INTRODUCTION:

The purpose of this project readiness package (PRP) is to outline the anticipated skills and resources required for developing a vibration dampening subsystem which will be implemented on a CubeSat. A project aimed at designing, testing, and ultimately launching a CubeSat was proposed by the organization RIT SPEX; this PRP is only considering the final anticipated phase of the CubeSat Launch stage, involving vibrational analysis and test qualification.

ADMINISTRATIVE INFORMATION:

PROJECT NAME:	RIT SPEX: CUBESAT COMMUNICATION SUBSYSTEM	
PROJECT NUMBER:	R15301	
DESIRED START TERM / END TERM:	FALL 2015 / SPRING 2016	
TECHNICAL FACULTY MENTOR:	UNKNOWN	
OTHER SUPPORT:	DR. AGAMEMNON CRASSIDIS	
PROJECT GUIDE:	UNKNOWN	
PRIMARY CUSTOMER:	NAME:	ANTHONY HENNIG
	COMPANY:	RIT SPEX
	EMAIL:	AIH2400@RIT.EDU
SPONSOR:	NO SPONSOR; FUNDING REQUIRED	

PROJECT OVERVIEW:

BACKGROUND:

Currently, the Rochester Institute of Technology is doing cutting edge research in a variety of different fields ranging from sustainability to biomedical sciences and everything in between. Since the launch of the first satellites, space has become an ever growing field of interest for research and experimentation. However, RIT currently does not have a presence in space. The goal of the RIT Space Exploration (or SPEX) team is to create an organization that supports students and their research of space systems engineering such that RIT can have a presence in space in the future.

Figure 1: Cubesat

The most common and inexpensive way to test different space system technology is through the use of CubeSats. CubeSats are a class of miniaturized research satellites called nanosatellites which are usually no larger than a loaf of bread [1]. While they are not inexpensive to develop and launch, they are significantly cheaper than their full sized counterparts which have the potential to be the size of a school bus [2]. This makes CubeSats a great tool for research [1]. Currently, CubeSats have attracted interest for both universities and industry. For example, a few of the many organizations invested in CubeSats include NASA, Planet Labs, and Los Alamos Laboratories [3].

MOTIVATION:

In this phase of their CubeSat Launch Initiative, the focus will reside on vibration analysis and test qualification for the specific corresponding Launch Vehicle (LV). As part of the CubeSat Community, all participants have an obligation to ensure safe operation of their systems and to meet the design and minimal testing requirements as stated by the LV. This is necessary to ensure the safety of the CubeSat and protect the LV, primary payload, and other CubeSats. CubeSat developers should play an active role in ensuring the safety and success of CubeSat missions by implementing good engineering practice, testing, and verification of their systems. Failure of CubeSats or interface hardware can damage the LV

or a primary payload and put the entire CubeSat program in jeopardy [6]. This MSD project will be tasked with analyzing the current state of the CubeSat in order to design a proper dampening system that will isolate the vibrations and shock experienced in an actual launch. Additionally, the project will require completing the necessary tests to prove its reliability.

DETAILED PROJECT DESCRIPTION:

The information provided below is intended to provide sufficient detail to RIT faculty regarding the challenges, scope, skills, and resources required in order to complete the project. The goal of this section is to define what the project entails so that an informed decision can be made by RIT faculty regarding the implementation of the proposed CubeSat vibration damping subsystem as a MSD project for 5th year engineering students.

CUSTOMER NEEDS AND OBJECTIVES:

