Characterization of Habian Motion

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***Abstract*—This project would be for the RIT SPEX High Altitude Balloon team. The goal is to create a map of the HAB condtions throughout flight. This would be extremely benefical when creating a HAB for an experiment. Being able to understand "habian" motion can allow the project engineers to adequately design the payload to survive flight conditions.**

NOMENCLATURE

HAB	High Altitude Balloon
RIT	Rochester Institute of Technology
SPEX	RIT Space Exploration
SPP	SPEX Project Proposal

I. INTRODUCTION

HIGH altitude balloons are scientific experiments that allow teams to test experiments in *space-like* conditions. Of course, this is only one type of many types of possible high altitude experiments. During the course of experiment design the team must include flight conditions in there engineering requirements. High altitude balloons are swung, twisted, and rocked during flight. What are the accelerations? What are the G's that the payload experiences? That is question this project will answer. This project will enlighten our understanding of how a high altitude balloon is affected during flight by the conditions of the atmosphere at any given location throughout. Hence, the idea of creating a map of habian motion.

II. PRIMARY OBJECTIVE

The *characterization of habian motion* project goal is to create a very detailed document, along with a visual component, that will allow all HAB teams around the world to understand the types of conditions that there HAB will endure through flight. The document will include many different components of HAB conditions (this will be further explained in the following secions). A few of these components are rotation and the acceleration in three dimensions. These can define the forces on the HAB during flights which in turn defines the necessary fixturing that the internal components of the HAB must have.

III. PROJECT DESCRIPTION

This project will rely on sensor data. As this will be our main form of data collection. For this project will want to collect as many forms of data as we can. This data includes the following; Rotational Acceleration, Acceleration in the x y z axis, temperature, thermal diffusivity, ambient pressure, wind velocity, *pendulum-like* motion, and altitude. Now, the RIT SPEX team has collected some of this data before but it is not adequate. The sensors are shielded within the HAB. This is good for component survival however it has dampened that data collection, such as temperature, pressure, etc. This time, the sensors will be exposed to the atmosphere, at least the ones that must be. The mechanical data collection does not need to be exposed to the atmosphere, including the dimensional accelerations and pendulum motion.

A. Atmospheric Data

The data that must be collected from the atmosphere are; temperature, atmospheric pressure (aka ambient pressure), thermal diffusivity, wind velocity, and solar intensity. The temperature is very important because all materials have an operational temperature. Once these temperature boundaries are breached the material's itegrity is compromised. Another very important condition is the ambient pressure. This pressure is important for understanding how electrical operations should be designed as the altitude increases. As altitude increases the diffusivity of thermal radiation made by the electronics changes and can create problems for the components such as overheating. Wind velocity is a mechanical component of flight, but, needs to be measured on the outside of the balloon independently of the other mechanical data collections. Lastly, the solar itensity must be measured. This is not temperature. The solar intesity is the thermal energy transmitted to the HAB from photons. As the ambient pressure decreases the energy of incoming photons increases, maybe not a lot but any measureable difference is important because future HAB electrical components may be very sensitive to this type of radiation.

B. Mechanical Data

The mechanical data that must be collected are; accelerations in the x y z dimensions independently, rotational acceleration , and pendulum acceleration. The accelerations in the x y z dimensions are of critical importance. This is the most definitive accelerations that we can use in the map of habian motion. The acceleration of the HAB in these dimensions will allow the HAB teams to understand the force to which the HAB is subjected. The acceleration in the angular sense is also of critical importance as this can cause many mechanical failures in the sense of securement. The twisting of wires or thread can cause torsional stress which after a certain amount of rotations can enter a non-newtonian situation that can cause incredible stress. This unanticipated stress can be the root of mechanical failure. Lastly, the data collection of the pendulum motion. HABs are mostly commony secured to the balloon through thread. When wind is applied to the HAB the resulting motion is analogous to a pendulum. This can be the root of

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a new type of stress. And as we know, stress is additive so it is important to understand all possible stresses that to which the HAB could be subjected. The pendulum equation can be easily utilized to analyze the stresses. But to do this we need to know two indpendent variables, theta (the angle through which the HAB moves) and the acceleration. Then we can apply the mathematical equation 1.

