INTRODUCTION:

A PROJECT READINESS PACKAGE (PRP) IS CONSTRUCTED TO PROVIDE A MULTIDISCIPLINARY SENIOR DESIGN (MSD) TEAM WITH GUIDELINES. THIS SPECIFIC PRP WILL DETAIL THE PROCESSES AND REQUIREMENTS ASSOCIATED WITH DESIGNING AND FABRICATING AN INTERFACE FOR A CUBESAT ATTITUDE CONTROL SYSTEM. AN ATTITUDE CONTROL SYSTEM IS A CRITICAL SYSTEM FOR PROPER CUBESAT FUNCTION; HOWEVER, IT IS NOT THE ONLY CRITICAL SUBSYSTEM. OTHER SUBSYSTEMS WILL BE DETAILED IN ADDITIONAL PRP'S WHICH CAN BE FOUND ON EDGE FOR ADDITIONAL REFERENCE OR INFORMATION.

Space Exploration has been a field of interest since the middle of the twentieth century when the Soviet satellite Sputnik was successfully launched into orbit. Since then, space has been cluttered with all sorts of vehicles—so many that lower earth orbit (LEO) has become cluttered past a critical point. When Donald Kessler and his team mathematically proved what is now known as the "Kessler Syndrome" in the late '70s, increased attention was put on the capacity of Earth's orbitcal fields. Nonetheless, the world has been launching satellites and other vehicles constantly over the past 60+ years for practical purposes and research purposes. The scientific community, in particular, has massive investments in spacecraft orbiting Earth and utilizes these vehicles to collect data on a daily basis for study. Because of these factors, the development of new spacecraft will be critical during this century. Due to the increased attention on the capacity of Earth's orbital fields, it will be essential that everything launched into space has a proven design and will succeed in its mission.

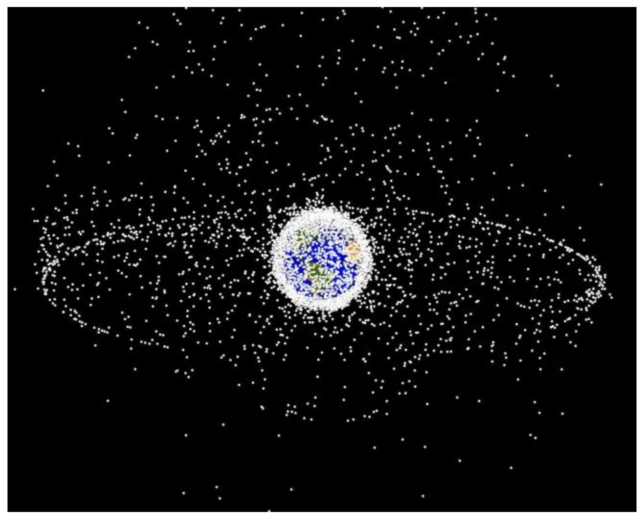

Figure I: Model depicting the amount of spacecraft orbiting earth

ADMINISTRATIVE INFORMATION:

- **Project Name (tentative):** Design of Magnetorquer Interface
- **Project Number, if known:** R15301
- **Preferred Start/End Quarter in Senior Design: 2171**
- **Primary Customer, if known (name, phone, email):**

Name	Dept.	Email
Anthony Hennig	ME	aih2400@rit.edu

Sponsor(s):

Name/Organization	Contact Info.	Type & Amount of Support Committed
RIT Space Exploration Team	facebook.com/ritspex	Club responsible for obtaining funds for MSD project and providing consultation on constraints and requirements

PROJECT OVERVIEW:

The RIT Space Exploration Team was established in the Fall of 2014. Their mission and initiative is to increase attention on space systems engineering the the RIT community. A Laser Uplink Communication (LUX) system is being researched by the team and they are seeking a platform to test their technology and put it to use. Through NASA's ELaNa program, the team is hopeful of launching a new class of satellites, deemed "CubeSats," into space. A CubeSat is a modular class of nanosatellites that is relatively new to the scientific community. The size 1-unit CubeSat is only 10x10x10 cm^3 , thus reducing the cost and preparation time of traditional satellites significantly.

