Pre-Burst Chaos

Howard L. Brooks[1]
DePauw University, Greencastle, IN 46135

It is generally assumed that the ascent of a hydrogen/helium filled weather balloon carrying a string of experimental payloads into the atmosphere is relatively uniform. The net force acting on the balloon is very small and the ascent rate is fairly constant. However, evidence has been obtained from some flights of some very turbulent behavior. In a few cases, the flight string and the balloon become inverted and the flight string has fallen through the balloon resulting in an early end to the flight. I will discuss some of these events and offer a simple explanation of a possible cause. I will encourage all experimenters to carry accelerometers on their flights to provide evidence of these events.

I. Introduction

TAYLOR University has been an active supporter of high altitude ballooning with their students. Students design, build, and fly small experiments into the stratosphere via a small weather balloon. In the Fall 2009 semester my son was one of these students. The flight occurred in October and was one of two balloons launched about 30 minutes apart. The flight came to a premature end when the flight string became inverted and fell through the balloon. (See Figs. 1-3) The other flight on that day from the same location did not experience this phenomena.

Figure 1. Horizontal Flight String at 82,000 feet

Figure 2. Parachute and spreader on top of balloon

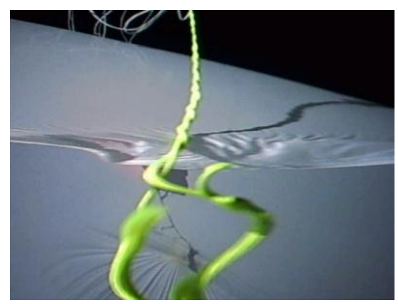

Figure 3. First pod penetrates the balloon envelope

Subsequently, I have become aware of at least three other flights with various degrees of turbulent behavior. The Balloon Assisted Stratospheric Experiments (BASE) program at DePauw has observed large amplitude swings of the flight string (at least 60 degrees) on two different occasions. StratoStar Systems has a video of their camera pod flying through the balloon on a flight for the Indiana Space and Earth Workshop on 12 November 2009. Examination of accelerometer data taken at 15 second intervals and radioed directly to a ground station has shown turbulent behavior on several flights as the flight string enters the jet stream, crosses the tropopause boundaries, or experiences a dramatic change in wind speed and direction.

It appears that the turbulent behavior occurs because the large cross section of the balloon is affected by the winds, even in the thinning atmosphere, while the payload packages, which do not change size, do not.

II. Accelerometers

Although photographic evidence is dramatic. A more systematic way to study this chaotic behavior is to use accelerometers. The BASE program has used two different accelerometers on some of its flights. The MESMIC

[1] Paul B. Kissinger Professor of Physics and Astronomy, 241 Julian Science Center

2125 dual-axis accelerometer[2] was used on our earlier flights. This device uses four temperature sensors to determine the orientation of a small gas bubble inside the integrated circuit. The output is a 100 Hz pulse whose width is proportional to the acceleration. The device has a sensitivity range from -3 g to +3 g, where g is the acceleration due to gravity at the surface of the earth. Since there are just two-axes of data, it is simpler to show the angle of tilt of the accelerometer away from the vertical. Fig. 4 shows the tilt data for a normal smooth ascent. The accelerometer was mounted in the lowest experimental pod. There are a few large amplitude swings, including one of nearly 60 degrees just after release. The colored lines indicate the +/- one standard deviation values of the tilt. There were a few moments at 20 degrees above 40,000 feet, but the flight was very calm and typical of most flights.

