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THE UNIVERSITY OF ARKANSAS

UNDERGRADUATE HONORS PROGRAM

BalloonSat Based Investigation of Atmospheric Electric

Potential for Sustainable Energy Production

By

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Thesis Committee:

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BalloonSat Based Investigation of Atmospheric Electric Potential for Sustainable Energy Production

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The Earth is daily bombarded with cosmic radiation which delivers ions to the atmosphere and creates new ions via the collision of the incoming particles with the atmospheric particles, stripping them of electrons. Generally, this process results in a positively charged atmosphere and a negatively charged surface of the Earth. This process causes an electrical current which flows throughout the atmosphere and into the Earth's surface and comprises a system referred to as "the global atmospheric electrical circuit." This electrical current is very small at the surface of the Earth, on the order of 10^{-12} amperes per square meter. The voltage potential difference between the surface and the atmosphere increases with altitude, with an approximate potential difference of +250 kilo-Volts between the ionosphere and Earth's surface. Using high-altitude balloons, the possibility of extracting usable amounts of energy from the electric energy present in the atmosphere at extreme altitude is to be investigated.

I. Introduction

Over the last several decades, humanity has become increasingly concerned with identifying and exploiting sources of renewable energy. Dependence on fossil fuels and the limited quantities thereof is acknowledged as a crucial weakness in society. These fuel sources will be exhausted, given time. Intense study has thus been applied to the field of renewable energy, looking for new sources of energy and new ways to harness it. In recent decades a pair of renewable energy sources, solar and wind, have held the most promise for reducing reliance on fossil fuels. Yet other potential sources are also being investigated, such as biofuels, tide power, and geothermal energy. One potential source of renewable energy has not received as much attention, however, even though it was considered over a century ago by Nikola Tesla.

The Earth is daily bombarded with cosmic radiation which delivers ions to the atmosphere and even creates new ions via the collision of the incoming particles with the atmospheric particles, stripping them of electrons. This process generally results in a positively charged atmosphere and a negatively charged surface of the Earth. This potential difference creates a current flowing throughout the atmosphere and into the Earth in a system referred to as "the global atmospheric electrical circuit." This current is very small, on the order of 10^-12 amperes per square meter at the surface of the Earth. This electrical current also commonly manifests in the more concentrated forms of lightning and auroras[1]. Weather phenomena are highly involved in the movement of charge through the atmosphere, as illustrated in Figure 1.
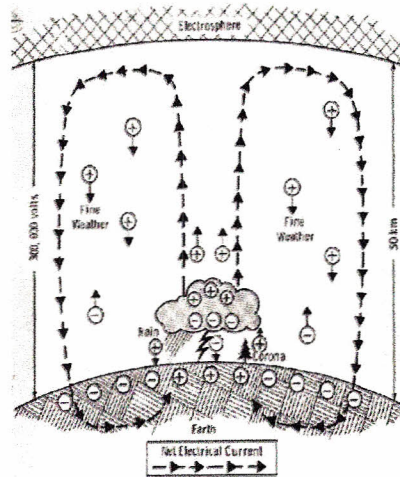

Figure 1. Weather phenomena influence upon the movement of electrical charge through the atmosphere[2].

As altitude increases, the electric field has a gradient of 100-300 V/m, depending on the season and other factors. There is an approximately +250 kV potential difference between the ionosphere and Earth's surface[1]. This voltage difference could provide huge amounts of energy if it could be harnessed to produce an electrical current. As current was drawn from the atmosphere, removing the relatively positive charge, the positive charge of the atmosphere would be constantly re-established by cosmic radiation and other sources of atmospheric ionization.

Unfortunately, little research has been executed with the goal of actually extracting energy from the atmosphere. Research has been done to map the strength of the electric field up through the layers of the atmosphere[3], to investigate the variability of the electric field[4], and to research the mechanisms of current flow[5]. The current flow has not been directly measured, but rather calculated from the known field and conductivity values. To the best of the author's knowledge, no attempt has been made to use the atmospheric potentials at high altitudes to induce a current in a circuit for direct measurement of this current.

