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Knowledge Engineering Visionaires in Neutron Star based Astronomical Content Observation in the Night Sky (Kevin Bacon)

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Knowledge Engineering Visionaries in Neutron Star based Astronomical Content Observation in the Night sky (KEVIN BACON)

by

Ian Cristobal Rowatt

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Honors Capstone Project Director: Dr. Kannan

Ian Rowatt 5/2/2024

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Sampson Gholston Digitally signed by Sampson Gholston Date: 2024.05.03 21:59:35 -05'00'

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Sean Lane Digitally signed by Sean Lane Date: 2024.05.05 14:16:18 -05'00'

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Date

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1.0 Abstract

Small satellites, often limited by size and resources, serve as formidable tools for space-based scientific studies. The Alabama CubeSat Initiative (ACSI), a prominent intercollegiate satellite program, employs the Orbital Detectors Investigating Neutron Stars and Engaging Young Engineers (ODINS-EYE) mission to measure Magnetar Giant Flares (MGF) from neutron stars. This student collaboration payload is on NASA's MoonBEAM spacecraft. MGFs are vital for studying energetic jet formation, but their measurement is challenging due to prior gamma-ray detector oversaturation. ACSI addresses this by developing an MGF detector using Model-Based Systems Engineering (MBSE) principles in ODINS-EYE's development, with SysML as the primary tool. SysML facilitates the integration of physical and functional aspects, offering a unified understanding of the mission across a diverse engineering workforce. This approach empowers researchers and engineers to efficiently refine designs and holds the potential to advance comprehension of cosmic objects. ACSI's use of MBSE and SysML goes beyond the constraints of small satellite missions, pushing the boundaries of space-based scientific exploration and transforming the astrophysics community's understanding of neutron stars. UAH’s undergraduate team, Knowledge Engineering Visionaries in Neutron Star based Astronomical Content Observation in the Night sky (KEVIN BACON), uses the previously aforementioned tools such as MBSE and SysML as well as Dassault Systems 3DExperience virtual environment to address the mission. Digital Engineering and ontologically defined architecture framework allow this team to effectively communicate and connect with NASA and other ACSI teams. The goal is to use these Systems Engineering tools to reduce risk of errors in system architecture, design, requirements, verification, and reliability during small satellite missions.

2.0 Program Overview

ACSI (Alabama CubeSat Initiative)

The Alabama CubeSat Initiative (ACSI) is a program focused on developing the workforce by teaching in spacecraft and systems engineering to both undergraduate and graduate students across the state of Alabama. It stands as the world's largest collegiate satellite program. ACSI is centered around two key projects: the Alabama Burst Energetics eXplorer (ABEX) and a suite of spacecraft buses, excluding the payload, known as the Space Transporter by Alabama CubeSat Initiative (Space TACSI). ABEX serves as an astrophysics payload aimed at investigating energy dissipation in astrophysical jets by exploring a gamma-ray burst energy domain that remains uncharted. Meanwhile, the Space TACSI bus family offers opportunities for hosting commercial, educational, and scientific payloads.

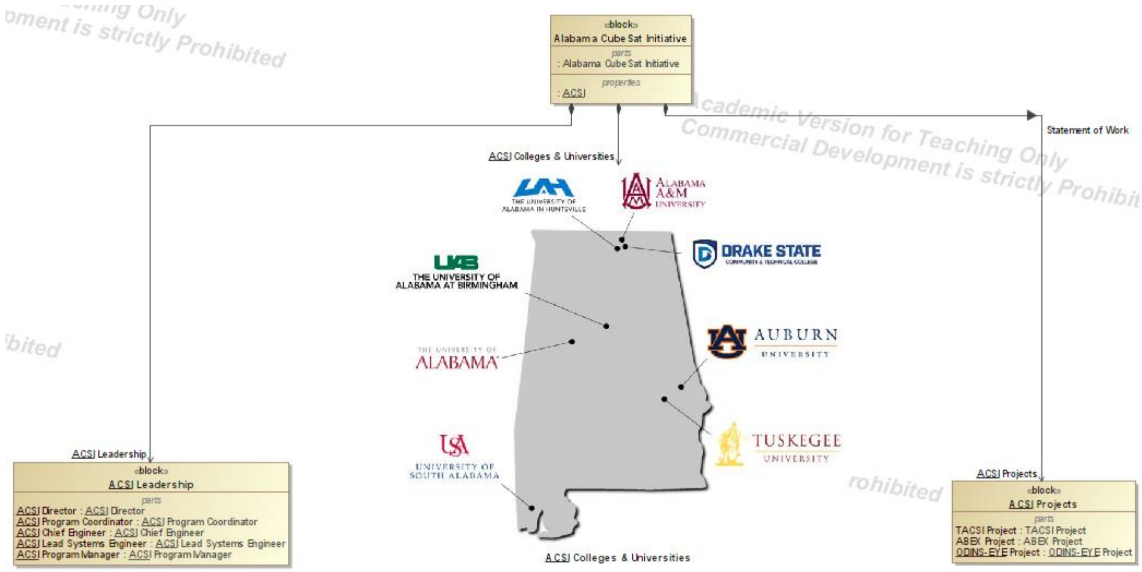

Figure 1: ACSI Breakdown

2. 1 Project Overview

The ODINS-EYE SC, a student-led instrument, is proposed to accompany the SmallSat MoonBEAM mission, dedicated to studying GRBs and other gamma-ray transients. ODINS-EYE focuses on observing galactic MGFs, which are exceptionally luminous phenomena that can oversaturate conventional gamma-ray detectors. Since both GRBs and MGFs are detected through passive monitoring instruments, the operational concept of MoonBEAM aligns perfectly with an instrument targeting MGFs.

Supported by the Alabama CubeSat Initiative (ACSI), the world's largest collegiate satellite program, and partially funded by the Alabama Space Grant Consortium, this SC benefits from extensive educational resources developed by ACSI. These resources cover the spectrum of space system architecture, design, verification, integration, and management, providing a robust framework for partner institutions to undertake space hardware projects in line with NASA's educational and representation objectives.

Student leaders from AAMU and JFDS are responsible for designing, architecting, analyzing, and testing the instrument, elevating its Technology Readiness Level (TRL) to 6 before its integration with MoonBEAM. The ACSI, through the CSIL at The UAH, offers management and systems engineering expertise, resources, and support. Additionally, the ACSI leverages a network of Subject Matter Experts (SMEs) from prior projects at the Jet Propulsion Lab and NASA's MSFC, ARC, and GSFC, who provide mentorship and guidance across all project phases, enhancing student engagement and educational outcomes. Scientists from the primary MoonBEAM instrument team also offer guidance on instrument design, scientific requirements, and data interpretation. With ODINS-EYE, student leaders from historically underrepresented groups have the opportunity to be pioneers in fully characterizing MGFs.

This Senior Design Team, known as KEVINBACON and hosted by UAH's CSIL, operates as a combined Systems Engineering and Project Management Team, utilizing Digital Engineering tools such as Magic System of Systems Architect (formerly Cameo) and Dassault Systemes 3D Experience to execute the project effectively.

