International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 11 Issue 12 December 2022 || PP 08-12

Analyzing Data Collected by HAB and Simulating Motion Behavior Using Physical Model via Python

Fengrong Han
Veritas Collegiate Academy

ABSTRACT : *High-altitude balloons (HAB) have been used to teach various aspects of physics for several years and have been applied in many high school and university atmospheric physics curricula. By formulating a model for that simulates the trajectory of the balloon, researchers can better identify and explain possible influencing factors on the data collected by their HAB that differs from the model. This work focuses on explaining the behavior of a HAB during its ascent and descent process by using an empirical and a physical model that assumes an ideal spherical balloon shape, static gravitational pull and mean atmospheric temperature. Using a Python program based on elementary physical principles, we show that the ascent velocity is approximately constant and the descent velocity varies in a predictable way as function of altitude. The velocity vs. height profile of the theoretical simulation approximate experimental flight data which shows the established model is accurate. This work may provide theoretical basis for high altitude balloon experiment.*

KEYWORDS -*High Altitude Balloon; Python; Air density; Drag coefficient (C_D); Atmospheric Pressure; Matplotlib*

Date of Submission: 01-12-2022 Date of Acceptance: 10-12-2022

I. INTRODUCTION

It is challenging to provide students from high school to undergraduate with significant, hands-on activities on the "space" side of aerospace due to the complexity of spacecraft related calculations and the tremendous expense of fuel needed for rocket launching for heavy spacecrafts.[1-4] High-altitude balloons (HAB) filled with Helium, however, can carry computers of approximately the same weight to altitudes in excess of 80,000 feet into the stratosphere with much cheaper costs.HAB experiment is inexpensive, and students from various levels of education can take part in the entire of it, including the launch, observe and record the movement trail of balloon using GPS-enabled radios as well as data analysis, which is interesting and educational.[5]

Moreover, for high school students, they all have the enough knowledge to analysis the motion behavior of HAB by using physical formulas and laws. To this work, we first analysis the data of HAB experiment did by tea member. And the motion model of HAB was successfully established via Python, based on which, the ascent and descent behavior of balloon were simulated. The computation results are useful for improving the dynamic research of high-altitude balloons.

II. MATERIALS AND METHODS

The overall structure of the HAB system is shown in **Fig.1**: balloon(s) on the top, parachute(s) connected between the balloon and the payload, and the payload(s) connected at the bottom. HAB are designed to reach about 26 km in our experiment and burst, after which a parachute is deployed to safely carry the payload back to Earth. As the balloon start to ascend, the research team immediately depart the launching site following the course of the balloon. Meanwhile, the computer saves and transmit altitude. **Fig.2** is the plotted using Google Earth, which shows the flightpath as well as launch, burst and landing locations of HAB.

In this work, we will assume that there is no wind, that the only forces exerted on the equipment are: force of buoyancy, gravity, and drag during the full process. In other words, we only study the motion behavior of the vertical direction. Here, we specify throughout that vertical upward is positive direction in this work. Python3.8.12was used to wrote code. Matplotlib was used to graph the formulated equation. Python math library used to support mathematical calculations. NumPy library used to simulate best fit-line of data points.

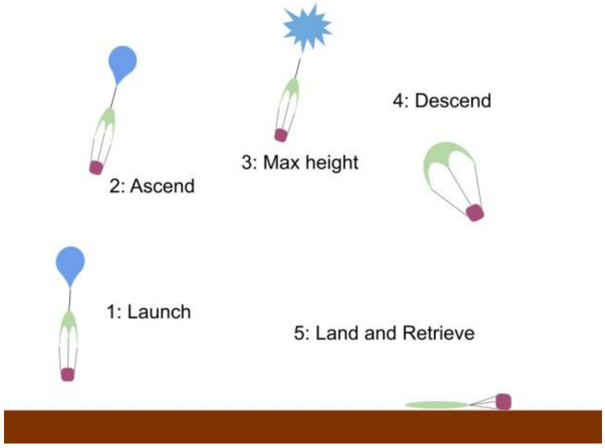

Fig.1 The elements of high-altitude balloon and it's typical flight profile.