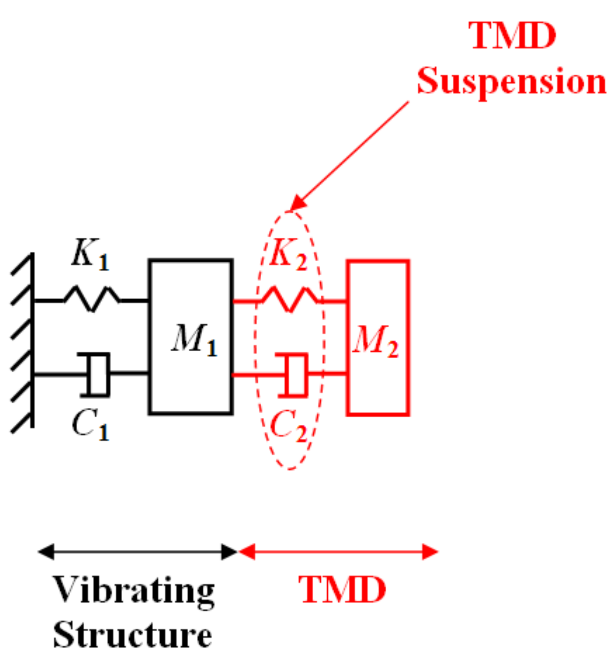
CR	Description	Customer Weights
4	Design capable of being built by MSD team	3
5	Cost Effective	5
6	"Clean" looking design for NASA proposal	1
9	Interface is durable	5
10	Dampens vibrations	3
11	Cost Effective	2
12	Minimizes material waste	2
13	Beat existing stock fixtures	4
15	Reproducibility of design	4
16	Testing of damping effectiveness	3
18	Components are housed in a single unit structure	1
26	CubeSat's electrical componets have a system to protect from effects of radiation in orbit.	5
27	Testing needs must be able to be completed at a MSD level.	5
29	Meets weight requirements	2
33	Cost effective testing.	4

*See appendix 3 for full list of CR's

FUNCTIONAL DECOMPOSITION:

POTENTIAL CONCEPTS: ***Potential concepts, skills, and tasks should not be shared with students.***

- **Tuned Mass Damper:** Also known as a harmonic absorber, a tuned mass damper is a device mounted in structures to reduce the amplitude of mechanical vibrations. Their application can prevent discomfort, damage, or outright structural failure. They are frequently used in power transmission, automobiles, and buildings.



- **Damping Sheet Stock:** Using damping sheet stock is an alternate method of isolating external vibrations. Highly dependent on geometry and used thickness; the thicker the sheet, the lower the natural frequency. It can be cut to shape, conforms to complex surfaces, commercially available and can be custom made to better

integration in its applications. Known use includes motor dampening, noise isolation and general household dampening. Simple.

- **Custom Composite Dampening Material:** If the students decide to, another possibility is to design a custom composite material with specific dampening properties. By choosing this approach, students will essentially be able to design a dampening system with precise dampening coefficients while minimizing weight and size.

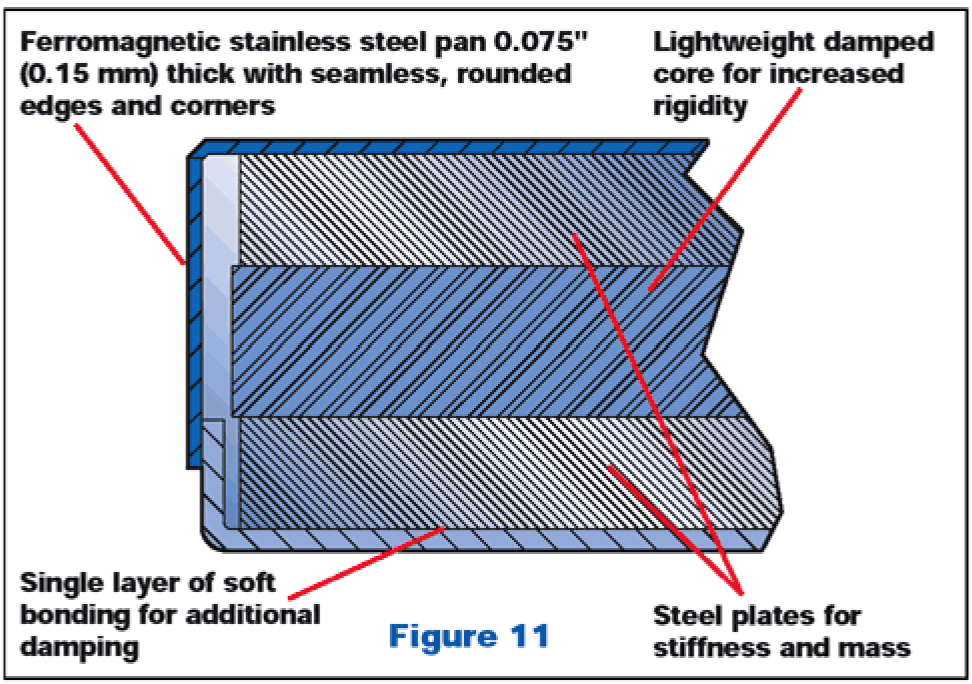


Figure 11

ENGINEERING REQUIREMENTS:

