several temperatures (room temperature, ice, and dry ice temperatures) and decide its physical location (in sunlight, shade, or internal to box).

<u>Team Innovative Experiment</u>: Is a creative open ended team experiment that you would like to do to investigate a science problem in near space. Experiments to monitor the atmosphere, the heavens, or remote sense the earth. Ideas would be study greenhouse gases, balloon volume with altitude, sound with altitude, chemical reactions in low pressure and temperature, other types of sensors, wind speed, life science experiments, heat transfer experiments, electrical experiments, fluid experiments, and so on.

The key is that you also select some of your basic sensors to help monitor the conditions of your Innovative Experiment so that you will be better able to interpret the results. For example, if you want to measure heating in a clear bottle with 1 atmosphere pressure you would need to have temperature sensors in your bottle and external to your bottle. You would also need to think about having a control bottle that did not get solar radiation to compare with.

Objectives:

The objective here is to do science and not just learn about science. The upper atmosphere (especially the stratosphere) is a greatly unexplored region and our sensors have the potential of making new discoveries. By doing science you will increase your scientific literacy and your understanding of the scientific method.

A partial list of the specific objectives includes:

- Learn how to work in teams and organize your efforts
- Learn how to operate a Basic Experiment and calibrate it.
- To measure and understand atmospheric properties
- To creatively develop your own team project to make some new measurements.

- To understand basic electrical: Voltage, Current, AD units, RF, Spread Spectrum,.
- To understand mechanical: Box and sensor structure
- To understand heat transfer in your boxes (temperature changes),
- To improve your math skills and use Excel to analyze real data
- Improve your problem solving abilities
- Learn how to document your team scientific results
- Learn the value of discovery and innovation
- Learn basic physics of buoyancy, free fall, terminal velocity, acceleration, and post burst chaos
- Participate in a major launch and recovery of eight teams on two balloons
- Understand wireless communication, GPS, real time data, and tracking
- Understand Jet Stream, troposphere, tropopause, stratosphere, pressure profile,…
- Safety knowledge, FAA and FCC regulations
- Connect your work to the scientific method and learning cycle

Procedure

Two boxes per lab, one team per box (6 students), Each team should build a box, launch three plug and play sensors, calibrate three Plug/play sensors, then develop their own experiment and provide ways to test it and understand the data.

Lab 10: Team organization, Research and Design of your Basic and Innovative experiment. Write up a one page summary paper of your experiment plan that includes: 1) Team member names and majors with team photo, 2) Team Name and Number, 3) Research and Experiment question to investigate (include any references to internet sites that you may have found), 4) Your Team Innovative Experiment preliminary design (include pointing directions and physical location), 5) How will you measure if your experiment worked? , 6) What Basic Experiment sensors will you include in your box? and 7) What materials do you need for your experiment. You should work with your lab instructors to make sure that your project is viable. Email your Lab 10 Summary paper to Professor Dailey at jfdailey@taylor.edu and later we will put your paper onto your team WIKI.

Lab11: Build and calibrate your sensors and integrate into payload boxes: 1)Improve your documentation, 2) make some neat drawings of your design (Block Diagram, Mechanical Assembly Diagram), 3) collect your materials for building, 4) build your box with wireless interface board, 5)Breakout what each team member is responsible for and who your team leader(s) is (are), 6) build and test your basic sensors, 7) build and test your Team innovative experiment, 8) calibrate your sensors, 9) Make sure you are taking pictures of all parts of the design process with team photo for your wiki, and 10) Assembly your box for launch. Balloon launch now scheduled for October 30, Prepare for launch and chase as discussed in expectations.

Lab 12: Data Analysis and WIKI: Include your results, photos, diagrams, altitude profiles of data, data interpretation, and discussion of problems and conclusions in your wiki.

Lab 13: Data Analysis, Documentation, Poster, and Presentation: In this lab you need to complete all aspects of your Basic and Innovative team experiment. You will make a poster and present it as a team to the whole group.