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l}\sin(\theta) \tag{1}$$

IV. Mechanical Design

A. Description

The mechanical design will feature a foam box. The dimensions of which will depend mostly on the necessary size of pcbs and the necessary length of the pendulum as well as the height of the deck plate camera. The pcbs will need to have accelerometers to measure acceleration in the x y z directions and around its center of mass (rotation). There is no accelerometer to measure the pendulum effect. So we employ a possible solution. This possible solution includes putting a pendulum in the HAB with a comparitively massive object on the end (compared to the mass of the pendulum mass per unit length). When the HAB swings the pendulum in the HAB will always point towards the center of the earth. So, we can figure out the swept angle using the equation 2.

$$\theta = \arccos(\frac{m}{l}) \tag{2}$$

Where m is the x-component of the pendulum length vector. This will allow us to use equation 1 to find the acceleration of the HAB and we can measure its mass so we can find the force of tension in the lacing chord connecting the HAB to the balloon (this assumes the parachute is the same as the lacing chord).

B. Design

The HAB will be secured in a net of nylon straps. This will ensure stability and mechanical safety as the nylon temperature range is approximately negative 40 degrees to positive 390 degrees fahrenheit. Although the temperatures of the atmosphere that the HAB travels through drop below negative 50 degrees, this should not be a problem as long as the weight that the nylon net holds is within its tensile limits and the HAB does not remain in that part of the atmosphere for a long duration.

In figure 1 the HAB Structural Design is displayed. There are parachute connections [1], nylon straps [2], the payload [3], a plexi-glass window [4], a GoPro [5], and a deck plate [6]. There is also a new connection proposal for the nylon net. It will be for connecting the nylon straps together for a quick-release mechanism.

1) The Parachute Connections: The parachute connections are made out of aluminum for strength and reduncey. The main reason for the aluminum is because these connections must have a high factor of safety. If the parachute connections fail, the HAB plummets to the ground at an increasing velocity [until terminal velocity is achieved] and will certainly be

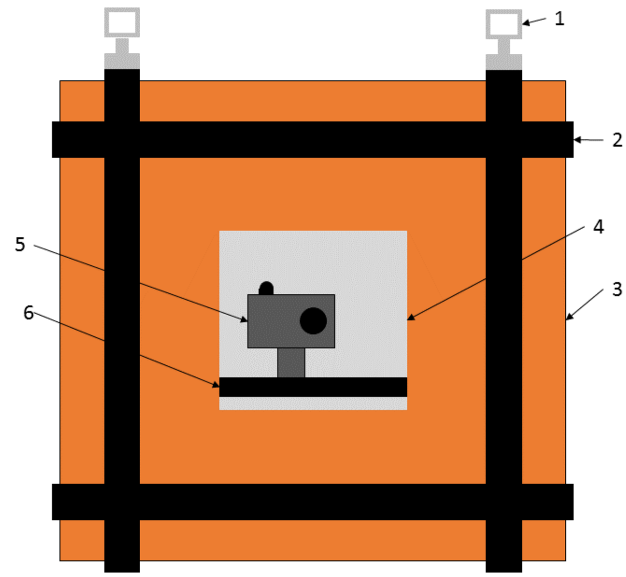

Fig. 1. A front view of the high altitude balloon payload.

destroyed while posing a safety threat to pedestrains. The connections are an assembly of two pieces secured by a 1/4-20 socket cap screws that is counterbored into the bottom piece so it does not protrude from the part and harm the surface of the HAB. Loctite will also be applied to ensure the screws do not rattle loose.

2) The Nylon Straps: The nylon straps are to be woven into a cross-netting arrangement for pressure distribution across the surface of the HAB payload. Nylon was chosen because of its heritage with HAB payload securement. The nylon will be stitched at a few intersections that coordinate properly with the corners as displayed in figure 1. The nylon strap will alleviate the personal stress entailed in the setup and launch of the RIT SPEX HAB Icarus mission payload. The nylon straps will have an aluminum connection that can be easily removed and vis versa. It is important that the nylon straps are appropriately tight around the payload as to not severly damage the outside of the HAB payload, while maintaining the structural integrity.

3) The Plexi-Glass Window/Gopro Integration: For this mission understanding the conditions of flight is the primary goal. Sometimes the human eye can allow teams to judge certain conditional circumstances that a sensor simply cannot, such as rain effect on the HAB [surface-wise]. To observe the conditions in such a manner a GoPro will be employed to record the entire flight. On past RIT SPEX HAB payloads and launches complications with the GoPro were a constant bother. It shutoff on the Icarus mission shortly before descent. The running theory for this failure is that the GoPro became too cold and the camera shutoff as a homostasis policy. To help alleviate this possiblity the GoPro will be wrapped in thermal wrap which will help the GoPro insulate itself through flight

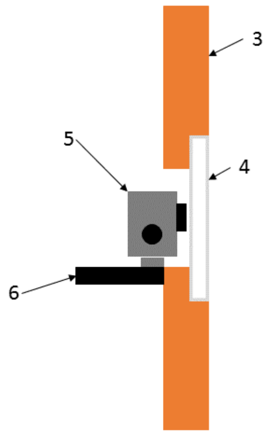

Fig. 2. A section view of the gopro secured in the HAB.

