University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Optimal Descent Device for In-Situ Turbulence analYsis (O.D.D.I.T.Y.)

Approvals

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1. Problem/Need

New developments in hypersonic flight have allowed aircraft to both fly farther, faster, and higher. This necessitates a more complete understanding of higher altitudes, specifically the region from 20-40 km in altitude. Weather balloons with sensor payloads are currently being utilized to carry out data collection and in-situ research in these regions. This data will be used to aid in the research and design of new vehicles that operate in the upper atmosphere.

Current weather balloon release valve systems have issues achieving altitudes above approximately 35km [1] due to the plastic deformation of the balloon. The current valve system relies only on elastic deformation of the balloon to expel helium from it. However the plastic deformation that is experienced above ~35km does not exert enough force on the balloon and results in the formation of a 'helium bubble' that cannot be forced into the release valve as it is currently designed. Consequently this bubble contains enough helium to prevent the system from descending and collecting the desired data. In order to solve this problem, helium needs to be dynamically evacuated from the bubble in a completely re-envisioned fashion than is currently utilized.

The dynamic evacuation of helium from the balloon will allow the sensor system to reliably reach higher altitudes than are currently achievable. This will expand the potential flight envelope for the currently used balloons and allow data to be collected at these higher altitudes. By having a dynamic system instead of the current passive evacuation of helium, the volume of gas released can be controlled and regulated. This will allow for the desired descent rate of 2 - 10m/s [Req. 1.0] to be more accurately controlled and tuned as needed on a per-flight basis. The dynamic system will also allow for a wider range of balloon that can be used for a given mission, as varying elasticity will no longer be an issue.

2. Previous Work

O.D.D.I.T.Y. is in support of the Hypersonic Flight in the Turbulent Stratosphere (HYFLITS) project, which is a larger project being undertaken by RECUV and Integrated Remote and In-Situ Sensing (IRISS) at CU Boulder. HYFLITS has the primary goal of identifying and quantifying the dynamics of stratosphere turbulence [3]. The strategy for conducting these measurements consists of launching a low-cost weather balloon, with a sensor package as a payload. As the balloon ascends through the atmosphere, however, it creates a wake and the air is perturbed around the data-collecting sensors; this is problematic for very sensitive instruments such as humidity and temperature sensors, along with sensor packages equipped with rapid response times. In order to prevent this contamination in the various sensors of the balloon's payload, data can be collected during the descent phase of the balloon's trajectory when no wake from the balloon is present [1]. The above mission concept has been able support a relatively low-cost budget as well as provide reliable measurements in the 20-40 km altitude range.

Background research was done to explore different methods to achieve a controlled descent of the gondola payload. The group found two main techniques; helium release valve (currently being used in HYFLITS) and a dual balloon launch system [1]. The paper addressing these two techniques [1] only discussed sounding balloons achieving altitudes of 35km before bursting, therefore, it does not include discussion on inelastic deformation of the balloon and the issues this presents. The information presented does, however, confirm the desired descent rate can be achieved through the venting of helium. The article also discusses a dual balloon system to bring the payload to the desired altitude. This setup is not a possibility for the project due to customer constraints, since it provides insight into other methods of achieving the same goal. This configuration uses a lifting balloon and a descent control balloon to raise the payload to the desired altitude. Once the altitude is reached, the lifting balloon is cut away from the payload. The payload then descends while attached to the descent control balloon. This provides a 'controlled' descent for the payload without needing a valve system.

Other investigations in the altitude control of such balloons have been conducted as well; such as the "Weather Balloon Altitude Control System" [4]. This system was developed with a slightly different goal in mind; to achieve neutral buoyancy at a desired altitude. While this project has no mention of using such a system to control the descent of a balloon, it uses a venting mechanism similar to what is currently being utilized by HYFLITS. This particular design utilized a rotating gate valve in order to facilitate the venting of helium at altitude. This is similar to the HYFLITS current implementation however; with no active means to vent helium besides a pressure difference, and is likely subject to the same shortcomings of the HYFLITS implementation. However, this project was subject to fairly similar operating conditions, especially with the mass requirement. This document contains a relatively in-depth discussion of valve types, attachment points (balloon connection and filling), and a high level system overview. However, it likely does not expand on the current capabilities afforded by the current HYFLITS venting mechanism.