II. Proposal

The goal of this research is to design a system to try and measure a current produced solely by the free electricity found in the atmosphere at increasing altitudes. This is intended to be a first step towards future extraction of energy from the atmosphere as a possible renewable source. It must be determined if it is possible to obtain usable levels of

power if future research is to take place in this area. The high altitude balloon launches will provide a perfect platform to run the experiment at increasing altitudes. Three separate launches will be undertaken in order to provide more data to insure accuracy of the measurements made and to look for any notable differences between flights. After recovering each launch via GPS tracking, the entire flight will be evaluated so that any problems can be avoided on the next flight. This will also provide time for an initial analysis of the data obtained during the mission.

In order to achieve this goal, a system must be designed that takes advantage of the mechanics of the electrical current movement through the atmosphere. Assuming the atmosphere can be modeled as a current source is the basis for the work of this project. By using a conductive sphere with a sufficient surface area to collect this current and pass it down a circuit we can measure the voltage drop across a resistance in the circuit. This will allow several objectives to be met.

First, the measured voltage drop can be used to calculate the actual current flowing through the circuit in accordance with Ohm's Law (**Eq. 1**):

$$\frac{V}{R} = I \qquad (Equation\ 1)$$

This calculated value of the current can be compared to the expected value. Any variations found from expected values can assessed against the altitude at the time of each measurement.

Secondly, the measurable voltage potential on each side of the resistor will allow the mapping of the electric field versus altitude during the flight. The circuit will comprise of an insulated wire with a charge collecting sphere at the upper end and a discharging needle at the lower end, separated by a set distance. Since the circuit will be suspended vertically with the only load, the resistor, located in the center, the voltage readings on either side of the resistor will be equivalent to the voltage at the upper and low ends of the circuit, as shown in Figure 2. By measuring the relative voltage difference between the two points, the change in the electric field can be plotted against altitude and compared to previously published measurements.
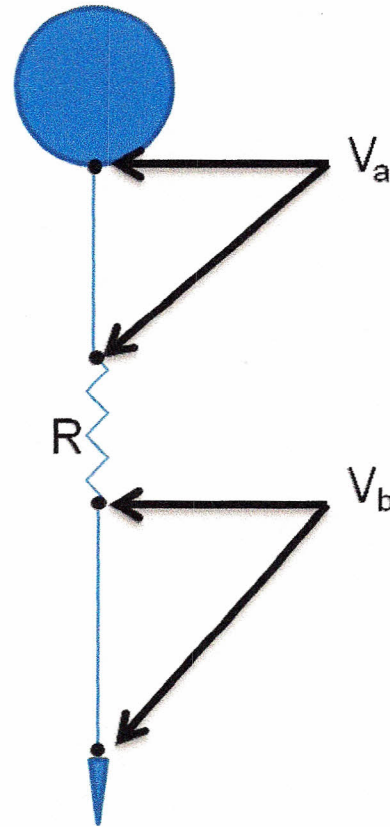

Figure 2: Simple Circuit Diagram of Experiment

III. Research Progress

In order to gain experience working with high altitude balloon launches, a practice launch, without any valuable payload, was planned. This served the purpose of becoming familiar with the launching procedures and requirements so that at the time the experiment launched, unfamiliarity with the balloon launching process would not inhibit the experiment or cause it to fail. After this practice launch, the experiment-carrying launch will take place.

A. Practice Launch

The launch took place on March 10, 2012. The launch payload was a low-cost, bare minimum package since it was a very real possibility that the balloon payload would be lost either due to GPS failure, a water landing, or due to a landing in an inaccessible site.

