Department of Aerospace Engineering Sciences
Senior Projects – ASEN 4018

PRV: BalloonSat Return Vehicle
Project Definition Document (PDD)

Document History

Release	Date	Description	Name
Initial	9/6/07	First Release	Eric Dickey
	9/13/07	First Revision	John T. Lee

Approval

Title	Name	Signature	Date
Customer			
Advisor #1			
Advisor #2			
CC			

Project Definition Document

Aerospace Senior Projects (ASEN 4018 & 4028)

1.0 Information

1.1 Project Title

High Altitude Research Return Vehicle (HARRV)

1.2 Project Customers

Chris Koehler
Space Grant
Koehler@thinker.Colorado.edu
(303) 492-4750

1.3 Group Members

Eric Dickey (303) 358-6834 Condor1X@aol.com	Matt Fetig (970) 371-4456 fetig@colorado.edu
Kelly Harcsztark (720) 320-3527 kengineer1@gmail.com	Dan Hood (720) 273-7981 hoodd@colorado.edu
John Lee (720) 206-7244 LeeJT@colorado.edu	Thanh Nguyen (303) 884-4809 thanh.nguyen@colorado.edu
Aaron Okken (719) 429-3690 okken@colorado.edu	Mark Schwartz (303) 929-2656 mark.schwartz@colorado.edu
Chris Sprague (303) 877-5519 Christopher.Sprague-1@colorado.edu	Mitchell Harris (303) 726-8408 mitchell.harris@colorado.edu

2.0 Background and Context

Approximately 800 locations around the world release weather balloons regularly, usually twice daily. In an overwhelming number of these launches the instrument package is lost[1]. This project addresses the issue of how to return a balloon payload from high altitude to a preplanned location. Space Grant Consortium currently builds several high altitude research payloads each year which are delivered on weather balloons to an approximate altitude of 100,000 feet. These payloads need to be recovered in order to serve their purpose. The payloads are typically recovered 50 to 150 miles from the launch site, and the recovery process involves chasing the balloon by car during its ascent and finding the payloads with an RF beacon[2]. By returning the payload to a predetermined location, the recovery effort will be reduced. A controlled delivery system from altitude would be useful for applications which require a payload to be delivered to a specific target. Such a system would allow researchers to perform experiments over inaccessible terrain, like heavily forested areas.

The 2006/07 PRV team attempted to solve the problem using a glider. The design was a blended-wing-body aircraft constructed out of composite materials and used a GPS autopilot for navigation and control (See Figure 1). Once the aircraft had flown to its target area a parachute would deploy to return the aircraft and payload to the ground safely. Early hot air balloon tests demonstrated a successful implementation of an autonomous flight control system. The group's final testing attempt from a weather balloon failed when the tether release mechanism did not separate the aircraft from the balloon[3].

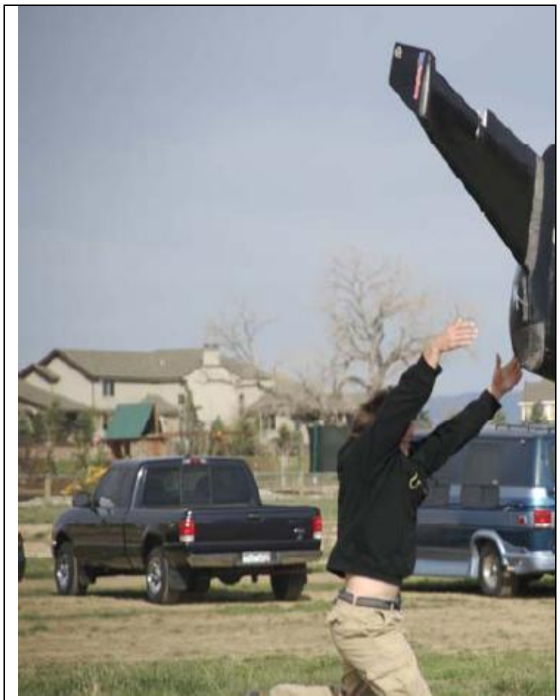

Figure 1: 2006/07 PRV Launch Goal
Figure 1: 2006/07 PRV Launch Goal
Figure 1: 2006/07 PRV Launch Goal
Goal

