University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018
Project Definition Document (PDD)
REcoverable ProTection After Reentry (REPTAR)

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Approvals

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Acronyms and Definitions	
CubeSat	A SmallSat obeying the NASA/CalPoly Cube form factor definitions (1, 3, 6, 12, or 27 U).
Descent	The period of flight when the vehicle is moving at subsonic speeds within the atmosphere.
ELaNa	The Educational Launch of Nanosatellites program.
Flight	The period between the vehicle's de-orbit burn and successful landing on the surface of the earth.
(E/M)GSE	(Electrical/Mechanical) Ground Support Equipment
Landing	The point in flight at which the vehicle comes to rest on the surface of the earth.
Recovery	The action taken by the ground team to find and collect the vehicle.
Re-Entry	The period of the mission during which the vehicle is transitioning from space to the earth's atmosphere.
REPTAR	REcoverable ProTection After Reentry
SmallSat	A satellite weighing less than 50kg at launch.
TPS	Thermal Protection System
UTTR	Utah Test and Training Range
Vehicle	The REPTAR system, Raytheon Payload, Raytheon Reentry System, and associated structures.

I. Problem or Need

Projections based on announced and future plans of developers and programs such as Educational Launch of Nanosatellites (ELaNa) indicate the potential for 2500 nano/micro satellites to be launched between 2014 and 2020.[1] A significant amount of money is spent and research is done to put together a payload for a SmallSat. Special payloads, with an appropriate form factor, are being designed to take advantage of this platform. Once their mission expires, SmallSats are typically either burned up in the atmosphere and not returned to Earth or remain in space as un-operational debris. However, some payloads are very expensive and have the potential be be re-used in future missions. If Raytheon were able to recover and reuse payloads, they would be able to dramatically reduce the costs of their SmallSat missions.

REPTAR will be a leading development in this endeavor by protecting and recovering a payload safely on the ground once it has passed the re-entry transition from supersonic velocity to subsonic velocity. This development will reduce costs by making payloads reusable. If this concept proves plausible in a limited budget, Raytheon could save money due to the ability to safely recover science, data, and instrumentation.

II. Previous Work

The ability to bring a satellite back has been explored using multiple concepts, with the majority of these projects being more focused on the re-entry aspect of the de-orbit. The University of Naples explored a deployable aerobrake system that doubled as a heat shield during the re-entry process. The structure was controlled by changing the heat shield angle allowing for a safe descent.[2] The project focused mainly on the re-entry aspect of SmallSat landing.

Andrews Space (now Spaceflight Industries) constructed an inflatable heat shield that would be deployed for de-orbit and landing. The system is attached to a payload as a separate entity and inflates during re-entry to act as an aerobrake. After the re-entry phase of the SmallSat to Earth, the landing phase was designed to have a crushable structure between the controllable heat shield and the payload, allowing for a somewhat soft landing.[3] However, most of the landing aspect of this project is not detailed in depth, leaving room for further development.

The RICE (Recovery of In-Space CubeSat Experiments), developed by Georgia Tech, described a mission to recover a SmallSat using a parachute for landing. The mission encompassed the re-entry and landing portions of a SmallSat's life. The idea was to survive the re-entry process and utilize a parachute once the payload reached subsonic speeds.[4] Although validation was not performed, the high altitude recovery mission was fully researched and simulated.

Compared to the projects focused on the re-entry portion of a satellite return, the REPTAR mission is strictly to land and recover a payload. REPTAR's procedures will be taking over once a satellite has safely re-entered the atmosphere and has been brought to a dynamic pressure range. Although some of the previous work has been researched with landing in mind, the projects were more concerned with re-entry, and landing validation was not conducted.

III. Specific Objectives

REPTAR will be a self-sustained unit able to land and recover any 1U (10 cm x 10 cm x 10 cm) payload. The REPTAR unit will take no more than 6U for the recovery and landing mechanisms. REPTAR takes over once the spacecraft has entered Earth's atmosphere and is traveling at subsonic speeds. After the Thermal Protection System (TPS) is jettisoned, controls are transitioned over to REPTAR. REPTAR will provide the means to slow the vehicle down for landing. It will then communicate its location for recovery by a search party.

