INTRODUCTION:

The proposed project for this Project Readiness Package (PRP) is to develop a set of cost effective deployable solar arrays for a CubeSat. These would be used by the RIT Space Exploration team (SPEX) on their first CubeSat.

ADMINISTRATIVE INFORMATION:

- Project Name (tentative): Cost Effective Deployable Solar Arrays for CubeSats
- Project Number, if known: R15301
- Preferred Start/End Semester in Senior Design:
  ☒ Fall ☐ Spring
- Faculty Champion: *(technical mentor: supports proposal development, anticipated technical mentor during project execution; may also be Sponsor)*

Name	Dept.	Email	Phone

For assistance identifying a Champion: B. Debartolo (ME), G. Slack (EE), J. Kaemmerlen (ISE), R. Melton (CE)

- Other Support, if known: *(faculty or others willing to provide expertise in areas outside the domain of the Faculty Champion)*

Name	Dept.	Email	Phone
Anthony Henning	MECE-Student	aih2400@rit.edu	804-691-7186

- Project "Guide" if known: *N/A*
- Primary Customer, if known (name, phone, email): RIT Space Exploration, Anthony Henning - aih2400@rit.edu
- Sponsor(s): *(provider(s) of financial support)*

Name/Organization	Contact Info.	Type & Amount of Support Committed

PROJECT OVERVIEW:

PROJECT 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.

Currently, the most common and inexpensive way to test different types of space system technology is through the use of CubeSats (figure 1). 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, some of which can be the size of a school bus [7]. This makes CubeSats a great tool for research [1]. Currently, CubeSats have attracted the interest of both universities and industry. For example, a few of the many organizations presently invested in CubeSats include NASA, Planet Labs, and Los Alamos Laboratories [8].

MOTIVATION:

In order for a CubeSat to power itself in orbit, solar panels are used. There are two primary ways for the solar panels to be implemented into the design of the CubeSat. They can either be placed directly on the CubeSat itself, or mounted onto deployable solar arrays which are attached to the CubeSat. While mounting the panels directly on the CubeSat is simple, it does not allow for nearly as much power generation as the deployable arrays. However, the deployable arrays are extremely expensive. When purchased premade, they can cost upwards of $10,000 [2]. The job of the MSD team would be to develop deployable solar arrays for a CubeSat that are not only reliable, but within the RIT SPEX budget.

Fig 1: Standard 1U CubeSat [1]

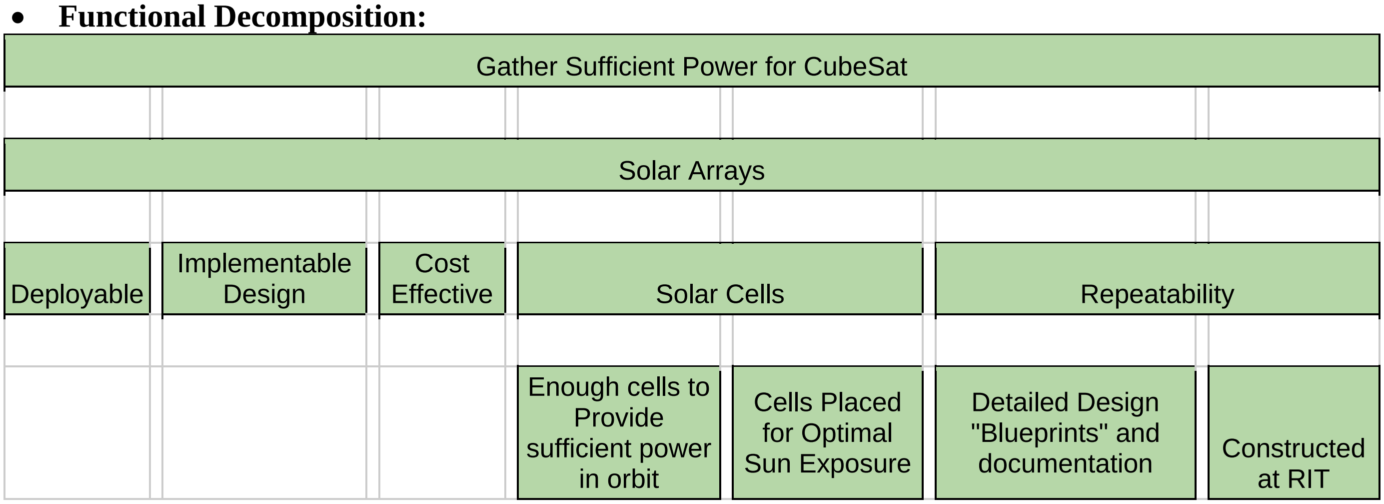
Fig 2: CubeSat with deployable solar arrays[2]