However, disadvantages to the above venting method have been identified. Based on previous flight records, it has been recorded that the valve at the neck of the balloon did not release enough helium to descend at a fast enough rate. When the balloon ascends to a high enough altitude, plastic deformation occurs in the balloon. This results in an insufficient amount of helium being released from the balloon to support a reliable descent. Therefore, the venting method needs to be further modified for optimal use.

This project serves to address the problems associated with balloon descent by improving upon the helium venting mechanism; allowing for sufficient helium evacuation can result in more useful data, potentially increase the altitude range of the data collected, and increase the maximum altitude of the balloon.

While looking at different methods for the helium to vent, it is also important to look into different balloon materials that can affect the available payload mass as well as having a higher burst altitude. Through the Kaymont website, different types of balloon that have different payload masses, neck diameter, burst altitude and burst diameters are shown [2]. These differences can be investigated to provide insight into which balloon can best work in this project, in addition to design a device that functions with all types of balloon necks.

In anticipation of designing a device that will deliver on all the requirements highlighted in section four, background research was done specifically addressing the third requirement of communication. The communication used by the HYFLITS project is currently XBee modules. These modules are "small radio frequency devices that transmit and receive data over the air using radio signals." [5] Using the same XBee modules allows for the possibility of the device and the payload to communicate. The XBee module that can be used in the device, can easily be configured to communicate with the current XBee, however, this is only one solution of many different possibilities.

Research was also done on possible heating and insulation strategies to ensure that all mechanisms within the system may operate throughout the duration of the flight. During the flight the balloon may experience temperatures as low as -60°C. The most common thermal regulation devices used in weather balloons are foam insulators. Different types of foams and other materials can be tested and explored. Some weather balloons also utilize heaters such as resistors [6]. These strategies can be further researched and tested in a freezer environment to determine the best solution.

3. Specific Objectives

The table listed below has all the levels of success that this group envisions for the project. Being able to complete level 1 in all the categories is the basic functions that this project will need to preform to match the current flight standards. Level 2 is one step above in each subsystem and allows the project to have more functions once the basic functions are met. Fulfilling level 3 is the ideal case where all the subsystems are more complex and high functioning as the team has envisioned and all goals are met.

Levels of Success	Altitude control	Descent Rates	Balloon Attachment	Communications	Survivability	Cutaway mechanism
Level 1	The balloon and Gondola will achieve a maximum altitude of 36 km and descend below 20 km	The Balloon and the Gondola maintain a descent rate of 2 to 10 m/s	The device will be able to attach to large Kaymont weather balloons (5 cm Diameter) Before the balloon has been filled with helium	Effectively shares a communication link with the gondola via XBEE radio	Hardware and electronics are able to withstand pressure and temperature of altitudes up to 36 km Battery lasts 6hr	The cutaway mechanism is functional at an altitude of 20 km and below
Level 2	The Balloon and the Gondola will achieve a target altitude of 40 km and will descend to 20 km	The Balloon and the Gondola maintain a descent rate between 2 and 5 m/s	The device will be able to attach to large Kaymont weather balloons (5 cm), and is easily adapted to Hwoyee balloons (9 cm) Before the balloon has been filled with helium	Effectively shares a communication link with the gondola via XBEE radio and receives data from gondola	Hardware and electronics are able to withstand pressure and temperature of altitudes up to 40 km Battery lasts 6hr with the option to sleep to conserve battery	The cutaway mechanism is functional at an altitude of 40 km and below if a situation requires it
Level 3	The system and Gondola will be able to target an Apogee up to 40 km and be accurate up				Level 1 and 2, and has the ability to abort the mission if conditions become undesirable	The cutaway mechanism has some fail safe internal logic for the gondola to execute

Fig. 1 Levels of Success

4. High Level Functional Requirements

The following list of requirements is arranged such that the first level (4.1-4.4) are the functional requirements, the second level (4.1.1-4.3.1) are the design requirements for this project.

