UNIVERSITY OF COLORADO BOULDER

ASEN 2002: INTRODUCTION TO THERMODYNAMICS AND AERODYNAMICS

Design Lab: Pre-lab

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Contents

Nomenclature

ρ	=	Density of Material [$\frac{kg}{m^3}$]
g	=	Gravity = 9.81 [$\frac{m}{s^2}$]
m	=	Mass of Object [kg]
W	=	Weight of Object [N]
P	=	Pressure [Pa]
V	=	Volume [m^3]
R	=	Gas Law Constant [$\frac{J}{kg*K}$]
T	=	Temperature [K]

Equations

$$\sum F_y = \rho_{Air} V_{Ball} g - (m_{Gas} g + m_{Payload} g + m_{Shell} g) = 0 \tag{1}$$

$$\sum F_x = 0 \tag{2}$$

$$F_{Buoyant} = \rho_{Air} V_{Ball} * g \tag{3}$$

$$W_{Gas} = m_{Gas} g \tag{4}$$

$$W_{Payload} = m_{Payload} g \tag{5}$$

$$W_{Shell} = m_{Shell} g \tag{6}$$

$$m_{He} = \frac{PV}{RT} \tag{7}$$

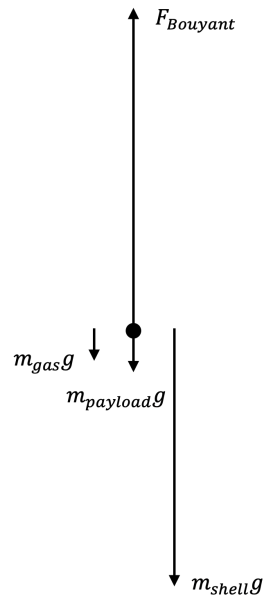
$$F_{Buoyant} = \rho_{water} V_{Ball} * g, \quad where \ \ \rho_{water} = 1000 \frac{kg}{m^3} \tag{8}$$

$$F_y = \rho_{water} V_{Ball} g - (m_{Gas} g + m_{Payload} g + m_{Shell} g) = 0 \tag{9}$$

$$m_{Payload} = \rho_{water} V_{Ball} - (m_{Gas} + m_{Shell}) \tag{10}$$

I. Neutral Buoyancy Experiment

In the balloon system, there are four main forces applied to the balloon: force of buoyancy, weight of the enclosed gas, weight of the payload, and weight of the balloon's shell. The magnitude of the buoyant force is equivalent to the sum of the weight of the enclosed gas, weight of the payload, and weight of the balloon's shell. These forces are all in the vertical, y, direction, resulting in a net force of 0 newtons (N).



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II. Heating Experiment

The thermal system in the experiment was the gas (helium) inside the balloon. Through radiation, heat was transferred to the gas from the heater, causing the balloon to become positively buoyant and float above the heater. Then, when the balloon was above the heater, heat radiates out from the gas to the surrounding air, leading to the balloon once again becoming negatively buoyant. The first law of thermodynamics, which posits that energy cannot be created or destroyed but can transform from one state to another, allowed for this cycle to occur.

Before the balloon was placed next to the heater, a mass was attached to it to ensure that it was negatively buoyant. The balloon was then placed near the heater, but not touching it. The heat radiating from the heater caused an increase in the temperature of the gas, leading to an increase in the volume of the gas. The first law of thermodynamics supports the observation that the heat/kinetic energy of the heater was transferred to the gas inside the balloon. As the volume increased, the buoyant force of the gas increased. When the magnitude of the work done by the buoyant force was greater than that of the force of gravity, the balloon became positively buoyant and floated upwards, away from the heater. As the balloon rose higher from the ground, it became surrounded by cooler air. Through radiation, heat was transferred from the gas in the balloon to the surrounding air. This resulted in the volume of the gas decreasing and the balloon becoming, once again, negatively buoyant. The gas in the balloon, once on the ground again, was returned to its starting temperature and energy.

The gas inside the balloon had its highest kinetic energy when it was just starting to float upward, but still in front of the heater. The gas' lowest kinetic energy was where it began and ended the cycle. An increase in the gases kinetic energy corresponds to an increase in its temperature, which in turn corresponds to an increase in volume and buoyancy. Without the heat introduced to the system by the heater, the balloon would never have left the ground.

III. Volume Measurement

We found the volume of our balloons using two different methods. We first found a dimensional estimate using the circumference of the balloon (1.07 m) length wise and approximated this balloon as a perfect sphere. Using the equation for the circumference of a circle and the equation of a sphere, we found that the value was approximately 21 Liters with an uncertainty of 7 Liters, this value was high due to error propagation. For our second approach, we dunked our balloon into water and recorded the displacement of water and subtracted the volume displaced by our hands; the volume was measured to be around 13 Liters with an uncertainty of .3 L due to error propagation and was calculated using rules of quadrature. The dimensional estimate has uncertainty because the balloon was far from a perfect sphere, and thus approximating this balloon as a sphere is relatively inaccurate. Also our measurement using the string was done quickly and thus, decreased our chances that our circumference around the width was interpreted accurately. This dimensional estimate error significantly increased when it was cubed once in the sphere equation. The tank volume measurement also presents some uncertainty in measurement. The volume of gas may become smaller in the tank because the tank will present a new environment that has a decrease in temperature and an increase in pressure causing the balloon volume to go down. The second uncertainty expected comes from human error from difficulty reading the shaky water and an inaccurate measurement of the volume displaced by the hands dunked into the tank.