Function	Engineering Requirements	Unit	Marginal	Ideal	Additional Comments
Dampen Vibrations	Random Vibration Qualification: Survives random vibrations in 3 axes	[dB]	2 min: MPE + 3 dB	3 min: MPE + 6 dB	MPE - Maximum Potential Environment estimated by specific launch vehicle; testing shall be performed for content that is not covered by random vibration testing. If MPE unknown, use information listed in GSFC-STD-7000A
FEA or CAD Simulations	CubeSat modeled and tested via computer simulations	[Yes/No]	Yes	Yes	Computer simulating actual test values
Isolate Effects of Shock	Shock Qualification: Survives instances of shock in both directions of 3 axes	[dB]	1 time: MPE + 3 dB	3 times: MPE +6 dB	MPE - Maximum Potential Environment estimated by specific launch vehicle

HOUSE OF QUALITY:

	Customer Requirements	Customer Weights	Dampen Vibrations	FEA or CAD Simulations	Isolate Effects of Shock	Detailed documentation pertaining to design and constructio process to allow for ease of recreation.	Weight should be minimal	Weight addition stays within CubeSat weight limitations for size.	Make sure that the barrier does not push the CubeSat over it size requirements so to be compatible with NASA's requirements	Mulitple trials must be able to be conducted for the testing of the radiation barrier using various layup material combinatio and thicknesses.
			Engineering Metrics							
4	Design capable of being built by MSD team	3	3	3	3	3				
5	Cost Effective	5	5		5	5				
6	"Clean" looking design for NASA proposal	1								
9	Interface is durable	5	5	5	5					
10	Dampens vibrations	3	3	3	3					
11	Cost Effective	2	2		2		2			
13	Beat existing stock fixtures	4	4	4	4					
15	Reproducibility of design	4	4	4	4		4			
16	Testing of damping effectiveness	3	3	3	3		3			
18	Components are housed in a single unit structure	1	1	1	1					
21	All components need to be cost effective and cheaper than existing solutions	3	3		3					
27	Testing needs must be able to be completed at a MSD level.	5	5		5					5
29	Meets weight requirements	2						2	2	
33	Cost effective testing.	4	4		4					
	Technical Targets (Specifications)		3 min: MPE + 6 dB	Yes	3 times: MPE +6 dB	Yes	15	1.2	10	5
	Units		[dB]	[Yes/No]	[dB]	[Yes/No]	grams	[kg]	[cm^3]	[Trials per Variation]
	Technical Benchmarking	*Better 5*								
		4								
		3								
		2								
		Worse 1								
		Raw score	164	85	164	68	108	4	4	40
		Relative Weight	7%	4%	7%	3%	5%	0%	0%	2%

CONSTRAINTS:

- For a 1U CubeSat, the overall mass must be less than 1.33 kg. [3]
- For a 1.5U CubeSat, the overall mass must be less than 2.00 kg. [3]

