Announcement of Partnership Opportunity
CubeSat Launch Initiative

SHAMROCK

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SHAMROCK

Satellite High-gain Antenna Mission for Reliable and Optimized Communication in K-Band

CubeSat Project Details						
Focus Area(s)	NASA Funding		Sponsoring Organization(s)	Collaborating Organization(s)	
	Y/N?	Organization		List	International (Y/N?)
☑ Education ☐ Workforce Dev. ☐ Science ☑ Technology	No	N/A	Blue Origin, Boeing, General Electric Foundation	Cheshir Industries, Fortify	No

CubeSat Mission Parameters	**Value**	
CubeSat Mission Name	SHAMROCK	
Mass (kg)	3.5	
Cube Size (ex., 1U, 2U, 3U, 4U, 6U)	2U	
Rail/Tab Length (mm) (ex., 340.5 mm, 366 mm)	300	
Readiness Date for Integration to Dispenser	2028	
Desired Orbital Lifetime after Deployment (years)	0.5	
Designated Operational Lifetime (years)	0.5	
Is an ISS deployment acceptable (400 km @ 51.6 degree inclination)	Yes	
Is a Sun Synchronous Orbit (SSO) acceptable? Yes or No	Yes	
Sun Synchronous Orbit (SSO) required? Yes or No	No	
Is the proposed mission compliant with the limitations in Section 5.1, or is an exception requested for consideration?	Yes	
Orbital Parameters	**Desired/Preferred Range**	**Acceptable Range**
Altitude (km)	400	300-800
Inclination (degrees)	51.6	20-70
Mean Local Time of the Ascending Node (MLTAN) N/A is SSO is not acceptable.	N/A	N/A

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Abstract

SHAMROCK, the **S**atellite **H**igh-gain **A**ntenna **M**ission for **R**eliable and **O**ptimized **C**ommunication in **K**-Band, strives to demonstrate low-power, low-cost, high-throughput communications through the use of a novel switched beam lens (SBL) antenna architecture for small form factor satellites like CubeSats. This technology enables high-throughput K-band communication links between Earth and satellites with significantly reduced power consumption and cost compared to traditional phased array antenna (PAA) solutions. Instead of active PAA beamforming, the SHAMROCK's SBL antenna consumes <1% of the power of a PAA on transmit because of passive beamforming through a lens while offering the same high-directivity beamscanning capabilities.

IrishSat, the University of Notre Dame's undergraduate satellite and space systems engineering design team, is the primary organization responsible for undertaking the SHAMROCK mission. This educational initiative closely collaborates with Dr. Jonathan Chisum's research lab through the University's Electrical Engineering Department. This project offers undergraduate students practical experience in satellite design, development, testing, and operation to prepare the next generation of space engineers with the technical and experiential skills necessary to kickstart successful, confident careers.

The SHAMROCK mission aligns with the National Aeronautics and Space Administration's (NASA) Strategic Objectives 2.1, 2.2, 2.4, 3.1, 4.2, and 4.3 - advancing essential communication technology for NASA's exploration and space economy goals [1]. SHAMROCK's high-throughput, power-efficient K-band system demonstrates a potential solution for sustainable communication infrastructure in extended cis-lunar operations, supporting Objective 2.1, and a scalable, affordable solution for LEO that meets the growing demands for space-based communication, in line with Objective 2.2. By delivering a robust, high-data-rate system, SHAMROCK fulfills Objective 2.4, providing autonomous technology to aid both human and robotic missions. Due to reduced launch mass and cost, SHAMROCK contributes to Objective 3.1, promoting innovation and economic growth by making high-performance communication more accessible. By modernizing infrastructure with a compact, efficient design, SHAMROCK supports Objective 4.2, enhancing mission readiness and operational reliability. Finally, by engaging students in real-world space projects, SHAMROCK contributes to building the next generation of science, technology, engineering, and mathematics (STEM) leaders.

SHAMROCK's merit and feasibility were reviewed through internal IrishSat reviews and external reviews by experts from academia and industry. Results demonstrated that the SHAMROCK mission strongly aligns with NASA's goals and provides an invaluable educational and developmental experience for undergraduate students. Reviewers noted high confidence in IrishSat's capability to achieve the mission objectives and success. Reviewers highlighted the team's professionalism and systems-based engineering approach, where responsible engineers integrate complex subsystems effectively. The club's history of proven success and years of hands-on experience were cited as major strengths. The payload was recognized for its innovative approach to high-throughput, power-efficient communication on a small platform. The undergraduate-led team structure

was seen as a unique asset, fostering direct project ownership, fresh perspectives, and leadership development. Overall, the feedback affirms IrishSat's readiness to deliver an impactful mission that meets technical and educational objectives.

1 Mission

1.1 Mission Overview

The SHAMROCK mission, a University of Notre Dame collaboration between IrishSat and Dr. Chisum's Electrical Engineering Department research lab, seeks to demonstrate novel technology capable of revolutionizing satellite communications through successful operations proving the capabilities of SBL antennas in a compact 2U CubeSat platform. The innovative communication system payload designed for high-throughput K-band communication will offer a low-power, cost-efficient alternative to the more complex PAAs often used in satellite communications [2]. By eliminating the need for mechanical deployment mechanisms and reducing active element requirements, SHAMROCK offers a viable, low-risk solution for future satellite and spacecraft missions. This low-budget design opens new possibilities for both NASA and commercial space devices seeking scalable, high-performance communications. The preliminary computer aided design (CAD) and block diagramming can be found in Appendix E for reference throughout the proposal.

Piloted by IrishSat, the University of Notre Dame's undergraduate space systems engineering team, SHAMROCK provides a hands-on educational platform that equips students with critical skills in satellite design, system integration, and mission operations. Leveraging the team's prior experience with high-altitude balloon projects, CubeSat prototypes, ground station development, and more, SHAMROCK prepares students for future careers in aerospace engineering while advancing satellite communication technology.

The exceptional merit of this communications scheme lies in its reduced requirements for power, cost, volume, and actuation, enabling high-performance communications in a scalable capacity. While traditional PAAs provide continuous high-gain beam steering, they impose significant constraints on satellite systems, requiring large power consumption, extensive housing space, and complex software [3], [4]. In contrast, SHAMROCK's SBL architecture uses one active antenna element to generate discrete high-gain beams that can maintain high-throughput communications links. Additionally, SHAMROCK's SBL architecture has the capability of producing quasi-omnidirectional beams allowing for low-throughput links in case of uplink or downlink beam steering failure. SBL architectures consume up to 100 times less power than typical PAAs [5], drastically reducing the need for power generation, storage, and heat dissipation, which allows for a smaller, cost-effective system. Analysis of the mission's technological merit and a comparison with similar implementations are in Section 4.3.2.

SHAMROCK's payload aligns with NASA's Strategic Goals 2, 3, and 4 (see Appendix A) as a successful demonstration will be highly promising for the coming age of innovations in satellite communications which will prove a driving force in the advancement of sustainable space exploration, fostering of economic growth through innovation, and enhancement of operational capabilities in space. Specifically, the resulting technology readiness level improvement from successful operations addresses NASA Strategic Objectives 2.1, 2.2, 2.4, 3.1, and 4.2. There is bright potential for the usage of this communications scheme in the development of future space infrastructure, with reduced costs and high performance enabling NASA's maturation of a sustainable and attainable architectural plan for both cis-lunar and low Earth orbit objectives.

2 Team Structure

The SHAMROCK mission is a University of Notre Dame-sponsored mission that operates as a joint effort between the CubeSat bus development student organization, IrishSat, and the payload technology development group, Dr. Chisum's research lab.

IrishSat, officially recognized by the University of Notre Dame's Club Coordination Council (CCC), operates as an Academic Division club of the Student Activities Organization (SAO) and is additionally supported by the Department of Electrical Engineering within the College of Engineering. As such, the organization must comply with the regulations of the University, College, Department, and SAO/CCC. This structure provides IrishSat with vital resources, including funding, technical support, and institutional backing, enabling the team to thrive.

Since its founding in 2020, IrishSat has rapidly grown, expanding to 80 active general members (see Appendix L) led by 26 team leads. The leadership structure is composed of executives (President, Chief Technology Officer, and Director of Research and Development), project leads, and technical leads who manage subteams and take on key roles. The team operates in a well-defined hierarchy, ensuring that leadership responsibilities are clear and each member of the club can play an integral part in IrishSat's success.

IrishSat projects enable all members, even as early as freshman year, to become the best that they can be. The organization places high emphasis on development and the enhancement of members' hard skills (technical space system design abilities) and soft skills (teamwork, collaboration, communication, and leadership) to create strong technical leaders and contributors. The team's success is largely due to its commitment to knowledge transfer and continuity. Leadership transitions occur every year as new talent enters the team, and departing members ensure their knowledge is passed on. This allows IrishSat to maintain a high level of expertise and adapt quickly to new challenges, creating a sustainable pipeline of talent and leadership.

IrishSat also partners with many professors and their research labs to enable members to gain meaningful research experience related to space. For the SHAMROCK mission, IrishSat is partnered with Dr. Chisum whose group develops circuits and antenna systems for millimeter-wave (MMW) wireless communications including systems in LEO. This group, in collaboration with IrishSat members, develops the high-data-rate SBL antenna system that acts as the payload of the SHAMROCK bus.

3 Schedule and Budget

3.1 Schedule

In accordance with the CSLI AoPO dates [6], IrishSat has developed a detailed timeline that supports a launch of the SHAMROCK mission in July 2028. The key dates are given in Table 1 and details can be found in Appendix F.

Table 1. SHAMROCK schedule

Task	Start	End
CSLI Proposal	Aug '24	Nov '24
Conduct Research on Critical Systems and Requirements	Aug '24	Dec '24
Design, Development, and Testing of Subsystems	Aug '24	August '26
Subsystem Integration and Testing	Aug '25	Aug '26
CubeSat PDR	Dec '24	Jan '25
CubeSat CDR	Apr '25	Apr '25
Launch Readiness Review (LRR)	Apr '26	May '26
Conduct Environmental Testing	Sep '26	Jan '27
Mission Readiness Review (MRR)	Feb '27	Mar '27
Handoff to NASA	Mar '28	May '28
Pre-Launch Verification	May '28	Jun '28
Orbit Data Analysis Period	Jun '28	Jul '29
Post-Launch Report	Mar '29	Apr '29

3.2 Budget

A detailed budget with an itemized list for CubeSat development, testing, and licensing is given in Table 2 showing that the total cost of SHAMROCK development is $26,896.04.

4 Merit Review

4.1 Process

IrishSat conducted a non-competitive intrinsic merit review on the SHAMROCK mission, focusing on the mission's educational and technological merit as well as its alignment with NASA's strategic objectives. IrishSat evaluated the educational merit of the development and operation of the SHAMROCK CubeSat bus with respect to its capacity to educate and engage students in STEM by talking with team members and getting feedback on how IrishSat has helped them learn. IrishSat evaluated the technological merit through numerous mission analysis sessions with Dr. Chisum, the SHAMROCK Mission Advisor and the principal investigator of the research payload, and Isaac Brej, IrishSat's Chief Technology Officer (CTO) and undergraduate researcher in Dr. Chisum's lab who works closely on the SHAMROCK payload. These meetings involved characterizing the proposed technology, investigating the benefits, and comparing it with existing designs. IrishSat and the lab conducted research into similar CubeSat missions and communications architectures to ensure the novelty and value of the SHAMROCK mission.

After the internal review, the proposal document was sent to a panel of qualified reviewers with technical experience in the areas associated with the mission. Reviewers were asked to rate the mission and document based on the evaluation criteria and provide comments to justify their ratings. Most reviewers also provided additional comments that did not align directly with the evaluation criteria. After receiving the feedback from the panel, IrishSat incorporated their comments into the proposal document and documented the changes made.

Table 2. SHAMROCK Budget

Part Name	Total Cost
Samsung 18650 Cells	$11.80
Battery Endcaps	$100.00
Battery Management System (BMS)	$200.00
Resistive Heater	$52.44
Power Board (MPPT and Control Board)	$400.00
2U Solar Panels	$15,000.00
Nichrome Burn Wire	$11.99
Torsional Spring	$7.49
Hinges	$11.98
Magnetorquer Wire	$12.29
Magentorquer Rods	$2.70
Magnetorquer Board	$200.00
Patch Antenna	$59.40
Heat Sink Panel	$38.40
Thermal Coatings	$400.00
Structural Panels	$30.00
Structural Frame	$50.00

Part Name	Total Cost
Fasteners	$7.59
Reaction Wheels	$6,000.00
Reaction Wheel Mount	$19.99
Ceramic Antenna Lens	Provided by Dr. Chisum's Lab
Switch Beam Lens Array	Provided by Dr. Chisum's Lab
Monopole Antenna	$4.97
Monopole Antenna Deployment Housing	$40.00
Sidekiq Z2 Module	Donated by Epiq Sol.
Flight Computer	$200.00
Testing Equipment	$200.00
Radio Licensing Fees	$35.00
Estimated Budget Inflation	$3,500.00
Total Cubesat Cost: $26,896.04	

The merit of SHAMROCK was assessed based on the following factors: Educational Value, Novelty, Potential Impact, and Alignment with NASA's Strategic Objectives.

4.2 IrishSat's Merit Review

4.2.1 Educational Merit

The SHAMROCK CubeSat bus, designed, built, and tested by the undergraduate team IrishSat, provides practical, hands-on experience in space systems engineering, aligning with NASA's 2022 Strategic Objective 4.3 to develop the next generation of space professionals [1], [7].

IrishSat organizes its CubeSat team members into eight technical sub-teams: Computing, Controls, Electronics, Power, Manufacturing, Safety, Structures, and Payload. Weekly meetings foster inter-team collaboration, allowing project leads to discuss progress and roadblocks, ensuring all members are aligned with mission objectives. This structure encourages hands-on learning across subsystems, cultivating systems engineering skills in a cohesive environment.

IrishSat's projects like Control of Hardware Attitude using Reliable Magnetorquers Satellite (CHARM-Sat), Gravitation, Orientation, Attitude, and Thermal (GOAT) Lab, Communication Systems, and a high-altitude balloon project named Information Recovery Integrated System (IRIS) provide specialized training critical to SHAMROCK's success. These projects help students gain expertise in a broad range of areas spanning topics such as signal processing, guidance and navigation, thermal management, and satellite communications strengthening IrishSat's interdisciplinary approach to engineering challenges. IrishSat emphasizes continuous learning through weekly tutorials on topics like Attitude, Determination, and Control Systems (ADCS), digital signal processing, circuit design, and system modeling. Every project lead contributes by teaching a tutorial, ensuring both new and seasoned members expand their technical knowledge relevant to space system design.

To support project management skills, IrishSat uses Agile development practices, promoting steady progress toward milestones while preparing members for professional environments. Regular design reviews also bring team members from different subsystems together to evaluate integration, assess risks, and refine the satellite's overall architecture, building students' systems engineering expertise.

IrishSat's technical education spans a comprehensive array of hard skills essential for space engineering. Members become proficient in tools like SolidWorks, COMSOL, and Python, learning structural analysis, thermal modeling, and control algorithms. They develop electrical skills through custom circuit design, soldering, and assembling electronics for mission-critical functions. The Communication Systems team gains hands-on experience with the SidekiqZ2 Software Defined Radio (SDR) for high-throughput communications, often pursuing Ham Radio Technician Licenses to deepen their expertise in regulated communications. In GOAT Lab, students utilize equipment such as flat-plate air bearings and Helmholtz cages to simulate launch and space conditions, mastering essential skills in testing and validation under realistic conditions.

IrishSat projects emphasize mission-oriented system design, allowing students to manage complex subsystems within realistic contexts. SHAMROCK's Structures team handles the physical framework, ADCS, and thermal systems, focusing on redundancy and durability, while the Electrical team manages mission control, power distribution, and payload integration, ensuring seamless coordination among subsystems. This comprehensive exposure helps members develop technical fluency and experience with interdisciplinary teamwork essential for complex engineering projects.

Each project enhances system engineering capabilities through specialized, mission-aligned applications. CHARM-Sat, developed with Near Space Launch (NSL), advances SHAMROCK's ADCS readiness by providing members experience with ICD standards, mathematical modeling, and rapid timelines. The IRIS balloon mission allows students to practice mission operations, precision recovery, and environmental resilience. As a finalist in the NASA's FLOATing ICE DRAGON (Formulate, Lift, Observe, And Testing; Data Recovery And Guided On-board Node) competition, IRIS enhances interdisciplinary skills and design and documentation according to NASA's standards. The Communication Systems project ensures reliable satellite-ground data transfer, with hands-on training in signal processing and SDR configuration. Together, these projects offer a rich, mission-focused learning environment that bridges academic learning with real-world aerospace challenges, preparing IrishSat members for meaningful contributions to STEM fields.

4.2.2 Technology Focus Area

The SHAMROCK mission will implement a novel architecture using SBL antennas for high-data-rate K-band communications on a miniaturized 2U platform, a significantly smaller platform than typically used for a CubeSat communications demonstrator. The SBL architecture has suitable high-gain beam steering for high-data-rate communications with reduced active element requirements compared to traditional PAA implementations. Section 1.1 asserts that this technology will consume 100 times less power than power-hungry PAA solutions, drastically reducing cost and complexity.

