Multidisciplinary Senior Design
SRAD High Powered Rocket Engine Proposal

Project Title:	**SRAD High Powered Rocket Engine**
Project Number: (assigned by MSD)	N/A
Primary Customer: (provide name, phone number, and email)	RIT Launch Initiative - launchinitiative@rit.edu
Sponsor(s): (provide name, phone number, email, and amount of support)	RIT Launch Initiative - $500 Independent Investors - $3000 Boeing - $500 (maybe) MSD - $500
Preferred Start Term:	Fall 2017
Faculty Champion: (provide name and email)	Gerald Fly, Lecturer - Mechanical Engineering gwfeme@rit.edu, 585-475-5269 (work)
Other Support:	Dr. Dorin Patru, Associate Professor - Electrical Engineering dxpeee@rit.edu, 585-475-2388 (work) Dr. Mark Olles, Assistant Professor, Mechanical and Manufacturing Engineering Technology, mwomet@rit.edu
Project Guide: (assigned by MSD)	N/A

Zachary Rizzolo, Oldaryln Castillo, Trevor Mothersell, & Tim Frey — 6/1/17

Prepared By — Date

Received By — Date

Project Overview:

RIT Launch Initiative is a team of passionate students that design, manufacture, and launch high powered rockets. Launch's goal is to raise awareness for aerospace and become an acknowledged and well-respected institution in this field by attending the Intercollegiate Rocket Engineering Competition (IREC) in Spring of 2018 and 2019. In 2019, RIT will enter the 'advanced' category which requires that the team deliver a rocket and corresponding payload to exactly 30,000 feet.

This endeavor cannot be achieved with commercial rocket motors; this type of accuracy will require a custom rocket engine built specifically for Launch's level 3 rocket. Building a custom engine will put RIT on the map, allow students to compete at the highest level with IVY League schools, and open up opportunities for future aerospace and propulsion projects for decades to come. In addition to its implications for IREC, this engine will create the possibility of collaborating with SPEX to deliver actual scientific payloads to our upper atmosphere.

A significant amount of research has already been conducted on this venture and the outcome is very plausible with the combined efforts of students from a variety of disciplines . Ultimately, this project will provide a customizable, safe, and high-performing rocket engine to RIT Launch and any other organization that may benefit from it in the future.

*Preliminary Customer Requirements (CR):

Safety	All materials must be safe to handle independently and when assembled.
Fuel	Must comply with any IREC and federal or state FAA regulations in regards to manufacturing, storage, and transportation.
Durability	Must be able to withstand extreme pressure and temperature conditions for the duration of rocket flight.
Modularity	The engine should be constructed in a manner that is easy to disassemble, service, and reassemble.
Reusability	The engine should be designed for maximum reusability of all components such that there will be minimal replacement parts necessary for re-launch.
Performance	Engine must be able to propel a rocket weighing at least 20 kg to 30,000 feet.
Environmental	Engine must not emit any harmful chemicals in accordance with IREC & FAA Regulations.
Manufacturing	Engine must be designed and fully manufactured in 2 semesters.

Documentation	Must come with thorough documentation on how to assemble, test, and safely launch.
Transportation	A safe and secure transportation system must be developed for general travel, specifically to and from launch sites.
Controllability	Engine can be throttled, and thrust output controlled as needed.

Preliminary Engineering Requirements (ER):