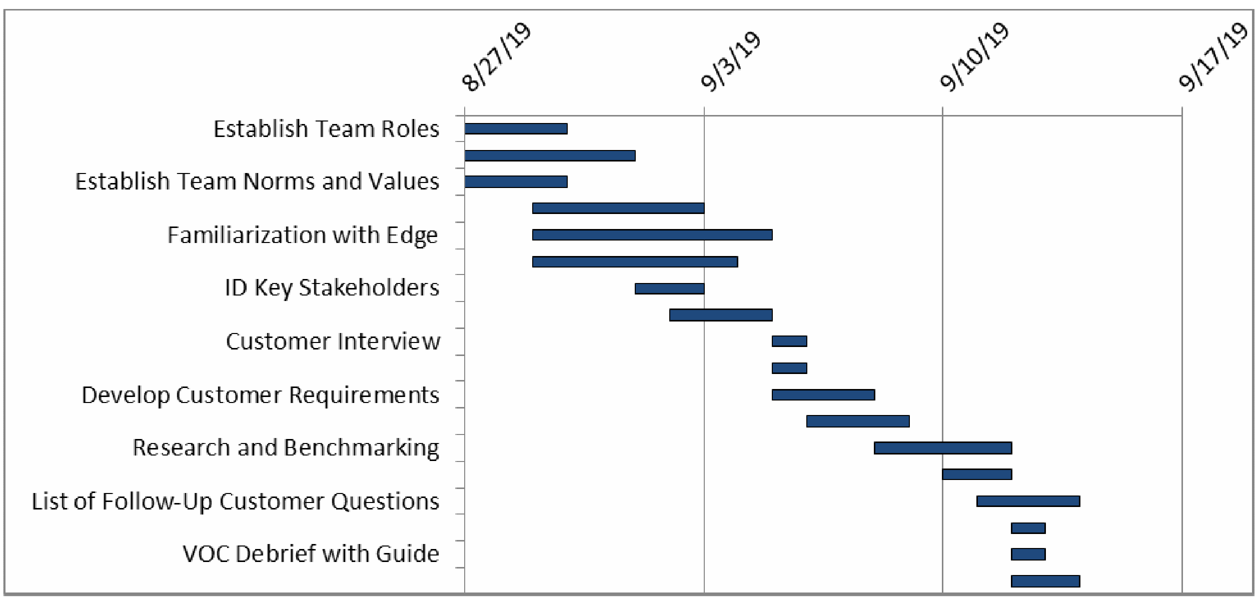
- For a 2U CubeSat, the overall mass must be less than 2.66 kg. [3]
- For a 3U CubeSat, the overall mass must be less than 4.00 kg. [3]
- CubeSat shall be no smaller than a 1U (10x10x10cm) form factor and no larger than a 6U (30x20x10cm) form factor. (dimensions are nominal) [7]

PROJECT DELIVERABLES: The chief deliverables of this phase of the RIT SPEX Cubesat Initiative is to pass minimal vibration environment requirements estimated by the individual Launch Vehicle (LV), thus qualifying them for a safe launch. The students must analyze the given system with all of its components and design a proper dampening system corresponding to the given LV requirements. After design, students will be required to perform required physical vibration and shock tests to prove their analysis and qualify for launch.

- Budget Estimate: $1500
  Currently, RIT does not have a vibration testing facility suitable for simulating the high levels of vibrations experienced during a launch. As NASA's CubeSat Launch Initiative requires such tests to be performed, students will likely have to find an external testing facility to use. A quote from one capable test facility, Innovative Test Solutions, gave an estimate of $1500 to be able to use their facilities for a day. Although this price is high, they are additionally capable of performing tests other than vibrations, including thermal and environmental testing [7]. If the RIT SPEX team chooses to use this facility, they could potentially perform all of the required tests in one location.

- Intellectual Property (IP) considerations: ISE student will likely need to obtain proprietary information regarding the launch vehicles from NASA.

- Other Information: Proposed Timeline for the Initial 3 Weeks of MSD 1



- Other Information: Proposed Timeline for MSD Project Phases

Academic Year	Team A	Team B
2015 - 2016	Structure	-
2016 - 2017	Solar Arrays	Attitude Control
2017 - 2018	Communication	Radiation Protection
2018 - 2019	Avionics	-
2019-2020	Vibration Mitigation	-

The RIT SPEX group will be working on their Cubesat Initiative project over multiple phases. Vibration analysis & testing phase will likely be a final stage following phases involving Power Generation, Attitude Control/Actuation, Avionics and Communication. Prior projects will give students vital information on mass placement in the Cubesat.

