University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document

RADIANCE
Research at high Altitude on Distributed Irradiance Aboard an iNexpensive Cubesat Experiment

Approvals

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1 Problem or Need

In November 1978, the Nimbus-7 spacecraft was launched with the Hoyt-Friedman radiometer on-board, an instrument which made precise measurements of solar radiation for the first time in history [1]. Since then, numerous spacecraft have been launched with instruments designed to take precise measurements of solar irradiance, enabling climate scientists to study the effects of a changing sun on the Earth's climate. Unfortunately, these instruments are expensive and time-intensive to produce, and thus our historical record of solar irradiance is incomplete due to gaps in funding, schedules, and instrument failure [2] [3]. Similarly, since each instrument on orbit may be produced by a different agency, calibration of sensors can vary up to 0.5%, leading to discrepancies and conflict between data sets [4].

Research at high **A**ltitude on **D**istributed **I**rradiance **A**board an i**N**expensive **C**ubesat **E**xperiment (RADIANCE) will be the first step towards a solution to the problems described above. RADIANCE is a self-sufficient 3U payload—each unit ("U") is a 10cm cube, resulting in a 10cm x 10cm x 30cm structure—that will house a spectrometer capable of taking solar irradiance measurements during a high-altitude balloon flight. It will be low-cost and designed for simplicity, addressing the need for an irradiance measurement system that can be produced at a regular cadence. Since the cost-per-unit is significantly reduced, multiple systems could be produced to cover the entire solar spectrum while still meeting the cost-reduction requirement. Reduced cost and simple manufacturing also allows for multiple systems to be produced simultaneously, eliminating the gaps and inconsistencies in the data record that have plagued climate scientists.

2 Previous Work

As emphasized above, solar irradiance data is essential to the atmospheric and Earth science communities, especially keeping a continuous record to monitor fluctuations due to the solar cycle and other secular changes in solar radiation [7]. The record of solar weather compiled by NASA and NOAA stretches back to 1978, but does have gaps and inconsistencies in the timeline [1] [3].

Modern solar irradiance measurements are made using active cavity electrical substitution radiometry, such as that done by the TCTE instrument on the USAF STPSat-3 (launched in 2013) and the TIM instrument on the NASA SORCE spacecraft, launched in 2003 [6] [5]. Both of these missions are full-scale, high-budget space missions, whereas RADIANCE aims to make solar irradiance observations more economically accessible. Additionally, having the ability to launch several low cost instruments concurrently will eliminate gaps in the data, help to filter out noise because of multiple sources for comparison, and help to calibrate other spectrometers.

RADIANCE shall be attached to the HiWind Gondola, which is a balloon payload built and operated by the High Altitude Observatory (HAO) at NCAR. The gondola is 1000 kg in mass and has flown before above the Arctic circle at an altitude of 40 kilometers in 2011 [9] [10]. Due to its size, instruments (such as RADIANCE) can easily be mounted on the sides of HiWind with mass being of minimal concern.

3 Specific Objectives

3.1 Deliverables

The main deliverables for the RADIANCE project are defined as follows:

- A completed structure that fulfills all Level 1 requirements at a minimum (see Table 1).
- All design, readiness, and manufacturing reviews shall be given as required of the ASEN 4018/4028 courses. These reviews shall include test plans and test results as appropriate.
- A Fall Final Report (FFR) and Project Final Report (PFR) shall be completed as required by the customer and the course. FFR and PFR shall include test plans and test results as appropriate.

- A "path to space" report that makes recommendations and demonstrates how RADIANCE could be modified to be ready for spaceflight. This document may be incorporated into the PFR.

Additionally, rigorous testing of RADIANCE will be required to verify that all requirements have been met. The specifics of what testing will depend on the ultimate design, but the team will develop test plans and perform tests to prove the successful completion of the project requirements. Furthermore, the testing plan shall take into account vendor-reported operating requirements for all off-the-shelf components used.

3.2 Levels of Success

Table 1 outlines the "levels of success" criteria that will determine success of the project. Items in Level 3 are intended to characterize the ultimate design, however the customer will consider the project a success if all Level 1 requirements are met. Please note that customer has specified that this project is not mass-critical for the HiWind flight (neither quantity or center of mass requirements).