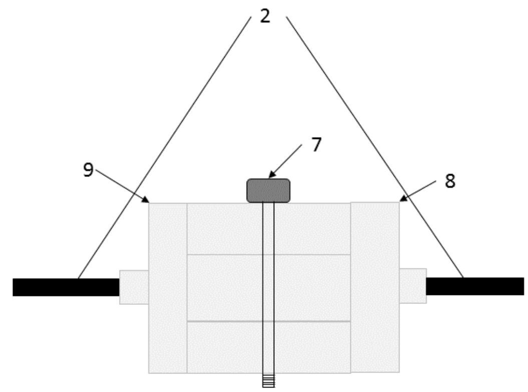

Fig. 3. A side view of the aluminum nylon strap connector.

and it will be inside the HAB payload. The GoPro will be able to record the outside of the HAB through a plexi-glass window that will be adhesively bonded to the HAB payload. The design can be seen in figure 2.

The GoPro will likely see the edge of the HAB payload because the angle of viewing is very large. Although, this should be fixable with simple video editting. Inside the HAB payload the GoPro will be fastened to a deck plate likely made out of 3D printed PLA or ABS. An aluminum plate may be necessary to keep the GoPro stable during the intense vibrations and forces sustained throughout flight. The GoPro is *top heavy* so it may repeat a performance from RIT SPEX HAB mission Icarus where it is knocked to a signifcantly different viewing angle to the point where the video footage is partial and mostly useless.

4) The Payload Deck Plate: The GoPro will sit on a deck plate inside the HAB payload. 3D Printing a rack such as the one designed by David Breen for the fourth RIT SPEX HAB mission. The rack can be simplifed because all that will be needed is two levels, one for the GoPro and one for the pendulum-camera system. There should be plenty of space for the necessary pcbs, as the HAB payload base geometry is a cube, which pcbs can conform to very easily. The second level will be mostly clear except for the GoPro, allowing more space for the pcbs to sit.

5) The Nylon Strap Connector: The nylon strap connector will allow the nylon straps to connect from either ends to be easily fitted around the HAB payload. They will be made out of aluminum as they are as integral to the structural integrity of the HAB payload as the parachute connectors are. They keep the nylon net around the HAB payload throughout flight. It is convinent to make them out of aluminum as they have a relatively simplistic geometry that can be easily manufactured on a milling machine. See figure 3 for a reference to its geometry.

There are two parts. One with a *U-like* geometry [9] and one with a *pin-like* geometry [8]. They fit together like a simple plastic clip, except more rectangular and made out of aluminum. Each is attached to one end of the nylon strap and the nylon strap is put through the rectangular hole on each part. Then the nylon strap is stitched with high-tensile strength thread when folded through the hole. There will be a 1/4-20 socket cap screw [7] that threads through the two pieces and can be secured with a nut or can just be threaded into aluminum. The latter is recommended as a nut may damage the side of the HAB payload. Flat and lock washers will be added to the 1/4-20 screw for reduncey. See figure 4 for a top view of the strap mechanism.

V. Avionics & Data Collection

An important part of any high altitude balloon launch is tracking the balloon. This allows the team to attempt payload recovery or signal for local HAM operators for help in honing down the exact landing location. Using APRS or a GPS system usually entails signal loss under 1000 - 10000 feet, because mountains usually cut off the signal.

A. Geolocational Tracking and Recovery

For this HAB launch, recovery is essential. It is unlikely we will be able to transmit the all the data to the ground station. This is mostly because of the signal loss expected below

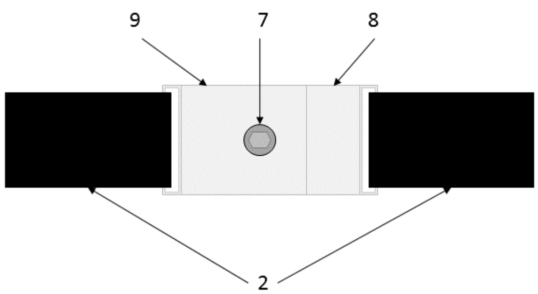

Fig. 4. A top view of the nylon strap mechanism.