STUDENT STAFFING:

ANTICIPATED STAFFING LEVELS BY DISCIPLINE:

Discipline	How Many?	Anticipated Skills Needed (*concise descriptions*)
EE		
ME	3	Vibrations; Stress analysis; Matlab; Composites; Material Science; Statistics; 3D CAD; GD&T; Design for Manufacturability; FEA
CE		
ISE	1	Project Management; Material Science; Math Modeling / Simulations
Other		

*for Skills Checklist, see Appendix 1

OTHER RESOURCES ANTICIPATED:

Describe resources needed to support successful development, implementation, and utilization of the project. This could include specific faculty expertise, laboratory space and equipment, outside services, customer facilities, etc. Indicate if resources are available, to your knowledge.

Category	Description	Resource Available?
Faculty	**Support from Dr. Dorin Patru in electronic component analysis**	☒
	Faculty advisor with advanced knowledge of vibration and composite analysis	☒
		☐

Environment	**Secure working environment and storage location**	☒
		☐
		☐
Equipment	**Packaging Science Dynamics Lab Vibration Table (RIT internal)**	☒
	Innovation Test Solutions (external test facility) [8]	☐
	Delphi Technical Center Rochester Vibration Laboratory (external) [5]	☐
	RIT Formula SAE Composites Lab	☒
	RIT CAST Composites Lab	☒
Materials	**Semi-built Cubesat**	☒
	Pre-determined internal components	☒
	Damping material/component of choice	☐
Other	**Individual transportation to off-campus test locations**	☐
		☐
		☐

Prepared by: Matthew Mares Date: 5/4/15

Appendix

Appendix 1: Skills Checklist

Mechanical Engineering

1	3D CAD		Aerodynamics
5	MATLAB programming		CFD
6	Machining (basic)		Biomaterials
2	Stress analysis (2D)	1	Vibrations
	Statics/dynamic analysis (2D)		Combustion engines
	Thermodynamics	2	GD&T (geometic dimensioning & tolerancing)
	Fluid dynamics (CV)		Linear controls
	LabView (data acquisition, etc.)	3	Composites
3	Statistics	4	DFM
			Robotics (motion control)
2	FEA		Composites
	Heat transfer	5	Other: Basic knowledge of electronic components and physical ratings.
	Modeling of electromechanical & fluid systems		Other:
	Fatigue & static failure criteria (DME)		Other:
	Specifying machine elements		

Reviewed by (ME faculty): ______________________________

Industrial & Systems Engineering

3	Statistical analysis of data – regression		Shop floor IE – methods, time study
3	Materials science		Programming (C++)
	Materials processing – machining lab		
	Facilities planning – layout, material handling		DOE
	Production systems design – lean, process improvement		Systems design – product/process design
	Ergonomics – interface of people & equipment (procedures, training, maintenance)		Data analysis, data mining
2	Math modeling – linear programming), simulation		Manufacturing engr.
1	Project management		DFx -- Manuf., environment, sustainability
	Engineering economy – ROI		Other:
	Quality tools – SPC		Other:
	Production control – scheduling		Other:

Reviewed by (ISE faculty): ______________________________

Appendix 2: Customer Requirements (original)

Need #	Category	Importance	Description
CN1	Technology	Critical	Risk Reduction testing on LUX Technology
CN2		Critical	Create layout of components for 1U Cubesat
CN3	Funding	Important	Need proper funding to perform necessary tests to gain project approval
CN4		Important	Need funding for material and hardware Costs
CN5		Important	Steady source of revenue
CN6		Desirable	Sponsors to provide technology and fund project to continue launch plan
CN7	Layout	Critical	Proposal accepted by NASA for ElaNa Launch
CN8		Critical	Help turn SPEX clud into an annual MSD project
CN9		Important	Need structure from successful Cubesat program to provide guidance to the launch
CN10	Time Frame	Important	Create roadmap with a reasonable timespan to aid in current progression
CN11		Important	Complete neccesary testing before proprosal submission in November

Appendix 3: Customer Requirements (revised)

