University of Colorado - Boulder

ASEN 4018
Senior Projects

Project Definition Document (PDD)

Weightless Integrated Instrument for Ground-based-deployable Laboratory Sensing (WIIGLS)

Team 11

Section 012

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College of Engineering & Applied Science
UNIVERSITY OF COLORADO **BOULDER**

Approvals

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Customer				
Course Coordinator				

1 Project Customers

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2 Team Members

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3 Problem or Need

In the study of deployable space structures, it is vital to experimentally characterize all aspects of the deployment dynamics in order to reduce risk when unfolding on-orbit. Deployable structures are useful in space mission design as they allow for large surface areas, usable during the mission for sub-systems like solar panels, sun shields, and radio dishes - while remaining constrained by typical launch vehicle dimensions. Folding panel mechanisms are of particular interest in this pursuit, as they package efficiently and are capable of unassisted deployment in microgravity. Notable examples include JPL's One Meter Reflectarray Antenna (OMERA) and NASA's 10m Starshade Inner Disk. Contemporary experimental setups to capture the deployment motion are complex and bulky. To this end: there is a need for accurate, swappable, low-cost sensors that can measure the dynamics of these panels in situ without extravagant cost or complexity. Our mission is to create a compact, modular sensor suite to characterize the dynamic motion of a deployable panel structure.

4 Previous Work

1. Starshade
NASA's Astrophysics Division has developed a technology to achieve better imaging of planets around a star's habitable zone, in order to search for signs of life. This technology, called Starshade, uses a large system of reflective panels to cover the light from a specific star, in order to get better view of orbiting planets and moons. However, the complexity of the resulting motion immediately after deployment makes it nearly impossible to predict the behavior of the Starshade in space. In September of 2018, NASA approved a plan to address the three most critical technologies for the Starshade, one of which included "deployment accuracy and shape stability". This plan allows for Sunshade technologies to move up to Technical Readiness Level 5 (TRL5) [1].

2. OMERA
JPL's OMERA is a foldable antenna designed to fit inside a CubeSat. This deployable structure, which can fold into a small volume, requires hinges with high precision. JPL has recognized that "large, deployable, high frequency apertures remain a limitation", and that the dynamic motion coupled with the necessary precision to unfold the panels accurately require instrumentation that is able to capture the motion of the deployable structure. Once deployed, the antenna will be used for high gain applications such as telecommunications [2].

The type of hinge being used is a high strain composite. The HSC hinge flexures in order to store energy. The stored energy is then spent on deploying the panel. Due to the structural nature of composites and the HSC hinge panel setup, simulating the dynamics of the HSC deployment has proven to be difficult and requires a simplified analysis, 2D behavior and fully rigid panels, on the vibrations present during the deployment [3]. The collection of accurate data is thus crucial given the required positional precision the hinge must accomplish in deploying the panel.

3. Tape-spring hinge
A study was conducted on the deployment dynamics of ultrathin composite booms with tape-spring hinges. The study outlines three major phases during deployment with the second phase causing the greatest challenge, the latching of the boom that connects to the tape-spring hinges. The dynamics during this phase proved to be difficult to simulate due to small variations in geometry of the hinges caused by reverse snap-through leading to large variations in the dynamics of the boom. A possible solution was proposed in the form of applying a viscous pressure loading on the tape-spring hinge surface but was not explored during the study [4].

5 Specific Objectives

The WIIGLS team will develop and implement a portable instrumentation package to be used to characterize the motion of a hinge used in deployable structures. **Level 1** objectives seek to build a fundamental understanding of the motion of the hinge, including gathering data such as time from hinge deployment to stop, and important spikes in motion. We also want the data to be easily recovered from the instrument, and the instrument to survive any motion it may encounter. Given the **Level 1** objectives are met, **Level 2** objectives include accurate characterization of motion in all three dimensions, achieving zero-gravity for testing, testing a multiple panel system, and decreasing overall size, weight, and cost.