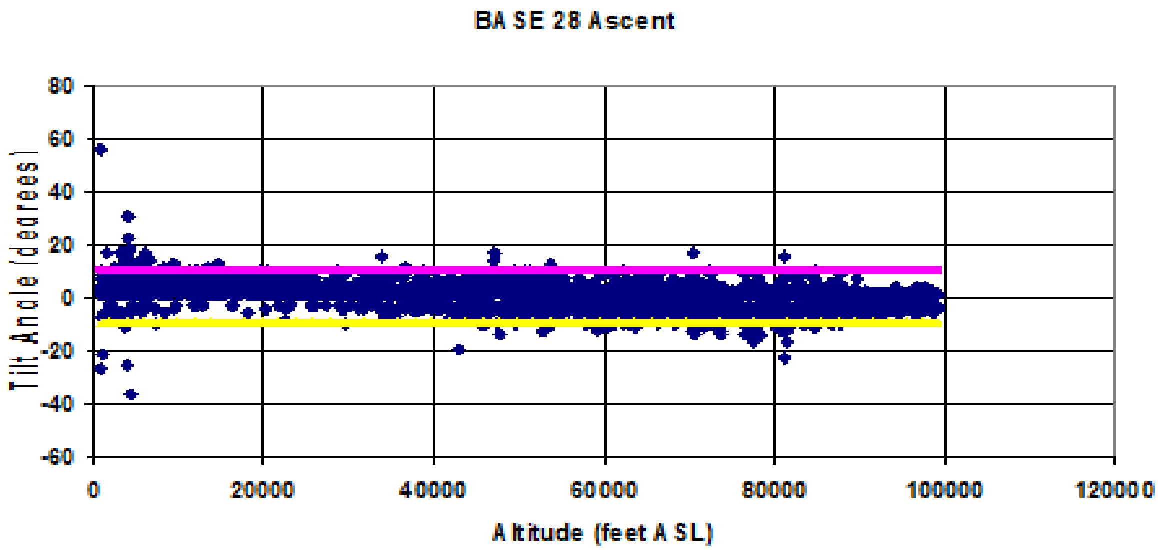

Figure 4. Tilt angle versus Altitude with the MESMIC 2125 for flight of BASE 28

However, Fig. 5 shows data from an ascent that included some large swings at higher altitudes. It must be noted

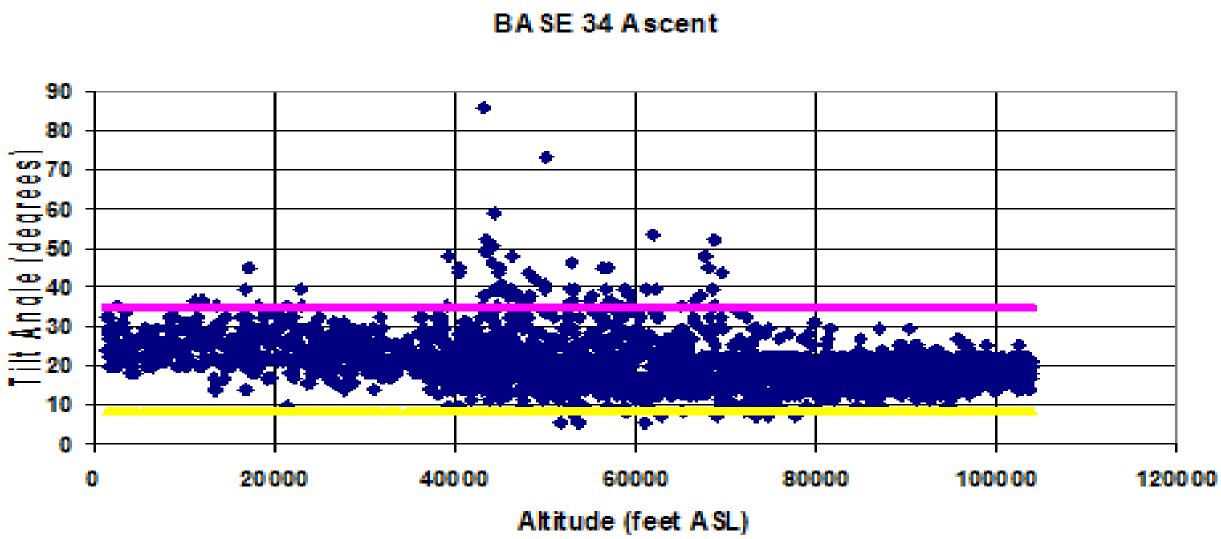

Figure 5. Tilt axis versus Altitude for BASE 34 flight

[2] Available from Parallax.com

that the accelerometer box flew at a steady tilt of about 20 degrees due to unequal string lengths. Nevertheless, there were several very large departures from the vertical between 40,000 feet and 70,000 feet.