Factor of Safety	Stresses applied cannot exceed 50% (FS of 2-3) of the yield stress of the material. a. Pressure vessels (tanks or combustion chamber) that are constructed with isotropic materials will have a burst pressure at least twice as large as the maximum operating pressure at any point in the engine's life cycle b. Pressure vessels constructed from non-isotropic materials (i.e. fiber reinforced plastics, FRP. composites, etc), or metallic vessels implemented with a composite overlay shall be designed to a burst pressure no less than 3 times the maximum expected operating pressure c. Vibrations on flight hardware is within specified supplier frequency range
Fuel	Use only hydrocarbon fuel sources
Durability	Fatigue life, transportation, and handling a. Maximum heat capacity and thermal resistance b. Yield stresses and yield strengths c. Max pressure capacity d. Vibrations
Modularity	Design for interfaces to be easily assembled and disassembled a. Total rocket assembly - take specific time b. No permanent adhesives c. Flight hardware (sensors, controls, electrical components, wiring) organized and designed in a comprehensible manner that is easy to follow, and won't cause major problems when disassembling or assembly engine body. Must follow ERSA and IREC wiring, and electrical regulations.
Reusability	a. Minimize the amount of parts that need replacing per launch b. Make combustion chamber servicing as easy as possible such that any excess fuel can be easily removed
Performance	a. Specific impulse (250-300 seconds) b. O/F ratio (2-5 for hydrocarbons) c. Effective exhaust velocity (Supersonic, around Mach 4) d. Characteristic velocity (combustion chamber performance) e. Thrust coefficient (0.6-1.9) f. Mass flow rate g. Burn time (5-20 seconds) h. Maximum total impulse of 40,960 N-sec.

Environmental	Restrict to the use of hydrocarbons. FAA, ERSA, EPA, and IREC regulations to use non-toxic chemicals and propellants. Toxic propellants are defined as requiring breathing apparatus, special storage and transport infrastructure, extensive personal protective equipment, etc.
Manufacturing	Have design and analysis completed after one semester, have manufacturing done mid way through second semester, and the remaining time for testing and validation. Testing and validation should begin April 1st.
Documentation	Assembly drawings, BOM, fluid circuit diagrams, part descriptions, specifications, contingencies, performance and test reports/data, hazard and risk analysis/data.
Transportation	Carrying cases or protective transportation container
Controllability	Injection system, control system, igniter, valves, engine will need to be throttled and re-startable/ignitable. Must follow FAA and IREC regulations.
Additional	
Total weight	Engine total weight must not exceed 100 pounds maximum.
Total volume	Volume of engine is to be restricted to 150 mm (6 in) diameter space
Storage	Oxidizer must be stored separate from fuel at all times (Storage capabilities of the fuel (hydrocarbons) and liquid/gaseous oxygen)
Stability	Propulsion system and engine must be stable. The engine must be able to launch a vehicle (rocket) with a launch rail departure velocity of at least 100 ft/sec to ensure vehicle stability and predicted flight path. Launch rails are 18 ft in length.
Manufacturability	Can be manufactured with readily available materials
Avoid Discontinuities	a. Nozzle must be designed to specific pressures to avoid shock waves, flow discontinuities, and flow separation. b. Combustion must avoid discontinuous mixtures, and minimize uncombusted propellant. c. Engine structure or materials must not have discontinuities that may cause failure such as cracks, poor qualities or conditions, etc
Propulsion Arming	The propulsion system must be armed, meaning it must require only one action. For ignition, an ignition signal (one action) is solely needed to ignite the propellant.
Ground-Start Ignition Circuit Arming	a. All ground-started propulsion system ignition circuits/sequences shall not be "armed" until all personnel are at least 50 ft (15 m) away from the launch vehicle. b. For engine test fires, engine must be secured firmly, and enclosed in secured space (bunker) before ignition circuits are “armed”.

Propellant Off Loading	Propulsion system shall implement a means for remotely controlled venting or off-loading of all liquid and gaseous propellants in the event of a launch abort.
Relief Device	Pressure vessels shall implement a relief device, set to open at no greater than the proof (yield) pressure.