Detailed Project Description:

- **Customer Needs and Objectives:**

	Customer Needs and Objectives	
Number	Importance	Description
CR30	Critical	Deployable arrays
CR31	Important	Easily implementable into chosen CubeSat design
CR32	Critical	Function correctly during launch
CR33	Important	Design capable of being built by MSD team
CR34	Critical	Cost Effective
CR35	Desirable	"Clean" looking design for NASA proposal

- **Functional Decomposition:**



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

Number	Function	Engineering Requirements	Unit of Measurement	Marginal Value	Ideal Value	Additional Comments
ER14	Deployable arrays	The arrays need to have a deployment mechanism that deploys consistently and effectively.	100% deployment	95% deployment	Yes	Testing needs to be done to assure arrays will deploy upwards of 95% of the time.
ER15	Implementable/ adaptable design	Array designs needs to implemented into chosen CubeSat design as well as be easily adaptable to future designs.	[Yes/No]	Yes	Yes	RIT SPEX has not finalized CubeSat deisgn. Arrays will need to be implemented into design once it is finalized.
ER16	Provide power during orbit	Solar cells need to be arranged on array to have the optimal amount of sun exposure. Need to produce enough energy to power CubeSat.	[W]	5W	7W	Run simulations to assure optimal solar cell placement.
ER17	Constructed at RIT	MSD team needs to build majority of design at RIT with minimal outsourcing.	[Outsourced%]	15%<=	10%<=	RIT SPEX needs to have ability to construct future arrays
ER18	Cost effective	Within the RIT SPEX budget.	[Yes/No]	Yes	Yes	No room to exceed budget. Must stay at or below.
ER19	Detailed design 'blueprints'	Detailed documentation pertaining to design and construction process to allow for ease of recreation.	[Yes/No]	Yes	Yes	RIT SPEX needs to have ability to construct future arrays. Documentation needs to be relatively easy to follow.

Potential Concepts:

Presently, due to their high efficiency of 25%-40%, gallium arsenide solar cells are used on the majority of CubeSats [3]. While these cells are extremely effective, they are very expensive. There are two major ways to combat this issue.

1) Purchase solar cells from a third party seller
2) Look into alternative types of solar cells

Third Party Sellers:

When solar cells are purchased from primary sellers such as Spectrolab and SolAero (formerly Emcore), they come with high performance guarantees. Every solar cell purchased from them will function correctly, and efficiently. However, these guarantees come at a very high price, upwards of $600 - $1000 per solar cell [5][6]. RIT SPEX will need approximately 8-10 cells. This cost will make those cells over budget, and therefore unfeasible. Cells can be purchased from third party vendors for significantly less, however they do not come with the reliability of the more expensive ones. One possible option for designing cost effective, deployable solar arrays is to purchase a large number of cells from various third party vendors and thoroughly test them. When you purchase cells from a third party vendor you get a less costly product, however, it may not meet the standards it claims to meet. Cells could be purchased inexpensively from these vendors and then tested for functionality, effectiveness etc. Those individual cells that meet the requirements will be used in the solar arrays, those that do not, can be discarded or saved for future projects.

Alternative Solar Cells:

While gallium arsenide solar cells are the most commonly used, they are not the only solar cells on the market. Another option would be to use silicon solar cells which are inexpensive, due in part to their lower efficiency levels (12%-18%) [4]. Due to the low efficiency, significantly more silicon solar cells would be required to generate sufficient power than their gallium arsenide counter parts. If the deployable arrays are designed to maximize surface area, it is possible that enough solar cells could be placed on the arrays to generate sufficient power. This would require extensive testing, but could lead to a successful and cost effective option in designing the deployable solar arrays.

- **House of Quality:**

			Engineering Metrics						Legend				
			ER1	ER2	ER3	ER4	ER5	ER6					
	Customer Requirements	**Customer Weights**	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 enough 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.	*1 Worse*	*2*	*3*	*4*	*5 Better*
CR1	Deployable arrays	5	5	3		4		5					
CR2	Easily implementable into chosen CubeSat design	4	4	5	2	5	4	5					
CR3	Function correctly during launch	5	5	3	5		4						
CR4	Design capable of being built by MSD team	3	5		3	4		5					
CR5	Cost Effective	5	5		5			1					
CR6	"Clean" looking design for NASA proposal	1	1	1		3							
	Technical Targets (Specifications)		Yes	Yes	7W	10%<=	Yes	Yes	A:Shields-1 CubeSat #1 B: MicroMas #2 C: Cornel University - Violet NanoSat				
	Units		% deployment	[Yes/No]	[W]	[Outsourced%]	[Yes/No]	[Yes/No]					
		Raw score	107	51	67	55	36	65					
		Relative Weight	28%	13%	18%	14%	9%	17%					