To better quantify the SHAMROCK mission merit, it is beneficial to consider a comparison with a similar satellite K-band communications platform created by Mixcomm utilizing PAA technology [5]. This PAA system consumes 140 mW per channel on transmit and 40 mW per channel on receive. Assuming 90% efficiency of the PAA implementation (conservative compared to Mixcomm PA efficiency number of 40%), the system dissipates 14 mW per channel maximum [5]. To design an antenna with a gain of 30 dB, the PAA would have approximately 1,000 channels, all of which need to be active due to phased arrays' reliance on active, electronic beam steering. This means the PAA implementation would have to consume up to 140 watts of power, losing 14 W to heat dissipation at a given time during operation. This requires significant battery storage, power generation, and heat dissipation capabilities which increases the size and complexity of the satellite. In contrast, the SHAMROCK mission argues that a PAA implementation for high-data throughput is an over-capable system requiring inefficient levels of power and complexity. Utilizing an SBL architecture significantly reduces the power consumption to 1 active channel at a time, drawing 1 mW on transmit and insignificant power on receive due to passive beam steering using a Gradient Index (GRIN) lens. Amplification of the transmitted or received signal could reach up to 1 W resulting in total power consumption 100 times lower than a similar PAA system while maintaining similar antenna gain. Evident from this comparison is a drastic reduction in system complexity as well as power generation and storage requirements. Figure 1 highlights the key differences between the two architectures.

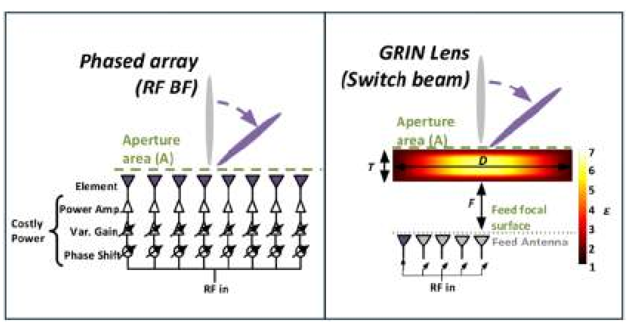

Figure 1. Comparision between PAA and SBL architecture

This novel technology is enabled due to recent advances in 3D printing technology and computational capabilities. Previous methods for creating the lens required time consuming and expensive efforts that was also subject to human error, hurting performance. New 3D printing capabilities have made this process significantly easier, shorter, and less expensive. Additionally, optimizing the SBL requires significant computational resources that have only been enabled in recent years.

To quantify, the recent improvements in 3D printing technology have reduced the cost of SHAMROCK's ceramic lenses to $1000 per unit, a significant reduction from $75,000 [8], [9]. Additional SHAMROCK cost savings include up to 4U of launch mass due to the smaller form factor compared to PAA alternatives, equating to $360,000 per satellite launch based on prevailing market rates. Also, the architecture enables a novel mode that produces a quasi-omnidirectional beam, ensuring stable low-gain communication links without the need for complex beam-searching algorithms. This allows SHAMROCK to maintain communication even in the event of uplink or beam steering failures.

The quantitative and qualitative merits of the SHAMROCK mission prove its promise to revolutionize small satellite communication by demonstrating the capabilities of SBL antennas in a compact 2U CubeSat platform. Designed for high-throughput K-band communication, SHAMROCK will offer a low-power, cost-efficient alternative to the PAAs implementations allowing for inter-satellite links, Earth-to-space data exchange, cis-lunar communication networks, and Earth science missions.

This technology of SHAMROCK lends itself to NASA Strategic Objectives 2.1, 2.2, 2.4, 3.1, and 4.2. Focusing on the modernization of infrastructure and technical capabilities (Strategic Objective 4.2), this 2U pathfinder mission provides a compact, efficient, and high-performance K-band system. By reducing the mass, power, and cost of communication hardware, this mission supports NASA's drive to modernize its technical infrastructure, enabling streamlined, cost-effective operations. SHAMROCK seeks to support and extend the strategic capabilities of NASA programs, enabling reliable, high-data-rate communication links that are adaptable to future space exploration needs. This meets the communication, launch service, and strategic capabilities needs of NASA's programs (Strategic Objective 2.4) and embodies a high-payoff space technology assisting in American leadership in the space economy (Strategic Objective 3.1).

More specifically, NASA strives to establish sustained human presence and operation in cis-lunar space and on the lunar surface (Strategic Objective 2.1). To have a sustained presence, the mission will act as a pathfinder for high-performance cis-lunar communications infrastructure with the 2U platform acting as either lunar-orbiting or earth-orbiting support equipment. According to NASA Glenn, in the Lunar Gateway architecture there is a need for Ka-band high throughput uplink and downlink capabilities from both Earth and the Moon of up to 100 Mbps, an exact demonstration the mission hopes to capture [10]. The SHAMROCK mission selected K-band frequencies from 24-24.25 GHz because these frequencies are available for amateur satellite operators and allows for 250 MHz of bandwidth. As long as similar amounts of bandwidth are available in the Ka-band, the transition between SHAMROCK's K-band (18-27 GHz) and NASA Lunar Gateway Ka-Band (27-40 GHz) requirements are feasible. This is because the RF circuitry and antennas designed by Dr. Chisum's lab supports frequencies from 2-40 GHz. Beyond the lunar economy, NASA also strives to expand the economy in LEO by leveraging the ISS and stimulating the growth of human spaceflight commercial activities (Strategic Objective 2.2). With multiple commercial space stations on the horizon and ISS still acting as a functioning laboratory in space, there is a need for simple, lightweight, and cheap systems with the ability to handle large amounts of data for downlinks like SHAMROCK. Additionally, commercial space companies like SpaceX have demonstrated how LEO constellations can support space flight by utilizing one to live-stream video during launch. Constellations like these could evolve to include miniaturized 2U, high throughput satellites to carry out these types of transmissions for a fraction of the cost.

4.3 External Panel Comments

4.3.1 Educational Focus Area

The external merit review panel highlighted SHAMROCK's significant educational value, noting its strong alignment with NASA Strategic Objective 4.3 to foster a diverse, skilled STEM workforce. Reviewers praised the mission's hands-on nature, with students directly responsible for leadership, system integration, subsystem design, and manufacturing, mirroring real-world engineering projects. This structure equips students with critical technical skills while also fostering systems thinking and project ownership. Furthermore, the project's inclusive recruitment practices bring together a wide array of majors and disciplines, enriching the team's diversity of perspectives. The educational approach of IrishSat was also noted for its focus on sustained knowledge transfer, ensuring that both technical and project management skills are passed on to new members annually. This process has been effective in retaining institutional knowledge, which prepares future cohorts to take on increasingly complex roles within the mission. The only suggested improvement was for SHAMROCK to involve more students in addition to Isaac directly in the payload development. However, reviewers acknowledged that the payload's technical complexity exceeds the capabilities of most undergraduates and wider involvement could possibly compromise the project's timeline and quantity. This feedback underscores IrishSat's current strategy of prioritizing educational growth without overextending students on tasks that may exceed undergraduate capabilities.

4.3.2 Technology Focus Area

The review panel recognized the SHAMROCK mission's technical innovations as both novel and potentially transformative. The development of a smaller, lighter, lower-complexity, and low-power communications system for CubeSats has a strong potential to impact the industry by reducing cost and complexity barriers. Reviewers acknowledged that this approach aligns well with NASA's goals of sustainable space missions and enhanced technological efficiency, particularly in the communications field. However, reviewers noted areas for improvement in presenting SHAMROCK's technical merit. While the benefits of the proposed system were described, the quantitative details needed to substantiate its advantages—such as specific power reductions, cost comparisons, and performance metrics relative to traditional PAAs—were difficult to locate in the proposal. The panel recommended a more explicit, organized approach to presenting technical data, including metrics that clarify SHAMROCK's technological innovations. For example, reviewers suggested that a comparison of SHAMROCK's anticipated power savings, mass reduction, and data throughput relative to current industry standards would provide stronger justification for the mission's impact claims. Implementing this feedback will help position SHAMROCK as a more compelling technology demonstration aligned with NASA's strategic priorities.

4.4 Review Process Outcomes

Outcomes were based on the assessment factors listed at the end of Section 4.1. The merit review process underscored SHAMROCK's high educational value, highlighting its unique position as an entirely undergraduate-led mission that emphasizes hands-on experience in space systems design, testing, and project management. Both the internal merit review and the feedback provided by external reviewers, designated the need to gain a deeper understanding of the research payload and foster more collaboration with the team developing it. This realization led to a dedicated meeting with Dr. Chisum, which explored the revolutionary aspects of the SBL antenna and investigated the specific innovations that bring substantial merit to this mission. Dr. Chisum guided the team through the technical aspects that make the SBL antenna novel, specifically its lower power and complexity in comparison to conventional communications systems. With this enhanced understanding, the team was able to refine the proposal, incorporating quantitative comparisons and metrics to substantiate the claims of the payload's reduced power demands and simplified design. This process not only clarified the mission's technological impact but also allowed the IrishSat team to align the various subsystems and operational strategies to best support the SBL antenna's requirements. As a result, the team gained a robust educational foundation in both payload mission requirements and the groundbreaking potential of this communications technology. This deeper knowledge extended the educational benefits of the mission to a broader group within IrishSat, enhancing both the technical understanding and the ability to effectively convey the mission's merit. Through these efforts, SHAMROCK's alignment with NASA's Strategic Objectives was strengthened and the mission's educational and technological value were reinforced, ensuring that both education and merit are strongly upheld.

5 Feasibility Review

5.1 Process

IrishSat conducted a feasibility review of the SHAMROCK mission in which the risk, resiliency, and probability of success of the mission were analyzed, as well as the alignment of the mission to NASA Strategic Objectives 2.4 and 3.1 (see Appendix A). This process examined the implementation of the SHAMROCK mission; specifically, how each subsystem team addresses mission requirements and risk mitigation in the development of the subsystem. Furthermore, general mission risks and mitigation measures were evaluated with a focus on past club successes and current testing instrumentation for flight preparedness.

After the internal review, IrishSat sent the proposal to a panel of qualified industry and academic reviewers to comment on the feasibility review conducted by IrishSat. Reviewers used a Google form to rate the document based on the evaluation criteria and provide comments to justify their rating. After receiving feedback from the panel, IrishSat incorporated their comments into the proposal document and documented the changes.

Feasibility of SHAMROCK was assessed based on the following factors: Team Experience, Team Expertise, Organizational Structure, Testing Capability, and Risk Analysis.

5.2 IrishSat's Feasibility Review

5.2.1 General Mission Risks and Mitigations

Launch and operational environments present risks including vibration, shock, radiation, and thermal conditions [11]. To address these, IrishSat leverages the GOAT Lab's in-house testing capabilities, enabling rigorous assessments of SHAMROCK's numerous subsystems including structural and ADCS components. The IrishSat GOAT Lab fabricated a three-dimensional gimbal system [12], [13] with embedded acrylic rings and low-friction bearings, an air bearing that allows for 2.5-axis testing, and a one-axis air table. These are used to validate the performance of individual actuators as well as full system operation, allowing for early feedback on control adjustments and stability. Additionally, a vibration table simulates launch conditions [14], testing for resonance frequencies that could compromise the CubeSat's structural integrity. NSL also provides access to a vibration table and TVAC chamber for broader testing ranges.

The GOAT Lab's Electrical team developed a Helmholtz cage that simulates the magnetic field conditions SHAMROCK will experience in orbit in X, Y, and Z directions within a range of -75 to 75 microtesla. The system's proportional-integral-derivative (PID) control feedback loop ensures field stability allowing for accurate testing of the magnetorquers. By providing validation for structural, thermal, and ADCS components, the GOAT Lab bolsters SHAMROCK's mission readiness by enabling early testing in simulated conditions that closely approximate the space environment.

IrishSat has many capabilities to test subsystems in near-space or LEO environments. The IRIS mission serves as a reusable high-altitude testing platform, offering near-space conditions with flights reaching 120,000 ft. IRIS enables the testing of SHAMROCK's operational resilience in extreme thermal conditions and validates subsystem functionality.

Additionally, IrishSat's collaboration with NSL on the CHARM-Sat mission further supports SHAMROCK's development by advancing the Technology Readiness Level (TRL) of SHAMROCK's ADCS. CHARM-Sat, a 0.5U CubeSat equipped with a magnetorquer-only ADCS solution, is scheduled for LEO deployment in 2025. CHARM-Sat is designed for high accuracy and low power consumption, offering a viable alternative to traditional reaction wheel-based systems. By reducing the complexity and power requirements, this design aligns with SHAMROCK's objectives for a compact CubeSat mission, proving key aspects of magnetic control in orbit. Furthermore, CHARM-Sat's development of a reduced sensor suite which removes reliance on external GPS or a comms link, will be directly applicable to SHAMROCK's ADCS design. This supports resilient, autonomous attitude control, improves SHAMROCK's TRL, and reduces mission risk.

Despite IrishSat's limited CubeSat flight experience, the team has won two NASA competition wins, FLOATing DRAGON (more information in Appendix P) and the Starshade challenge, and partnered with the NSL to develop a ThinSat system. This demonstrates IrishSat's competence in mission design, performance metrics, compliance with NASA standards, and the ability to pass NASA's pre-flight requirements, establishing a strong foundation for SHAMROCK's success.

5.2.2 Subsystem Risks and Resiliency

High Data-rate Communications Payload The high-data-rate, K-band communications demonstrator is a SHAMROCK subsystem composed of two defining elements: the switched beam antenna array and the gradient index lens. These two technologies are combined to create the SBL antenna architecture functioning at 24 GHz, launching the payload signal at the selected beam angle by using the programmable RF switch matrix produced by Dr. Chisum's RF Antenna Lab.

The GRIN lens requires a critical focal distance which is a potential risk for mission success. The payload design implements an SBL antenna that requires no deployment mechanism, minimizing the risk of failure and maintaining the required focal distance for operation. Beam steering and uplink failures present another operational risk. To mitigate scenarios like this, the SHAMROCK payload architecture is capable of producing a quasi-omnidirectional beam using a novel technique, allowing for redundant low-gain link capabilities in the event of payload or bus communications failure. This low-risk, redundant implementation makes the design suitable for CubeSat missions. Additionally, this subsystem uses low risk, high-resiliency materials. The GRIN lens will be constructed from alumina, a low-loss material that can withstand extreme temperatures up to 1500°C [14], [12]. The result is a low-risk, low-cost solution for high-throughput communications.

ADCS The ADCS carries out mission-critical detumbling and pointing to enable solar charging, establish a communications link, and maintain payload stability. The SHAMROCK ADCS uses a custom-designed NSL magnetorquer module and reaction wheels supported by unscented Kalman filters and Proportional-Derivative (PD) controllers and tested through orbital simulations.

Hardware failures, calibration drift, or algorithmic instability present risks for the ADCS. GOAT Lab's testing capabilities allow for hardware-in-the-loop simulations, vibration testing, thermal cycling, and controlled magnetic field environments within a Helmholtz cage. This iterative testing process ensures issues are identified and corrected early, preventing in-orbit failures. A fourth, off-axis reaction wheel is included to maintain control if any reaction wheel malfunctions, providing robust pointing capabilities and ensuring SHAMROCK's subsystems can operate reliably.

Power The power subsystem autonomously manages energy capture, storage, and distribution across the CubeSat's components, encompassing solar energy harvesting with maximum power point tracking (MPPT), a battery pack supported by a custom battery management system (BMS) for charge control, cell balancing, and thermal management. The power subsystem will be the only active system upon launch, ensuring optimal energy storage and regulating power until SHAMROCK reaches LEO and will autonomously activate the flight computer and other satellite systems.

Overloading, overheating, and power interruptions are possible risks for the power subsystem. Smart distribution of power to individual subsystems reduces over-voltage risk and allows specific components to be independently shut off. Real-time power monitoring delivers continuous feedback, facilitating adjustments to consumption in response to the satellite's operational conditions. Integrated thermal sensors ensure stable temperature management within the battery pack, while the BMS's cell balancing minimizes power fluctuations. By incorporating these functionalities, the subsystem sustains critical power management and reduces power risks. Additionally, critical systems will have dedicated, redundant batteries to sustain critical events like detumble. As with other subsystems, extensive pre-flight testing, including load assessments and fault simulation will validate the subsystem and ensure reliable operation.

Bus Communications Systems The bus comms system facilitates reliable S-band data transmission between SHAMROCK and the IrishSat ground station. The system supports continuous data processing, enabling smooth communication flows with all filtering, amplification, and mixing handled by the SDR with no external circuitry required.

Signal degradation from noise, data loss, and SDR hardware failures present key risks for the communications system. Error correction algorithms restore data accuracy upon reception, ensuring communication across varying conditions. The team conducts extensive pre-launch testing and link budgeting to understand expected mission performance. Built-in software and hardware redundancy coupled with regular in-mission diagnostic checks enhance the communication system's resilience. This ensures SHAMROCK's data transmission objectives are met, even under challenging orbital conditions.

Ground Station The IrishSat ground station is fully functional, having downlinked data from the International Space Station using a dual Yagi-Uda antenna array with a motorized rotor capable of 450 degrees of azimuth and 180 degrees of altitude rotation. Given SHAMROCK's use of the S and K-bands, components will be retrofitted to meet these frequency requirements.

Tracking errors and rotor misalignments present operational risks to the SHAMROCK mission. These errors could disrupt communication and are mitigated through rigorous calibration, real-time system monitoring, and backup power supplies for uninterrupted operation. This system interfaces with bus and payload communications systems, both of which use filtering and error correction protocols to ensure data integrity. Continuous software updates and system calibrations will be scheduled throughout the mission to optimize performance. This ensures every available communication window is utilized effectively to support SHAMROCK's objectives.

Flight Computer and Software Design The flight computer for SHAMROCK is a multi-core, space-rated PCB designed to interface with all SHAMROCK subsystems. The flight computer's real-time operating system (RTOS) will manage task distribution across the cores, ensuring optimal execution of mission-critical functions. The SHAMROCK dynamic state machine allows the flight computer to make real-time decisions to optimize computation and decision-making, ensuring mission longevity.