	Level 1	**Level 2**	**Level 3**
Inst.	Take solar irradiance measurements at 1 spectrum/min during cruise Take environmental measurements during cruise	Take all measurements (environmental, housekeeping, and solar irradiance) during full flight Capture images of the sun in the visible spectrum	Take solar irradiance measurements at 1nm resolution covering 250-1000nm during the full flight Capture 1 photo/min of the Sun for full flight Provide absolute calibration data of the instrument
TCS	All systems survive thermal conditions of ascent and descent All systems operate during thermal conditions of cruise	—	All systems survive and operate during the thermal conditions of the full flight (ascent, cruise, descent)
Data	Record solar irradiance and attitude data on a durable data storage device with sufficient capacity (to meet relevant Level 1 requirements)	Record solar irradiance, attitude, and environmental data on a durable data storage device with sufficient capacity (to meet relevant Level 2 requirements)	Record solar irradiance, attitude, environmental, and housekeeping data on a durable data storage device with sufficient capacity to meet relevant Level 3 requirements
EPS	Package operates on HiWind power supply	Package operates on a power supply independent of HiWind Package interfaces with HiWind for emergency power supply	Package operates on a power supply independent of HiWind Package will have sufficient battery backup to operate ascent/descent
ADS	Determine and record attitude to $\pm 1^\circ$ of accuracy	Determine and record attitude to 1 arcminute of accuracy	Determine and record attitude to below 1 arcminute of accuracy
Struc.	Structure must be 10cm x 10cm x 30cm, with allowances for solar panels to exceed these dimensions Data is recoverable after experiencing TBD force of landing Structure can be affixed to HiWind	Data is recoverable and the spectrometer is still usable after experiencing TBD force of landing	Full structure (including all components) can withstand TBD force upon landing and remain functional

Table 1: Levels of Success Matrix

4 Functional Requirements

4.1 Concept of Operations

The long-term concept of operations for is to create a network of small satellites that can provide continuous, calibrated, and reliable data on solar irradiance to further the study of climate science. The RADIANCE project is the road to this goal by developing the prototype and fly it on a weather balloon in the Troposphere at 40 km. This flight will take place over the course of two weeks taking solar and atmospheric data.