- Constraints:
  - Cannot exceed the budget provided by RIT SPEX
  - Must produce efficient energy to power CubeSat in orbit
    - Value will be provided by RIT once it is known
  - Must not interfere with any of the electrical components of the CubeSat
  - Cannot alter the design of the CubeSat created by RIT SPEX

- **Project Deliverables:**
  - The main deliverable of this project is a set of deployable solar arrays for a CubeSat that achieves the items listed below.
    - Within the RIT SPEX provided budget
    - Design must be adaptable to future CubeSat designs
    - Design and construction process must be well documented to allow for easy re-creation for future CubeSats
    - Design choices must be documented and justified

- Team must prove designed solar arrays will generate the proper amount of energy to power the CubeSat in orbit.

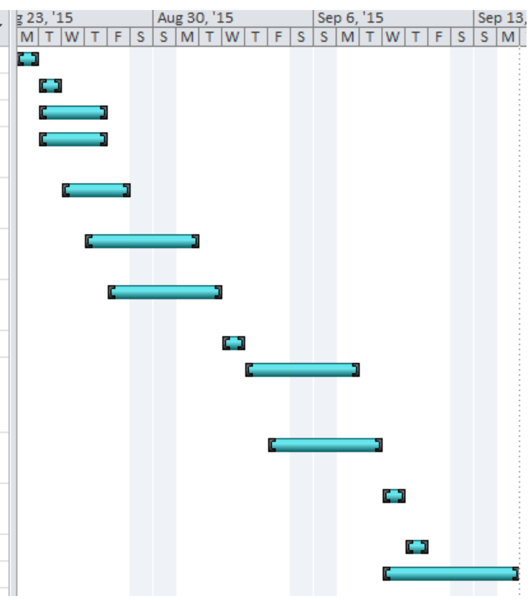
- **Budget Estimate:**
  - Due to the RIT SPEX club being in their early stages, assessments of what funding RIT SPEX will be able to provide has not been done. In the future, the budget that they will supply to the MSD team will become clear.
  - Due to the cost of materials, a budget estimate has been provided below.

Budget	
Solar Cells	$250
Array Construction Materials	$125
Array Circitry	$125

- Intellectual Property (IP) considerations: At this time there are no intellectual property concerns.

- Other Information: Sample 3 Week MSD Plan

Task Name	Duration	Start	Finish	Predecessors	Resource Names	Add New Column
Initial Team Meeting	1 day	Mon 8/24/15	Mon 8/24/15			
Review PRP	1 day	Tue 8/25/15	Tue 8/25/15			
Establish Team Roles	3 days	Tue 8/25/15	Thu 8/27/15			
Define and Finalize Team Norms and Values	3 days	Tue 8/25/15	Thu 8/27/15			
Prepare Interview Questions for Customer	3 days	Wed 8/26/15	Fri 8/28/15			
Schedule Customer Meeting	3 days	Thu 8/27/15	Mon 8/31/15			
Break down project and identitfy subsystems	3 days	Fri 8/28/15	Tue 9/1/15			
Customer Interview	1 day	Wed 9/2/15	Wed 9/2/15			
Follow up questions from customer interview	3 days	Thu 9/3/15	Mon 9/7/15			
Schedule Customer Meeting	3 days	Fri 9/4/15	Tue 9/8/15			
Follow up customer interview	1 day	Wed 9/9/15	Wed 9/9/15			
Work on EDGE page	1 day	Thu 9/10/15	Thu 9/10/15			
Project Benchmarking	4 days	Wed 9/9/15	Mon 9/14/15			



- **Continuation Information:** If a future Masters student were to do a thesis project on alternatives to solar cells to supply energy to CubeSat it could allow for a second iteration of this project to occur based on the information gained by the student's thesis.

- Timeline for all PRPs related to CubeSat Development:

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 timeline above provides an outline for the order in which all the MSD projects relating to CubeSat development must take place. Developing solar arrays cannot begin until the structure of the CubeSat has been designed.