Hardware malfunctions, radiation-induced errors, and firmware vulnerabilities such as memory overflows or processing delays present potential risks to the mission. Mitigation through testing, including hardware-in-the-loop simulations, radiation tolerance assessments, and thermal cycling will validate the system for in-orbit conditions. Error detection and correction algorithms, watchdog timers, and redundant power pathways will help address unexpected failures. In-depth testing will validate the RTOS and state machine transitions, and stress tests will ensure that the flight computer can reliably switch between modes as required. This approach will enable stable operation of the flight computer and the SHAMROCK mission.

Structural/Thermal Design The IrishSat SHAMROCK structures and thermal team implements a passive and active thermal control system, designs and analyzes the structure and layout of the satellite, and implements the deployment of the uplink antenna and solar panels. The active thermal system uses resistive heaters to keep the batteries within their operational temperature during charging and discharging whereas the passive thermal system uses a copper heat sink panel that doubles as the 10 cm x 20 cm bus panel. The antenna and solar panel deployment design utilizes a torsion spring hinge with a burn wire mechanism to trigger the release of the solar panels.

Overheating components and batteries, misplacement of subsystems within the bus, vibrational fatigue, and deployment failure of antennas or solar panels due to burn wire failure all represent risks to mission success. To address overheating, all of the satellite's hottest subsystems, including the magnetorquer module and batteries, will interface with the copper heat sink panel to expel heat. The outside of the heat sink will be covered with a thermal control coating (TCC) to limit the radiative heat transfer from the Sun to the satellite. To verify the effectiveness of this thermal management design, the team will utilize SOLIDWORKS thermal flow simulation to analyze the heat transfer around the satellite at different phases of the mission cycle and orbit. With poor subsystem placement in the satellite, heat transfer can become an issue for overheating. The results of the thermal simulations provided data on how to configure the different subsystems within the satellite to optimize thermal performance. The configuration shown in Appendix E minimizes associated thermal risks.

To address vibrational risks, the team uses SOLIDWORKS Finite Element Analysis to examine the effect of vibrational fatigue during launch on the satellite frame and subsystems. To validate the FEA, the SHAMROCK Structures team will collaborate with GOAT Lab to perform vibration testing on the satellite. Additionally, deployment failures have been addressed by adding redundant burn wires linked to different power sources. The length and tension of the burn wires have been optimized to limit power consumption while still providing a secure attachment that will hold during launch.

5.2.3 Probability of Success

Minimal and nominal mission success for SHAMROCK is defined by the mission requirements listed in Appendix Q. The probability of meeting these requirements and having a success mission was assessed by these metrics and qualities: analysis of subsystem risks, feasibility and effectiveness of mitigation strategies, and external reviewer comments on feasibility and potential mission success. Through internal reviews of IrishSat capabilities in general mission design and subsystem development and testing shown in Section 5.2, the team has strong confidence in its current abilities to identify potential points of failure and design a successful, operational system. This internal confidence in SHAMROCK mission success is echoed by the qualified review panelists who have designed successful space systems in industry. This high confidence in the SHAMROCK mission by reviewers is reflected in Section 5.3 and Appendix J.

To clarify, all concerns seen from reviewers in Appendix J about the probability of mission success such as lacking attention to risk analysis and mitigation, TRL, and defining mission success have been addressed in the updated proposal. Due to these internal and external reviews and associated adjustments to the proposal and mission design, there is strong confidence in mission success.

5.3 External Panel Comments

The external panel noted many positives that indicate that the mission is highly feasible and also provided comments on various ways to improve mission feasibility even further. Reviewers noted the impressive track record of successful projects and an organizational structure that sets the team up for success. The team demonstrated impressive knowledge of satellite design, and experience working with NASA and commercial companies on other projects indicates that the team is well prepared to execute the SHAMROCK mission. Reviewers indicated that improvements to the feasibility of the mission could be made by placing a larger emphasis on systems engineering to minimize integration issues. A revised timeline that better aligns with industry standards was also suggested, noting that three months between PDR and CDR is not long enough to adequately mature the design. Reviewers also commented that a more detailed risk assessment should be conducted and mitigation methods put in place.

5.4 Review Process Outcomes

Outcomes were based on the assessment factors listed at the end of Section 5.1. The internal review of the SHAMROCK mission highlighted critical opportunities to strengthen IrishSat's operations, leading to transformative changes that have made this the most productive period in the CubeSat team's history. A key issue identified in the feasibility analysis was a lack of cohesive system knowledge across the team: while each subsystem was making progress and achieving its own milestones, only a limited number of engineers had a comprehensive understanding of SHAMROCK's overarching system requirements, the interdependencies of subsystems, and the integration processes required for mission success. These knowledgeable leads could envision the complete SHAMROCK bus, but without clearly documented requirements and dependencies or regular big-group discussions, the entire CubeSat team lacked a unified perspective on how individual components fit into the mission as a whole.

Without this shared understanding, team members were able to excel in their respective areas but lacked the insight to fully align their work with mission requirements or understand the purpose behind certain design directives. Recognizing this gap, the team made a strategic shift to approach every member as a "systems engineer" with responsibility for a specific aspect of the mission. To instill this systems-thinking mindset, each meeting for a two-week period was dedicated to requirements analysis and system-level discussions to define mission goals, outline requirements, establish physical structures, electrical interfaces, and software architecture, and derive the specific needs of each subsystem.

Through these discussions, members gained an education in mission design, understood the rationale behind each requirement, and developed ownership of their individual components — whether large or small — within the full mission context. This systems-oriented focus extended from general members up through project and technical leads to the executive team. With members now empowered by a deeper understanding of the mission, project leadership was able to delegate more effectively and trust members with independent design decisions. This also freed leadership to focus on higher-level mission analysis, including simulations in NASA's General Mission Analysis Tool (GMAT) conducted by the CubeSat Mission Director.

These operational shifts have significantly increased the mission's feasibility, leading to improved project productivity, enhanced subsystem and component design, and a faster pace of successful milestones. Numerous reviewers commended IrishSat's systems engineering approach, noting that the organization's operational structure—where each engineer takes ownership of specific aspects of the mission—stood out as one of its greatest strengths. This emphasis on systems thinking and distributed responsibility has also deepened knowledge transfer across the team, ensuring that as experienced seniors graduate, there is a robust base of mission-aware engineers prepared to take ownership of SHAMROCK, continually driving development in alignment with bus and payload requirements.

5.5 Financial Support

IrishSat has secured comprehensive financial support to cover all development costs for the SHAMROCK mission, demonstrating the team's readiness and commitment to meet project expenses without requiring additional funding from NASA beyond launch support. IrishSat's funding sources are well-established, diverse, and aligned to fully support the CubeSat's development through to completion. The total sum of funding secured is more than sufficient to cover all budgetary costs, as detailed in Appendix G.

Corporate sponsorships, including ongoing partnerships with companies like Boeing and General Electric, continue to contribute significantly. Additionally, IrishSat receives departmental funding from Notre Dame's Electrical Engineering department and supplemental support from Notre Dame Development, which allocates funds at the university's discretion to projects that align with institutional goals. Notre Dame Research has also reaffirmed its pledge to cover any potential overdraft, ensuring that any unforeseen expenses will be fully addressed. This commitment is supported by a Letter of Intent from Dr. Jeffrey Rhoads, Vice President of Notre Dame Research, included in Appendix H. IrishSat also conducts targeted fundraising efforts, notably through Notre Dame Day, which has consistently generated additional support for projects. These combined funding sources and pledges secure IrishSat's financial foundation, providing confidence in the ability to independently manage all development costs, thereby justifying NASA's investment in SHAMROCK's launch costs.

A 2022 NASA Strategic Objectives

Strategic Goal 2: Extend human presence to the moon and on towards Mars for the sustainable long-term exploration, development, and utilization.

- **Strategic Objective 2.1:** Explore the surface of the moon and deep space. Extend human presence into cis-lunar space to allow for sustained operations on the lunar surface and then on towards Mars to unlock mysteries of the universe.
- **Strategic Objective 2.2:** Develop a human spaceflight economy enabled by a commercial market. Expand the space economy by leveraging the ISS and stimulating the growth of human spaceflight commercial activities.
- **Strategic Objective 2.4:** Enhance space access and services. Meet the communication, launch service, and strategic capabilities needs of NASA's programs.

Strategic Goal 3: Catalyze economic growth and drive innovation to address national challenges.

- **Strategic Objective 3.1:** Innovate and advance transformational space technologies. Develop revolutionary, high-payoff space technologies driven by diverse ideas to transform NASA missions and ensure American leadership in the space economy.

Strategic Goal 4: Enhance capabilities and operations to catalyze current and future mission success.

- **Strategic Objective 4.2:** Transform mission support capabilities for the next era of aerospace. Re-build, modernize, and right-size NASA's mission-enabling capabilities to ensure mission readiness and cultivate a reliable foundation for future innovations in aerospace and science.
- **Strategic Objective 4.3:** Build the next generation of explorers. Engage students to build a diverse future STEM workforce.

B Target Orbit

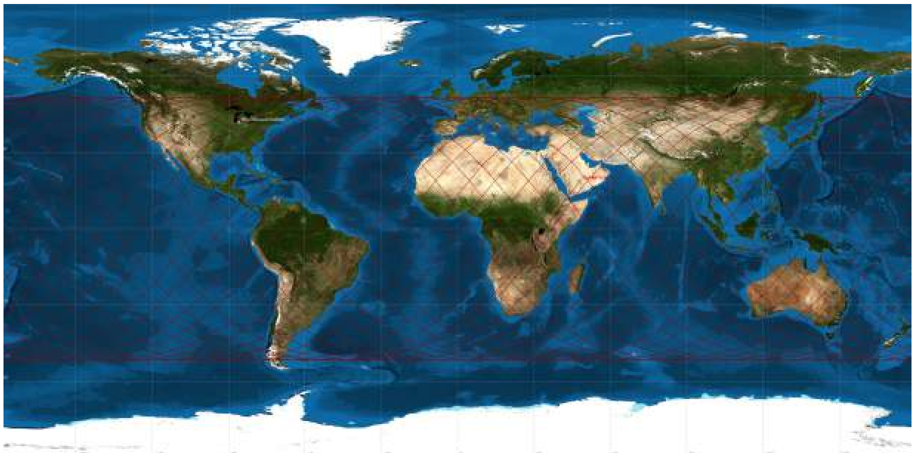

Figure B.1. Target SHAMROCK orbit, propagated for 48 hours and visualized using NASA's GMAT simulation tool. The above figure depicts the orbit in an Earth-centered, Earth-fixed ground track. Both Figure 1 and Figure 2 are for an ISS deployment orbit with the following orbital elements: eccentricity $e = 0.007$, inclination $i = 51.6$ degrees, semimajor axis $a = 6,738$km, longitude of ascending node $\Omega = 324.83$ degrees, argument of periapsis $\omega = 144.54$ degrees, true anomaly $\nu = 100$ degrees. This is the target orbit that meets SHAMROCK's orbital requirements detailed in the CubeSat Mission Parameters.

Target: SHAMROCK

Observer: ND_GroundStation

Start Time (UTC)	Stop Time (UTC)	Duration (s)
01 Jan 2028 21:49:40.316	01 Jan 2028 21:52:30.643	170.32666553
01 Jan 2028 23:22:40.720	01 Jan 2028 23:29:38.522	417.80208908
02 Jan 2028 00:59:16.887	02 Jan 2028 01:04:48.508	331.62142597
02 Jan 2028 02:36:24.657	02 Jan 2028 02:40:31.251	246.59462341
02 Jan 2028 04:11:58.231	02 Jan 2028 04:17:35.550	337.31898735
02 Jan 2028 05:47:23.174	02 Jan 2028 05:53:28.852	365.67779080
02 Jan 2028 22:17:31.687	02 Jan 2028 22:24:03.177	391.49025860
02 Jan 2028 23:53:06.073	02 Jan 2028 23:59:33.868	387.79479201
03 Jan 2028 01:30:21.645	03 Jan 2028 01:34:48.631	266.98611378
03 Jan 2028 03:06:37.026	03 Jan 2028 03:11:27.394	290.36765909
03 Jan 2028 04:41:51.172	03 Jan 2028 04:48:11.498	380.32537090
03 Jan 2028 06:18:26.079	03 Jan 2028 06:21:59.062	212.98345708

Number of events : 12

Figure B.2. GMAT generated list of available SHAMROCK contacts with the IrishSat Ground Station located on Notre Dame's campus over the 48 hour period. Note that 12 contacts are established with an average possible link time of 316 seconds.

C Payload Concept and Implementation

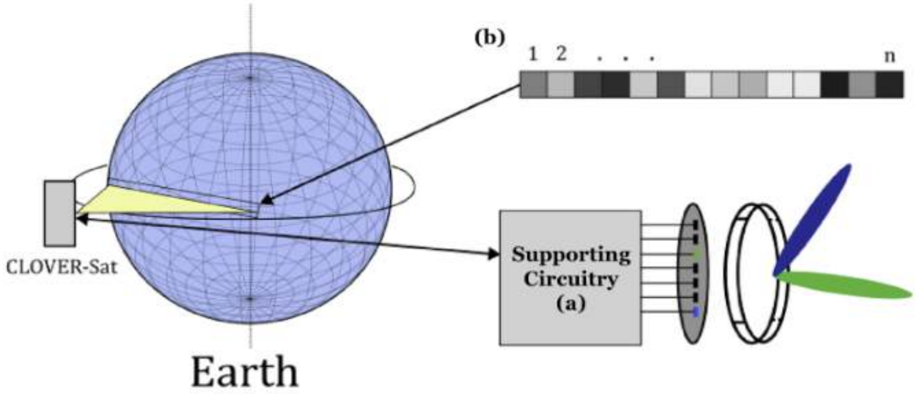

Figure C.1. SHAMROCK mission concept, depicting the 2U satellite in LEO performing high data rate downlink in the K-band using beam switching capabilities. (a) The RF-supporting electronics include a radio to produce the desired IF signal, an upconverter module to produce the RF transmission signal, a K-band RF switch matrix to implement switch beam capabilities, and a digital control circuit to quickly switch beams during operations. (b) The high throughput data transmitted/received via 1D SBL array.

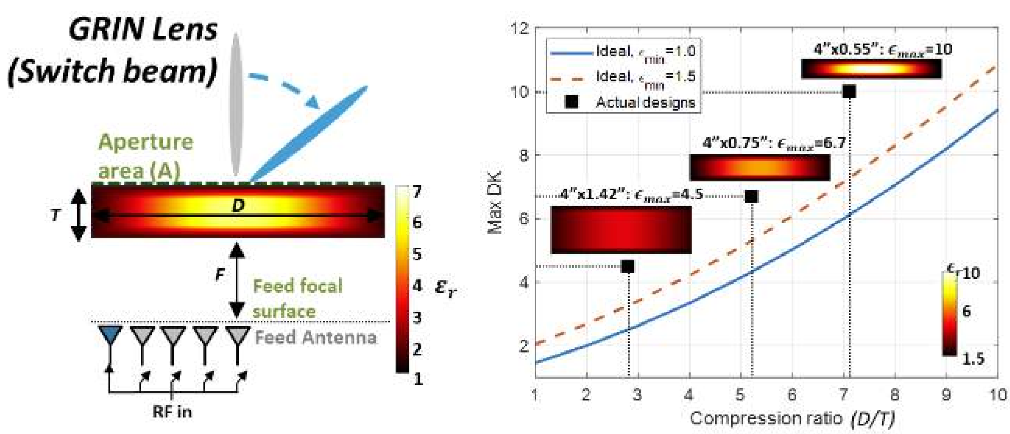

Figure C.2. Explanation of GRIN Lens used in a switch beam implementation. This shows in operation how the variable effective dielectric constant throughout the lens allows for high-gain beamforming. Additionally, by utilizing higher effective dielectric constants, the lens can be made thinner to suit a small-sat platform like the 2U mission design.

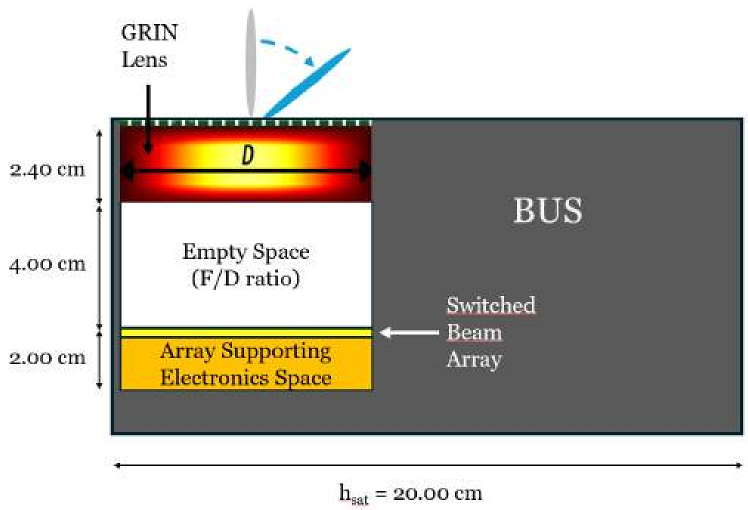

Figure C.3. Implementation of SBL array architecture on a 2U platform. The empty space represents the required distance between the antenna array and the lens for optimal operations. This is half of the diameter of the lens (F/D ratio = 0.5, focal distance over diameter). This figure shows that even taking into consideration supporting electronics space, the design still has over 1U of space for bus operations and function. This figure was made with conservative estimates of lens size, diameter, and target F/D ratio to characterize the worst-case spacing on the 2U mission. As shown in the figure, the SBL array does not require any deployment, reducing complexity and risk.