Figure II: Basic skeleton CubeSat Shell

Where traditional satellites can cost millions to hundreds of millions of dollars and take years of preparation time, CubeSats can go up in less than a year and cost less than $100,000 to fabricate. Units can be constructed in any multiple (2U, 3U, 6U) if more space is required. Adding another module to the CubeSat is simply a result of needing additional space for componentry. The cost and preparation time of larger CubeSat's is slightly greater, but ultimately, if the space for hardware is needed inside the unit, the benefits of a larger structure will be worth it. Building the satellites is one thing, but launching them is a completely different—and expensive—challenge. However, through NASA's sponsored (ELaNa) program, the RIT SPEX team could be granted a free ride in to space. In a time where space is being cluttered with an excess of debris and defunct satellites, it is crucial that every piece of technology entering LEO will function properly and be

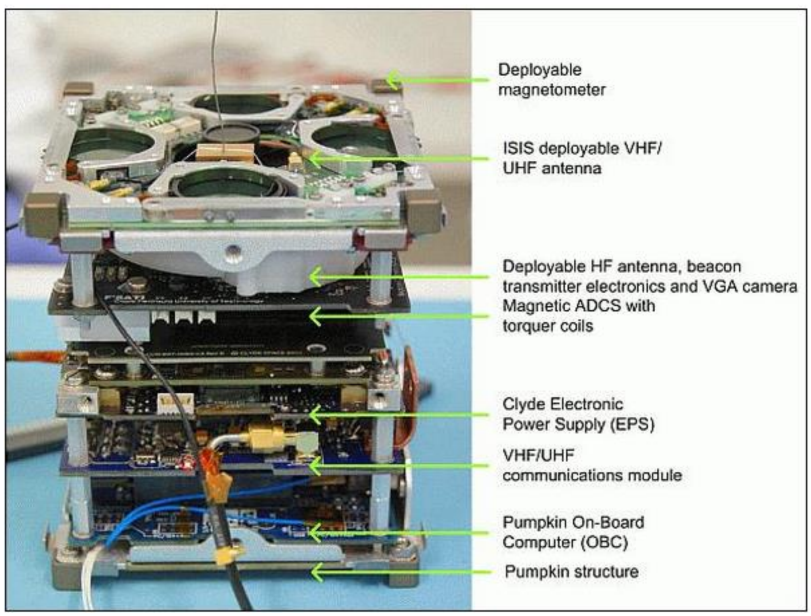

Figure III: Exploded view of ZACUBE-I

successful. Because of this, NASA is very critical of the designs that are proposed to be entered into their ELaNa program.

One of the many challenges that come with fabricating a satellite is the integration of an attitude control system. The team has selected a passive system for their CubeSat since they still in their infant stages and active control systems provide significant complexities. Thus, magnetorquers have been proven to be the most viable passive attitude control medium. However, due to the size of the satellite and the complexity of the system, the components are often crammed into the module in any way that will fit. However, through benchmarking it was observed that magnetorquers can only survive vibration frequencies up to 15 Grms. This means that overlooking the design of the placement and physical integration of the magnetorquers into the system may not be wise for durability and overall performance of the attitude control system.

Listed below are websites and research related to magnetorquers:

http://sites.sg.rit.edu/spex/mission/
http://www.hindawi.com/journals/jcse/2013/657182/
http://www.cubesatshop.com/index.php?page=shop.product_details&flypage=flypage.tpl&product_id=75&category_id=7&option=com_virtuemart&Itemid=69

DETAILED PROJECT DESCRIPTION:

- **Customer Needs and Objectives: The RIT SPEX team requires the successful integration of an attitude control system. A passive system, namely magnetorquers, has been chosen as a viable method for controlling the CubeSat. The customer is looking for a way to develop a lightweight, mechanical damping interface to connect the magnetorquer rod to the structure.**

CUSTOMER REQUIREMENTS:

CR19	Funding	Critical	All components need to be cost effective and cheaper than existing solutions
CR20	Funding	Desirable	The design should consider the waste of material during machining process to save money
CR21	Layout	Critical	The magnetorquer interface needs to be able to withstand launch conditions
CR22	Layout	Critical	The interface must cause no damage to other components within vehicle, nor obstruct their placement
CR23	Layout	Critical	The interface design must be compatible with existing environment
CR24	Technology	Desirable	The design must beat existing products on market in terms of weight, size, and damping
CR25	Technology	Important	The interface design must be easy to install and attach the existing environment so minimal damage is induced
CR26	Technology	Critical	The interface design must be easily reproduced. Multiple interfaces will be necessary, so the design should consider machining difficulities
CR27	Technology	Important	The damping should be simulated via CAD or FEA. Rendered conditions should mimic those seen observed during launch

- **Functional Decomposition:**

Connection of Magnetorquer Rod to CubeSat

Physically link with rod

Develop a clasp to hold rod securely

Dampen vibrations from launch and deploying from pod

Infuse damping mechanism to interface

Link with Existing Environment

Design interface to mesh with existing environment

- **Potential Concepts*:***

1) The design could integrate damping pads into the base of the interface where it connects with the CubeSat. Damping pads would offer an easy to design solution to mitigating the vibration delivered to the rods. The physical connection medium should be designed to be lightweight, small, and diffuse vibrations.
2) The design could use very small shock absorption instruments at the base of the physical interface. The design should be lightweight, small, and cost effective while still maintaining the mechanical durability desired by the customer.
3) Some sort of damping pads could be used at the interface between the rods and the clasp holding the rods. Once again, the design connecting this clamp to the CubeSat should be lightweight yet still maintain mechanical durability.

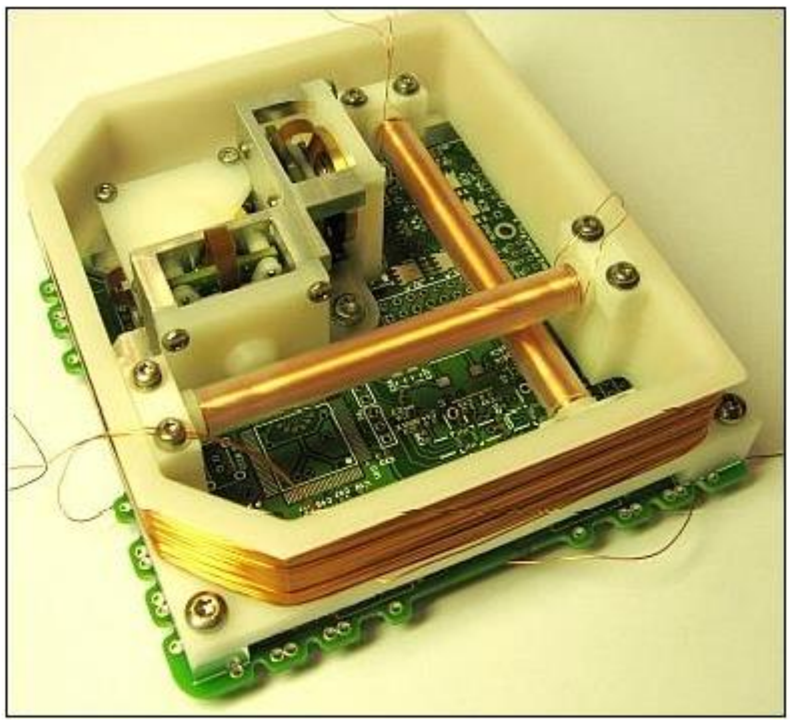

Figure IV: Existing design of PCB with integrated Magnetorquers taken from [Delfi-n3Xt CubeSat]