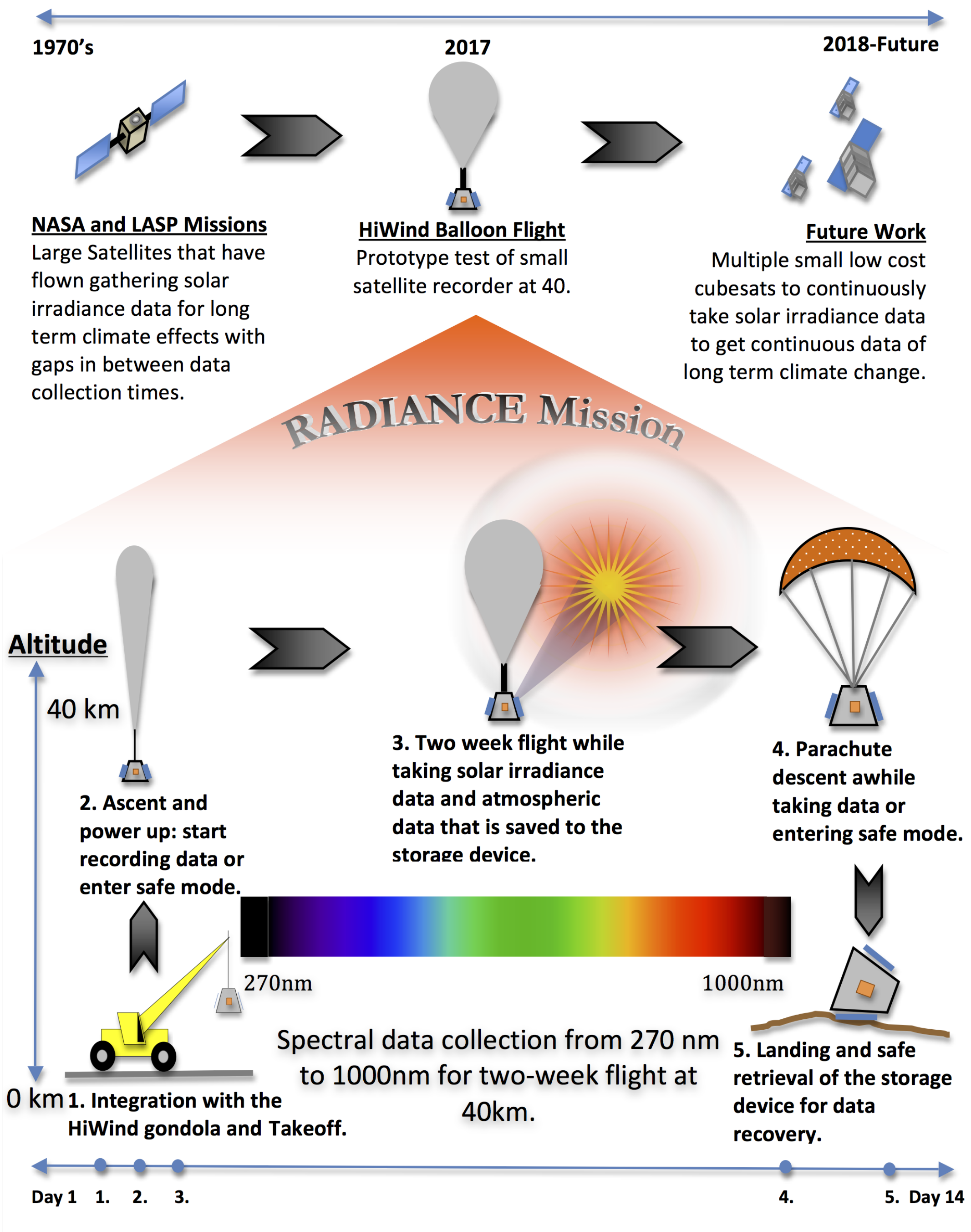

Figure 1: Concept of Operations for RADIANCE and where this project fits within a larger framework

As can be seen in Fig(1) RADIANCE's flight will be broken down into five stages. The First stage is the integration, activation, and launch of the RADIANCE prototype on-board the HiWind gondola. Stage two is to start taking data during the ascent to 40 km while surviving the various environments that will be encountered on ascent. Stage three takes place once HiWind reaches it's altitude of 40 km and RADIANCE records continuous solar irradiance data to a storage device over the two week circumpolar flight around the Antarctic. Stage four is the descent back through the atmosphere where RADIANCE will record data, but more importantly survive descent. Finally stage five is the recovery of the RADIANCE module off of the grounded HiWind gondola and the recovery of the storage device with the gathered data for processing.

Once successful RADIANCE can be used to develop a space worthy 3U cubesat that can be used to create a network of satellites that would then provide continuous solar data to earth to further the knowledge of long-term climate change.