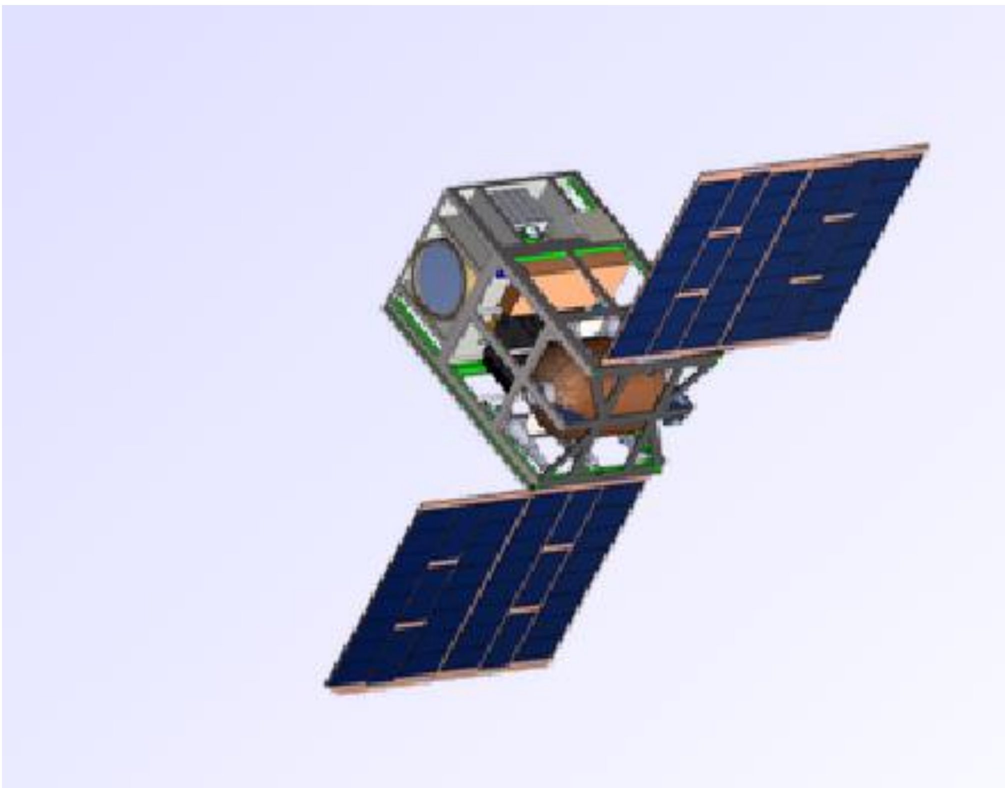

Figure 2: MoonBEAM

2. 2 Team Info

Team Kevin Bacon consists of four undergraduate engineers working on their senior design project. The members of this project and their area of expertise include:

Table 1. Team Members

Cameron Bentley	Industrial and Systems Engineering
Sean Hunter	Mechanical Engineering
Ryan O’Neil	Industrial and Systems Engineering
Ian Rowatt	Aerospace Engineering

The roles for the team members for Fall 2023 are detailed below:

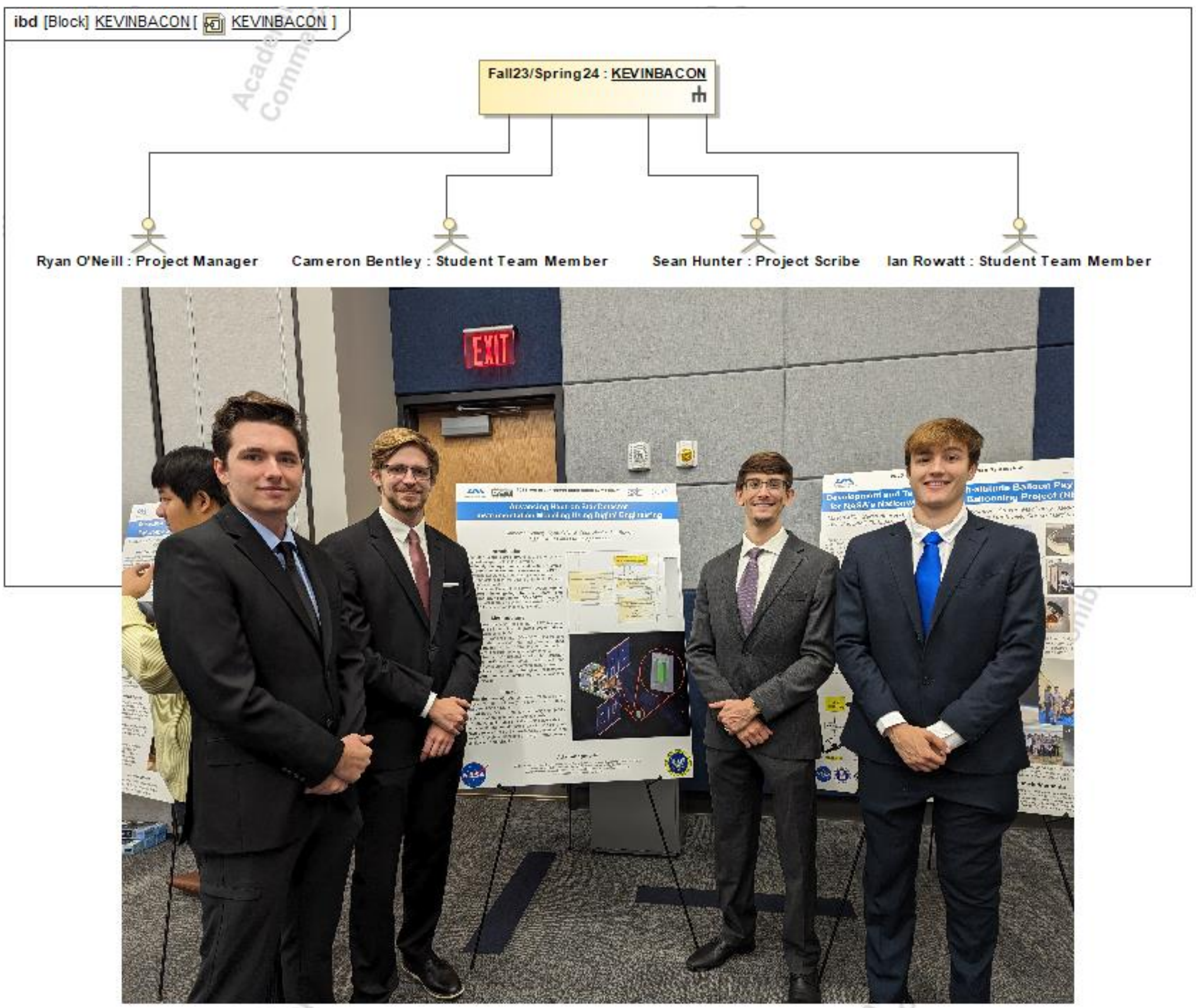

Figure 3. Team Info

2.3 Organizational Breakdown Structure

The OBS (Organizational Breakdown Structure) below, created by chief engineer, Michael Halvorson, displays the responsibilities of the institutions in ACSI working on this project. This can be found in 7.0 Appendix Figure A1.

2.4 Schedule

This ACSI project is intended to be a multi-year plan in which this year's undergraduate team will be passing it off. The schedule below charts the next course of action. The Gantt chart was created using the project management tools in 3DExperience. 3DExperience by Dassault Systèmes is a comprehensive platform for businesses, offering tools and applications for product design, collaboration, and project management across various industries. It enables teams to create 3D models, simulate product behavior, and optimize designs before production. With features for data management and lifecycle control, it ensures the integrity and accessibility of product data throughout its lifecycle. Additionally, it supports manufacturing planning, supply chain management, and customer experience initiatives to enhance efficiency and competitiveness.