Constraints:

1. Budget - will likely cost several thousand dollars
2. IREC, ERSA, NMSA, and FAA regulations, rules, and requirements
3. FAA regulation of max total impulse of 40,960 N-sec for IREC SA Cup
4. Sensors (quality and robustness) - Can they withstand extreme conditions?
5. Manufacturing and storage feasibilities
6. Resources, chemicals, materials accessibility and feasibility
7. Special permits, licenses, or training that may be required
8. Location/setting
9. Additional: (http://www.soundingrocket.org/uploads/9/0/6/4/9064598/sa_cup_irec_rules___requirements_document_20170217__baseline_.pdf) (http://www.soundingrocket.org/uploads/9/0/6/4/9064598/sa_cup_irec-design_test___evaluation_guide_20170217__baseline_.pdf)

Potential Concepts:

Propulsion/Rocket Engines Solutions:

Rocket engines are a form of propulsion systems that propel vehicles by emitting high velocity gases in the opposite direction of motion. This occurs due to Newton's law of momentum. Chemical rocket engines are a form of rocket engine that uses the chemical energy stored in the propellant to propel a vehicle forward. They do this by transforming the stored chemical energy in the fuel into thermal energy through combustion, and then transforming that thermal energy into kinetic energy (usually using a nozzle) in the form of high velocity gases. A rocket engine is composed of a propellant (energy source), combustion or thermal pressure chamber, and a nozzle. Solutions for chemical rocket engines are proposed below.

Solution 1: Solid Rocket Engine
Solution 2: Liquid Rocket Engine
Solution 3: Hybrid Rocket Engine

The solutions proposed are bipropellant rocket engines, meaning the propellant is composed of an oxidizer and fuel source, and they are both required for the engine to operate.

Solid Engine**:** A solid rocket engine contains both a fuel and oxidizer mixed together into a solid, cylindrical grain. The grain is hollow such that the fuel/oxidizer mixture will ignite and burn continuously from the inside out.

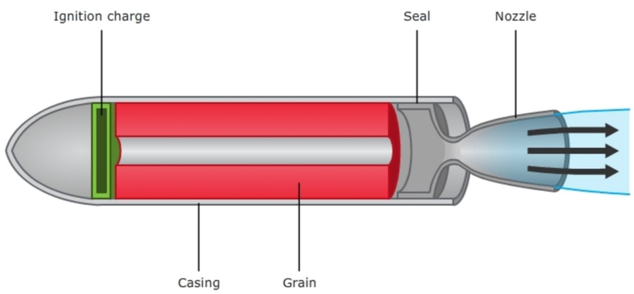

Figure 1: Solid Engine Diagram

Liquid Engine**:** A liquid rocket engine contains liquid fuel and oxidizer. The fuel and oxidizer are stored separately, typically in 2 high pressure tanks which are then injected and mixed into the combustion chamber simultaneously through a hydraulic system.

Figure 2: Liquid Engine Diagram

Hybrid Engine**:** A hybrid rocket engine is a form of rocket chemical propulsion that uses a solid fuel grain, located in the combustion chamber, along with a liquid/gaseous oxidizer to develop thrust. The oxidizer is injected into the fuel grain through a pneumatic/hydraulic system.

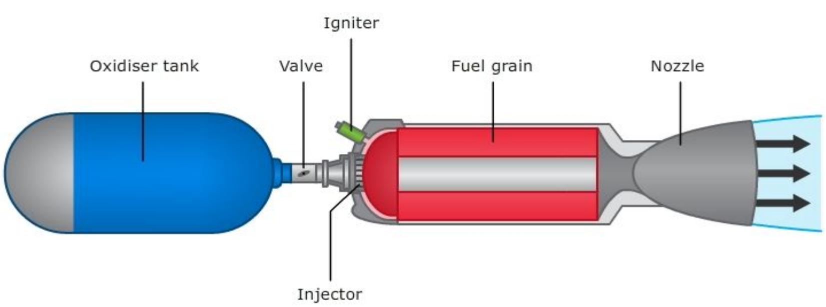

Figure 3: Hybrid Engine Diagram

Fuel Grain: For solid and hybrid engines, casting the fuel grain port in different configurations can yield different burn characteristics. Star configurations tend to be popular for a relatively even burn and regression rates. Fuel grains are usually composed of composite materials for a more efficient burn.

Figure 4: Fuel Grain Configurations

Nozzle: There are 2 main types of converging-diverging rocket nozzles. These are the conical and bell nozzle. Other types of nozzles can branch of from these main categories. For simpler engines, it is recommended to use a conical CD nozzle with a divergence angle no greater than 15 degrees.

