BalloonSat and LabPro: High Altitude Balloon Experiments for High School Students

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Abstract

BalloonSat is a NASA and Arkansas Space Grant Consortium funded program that gives secondary education students the opportunity to design and build scientific payloads to send to high altitudes aboard helium filled weather balloons. Recently a flight was conducted with Vernier's LabPro data acquisition system recording atmospheric temperature and pressure. Altitude was inferred from post-flight GPS data that indicated the balloon reached the edge of the stratosphere. The transition from the troposphere to the tropopause and then to the stratosphere is indicated by abrupt changes in temperature. The data taken demonstrates the atmospheric pressure's exponential dependence on altitude as well as the wet adiabatic lapse rate in the troposphere. Hands-on experiments such as these utilizing data acquisition devices common in the technology enhanced classroom offer secondary education students and teachers the opportunity to do meaningful scientific explorations of the Earth's atmosphere.

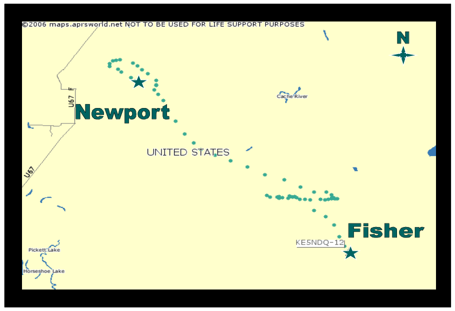


Figure 1 Map of GPS Data from Flight ABS-06

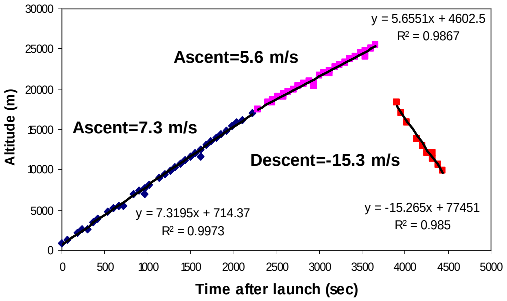
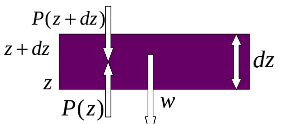


Figure 2 Initial GPS data vs Time

Figure 3 Students involved in BalloonSat program assisting in inflation of the balloon.

Flight Information

The first flight that we launched was last fall at 10:00 am from ASU Newport. The balloon landed in Fisher, AR at 11:40, which was 15 miles from the launch site (shown in Figure 1). The helium filled latex balloon, parachute, payloads, and GPS package reached an altitude of 83,400 ft. Our 822g payload contained a Vernier LabPro, operated remotely on four AA batteries, a stainless steel temperature probe, and a gas pressure sensor. The initial data is shown in Figures 2 and 4. To find the theoretical values for our pressure vs altitude data we treated atmosphere as a slab of air:



Using Newton's second law

$$AP(z)-AP(z+dz)-\rho Adzg=0$$

$$\frac{dP}{dz}=-\rho g$$

$$\rho=\frac{mP}{kT}$$

$$\frac{dP}{dz}=-\frac{mg}{kT}P$$

$$\int_{p_0}^{P}\frac{dP}{P}=-\frac{mg}{kT}\int_0^z dz$$

$$\ln\left(\frac{P}{P_0}\right)=-\frac{mgz}{kT}$$

$$\frac{P}{P_0}=e^{-\frac{mgz}{kT}}$$

$$P=P_0e^{-\frac{mgz}{kT}}$$

The fit of our data to this theoretical equation is shown in Figure 5. To find the theoretical values for the temperature vs altitude data we used the Equipartition theorem, the first law of thermodynamics, and the differential of the ideal gas law:

$$\frac{f}{2}\frac{dT}{T}=-\frac{1}{V}\frac{NkdT-VdP}{P}$$

We can get the change in temperature:

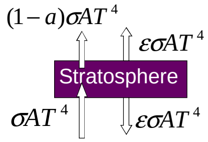
$$dT=\frac{2}{2+f}\frac{T}{P}dP \qquad dT=-\frac{2}{f+2}\frac{mg}{k}=-\frac{2}{f+2}\frac{Mg}{R}$$