We have also flown the Freescale MMA 7361 three-axis accelerometer[3]. This accelerometer uses three sets of micromachined dual capacitors. The capacitors have two fixed plates with a common middle plate that swings as the chip experiences accelerations. The shifting position changes the capacitance and the output voltage. The chip has various sensitivity settings of +/- 1.5 g or +/- 6 g. Zero acceleration corresponds to the mid-point voltage of 1.65 Volts since the chip operates on 3.3 Volts. Fig. 6 shows data from the Freescale chip. Again, there are large accelerations between 25,000 feet and 50,000 feet. There was a single large acceleration just above 80,000 feet.

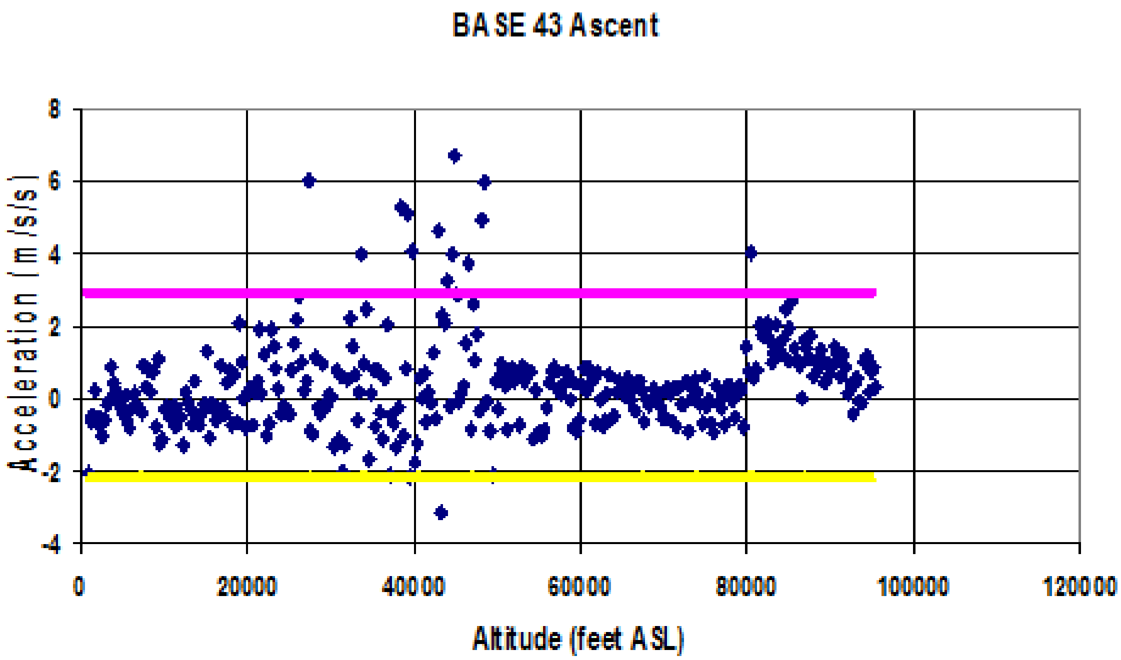

Figure 6. Total acceleration versus altitude for BASE 43

III. Possible Causes of Turbulent Interactions

I will discuss two possible causes for the turbulent interactions: clear air turbulence and atmospheric gravity waves. Fortunately there are ways to maximize the opportunity to fly a balloon system into these regions of the atmosphere and experience a chaotic ascent.

A. Clear Air Turbulence

Clear air turbulence is a problem for commercial aviation. The phenomena arises at the boundary between different layers of the atmosphere. At these boundaries, where the wind direction and wind speed changes, there are typically eddies in the atmosphere that are similar to the flow of water in a stream near to the bank of the stream. Since this turbulence can disrupt a smooth flight, pilots like to avoid these regions. Maps are produced by the National Oceanographic and Atmospheric Administration and available online.[4] The adventurous balloonist could launch a flight when the forecast indicates a likely occurrence of clear air turbulence. Unfortunately these plots are limited to the lower regions of the atmosphere where commercial airplanes cross the skies.

[3] Available from Sparkfun.com
[4] Available at www.turbulenceforecast.com/clear_air_turbulence.php

B. Atmospheric Gravity Waves

Another possible cause is atmospheric gravity waves. These disturbances in the atmosphere might be caused by landforms like mountains. Some might be driven by convective air movement caused by thunderstorms. Occasionally, strong frontal boundaries between weather systems may create these waves in the air. The boundaries of the jet stream can produce the phenomena. It is possible that energetic particles from an active sun could stimulate these waves.