4.2 Functional Block Diagram

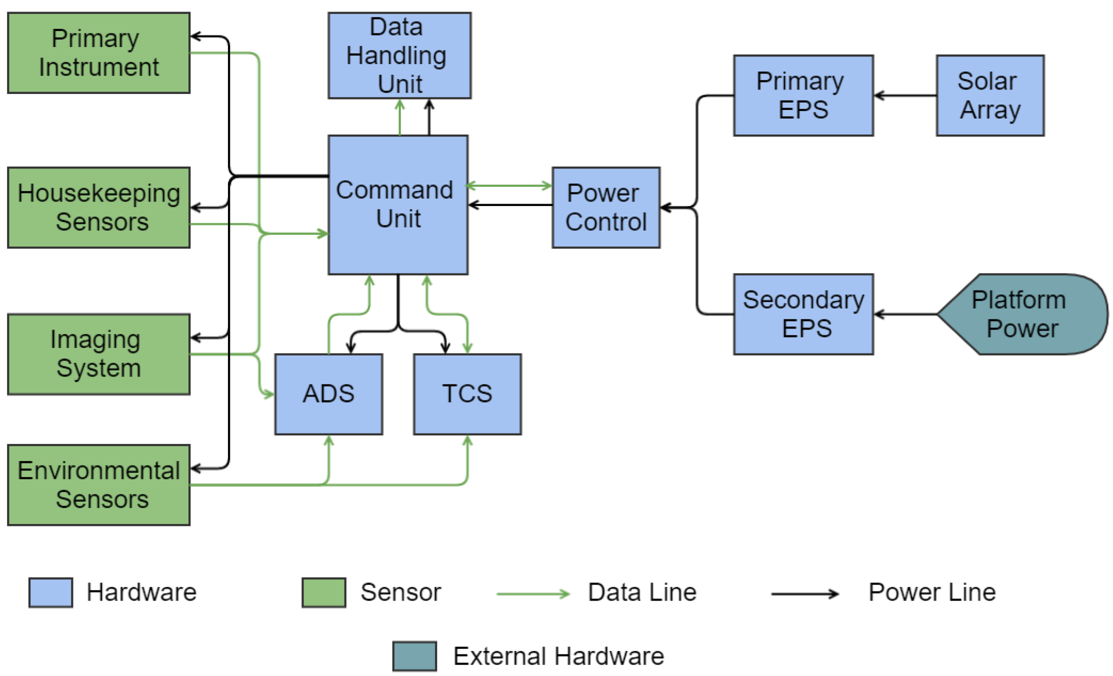

Figure 2: The Functional Block Diagram of the system.

The system is focused around the command unit, shown in the center of the FBD in Fig. (2). This unit records data from the primary instrument, the spectrometers, as well as from the the housekeeping sensors and imaging system. The imaging system also provides data to the Attitude Determination System (ADS), alongside the environmental sensors, so the ADS can calculate the attitude of the payload. The Thermal Control System (TCS), also uses data from the environmental sensors to monitor the payload. The command unit takes relevant data recorded by the sensors, ADS, and TCS, and sends it to the data handling unit for storage. The system uses a solar array as the primary power system, with the option of drawing power from the HiWind gondola as a back up power source. The use of both power systems is regulated by the power control unit, which determines which system is to be used.

5 Critical Project Elements

ID	Critical Element	Reasoning
CPE1	Spectrometer Selection	Number/resolution of spectrometers will greatly determine electrical, software, mechanical design, and cost.
CPE2	EPS Design	EPS required to be robust and reliable, as entire payload relies on EPS.
CPE3	Thermal Design	Team has little experience with thermal design. Flight conditions vary.
CPE4	System Testing and Verification	System will be unreachable during deployment, even small failures may be catastrophic to mission success.
CPE5	Data Storage/Retrieval	Return of the data is fundamental to the success of the project.
CPE6	Interface/Systems Engineering	Project will require integration and interface of many off-the-shelf components for component electrical and data handling needs.

6 Team Skills and Interests

Team Member	Skills/Interests	Relevant CPE
James Pavek	Software, Electronics, Interface	CPE2, CPE5, CPE6
Brandon Antoniak	Systems, Thermal, Interface	CPE1, CPE3, CPE6
Russell Bjella	Software, Systems, Electronics, Instrumentation	CPE1, CPE2, CPE5
Katelyn Dudley	Software, Thermal, Testing, Interface	CPE3, CPE4, CPE6
Alec Fiala	Systems, Software, Electronics, Interface	CPE2, CPE4, CPE6
Jenny Kampmeier	Instrumentation, Testing, Manufacturing	CPE1, CPE4, CPE5
Jeremy Muesing	Manufacturing, Software, Electronics, Systems	CPE2, CPE4
David Varley	Electronics, Manufacturing	CPE2, CPE5
Lance Walton	Mechanical, Manufacturing, Testing, Systems	CPE3, CPE4, CPE5

7 Resources

ID	CPE Name	Resource/Source
CPE1	Spectrometer Selection	Will consult with spectrometer specialists, such as Professor Xinzhao Chu, Greg Kopp at LASP, Chris Koehler at SpaceGrant, or customer's expertise.
CPE2	EPS Design	ITLL's Altium Designer software, expertise from Bobby Hodgkinson, Tim May, and Trudy Schwartz may be required.
CPE3	Thermal Design	Solidworks simulations, equipment to test the payload at cold temperatures. Will consult SpaceGrant and Chris Koehler for expertise on high-altitude balloons.
CPE4	System Testing and Verification	Consult with Matt Rhode and other external expertise and PAB members. May require pursuit of additional funding for spectrometer calibration equipment
CPE5	Data Storage/Retrieval	Consult with Trudy Schwartz and Bobby Hodgkinson for DAQ expertise.
CPE6	Interface/Systems Engineering	Consult with Bobby Hodgkinson and Trudy Schwartz. Consult with Tim May for electrical interfacing.

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