3.0 Goal

The goal of our project is to design, build,

[1] "NWS Radiosonde Observations Factsheet". Available http://www.ua.nws.noaa.gov/factsheet.htm , Sept. 2007.
[2] Koehler, Chris. Personal interviews. Dates of interview: 8/30/07 - 9/12/07.
[3] 2006/2007 PRV Final Report. CU Boulder, Colorado. Available http://www.colorado.edu/ASEN/SrProjects/Archive/2006-07/SpringReport/SR_PRV.pdf Sept. 2007.

and test a vehicle that will return BalloonSat payloads from a weather balloon at 100,000 feet to an easily recoverable location. The vehicle will be completely autonomous and will not significantly interfere with the science payloads.

4.0 Objectives

The vehicle shall be carried by a weather balloon to an altitude of approximately 100,000 feet, at which point it will detach from the balloon along with its Space Grant BalloonSat payloads. In order to return the payloads to an easily recoverable location (e.g. close to road access, free of landing hazards, etc.), it will autonomously navigate to a user-selected landing site. Upon reaching its destination, the vehicle will initiate a landing sequence, which will return to the ground with the payloads undamaged. The vehicle must be capable of operating without any user input during flight.

5.0 Functional Block Diagram

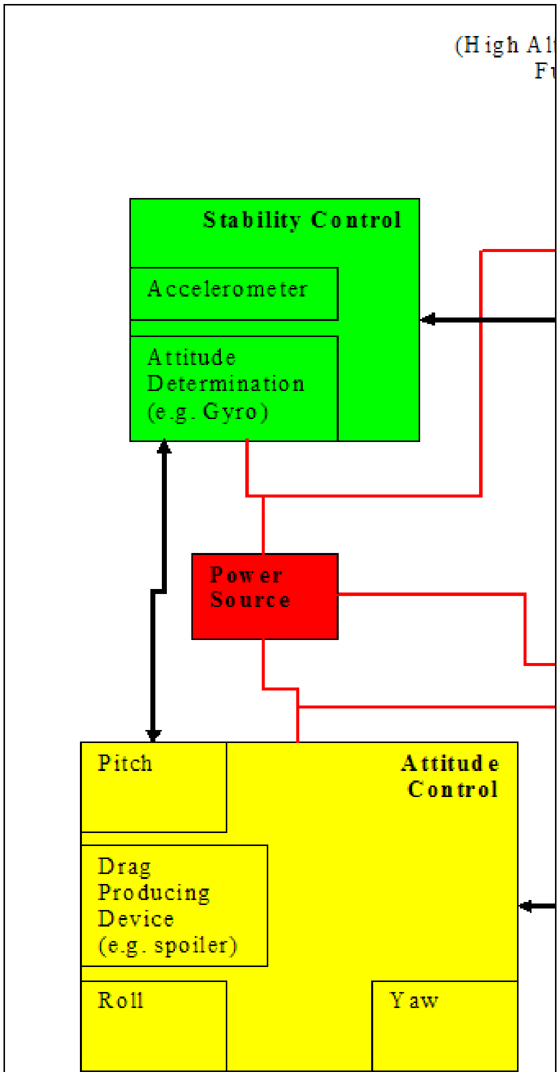

Figure 2: Functional Block Diagram
Figure 2: Functional Block Diagram
Figure 2: Functional Block Diagram