The Scientific Method

The scientific method consists of six steps:

1. State the **Problem** (what is the relationship to be observed?)
2. **Research** previous work

3. Develop a **hypothesis** for your problem statement based on research
4. Design and Perform an **experiment** to prove your hypothesis
5. **Observe** the results of your experiment
6. Come to a **conclusion** about your hypothesis based on your observations

Stated simply, these steps can be listed: Problem, Research, Hypothesis, Experiment, Observe, Conclude.

It should be noted that the steps make no mention of the level of complexity of the problem statement; in many cases, a simple, small-scope problem statement can be more instructive than a large, complex one. The reason for this is as follows: the tighter the scope of your project, the fewer the variables, and therefore, the easier it is to observe the cause-and-effect relationship in your experiment and results.

The Tools

You will be introduced to the various tools available to you to design and deploy a high-altitude balloon project in this lab. You will be familiarized with the pieces that you need to be successful (the cameras, sensors, microcontrollers, pods, and more), and then asked to follow the scientific method through to completion, using the tools and equipment available to you. You will also be introduced to some of the thought processes necessary to design a successful scientific experiment. For example, it is important to determine:

- What will be changing as a result of the conditions of the experiment?
- What are the measurements that can be performed to verify those changes?
- These two questions set up a "control," or the baseline for an experiment
- What can I introduce to change those measurements or impact the results?
- Is there a relationship that is not well defined that needs to be observed?
    - These two questions set up your problem statement
- What experiments have been done similar to the one that is being proposed?
- What data or results have been found as a result?
- What can I learn from those experiments and results?
- With what I've learned, what do I predict the results of my experiment will be?
    - This series of questions takes you through the research phase, and leads to a hypothesis
- How do I need to set up my experiment?
- What is the schedule for what needs to be done for my experiment to work?
- Did my experiment work? (nail biting here)
    - This is the experimentation section of the process
- What does the data say about my hypothesis?
- What does the data say about how my experiment was set up?
- What does the data say about what should be done differently next time?
    - In this section, you will be observing the results of your experiment
- Can I come to a complete, specific prove/disprove determination on my hypothesis based on my results?
- If I can, what is that determination?
- If not, why? What are other possibilities? Other experiments to explore those possibilities?
    - This is the conclusion section of the process

Note that the above series of questions is intended to be a guideline – not a comprehensive laundry list of items to answer.

The Data & Altitude Profiles

As you plan for your experiment, an important determination to make is what will be acting as your cause, and what effect you wish to observe. In the case, for example, that you will need to generate a plot of your data, you will need to identify the proper orientation of your data on the axes of the plot, and state that clearly. The most common layout for a data plot is to have the independent variable (your input) on the horizontal ('X') axis, with the dependant variable (your data as a result of the input) on the vertical ('Y') axis. However, in the case of a high-altitude balloon flight, the altitude of the balloon is sometimes used as the independent variable. In this case, altitude is placed on the vertical axis, and the data is placed on the horizontal axis. This layout is called an "altitude profile." Regardless of which layout you chose, if you plot your data, it is important that you label your axes with what is represented, and the units in which it is being measured. For example, the label for an altitude axis would be: Altitude (Feet)

Expectations: *On launch day*

One person helping launch team, One person Checking out team payload, One person going on chase, One person documenting launch, Team members at launch site one hour prior to release. In addition, it is expected that teams will meet outside of lab to complete the data analysis and conclusion portions of the lab.