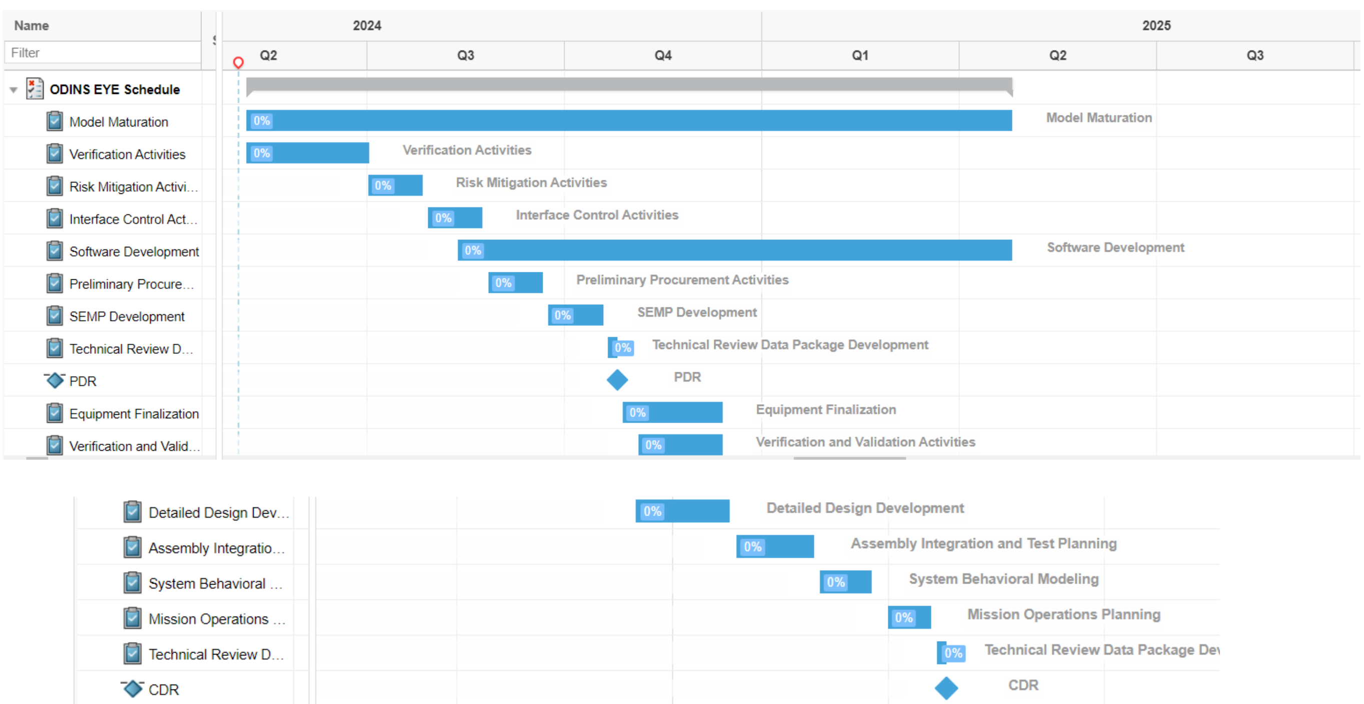

Figure 4. Schedule

3.0 Applicable Documents

NASA 7123.1D Appendix G
MSP_SC_Proposal
2021 SPA RUG with DNH
Student Mission Directorate Policy
MoonBEAM Key Milestones/Phase Durations
MoonBEAM Student Collaboration Concept
MIL-STD-961d

4.0 Objectives and Methodology

The main objective of UAH's undergraduate team, Knowledge Engineering Visionaries in Neutron Star based Astronomical Content Observation in the Night sky (KEVIN BACON), is to complete a model-based review to complete a Preliminary Design Review (PDR) based on NASA's entrance and success criteria found in NASA 7123.1D Appendix G.

4.1 Integrated System Model

The ISM organizes the ODINS-EYE facilitates a unified understanding of the entire mission architecture across a multidisciplinary engineering workforce and has been developed with the use of SysML(Systems Modeling Language).

4.2 MBSE (Model-Based Systems Engineering)

Model-Based Systems Engineering (MBSE) revolutionizes the way engineers approach complex system development by placing models at the forefront of the whole development process. Gone are the days of solely relying on fragmented documents and disparate tools to capture system requirements and designs. MBSE introduces a cohesive methodology where integrated models serve as the primary artifacts, offering a unified representation of the system. This shift streamlines communication and collaboration among multidisciplinary teams, breaking down silos and fostering a holistic understanding of the system under development.

One of the core issues MBSE tackles is the inherent complexity of modern engineering projects like ODINS-EYE. As systems grow increasingly intricate, traditional approaches struggle to manage the many interdependencies across hardware, software, and human elements. MBSE steps in to address this challenge by providing system knowledge within explicit models. These models not only capture the system's structure but also its behavior, requirements, and constraints. By leveraging computational analysis on these models, engineers can spot inconsistencies, are able to identify potential issues early on, and explore alternative design options efficiently. This proactive approach leads to better decision-making, reduced risk of errors, and faster time to market for products and systems.

SysML, a specialized extension of the Unified Modeling Language (UML), stands as a vital component within the MBSE framework. Tailored specifically for systems engineering, SysML offers a robust set of constructs and diagrams to comprehensively model complex systems. It allows engineers to represent system architectures, requirements, behavior, and parametric relationships in a standardized manner. With SysML's versatility, it finds applications from various domains, including aerospace, automotive, defense, and telecommunications. Embracing SysML within MBSE empowers organizations to harness its capabilities to face the challenges of developing sophisticated systems in today's fast-paced, technology-driven landscape. As we delve deeper into SysML, we unlock the potential to create precise, unambiguous models that serve as the blueprint for realizing innovative and reliable systems.

4.3 Concept of Operations

In systems engineering, a Concept of Operations outlines how a system is intended to operate from the perspective of its users and operators. The activity diagram below reveals the use cases of ODINS-EYE which will be discussed later as well as a chain to help display a chain of operation. The diagram also reveals how the satellite and ODINS-EYE will be integrated with each other.