IV. Mass Budget

The group used 2 different methods to estimate the mass of the Helium gas in the small scale balloon in this prelab. The first method the group used was the force balance relations for the neutrally buoyant balloon. Since the group used the payload mass for the neutrally buoyant balloon in their force balance calculations, they were able to assume that the balloon was stationary and not accelerating. Therefore the net force acting on the balloon must be 0. From this assumption, the group could develop the force balance equation shown below as equation 1 In section I Neutral Buoyancy Experiment. This equation was solved for the mass of the gas using MATLAB. The MATLAB code used for calculating the Helium gas mass using the force balance method can be found in the Appendix. After computation, the mass was calculated to be 2.399 grams.

The second method the group used to calculate the mass of the Helium gas inside the balloon was the ideal gas relation in conjunction with the volume of the balloon that the group measured and discussed in section III. The ideal gas equation is given by equation 7 where P is the atmospheric pressure on that day at the PILOT lab plus 10 Pascals of gauge pressure inside the balloon. V is the volume of the balloon calculated by submerging it in water. The process and analysis of the balloon calculation is outlined in more detail above in section III. Volume Measurement. M is the mass of helium gas that we are solving for. R is the specific gas constant for Helium in $\frac{J}{Kg*K}$ and T is the room temperature of the pilot lab in Kelvin. Equation 7 was then solved for m using MATLAB. The code used to compute the mass of the gas using the Ideal Gas Equation is included in the Appendix. After computation, the mass of the gas using the Ideal Gas Equation was computed to be 1.826 grams.

$$m_{He} = \frac{PV}{RT} \tag{7}$$

The group considered the results and approach for each of the two methods for calculating the mass of the gas and determined that the more accurate method is the Ideal Gas calculation. By comparing the sources of error for the mass calculation using the two methods it is easier to determine which is more accurate. It can be observed that the Ideal Gas Equation only has one source of error, this error is the volume measurement. This measurement is repeated twice with two different methods so the error is greatly reduced. The force analysis equation however had several sources of error including each of the measurements of the payload masses and the balloon components themselves. The force balance method also had the potential to be inaccurate because achieving perfect neutral buoyancy is difficult when working with masses that small. Another factor that decreases the accuracy of the force balance approach is obtaining perfect neutral buoyancy. This was difficult in lab because there were so many air currents in the pilot lab the balloon could easily be taken by them and give the team a false reading.

Provided Below is a mass budget table of the fractional percent for each balloon system component to the total system mass. as well as the individual masses and quantities of each of the payloads

Mass Budget

Item	Mass (g)	Fractional Percent of Total
Balloon Shell (x1)	9.651	74.6%
String (35")	0.463	3.58%
Paper Clips (x1)	0.501	3.88%
Washers (x6)	.486	3.62%
He Gas	1.8256	14.12%
Total	12.927	100%

Table 1 Mass Budget Analysis of All Balloon System Components

V. Design Parameters

In order to increase the balloons ability to lift a larger payload, the balloon would need a larger volume of gas that it takes up. This is because the buoyant force is given by

$$F_{Buoyant} = \rho_{Air} V_{Ball} * g$$

By using this equation, we can see that as volume of the displaces air increases, the buoyant force also increases.

Another option would be reducing the shell thickness. By doing this, the weight of the balloon decreases, making the force in the negative, y, direction smaller.

$$F_y = \rho_{Air} V_{Ball} g - (m_{Gas} g + m_{Payload} g + m_{Shell} g) = 0$$

Then the net force increases as the m_{Shell} decreases.

the same method can be used to find the buoyant force of an object in water as the buoyant force of an object in air. However, the displaced fluid, water, has a different density than air.

$$F_{Buoyant} = \rho_{water} V_{Ball} * g, \quad where \;\; \rho_{water} = 1000 \frac{kg}{m^3} \tag{8}$$

If the same balloon were to be used, the net force on the balloon would be equal to 0.

$$F_y = \rho_{water} V_{Ball} g - (m_{Gas} g + m_{Payload} g + m_{Shell} g) = 0 \tag{9}$$

The only unknown is the mass of payload, so $m_{Payload}$ can be solved for

$$m_{Payload} = \rho_{water} V_{Ball} - (m_{Gas} + m_{Shell}) \tag{10}$$

giving mass of the payload a final value of 3.78 kg

Appendix

MATLAB Code

```matlab
%Author: Isaac Timko
%ASEN 2002
%Design Lab - Pre-lab Balloon Analysis

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%housekeeping
clc
clear
close all


%%%%%% Ideal Gas Equation %%%%%%

P = 84090+10;              %Pa
RHe = 2.0769 *10^3;        %m^2/s^2*K
V = .013428;               %m^3
T = 297.85;                %K
g = 9.81;                  %m/s^2

%solving PV=mRT for mass
Mass = (P * V ) / (RHe * T);

%the final mass in g for the IGE
disp(Mass*1000)


%%%%%%% FORCE BALANCE ANALYSIS %%%%%%%%

Rair = .280*10^3;    %J/Kg*K
mPayload = 1.028;    %g
mString = .463;      %g
mBalloon = 9.651;    %g

RhoAir = P/(Rair*T); %kg/m^3

Mgas = (RhoAir*V) - (mPayload + mString + mBalloon)/1000;

%the final mass in g for the FBA
disp(Mgas*1000)


%%%%%%%%%%%%PAYLOAD ANALYSIS IN WATER %%%%%%%%%%%%%

RhoH2o = 1000;       %kg/m^3
mString = .463;      %g
mBalloon = 9.651;    %g

%Calculating the Bouyant force without g
```

```
Fbouy = RhoH2o * V ; %N

%calculating the Nessesary mass of the payload for neutral bouyancy
mPay = Fbouy - (Mass) - (mBalloon);

%the final mass in kg for the FBA in water
disp(mPay)
```

References

[1] ASEN 2002 Textbook
Cengel, Yunus A., et al. Fundamentals of Thermal-Fluid Sciences. 5th ed., McGraw-Hill Education, 2016.