Table 1: Objectives & Success Levels

Objective	**Success Level 1**	**Success Level 2**
Data Collection	Record total deployment time, and characterize 2 linear accelerations and 1 rotational acceleration during deployment.	Record total deployment time, and characterize 3 linear accelerations and 3 rotational accelerations during deployment as well as during the resonance period.
Endurance	1 hour active data collection, 1 hour standby.	2 hours active data collection, 1 hour standby.
Physical Attributes	Less than 10mm thick, 30cm x 20cm. Weighs less than 300g. MOI is known.	Less than 5mm thick, 20cm x 20cm. Weighs less than 150g. MOI is known.
Cost	Less than $750 for a single unit.	Less than $500 for a single unit.
Testing	TBD physical model, single (1) hinge. Instrument will survive testing with no functional damage.	Physically accurate model to within TBD% error, Multiple (2+) sensors can be operated concurrently without interference. TBD offloader to simulate zero gravity. Instrument will survive testing with no damage.
Ease of Use	Instrument can be easily installed and uninstalled without damage.	Instrument can be easily installed and uninstalled in less than 5 minutes and without damage.

6 High-Level Functional Requirements

6.1 Functional Requirements

Requirement 1: Data Collection

The system shall be able to accurately record the deployment motion modes of its attached structure.
This requirement is passed down directly from the customer, and is part of the system's main functionality.

Requirement 2: Endurance

The system shall be able to collect data independently and uninterrupted for a minimum of 1 hour.
This requirement is a function of the system's desired function within a system of deploying panels. For the system to achieve its design objective, it must collect data for the duration of the experiment.

Requirement 3: Physical Dimensions

The system shall be able to securely attach to the provided panel structure with dimensions of 30cm x 20cm x 1cm without interfering with deployment
To complete the desired testing objective, the system must measure the unaltered characteristics of the panel unfolding process. To accomplish this goal, the system needs to fit within the panel dimensions and affect the dynamics of deployment as little as possible. This includes the preceding physical dimensions as well as a known mass distribution.

Requirement 4: Cost

The system shall cost less than $750 for a single operational sensor.
The envisioned deployment environment of this system involves a sensor per panel on a multi-panel assembly. To achieve this within a reasonable total cost, each individual sensor shall be as inexpensive as is feasible.

Requirement 5: Ease of Use

The system shall be accessible and removable from the panel structure without damage.
To collect data in a deployment environment without attrition or additional staffing, the sensor assembly should be removable from the panel structure with no damage to either component.