- **Specifications (or Engineering/Functional Requirements):**

	Function	Eng. Requirements and Metrics	Unit of Meas.	Marginal Value	Ideal Value	Additional Comments	Test to Verify Performance
ER40	Link with Existing Environment	The magnetorquers need to physically mount and be compatible with the existing design of the structure without damaging the structure or causing stresses	[Yes/No]	Yes	Yes	Modeling will need to confirm room for magnetorquers	N/A
ER41	Physically link with rods	The mechanism should contain a clasp capable of holding the rods in a manner which does not cause damage	[Yes/No]	Yes	Yes	The clasp could contain damping pads to help mitigate vibrations	N/A
ER42	Dampen vibrations from launch and deploying from pods	The mechanism will need to keep the vibrations frequencies under the specified magenetorquer constraints listed on the specification sheet	[g rms]	<15	<10	Document signs of damage and stress; specific requirements vary between Launch Vehicles (LV's)	Cubesat to undergo vibration test simulating initial launch environment
ER43	Dampen vibrations from launch and deploying from pods	Survive impact force during ejection	[N]	8	12	Document signs of damage and stress	Cubesat to undergo vibration test simulating secondary launch environment
ER44	Infuse damping mechanism to interface	The damping mechanism should not exceed more than an eighth of the length of the chosen magenetorquers.	[mm]	3	1	The magnetorquer length could vary depending on the size of the CubeSat	CAD Modeling should be done to ensure all interfaces are compatible
ER45	Infuse damping mechanism to interface	The damping mechanism should be lightweight	[g]	15	5	N/A	N/A

- **Important Budget Considerations*:***

The cost of fabrication for the interfaces will depend on the choice of material and damping method. Since this is a low-cost project, there is more freedom and less constraints on budget. However, an ideal, marginal, and cap for the fabrication of for interfaces is as follows:

IDEAL	**$150**
MARGINAL	**$225**
CAP	**$300**

- **House of Quality*:***

			Engineering Metrics							Customer Perception				
	Customer Requirements	**Customer Weights**	Link with PCB	Physically link with rods	Dampen Vibrations from launch and deploying from	Survive Impance Force during ejection	Infuse dampening mechanism to interface	Mechanism should not exceed more than an eighth	Mechanism should be lightweight	1 Worse	2	3	4	5 Better
1	Compatible with Rods	5	5	5										
2	Compatible with PCB	5	5	5	5									
3	Durable	4	4	4	3	5	5							
4	Dampens Vibrations	5	4	4	5	5								
5	Cost Effective	2	3	3	2			3	3					
6	Minimizes Material Waste	2	2	2		1	2	2	2					
7	Beat Existing Stock Fixtures	4	5	5	5			5	5					
8	Ease of Installation	4	3	3										
9	Reproducibility of Design	4	4	4			5	5	4					
0	Testing of Dampening Effectiveness	3			5	4								
11	Adds minimal inertia to vehicle	5						4	5					
	Technical Targets (Specifications)		Y	Y	Less than 10	12	Y	1	5	A:Shields-1 CubeSat #1 B: MicroMas #2 C: Delfi-n3Xt CubeSat D. ZACUBE-I				
	Units		Y/N	Y/N	Grms	N	Y/N	mm	grams					
		Raw score	144	144	101	59	44	70	71					
		Relative Weight	23%	23%	16%	9%	7%	11%	11%					

- **Feasibility Analysis**

Risk	Solution
Magnetorquer electrical connection is covered by the interface4	The magnetorquer is going to require a connection to the power supply to produce the dipole moment. The design of the interface will need to account for the connection port and ensure that a sound connection is still capable
Magnetorquer Interface is heavier and/or larger than off-the-shelf models	If the magnetorquer interface is not lighter and smaller than existing products, the project will not be a success. Therefore, different materials or designs should be expllored to overcome these obstacles
Magnetorquer damping mechanism is not effective at reducing the stresses encountered from space missions	Proper benchmarking should be done to ensure that the launch conditions are understood so the design can counteract these conditions appropriately. In addition, testing via software may be appropriate to test the effectiveness of the design
The scope and difficulty of the assignment is beyond an MSD group	Work with the SPEX team to identifiy specific goals and systems that can be broken down into their own senior design project. As an example, folding solar panels or design of an avionics system could be their own project.
The required funds are not gathered and the project cannot be completed	The SPEX team waits a semeste to rework a funding plan for the next phase of the project. This can be completed by looking to outside sponsorship, educational outreach programs, campus fund raising events, and through advocating for donations.