III. RESULTS AND DISCUSSION

3.1 The ascent behavior of HAB

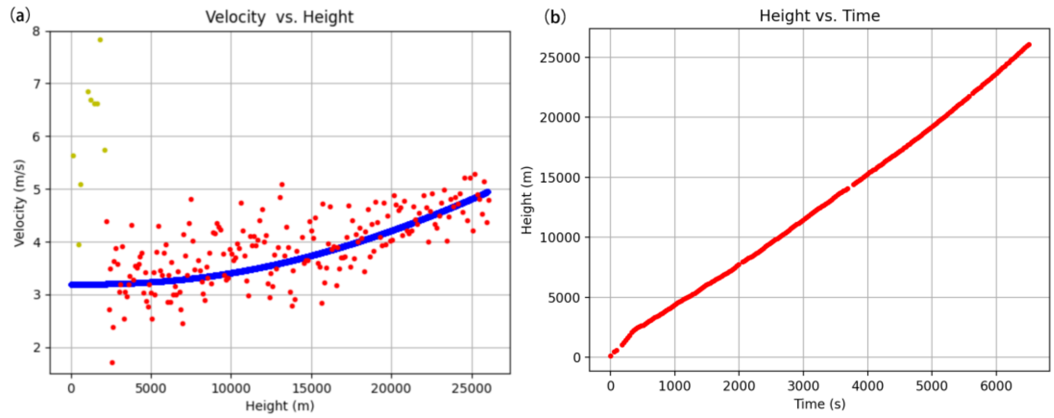

Fig.3 The velocity*vs.* height profile (a) during ascent process from experiment data (red plot) and stimulate data (blue plot), and the height *vs.*time profile from experiment (b).

As shown in **Fig.3a**, when launched, it is obvious throughout the data that HAB rose at a constant velocity of about 3.87 m s^{-1} during its ascend from 0 to about 26 km. The initially velocity of the HAB accelerate along the vertical direction. This result also can be achieved form height *vs.* time plot. **Fig.3b** shows thatthe relationship between height and time is linear with slop of 3.82. The above results indicate that HAB uprise with a constant velocity. Thus, we see that the observed constant average ascent rate of weather balloons is a consequence of the dependence on altitude of the balloon aerodynamic drag coefficient and of the atmospheric temperature profile. The reason why the observed ascent velocity of HAB relies on a constant value were explain by using elementary physical laws equations. To establish a physical model, we assume that temperature and acceleration of gravity are constant, and, for simplicity, we first assume a constant pressure and density of atmosphere, and constant volume and density of Helium of the balloon. Assuming the balloon would quickly reach equilibrium, so that:

$$F_B - mg - F_d = 0 \qquad (1)$$

where

$$F_B = (\rho_{air} - \rho_{He})V_g = (\rho_{air} - \rho_{He})\frac{4\pi R^3}{3}g \qquad (2)$$

is the buoyant force and

$$F_d = \frac{1}{2} C_D \rho_{air} A v^2 = \frac{1}{2} C_D \rho_{air} \pi R^2 v^2 \quad (3)$$

is the drag force. Combining eq.1 and eq.3, we get

$$v = \sqrt{\frac{2g[(\rho_{air} - \rho_{He})V - m]}{C_D \rho_{air} A}} \quad (4)$$

in which $C_D$is the drag coefficient, which equals to 0.5 when assuming the balloon to be a perfect spherical object. ρ_{air} is the density of air, A is the cross-sectional area of the balloon, v is its vertical velocity. Since the drag force increases as the balloon speeds up, the system quickly reaches equilibrium (constant v). The helium filled balloon is launched at sea level with a volume, V, of about 3 m^3 and a payload, m, of 1.6 kg. Force of buoyancy (eq. (2)) and gravity is simple, derivable from high school physics. As the velocity increases, the balloon experiences an increasing drag force, F_d,exerted by friction of air, shown by (eq. (3)). Then we take account of the variation of air density. Generally, air density was assumed to follow the Boltzmann distribution:

$$N(h) = N_0 e^{-mgh/kT} = N_0 e^{-h/H} \quad (5)$$

where m = 28×m_{AMU} = 4.6×10^{-26} kg (Mass of N_2 molecules, considering the 78% of its percentage in the atmosphere); g = 9.8 m s^{-2} (gravitational acceleration); h is the height, unit is meter (m); k = 1.38 × 10^{-23} J/K (Boltzmann constant); T = 250 K (mean temperature of the atmosphere). So, air density would become:

$$\rho_{air}(h) = \rho_0 e^{-h/H} \quad (6)$$

According to the eq. (7), we know that the air density (ρ_{air}) decreases due to the increase of height (h). However, the amount of helium gas within the balloon is constant, hence, the volume of the balloon would expand due to the difference of internal and external pressure. Moreover, we can assume that atmospherically pressure would also follow the Boltzmann distribution:

$$p_{air}(h) = p_0 e^{-h/H} \quad (7)$$

where p_0 = 1.01 × 105 N/m^2 (atmospheric pressure at sea level), H (mean height of the atmosphere, 7570 km).

To calculate the volume of the balloon, we first assume that it follows the ideal gas law (eq. (9)):

$$V(h) = \frac{nRT}{p(h)} = \frac{nRT}{p_0} e^{h/H} \quad (8)$$

thus, creating a varying function of volume of height, Now, the assumption of equal pressure is inaccurate, as the surface tension would limit the expansion of the balloon's volume, leading to a volume smaller than predicted. A possible empirical model is shown below, where exponent β is modified accordingly.

$$V'(\mathrm{h}) = V[\frac{1}{2}(1 + e^{-h/H})]^{\beta} (9)$$

Hence, we can find:

$$R(h) = \sqrt[3]{\frac{3V'(h)}{4\pi}} \quad (10)$$

Here R is radius of balloon. Using radius, R(h), we can then derive cross-sectional area, A(h) as the function of height:

$$\mathrm{A(h)} = \pi R^2(h) \quad (11)$$

As the volume expands, the internal density of helium would also change as shown in eq. (11), ultimately affecting the force of buoyancy.

$$\rho_{He}(h) = n_{He} m_{AMU} V_0 / V'(h) \quad (12)$$

From Eq. (4), (6), (8) and (12) this condition yields for the terminal speed. It is hardly surprising that a balloon should rise up with a constant velocity (after initial acceleration) in the case of a uniform atmospheric density (eq. (4)). What is surprising is that a same result is obtained by using physical law for HAB that rise in air of varying density and pressure, with the balloon radius and drag coefficient also changing, and the result is shown in **Fig. 3a**. It is clearly that stimulate result indicate HAB uprise with a constant velocity about 3.75 m s^{-1}, which is very close to that of experiment result.

3.2 The descent behavior of HAB

It clearly that the balloon burst where the balloon volume reaches its maximum tension or elastic deformation by analysis experiment data. However, HAB still possess speed of upward motion. Hence HAB still uplift and arrive the maximum height of 26 km as shown in **Fig.4**. In physical model, the descent process was researched using thehighest position as the starting position.

As the balloon reached the maximum height, the balloon volume also reaches its maximum tension or elastic deformation, causing it to burst. Now, the descending should be simpler as the only forces that are present if gravity and drag force. First, we assume that the balloon reaches equilibrium during the descend, or reaches its terminal velocity as drag force become as great as gravity, it means:

$$F_D = \frac{1}{2} C_D \rho_{air} v^2 A = mg \quad (13)$$

$C_D$and A are unknow for the falling gondola, but it should be constant due to its rigid material and shape as shown in eq. (15):

$$\rho_{air}(h)v^2(h) = \frac{2mg}{C_D A} = k = constant \quad (14)$$

therefore, we can derive:

$$v(h) = \sqrt{\frac{k}{\rho_{air}(h)}} \quad (15)$$

by substituting the Boltzmann distribution of air density from earlier and an estimated constant C_D and A. When considering the various of the air density, as shown in **Fig.4**, the simulate result when k equal to 39 is similar to the experiment result.