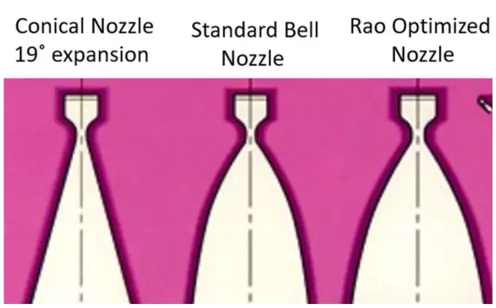

Figure 5: Nozzle Types

Pneumatic/Hydraulic System: Different pneumatic/hydraulic methods for pumping the propellant through the injector and into the combustion chamber exist. Examples are pressure feed systems and turbopump feed systems.

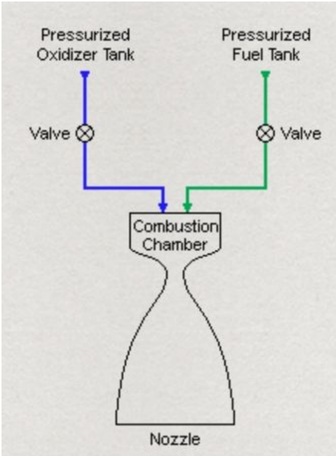

Figure 6: Pressure Fed System

A pressure feed system holds either the oxidizer/fuel or both under high pressure in the tanks they are being stored. Valves, actuators, and regulators are used to release and control the pressurized oxidizer/fuel (propellant). The pressure feed system uses the pressure of the propellant tanks to pump the propellant into the combustion chamber. The pressure of the tanks must be greater than the pressure of the combustion chamber for this method to work.

Figure 7: Turbopump Fed System

A turbopump feed system is more complex since it requires more components and piping. A turbopump feed systems holds the propellant under moderate pressures, and uses pumps/condensers to move the propellant into the combustion chamber. Valves, actuators, and regulators are used to control the pumping process. The pumps are usually powered by a turbine, which uses part of the propellant to, when preheated, to operate.

Though there are many types of rocket engines, the hybrid rocket engine is the safest to handle and easiest to store, making it the perfect candidate for MSD.

Functional Decomposition:

Part/System	Functionality
Propellant Tanks	a. (Liquid Engines) The propellant tanks store the propellant of the engine at high pressures. The propellant is composed of a liquid oxidizer and liquid fuel. Both are stored separately from each other in different tanks in the engine. b. (Hybrid Engine) The propellant tank only stores the oxidizer of the propellant separate from the fuel grain. If it's liquid, oxidizer stored at slightly lower pressures. Gaseous oxidizers are usually stored at higher pressures because they are not as efficient as LOX and therefore more needs to fill the tank.
Pneumatic/Hydraulic System	a. (Liquid Engine) The pneumatic/hydraulic system is designed to pump both the fuel and oxidizer from the tanks into the injector by applying a pressure. b. (Hybrid Engine) The pneumatic/hydraulic system is designed to pump the oxidizer from the tank into the injector by applying a pressure.
Injector	a. (Liquid Engines) It takes the fuel and oxidizer and creates a fine spray that is injected into the combustion chamber and mixed. b. (Hybrid Engines) It takes the oxidizer and creates a fine spray that is injected into the combustion chamber and mixed with the fuel grain.
Ignitor	For both liquid and hybrid engines, it ignites the mixed propellant in the chamber, causing combustion to occur.
Combustion Chamber	Enclosed space where combustion occurs, and designed to sustain the extreme pressures and temperatures from the combustion of the propellant. For chemicals engines, it's where the chemical energy of the propellant stored transforms into thermal energy.
Fuel Grain	Liquid engines are not composed of a fuel grain. The fuel grain is located in the combustion chamber of a hybrid engine, it is the shape of the solid component of the propellant. It should be designed to maintain a constant area of combustion and regression rate.
Nozzle	It converts the thermal energy produced in the combustion chamber into kinetic energy. Converging-diverging nozzles accelerate and