Atmospheric gravity waves can have wavelengths from ten kilometers to hundreds of kilometers with periods of ten minutes to several hours. The ripples have been seen in some cloud formations, including nacreous clouds in the troposphere, noctilucent clouds in the mesosphere, and airglow in the thermosphere. Looking at the clouds in the background of Fig. 1 shows the ripple pattern associated with gravity waves. Occasionally, atmospheric gravity waves in the atmosphere can reach the surface of the open sea causing water waves.

IV. Wind and Flight String Interaction

The force of the wind on an object is proportional to the density of the air and the cross sectional area of the object. Since the payload boxes are fixed size, the force on them by the wind decreases with increasing altitude. However, the balloon expands as it ascends and it can still experience a significant force. (See Table 1) Momentum must also be considered. The momentum of the payload boxes is essentially upward and does not change because of the wind. If the system receives a strong horizontal force on the balloon, then the upward momentum of the boxes may lead to the boxes rising relative to the balloon.

Altitude (feet)	**Volume (cubic feet)**	**Area (square meters)**	**Air Density (kilogram/cubic meter)**	**4.5 m/s Wind Force (Newtons)**
0	**300**	**5**	**1.22**	**62**
36,000	**1,300**	**14**	**0.36**	**50**
66,000	**5,500**	**35**	**0.09**	**31**
105,000	**35,000**	**120**	**0.01**	**16**

I have modeled the behavior of balloon-flight string system using Interactive Physics version 2.5 using a 1.5 kilogram balloon, 300 cubic feet of helium (mass of 1.5 kilograms), 3 payloads on 3 meter strings: top payload of 0.4 kilograms, middle payload of 0.5 kilograms, and bottom payload of 2 kilograms. The total weight of the system is 58 Newtons. The model assumes a constant ascent rate of 1200 feet/minute (6 meters/second). At slower ascent rates the results show only small amplitude deflections from the vertical. Figures 7-9 show the effect of a horizontal wind force on this system. Figure 7 is similar to a typical smooth ascent as was experienced on BASE 28 (see Fig. 4). Figure 8 is a little stronger than what was experienced on BASE 34 (see Fig. 5) and BASE 43 (see Fig. 6). Figure 9 models an event like that which my son's experiments saw on the Taylor flight in October 2009.

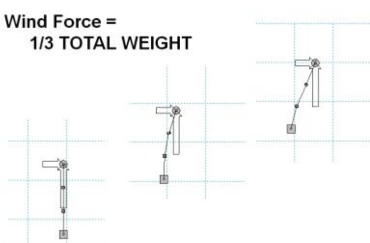

Figure 7 Simulation
Wind = 1/3 Weight

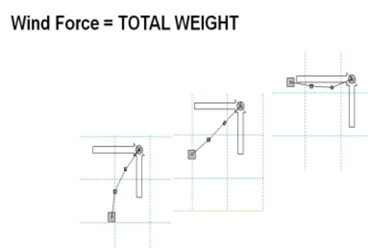

Figure 8 Simulation
Wind = Weight

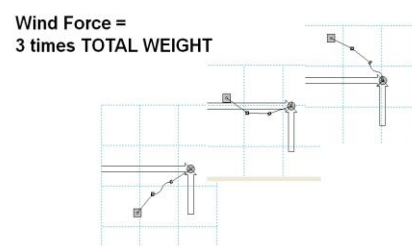

Figure 9 Simulation
Wind = 3 times Weight

V. Conclusion

The ascent of small weather balloons with an experimental payload string may not be as uniform as expected. There are numerous accounts of turbulent events. If the flight system is climbing at rapid rate, greater than 6 meters/second, then it is possible for large amplitude swings to occur. In the most extreme cases, the flight string may rise above the balloon and end the flight prematurely by colliding with the balloon as the string attempts to return to its normal position. It is recommended that as many flights as possible should carry accelerometers to record the departures from a smooth ascent. Forecasts of clear air turbulence and direct visual monitoring of the sky may provide opportune times to launch a flight string and experience pre-burst chaos.

Acknowledgments

This work was supported by the Faculty Development program and the Paul B. Kissinger Endowed Professorship at DePauw.