6.0 System Operational Timeline (Concept of Operations)

Concept of Operations

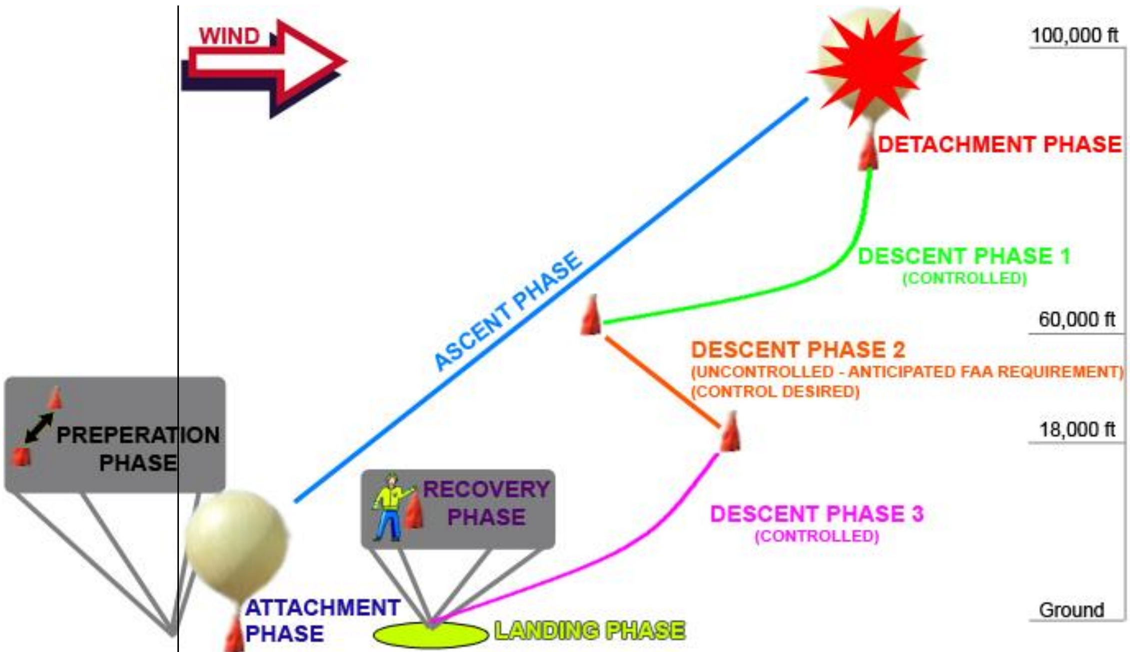

Figure 3:
Concept of Operations

Figure 3: Concept of Operations

Figure 3: Concept of Operations

The above concept of operations diagram assumes uniform wind direction through all layers of the atmosphere. The vehicle will ascend with a weather balloon to approximately 100,000 ft, where the balloon will burst. The vehicle will then detach itself from the balloon and descend to 60,000 feet, where it will then enter a required[4] uncontrolled phase. At this point, the vehicle will be required to either be in direct contact with a pilot or in a freefall mode under a parachute. Once the vehicle reaches 18,000 feet, the vehicle can then return to an autonomously controlled flight. Once the vehicle is within visual range of the landing zone, the vehicle enters the landing phase.

[4] This requirement was determined by the FAA

7.0 Project Requirements

Requirement	Description	Motivation	Parent Ref.	Verification Method
0.PRJ.1	Payload capacity must be at least 5 BalloonSats	All payloads can be launched in 2 missions	Goals and objectives	Payload test fit, weight measurement
0.PRJ.2	Vehicle shall autonomously navigate to designated landing zone from 100,000 feet altitude	Mission profile	Goals and objectives	Flight testing
0.PRJ.3	Vehicle shall have a horizontal flight range of at least 10 miles	Able to reach point of road access	Goals and objectives	Design analysis and flight testing
0.PRJ.4	Vehicle shall land within 1/4 mile of target landing site	Customer requirement	Goals and objectives	Flight testing
0.PRJ.5	Vehicle and payloads shall be in reusable condition on landing	Customer requirement	Goals and objectives	Recovery system analysis and testing, post flight inspection
0.PRJ.6	Vehicle shall allow each payload a view to the atmosphere	Payloads' science instruments must function as intended	Goals and objectives	Design analysis and flight testing
0.PRJ.7	Vehicle shall operate in a manner compliant with all applicable local, state, and federal regulations	Flights must be approved by FAA	Goals and objectives	Obtain FAA approval for flight