CR	Description	Customer Weights
1	Deployable arrays	5
2	Easily implementable into chosen CubeSat design	3
3	Function correctly during launch	5
4	Design capable of being built by MSD team	3
5	Cost Effective	5
6	"Clean" looking design for NASA proposal	1
7	Compatible with Magnetorquer rods	5
8	Compatible with existing environment	5
9	Interface is durable	5
10	Dampens vibrations	3
11	Cost Effective	2
12	Minimizes material waste	2
13	Beat existing stock fixtures	4
14	Ease of installation	4
15	Reproducibility of design	4
16	Testing of damping effectiveness	3
17	Compatability with NASA Communication System	3
18	Components are housed in a single unit structure	1
19	3-axis attitude control and sensing	3
20	Functional Flight Software	3
21	All components need to be cost effective and cheaper than existing solutions	3
22	Able to determine orbital location	3
23	Able to log all operational status, location, communication, and sensor data for entire durat	2
24	CubeSat's electrical componets have a system to protect from effects of radiation in orbit	3
25	Adds minimal inertia to vehicle	5
26	CubeSat's electrical componets have a system to protect from effects of radiation in orbit.	5
27	Testing needs must be able to be completed at a MSD level.	5
28	Radiation protection system must be passive system.	5
29	Meets weight requirements	2
30	The system cannot interfer with other primary functions and systems.	5
31	Radiation hardened components must be able to function with the same performance as th	5
32	The radiation barrier, if selected based on pricing, must have a lead time <= time for the R	3
33	Cost effective testing.	4

Appendix 4: House of Quality

QFD Matrix

PHASE I QFD

Dampen Vibrations
Array designs needs to implemented into chosen CubeSat design as well as be easily adaptable to future designs.
Solar cells need to be arranged on array to have the optimal amount of sun exsposure. Need to produce emough energy to power CubeSat.
MSD team needs to build majority of design at RIT with minimal outsourcing.
Within the RIT SPEX budget.
Detailed documentation pertaining to design and construction process to allow for ease of receration.
Link with existing environment
Physicall link with rods
Survive ejection forces
Dampen vibrations from launch and deploy
Infuse damping mechanism to vehicle
Weight should be minimal
Determine Location via GPS/GNSS at given rate
Determine Attitude via Gyroscope or AHRS at given rate
Compatable with Power Sensors
Compatable with Solar Panel I/O
Compatable with Attitude Control I/O
Compatable with Communication I/O
HDD/SDD Capacity to store logs for duration of flight
Compatable with subsystem sensors or subcontrols
Fit inside MSD designed structure
Ensure functionality of solar panels on the surface of the CubeSat via their power output.