1000 feet, since impact conditions are critical for the mission statement. For redundency we will have a geolocational positioning system [GPS] and an automatic packet reporting system [APRS]. Local HAM operators will be asked to help in the exact positioning of the HAB payload. Once the location is known a designated team of HAB-Hunters will retrieve the payload. Immediately prior to launch, the team will return to mission control to track the HAB's trajectory. One monitor will be designated to following the APRS data and another will be designated to viewing the trajectory in three dimensions on Google Earth®. This three dimensional trajectory can be saved and cataloged while being used for a better visualization when discussing the HAB mission.

B. Avionics & Data Collection

The avionics for this payload will include creating and populating mutliple pcbs for decreased design complexity to allow high degree of confidence in the functionality of the boards. The pcbs must include a IMU for gravitational tracking. This allows a fixed radial vector that can be used for more advanced data analysis. There will be a sensor for temperature and ambient pressure. It must also include rotational acceleration sensor and a three dimensional acceleration sensor [x y z]. There will also be a fully functioning solar panel. It will be placed on the side [except the GoPro side] and the rate at which it absorbs the kinetic energy of the solar photons will be recorded and analyzed. Concerning the available space for pcb placement, there will be very few other objects inside the payload. There will certainly be a GoPro for video footage, a pendulum for tracking the sweep angle, and a smaller camera designated to recording the moion of the pendulum. The pcbs will likely have the entirety of the bottom deck plate [which will have an abs cover for to allow the pcbs to connect through standoffs. The second deck plate will also be made of abs for similar reasons.

1) Pendulum Motion Data Collection: A difficult part of this mission will be correcting calculating the pendulum forces on the HAB payload. This is important for finding the extra strain placed upon the parachute-payload connection. This includes the aluminum connections and the thread. It will also allow further analysis into the wind conditions. Because the x y z sensors will only capture the wind-caused accelerations for a couple seconds. This is because when the payload starts to move, the radial connection to the balloon will cause the payload to swing as a pendulum. This can skew the data if constant cross-product [between radial vector (moment arm) and wind force] are assumed. The torque of the HAB payload is determined by $\vec{r}$ x $\vec{F}$.

The solution to finding the sweep angle of the payload [angular displacement from vertical axis] will be tracking the motion of the HAB payload pendulum with a video. The pendulum will hang a heavy mass and when the HAB payload swings to the side, the pendulum inside the HAB payload will seem to swing [even though it is a constant angle with respect to an outside observer]. Once the pendulum reaches its maximum amplitude it will be measured using a caliper or a ruler. There will be a series of circles drawn on the inside of the lid of the payload. They will have varying radii and using these radii the projection of the length vector onto the local x-axis [parallel to HAB lid] will yield the necessary data to calculate the swept angle. See figure 5 for a representation of these vectors. The projected vector is created by projecting $\vec{l}$ onto $\vec{t}$. The $\vec{h}$ serves a representation of the local vertical [y axis].

VI. Summary & Conculsion

The ultimate goal of this mission is to create a very detailed and extensive report on HAB flight conditions as a function of several arguements [a HAB flight map]. For the best results, testing in different weather conditions and overall environments will yield more data that can cover a wider range of HAB experiments. For the first flight a single arguement for the HAB map will suffice, the arguement being altitude. As other experiments are conducted, other arguements will be available, such as average humidity, heat, or average regional temperature.

After this map is created, HAB teams all over the world can use it for creating a HAB structural design. It will be a great opportunity for SPEX to have their name on such a document. And it is a very plausible mission with a high level of feasibility as much of the necessary instrumentation has been flown and used on the previous SPEX HAB missions.

Acknowledgements

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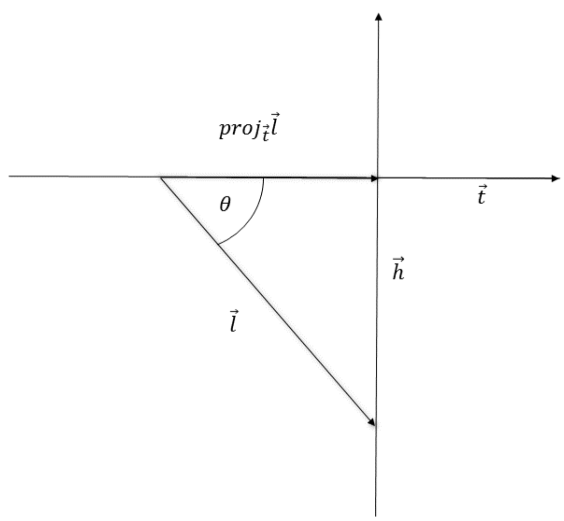

Fig. 5. A representation of the projected vectors and the sweep angle.