D Switched Beam Lens Antenna vs Phased Array Antenna

Feature	**Phased Array Antenna (PAA)**	**SHAMROCK's Switched Beam Lens (SBL)**
Beamforming Capability	Continuous high-gain, dynamic beam steering	Discrete high-gain, quasi-omnidirectional beam mode available
Power Consumption	High (up to 140W for full functionality)	Ultra-low (<1% of PAA, 1W)
System Complexity	Complex with active elements and extensive software control	Simplified with passive beam steering and 1 active element
Size and Weight	Large, requires significant housing space	Compact, fits within a 2U CubeSat platform
Manufacturing Cost	High due to active components and complex assembly	Low, leveraging recent advancements in 3D-printed ceramic lenses
Thermal Management	Requires robust cooling due to high power usage	Minimal cooling needed due to low power consumption
Redundancy and Reliability	Limited redundancy, complex failure modes	Enhanced reliability with quasi-omnidirectional fallback mode
Applications	Large satellites and high-budget missions	Small satellites, low-cost missions, scalable for constellations
Impact on Launch Mass and Cost	Significant mass and cost implications	Reduces mass and cost by up to 4U and $360,000 per satellite launch
Alignment with NASA Goals	Meets basic communication needs	Directly supports NASA's cis-lunar and LEO infrastructure goals

Table D.1. Comparison between Phased Array Antennas (PAA) and SHAMROCK's Switched Beam Lens (SBL) Antenna

E SHAMROCK Bus

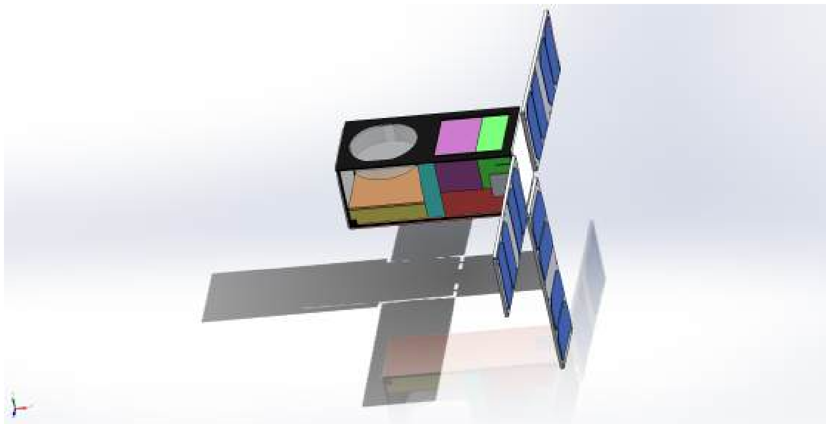

Figure E.1. The SHAMROCK Bus. The 2U system displays the spaces allocated for each subsystem within the CubeSat, as well as the deployed solar panels and frame. The front-facing side of the bus has been made clear so the interior of the CubeSat can be seen. The clear, circular component designates the ceramic lens. Orange designates the space for the SBL antenna. Yellow allocates the magnetorquer module. Blue designates the monopole antenna deployment module. Purple allocates the reaction wheel ADCS module. Greenhouses the PCBs, specifically the power (controls and MPPT) board, the flight computer, and the SDR. Red signifies the batteries and BMS. The copper plate, located on the underside of the CubeSat, is the heat sink, in which the outside face is covered in a thermal control coating (TCC). The frame itself is black, with the gray components designating hinges and springs that will connect the CubeSat faces together.

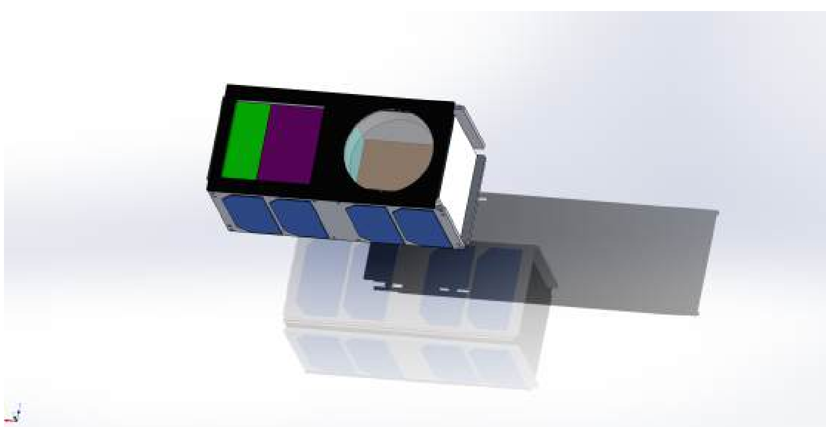

Figure E.2. The SHAMROCK Bus before solar panel deployment.

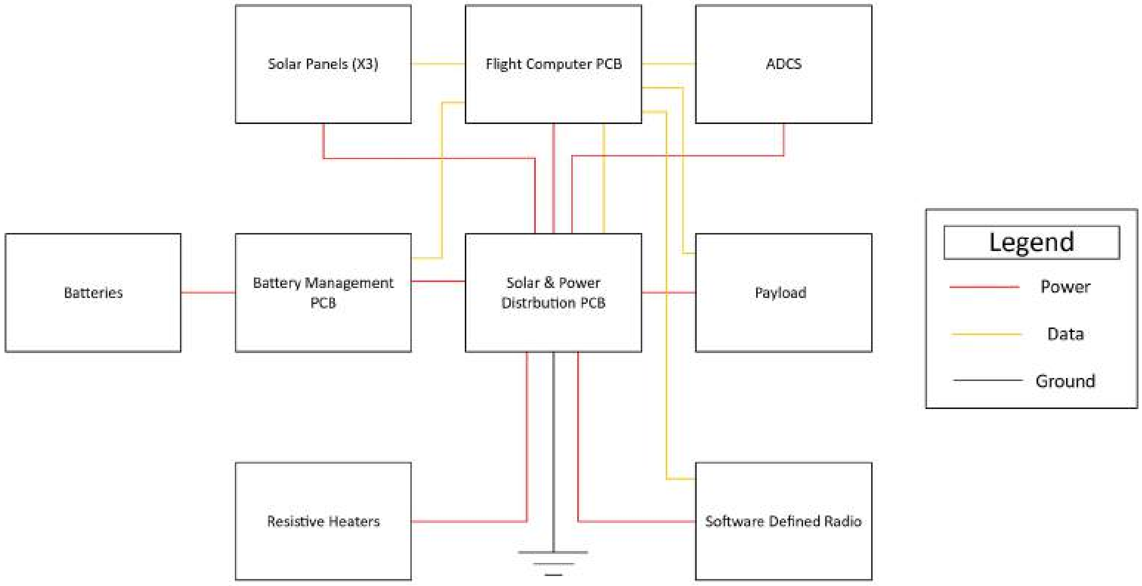

Figure E.3. The SHAMROCK mission risk mitigation and implementation block diagram.

F Project Timeline

Table F.1. SHAMROCK Project Schedule.

TASK	START	END
SHAMROCK Mission Definition and Admin		
Fundraise	Mar '24	Jun '28
Receive and Review Proposal Feedback	Mar '24	Mar '24
Demonstrations of Key Prototypes	Mar '24	Apr '24
Appoint New Leadership	Mar '24	Aug '24
Payload Redesign	Jul '24	Aug '24
Organize Subteams	Jul '24	Aug '24
Payload Development	Aug '24	Oct '24
New Member Integration	Aug '24	Dec '24
Elect and Appoint New Leadership	Mar '25	Aug '25
New Member Integration	Aug '25	Oct '25
Elect and Appoint New Leadership	Mar '26	Aug '26
New Member Integration	Aug '26	Oct '26
Elect and Appoint New Leadership	Mar '27	Aug '27
New Member Integration	Aug '27	Oct '27
Elect and Appoint New Leadership	Mar '28	Aug '28
New Member Integration	Aug '28	Oct '28
Elect and Appoint New Leadership	Mar '29	Aug '29
CSLI Proposal	**Aug '24**	**Nov '24**
Read NASA CSLI AoPO and Documentation	Aug '24	Nov '24
Draft CSLI Proposal Outline	Aug '24	Sep '24
Draft CSLI Sections Needed	Aug '24	Oct '24
Redefine CubeSat Payload Mission	Sep '24	Oct '24
Form Mission Requirements	Oct '24	Oct '24
Finalize CSLI Proposal for Review	Oct '24	Oct '24
Conduct Internal Merit and Feasibility Reviews	Oct '24	Oct '24
Send Out Proposal to Reviewers	Oct '24	Oct '24
Conduct Cost Analysis	Oct '24	Oct '24
Confirm Research Budget Guarantee	Oct '24	Oct '24
Edit Proposal in Accordance with Feedback	Oct '24	Nov '24
Submit CSLI Proposal to NASA	Nov '24	Nov '24
Technology Development		
Conduct Research on Critical Systems and Requirements	Aug '24	Dec '24
Design and Development of In-House Subsystems	Aug '24	May '25
⋮	⋮	⋮

TASK	START	END
⋮	⋮	⋮
Develop In-House Test Equipment	Aug ’24	May ’25
Conduct Frequent Informal Subsystem Design Reviews	Sep ’24	May ’25
Sort systems between in-house development and COTS	Oct ’24	Nov ’24
Subsystem Integration Testing	Oct ’24	Nov ’24
Compile findings and concepts in PDR Draft	Dec ’24	Dec ’24
Write and finalize CubeSat PDR	Dec ’24	Jan ’25
Internal PDR Review	Dec ’25	Dec ’25
PDR Feedback Implementation	Dec ’25	Jan ’25
Design integrations between subsystems	Jan ’25	Jan ’25
Prototype subsystems for proof of concept	Jan ’25	Jan ’25
Evaluate and select subsystems for maturation	Jan ’25	Jan ’25
Write and Finalize CubeSat PDR	Jan ’25	Jan ’25
Make functional models of developed subsystems	Feb ’25	Ma ’25
Test individual components and subsystems	Mar ’25	May ’25
Internal CDR Review	Mar ’25	Mar ’25
CDR Feedback Implementation	Apr ’25	Apr ’25
Conduct End of Year Demonstrations	Apr ’25	Apr ’25
Make changes to subsystems from CDR review	May ’25	Aug ’25
Integrate functional models and COTS into Engineering Model	Aug ’25	Dec ’25
Test integrated Engineering Model for functionality	Dec ’25	Mar ’26
Launch Readiness Review (LRR)	Apr ’26	May ’26
Make changes to subsystems from testing	Jun ’26	Aug ’26
Conduct Environmental Testing	Sep ’26	Jan ’27
Mission Readiness Review (MRR)	Feb ’27	Mar ’27
Public Outreach/Conference Publications	Jan ’28	Apr ’29
Launch Preparation and Mission	**Mar ’28**	**Jun ’28**
Handoff to NASA	Mar ’28	May ’28
Pre-Launch Verification	May ’28	Jun ’28
Launch	**Jul ’28**	**Jul ’28**
Data Analysis Period	Jun ’28	Jul ’29
Mission Operations	Aug ’28	Aug ’29
In-Orbit Check-Out and Validation	Aug ’28	Dec ’28
Post-Launch Operations Review	Aug ’28	Sep ’28
Post-Launch Report	Mar ’29	Apr ’29

G Project Budget

Table G.1. SHAMROCK Budget.

Part Name	Satellite Component	Quantity	Price	Total
Samsung 18650 Cells	Battery Pack	4	$2.95	$11.80
Battery Endcaps	Battery Pack	2	$50.00	$100.00
Battery Management System (BMS)	Battery Pack	1	$200.00	$200.00
Resistive Heater	Battery Pack	1	$52.44	$52.44
Power Board (MPPT and Control Board)	Power Board	1	$400.00	$400.00
2U Solar Panels	Solar Panels	3	$5,000.00	$15,000.00
Nichrome Burn Wire	Solar Panels	1	$11.99	$11.99
Torsional Spring	Solar Panels	1	$7.49	$7.49
Hinges	Solar Panels	1	$11.98	$11.98
Magnetorquer Wire	Magnetorquer Module	1	$12.29	$12.29
Magentorquer Rods	Magnetorquer Module	1	$2.70	$2.70
Magnetorquer Board	Magnetorquer Module	1	$200.00	$200.00
Patch Antenna	Bus	1	$59.40	$59.40
Heat Sink Panel	Bus	1	$38.40	$38.40
Thermal Coatings	Bus	1	$400.00	&400.00
Structural Panels	Bus	6	$5.00	$30.00
Structural Frame	Bus	1	$50.00	$50.00
Pack of Bus Fasteners	Bus	1	$7.59	$7.59
Reaction Wheels	Reaction Wheels	4	$1,500.00	$6,000.00
Reaction Wheel Mount	Reaction Wheels	1	$19.99	$19.99
Ceramic Antenna Lens	Payload	1	Dr. Chisum's Lab	–
Switch Beam Lens Array	Payload	1	Dr. Chisum's Lab	–
Monopole Antenna	Communication Systems	1	$4.97	$4.97
Monopole Antenna Deloyment Housing	Communication Systems	1	$40.00	$40.00
Sidekiq Z2 Module	Communication Systems	1	Donated: Epiq Solutions	–
Flight Computer	Flight Computer	1	$200.00	$200.00
Radio Licensing Fees	Bus, Payload	1	$35.00	$35.00
Estimated Budget Inflation	SHAMROCK CubeSat	–	$3,500.00	$3,500.00
Total CubeSat Cost				$26,896.04

H Funding Letter of Intent

UNIVERSITY OF NOTRE DAME | RESEARCH

Jeffrey F. Rhoads
Vice President for Research
Professor of Aerospace and Mechanical Engineering

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+1 574-631-8384 | jrhoads2@nd.edu | research.nd.edu

November 15, 2024

University of Notre Dame Research
317 Main Building
Notre Dame, IN 46556 USA

NASA/Goddard Space Flight Center Procurement Office,

I am writing on behalf of Notre Dame Research to formally express our intent to collaborate with IrishSat in supporting their undergraduate CubeSat project at the University of Notre Dame. As a distinguished research institution committed to fostering innovation and excellence in education, we are genuinely excited about the potential of IrishSat's SHAMROCK-Sat mission and we recognize the intrinsic value and contributions this will make toward space exploration and scientific discovery.

The SHAMROCK-Sat mission, orchestrated by a team of devoted undergraduate students under the guidance of experienced faculty members, aims to demonstrate the viability of a novel antenna - first developed by an electrical engineering research professor Dr. Jonathan Chisum. This mission embodies the spirit of pioneering advancements in aerospace and electrical engineering. Notably, this initiative resonates with our university's overarching mission to provide immersive, hands-on research opportunities for students, thereby catalyzing progress in these pivotal fields.

In alignment with our commitment to facilitate and propel meaningful research endeavors, Notre Dame Research is prepared to extend partial financial support (amount to be determined) for the remaining material costs associated with the CubeSat bus. This commitment underscores our unwavering dedication to ensuring the success and sustainability of the SHAMROCK-Sat mission.

We look forward to the prospect of a collaborative partnership that not only furthers the goals of IrishSat but also exemplifies the synergy achievable through the convergence of academic prowess and innovative exploration. Please consider this letter as a formal declaration of our commitment to supporting this noteworthy undertaking.

Sincerely,

Jeffrey F. Rhoads

Figure H.1. Letter of Support from Dr. Jeffrey Rhoads, Vice President for Research at the University of Notre Dame, reaffirming Notre Dame Research's commitment to provide partial financial support for the SHAMROCK mission's remaining material costs, ensuring the mission's financial stability.

I SHAMROCK Reviewers and Credentials

Table I.1. Review Panelist Credentials.

Reviewer	Credentials	Organization/Institution
Paul Rumbach	Associate Teaching Professor of Aerospace and Mechanical Engineering and Research Scientist	University of Notre Dame
Will Karpick	Space Systems Engineer	Northrop Grumman
Bill Goodwine	Professor of Aerospace and Mechanical Engineering	University of Notre Dame
David Forseth	Distinguished Member of Technical Staff	General Dynamics Mission Systems
Tom Harkins	Systems Engineering Leader	Northrop Grumman
Juwan Jeremy Jacobe	Research Physicist	United States Naval Research Laboratory
Meenal Datta	Assistant Professor of Aerospace and Mechanical Engineering	University of Notre Dame
Gary Bernstein	Professor of Electrical Engineering	University of Notre Dame

J SHAMROCK Reviewer Panel Feedback

Table J.1. Educational Merit - External Review Feedback.

Educational Merit		
Reviewer	**Rating**	**Explanation**
Paul Rumbach	9	None
Will Karpick	9	"Students are responsible for team leadership, system integration, subsystem design, and manufacturing. The project models industry programs by requiring students to make engineering decisions throughout the project's lifecycle. This begins with the initial design, where students have decided to pursue their own design and manufacturing or a COTS product. These design decisions are the responsibility of the students. These designs must be capable of meeting manufacturing, also the student's responsibility, a design consideration often missed in theoretical projects in the student's curriculum. System integration is a new topic for many students that requires their own research and development of best practices through personal experience. These project phases are often forgotten in undergraduate education, but SHAMROCK would allow students to gain real experience through ownership of these aspects of the project. An increase in educational merit could be realized through student development of the payload. However, due to the often complexity of payload development and the desire to manage student's capability, this is not seen as a substantial negative."
Bill Goodwine	8	"The proposal does this well."
David Forseth	9	"I thought the proposal did a good job of explaining the projects IrishSat has worked on and how knowledge is transferred to new team members. One suggestion may be to briefly highlight how you recruit new members either through on-campus activities or social media."
Tom Harkins	10	"There is no more direct way to support the goal of a skilled STEM workforce than by having direct hands-on experiences, exactly like the IrishSat team is building. Involving multiple disciplines/majors across the University in the CubeSat project is an example of attracting diverse groups, one of NASA's explicit goals. The supplementary projects listed in Section 2.1 (Team Structure) feed into this."
Juwan Jeremy Jacobe	9	"Merit review section identifies technical and soft skills learned by students across various disciplines. Team highlights an interdisciplinary work environment committed to the professional development of its members."
Meenal Datta	None	"In addition to pointing out how this mechanism will benefit undergrads (which you've done), it would be great to highlight the unique advantages of your undergrad-led team (i.e., why will undergrads be more successful, assuming other applicants will be a mixed bag)."
Gary Bernstein	None	Notes: refine CHARM-Sat description, IrishSat team description isn't clear enough, make block diagram to explain team connections, go more into depth on how SHAMROCK relates to NASA Objectives

Table J.2. Technological Merit - External Review Feedback.