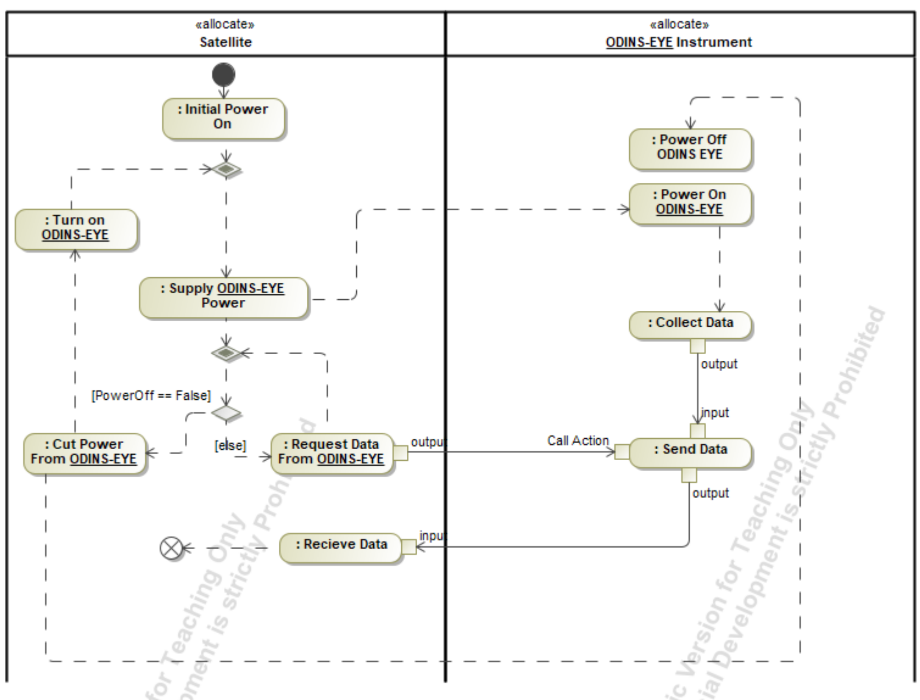

Figure 5. Concept of Operation

5.0 ODINS-EYE

Magnetar Giant Flares are some of the brightest energy bursts in the universe. Deployed sensors in the past have become oversaturated by MGFs which has prevented comprehensive studying and research of the cosmic mystery. The figure below lays out a model which displays how ODINS-EYE is integrated with the MoonBEAM spacecraft (where OE denotes ODINS-EYE).

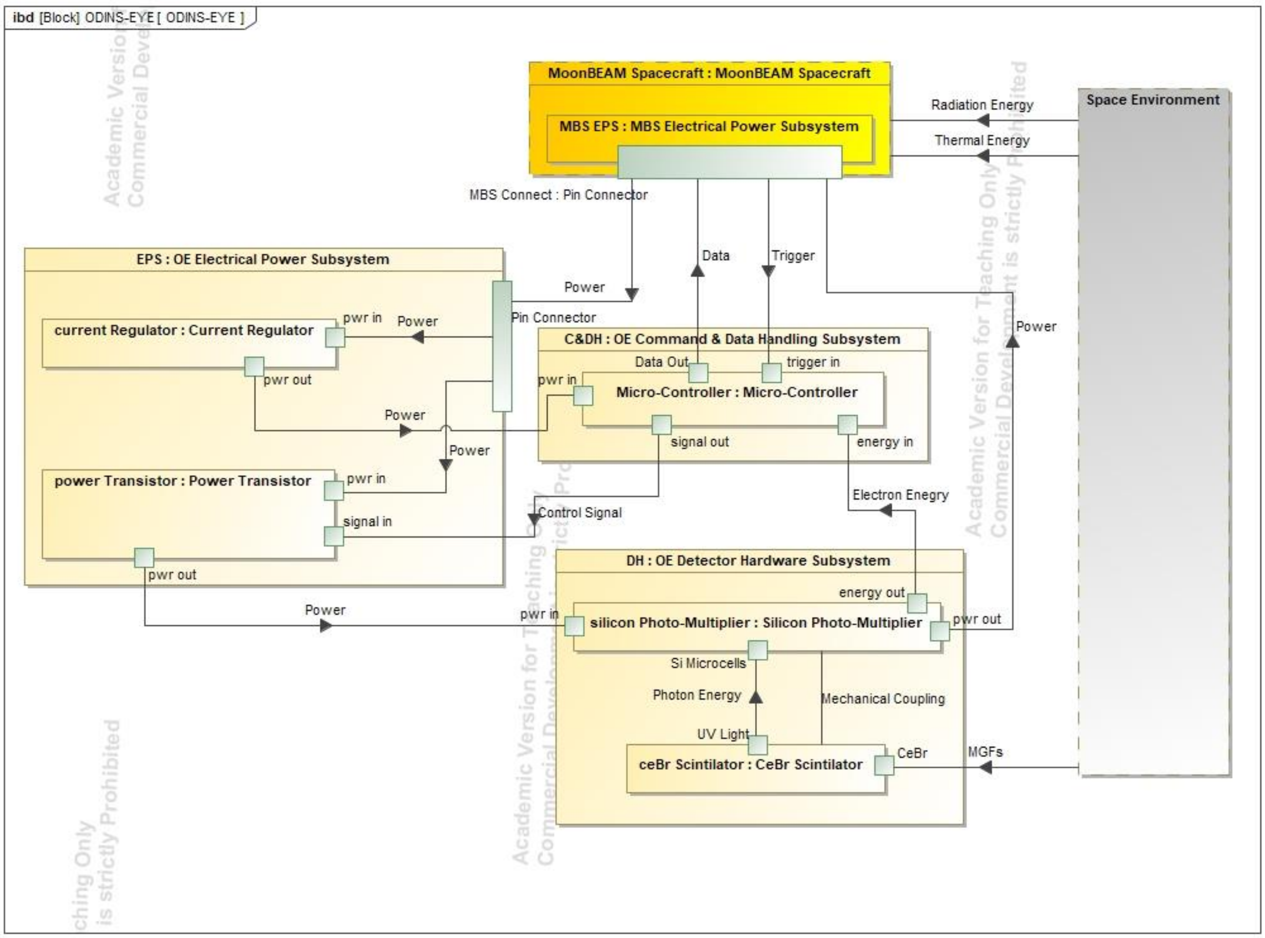

Figure 6. ODINS-EYE

5.1 System Requirements

In Systems Engineering, requirements are used to describe capabilities, characteristics, and constraints that a complex system must satisfy to fulfill Stakeholder's needs and to fulfill the intended purpose of the system. The stakeholders involved in this project will be discussed later. The syntax used to develop the requirements was created by chief engineer, Michael Halvorson, as a part of his doctoral research on creation of Requirements through an Architectural framework. The goal of the syntax is to create a machine-readable code that can be replicated, automated, or understood by a computer.

For functional requirements the syntax follows: *The system element shall function*. The syntax begins with a definite article followed by a descriptive name or system element. The shall represents a modal auxiliary verb. The function aspect of the syntax can be broken down into two parts: a bare infinitive and a descriptive noun. An example of a functional requirement used in this project is: *The ODINS-EYE instrument shall observe Magnetar Giant Flares*.

For capability requirements, the syntax follows: *The /system element/ shall /function/ relational operator/ level of performance.* The syntax begins with a definite article followed by a descriptive name or system element. The shall represents a modal auxiliary verb. The function aspect of the syntax can be broken down into two parts: a bare infinitive and a descriptive noun. A relational operator which in this case is a function to a level of performance that represents a stakeholders' needs. An example of a capability requirement used in this project is *The ODINS-EYE detector shall detect gamma-ray photon energy less than or equal to 1000 keV.*

For interface requirements, the syntax follows: *The /system element/ shall/ function.* An interface requirement includes 2 system elements, a supplier and a client. An example of an interface requirement is: *The ODINS-EYE Command and Data Handling Subsystem shall maintain reference distance exactly equal to TBD22 mm plus or minus 0.001mm through the command and data Handling Physical Interface connecting the command and data Handling Subsystem and the PCB.*

For constraint requirements, the syntax follows: *The /system element/ shall /function/ relational operator/ constraint.* The syntax begins with a definite article followed by a descriptive name or system element. The shall represents a modal auxiliary verb. The function aspect of the syntax can be broken down into two parts: a bare infinitive and a descriptive noun. A relational operator which in this case is a function to a level of performance that represents a stakeholders' needs. The constraint aspect usually sets the boundaries about characteristics of a system element or instrument such as mass, size, etc. An example of a constrain requirements is: *The ODINS-EYE instrument mass shall be less than 0.3 kg.*

In this project, there were requirements for the ODINS-EYE detector, ODINS-EYE PCB, ODINS-EYE Command and Data Handling system, ODINS-EYE detector hardware, ODINS-EYE Electrical Power System, ODINS-EYE Chassis, and for ODINS-EYE structural integrity.