Deliverables

You will be using the Blackboard Wiki tool to present your experiment and findings. The procedure for using the Wiki tool will be reviewed in lab, and is similar to many blogging tools in existence. Your teams Wiki must include (but is not limited to):

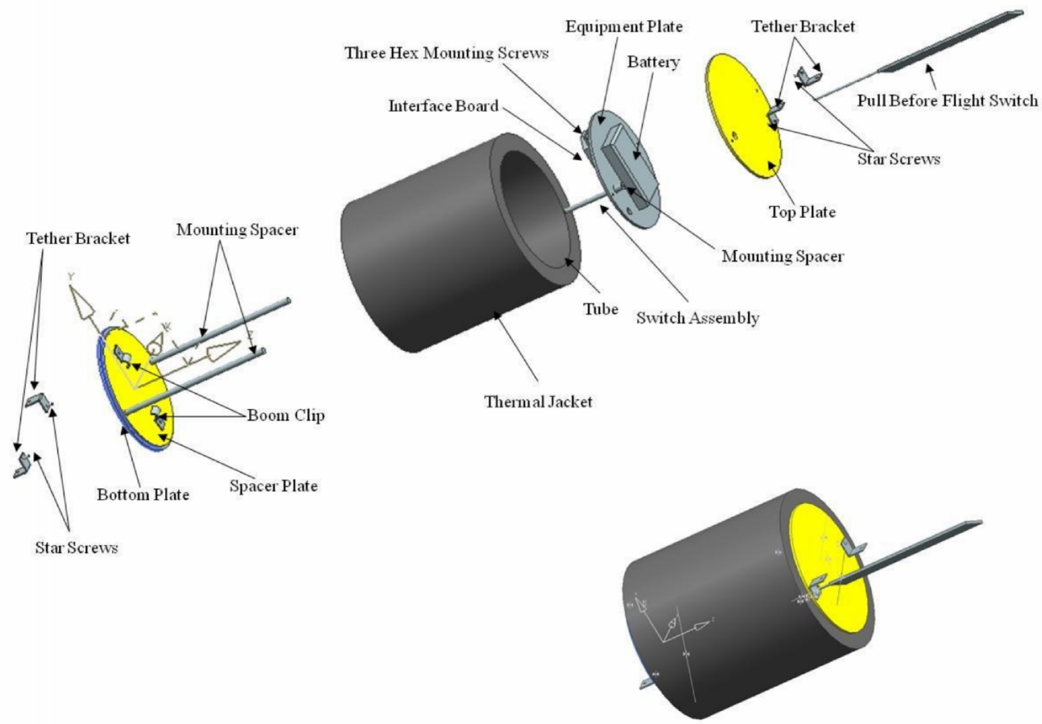
- Front Page
    - Team Name
    - Full Name of each team member
    - Problem Statement
- Research Page
    - Research on your problem statement, in your own words (give citations!)
    - Hypothesis based on your research
- Experimental Plan Page
    - How you plan on testing your experiment – give all of the details
    - Launch day checklist
- Launch Report Page
    - How did the launch go?
    - Was the checklist followed?
    - Did the experiment appear to work on the launch pad?
- Data Analysis Page
    - Images, plots, or other information from your experiment (can be an attached file)
    - A description of your data (on the wiki page)
    - Your group's conclusion regarding your hypothesis, based on your data (this includes suggestions for further experiments)

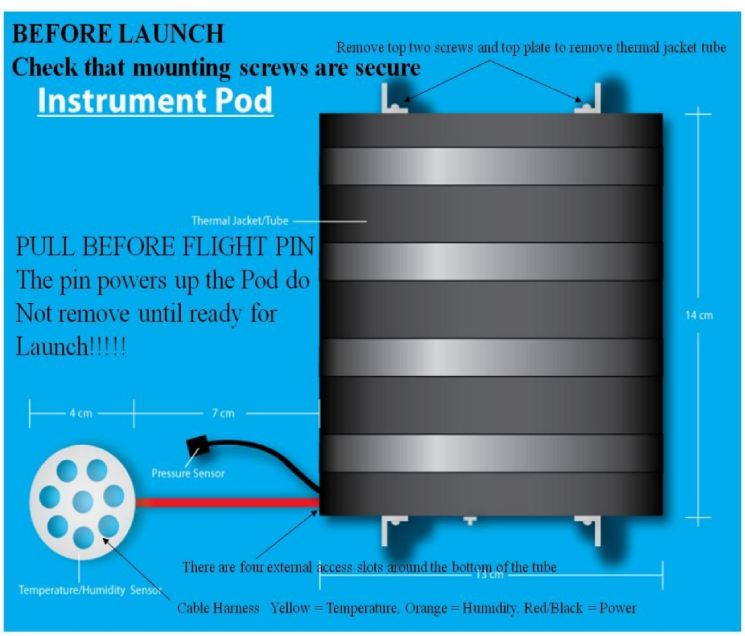
Your grade in this lab will be determined by your group's application of the scientific method and the extent to which that application is completely documented on your Wiki site, and the peer assessment forms.