	expand the pressurized hot gases in the combustion chamber to high velocities. The resulting momentum of the exhaust gases produces thrust.
Sensors	Monitor, measure, and report different properties and loads (Pressures, Temperatures, Strains, Forces, Velocities, Flow Rates, Voltages, etc). Respond and provide feedback to user, control system, or computer of the physical properties being measured.
Control System/Flight Hardware	Monitors and controls different actions of the propulsion system. Receives, stores, and monitors sensor information, and produces a desired output if needed. Valves, actuators, and igniters are examples of parts that need to be controlled.
Fuel Grain Casing	Casing designed to protect, store, transport, and seal the fuel grain before use.
Engine Casing	Casing designed to protect, store, transport, and seal rocket engine.
Test Stand/Fixture	Designed to keep engine fixed either horizontally or vertically during testing, and measure engine thrust or other properties.

Budget Information:

Material	**Cost**
Oxidizer, fuel, propellant	$300
Nozzle materials	$750
Combustion chamber materials	$600
Controllers, flight hardware, sensors, actuators, batteries	$250
Pneumatic/hydraulic system (tanks, piping, valves, fittings, etc)	$250
Engine casing, propellant casing, transportation containers	$350
Test stands and fixtures.	$300
Other (Software, equipment, tools, miscellaneous, etc.)	$250
TOTAL	$3,050

Intellectual Property:

We will be planning to keep the IP on the project, unless a sponsor arises that requires otherwise. We are open to all considerations. The project is currently not expected to be confidential in anyway.

Project Resources

Faculty list individuals and their area of expertise (people who can provide specialized knowledge unique to your project, e.g., faculty you will need to consult for more than a basic technical question during office hours)	**Initial/ date**
Alexander Liberson, Mark Olles, Michael Scharlau, Dorian Petru, Gerald Fly, Stephen Boedo, Jason Kolodziej.	
Environment (e.g., a specific lab with specialized equipment/facilities, space for very large or oily/greasy projects, space for projects that generate airborne debris or hazardous gases, specific electrical requirements such as 3-phase power)	**Initial/ date**
Access to the bunker located on campus for testing procedures. Space needed for storage of propellant chemicals, and space for storage of overall engine system and electronics.	
Equipment (specific computing, test, measurement, or construction equipment that the team will need to borrow, e.g., CMM, SEM,)	**Initial/ date**
Materials (materials that will be consumed during the course of the project, e.g., test samples from customer, specialized raw material for construction, chemicals that must be purchased and stored)	**Initial/ date**
Other	**Initial/ date**

Anticipated Staffing By Discipline:

Dept.	**# Req.**	**Expected Activities**
BME	0	N/A
CE	1	a. Work on the development of the control system for the rocket engine, b. Assist in the simulations and numerical analysis of the rocket engine c. Work with EE to develop the software and flight hardware for the rocket engine. d. Work on the testing and implementation of controls and engine testing.

EE	1	a. Work on the development of hardware and software of the rocket engine b. Analyze system to develop controllers such as PID controllers c. Design circuits and analog devices d. Work with ME to set up and work with sensors and instrumentation.
ISE	1	a. Work with all members of the team for system integration and make sure all parts come together nicely b. Provide management and work with the manufacturing process to insure completions of tasks, c. Work with members to make sure that the requirements are being met and regulations are being followed d. Organize documentations e. Manage project economic factors.
ME	4	a. Work on the design, simulation, and analysis of the rocket engine b. Work on simulations and material selections for the rocket engine c. Work with EE to integrate sensors for controllers and testing, d. Work on the manufacturing and quality assurance of the engine e. Work on the testing and validation of the rocket engine

Recruited Members

1. *Zachary Rizzolo - ME*
2. *Oldarlyn Castillo - ME*
3. *Tim Frey - ME*
4. *Trevor Mothersell - ISE*

Skills Checklist:

Biomedical Engineering

	BME Core Knowledge		BME Elective Knowledge
	Matlab		Medical image processing
	Aseptic lab techniques		COMSOL software modeling
	Gel electrophoresis		Medical visualization software
	Linear signal analysis and processing		Biomaterial testing/evaluation
	Fluid mechanics		Tissue culture
	Biomaterials		Advanced microscopy
	Labview		Microfluidic device fabrication and measurement
	Simulation (Simulink)		Other (specify)
	System physiology		
	Biosystems process analysis (mass, energy balance)		
	Cell culture		
	Computer-based data acquisition		
	Probability & statistics		

	Numerical & statistical analysis		
	Biomechanics		
	Design of biomedical devices		

Computer Engineering

	CE Core Knowledge		CE Elective Knowledge
2	Digital design (including HDL and FPGA)		Networking & network protocols
1	Software for microcontrollers (including Linux and Windows)		Wireless networks
3	Device programming (Assembly, C)	3	Robotics (guidance, navigation, vision, machine learning, control)
1	Programming: Python, Java, C++		Concurrent and embedded software
2	Basic analog design	1	Embedded and real-time systems
3	Scientific computing (including C and Matlab)		Digital image processing
	Signal processing		Computer vision
1	Interfacing transducers and actuators to microcontrollers		Network security
			Other (specify)

Electrical Engineering

	EE Core Knowledge		EE Elective Knowledge
1	Circuit Design (AC/DC converters, regulators, amplifies, analog filter design, FPGA logic design, sensor bias/support circuitry)		Digital filter design and implementation
	Power systems: selection, analysis, power budget		Digital signal processing
1	System analysis: frequency analysis (Fourier, Laplace), stability, PID controllers, modulation schemes, VCO's & mixers, ADC selection	2	Microcontroller selection/application
1	Circuit build, test, debug (scope, DMM, function generator		Wireless: communication protocol, component selection
1	Board layout		Antenna selection (simple design)
	Matlab		Communication system front end design
	PSpice	1	Algorithm design/simulation
3	Programming: C, Assembly	3	Embedded software design/implementation
	Electromagnetics: shielding, interference		Other (specify)

Industrial & Systems Engineering

	ISE Core Knowledge		ISE Elective Knowledge
1	Statistical analysis of data: regression	1	Design of Experiment
	Materials science	2	Systems design – product/process design
	Materials processing, machining lab	1	Data analysis, data mining
	Facilities planning: layout, mat'l handling	1	Manufacturing engineering
1	Production systems design: cycle time, throughput, assembly line design, manufacturing process design	3	DFx: manufacturing, assembly, environment, sustainability
	Ergonomics: interface of people and equipment (procedures, training, maintenance)	2	Rapid prototyping

	Math modeling: OR (linear programming, simulation)	3	Safety engineering
1	Project management		Other (specify)
	Engineering economy: Return on Investment		
	Quality tools: SPC		
2	Production control: scheduling		
	Shop floor IE: methods, time studies		
1	Computer tools: Excel, Access, AutoCAD		
	Programming (C++)		

Mechanical Engineering

	ME Core Knowledge		ME Elective Knowledge
1	3D CAD	2	Finite element analysis
2	Matlab programming	1	Heat transfer
3	Basic machining	2	Modeling of electromechanical & fluid systems
2	2D stress analysis	1	Fatigue and static failure criteria
2	2D static/dynamic analysis		Machine elements
1	Thermodynamics	3	Aerodynamics
1	Fluid dynamics (CV) - 1	1	Computational fluid dynamics
3	LabView		Biomaterials
	Statistics	2	Vibrations
2	Materials selection		IC Engines
			GD&T
		2	Linear Controls
		1	Composites - 2
			Robotics
			Other (specify)

Notes

We know that funding could possibly raise a red flag on this project so it is important to note that we already have $3500 accounted for, including the stipend from MSD. This is already more than the estimated budget, without additional fundraising. If there are any questions or concerns of any kind, please do reach out to us. We have put a great deal of thought into this project and think that it would be a great opportunity for us personally, as well as RIT.

Thank you very much!