5. 2 Logical Decomposition

The scope of ODINS-EYE includes the ODINS-EYE Instrument, ODINS-EYE Enabling Systems, ODINS-EYE Enterprise System, and the ODINS-EYE environment.

5.2.1 Enabling Systems

The enabling systems of ODINS-EYE consists of the MoonBEAM Spacecraft and the satellite which are not directly a part of the instrument; however, are required for ODINS-EYE to function. The figure below signifies that ODINS-EYE must be integrated with the components of MoonBEAM: Electrical Power Subsystem, Thermal Subsystem, Telemetry, Tracking, and Command Subsystem, Guidance Navigation and Control Subsystem, Structural Integrity, Mechanisms, and Flight Software.

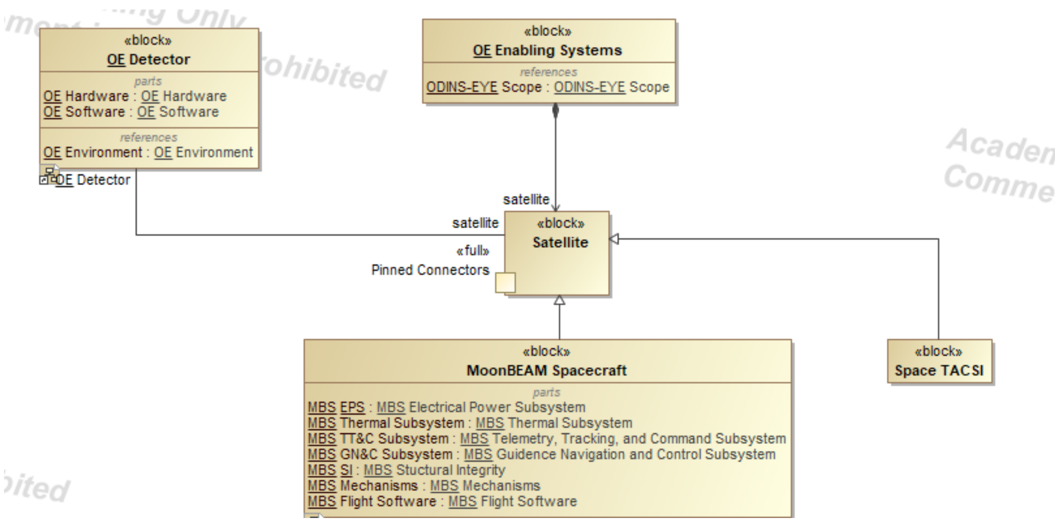

Figure 7. Enabling Systems

5.2.2 Enterprise System

The enterprise system in the context of ODINS-EYE refers to a comprehensive framework that encompasses various interconnected components, processes, and stakeholders.

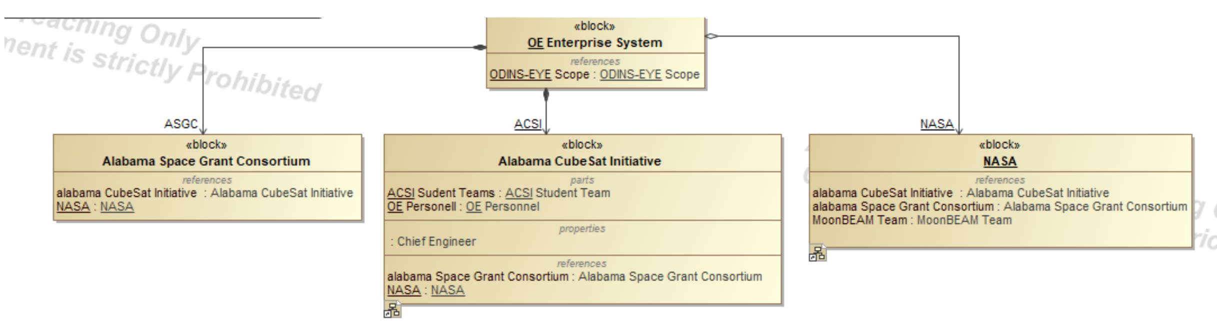

Figure 8. Enterprise System

5.2.2.1 Stakeholders

The stakeholders in this project are divided into two separate categories: Stakeholder involvement and Stakeholder Type. The stakeholders' involvement is either Internal or External. The stakeholders' type is either Active, Passive, and Sponsor.

5.2.2.1.1 Active Internal Stakeholder

An active internal stakeholder is an individual or group within an organization who has a direct and significant interest in its operations, decisions, and outcomes, and actively engages with and influences the organization's activities. The active internal Stakeholders in this project are:

- Alabama CubeSat Initiative
- The University of Alabama in Huntsville
- Alabama A&M University
- J.F. Drake State Community and Technical College
- CSIL

5.2.2.1.2 Passive External Stakeholder

A passive external stakeholder is an entity or party outside of an organization, such as customers, suppliers, or the general public, who possesses an interest in the organization's actions or performance but does not actively engage or influence its operations or policies. The passive external stakeholders in this project are:

- Vendors (unknown)
- NASA Headquarters
- NASA Marshall
- Alabama Space Grant Consortium

5.2.2.1.3 External Sponsor

An external sponsor, on the other hand, is typically a party outside the organization, such as a partner, investor, or benefactor, who provides financial or other forms of support for a project or event. The external sponsors in this project are:

- NASA Marshall
- NASA Headquarters
- Dassault Systems
- Alabama Space Grant Consortium

5.2.2.1.4 Active External Stakeholder

An active external stakeholder is a person, organization, or entity outside of the organization that has a vested interest in its actions, performance, or success, and takes proactive steps to interact with and impact the organization's objectives or policies. The active external stakeholders in this project are:

- Subject Matter Experts

5.2.2.1.5 Passive Internal Stakeholder

A passive internal stakeholder is an individual or group within an organization who has a vested interest in its activities but takes a relatively passive or uninvolved role, often not actively participating in decision-making or operations. There are no passive internal stakeholders in this project.

5.2.2.1.6 Internal Sponsor

An internal sponsor is an individual or group within an organization who advocates for and supports a project or initiative from within the company, often providing resources and guidance. There are no internal sponsors for this project.

5.2.3 ODINS-EYE Environment

The ODINS-EYE environment consists of the following environments: Development Environment, Space Environment, and Transportation Environment. The environment must be considered while completing a risk assessment. The Development Environment is the stage at which testing, and the assembly of ODINS-EYE occurs. The Space Environment is the atmosphere and location in which the instrument will collect data. Lagrange point refers to a point of equilibrium in which an object like MoonBEAM with a controlled mass, is under the gravitational influence of two massive orbiting bodies. L3 is a Lagrange point on the opposite side of the Earth to the moon. The Transportation Environment details all of the vehicles or systems that will carry ODINS-EYE.