6.2 Concept of Operations

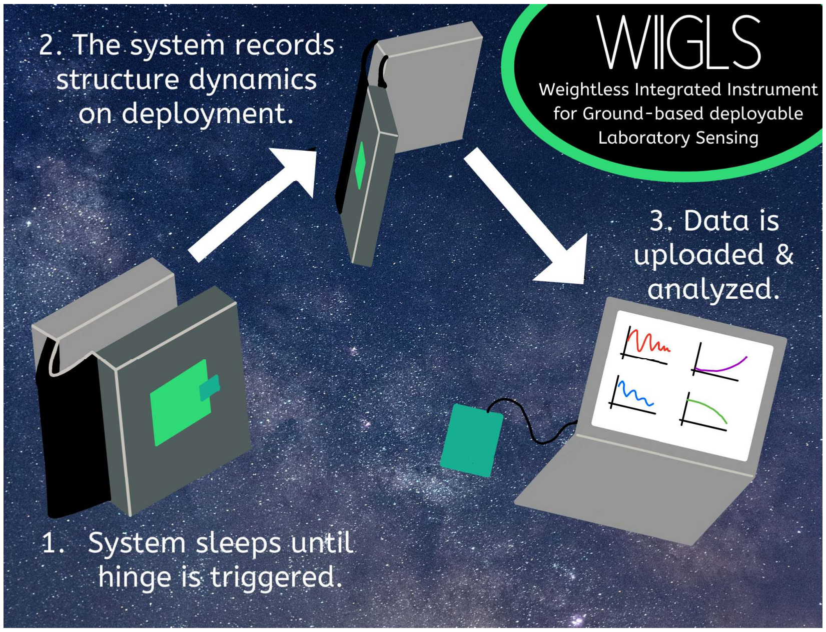

Figure 1: WIIGLS Mission Concept of Operations

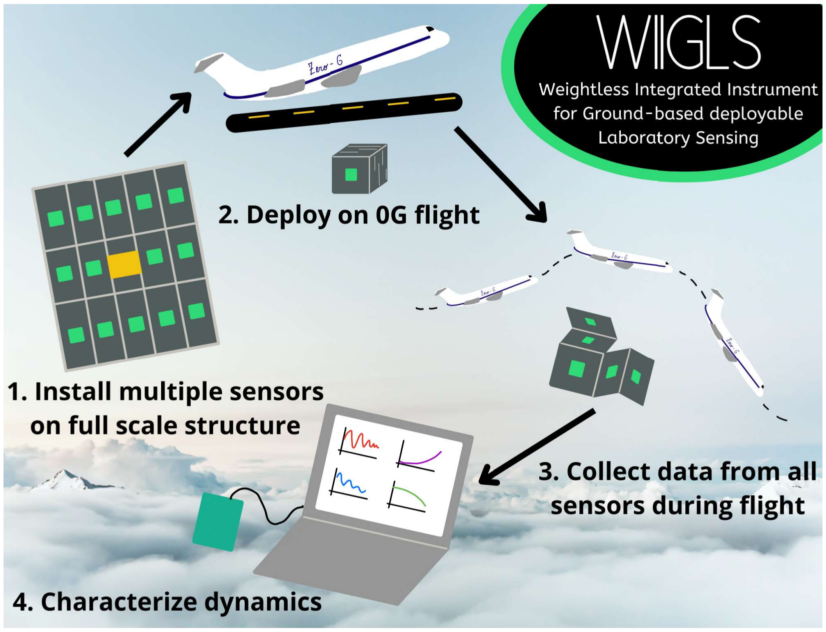

Figure 2: Broad Scope WIIGLS Mission Concept of Operations

7 Critical Project Elements

Table 2: Critical Elements

ID	Critical Elements	Reasoning
CPE1	Sensing Hardware	The system will possess the capability to detect the dynamics of the system. Failure would result in the inability to produce useful data about the deployable structure.
CPE2	Data Collection	The system must be able to detect, record, and store the system dynamics during deployment.
CPE3	Power Source	The system must include a battery or a similar power source in order to gather data independently.
CPE4	Survivability	The system must be able to survive and operate under the high G force conditions and vibrations of a deployment. Failure would result in the inability to use the system in future tests and inaccurate or nonexistent data collection.
CPE5	Testing/Validation	The system shall be tested to be meeting the requirements as specified by the customer. The system will be tested under the influence of Earth's gravity in a lab setting.
CPE6	Budget	The system must cost less than $750 for a single sensor suite. The total cost of the project, including testing and hardware must be within the given budget of $4000.

8 Sub-System Breakdown and Interdependencies

A system designed to meet the functional requirements detailed prior will necessarily consist of four different subsystems - an onboard power subsystem to supply and regulate electrical power to other subsystems, a sensing subsystem involving the physical instrumentation to collect the required data & filter it, a processing subsystem to parse and interpret the data from the sensing subsystem, and a storage subsystem to save collected data in a permanent, readable format. All four of these subsystems will have to share resources, fitting within the prescribed form factor with no interference and sharing data. As a high-level overview, data will flow from the sensing subsystem through the processing subsystem before ending at the storage system, and electrical power will flow from the power subsystem to all other subsystems, as detailed in Fig. 3 below.