	Customer Requirements	**Customer Weights**	Dampen Vibrations	FEA or CAD Simulations	Isolate Effects of Shock	The arrays need to have a deployment mehcanism that deplo consistently and effectively.	Array designs needs to implemented into chosen CubeSat design as well as be easily adaptable to future designs.	Solar cells need to be arranged on array to have the optimal amount of sun exsposure. Need to produce emough energy t power CubeSat.	MSD team needs to build majority of design at RIT with minimal outsourcing.	Within the RIT SPEX budget.	Detailed documentation pertaining to design and constructio process to allow for ease of receration.	Link with existing environment	Physicall link with rods	Survive ejection forces	Dampen vibrations from launch and deploy	Infuse damping mechanism to vehicle	Weight should be minimal
1	Deployable arrays	5				5	3		4		5						
2	Easily implementable into chosen CubeSat design	3				4	5	2	5	4	3						
3	Function correctly during launch	5				5	3	5		4				3	3		
4	Design capable of being built by MSD team	3	3	3	3	5		3	4		3			3	3		
5	Cost Effective	5	5		5	5		5			5						
6	"Clean" looking design for NASA proposal	1				1	1		3					4	4	1	
7	Compatible with Magnetorquer rods	5										4	4	2	2	5	5
8	Compatible with existing environment	5										4	4	2	2	4	5
9	Interface is durable	5	5	5	5							4	4	5	5		
10	Dampens vibrations	3	3	3	3							3	3	2			
11	Cost Effective	2	2		2							5	5	5	3	4	2
12	Minimizes material waste	2										5	5	5	5	5	2
13	Beat existing stock fixtures	4	4	4	4							5	5	3	4		
14	Ease of installation	4										3	3	2			
15	Reproducibility of design	4	4	4	4							5	5			3	4
16	Testing of damping effectiveness	3	3	3	3							5	5	5	5	5	3
17	Compatability with NASA Communication System	3															
18	Components are housed in a single unit structure	1	1	1	1												
19	3-axis attitude control and sensing	3															
20	Functional Flight Software	3															
21	All components need to be cost effective and cheaper than existing solutions	3	3		3												
22	Able to determine orbital location	3															
23	Able to log all operational status, location, communication, and sensor data for entire duration of flight	2															
24	CubeSat's electrical componets have a system to protect from effects of radiation in orbit	3															
25	Adds minimal inertia to vehicle	5										4	4	3		2	5
26	CubeSat's electrical componets have a system to protect from effects of radiation in orbit.	5															
27	Testing needs must be able to be completed at a MSD level.	5	5		5												
28	Radiation protection system must be passive system.	5															
29	Meets weight requirements	2															
30	The system cannot interfer with other primary functions and systems.	5															
31	Radiation hardened components must be able to function with the same performance as the non-hardened counterparts.	5															
32	The radiation barrier, if selected based on pricing, must have a lead time <= time for the RH components	3															
33	Cost effective testing.	4	4		4				5								
	Technical Targets (Specifications)		3 min: MPE + 6 dB	Yes	3 times: MPE +6 dB	Yes	Yes	7W	10%<=	Yes	Yes	Yes	Yes	12	>10	Yes	15
	Units		[dB]	[Yes/No]	[dB]	% deployment	[Yes/No]	[W]	[Outsourced	[Yes/No]	[Yes/No]	Yes/No	Yes/No	N	G rms	Yes/No	grams
	Technical Benchmarking	*Better 5*															
		4															
		3															
		2															
		Worse 1															
		Raw score	164	85	164	103	46	65	70	32	68	176	176	149	120	101	108
		Relative Weight	7%	4%	7%	5%	2%	3%	3%	1%	3%	8%	8%	7%	5%	4%	5%

Engineering Metrics

Engineering Metric	Target	Units	Importance	%
Determine Location via GPS/GNSS at given rate	[1 m], [1 Hz]		49	2%
Determine Attitude via Gyroscope or AHRS at given rate	[0.1 deg],[5 Hz]		64	3%
Compatable with Power Sensors	Yes	[Yes/No]	25	1%
Compatable with Solar Panel I/O	Yes	[Yes/No]	25	1%
Compatable with Attitude Control I/O	Yes	[Yes/No]	40	2%
Compatable with Communication I/O	Yes	[Yes/No]	40	2%
HDD/SDD Capacity to store logs for duration of flight	1000 days	[days]	12	1%
Avionics functionality to log status	Yes	[Yes/No]	22	1%
Compatable with subsystem sensors or subcontrols	Yes	[Yes/No]	43	2%
Avionics are within voltage specifications and current capacities	Yes	[Yes/No]	15	1%
CubeSat is shielded or Avionics have radiation shielding	Yes	[Yes/No]	15	1%
Fit inside MSD designed structure	Yes	[Yes/No]	12	1%
Provide temperature margin from max operational temp.	15	[Δ°C]	14	1%
Radiation barrier does not effect the signal frequency require for comms.	435	[MHz]	25	1%
Radiation protection system selected minimizes cost (and by extension, lead time) the most while maintaining equal or bet protection.	Yes	[Yes/No]	25	1%
Weight addition stays within CubeSat weight limitations for size.	1.2	[kg]	4	0%
Apply various thickness layers of radio frequency tantalum t aluminun, copper, titanium or carbon fiber.	TBD	[mm]	45	2%
Make sure that the barrier does not push the CubeSat over its size requirements so to be compatible with NASA's requirements	10	[cm^3]	4	0%
Multiple trials must be able to be conducted for the testing of the radiation barrier using various layup material combinatio and thicknesses.	5	[Trials per Variation]	40	2%
Ensure radiation barrier does not effect the proper margin between avionics maximum temperature and operational temperature.	15	[Δ°C]	25	1%
Radiation hardened components works without requiring any additional inputs.	Yes	[Yes/No]	15	1%
Ensure that the selected radiaiton protection system functions and protects electrical components.	Yes	[Yes/No]	50	2%
Ensure functionality of solar panels on the surface of the CubeSat via their power output.	Yes	[Yes/No]	25	1%