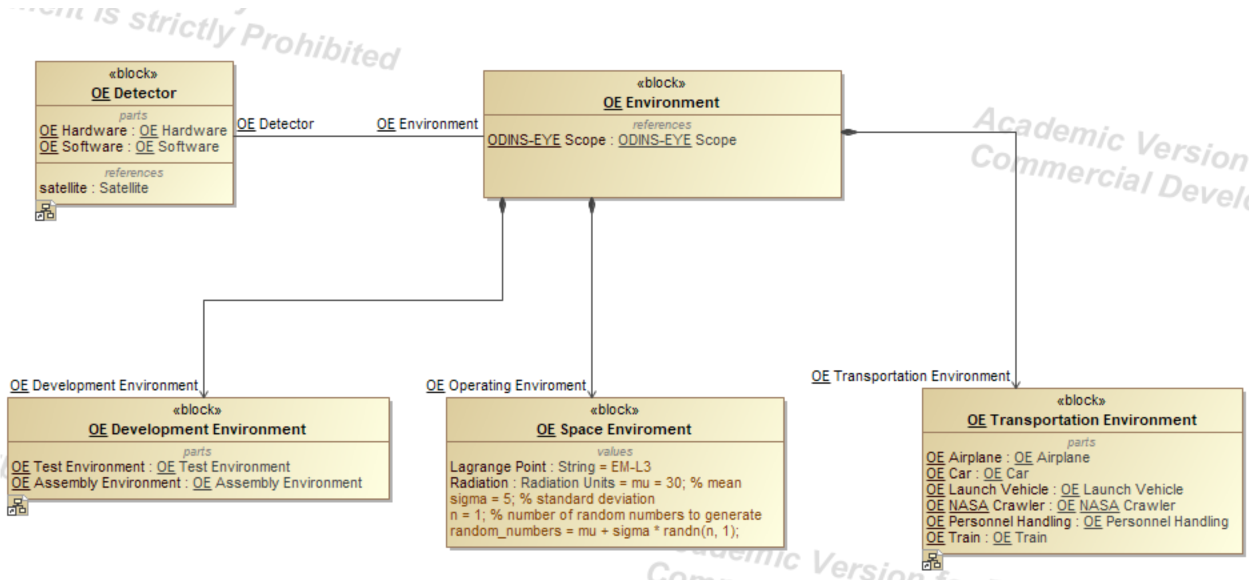

Figure 9. ODINS-EYE Environment

5.2.4 ODINS-EYE Instrument

Two ODINS-EYE detectors, each one supported by a detector assembly, are placed on opposite sides of MoonBEAM. A detector is comprised of a $1mm^3$ CeBr scintillator coupled to a Silicon Photomultiplier with a 2 mm thick aluminum housing to attenuate low-energy gamma rays. The reasoning behind selecting CeBr is due to its quick 20 ns scintillation pulse time which is fast enough to detect MGF photons. When ODINS-EYE gets a trigger signal from the primary MoonBEAM device, it saves the detected photon rate as a 20 µs histogram in its memory, starting from 1 second before the trigger and lasting 3 seconds after. This process allows ODINS-EYE to generate a detailed gamma-ray lightcurve for the intense pulse of a Magnetar Giant Flare (MGF), with enough temporal precision to discern the pulse rise time, as observed at 70 µs for a single MGF. The design of the SC instrument and MoonBEAM interface is part of MoonBEAM Phase B development. The operational modes that the instrument has includes off, data collection, and data response.

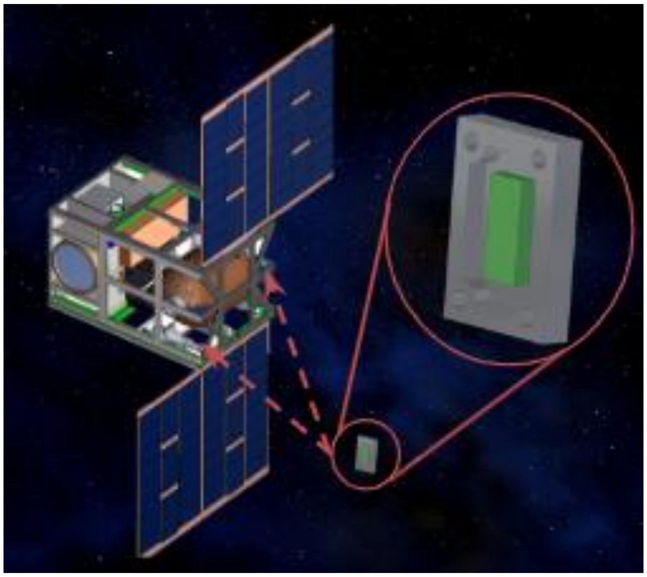

Figure 10. ODINS-EYE instrument

5.3 Functional Decomposition

5.3.1 Functions and Capabilities

Behaviors are derived from functions and capabilities (shown in Appendix). There are four main types of behavior diagrams: Use Case diagrams, Activity Diagrams, Sequence Diagrams, and State Machine Diagrams. In this portion of the project, we will be looking at Use Cases.

5.3.2 Use Cases

Use cases are a description of how a system or product is intended to be used, outlining specific interactions and scenarios to achieve certain goals or functions. A use case diagram is meant to show communications between a high-level capability with the external user. The use cases below describes the top-level capabilities. The use cases in this project consists of interactions between the ACSI Structural Integrity and ACSI Software team with the ODINS-EYE instrument. The use cases in this project also include interactions between the host satellite and the ODINS-EYE instrument and are detailed below.