You must have your experiment complete by the time of the launch. All documentation material for this lab will be due one week after Lab 11 date.

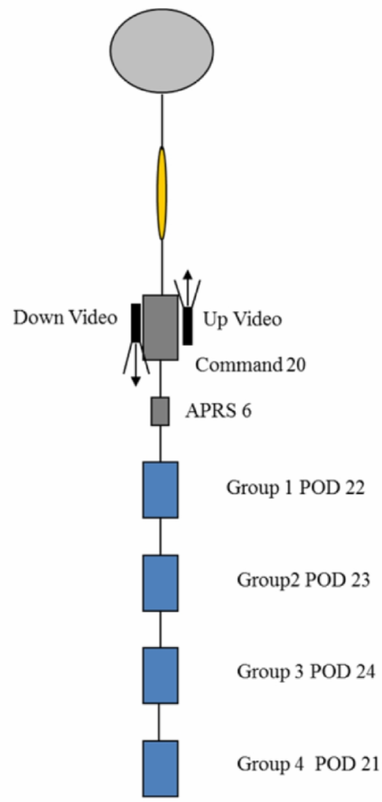
Conclusion

Your instructors are here to help. If you are confused or if your group needs assistance, please let us know!


Equipment Plate
Tether Bracket
Three Hex Mounting Screws
Battery
Pull Before Flight Switch
Interface Board
Star Screws
Top Plate
Mounting Spacer
Tether Bracket
Mounting Spacer
Tube
Switch Assembly
Boom Clip
Thermal Jacket
Spacer Plate
Bottom Plate
Star Screws


BEFORE LAUNCH
Check that mounting screws are secure
Instrument Pod
Remove top two screws and top plate to remove thermal jacket tube
Thermal Jacket/Tube
PULL BEFORE FLIGHT PIN
The pin powers up the Pod do
Not remove until ready for
Launch!!!!!
14 cm
4 cm
7 cm
Pressure Sensor
There are four external access slots around the bottom of the tube
13 cm
Temperature/Humidity Sensor
Cable Harness: Yellow = Temperature, Orange = Humidity, Red/Black = Power

Astronomy Spring 2011
36 Students
6 Groups



Launch Site Weather

Site: Taylor University
Launch Time: ???
Wind: ??? 1.2 M/S
Direction: ???South
Temp.:??? 6.7c
RH: ???88.1%
Baro: ???995.2 hPa

High Altitude Research Platform Astronomy LAB worksheet (Add spaces between questions)

1. What is the Analog input resolution?
2. How do you convert the RAW number to voltage?
3. What is the analog input voltage range?
4. How do you convert the RAW number to Temperature in C?
5. How do you convert the RAW number to Humidity in RH?
6. How do you convert the RAW number to Pressure in HPA?
7 How did you calibrate your Temperature and Humidity probes?
8 What is the Frequency range of the Downlink from the balloon?
9 How does the Command POD communicate to your POD?
10 What are the Layers of the Atmosphere?