The tracking equipment was comprised solely of an Iphone 3GS running on a cellular network. Consideration was given to using more sophisticated GPS tracking equipment on this initial flight, but to risk losing such an expensive piece of hardware on the flight was determined to be imprudent. Instead, the Iphone was chosen because it had a faulty screen and its loss would be of negligible impact financially or experimentally. This Iphone had a faulty screen rendering it not usable to a normal operator, but usable enough to allow the launch crew to activate the GPS tracking. The Iphone's inbuilt GPS tracking communicated with the cellular network to provide location data on a webpage via an Iphone application. While the GPS lost cell service

Figure 3. Balloon and payload immediately before launch.

as it ascended to higher altitudes, it was able to track the balloon below 30,000 feet fairly reliably, giving us the most crucial piece of information: the landing point.
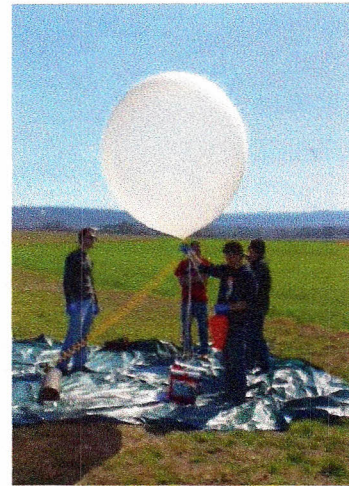
A group of AIAA student members interested in high altitude ballooning assisted in the project and were able to send up two light cameras to take some video of the flight as well, rounding out the payload complement.

The balloon lifted off at approximately 10:55 a.m. and landed at approximately 12:51 a.m., a straight-line distance of 41.04 miles east-northeast of its original location. Before launch, a web-based flight path estimation tool for weather balloons was used and predicted a landing point approximately 23 miles southeast of the actual landing point. Interestingly, it predicted a straight-line distance of approximately 45 miles, within about 10% in magnitude the travel distance of the actual balloon. In Fig. 4 the actual path and predicted path are compared.

Figure 4. Predicted flight path shown in purple, actual tracking results shown in blue, ground track shown in bolded yellow, straight-line distance between predicted and actual landing point in thin yellow.

This flight yielded some several insights which will serve further flights well.

First, the weather balloon prediction applet lacks the accuracy necessary to pinpoint a landing zone with any useful certainty. The applet seems to err on the directional component of the prediction. The time of travel and final distance from the launch site seem to be accurate enough to provide a general idea of how far the balloon will travel, which is useful. As for precision pinpointing of flight path, the inaccuracy is simply too great.

Secondly, for the practice launch the balloon was determined to be sufficiently full of helium when it reached the manufacturer specified "inflation diameter". During the flight, the tracking information indicated that the balloon, after ascending to a maximum point, descended to and maintained altitude in the 27,000 ft range for approximately 35 minutes. This was not ideal behavior and indicated that the balloon was under-inflated. The balloon was designed to ascend indefinitely until it bursts from the lack of external pressure. The balloon was, by chance, able to burst for a reason unknown, which allowed the payload to be recovered. For future flights, the crew will err on the side of over-inflating the balloon with respect to the desired lift force, which will result in less altitude at the bursting point, but will guarantee the balloon bursts. An under-inflated balloon, if does not burst, can sail for hundreds of miles until something is able to bring it down.

Finally, the first flight validated a design that is to be of key importance in the future of high altitude balloon launches at the University of Arkansas. Current practice in ballooning tends to inflate the balloon and then twist and tie the neck of the balloon (much like a party balloon) around a metal ring. The payload is also attached to this metal ring via line riggings. Feeling this was an inefficient and time wasting method, a neck plug was designed which featured a quick-connect valve, as seen on commercial air compressors. The plug was 3D-printed out of ABS plastic and coated in E-Z Lam epoxy to seal it. Thread tape sealed the centerline hole as the quick-connect valve was threaded into it. This system enabled the helium tank to be easily connected to the balloon for filling. Once the inflation was complete, the hose is unhooked from the valve in the neck of the balloon and the helium is sealed in. A screw clamp or zip-ties can be used outside the neck to hold the plug in place. Zip-ties were used on the initial flight, as seen in Fig. 6, but a screw clamp will be used on future flights. In the future, payloads can be attached to the balloon via the quick-connect as well though for the practice flight a clip hole for a caribiner was included on the neck plug.
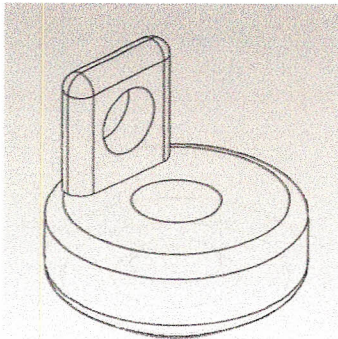