Technological Merit		
Reviewer	**Rating**	**Explanation**
Paul Rumbach	6	"It was not presented in a straightforward, convincing manner. I really had to dig deep into the proposal to find any kind of technical information about this."
Will Karpick	8	"NASA's objective to grow the commercial space economy will only be realized through decreased costs allowing for ease of entry to the market. Technology that is not only smaller and lighter for lower launch costs but also less complex is a worthy development. A more detailed demonstration of the decreased complexity compared to industry standard communication design would improve SHAMROCK's argument. The lower launch cost and Gateway Communications whitepaper are helpful, but further detailing the design compared to industry standard in a quantitative analysis would improve the proposal's merit."
Bill Goodwine	3	"From: CSLI_AoPO+FINAL-2024.pdf, page 22: c) Technology – Does the proposal demonstration enhance future missions, reveal a flaw in a potentially enhancing technology, or otherwise impact the trade space for enhancing technologies? I believe that section 3.2 should contain much more technical information. You describe current communication demonstrators as "big, power hungry and inefficient." How power-hungry and how inefficient are they (in numbers)? What the numbers for your proposed system, and how much better are they? Can the provide the same bandwidth in half the volume and one third of the power, or what? Which is cheaper? Does it matter? Simply asserting your way is better probably won't convince anyone who needs to make the final decisions."
David Forseth	8	"Thought the technical solution was well explained. A few specific comments: In section 3.3, the cis-lunar space solution describes the need specifically for Ka-band high throughput. Elsewhere in the document K-band is described, I think with target frequencies of 24 to 24.25 GHz. Is there any technical issue with transferring the solution to Ka-band in the future. It may be good to discuss the difference just to alleviate any concerns about the difference or highlight additional steps to move to a Ka-Band solution to support the cis-lunar objective. Space-to-Space vs Space-to-Ground: In the Abstract, concerning the statement: 'This innovative technology enables high-throughput K-band communication links between Earth and other satellites...' I'd suggest: 'This innovative technology enables high-throughput K-band Earth to Space and Space to Space communication links....' Something to make it a bit clearer that both types of links are under consideration. Appendix C Payload Concept and Implementation: Are there additional details on testing goals once the cubesat is in orbit: - Data rates you hope to achieve - Assuming a single cubesat is deployed testing will only be Space to Earth. In the proposal Space to Space links is also addressed. Are there other challenges space to space would introduce that would need to be done beyond this work? Or does the Space to Earth findings inform feasibility of Space to Space? In Appendix C itis mentioned that SBL doesn't require deployment. I wasn't sure what this meant. Is this saying it is a fixed non-moving component with the cubesat. Suggest clarifying what is meant by 'deployment'."
⋮	⋮	⋮

Reviewer	**Rating**	**Explanation**
⋮	⋮	⋮
Tom Harkins	9	"2.1: Addressed – cited Lunar Gateway requirement for high throughout K-band Comms 2.2: Addressed – section 3.3 explains the technology demonstration mission with reduced mass/power/complexity (presumably heat as well) 2.4 & 3.1 & 4.2: Addressed – serves American leadership in space technology/economy Achieving a quasi-omnidirectional beam for high-data throughput is novel."
Juwan Jeremy Jacobe	6	"While described technology is compelling for mass and power gains, more concrete measures for how it meets with objectives is needed to quantify the mission's merit. For example, Section 3.3 states that mission will contribute towards Strategic Objective 2.1 through its communications capabilities, proposal does not quantify does not quantify the gains made: i.e. if the technology is shown to be capable in orbit, what does that enable now? What kind of cislunar to earth satellite network is needed for a sufficient data link and how does the proposed technology improve cost-effectiveness of such a constellation vs. conventional technologies? Another example: paragraph describing alignment with Strategic Objective 2.2 mentions that LEO constellation of 2U CubeSats with proposed technology can carry transmission for a fraction of the cost — what is that fraction? With quantities like these, the contribution towards and alignment with NASA objectives would be more readily apparent. "
Gary Bernstein	None	Notes: -What is the lens? How many transmitters? Compare to PAA - say more about low-gain connections and low-throughput capabilities being good things - go more into depth on how SHAMROCK relates to NASA Objectives -fix structure for better flow

Table J.3. Feasibility - External Review Feedback.

Feasibility		
Reviewer	**Rating**	**Explanation**
Paul Rumbach	7	"Again, I really had to dig deep to find any convincing technical details. Overall, I thought the proposal was long on words, short on technical detail."
Will Karpick	8	"The substantial research and risk reduction activities performed by the team gives confidence the team has developed the best practices and experience necessary to execute a satellite project from design to operations. The team has built from past failures and has developed an impressive track record of successful projects. Developing ground infrastructure, testing infrastructure, and prototype satellites are all important for reducing risk, giving confidence to schedule and technical execution. A larger emphasis on systems engineering in the project life cycle would improve confidence in the team to execute. The team's experience with system integration is limited, and developing a clear systems engineering approach should be a point of emphasis to minimize integration issues early in the project life. The project timeline could be refined to better align with industry standards. Three months between PDR and CDR is likely not feasible to adequately mature the design. Additionally, design review feedback response will likely need more than a month to be executed to sufficient detail. To reduce potential issues and misses in the system reviews, it is recommended for the team to perform subsystem reviews prior to each system review. The appearance of a one-year margin between MRR and Hand-off to NASA maintains confidence in the schedule, however a more explicit margin allocation is desirable. A more detailed description of lessons learned and heritage systems would improve the feasibility confidence. Understanding the improvements the team has made would be beneficial. Furthermore, a more detailed chart of showing when the various systems were designed, developed, operated, and improved across the various projects would allow greater confidence in the ability of the team to leverage their experience. Overall, the team demonstrates an impressive knowledge of satellite design and the space industry. They have a strong student bench to draw from their experience and to execute to their design and schedule. There is substantial confidence in the team's ability to design, build, and operate a satellite mission."
David Forseth	9	"Thought the teams experience of the project team on other projects and competitions was explained well."
Tom Harkins	5	"Team's experience is excellent – good to highlight past successes. Additional Recommendations: • 1: Consider a dedicated sub-section on risks – discuss how IrishSat mitigates them (e.g. no deployables). Any major/showstopping risks? Stating them and describing how they're addressed will demonstrate an understanding of the weaknesses of the system/design • 2: The proposal is generally lacking figures, flowcharts, block diagrams, etc that would make it easier to follow/understand aspects of the design than simply text. There are also varying levels of detail for each subsystem • 3. Comment on how the SBL payload will mature, in terms of TRL. NASA may want to use or further fund this type of development effort, so having a clear plan to reach high TRL will lend credibility"
⋮	⋮	⋮

Reviewer	Rating	Explanation
⋮	⋮	⋮
Juwan Jeremy Jacobe	5	"Proposal shows that team has sufficient expertise through prior experience in iterative and competitive projects, but further clarification needed to highlight mission's feasibility: - Mission dimensions are not concretely defined: what is the mission's expected lifetime and why? How much data collection will you need to do? I.e. what is a "mission success" for you? - No risk mitigation plan for either the design process or mission operations. Having this would demonstrate (1) your preparation for the mission and (2) the margin of safety you have in case things don't go wrong. For example, you could address the case where your spacecraft can't control attitude beyond to a certain precision; how likely is that to happen, to what degree would that harm the mission, and lastly, how can you mitigate this as much as possible? - No probability of success highlighted within the feasibility review"
Gary Bernstein	None	Notes: -support ICE/FLOATing DRAGON description more. How will design be adopted by NASA, and for what? - names of subteams needs to be more clear - explain more of the resources Notre Dame has for IrishSAT - define certain elements (PID, MARK2), earlier and better

Table J.4. Overall NASA Alignment - External Review Feedback.

Overall NASA Strategic Plan Alignment		
Reviewer	**Rating**	**Explanation**
Paul Rumbach	8	None
Will Karpick	9	"A combination of education and technology development align the SHAMROCK mission with NASA's Strategic Plan. Providing commercially viable technology and developing talented and experienced engineers are clear priorities to NASA and are met by SHAMROCK. For areas of improvement, see both the educational and technological merit review."
Bill Goodwine	8	"Seems very well aligned to education as well as the specific parts of the strategic plan you cite."
David Forseth	8	"As mentioned above felt the proposal had good mapping to the NASA education and technical objectives."
Tom Harkins	10	"As stated above, all core aspects of the NASA Strategic Plan are addressed."
Juwan Jeremy Jacobe	7	"The proposed SHAMROCK mission describes a compelling technology with applications for cis-lunar and LEO communications infrastructure and a valuable hands-on project for STEM students. Though the technology demonstration is certain to address the NASA objectives mentioned in the proposal, further detail and quantification is needed to establish to what extent it furthers each objective in light of a successful demonstration."

K IrishSat Organizational Structure

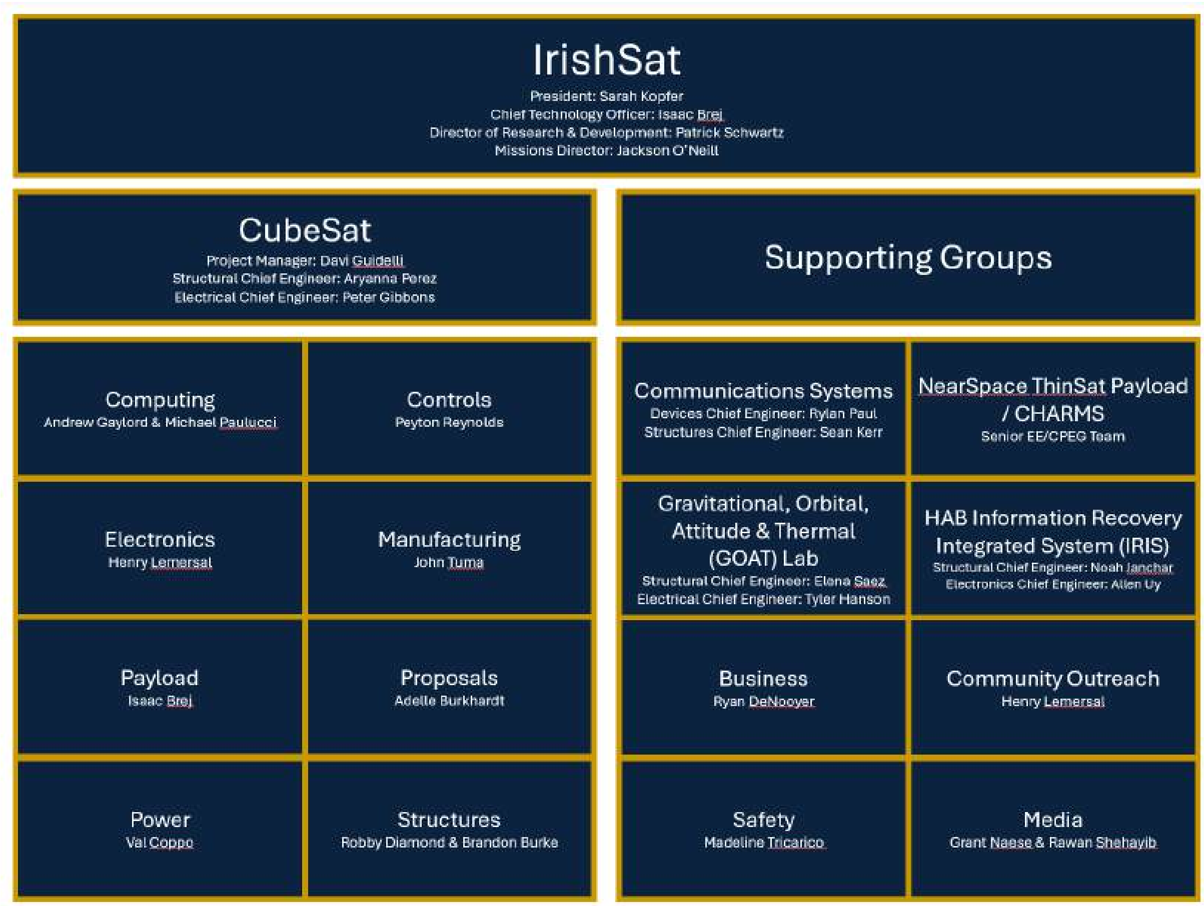

Figure K.1. The IrishSat organizational structure showing key leadership roles, technical teams, and supporting groups. The structure highlights the team's collaborative approach to satellite development, with the CubeSat project as the central focus and various specialized teams contributing to subsystem design, testing, and mission success. Under each team name, the associated lead[s] is listed.

L SHAMROCK Technical Development Structure

Figure L.1. This structure outlines the key technical groups involved in every stage of SHAMROCK's mission, from initial design and development through integrated system development and rigorous testing. It reflects the team's commitment to comprehensive, end-to-end design and rapid iteration. By organizing technical divisions to independently develop and integrate systems in parallel, SHAMROCK can efficiently transition between phases of design, testing, and analysis. This streamlined approach ensures that each subsystem, whether directly involved in core CubeSat operations or in broader mission support, contributes to a unified, resilient system. Each division, from Design and Development to Integrated System Development and Testing, plays a crucial role in aligning the project with mission objectives, ensuring that all technologies are purposefully developed, tested, and refined to achieve mission success. The collaborative nature of these divisions supports both the primary CubeSat mission and auxiliary systems, fostering an environment of integrated innovation and mission readiness.

M IrishSat Team Makeup

Name	Graduation Year	Major
Executives		
Sarah Kopfer	2025	Computer Engineering
Isaac Brej	2025	Electrical Engineering
Patrick Schwartz	2025	Mechanical Engineering
Leadership		
Aryanna Perez	2025	Aerospace Engineering
John Tuma	2025	Aerospace Engineering
Peter Gibbons	2025	Electrical Engineering
Ryan DeNooyer	2026	Accounting, Finance
Adelle Burkhardt	2026	Aerospace Engineering
Brandon Burke	2026	Aerospace Engineering
Elena Saez	2026	Aerospace Engineering
Jackson O'Neill	2026	Aerospace Engineering
Allen Uy	2026	Computer Engineering
Sean Kerr	2026	Aerospace Engineering
Andrew Gaylord	2026	Computer Science
Michael Paulucci	2026	Computer Science, Math
Tyler Hanson	2026	Electrical Engineering
Rylan Paul	2027	Electrical Engineering
Val Coppo	2027	Electrical Engineering
Davi Guidelli	2027	Mechanical Engineering
Noah Janchar	2027	Mechanical Engineering
Robby Diamond	2027	Mechanical Engineering
Madeline Tricarico	2027	Physics, Russian
Grant Naese	2028	Aerospace Engineering
Rawan Shehayib	2028	Computer Engineering
Members		
Micheline Denn	2025	Aerospace Engineering
Aidan Oblepias	2025	Electrical Engineering
Josiah Owens	2025	Electrical Engineering
Nathaniel Holt	2026	Aerospace Engineering
Jack Decker	2026	Computer Engineering
Alyssa Riter	2026	Computer Science
Anna Arnett	2026	Computer Science
Luca Watson	2026	Computer Science
Sophie Lama	2026	Computer Science
Nicholas Mark	2026	Electrical Engineering
William Stotz	2026	Electrical Engineering
Ethan Stone	2026	Electrical Engineering, Physics
Christian Leonard	2026	Mechanical Engineering
Jacobo Wiesner	2027	ACMS, Computer Science

Daniel Skojac	2027	Aerospace Engineering
Henry Blatchford	2027	Aerospace Engineering
Matthew Jones	2027	Aerospace Engineering
Nolan Hines	2027	Aerospace Engineering
Orianna Saade	2027	Aerospace Engineering
Cody Chun	2027	Computer Engineering
Elias Beardmore	2027	Computer Engineering
Rene Alzina	2027	Computer Science
John Nisbet	2027	Electrical Engineering
William Sinclair	2027	Electrical Engineering
Charlie Krebs	2027	Mechanical Engineering
Gabriel Angaiak	2027	Mechanical Engineering
Jack Blum	2027	Mechanical Engineering
Lauren Catalano	2027	Physics
Clara Baldwin	2028	Aerospace Engineering
David Scully	2028	Aerospace Engineering
Ellie Grieco	2028	Aerospace Engineering
Henry Fitzthum	2028	Aerospace Engineering
Josefa Diuana	2028	Aerospace Engineering
Kathryn Huth	2028	Aerospace Engineering
Luke Tocco	2028	Aerospace Engineering
Michael Kuczun	2028	Aerospace Engineering
Stephen Tirpak	2028	Aerospace Engineering
Andres Perez	2028	Computer Engineering
Brandon Forseth	2028	Computer Engineering
Garrett Connell	2028	Computer Engineering
Kristofer Ulanday	2028	Computer Engineering
Qingci Meng	2028	Computer Engineering
Abe Packee	2028	Computer Science
Brian Sagon	2028	Computer Science
Daniel Burke	2028	Computer Science
Peter Bae	2028	Computer Science
Christopher Gutowski	2028	Electrical Engineering
Jack Whitman	2028	Electrical Engineering
Joshua Kannappilly	2028	Electrical Engineering
Kerry Gutowski	2028	Electrical Engineering
Meghan Moy	2028	Electrical Engineering
Nick Martin	2028	Electrical Engineering
Nicolas Cavalluzzi	2028	Electrical Engineering
Angel Parada Hercules	2028	Mechanical Engineering
Ib Malanog	2028	Mechanical Engineering
Lukas Parada Hercules	2028	Mechanical Engineering
Sarah Sargent	2028	Mechanical Engineering
Owen Conway	2028	Mechanical Engineering
James Burke	2028	Physics

Christopher Qian	2028	Physics, Aerospace Engineering
Kristijonas Bernatonis	2028	Physics, Math

Figure M.1. The SHAMROCK mission is led by a team of undergraduate students from various disciplines, creating a unique learning environment. Unlike seasoned engineers, students bring fresh, out-of-the-box ideas that challenge conventional approaches, as they enter with minimal prior experience. This structure promotes hands-on learning and project ownership, empowering students to develop technical skills, leadership, and problem-solving abilities through direct involvement in every phase of the mission. While the rotation of students due to graduation presents a challenge, it also ensures a continuous infusion of new perspectives and offers the opportunity for students to step into new roles and follow a common trajectory that puts them into leadership positions.