8.0 Top Level System Requirements (0.SYS)

Requirement	Description	Motivation	Parent Ref.	Verification Method
0.SYS.1	Combined vehicle/payload shall weigh less than 20 lbs	Balloon capacity	0.PRJ.1	Weigh vehicle
0.SYS.2	Vehicle shall be able to accommodate at lease 5, 5" cube payloads	Payload volume constraint	0.PRJ.1	Test fit payloads
0.SYS.3	All subsystems shall survive in a temperature range of -80° to 120° F	Launch environment	0.PRJ.2	Thermal testing
0.SYS.4	All subsystems shall survive partial vacuum conditions down to 1.0 kPa	Launch environment	0.PRJ.2	Vacuum testing
0.SYS.5	Vehicle shall be capable of operating without user input	Project requirements	0.PRJ.2	Flight testing
0.SYS.6	Vehicle shall employ a recovery system which will return it to the ground with a vertical velocity of no greater than 20 ft/s	Preventing destruction of payload or vehicle	0.PRJ.5	Recovery system analysis and testing
0.SYS.7	Vehicle shall be capable of radio communications with a ground station in a 20 mile line-of-sight range	Balloon tracking and manual control capabilities	0.PRJ.7	Communication system specifications, flight testing
0.SYS.8	Redundant systems shall return the vehicle safely to ground if the primary navigation system fails	Increase mission success probability	0.PRJ.5	Flight testing
0.SYS.9	Autonomous operation can be overridden from the ground station	Makes the FAA happy	0.PRJ.7	Flight testing, ground test of manual system

9.0 Minimum Requirements for Success

The minimum requirements for success are the same as the top level requirements (refer to Section 8).

10.0 Deliverables

1. A functional system, including a vehicle and ground systems, which meet the minimum goals and requirements defined by the PDD.
2. An operation manual which includes operation instructions, specification sheets, and trouble shooting.
3. A maintenance manual which includes technical drawings and schematics.
4. Any required certifications already obtained.

11.0 Technical Risk

11.1 Airspace Access and FAA Clearance

It is critical for airspace clearance in order to perform flight testing of the PRV recovery system. Currently FAA policy for granting a certificate of waiver or authorization (COA) to unmanned aerial system (UAS) is outlined in AFS-400 UAS Policy 05-01. A major concern is the requirement that the vehicle is equipped with a transponder if the vehicle operates beyond visual range from an observer (defined as within one mile horizontally and three-thousand feet vertically). Equipping the UAS with a transponder may strain the project financially and may complicate weight requirements. Furthermore, while the system is flying between 18,000 and 60,000 feet (class-A airspace) the aircraft must be on an instrument flight plan with a pilot capable of taking control of system and in contact with air traffic control (ATC).

Starting a dialog with local FAA officials and CU faculty that have insight to the UAS airspace issue may offer solutions in dealing with the requirements. Development of a communication system between the vehicle and ground could allow control of the future vehicle and a satisfaction of some of the FAA requirements. The instillation of a transponder on the vehicle can also be further investigated to satisfy requirements.

11.2 Materials Performance in Harsh Environment

The vehicle will travel to an altitude up to one hundred thousand feet where pressure and temperatures will reach extreme lows. These environmental factors could have adverse effects on construction methods and vehicle's materials such as out-gassing or change in expected material performance (e.g. brittleness, ductility, etc). Electronic sensors, batteries, and other electronic components may malfunction due to the low pressures and temperatures experienced as well. Electrical systems will be critical to the system functionality and need to be protected.