Works Cited:

[1] "CubeSat Launch initiative (CSLI)." NASA, Web. 6 Feb. 2015.
[2] "Deployable CubeSat Solar Panels." *CubeSat Systems* . Clyde Space , Web. 25 Apr. 2015.
[3] "Inorganic Photovoltaics." *NanoFlexPower*. NanoFlex, Web. 5 May 2015.
[4] "Silicon Solar Cell Parameters." *PVeducation.org*. Ed. Christiana Honsberg. PVeducation, Web. 5 May 2015.
[5] "Space Solar Cells / Coverglass Interconnected Cells (CIC)." *Space Solar Cells* . SolAero Technologies , n.d. Web. 6 May 2015.
[6] "Photovoltaics." *SpectroLabs*. Boeing, Web. 5 May 2015.
[7]"What Is a Satellite?." NASA, n.d. Web. 6 Feb. 2015.
[8] P. M. Swartwout, "CubeSat Database," St. Louis University. [Online]

STUDENT STAFFING:

- Anticipated Staffing Levels by Discipline:

Discipline	How Many?	Anticipated Skills Needed (*concise descriptions*)
EE	1	Power Budgets, thermal trigger circuitry design and implementation
ME	4	CAD modeling, stress analysis, optimization in design
CE		
ISE		
Other		

OTHER RESOURCES ANTICIPATED:

Category	Description	Resource Available?
Faculty	**Faculty advisor with advanced knowledge of solar cells**	☐
		☐
		☐
Environment	**Sterile and contained test environment to assure solar cells are not damaged and test results are accurate**	☒
		☐
		☐
Equipment	**IV tester to allow for testing of solar cells**	☐
	Software to allow for satellite simulations	☐
		☐
Materials	**Solar Cells (Will be purchased by MSD team)**	☒
		☐
		☐
Other		☐
		☐
		☐

Skills Checklist:

Project Name (tentative): SPEX

Checklist Completed by (name): Anna Jensen

1: High Importance, 3: Somewhat Important, 5: Not Important, but useful

Mechanical Engineering

1	3D CAD		Aerodynamics

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

Reviewed by (ME faculty): ______________________________

Industrial & Systems Engineering

	Statistical analysis of data – regression		Shop floor IE – methods, time study
	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
	Math modeling – linear programming), simulation		Manufacturing engr.
	Project management		DFx -- Manuf., environment, sustainability
	Engineering economy – ROI		Other:
	Quality tools – SPC		Other:
	Production control – scheduling		Other:

Reviewed by (ISE faculty): ______________________________

Electrical Engineering

1	Circuit design: AC/DC converters, regulators, amplifier ckts, analog filter design, FPGA Logic design, sensor bias/support circuitry		Digital filter design and implementation, DSP
1	Power systems: selection, analysis, power budget		Microcontroller selection/application

	determination		
	System analysis: frequency analysis (Fourier, Laplace), stability, PID controllers, modulation schemes, VCO's & mixers, ADC selection		Wireless protocol, component selection
	Circuit build, test, debug (scopes, DMM, function generators)		Antenna selection (simple design)
1	Board layout		Communication system front end design
5	MATLAB		Algorithm design/simulation
	PSpice		Embedded software design/ implementation
	Programming: C, Assembly		Other:
	Electromagnetics (shielding, interference)		Other:
			Other:

Reviewed by (EE faculty): ____

Computer Engineering

	Digital design (including HDL and FPGA)		Wireless networks
	Software for microcontrollers (including Linux and Windows)		Robotics (guidance, navigation, vision, machine learning, and control)
	Device programming: Assembly language, C		Concurrent and embedded software
	Programming: Java, C++		Embedded and real-time systems
	Analog design		Digital image processing
	Networking and network protocols		Computer vision
	Scientific computing (including C and MATLAB)		Network security
	Signal processing		Other:
	Interfacing transducers and actuators to microcontrollers		Other:
			Other:

Reviewed by (CE faculty): ____

Chemical Engineering

	Energy and material balances on chemical systems		Electrochemistry
	Fluid dynamics and Heat transfer		Inorganic chemistry
	Thermodynamics (traditional and chemical)		Environmental science and sustainability
	Mass transfer and separation process design: distillation, multistage absorption and stripping, batch and fixed-bed adsorption, liquid-liquid extraction, crystallization, membrane separations.		Advanced material science, polymer science

☐	Chemical reactor design: chemical kinetics, equilibrium, and catalysts.	☐	Surface tension and interfacial phenomena
☐	Engineering lab skills: rheology (in Newtonian and non-Newtonian systems), pressure, temperature, concentration. Pilot lab systems; delivery system assembly including pumps, valves and pressure sensors.	☐	
☐	MATLAB and EXCEL: solve complex chemical engineering mathematics problems	☐	
☐	Advanced chemistry knowledge: general, physical, and organic	☐	
☐	Micro- and nano-scale phenomena and process design	☐	
☐	Basic chemistry-based material science	☐	
☐	Basic engineering economics	☐	Other:
☐	Basic Process Control	☐	Other:
☐		☐	Other:

Reviewed by (ChemE faculty): ______________________________

Prepared by: Anna Jensen Date: 4/30/2015