4.1 Requirements

- 4.1. The system shall achieve descent rates between 2m/s and 10m/s from the target altitude until it reaches 20km altitude.
  - 4.1.1. The system shall evacuate helium from the balloon without damage to the balloon.
- 4.2. The system shall survive until the gondola is cut away from the balloon.
  - 4.2.1. The system shall maintain operational capabilities in both the pressure and temperature environments associated with the target altitude
  - 4.2.2. The system shall be disposable.
  - 4.2.3. The system shall be self-contained and self supporting other than the gondola radio link.
- 4.3. The device shall have a communication link with the gondola
  - 4.3.1. The system shall receive data from the gondola
- 4.4. The system shall not interfere (physical or EM interference) with the data gathering equipment.

4.2 CONOPS

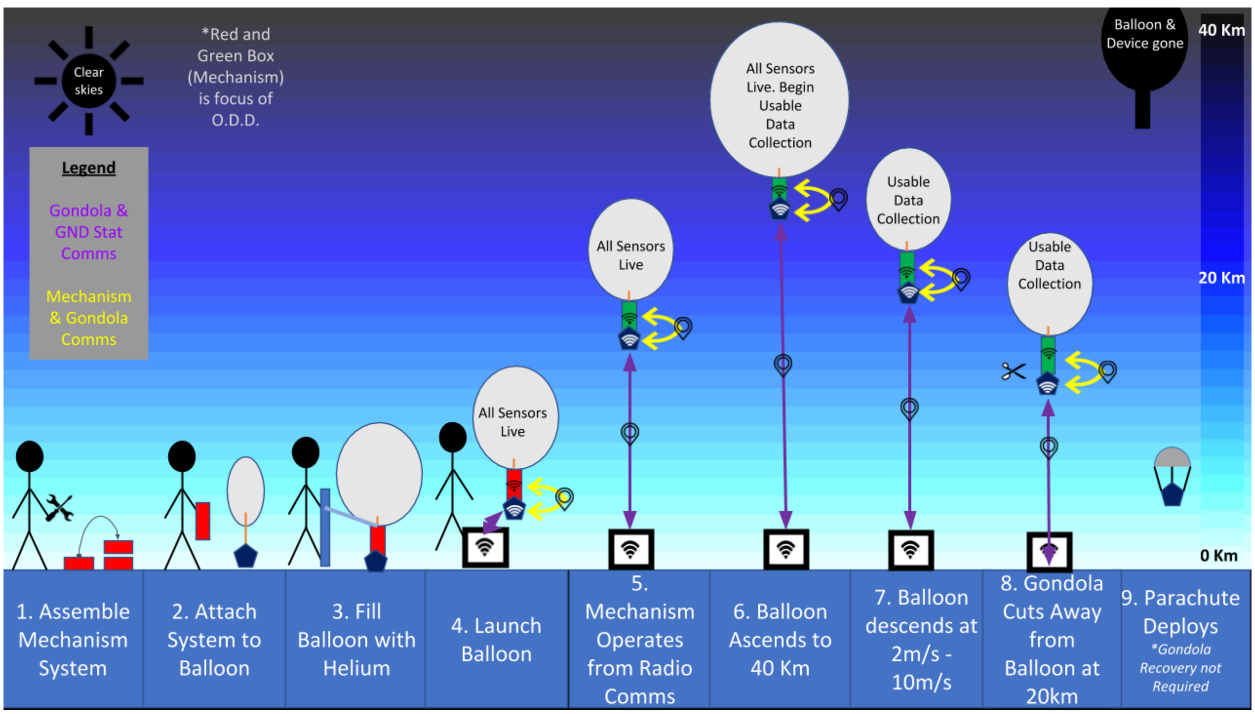

Fig. 2 CONOPS

5. Critical Project Elements

5.1 RF Communications Link

The system shall be capable of 2-way wireless communication with the gondola. This will ensure that the system can receive data via this link and report key system status'. The system shall utilize XBee radio in conjunction with the gondola to meet this project element.

5.2 Altitude Control Mechanism

The systems main hardware shall consist of a mechanism meant to expel helium from the balloon at a rate that shall cause a descent velocity of 2 m/s and below 10 m/s to ensure optimum data collection by the sensors on-board the gondola. It shall also operate in such a fashion that the balloon will be able to reach altitudes between 20 and 40 km and be able to reliably descend following data collection. This system shall be cheap, less than $200, to ensure easy reproduction in future flights. Furthermore the fabrication of this system shall be simple enough to replicate before every test flight with ease. The system shall also be light, at or below 300g, to ensure proper balancing of the balloon so that it may reach the proper altitude unimpeded.