- **Constraints:**

- The weight of the damping medium as well as the weight of the physical connection mechanism needs to add minimal inertia to the vehicle
- The device cannot hinder the performance of the satellite nor the rods
- The cost must stay within the budget of the SPEX Team
- Any changes that SPEX makes to their design must be factored into the design of the interface

- **Product Deliverables:**

- Ultimately, a part needs to be machined and integrated with some sort of damping mechanism that has proven to reduce vibration frequencies transferring to the rods
- A manual or sheet calling out all instruction steps needs to be developed for the customer
- The test results need to be delivered documenting the vibration damping success
  a) Empirical testing may be outside scope of project, but simulations should be done
  b) Results need to be summarized and provided in a report for the customer
- Team will undergo a series of design reviews in the second semester of the fabrication phase
- Team members will need to record all benchmarking used in the design of their mechanism and document reasons for the decisions they make
  a) Need to be summarized in a report along with the simulated results of the vibration reducing mechanism

- **Budget Estimate**

- Since the team is still in their infant stages, monetary assessments have not yet been done and fundraising has not been done. However, down the road, it should become more evident of available funds for the project.
- Depending on the material chosen and the means of damping vibrations, the design should stay under $200 for the six required clasps

STUDENT STAFFING:

- **Skills Checklist:**

Skill	Priority*
Vibration	1
Matlab	2
CAD	1
Machining	2
Materials	2
Circuit Boards	3
Stress Analysis	2
Fatigue and static failure criteria	2
Materials Science	2
Materials Processing	2

***The priority scale used ranks 1-3 with 1 as a high priority**

- **Anticipated Roadmap**

Academic year	Team A	Team B
2015 - 2016	Structure	-
2016 - 2017	Power acquisition	Attitude control
2017 - 2018	Communication	Radiation protection
2018 - 2019	Avionics	-
2019-2020	Vibration mitigation	-

** Table of proposed timeline for all the PRPs related to developing a CubeSat. The structure of the CubeSat must be developed prior to any other system. After developing the outer structure of the CubeSat, internal subsystems can begin development. It's expected that the power acquisition and attitude control systems can be developed concurrently. Likewise, it's expected that the communication and radiation protection systems can be developed simultaneously Then, the overall avionics of the CubeSat can be developed to ensure proper functionality between all subsystems. Lastly, vibration mitigation must be considered in the final PRP to ensure that the completed CubeSat will survive launch and possibly re-entry.*

- **Anticipated Staffing by Levels**

Discipline	How Many?	Anticipated Skills Needed (*concise descriptions*)
EE	0	
ME	4	Very high level of vibrations and vibration reduction will be necessary. In addition, knowledge of how to simulate vibrations into Matlab or other FE software will be useful. Other skills needed are basic CAD and machining practices.
CE	0	
ISE	0	
Other	N/A	

- **MSD Plan for first 3 weeks:**

Week	Description	Total Days	Required Staffing
1	Review PRP and Assign Team Roles	21	All members
2-3	Reassess Customer requirements and meet with stakeholder	14	Lead Engineer and stakeholder contact
2-3	Begin to benchmark existing products and review existing benchmarking	14	All members
3	Reconstruct customer requirements to reflect current needs	7	All members
3	Begin rough sketches of design	7	Designer

- **Other resources needed:**

Category	Description	Resource Available?
Faculty	Dr. Ghoneim for vibration consultation	☒
Environment	Machine Shop	☒
	Computer Lab	☒
Equipment	Mills and Lathes	☒
	Basic Fabrication Tools	☒
		☐
Materials		☐
		☐

References::

1) http://www.space.com/23039-space-junk-explained-orbital-debris-infographic.html
2) http://www.nasa.gov/directorates/heo/home/CubeSats_initiative.html
3) http://www.cubesatshop.com/index.php?page=shop.product_details&category_id=7&flypage=flypage.tpl&product_id=102&option=com_virtuemart&Itemid=69&vmcchk=1&Itemid=69
4) http://www.ssbv.com/ProductDatasheets/page39/page55/index.html
5) http://www.spacecraftresearch.com/files/ZeledonPeckGNC2013.pdf
6) http://www.nps.edu/Academics/Institutes/Cebrowski/STEM/doc/Christine%20Poster.pdf
7) http://arc.aiaa.org/doi/abs/10.2514/3.19717