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High Altitude Ballooning: A Comprehensive Review

Amanda Maxham* Eric Lujan, Ian Rabago and Han Oel Lee
Department of Physics and Astronomy, University of Nevada, Las Vegas, Las Vegas, NV, 89124, U.S.A.

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ABSTRACT
The abstract will go here. It's a summary of the below paper.

1 INTRODUCTION

With the recent interest in high altitude ballooning from both University, amateur radio and non-specialists, many are seeking out more information on the science behind high altitude ballooning. In this paper, we review some of the science, equipment and calculations behind how to have a successful launch and feature a few interesting student projects.

2 TERMINAL VELOCITY OF ASCENT

A launched balloon is acted on by three forces in the z-direction, the upwards buoyant force, F_B, the downward force of the combined weight of the balloon, gas inside the balloon and the payloads attached, F_g, and the drag force, F_d (see figure xx). After the balloon is launched, the over balance of the upward buoyant force causes the balloon to accelerate upwards. Figure 07 shows an altitude vs. time plot for a high altitude weather balloon launch which is typical of these types of flights. The downward drag force quickly overcomes the initial upward force, causing the balloon to reach terminal velocity and remains at a constant velocity throughout the flight despite the changing surface area of the balloon and air density both of which can effect drag.

A given mass of He displaces 7.125 times its mass in air, therefore, the upwards force of the helium can be calculated by

$$F_{He} = (7.125 m_{He} - m_{He}) \cdot 9.81 \tag{1}$$

where m_{He} is the mass of helium in the balloon in kilograms.

As the balloon accelerates, the values of the three forces can be combined to a net upwards force that can be described as follows:

$$\Sigma F = F_{He} - F_g - F_d \tag{2}$$

These forces are at equilibrium when the balloon reaches terminal velocity, which results in $\Sigma F = 0$.

2.1 Time

The approximate time it takes to reach terminal velocity can be computed if terminal velocity and the acceleration are known by using the following formula where a represents the initial acceleration of the balloon:

$$V = \frac{1}{2} a \cdot t^2 \tag{3}$$

In order to determine the initial acceleration of the balloon, we can apply Newton's second law:

$$\Sigma F = ma \tag{4}$$

2.2 Experimental application

In our launch, we were able to measure the rate of ascent at terminal velocity due to the presence of GPS receivers on the balloon. We found that the ascent rate was approximately 5.59 m/s. In addition, we estimate the mass of helium that went into the balloon as 1.63 kg. By applying Equation 1, we computed that the value of F_{He} is 97.94 N.

$$F_{He} = 9.81(7.125 \cdot 1.63 - 1.63) = 97.94 \tag{5}$$

Since we know that the total mass of the balloon and its payloads is 7.736 kg, F_g has a value of 75.89 N.

$$F_g = 7.736 \cdot 9.81 = 75.89 \tag{6}$$

To find F_d, we can apply the drag equation:

$$F_d = CA(\frac{\rho \cdot V^2}{2}) \tag{7}$$

Where ρ is the density of the air (1.2kg/m^3), V is the balloon's velocity, A is the cross-section area of the balloon (1.49π m^2) , and C is the drag coefficient of the balloon (0.25 in our case).

By applying Equation 2, we find that the initial net upward force on the balloon is 22.05 N.

$$\Sigma F = 97.94 - 75.89 - 0 = 22.05 \tag{8}$$

The initial acceleration of our balloon can be determined by applying Newton's second law to our known values:

$$22.05 = 7.736 \cdot a \tag{9}$$

This results in an initial acceleration value of 2.85 m/s^2

By taking these values and implementing them in Equation 3, we can predict the approximate time that it takes for the balloon to accelerate to terminal velocity.

$$5.59 = \frac{1}{2} \cdot t^2 \tag{10}$$

We can estimate that our balloon will reach terminal velocity (5.59 m/s) after 3.34 seconds of acceleration.