VIII. Appendix 2 Sophomore Engineering Lab

LAB 7-10 Major Team Design Project (4-5 weeks)

Balloon Launch 262, April 18, 2011 Plan

1. **Introduction:** In this lab you will put together mechanical, thermal, analog and digital systems that perform useful functions for a unique balloon launch opportunity. You will work individually and in teams just as if you were in graduate school or industry to solve real problems when you don't have all of the answers. We might have to redesign things, order some additional parts, and spend time debugging. The important part of this lab is to work in teams, plan ahead so that your design will come together, and do adequate testing of your experiments to assure performance in flight.
2. **Objectives:**
    a. Work on a unique design where everything is not defined but the general requirements are understood. (This is the Real World)
    b. Meet a schedule and work together as teams to get the job done
    c. **Order Parts** and find equipment
    d. Learn mechanical, digital, analog, communication, and atmospheric properties.
    e. Optional to reprogram your Lab 1-2 IO Board in PBASIC or C
    f. Learn how to test and debug a system so that it will work in a rugged environment.
    g. Learn proper workmanship to build a reliable system
    h. Have fun learning how to do a high-altitude balloon launch
    i. Learn how to do record data and perform data analysis
3. **Development Plan:**
    a. Each lab section will be assigned a flight cylinder tube and a list of possible experiments that each student is to research and develop for flight. You will need to understand your sensor choice, interface electronics, pointing directions and field of views, performance and calibration, and integration into a flight system with your team. You should use your Astro-Board Microcontroller to collect and store your data in EEprom for readout after the flight. Each team will also have access to their real-time analog telemetry.
    b. During lab time each group should plan out their experiments, divide up the work, make a schedule out for the subsystems, and document their development plan for the week. Make sure you have already secured all for your parts and projects. If needed, also set up time on Saturday (before launch, April 18) to complete your experiment and test it.
    c. In class you will be responsible to demonstrate and present your part of the project to the class and in the TU Poster session with the expected results.
4. **Launch:**
    a. Launch is scheduled for April 18. You should be present at launch to verify your experiment and record the necessary data. You may also want to participate on the Chase Recovery effort.
5. **Lab Documentation: (Your Semester Lab Project- 4 labs)**
    a. You need to document your part of the project and show your data analysis.
        1. Full engineering/science technical report showing background information, block diagram, Mechanical schematic, test data, waveforms, pictures of unit details, calibration data, software programs, live LabView results, EEPROM results (You also need to show and plot your stored microcontroller data in Excel), Data Analysis, Summary
        2. Follow technical report format
    b. We will also be putting together two or three posters for presentation in May

6. LAB 7 Experiment Breakdown for Lab Sections

You should know your ABET project part and the additional Systems Learning project part. The projects that you selected are listed below

Morning lab

a. Name 1: Ion Current of the Global Electrical Circuit (ION): Fly baseline PASCO electrometer and Build electrometer with transistors and Perforated Board
b. Name 2: LabView Data Visualization and Solar Array (LDV): Fly solar array and develop general purpose Labview dashboard
c. Name 3: Geiger Counter: Fly Baseline Geiger counter and Build long Geiger counter with circuit and HV supply
d. Kevin: Dual Locking Boom Deployment (LBD): Put camera on three foot boom and deploy at selected altitude. Opposite boom with balanced mass.
e. Cade: Precise Measurement of Atmospheric Gas Composition (AGC) at Various Altitudes: Atmospheric minor constituent gas sampling, Build four electrically controlled valves activated with altitude for filling four flasks. Complete with ground spectroscopic analysis.

Afternoon Lab

f. Seth: Power Output of Photovoltaic Cells with Altitude (PCA): Fly baseline PASCO visible sensor and compare with our visible sensor and data from David's Solar Array. Understand IV curve, wavelength sensitivity and altitude variation.
g. Adam: Wind Energy Sensor (WES): Fly cup anemometer on tether to determine wind velocity and power, measure tether angle versus wind speed,
h. Dan: UV Radiation Altitude (UVA) Variation:
i. Matt: Balloon Electric Field (BEEF) sensor: Atmospheric Electricity: Electric Field and Power
j. Ben: IR Radiation Altitude (IRA) Sensors:

LAB 5 Mechanical Drawing

a. Draw Ortho and 3D of hammer
b. Draw your basic instrument layout

Other Requirements: Additional Handouts and requirements are given out during the four Lab period.