N IrishSat Team Demographics

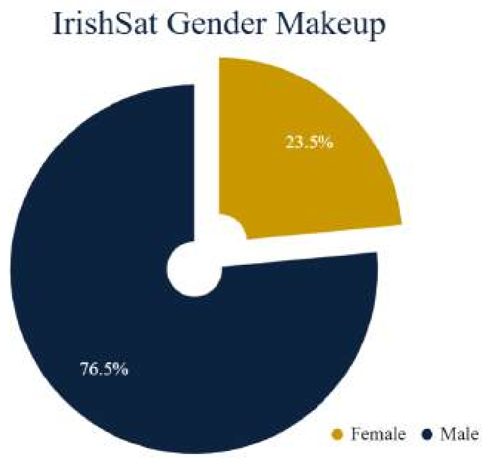

Figure N.1. IrishSat is proud to foster a diverse team environment, with women making up 23.5% of membership. This representation exceeds the average female participation in the space industry (20-22%), as reported by the United Nations and the International Organization for Standardization (ISO). This strong presence of women enhances the team's innovation, perspective, and overall success, aligning closely with initiatives like the UN's Space4Women, which aims to empower women in space and STEM. Women in IrishSat play key roles across all aspects of the SHAMROCK mission, from subsystem design to project leadership. IrishSat's 23.1% female leadership, mirroring the club's composition, exemplifies a commitment to creating pathways for women in STEM, ensuring they have active and influential roles in space exploration and technology development. The team is led by a female president, Sarah Kopfer—a computer engineering major who will be joining Blue Origin as an aerospace systems engineer. Other key female leaders include the proposal lead, Adelle Burkhardt, an aerospace engineering major; SHAMROCK structures lead, Aryanna Perez, an aerospace engineer who will be working at SpaceX; GOAT Lab structures lead, Elena Saez, also an aerospace engineering major; safety lead, Madeline Tricarico, a physics major; and media lead, Rawan Shehayib, a computer engineering major. IrishSat also promotes an inclusive environment that supports the professional growth of women. Through hands-on projects, mentorship, and knowledge transfer, IrishSat prepares female members for impactful careers in the evolving space industry. This mission aligns directly with NASA's Strategic Goals and the United Nations Sustainable Development Goals (SDG), particularly SDG 5 (Gender Equality) and SDG 4 (Quality Education), through cultivation of a diverse and skilled pipeline of future space engineers. With focus on inclusivity and gender equity, IrishSat not only equips students for successful careers in the space industry but also contributes to a more equitable and representative future for aerospace and STEM fields worldwide.

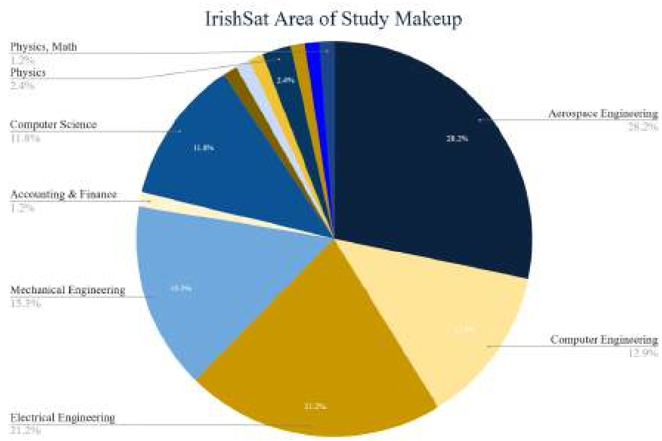

Figure N.2. IrishSat is made up of a diverse group of students with a wide range of academic backgrounds. The largest group is Aerospace Engineering, comprising 29.2% of the team, followed by Electrical Engineering at 21.3%, Mechanical Engineering at 15.7%, and Computer Engineering at 12.4%. Other represented fields include Computer Science (11.2%), Physics, and interdisciplinary studies like Physics and Russian, Electrical Engineering and Physics, and more specialized combinations. This diversity allows IrishSat to approach design challenges from various technical perspectives, enriching solutions with expertise in structural mechanics, software development, electronics, and theoretical analysis. The executive board exemplifies this academic diversity: the President is a Computer Engineering major, the Chief Technology Officer is an Electrical Engineering major, and the Director of Research & Development is a Mechanical Engineering major. IrishSat actively encourages members to explore their academic passions and utilize their unique skills within the organization. Through project involvement, mentorship, and major discernment support, members have the opportunity to explore different areas of space engineering, discovering their strengths and areas of interest within the field. This interdisciplinary team composition is instrumental in advancing the SHAMROCK mission and building a strong pipeline of skilled space engineers for the future.

O Major Accomplishments of IrishSat

Date	**Accomplishment**
2020	IrishSat was founded.
April 2021	*IRIS* launched for the first time.
April 2022	*IRIS* launched for the second time.
April 2022	The *GOAT* and *CubeSat* teams conducted first integrated demonstration.
May 2022	*CubeSat*'s senior electrical engineers won the school senior design competition with their *CubeSat* power management board design and demonstration.
January 2023	*IRIS* became a finalist in the NASA Floating Dragon competition.
August 2023	*IRIS* completed successful NASA integration and an undeployed flight aboard a NASA gondola from New Mexico.
November 2023	IrishSat submitted its first CSLI proposal to NASA.
January 2024	*Starshade* won the NASA Starshade competition.
April 2024	IrishSat received the NearSpace Launch opportunity.
April 2024	*IRIS* launched for the third time.
2025	*CHARMS* is scheduled for launch.

P FLOATing/ICE DRAGON

IRIS was IrishSat's first major project, launched in 2020 as a high-altitude balloon mission aimed at providing near-space research capabilities. The initial two launches were unguided and focused solely on data collection for a professor's research, but both missions faced recovery challenges, landing in unrecoverable terrain.

By fall 2022, the team pivoted to developing steerable capabilities for IRIS, aiming for controlled descents to ensure safer recoveries. Simultaneously, NASA announced the FLOATing DRAGON competition, which called for a steerable node deployed from a high-altitude balloon, aligning perfectly with IrishSat's objectives. After two months of brainstorming, the team submitted a successful Preliminary Design Review (PDR) in October 2022, followed by a detailed Critical Design Review (CDR) in December. In January 2023, IrishSat was selected as one of six finalists in the competition, marking the first time the team earned national recognition for its work.

Over the next seven months, the team worked closely with NASA's Balloon Program Office (BPO) to rapidly develop and refine their autonomous, steerable node. Despite FAA restrictions preventing node deployment during the final August 2023 launch in New Mexico, IRIS was one of only three finalists to ascend aboard NASA's gondola, demonstrating the team's technical capabilities and rapid progress.

In September 2023, NASA extended the competition under the name ICE DRAGON, giving finalists additional time to refine their designs. The team has since downsized components, added new functionality, and developed a custom flight computer. An April 2024 campus launch provided valuable data for further improvement, positioning IrishSat for the next integration phase in June 2024 and the final launch in January 2025 from Antarctica.

The rapid development and success of the IRIS project, progressing from a new club's first initiative to earning national recognition and a finalist spot in a NASA competition, underscores IrishSat's remarkable growth. The team continues to refine the IRIS platform and looks forward to potentially having its design adopted by NASA, marking a significant step forward for the club in advancing space technology.

Q Preliminary SHAMROCK Mission Requirements

Requirement	Requirement Description
R1	SHAMROCK and ND Ground Station achieve communications link.
R1.1	SHAMROCK ADCS achieves detumble to within 1 degree per second, per axis.
R1.2	SHAMROCK ADCS aligns switch beam array with Ground Station within $\pm\frac{1}{2}$ of the HPBW of the switch beam array.
R1.3	Ground Station aligns antennae within $\pm\frac{1}{2}$ of the HPBW of the Ground Station.
R1.4	SHAMROCK uses switch beam array to acknowledge Ground Station command and transmits acknowledgment successfully.

Table Q.1. Preliminary Mission Requirements for Minimum Successful Mission

Requirement	Requirement Description
R2	SHAMROCK and ND Ground Station achieve communications link with 100 Mbps of effective data throughput.
R2.1	SHAMROCK ADCS achieves detumble to within 1 degree per second, per axis.
R2.2	SHAMROCK ADCS aligns switch beam array with Ground Station within $\pm\frac{1}{2}$ of the HPBW of the switch beam array.
R2.3	Ground Station aligns antennae within $\pm\frac{1}{2}$ of the HPBW of the Ground Station.
R2.4	SHAMROCK sends data to Ground Station and 100 Mbps of effective throughput is measured at the Ground Station.

Table Q.2. Preliminary Mission Requirements for Nominal Successful Mission

R Points of Contact Resumes

Jackson E. O'Neill

joneil23@nd.edu | (414) 837-8118 | Campus: St. Edward's Hall, South Bend, IN 46617

EDUCATION

University of Notre Dame, South Bend, IN — August 2022 - May 2026
Major: Aerospace Engineering (B.S.) | Minor: Engineering Corporate Practice — GPA: 3.84
Dean's List: Fall 2022, Spring 2023, Spring 2024

University of Notre Dame Summer Study Abroad, Berlin, Germany — May 2023 – July 2023

EMPLOYMENT

Woodward Inc. Niles, IL
Test Engineering Intern — May 2024 - August 2024
- Updated and upgraded the documentation and design for the final acceptance test stand for the TRAS lock on the Boeing 737 MAX. Discussed changes with test stand operators to ensure improvements don't disrupt production efficiency. Reworked the hydraulic loop to ensure material compatibility with the working fluid.
- Consulted existing documentation including 3D CAD models, AutoCAD drawings, and schematics - finding discrepancies and consulting with engineers to best rectify them.

Independent Professor Research, University of Notre Dame, IN
Undergraduate Researcher under Dr. Leonov, Aerospace & Mechanical Engineering — February 2024 - Present
- Designed a gas injection system for use in a high-Mach wind tunnel, primarily using SolidWorks to track routes of tubing and interfaces between in-line valves, regulators, mass flow controllers, and tanks.

Struck Corporation, Cedarburg, WI
Industrial Engineer Intern — June 2023 - July 2023
- Modernized the parts inventory by converting 50 in-demand parts from hand drawings and 2D AutoCAD files into DXF files and 3D modeled parts using SolidWorks, Autodesk Inventor, CamCode, and FlowPath.

ENGINEERING EXPERIENCE

IrishSat, University of Notre Dame, IN
CLOVER-SAT Director of Operations — May 2024 - Present
- Lead the teams responsible for designing a CubeSat small satellite and its payload, testing it, and operating it from the ground. Interacting with 100+ team members to ensure individual needs are met, technically and personally.
- Guide the teams with proper design and documentation practices, conducting research to provide reasoning for engineering decisions. Utilizing software like MATLAB & SolidWorks to validate and improve existing designs. Interfacing with mission partners to ensure requirements are understood and documented properly.

CubeSat Chief Engineer — May 2023 – May 2024
- Facilitate integration between all subsystems and serving as the technical liaison for all members of the project.
- Form action plans and Gantt charts to organize a team of 40+ members to advance CubeSat development from ideation and prototyping to design refinement and review.

Prototype Satellite Structure and Orientation Engineer — August 2022 – May 2023
- 3D Modeled the structure and designed the attitude determination and control (ADC) system of a prototype cube satellite for the Notre Dame IrishSat CubeSat team.
- Calculated the required mass and radius of three Attitude Control flywheels used in the ADC system.

Ground Station Structures Engineer — September 2022 - Present
- Lead the project to reinforce an existing ground station antenna tower to communicate with IrishSat's CubeSat
- Utilized Autodesk Fusion 360 to design parts for waterjet manufacturing.

Servo Actuated Valve Project, University of Notre Dame, IN — November 2023
- Designed and 3D modeled a water valve using given design constraints and requirements.
- Actuated water valve using an Arduino controlled servo motor.
- Analyzed data using Excel to determine the time the valve should be open for a desired amount of water to pass through.

ACTIVITIES

Habitat For Humanity, South Bend, IN / Cedarburg, WI — September 2022 - Present
- Led an effort to construct a wooden Christmas lights display that raised over $2300 for Habitat for Humanity.
- Volunteered with student group to prepare ground for sod installations and prefabricate walls.

SKILLS AND INTERESTS

Skills: Autodesk Fusion 360 | Autodesk Inventor | AutoCAD | SolidWorks | Microsoft Excel | Welding | Lathe | Mill | Microsoft Word | Forklift Operator | Hand Tools | Intermediate German | Basic Electrical Work | MATLAB | Python | GD&T | Windchill PLM | Microsoft Visio

Interests: Classic Rock | College Football | History | Heavy Machinery | Space Travel | Gaming | Space History | CubeSats

Sarah Kopfer

skopfer@nd.edu | 262-613-7477 | https://www.linkedin.com/in/sarah-kopfer/

Computer Engineering Student at the University of Notre Dame

I am passionate about the advancement of space exploration technology and highly driven by the goal of innovating intricate embedded systems for electronics with in-space applications. I look forward to integrating my computer engineering education with space grade avionics and full electrical systems to be on the cutting edge of revolutionizing human space exploration.

Education

University of Notre Dame '25 | Computer Engineering (BS) | Engineering Corporate Practice Minor
Cumulative GPA: 3.822 | Dean's List | Provost Merit Scholarship

Aerospace Experience

Incoming Aerospace Systems Engineer for MK1 Lunar Lander | BLUE ORIGIN Aug 25

World Lead | FemSAT.ai by Cadence Aug 24-CUR

- Leading the mission of designing, developing, and launching the world's first AI spacecraft produced entirely by women through assembling, leading, and providing technical guidance to the team of world class female students and professionals.

Electrical Systems Engineering Intern | BLUE ORIGIN May 24-Aug 24

- Spearheaded the design and development of three advanced electrical systems tools within the MK1 lunar lander vehicle test bed hardware-in-loop team, resulting in a 200x increase in testing efficiency, elimination of human error, and enhancement of system-wide verifications, ensuring rigorous validation and accuracy of electrical connections.
- Designed versatile tools with universal applicability across all Zuken-designed electrical systems, ensuring seamless integration and broad usability across Blue Origin's portfolio.
- Engineered a suite of Zuken tools that autonomously identify and export harness connections, generate test scripts, and automate project file documentation, significantly reducing manual effort, improving testing reliability, and facilitating seamless integration and error detection.
- Optimized tool functionality through cross-disciplinary collaboration with hardware, software, test, and systems engineers, identifying key automation features that substantially improved testing speed, reduced costs, increased efficiency, and strengthened validation and verification processes.

University Researcher | NASA JPL High-Performance Space Computing Jan 24-May 24

- Researching under Prof. Morrison in collaboration with Pete Fiacco and two undergraduate students to understand and improve upon space computing modules leveraging RISC-V and the emerging HPSC hardware that will be utilized in the next generation of space systems by analyzing performance of previous space mission computer performance.

President | IrishSat Dec 21-CUR

- Leading a team of 100+ interdisciplinary engineers across four major projects, including a CubeSat, Ground Station, Helmholtz Cage, and autonomously guided, HAB-dropped payload.
- Engineering the embedded system flight computer for a magnetorquer-only ADCS payload on a ThinSat, set for deployment in LEO as part of NearSpace Launch's 2025 mission.
- Guiding CLOVER-Sat CubeSat development for NASA's CubeSat Launch Initiative while overseeing design, integration, and implementation of prototypes for payload, power management, communications, attitude control, and data processing.
- Competing as finalist in NASA's FLOATing/ICE DRAGON Challenge, responsible for developing, integrating, and testing avionics to autonomously steer a dropped payload with a servo-controlled parafoil.
- Designing, routing, testing, assembling, and programming tailored PCB flight computers for both the CubeSat and HAB projects, optimizing to meet stringent power, size, computing, and environmental constraints.

Other Work Experience

Systems Engineering & Validation Intern | Ford Motor Company May 23-Aug 23

- Developed Python code to aid in diagnosing causes of key-off load power consumption and SOC drainage within complex electrical networks by analyzing hundreds of thousands of signals transmitted during electric vehicle (EV) testing.
- Implemented Python code which projects and models true field performance of EV batteries to determine optimal battery specifications through computational analysis of test & target data.

Hardware Track Accelerate Program | IBM May 23-Jul 23

- Researched and presented the ways changing workloads are affecting computer hardware system design, specifically regarding quantum computers and various technological approaches to their development.