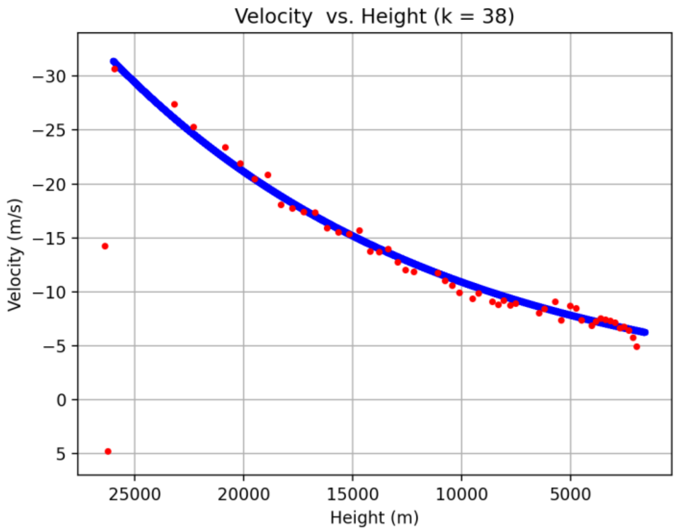

Fig.4 The velocity*vs.* height profile during descent process from experiment data (red plot) and simulated data (blue plot).

IV. CONLCUSION

In combination with the physics knowledge of high school and the empirical formula, the vertical motion model of HAB in the ascending and descending process was successfully established by using Python. The calculations in this paper are simple and is based on some reasonable assumptions. The simulated data are in good agreement with that of the experimental and all results can reproduce. Knowledge can be applied to promote students' interest in learning. Our theoretical formula is adjusted to best-fit the experimental data we collected, which means to predict future experiments, components such as drag coefficient, mass, as well as beta could differ according to different equipment used.

REFERENCES

This heading is not assigned a number.

1. De Schrijver, E.; Van Malderen, R. In Asgard-II, III and III-b balloon flights: growing a worldwide hand-on space eduction project for secondary school students, 21st ESA Symposium on European Rocket and Balloon Programmes and Related Research, Thun, Switzerland, Jun 09-13; Thun, Switzerland, **2013**; pp 597-601.

2. Guzik, T. G.; Besse, S.; Calongne, A.; Dominique, A.; Ellison, S. B.; Gould, R.; Granger, D.; Olano, D.; Smith, D.; Stewart, M.; Wefel, J. P., Development of the High Altitude Student Platform. Advances in Space Research **2008,** 42 (10), 1704-1714.

3. Flaten, J.; AseeIn Using High-Altitude Ballooning to Give Freshmen a Hands-on Introduction to the "Space" Side of Aerospace, ASEE Annual Conference, Atlanta, GA, Jun 23-26; Atlanta, GA, 2013.

4. Denny, M., Weather Balloon Ascent Rate. The Physics Teacher **2016,** 54 (5), 268-271.

5. Guzik, T. G.; Wefel, J. P., The high altitude student platform (HASP) for student-built payloads. Advances in Space Research **2006,** 37 (11), 2125-2131.

Books:

[1] R.E. Moore, *Interval analysis* (Englewood Cliffs, NJ: Prentice-Hall, 1966).

Note that the title of the book is in lower case letters and italicized. There is no comma following the title. Place of publication and publisher are given.

Chapters in Books:

[2] P.O. Bishop, Neurophysiology of binocular vision, in J.Houseman (Ed.), *Handbook of physiology,* 4 (New York: Springer-Verlag, 1970) 342-366.

Note that the place of publication, publisher, and year of publication are enclosed in brackets. Editor of book is listed before book title.

Theses:

[3] D.S. Chan, *Theory and implementation of multidimensional discrete systems for signal processing*, doctoral diss., Massachusetts Institute of Technology, Cambridge, MA, 1978.

Note that thesis title is set in italics and the university that granted the degree is listed along with location information

Proceedings Papers:

[4] W.J. Book, Modelling design and control of flexible manipulator arms: A tutorial review, *Proc. 29th IEEE Conf. on Decision and Control*, San Francisco, CA, 1990, 500-506

Fengrong Han. "Analyzing Data Collected by HAB and Simulating Motion Behavior Using Physical Model via Python." *International Journal of Engineering Science Invention (IJESI)*, Vol. 11(12), 2022, PP 08-12. Journal DOI- 10.35629/6734