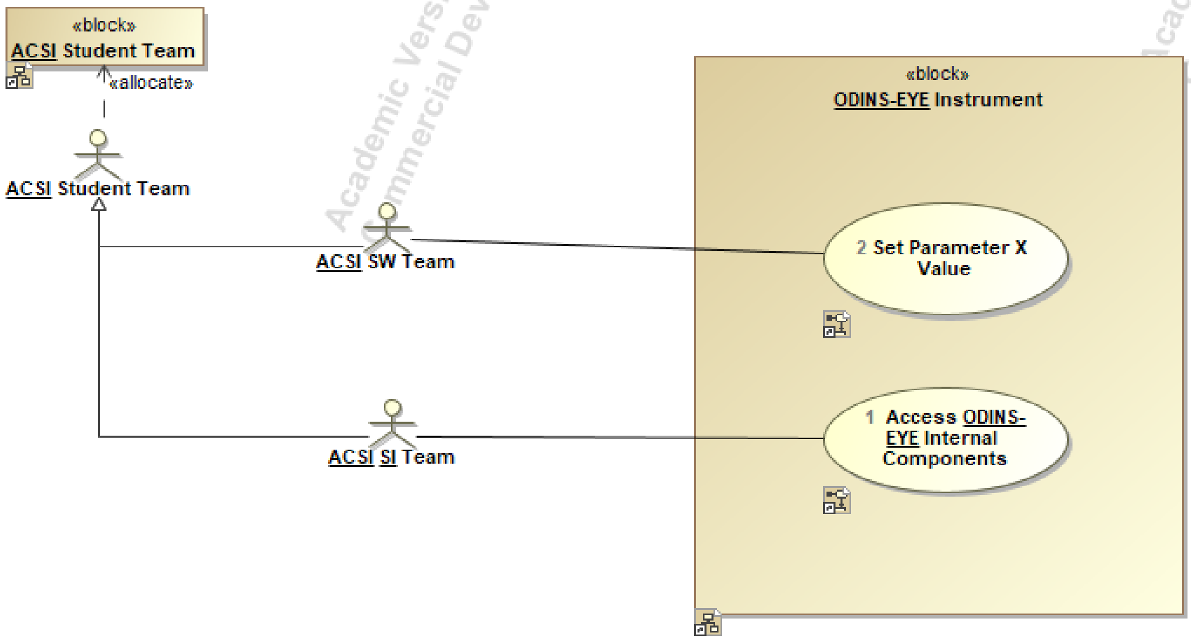

Figure 11. ACSI Use Cases

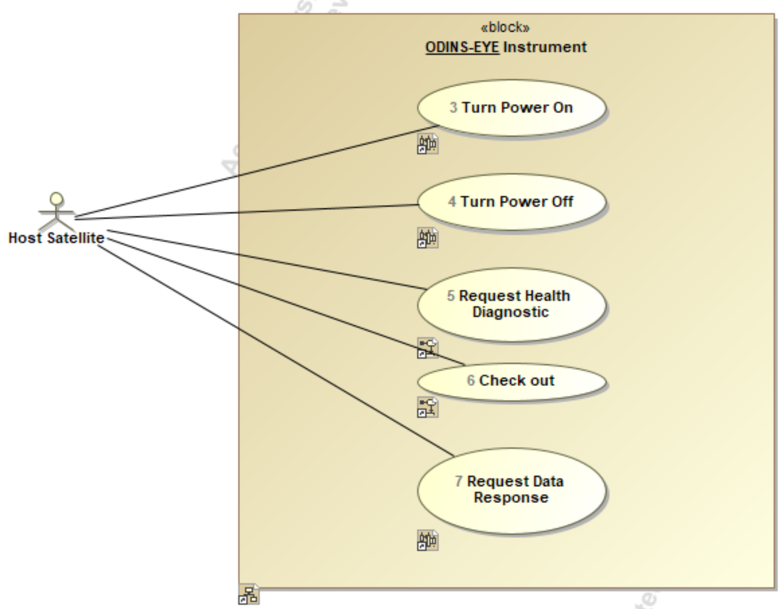

Figure 12. Host Satellite Use Cases

5.4 Verification

The Technical Performance Parameters (TPPs) in this project dealt with the mass of ODINS-EYE, the time frame in which data was collected, photon flux, and the power the instrument required. While the scope of this project did not include the actual hardware or any type of design analysis, an example of a TPP that was looked at was the projected change of mass over the span of the different design reviews was looked at. The figure below shows how the projected mass of the instrument will decline.

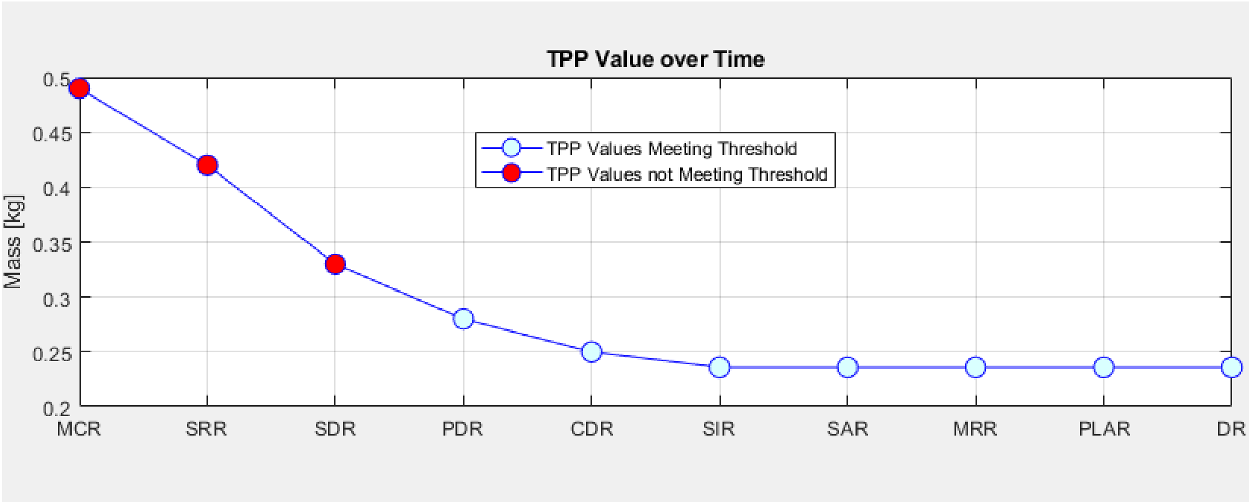

Figure 13. Technical Performance Parameters (Mass)

5.5 Risks

Many of the risks associated with the project regarding MoonBEAM were **Do No Harm** to the MoonBEAM satellite. Regarding the development of this ACSI project, a few of the concerns that did arise were that it was a comprehensive multi-year plan which makes it difficult to adapt to a senior design course and curriculum. There were 83 total risks that were assessed and graded on a scale between the likelihood that ODINS-EYE was going to face one of these risks and the consequences that the risk would cause. To objectively quantify the consequence on a scale of 1-5, the average of safety, performance, regulations, cost, and scheduling conflicts was found. A Risk criticality matrix was created to help assess and visualize the risks that required the strongest mitigation strategies. For example, Risk ID 5 was "Given that communication and interfacing challenges are present when integrating different cultures across a geographically dispersed team, there is a possibility of communication issues adversely impacting overall project efficiency, which can result in failure to stay on schedule." This risk discussed the importance of effective communication with a plethora of teams throughout Alabama. The mitigation technique to prevent this issue was as follows "3DExperience offers a unique, potentially groundbreaking project management environment to allow the integration of multiple teams in an efficient manner.