Software Development Intern | Splash Clinical LLC May 23-Jul 23

Campus Leadership & Extracurriculars

CSE Courses Teaching Assistant Aug 23-CUR

Engineering Leadership Council Senior Director of Sponsorship Aug 21-CUR

Skills & Abilities

- Embedded System Design, Development, Testing
- Printed Circuit Boards
- Python
- C
- Git
- Linux
- Shell
- RISC-V
- KiCad
- Zuken
- Cadence Virtuoso
- MATLAB
- Verilog
- Fusion 360
- Lab Experience
- Systems Integration
- Interdisciplinary Leadership

Isaac Brej 1924 Victory March Way, Notre Dame, IN 46556 | 330.441.2229 | ibrej@nd.edu | LinkedIn Profile

EDUCATION

University of Notre Dame | Notre Dame, IN *Class of 2025*

- BoS in Electrical Engineering; Minor in Engineering Corporate Practice, Dean's List, IEEE-HKN Honors Society **GPA**: 3.99/4.0
- Coursework: Living and Working on the Moon, Communications Systems Lab, Modern Methods for Electromagnetic Application, System Theory and Application, Random Phenomenon in Electrical Eng., Applied Embedded System Design

LEADERSHIP AND INVOLVEMENT

IrishSat | University of Notre Dame | Notre Dame, IN *December 2021 - Present*

Chief Technology Officer; Lead Communications Engineer on LEO Satellite Design Team

- Leading a team of 60 active space engineers in designing and integrating 6 separate projects such as CubeSat development, research payload creation, and high altitude balloon testing to pursue NASA's CSLI to enable Notre Dame research in LEO.
- Spearheaded a subteam of 14 engineers who design and test software-defined radio architectures implementing digital signal processing for robust CubeSat communications and operating a satellite ground station to uplink and downlink data.

Engineering Leadership Council | University of Notre Dame | Notre Dame IN *September 2021 - Present*

Director of Community Outreach; CCI Robotics Creator / Instructor; ND Engineering Tutoring Program Creator / Coordinator

- Striving to make an impact with my education and passions by sharing my love for engineering and learning with the surrounding community of South Bend. This position requires articulation skills, patience, and a positive attitude.

PROJECTS

IrishSat CubeSat End-to-End Communications Design *July 2023 - Present*

NASA-collaborating CubeSat project, Ground Station and CubeSat Design and Fabrication

- Developing an end-to-end digital signal processing simulation script in C incorporating BPSK modulation, raised-cosine Nyquist pulse shaping, channel simulation including AWGN noise and phase and frequency offsetting, Muller and Mueller Clock Recovery, coarse and fine frequency detection and correction, frame synchronization, and cyclic redundancy checking.
- Fine-tuning full system hardware and software design including design of system requirements for our CubeSat and ground station featuring research payload hardware, CubeSat flight computer, Software Defined Radio (SDR) Linux computer and RFIC, USRP ground station SDR, and ground station host computer for creation of a full duplex communication link.

Notre Dame Engineering Tutoring Program *July 2023 - February 2024*

South Bend Area Community Outreach Program to connect ND students with local tutoring opportunities

- Coordinated with 4 different South Bend organizations with over 20+ combined locations to connect 40+ Notre Dame engineers with athletic, academic, and professional programming in the surrounding community for K-12 students.

Lunar Lander Mission Design *June 2024 - July 2024*

Five-week *Space Mission Design Course taught by Notre Dame Alumnus*

- Optimized a lunar lander mission to deliver a 50 kg payload to the lunar surface through python modeling which drove decisions between 4 launch vehicles, 4 propellant types, 4 rocket engines, as well as basic tank and subsystem design.
- Applied foundational space mission design concepts and tools including the rocket equation, the Vis-viva equation, delta-v and mass budgets, mission staging and design, basic orbital dynamics, and engine and propellant characteristics.

WORK EXPERIENCE

LEO Research Project Assistant | Professor Jonathan Chisum | Notre Dame, IN *August 2023 - Present*

- Designed, modeled, and simulated a full, space-grade radiometer using ADS and HFSS to interface with Phased Array Fed Lens Antennas for LEO CubeSat to take emissivity measurements at 23.8 GHz of Earth using electronic beam scanning.
- Performed cascade analysis to analyze theoretical gain and noise performance and modeled the full system in Ansys High Frequency Structure Simulator to execute full-wave simulations to examine system frequency response and S parameters.

Vulcan Avionics Components Intern | United Launch Alliance | Denver, CO *May 2024 - July 2024*

- Designed in KiCad and analyzed in Pspice the timing and logic design of a high-speed testing PCB which induces data corruption into flight computer data lines to qualify flight assembly for handling single-fault events for the Vulcan rocket.
- Fabricated electrical testing harnesses for critical Centaur upper stage tank testing at NASA Marshall Space Flight Center, essential for the certification of the Vulcan rocket to fly government, NASA, and commercial payload into orbit.
- Lead technical writing effort to modernize, reduce cost, and create new specifications of video capture systems for Vulcan.

Software Engineering Intern | Mathworks | Natick, MA *May 2023 - August 2023*

- Completed major product enhancements to a MATLAB object-oriented internal driver infrastructure so customers can connect to, communicate with, and control external hardware such as an oscilloscope through the MATLAB interface.

SKILLS AND INTERESTS

Soft Skills: *Curiosity and Inquisitiveness, Team Leadership and Management, Accountability, Communication and interdisciplinary Team Navigation, Time and Project Management, Attention to Detail, Adaptability, Consistency, Critical and Creative Thinking*

Technical Skills: *Software-Defined Radio, Digital Signal Processing, Communications System Design and Implementation, PCB Design and Fabrication, RF Component Design and Simulation, ADS filter design, Ansys HFSS, Embedded System Design*

Patrick Schwartz

patrickjschwartz26@gmail.com | 715-220-5961 | www.linkedin.com/in/patrick-schwartz26

EDUCATION

University of Notre Dame / Notre Dame, IN
Bachelor of Science in Mechanical Engineering — Expected Graduation: May 2025
GPA: 3.918

EXPERIENCE

IrishSat

Director of Research and Development — May 2024 – Present

- Lead 80-person team in developing new technology for CubeSats and High-Altitude Balloon systems
- Wrote Extended Kalman Filter (EKF) in Python for CubeSat state estimation
- Modeled dynamics of CubeSat with reaction wheels in state space and simulated output for given control input in Python and MATLAB
- Designed a PD controller in Python for CubeSat attitude control using reaction wheels
- Applied least squares to estimate unknown parameters of CubeSat system from simulated data
- Spearheaded outreach initiatives to engage local schools in space-related activities
- Collaborated with NearSpace Education to develop a payload to launch on a 0.5U CubeSat in 2025

High-Altitude Balloon Chief Engineer — September 2021 – May 2024

- Directed a 10-person multidisciplinary team of High-Altitude Balloon (HAB) mission in the planning, design, analysis, and testing of robotic parafoil for autonomous guidance of payload
- Secured a $15,000 NASA grant to develop the system, including integration for Antarctic launch
- Selected as 1 of 6 finalists for NASA's FLOATing DRAGON design competition to develop system for an automated deployment and steered descent of a node from 120,000 ft
- Successfully managed flight application and integration process and launched with NASA's BPO
- Designed mechanical systems and conducted Finite Element Analysis (FEA) in Fusion 360 to validate structural integrity for HAB flight
- Developed a Model Predictive Controller (MPC) in Python for autonomous guidance of the system
- Implemented a Model Free Controller (MFC) in C to run on custom flight computer for GNC
- Designed and fabricated a Printed Circuit Board (PCB) in KiCad for the system
- Debugged and tested communications system with a LoRa (Long Range) radio on Arduino and learned about memory management and telemetry
- Created Python to log and map real-time telemetry during HAB flight
- Conducted flight simulations in Python to optimize release points and predict landing accuracy
- Modeled the descent with second order, nonlinear differential equations in MATLAB

RESEARCH

Wearable Robotics Lab — June 2024 - Present

- Developed a real-time method for predicting joint angles and torques from center of mass trajectory via convex optimization in MATLAB
- Modeled human dynamics during sit-to-stand transitions in MATLAB

EXTRACURRICULARS AND VOLUNTEER EXPERIENCE

Differential Equations Tutor — October 2023 – Present
VEX Robotics Volunteer / Volunteer — November 2022 – Present
Fighting Irish Science Olympiad / Volunteer — November 2021 – Present
Ultimate Frisbee Club / Member — September 2021 – Present

SKILLS

SolidWorks | Python | Fusion 360 | MATLAB | C | KiCad | FEA | AutoCAD | Arduino | PCB | Git | MS Excel

Adelle Burkhardt

(317) 412-0995 | adelleburkhardt@gmail.com | LinkedIn

EDUCATION

University of Notre Dame | Notre Dame, IN — May 2026
Bachelor of Science — *GPA: 3.342*
Major: Aerospace Engineering

Engineering Study Abroad | Berlin, Germany — May 2023 – July 2023

LEADERSHIP AND ACTIVITIES

IrishSAT | University of Notre Dame — August 2023 – Present
Proposals Lead and member of Gravitational, Orbital, Attitude, and Thermal (GOAT) Laboratory

- Leading the technical writing and compilation of IrishSAT's CubeSat Launch Initiative (CSLI) and University Nanosatellite Program Mission Concept (UNPMC) proposals, as well as researching further small satellite opportunities
- Working with a team on the design and construction of a multi-dimensional gimbal for a 2U cube satellite to test the reaction wheels as well as verify the performance of implemented magnetorquers within a Helmholtz cage with a goal of simulating components of Low Earth Orbit (LEO) conditions

McInerney Fellows | University of Notre Dame — August 2023 – Present
Peer Mentor

- Promoting McInerney Fellows events, supporting first-generation, low-income undergraduates, and volunteering in the South Bend community
- Representative of the cohort of first generation, low-income students at Notre Dame

Transformational Leaders Program | University of Notre Dame — August 2022 – Present
Program Member

- Participant around Notre Dame's campus through program social events and local community service that highlight underrepresented groups at Notre Dame

Ultimate Frisbee | University of Notre Dame — August 2022 – Present
Team Member

- Participate in and travel for Notre Dame's women's club ultimate frisbee developmental team

RELATED COURSEWORK AND PROJECTS

Aerospace Industry, Economics, and Regulation Project | Berlin, Germany — May 2023 – July 2023

- Collaborated as a team of 4 to evaluate the current picture of the aerospace industry's economics and regulations, analyzing public to private sphere contracts such as the SpaceX's Dragon and Boeing's Starliner, and projecting the future of aerospace industry relations

Design Tools | University of Notre Dame — August 2023 – December 2023

- Facilitated the design of a delivery cart system as a team of 4, applying SolidWorks skills
- Utilized machinery such as laser cutters, water jets, 3-D printers, drill press, bandsaw, and sanders to assemble a delivery cart that transports an assigned item

Engineering Design Thinking | University of Notre Dame — January 2023 – May 2023

- Incorporated the design process to create a kinetic sculpture that displayed irregular motion in the presence of varying wind speeds
- Worked in a team of 4 to iterate through several design trees and models to create a sculpture that met preconceived requirements

Computing Numerical Methods and Data Science | University of Notre Dame — January 2024 – May 2024

- Programed a system to model an inverted pendulum in Python with a corresponding computer aided simulation, with the goal of maximizing the height of the pendulum's swing and balance

TECHNICAL SKILLS

Technical: Proficient in SolidWorks, technical writing, MATLAB, LaTeX, Microsoft Office. Intermediate experience with Python, basic lab machinery (drill press, bandsaw, Dremel, laser cutter, water jet, 3-D printer)

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Chisum, Jonathan

POSITION TITLE: Associate Professor of Electrical Engineering

ORGANIZATION AND LOCATION: University of Notre Dame, Notre Dame, IN, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
University of Colorado at Boulder, Boulder, CO, USA	PHD	2011	Electrical Engineering
University of Colorado at Boulder, Boulder, CO, USA	MS	2008	Electrical Engineering
Seattle Pacific, Seattle, WA, USA	BS	2003	Electrical Engineering

Appointments and Positions

2022 - present Associate Professor of Electrical Engineering, University of Notre Dame, Notre Dame, IN, United States
2015 - 2022 Assistant Professor of Electrical Engineering, University of Notre Dame, Notre Dame, IN, USA
2012 - 2015 Member of Technical Staff, Spectrum Operations, Massachusetts Institute of Technology Lincoln Laboratory, Lexington, MA, USA
2003 - 2006 Hardware Design Engineer, Ballard Technology, Inc., Everett, WA, USA

Products

Products Most Closely Related to the Proposed Project

1. Wang W, Estes N, Garcia N, Bolstad M, Chisum J. Beamforming Phased-array-fed Lenses with >0.5λ-spaced Elements. IEEE Trans. Antennas Propag.. 2023 January; 71(3):2208-2223. DOI: https://doi.org/10.1109/TAP.2023.3240085
2. Garcia N, Chisum J. Compound GRIN Fanbeam Lens Antenna with Wideband Wide-angle Beamscanning. IEEE Trans. Antennas Propag.. 2022 June; 70(10):7501-7512. DOI: https://doi.org/10.1109/TAP.2022.3182420
3. Garcia N, Chisum J, Wang W. Feed Corrective Lenslets for Enhanced Beamscan in Lens Antenna Systems. Opt. Express. 2022 April; 20:13047-13058. DOI: https://doi.org/10.1364/OE.449130
4. Garcia N, Chisum J. High-efficiency, Wideband GRIN Lenses with Intrinsically Matched Unit-cells. IEEE Trans. Antennas Propag.. 2020 April; 68(8):5965-5977. DOI:

Scott S. Howard

Associate Professor, University of Notre Dame
showard@nd.edu

Professional Experience

University of Notre Dame – Notre Dame, Indiana: **2011-present**
Associate Professor, Electrical Engineering, College Bioengineering Program
Research Area: Biophotonics & molecular imaging platform development
Courses: Electromagnetism; Fundamentals of Photonics; Biomedical Devices; Embedded Systems
Outstanding Teacher, Department of Electrical Engineering, 2017

Professional Preparation

Cornell University – Ithaca, New York: *Post-Doctoral Research Associate* **2008-2011**
Advisor: Professor Chris Xu, School of Applied and Engineering Physics
Multiphoton Microscopy, Fluorescence Lifetime Imaging Microscopy

Princeton University - Princeton, New Jersey: **2008**
Post-Doctoral Researcher, Electrical Engineering
Supervised graduate and undergraduate students in semiconductor laser research
Director of NSF ERC MIRTHE High School Unit Program

Ph.D., Electrical Engineering **2003-2008**
Advisor: Professor Claire Gmachl, Department of Electrical Engineering
Newport Award for Excellence in Photonics Research

University of Notre Dame – Notre Dame, Indiana: *B.S., Electrical Engineering* **1999-2003**
Magna Cum Laude, Laurence F. Stauder Award for Achievement in Electrical Engineering
SRC Undergraduate Research Fellowship, Intel Undergraduate Research Award Finalist

Recent Journal Publications

Mannam, V., Yide Zhang, Yinhao Zhu, Evan Nichols, Qingfei Wang, Vignesh Sundaresan, Siyuan Zhang, Cody Smith, Paul W Bohn, **Scott Howard**, "Real-time image denoising of mixed Poisson-Gaussian noise in fluorescence microscopy images using ImageJ," *Optica* 9(4), (2022): 335-345

Zhang, Y., Guldner, I. H., Nichols, E. L., Benirschke, D., Smith, C. J., Zhang, S., & **Howard, S. S "**Instant FLIM enables 4D *in vivo* lifetime imaging of intact and injured zebrafish and mouse brains." *Optica***.** *8*(6), (2021): 885–897.