					5			5														
											3	5										
	5																					
5	5	5	5	5	5	1	3	3	5			3										
3	3					1	1	3														
5	5			5																		
5	5	5	5	5	5	3	5	5														
										5	3											
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																5		5				
																				3		
															2		2					
													5						5			5
																		3			5	
														3								
														4		5						

Customer Perception

1 *Worse*
2
3
4
5 *Better*

A:Shields-1 CubeSat #1
B: MicroMas #2
C: Cornel University - Violet NanoSat

Appendix 5: LSP – Test Requirements [7]

Table 1 – Dispenser and CubeSat Environments Test Table

Tests	Qualification by Test	Protoflight Test	Acceptance Test
Random vibration[6] (CubeSat and Dispenser) Ref Mil-Std 1540C	MPE + 6 dB for (3) minutes, each of (3) axes [1]	MPE+3 dB for (2) minutes, each of (3) axes [1]	MPE for (1) minute, each of (3) axes [1]
Sinusoidal Vibration[6] (CubeSat and Dispenser) Ref Mil-Std 1540C	MPE + 6 dB. Testing shall be performed for content that is not covered by random vibration testing	1.25 x MPE. Testing shall be performed for content that is not covered by random vibration testing	MPE. Testing shall be performed for content that is not covered by random vibration testing [1]
Shock[6] (CubeSat and Dispenser) Ref Mil-Std 1540C	MPE + 6 dB, 3 times in both directions of 3 axes [1, 3]	MPE + 3 dB, 1 times in both directions of 3 axes [1, 3]	N/A
Thermal Vacuum Cycle (Dispenser Only) Ref.: MIL-STD 1540 B, GSFC-STD-7000	MPE[2] +/- 10° C Minimum Range = -14 -3/+0°C to +71 -0/+3°C Cycles = 8 Dwell Time = 1 hour min. @ extreme Temp. after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr	MPE[2] +/- 10° C Minimum Range = -14 -3/+0°C to +71 -0/+3°C Cycles = 4 Dwell Time = 1 hour min. @ extreme Temp. after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr	MPE[2] +/- 5° C Minimum Range = -9 -3/+0°C to +66-0/+3°C Cycles = 2 Dwell Time = 1 hour min. @ extreme Temp. after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr
Thermal Vacuum Bake out (Dispenser Only) Ref.: MIL-STD 1540 B, GSFC-STD-7000	N/A	Min. Temp 70°C [4, 7] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transition = N/A Vacuum = $1x10^{-4}$ Torr	Min. Temp 70°C [4, 7] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transition = N/A Vacuum = $1x10^{-4}$ Torr
Thermal Vac Bake out (CubeSat Only) Ref.: MIL-STD 1540 B, GSFC-STD-7000	N/A	Min. Temp 70°C [5, 8] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transition = < 5° C/minute Vacuum = $1x10^{-4}$ Torr	Min. Temp 70°C [5, 8] Cycles = 1 Dwell Time = Min. 3 hour after thermal stabilization Transiton = < 5° C/minute Vacuum = $1x10^{-4}$ Torr
Hardware Configuration	Dispenser – Flight identical unit (includes NEA, cable and connector) **CubeSat** – Flight Identical unit	Dispenser – Flight unit (includes flight NEA, cable and connector) **CubeSat** – Flight unit	Dispenser – Flight unit (includes flight NEA, cable and connector) **CubeSat** – Flight unit

Appendix 6: References

[1] "CubeSat Launch initiative (CSLI)." NASA, n.d. Web. 6 Feb. 2015.

[2] "What Is a Satellite?." NASA, n.d. Web. 6 Feb. 2015.

[3] P. M. Swartwout, "CubeSat Database," St. Louis University. [Online]. [Accessed 7 February 2015].

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