Figure 5. Neck plug. Quick-connect valve threads into centerline hole.
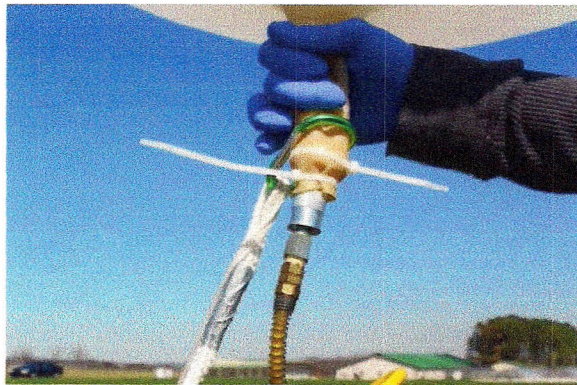

Figure 6. Close-up of the quick connect system utilized for inflation.

B. Experiment Apparatus

An overview of the final design features of the experiment equipment is presented in the following.

The charge collecting sphere was a 0.254 meter (10 inch) diameter Styrofoam sphere which was intended to be coated with a conductive spray paint based on copper and silver particulates. The lead time on the conductive spray paint turned out to be too long and the material was not shipped in time. As a result, the sphere was covered in aluminum foil attached via more epoxy. This is less than ideal but should still allow the experiment to run. The sphere has a conductive surface area of 0.203 square meters. The sphere has four wire leads

Figure 7: Close up of the sphere with two of the electrical leads visible.

soldered onto it and secured with an epoxy covering. The wire leads merge and flow into the resistor suspended below. The sphere is connected via rope to the balloon above.

Below the sphere is a 3D printed, ABS plastic box which houses the electronics for the mission. The data recorder, pressure sensor (for altitude), and GPS tracking (via smartphone) are located here. A parachute to slow the descent is also attached to the box via a carabiner.

The four leads coming from the sphere merge into a length of wire that extends 5 meters (measured from the sphere to the discharging needle at the lower end). Located in the middle of the wire is a 100 mega-ohm resistor. The resistor has voltage measuring wire leads coming from each side of it and leading to the data acquisition box.
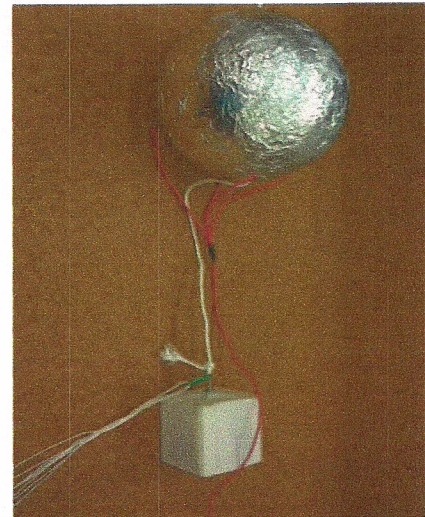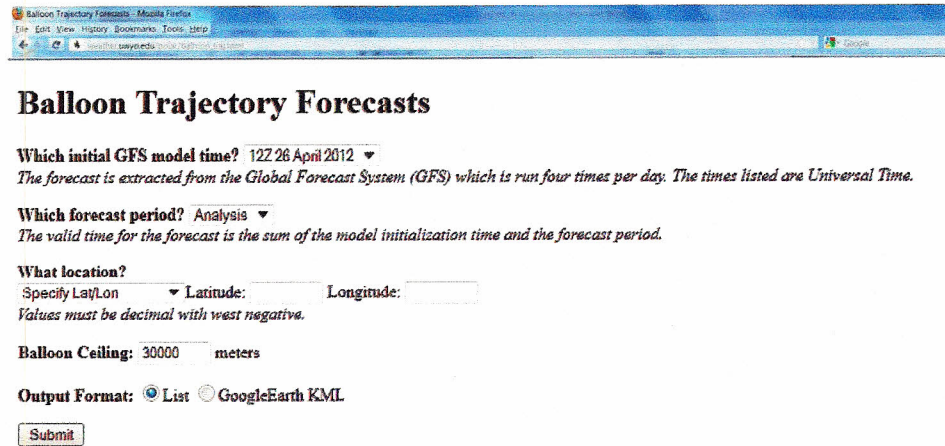