Aquino, B., Castruccio, S., Gupta, V., & **Howard, S.** "Spatial modeling of mid-infrared spectral data with thermal compensation using integrated nested Laplace approximation." *Applied Optics*, *60*(27), (2021): 8609

Aquino, B., Gupta, V., & **Howard, S**. "Optical Spectroscopy Sequential Wavelength Selection Using a Higher Leverage Approach." *IEEE Sensors Letters*, *5*(6), (2021)

Olson, K. R., Briggs, A., Devireddy, M., Iovino, N. A., Skora, N. C., Whelan, J., Villa, B. P., Yuan, X., Mannam, V., **Howard, S**., Gao, Y., Minnion, M., and Feelisch, M. "Green Tea Polyphenolic Antioxidants Oxidize Hydrogen Sulfide to Thiosulfate and Polysulfides: A Possible New Mechanism Underpinning Their Biological Action" *Redox Biol.* 37, (2020): 101731

Mannam, V., Zhang, Y., Yuan, X., Ravasio, C., and **Howard, S. S**. "Machine Learning for Faster and Smarter Fluorescence Lifetime Imaging Microscopy" *JPhys Photonics* 2, no. 4 (2020): 42005

S Reviewer Resumes

PAUL RUMBACH
University of Notre Dame
379 Fitzpatrick Hall
prumbach@nd.edu
574-631-0098

HIGHER EDUCATION

Ph.D. Mechanical Engineering, University of Notre Dame, Notre Dame, IN, 2016.
B.S. Applied Physics, Indiana University, Bloomington, IN, 2010
B.S. Mathematics, Indiana University, Bloomington, IN, 2010

PREVIOUS POSITIONS

2017 to Present - **Associate Teaching Professor** - Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN

2017 to Present - **Research Scientist** - Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN

2015 to 2017 – **Course Instructor** - Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN

2015 to 2017 - **Postdoctoral Research Fellow** - University of Notre Dame (Dr. David Go) , Notre Dame, IN

2011 to 2015 - **Graduate Research Assistant** - University of Notre Dame (Dr. David Go) , Notre Dame, IN

2008 to 2012 - **Undergraduate Research Assistant** - Indiana University Cyclotron Facility (Dr. Sokol and Dr. Kaiser), Bloomington, IN

TEXTBOOKS

P. Rumbach, *Undergraduate Lectures in Measurements and Data Analysis*, 2021, BreviLiber.

REFEREED PUBLICATIONS

[1] O. Dubrovski, J. Yang, F. Veloso, D. B. Go, H.-C. Chang, and **P. Rumbach**, “Universal interfacial dynamics due to resonant coupling between electron plasma patterns and capillary wave dynamics,” *Physical Review Letters* (2024 – Currently under peer review).
[2] D. C. Martin, D. M. Bartels, **P. Rumbach**, and D. B. Go, “Experimental confirmation of solvated electron concentration and penetration scaling at a plasma-liquid interface,” *Plasma Sources Science and Technology* (2021).
[3] H. E. Delgado, D. Elg, D. M. Bartels, **P. Rumbach**, and D. B. Go, “Chemical Analysis of Secondary Electron Emission from a Water Cathode at the Interface with a Nonthermal Plasma,” *Langmuir*, **36**, 1156-1164 (2020).
[4] **P. Rumbach**, A. E. Lindsay, and D. B. Go, "Turing patterns on a plasma-liquid interface," *Plasma Sources Science and Technology*, **28**, 105014 (2019).
[5] H. E. Delgado, R. C. Radomsky, D. C. Martin, D. M. Bartels, **P. Rumbach**, and D. B. Go, "Effect of Competing Oxidizing Reactions and Transport Limitation on the Faradaic

William Karpick

wkarpick@gmail.com | (319) 899-6660

CAREER

Northrop Grumman — **Rolling Meadows, IL**

Space Systems

Systems Engineer — *2024-Present*

Systems Engineer Associate — *2022-2024*

EDUCATION

University of Notre Dame — **Notre Dame, IN**

College of Engineering: *Bachelor of Science* in *Aerospace Engineering* — *May 2022*

- Dean's List Honors — *Fall 2018*
- Cumulative GPA: 3.64 / 4.00

UNDERGRADUATE ACTIVITIES

IrishSat — **Notre Dame, IN**

Founder and President — *2021-2022*

- Directed the operations of 5 projects within the organization, involving over 35 students and $38,000, including a prototype satellite, testing laboratory, and a communications ground station.
- Conducted presentations to stakeholders detailing the team's growth and objectives for the year.
- Lead weekly team meetings and implemented agile methodologies including Kanban boards and Gantt Charts.
- Mentored underclassman on design techniques and methodologies for assessing project development.

Founder and Project Manager — *2020-2021*

- Founded the first satellite development team at Notre Dame to partake in NASA's CubeSat Launch Initiative.
- Organized Preliminary and Critical Design Reviews involving 25 students for an Unmanned Free Balloon Mission.
- Constructed a thermal insulation system to maintain a payload temperature of 4 °C in an environment of -60 °C.
- Managed the 5.4 kg weight budget through collaboration with system leads to ensure a 35 km peak altitude.
- Created a Matlab code utilizing an online simulation of balloon missions to determine the flight feasibility.
- Evaluated flight readiness as the flight director and planned the launch procedure for two successful launches.

Conceptual Lunar Lander Mission Design — **Personal**

CLPS Mission Designer — *Summer 2021*

- Prepared a mission capable of delivering a 92 kg, 325 W payload to the lunar surface for a cost of $535 M.
- Developed trade studies using a Python script to optimize launch vehicle, engine type, tank design, and other factors.
- Authored a 10-page memo outlining the delta-v budget, propellant budget, and mass budget with associated margins.

Rocketry Team — **Notre Dame, IN**

Systems and Safety Team Member — *2019-2020*

- Devised the solids testing plan to determine the optimal bulkhead material allowing for sufficient strength and weight.
- Created FMEA tables detailing the possible structural failure modes of the launch vehicle and their associated risk.

CURRICULUM VITAE

Bill Goodwine

376 Fitzpatrick Hall
Notre Dame, Indiana 46556
http://controls.ame.nd.edu/~bill
ResearcherID: N-1393-2013
January 31, 2023

Higher Education

California Institute of Technology — Pasadena, California
- PhD, Applied Mechanics, 1998
- Thesis Adviser: Joel W Burdick
- Thesis Title: Control of Stratified Systems with Robotic Applications
- MS, Applied Mechanics, 1993

Harvard Law School — Cambridge, Massachusetts
- Juris Doctor, *cum laude*, 1991

University of Notre Dame — Notre Dame, Indiana
- BS in Mechanical Engineering, with High Honors, 1988

Professional Experience

University of Notre Dame — Notre Dame, Indiana
- Professor, August 2017 – present
- Associate Professor, August 2004 – July 2017
- Associate Department Chair, Department of Aerospace and Mechanical Engineering, August 2008 – August 2012
- Director of Undergraduate Studies, Department of Aerospace and Mechanical Engineering August 2007 – August 2012 and August 2018 – December 2022
- Assistant Professor, August 1998 – July 2004
- Instructor, January 1998 – July 1998

The Boeing Company
- Instructor, Introduction to Nonlinear Analysis with Application to Controls, Boeing Commercial Aircraft and the Ed Wells Partnership, Everett, Washington, June 2012
- Instructor, Introduction to Nonlinear Analysis with Application to Controls, Boeing Commercial Aircraft Fight Control Systems and Autopilot Groups, Everett, Washington, July 2008
- Instructor, Advanced Topics in Nonlinear Analysis with Application to Controls, Boeing Commercial Aircraft Fight Control Systems and Autopilot Groups, Everett, Washington, July 2008
- Boeing Welliver Faculty Fellow, Various locations,[1] June 2007 – August 2007

Entelos, Inc — Foster City, California
- Visiting Research Engineer, May 2005 – August 2005 and January 2006 – May 2006
- Duties include human metabolic biosimulation research.

California Institute of Technology — Pasadena, California
- Graduate Student, September 1992 – December 1997

[1] El Segundo, CA; Huntington Beach, CA; Long Beach, CA; Anaheim, CA; Everett, WA and St Louis, MO.

David A Forseth

3621 W Dublin St
Chandler, AZ 85226

Work: Dave.Forseth@gd-ms.com
Personal: forseth.dave@gmail.com
480-284-9440

Professional Experience

2023-Present Distinguished Member of the Technical Staff, General Dynamics Mission Systems

Software development team Product Owner for Space Development Agency Ground System. System will support a Low Earth Orbit constellation of Space Vehicles providing communications, compute, and missile tracking solutions

- Developing system interface design with Battle Management Command, Control and Communications contractor to integrate Space Vehicle and Ground compute environments.
- Agile Product Owner role for development of ground system applications deployed to Hybrid On-Prem/Cloud platform.

2012-2023 Software Engineer Technical Staff, General Dynamics Mission Systems

Software technical lead for NASA TDRSS Space Network Ground Segment Sustainment project.

- Led a team responsible for the planning and scheduling engine subsystem of the TDRS ground segment. Team developed Java based custom software interfacing with STK Scheduler COTS software.
- Developed HMIs to support NASA Space Network operators planning and scheduling of TDRS data services.

Secure Mesh Network Internal Research and Development

- Investigate applicability of network routing protocols including OSPF and MPLS to spaced based mesh network.
- Utilizing AWS Cloud services for emulation and testing of satellite constellation SV applications and networking.

2005-2012 Software Engineer Technical Staff, General Dynamics C4 Systems

Software development for a 3GPP based Radio Access Network (RAN) call processing subsystem for MUOS program

- Led feature design efforts within the RAN Base Station and Network Controller products.
- Led RAN Early Integration test team. Frequent interfacing with downstream test teams, system engineering, and development teams.

2001-2005 Senior Staff Software Engineer, Motorola, Government and Enterprise Mobility Solutions, Trunking Controller Product Group

Technical team lead for APCO Project 25 compliant trunked system call controller products. Projects included: development of reliable transport layer interface to dispatch consoles, capacity expansion to support a nationwide Tetra system, addition of data capability to controller products.

- Developed migration requirements defining compatibility and system downtime expectations for a system release upgrade.
- Worked with network interfaces using TCP, UDP, SNMP protocols and IP multicast for transport of control plane signaling and voice packets within system.
- Contributed to development of processes to estimate and manage critical computer resources (memory and CPU usage). Performed utilization estimates early in project lifecycle to mitigate risks due to increased system capacities.

1994-2001 Software Engineer, Motorola, Government and Enterprise Mobility Solutions, Subscriber Product Group

Software engineer for two-way trunked and conventional system subscriber products.

- Developed mobility management (site roaming) software for APCO Project 25 compliant mobile and portable subscribers from requirements through test/debug phases. Included use of SDL for design and simulation.
- Led team in development of dual protocol radio that enabled a customer migration path from a Motorola proprietary to APCO Project 25 standard protocol. Project achieved significant shared code reuse between protocols.

1993-1994 Software Engineer, Johnson Controls Inc., Controls Group Division

Software engineering intern during summer after junior year and then throughout senior year of college.

- Performed design, programming, and testing of Windows based GUI for Metasys facilities management system.

Education

1990-1994 B.S. Computer Engineering, Milwaukee School of Engineering, Milwaukee WI

Tom Harkins

(617) 827-8947 · tharkins1@gmail.com · Leesburg, VA

Systems Engineering Leader with experience directing large technical teams while managing cost, schedule, and customer relationships, performing spacecraft ground and flight operations, launch processing and integration, end-to-end requirements, proposals, and new business development.
Reliable, observant, proactive manager with excellent written and oral communication skills. *Security Clearance: None*

PROFESSIONAL EXPERIENCE

NORTHROP GRUMMAN – TACTICAL SPACE SYSTEMS DIVISION (TSSD) **2022 – Present**
Mission Robotics Vehicle (MRV) / Mission Extension Pod (MEP) – Systems Engineering
Dulles/Sterling, VA

- Directed 50+ engineers, completing significant technical compatibility milestones for MEP's first 3 customer spacecraft (first time in history that 3 spacecraft will dock in orbit). Continuously under-ran an $8+ MM control account budget.
- Completed technical, cost, and schedule bases of estimate for geostationary spacecraft life extension servicing missions
- Chaired dozens of customer technical exchanges and 2 successful compatibility reviews (company payment milestones)

NORTHROP GRUMMAN – STRATEGIC SPACE SYSTEMS DIVISION (SSSD) **2008 – 2022**
NASA James Webb Space Telescope (JWST) – Ground & Flight Operations **2013 – 2022**
Greenbelt, MD / Baltimore, MD / Redondo Beach, CA

- Awarded the aerospace industry's most prestigious award, the Robert J. Collier Trophy, as part of the JWST team
- Interviewed as a NASA subject matter expert for television (live shots), podcasts, and panel discussions. Featured at NASA Goddard Space Flight Center, Smithsonian Air & Space Udvar-Hazy Center, and Maryland Science Center
- Led cross-organizational RF Comm team through rehearsals, launch, and successful activation of all flight hardware
- Originated and developed Loss of Communications philosophy and procedure, which became NASA project standard
- Championed, designed, and implemented the concept and products to mitigate an Observatory single point failure
- Operated RF Communications flight-like hardware for on-site tests with European Space Agency (Darmstadt, Germany)
- Owned Observatory Limitations & Constraints (L&C) process, ensuring consistency of 650+ implementation directives

Systems Engineering Associate (SEA) Rotation Program – CA / Melbourne, FL **2012 –2013**

- Defined nominal and contingency sequences (commands and telemetry) for operation and recovery of flight hardware
- Guided Requirements IPT during proposal phase of new business capture effort, reporting to Chief Engineer weekly

Launch Systems Integration – Redondo Beach, CA / Cape Canaveral, FL **2010 –2012**

- Performed requirements verification and validation, lessons learned adjudication, and physical hardware inspections
- Co-led bi-monthly working group to resolve mission-specific technical issues with external stakeholders

Rehearsal Anomaly Team – Redondo Beach, CA / Cape Canaveral, FL **2008 – 2009**

- Developed interactive tool for visualizing day-of-launch data links among spacecraft, launch site, and ground network
- Participated in on-console inter-center exercise to assess personnel readiness for day-of-launch countdown activities

EDUCATION

Master of Science, Astronautical Engineering, University of Southern California, CA **2012**
Bachelor of Science, Aerospace Engineering, University of Notre Dame, IN **2008**

- Reviewed Notre Dame CubeSat team's proposal for NASA CSLI program as technical advisor **2023**

TRAINING & CERTIFICATIONS

Lead Systems Engineer – Instructor-led training course **2024**
Control Account Manager (CAM) / Earned Value Management System (EVMS) Trained **2023**
International Trade Compliance – ITAR/EAR Regulations Trained **2023**
NG Leadership Development Program (Mentorship series with senior-level Director) **2018**
Dale Carnegie Course (Personal/professional relationships, public speaking, and effective communication) **2015**

COMPUTER SKILLS

- Microsoft Office: Access, Excel, OneDrive, OneNote, PowerPoint, Project, SharePoint, Teams, Visio, Word
- CAD: Blender, Creo, Creo View, Pro/Engineer (Pro/E)
- Other: Confluence, DataViews, Eclipse Command and Telemetry, Google Suite, JIRA, LaTeX, Systems Tool Kit (STK)

JUWAN JEREMY T. JACOBE

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EDUCATION

University of Notre Dame Notre Dame, IN
B.S. Physics | Concentration in Applied Physics | Supplementary Major in German Aug 2020 – May 2024
Magna Cum Laude | Dean's List Fall 2020 – Spring 2024 GPA: 3.963/4.000

EXPERIENCE

United States Naval Research Laboratory Oct 2024 – Present
Research Physicist, Astrodynamics and Navigation Section Washington, D.C.

- Developed high fidelity, very low Earth orbit (VLEO) spacecraft simulations for characterizing power, thrust and attitude requirements to facilitate design of a low-drag, electric propulsion spacecraft
- Implemented various low-thrust station-keeping maneuver concepts of operations in VLEO simulations to test design feasibility of propulsion system
- Supporting developer and maintainer of OCEAN, an orbit determination and propagation software suite used for operations of DoD-sponsored satellite missions

Robotics, Optimization, and Assistive Mobility Lab, College of Engineering Sept 2023 – Oct 2024
Research Associate Notre Dame, IN

- Continued research work with Dr. Patrick Wensing after graduation from undergraduate research project to write paper as primary author for submission into *Mechanism and Machine Theory*
- Developed computational methods for gauging identifiability of inertial parameters of rigid body systems with parallel and series-parallel kinematic structures such as humanoid robots
- Demonstrated method's provable correctness and generality through rigorous application of complex and real algebraic geometry concepts
- Developed optimal heuristics for Gröbner basis computations of algebraic ideals representing kinematic constraints of parallel rigid body systems

EXTRACURRICULAR ACTIVITIES

IrishSat Aug 2021 – April 2024
Director of Research & Development University of Notre Dame

- Director of R&D of two years of student satellite development group IrishSat, with goal of participating in NASA's CubeSat Launch Initiative (CSLI) to launch and operate CubeSats in orbit
- As team's lead technical writer, wrote 30-page NASA CSLI proposal and 14-page DoD UNP proposal proposing 2U CubeSat mission demonstrating novel phased array fed lens antennas
- Codeveloped orbital dynamics and geomagnetic field software to simulate low-Earth orbit magnetic fields in Helmholtz cage satellite testbed for team's test instrumentation lab

SKILLS

Software: Python, Java, C, C++, Matlab, Mathematica, LabView, Git
Language: English, Tagalog, German

Biography of Gary H. Bernstein
Frank M. Freimann Professor of Electrical Engineering
Department of Electrical Engineering
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Gary H. Bernstein received the BSEE from the University of Connecticut, Storrs, with honors, in 1979 and MSEE from Purdue University, W. Lafayette, Indiana, in 1981. During the summers of 1979 and '80, he was a graduate assistant at Los Alamos National Laboratory, and in the summer of 1983 interned at the Motorola Semiconductor Research and Development Laboratory, Phoenix, Arizona. He received his Ph.D. in Electrical Engineering from Arizona State University, Tempe, in 1987, after which he spent a year there as a postdoctoral fellow. He joined the Department of Electrical Engineering at the University of Notre Dame, Notre Dame, Indiana, in 1988 as an assistant professor, and was the founding Director of the Notre Dame Nanoelectronics Facility (NDNF) from 1989 to 1998. Dr. Bernstein received an NSF White House Presidential Faculty Fellowship in 1992. Promoted to rank of Professor in 1998, he served as Associate Chairman from 1999 to 2006. Bernstein was named the Frank M. Freimann Professor of Electrical Engineering in 2010, and served as the Associate Director of the Notre Dame Center for Nano Science and Technology from 2013 to 2017.

Bernstein was named a Fellow of the IEEE in 2006, and with his student received the *Sensors and Transducers Journal* Best Paper of the Year Award for 2006 and, as lead author, the *IEEE Transactions on Advanced Packaging* Best Paper of the Year Award in 2007. He received the Innovation Excellence Award from the Indiana Economic Development Center and Forbes Summit Group, Indianapolis, November, 2014, and the 1st Source Commercialization Award for Quilt Packaging development, April, 2016. Bernstein was named a Fellow of the National Academy of Inventors in 2020.

Scientific, Technical and Management Performance on Prior Research Efforts
Bernstein has served as PI on over $10M in funded research and participated as PI or Co-PI on over 95 funded programs in his 36 years at Notre Dame. The results of these programs have led to Bernstein as author or co-author of 17 patents and more than 300 publications in the areas of electron beam lithography, nanomagnetics, quantum electronics, high-speed integrated circuits, electromigration, MEMS, infrared sensors and electronics packaging. Bernstein is cofounder of Indiana Integrated Circuits, LLC (www.indianaic.com) based in South Bend, IN, which spun out of his innovations in electronics packaging.

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