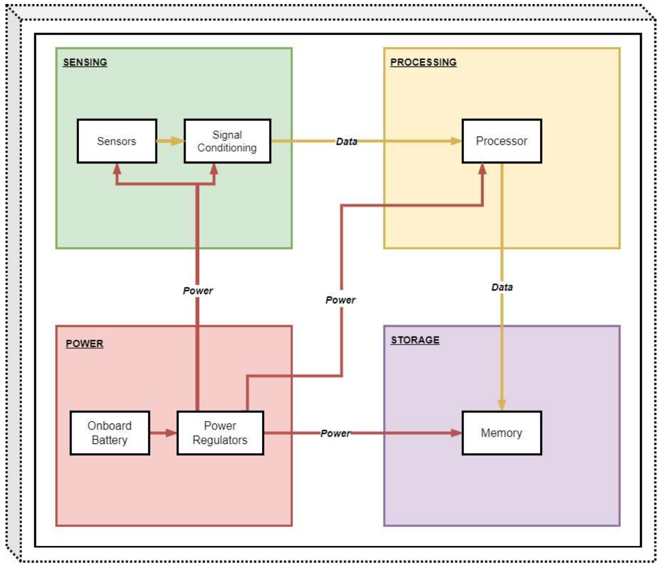

Figure 3: High-Level Subsystem Overview

9 Team Skills and Interests

Table 3: Team Skills

Team Members	**Critical Project Elements**
Olivia Epstein	CPE1, CPE2, CPE3, CPE4, CPE5, CPE6
Céu Gómez-Faulk	CPE1, CPE2, CPE5, CPE6
Victoria Lopez	CPE1, CPE3, CPE4, CPE5
Matthew J. Pabin	CPE1, CPE4, CPE5
Tristan Workman	CPE1, CPE4, CPE5, CPE6
Anabel de Montebello	CPE1, CPE2, CPE4, CPE5
Alexander Bergemann	CPE1, CPE3, CPE4, CPE5
Gerardo Romero	CPE1, CPE2, CPE5
Madison Ritsch	CPE1, CPE2, CPE5, CPE6

10 Resources

Table 4: Resources

ID	Critical Project Elements	Resource & Source
CPE1	Sensing Hardware	PCB Fabrication - Electronics Shop
CPE2	Data Collection & Analysis	Mentorship - Dr. Melvin Rafi
CPE3	Power Source	Battery and Safety Considerations - Electronics Shop
CPE4	Survivability	Test Engineering Mentorship - Erik Knudsen
CPE5	Testing/Validation	Mentorship - Erik Knudsen
CPE6	Budget	Finance Professionals - Jacquelyn Stang & Kayla Vandegrift

References

[1] NASA Astrophysics Div., (2021, August 12), "Exoplanet Program: Starshade Technology Development.", NASA https://exoplanets.nasa.gov/exep/technology/starshade/.

[2] Sauder, Jonathan F.,(2019, January 7), "Deployment Mechanisms for High Packing Efficiency OneMeter Reflectarray Antenna (Omera)." NASA, NASA Jet Propulsion Lab, https://trs.jpl.nasa.gov/handle/2014/48369.

[3] Dharmadasa, B., University of Colorado Boulder, Mejia-Ariza, J. M., NASA Jet Propulsion Laboratory, Arya, M., Sauder, J. F., Focardi, P., Bradford, S. C., Jimenez, F. L. (2021, December 29). "Design of Flexures for Deployable Reflectarrays using High Strain Composites". AIAA SciTech Forum. Retrieved September 10, 2022, from https://arc.aiaa.org/doi/abs/10.2514/6.2022-0651

[4] H. Mallikarachch, S. Pellegrino, S., Adams, S. and Mobrem M., Seffen K., Walker, Aglietti G., Lysmer J. and Kuhlemeyer R., Jin, Augello, R., Mansourinejad, H. (2014, April 3). "Deployment Dynamics of Ultrathin Composite Booms with Tape-Spring Hinges". Journal of Spacecraft and Rockets, https://arc.aiaa.org/doi/10.2514/1.A32401