This risk can be mitigated by gaining access to facilities that can simulate the high altitude environment. These simulations would clarify what can be expected from candidate materials and solutions to potential hurdles in manufacturing. Electronics reliability can be tested and verified before flight.

11.3 Vehicle Tolerance to High g-forces

The vehicle will reach high velocities when travelling through the thin air at high altitude which will result in high aerodynamic loading when the vehicle enters the thicker atmosphere and adjusts its trajectory. The structure of the vehicle must be sufficiently robust to handle the forces encountered and maintain its functionality.

Aerodynamic testing and then modeling of the vehicle will need to be performed to accurately predict what forces will be encountered. Static load testing and other analysis tools will need to be used to correctly determine the vehicles structural limitations.

11.4 Flight Testing Capabilities

Flight testing of the vehicle will be an expensive and possibly complicated endeavor. Last year's PRV group performed flight testing from a hot-air balloon which cost five-hundred dollars per test. This heavily burdens the finances of the project and limits the amount of flight testing that can be conducted. Increasing the amount of low altitude flight testing would allow for more information to be learned about the vehicle, and translate into a greater probability of success in the actual high altitude mission.

The flight testing expenses could possibly be reduced by finding other options for testing. One possible option is utilizing an airplane to carry the test vehicle to altitude for a cheaper fee, or finding ways to reduce the cost of operating a balloon.

12.0 Anticipated Engineering Expertise

Technical Area	How Applied / Indicate Team Member Responsible
Aerodynamic Design	Develop stable lift, drag and control surfaces.
Precision Mechanical Design	Develop conceptual and detailed solid 3D models of the device as a whole and its components.
Composite Construction	System Structure.
Electromechanical Actuators	Actuator Subsystem.
Analog Electronics	Design of the actuation and sensing subsystems.
Digital Electronics	Design of the non-analog sensing subsystems.
Control Software	Real-time control subsystem.
Autopilot Software	Real-time orientation and navigation system.
Mechanical Fabrication	Part machining.
Electronic Fabrication	Analog and digital electronic subsystem fabrication.
Mechanical and Dynamic Test	Testing and verification of each subsystem and the system as a whole.

13.0 Resources

13.1 Facilities

- Thermodynamic Testing Facilities, for low temperature testing to simulate the upper atmosphere.
- Vacuum Testing Facilities, for low pressure testing to simulate the upper atmosphere.
- Loading Testing
    - Static Load Testing, for structure testing of a possible high g pull - out maneuver.
    - Shake Table (or similar device), for electronic testing of possible high g pull-out maneuver.
- Altitude Testing, both low altitude (e.g. hot air balloon) and high altitude (e.g. weather balloon) for verification of vehicle’s auto pilot and performance.
- Wind Tunnel, for verification of aerodynamic qualities of vehicle.

13.2 Additional Advisors

- Brian Argrow, for assistance in FAA regulations and aerodynamic design.
- Eric Frew, for assistance in the implementation of the autonomous operation sub system.
- Bill Pisano for assistance with the construction and implementation of microcontrollers.

13.3 Funding

This project will have an initial fund of $4,000, provided by the University of Colorado Senior Project Fund. Additional funding will most likely be required. These funds will be applied for through organizations that may have interest in the success of this project. Initially, the funds will be sought through university related organization, such as the Undergraduate Research Opportunity Program (UROP) and the Engineering Excellence Fund (EEF). The search for funding will then be expanded, as needed, to the customer, NASA's Colorado Space Grant Consortium, and potential customers, such as the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service (NWS).

14.0 Acknowledgements

14.1 Customer

Chris Koehler contributed to the development of our requirements and goals of the project.

14.2 Faculty Members

The PAB members :Scott Palo, Robert Culp, Jean Koster, Donna Sue Gerren, Lakshmi H. Kantha, Dennis Akos, Mohmed Hussein, Ryan Starkey, Matt Rhodes, and Trudy Schwartz for their inputs regarding the requirements and objectives of the project.

14.3 Others

Benjamin Reese for providing PDD of previous year.