We can find the forces present at terminal velocity by re-applying the above equations:

$$F_{He} = 97.94 \tag{11}$$

$$F_g = 7.736 \cdot 9.81 = 75.89 \tag{12}$$

$$F_d = 0.25 \cdot 1.49\pi(\frac{1.2 \cdot (5.59)^2}{2}) = 21.94 \tag{13}$$

At terminal velocity, ΣF is approxmiately equal to 0.1 N.

$$\Sigma F = F_{He} - F_g - F_d = 97.94 - 75.89 - 21.94 = 0.11 \tag{14}$$

Please note that the preceding methods are for estimation purposes only. Calculus (particluarly deriviatives) can be used to accurately predict the time a balloon reaches terminal velocity, but these equations have not yet been adapted for use in a positive vector field.

3 THE COMPOSITION OF PARTICLE SPHERE VISIBLE UPON BALLOON BURST

This section will be furthered in experimental trials and will be published independently.

See notices of deletion in Appendix A.

4 THE EFFECT OF WIND VECTORS ON THE ASCENT AND DESCENT PATHS OF HIGH-ALTITUDE BALLOONS

Figure 1 shows the path of a high altitude balloon flight from the Flying Apple Space Technologies (FAST) group associated with the University of Nevada, Las Vegas (UNLV). This trajectory, like others, shows the interesting property that the launch, burst and landing points are all found to lie on a single straight line. Further, the rising part of the flight path, between launch and burst and the descending part of the curve between burst and landing appear to be mirror images of each other, with the descending part being a foreshortened image.

Wind speed and direction as a function of altitude can be described as a vector field that applies a force to a balloon or parachute and cause displacement along the path. The relationship between the ascent rate, descent rate, and this vector field gives rise to this flight path pattern and is described mathematically below.

4.1 Vector equations

As a balloon ascends through the atmosphere, it is affected by multiple wind vectors. The balloon quickly reaches terminal velocity (within x seconds, see figure xx) and rises with a constant velocity until burst. After burst, the payloads on the flight string also quickly reach terminal velocity, whether carried down on a parachute or not.

The wind exerts three forces on the balloon or parachute F_x, F_y and F_z at any point, with the three dimensional plane defined such that the positive z-axis points normal to the surface of the Earth. Assuming that the wind force in the z-direction, F_z is negligible, the vector wind field in the x-y plane causes the balloon to move laterally as it travels upwards or downwards through this field. Assuming that the balloon and payloads travel through the same vector field on the way up as the way down, this causes the three points, launch point, burst, and landing, to lie along the same line. The ascent path appears to be rotated 180° about the burst point and scaled by a factor to create the descent path.

If κ is ratio of the ascent velocity of the balloon in the z-direction, v_+, and the descent velocity of the payloads in the negative z-direction is v_-, then,

$$\kappa = \frac{v_+}{v_-} = \frac{d_-}{d_+} = \frac{t_-}{t_+} \tag{15}$$

4.2 List of Equations

These equations are from the previous LaTeX file, and listed here for reference as well as for future insertion.

$$D_t = D_a + D_d \tag{16}$$

$$D_d = K \cdot D_a \tag{17}$$

$$K = \frac{r_a}{r_d} \tag{18}$$

$$D_d = (\frac{r_a}{r_d}) \cdot D_a \tag{19}$$

$$D = D_a + (\frac{r_a}{r_d}) \cdot D_a \tag{20}$$

$$t_l = t_a + t_d \tag{21}$$

$$t_d = K \cdot t_a = \frac{r_a}{r_d} \cdot t_a \tag{22}$$

$$t_l = t_a + \frac{r_a}{r_d} \cdot t_a \tag{23}$$

These equations are listed in the order that they appear in the original document.

5 LATEX BACKPRESSURE AND LIFT

5.1 A Conceptual

Backpressure (also known as "membrane pressure") is the inwards pressure that the elasticity of the balloon places on the gases contained therein. It was determined that backpressure changes over the course of the flight, due to differing balloon radius and atmospheric pressures, and can have a significant effect on the amount of lift that the gas provides. The pressure inside the balloon P_t can be represented mathematically