Figure 8: Sphere, data acquisition box, and electrical leads (in red)

C. Experiment Launch

The launching of the experiment has not yet occurred at the time of this writing. Delays in the acquisition and assembly of various components and launch support materials, coupled with inadequate weather have pushed the launch date back multiple times. From a launch location in northwest Arkansas, the balloon tends to fly east toward a sparsely populated, mountainous region. Thus, the risk of losing the balloon payload due to an inaccessible landing site or GPS failure due to sparse cellular networks rises if the balloon were to travel into this region. Weather patterns do occur which result in shorter flight paths of the balloon (such as the one experienced during the practice launch), so waiting for these occurrences is desirable. The distance the balloon flies can vary greatly as the wind

speed and direction varies with altitude. Using a publicly available trajectory prediction application maintained online by the University of Wyoming, balloon trajectories can be predicted based on current weather forecasts and data after supplying the latitude and longitude of the launch site. Monitoring of the weather and predicted trajectory via this application allow a prudent selection of a launch occasion.

Figure 9: Balloon trajectory prediction application, http://weather.uwyo.edu/polar/balloon_traj.html

Unfortunately, as mentioned, a launch of the balloon with the actual experiment has not yet occurred. The launch is hopefully to take place before the May 12th, 2012, should the weather, wind patterns, and other factors permit it with a reasonable chance of recovery.

D. Launch Expectations and Concerns

One of the main concerns for the success of this experiment lies in the fact that the atmosphere was assumed to be modeled as a current source. If, in fact, it is more accurately behaving as a voltage source, this experiment may not work at all as the equipment was not designed in view of that concept. If the atmosphere behaves that way, the entire circuit may well separate charges within itself to neutralize voltage differentials instead of simply providing a less resistive path to already existing current flow.

Another concern with the launch is that it is entirely possible that the voltage potential measured over the 5 meter span of the circuit may be particularly high at some point in the flight and burn out either the measurement device or the data recording device. Given the scale of the atmosphere it is impossible to predict where local areas of higher voltage might exist and thus the chance of travelling through one cannot be ruled out.

When launch occurs, given the payload size and balloon size and inflation, a maximum altitude of around 16,000 meters is expected. Many factors can affect the actual burst altitude such as balloon skin imperfections, temperature of the helium, and atmospheric pressure conditions, so 16000 meters is a rough estimate at best.

Given a 5 meter vertical length of the circuit, a voltage potential difference anywhere from 500 to 1500 volts can be expected, depending entirely upon the local conditions of the atmosphere which vary with the season, time of day, and other factors.

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E. Future Work

After this experiment is complete, the work done on the high altitude balloon launches will be continued at the University of Arkansas. This project has already generated interest among younger students at the University and promoted AIAA in the process. The launches can also serve as a convenient platform for other research projects that need access to a near-space environment.

Acknowledgments

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