5.3 Adjustable Neck Attachment Hardware

The system shall have a neck attachment such that it is capable of interfacing with multiple brands of high altitude balloon. Specifically it shall be capable of interfacing with the two brands of balloon utilized for the mission, Kaymont balloon (5cm) and Hwoyee balloon (9cm). This attachment shall also be a non-invasive component to the rest of the systems essential hardware.

5.4 Insulation and Heating

The system shall include measures to ensure proper insulation and heating of the mechanism so that it may function properly in the target altitudes. These insulating and/or heating elements shall be both light weight and low cost to ensure fulfillment of weight and budget requirements.

5.5 Gondola Cut-Away Mechanism

The system shall be able to sense the current altitude and be pre-programmed to cut the balloon away from the gondola for recovery. The altitude data needed for cut-away determination shall be provided by devices on-board the gondola and will be transmitted wirelessly to the cut away mechanism. The mechanism shall also include a fail safe in the event of a failed mission so that the gondola may still be recovered.

5.6 Documentation and Ease of Assembly

The methods of construction for the system shall be well documented as to ensure ease of assembly by future parties. This documentation shall include but not be limited to 3D models, dimensional drawings, and a build guide detailing all components and steps required to assemble the system.

6. Team Skills and Interests

Team Member	Associated Skills	Critical Project Element(s)
Stephen Chamot	CAD (Solidworks), 3D printing, MATLAB, Manufacturing	CPE-5.2, -5.3, -5.5
Alexander Larson	Circuitry Design, Manufacturing, Soldering, Prototyping, MATLAB, 3D Modeling, Communications	CPE-5.1, -5.3, -5.5, -5.6
Corey LePine	Circuitry Design, PCB design, Soldering, Arduino, Communications	CPE-5.1, -5.4, -5.5
Emily Riley	MATLAB, CAD (Solidworks), Manufacturing	CPE-5.2, -5.3, -5.4
Thania Ruiz	Soldering, Circuit design, Arduino, MATLAB, 3D printing, Aerodynamics	CPE-5.1, -5.2, -5.3
Steven Priddy	CAD (Solidworks), MATLAB, Python, Java, C++, Mechanical design, Arduino	CPE-5.2, -5.1, -5.5
Elliot McKee	Fluids/Aerodynamics (CFD), Controls+Simulation (Simulink) MatLab, C++, Soldering/Electronics, CAD (Solidworks)	CPE-5.2, -5.4, -5.1
Marcus Bonilla	MATLAB, Soldering, Circuit design, Arduino, Laser cutting, Communications	CPE-5.2, -5.3, -5.4 , -5.6
Michael McCuen	CAD (Solidworks), MATLAB, Mathematica, Soldering, Basic Circuit design, Arduino, Laser cutting	CPE-5.2, -5.3, -5.4, -5.5
Anders Olsen	CAD (Solidworks, Fusion360), 3D printing, Mechanical design, Manufacturing, Composites	CPE-5.2, -5.3, -5.4, -5.5, -5.6

7. Resources

Critical Project Elements	Resource/Source
5.1 RF Communications Link	Dr. Lawrence, Dr. Akos, PILOT Lab
5.2 Altitude Control Mechanism	Dr. Lawrence, Prof. Hodgkinson, Prof. Rhode, PILOT Lab
5.3 Adjustable Neck Attachment Hardware	Prof. Hodgkinson, Prof. Rhode, PILOT Lab
5.4 Insulation and Heating	PILOT Lab, Pressure Chamber, Prof. Schwartz
5.5 Gondola Cut-Away Mechanism	Legacy Module, Prof. Rhode
5.6 Documentation and Ease of Assembly	Prof. Rhode, Prof. Hodgkinson

References

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[4] Basta, T., Miller, S., Clark R. T., "Weather Balloon Altitude Control System," Senior Design Final Report, Electronics and Computer Engineering Dept., Montana State Univ., Bozeman MT, 2015

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[6] Hauser, A., Leusink N., Clayton, R., Klimek, R., "Payload Evolution and Engineering: A Reevaluation of the Strength, Efficiency, and Design of High-Altitude Balloon Payloads"
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