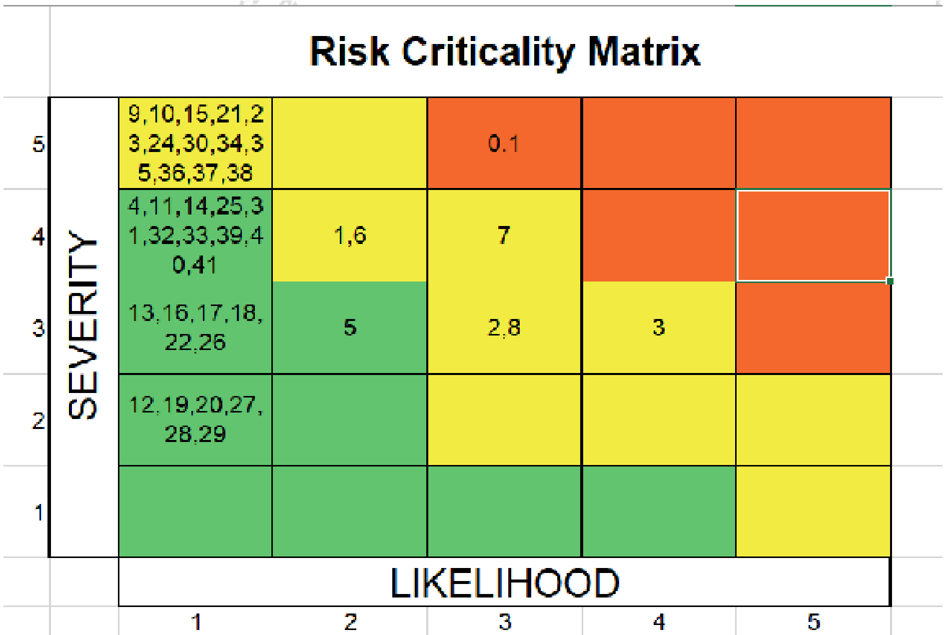

Figure 14. Risk Criticality Matrix

6.0 Conclusion and Results

The KEVIN BACON faced several setbacks that eventually led to the impediment of progress and their ability to complete the projects. Obstacles include licensing complications with SysML, having to change launch system/satellite for ODINS-EYE, and being constrained by the capabilities of their sociotechnical tools. The MoonBEAM project, the satellite in which the ODINS-EYE instrument(s) was to be placed on, was not selected by NASA due to financial constraints. The undergraduate team had to ultimately alter their launch system and schedule. Incorporating another ACSI project developed by chief engineer, Michael Halvorson, Space TACSI (Space Transporter by Alabama CubeSat Initiative, enabled KEVIN BACON to continue the work of their senior design project. However, many of the work products as well as the model were based on the integration of ODINS-EYE with MoonBEAM which led to complications that had to be discoursed and resolved. Even though NASA's MoonBEAM project was not selected, future possibilities and uncertainties caused the undergraduate team to navigate ODINS-EYE towards an instrument that could be integrated onto a variety of different launch systems or space missions as a secondary payload. Of those launch systems, Artemis 3, remains the most promising; however, team KEVIN BACON awaits the release of secondary payload solicitations for the mission.

The main way that KEVIN BACON was constrained by the capabilities of their sociotechnical tools was through the limitations of their knowledge and experience. The design for ODINS-EYE is complex and its function to study Magnetar Giant Flares exceeds the current skill level of the undergraduate team. This has also led to areas of underdevelopment and slow progress on the project.

Although not all work products were not completed in the maturation status required for a PDR (Preliminary Design Review), the KEVIN BACON team made considerable progress. Areas that need work for progress in this project are verification and risk mitigation. While initial attempts were made for verification, the project requires complex verification techniques that were above the experience level of the undergraduates on KEVIN BACON. Of those more sophisticated techniques include better ways to assess Technical Performance Parameters. The goal is to accurately display or communicate the development, design, and integration of these parameters. An accurate projection of each projection for each design review will allow teams to plan accordingly. There were also initial attempts to create a comprehensive list of risks and a risk criticality matrix associated with ODINS-EYE; however, more iterations are required to be able to accurately assess and mitigate risks. Techniques that can precisely measure the likelihood and criticality of a risk are of extreme importance. Having a more defined, accessible tool where grades for criticality and likelihood can be derived from will allow the Risk criticality matrix to correctly display the most consequential risks and permit cohort among the plethora of teams involved. More specific risks and mitigation strategies should be employed to help inform teams what the desired solution to a risk is. Having a risk that points out an inherent risk of a specific subsystem with details would also enable a definite, extensive mitigation strategy to be written.

7.0 Appendix

ODINS-EYE Organizational Breakdown Structure						
		Document Classification:	*Public*			
		Distribution Type:	*Unlimited*			
		Revision:	*1.2*			
		Updated:	*8/29/2023*			
		Point of Contact(s) for a team are marked in green.				
OBS ID	**Acronym**	**Name**	**Personnel Name / POC**	**Institution / Affiliation**	**Acronym**	**Email**
1	STRUCT	**Structural Integrity**				
1.1	Co-I	Co-Investigator		*Alabama A&M University*	AAMU	
1.2	Co-I	Co-Investigator		*Alabama A&M University*	AAMU	
1.3		Undergraduate Team Manager		*Alabama A&M University*	AAMU	
1.4		Undergraduate Team Scribe		*Alabama A&M University*	AAMU	
2	DH	Device Hardware				
2.1	PI	Principal Investigator	P. Veres	*Drake State Community and Technical Colleg*	JFDS	
2.3		Undergraduate Team Manager		*Drake State Community and Technical Colleg*	JFDS	
2.4		Undergraduate Team Scribe		*Drake State Community and Technical Colleg*	JFDS	
3	C&DH	**Command & Data Handling**				
3.1	Co-I	Co-Investigator	R. Yaqub	*Alabama A&M University*	AAMU	
3.2	Co-I	Co-Investigator	A. Scott	*Alabama A&M University*	AMMU	
3.3		Undergraduate Team Manager		*Alabama A&M University*	AAMU	
3.4		Undergraduate Team Scribe		*Alabama A&M University*	AAMU	
4	EPS	**Electrical Power System**				
4.1	Co-I	Co-Investigator	R. Yaqub	*Alabama A&M University*	AAMU	
4.2	Co-I	Co-Investigator	A. Scott	*Alabama A&M University*	AAMU	
4.3		Undergraduate Team Manager		*Alabama A&M University*	AAMU	
4.4		Undergraduate Team Scribe		Alabama A&M University	AAMU	
5	SW	**Software**				
5.1	Co-I	Co-Investigator	X. Zhao	*Alabama A&M University*	AAMU	
5.3		Undergraduate Team Manager		*Alabama A&M University*	AAMU	
5.4		Undergraduate Team Scribe		*Alabama A&M University*	AAMU	
6	SCI	**Science**				
6.1	Co-I	Co-Investigator	M. Briggs	*University of Alabama in Huntsville*	UAH	
6.2		Chief Scientist		*University of Alabama in Huntsville*	UAH	
7	MGT	**Project Management**				
7.1	PI	Principal Investigator	P. Veres	*University of Alabama in Huntsville*	UAH	
7.2	PM	Project Manager	Cameron Bentley	*University of Alabama in Huntsville*	UAH	cdb0055@uah.edu
7.3	PM	Project Scribe	Ian Rowatt	*University of Alabama in Huntsville*	UAH	icr0004@uah.edu
7.4	CE	Acting Chief Engineer	Michael Halvorson	*University of Alabama in Huntsville*	UAH	mch0043@uah.edu
8	SE	**System Engineering**				
8.1	PI	Principal Investigator	Dr. Dale Thomas	*University of Alabama in Huntsville*	UAH	dale.thomas@uah.edu
8.2	LSE	Lead System Engineer		*University of Alabama in Huntsville*	UAH	
9	AI&T	**Assembly, Integration, & Test**				
9.1	Co-I	Co-Investigator	M. Kingsburry	*Drake State Community and Technical Colleg*	JFDS	
9.2	Co-I	Co-Investigator	T. Clark	*Drake State Community and Technical Colleg*	JFDS	
9.3	AFT	**Assembly Facility Team**		*Drake State Community and Technical Colleg*	JFDS	
10	SME	**Subject Matter Experts**				
11	VEND	**Vendors**				
12	SP	**Service Providers**				

Figure A1. Organizational Breakdown Structure

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8.0 Acknowledgments

Table 2. Acknowledgments

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Professor	Dr. L. Dale Thomas
Chief Engineer	Michael Halvorson
Team Member (Lead Systems Engineer)	Cameron Bentley
Team Member	Sean Hunter
Team Member	Ryan O'Neil
Team Member	Ian Rowatt
Other Consultants	Shreyas L Raghu

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