Using dP/dz:

$$\frac{dP}{dz}=-\frac{mg}{kT}P \qquad \frac{dT}{dz}=-\frac{2}{7}\frac{(0.029\,kg/mol)(9.8\,m/s^2)}{(8.315\,J/molK)}$$

$$\frac{dT}{dz}=-.0098\,K/m=-9.8\,K/km$$

To calculate the theoretical temperature for the tropopause we must use the average temperature in the troposphere and Stefan's Law:



Stefan's Law

$$P=A\sigma T^4$$

$$P_{in}=P_{out}$$

$$a\sigma AT_t^4=2\varepsilon\sigma AT_s^4$$

$$T_s=\left(\frac{a}{2\varepsilon}\right)^{\frac{1}{4}}T_t$$

Since the absorptivity and emissivity of the stratosphere are equal:

$$=\left(\frac{1}{2}\right)^{\frac{1}{4}}\left(-21.4^{O}C\right)$$

$$T_s=-61.1^{O}C$$

Where *a* is absorptivity, ε is emissivity, *T* is temperature, *A* is surface area, and σ is Stefan's constant.

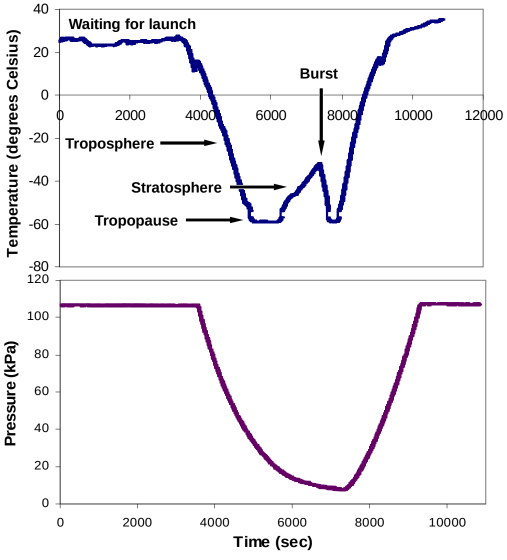
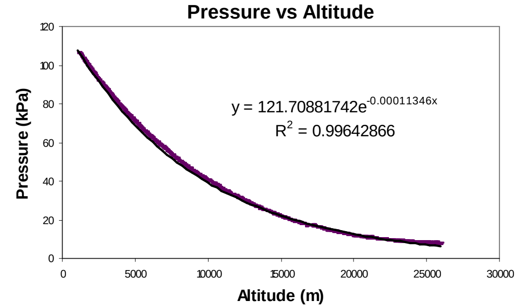
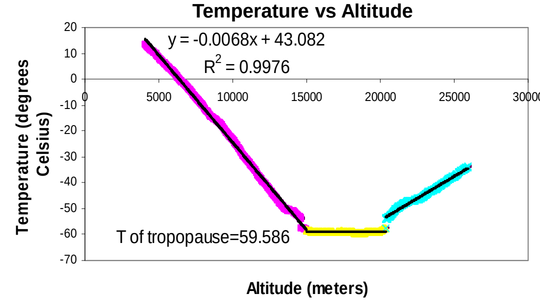


Figure 4 Initial Data taken with the LabPro, Stainless Steel Temperature Probe, and Gas Pressure Sensor



$$P=P_0e^{-\frac{mgz}{kT}}=P_0e^{-\frac{(.029\,kg/mol)(9.8\,m/s^2)z}{(8.315\,J/molK)(250\,K)}}=P_0e^{-.0001z}$$

Figure 5 Pressure vs Altitude Data compared to theoretical value (using an average temperature of 250K)



$$\frac{dT}{dz}=-\frac{2}{7}\frac{(0.029\,kg/mol)(9.8\,m/s^2)}{(8.315\,J/molK)}$$

$$\frac{dT}{dz}=-.0098\,K/m=-9.8\,K/km$$

Measured: dT/dz=-6.8 °C/km

Since this comparison is made to a dry adiabatic lapse rate it is natural for the values to not be exact. Compared to the US Standard Atmosphere (1976) from CRC Handbook of Chemistry and Physics for the US wet lapse rate of **-6.5 °C/km**, we can see it is much closer.

Figure 6 Temperature vs Altitude Data compared to theoretical value

Acknowledgments

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http://www.arkballoons.com/