The volume requirements are derived from Cal Poly CubeSat Standards.[5] With a 6U total size including payload, the TPS could be a size of 6U and the entire re-entry vehicle would be 12U in size. With a 4U total size including payload, there would be 8U available on the vehicle for TPS and additional payload. With a 3U total size including payload, the TPS could be 3U in size, and the entire vehicle could be a standard 6U in total size instead of 12U.

The maximum loading that the payload may endure is taken directly from launch requirements for CubeSats aboard popular launch vehicles. If the payload is able to survive launch, it will be able to survive landing. Making the loading requirements more stringent than launch requirements is unnecessary as the payload will be designed to survive launch. Launch requirements vary between launch vehicles, and SpaceX's Falcon 9 has a relatively violent launch compared to most launch vehicles, so the payload must be able to undergo 8.5 G's.[6] ULA's Delta IV has a smoother launch and the payload must only undergo 6.5 G's.[7] It will be easier for the team to keep the payload beneath 8.5 G's than below 6.5 G's upon landing, but if the vehicle can keep the payload beneath 6.5 G's, the list of potential launch vehicles increases. Also, a lower maximum loading will allow REPTAR to recover more fragile payloads. Additionally, lower G's allow more fragile payloads to be recovered. It is noted that REPTAR will need to also survive launch, but surviving launch is a requirement and not a specific objective.

The communication levels of success were drawn from the fact that REPTAR is intended to land with the payload in the Utah Test and Training Range (UTTR). With a search team in the center of the UTTR, the furthest point on the range is 42 miles away. A transmission range of 45 miles would allow REPTAR to alert the search team of its

Criteria	Volume	Max Loading	Communication
Level 1	Total volume of REPTAR including payload shall not exceed a maximum of 6U Standard.	The payload shall endure a maximum loading of 8.5 G's.	REPTAR shall communicate its location over a range of 20 miles.
Level 2	Total volume of REPTAR including payload shall not exceed a maximum of 4U Standard.		REPTAR shall communicate its location over a range of 30 miles.
Level 3	Total volume of REPTAR including payload shall not exceed a maximum of 3U Standard.	The payload shall endure a maximum loading of 6.5 G's.	REPTAR shall communicate its location over a range of 45 miles.

Table 1: Levels of Success

location if it lands anywhere within the UTTR. A transmission range of 30 miles would allow REPTAR to alert the search team of its location unless it lands in the North-East region of the UTTR. A transmission range of 20 miles, two search teams are needed: a Northern and a Southern team. A landing in the UTTR would result in at least one of the two teams receiving the location of REPTAR. This justification is shown in Figure 1 The location transmission range will be verified through field testing to be defined.

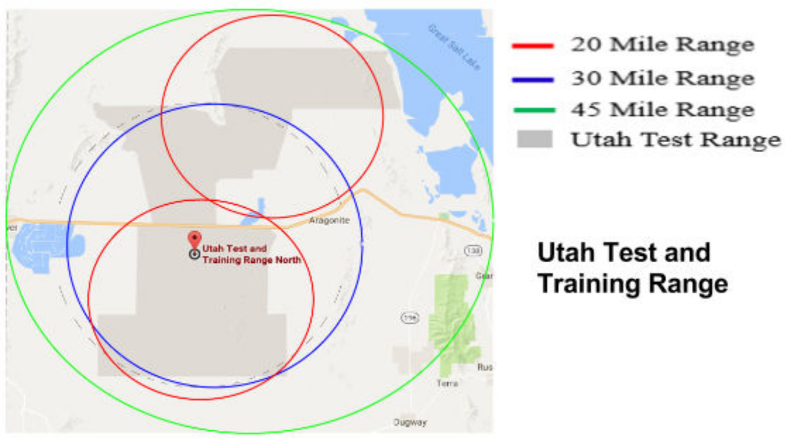

Figure 1: Range of Communication in UTTR for Levels of Success

IV. Functional Requirements

The CONOPS (CONcept of OPerationS) depicted in Figure 2 outlines the four distinct phases of the mission. In Phase 1, the SmallSat is launched into orbit to perform its mission. During this phase, the REPTAR system must survive launch conditions. In Phase 2, the SmallSat system is in orbit about the Earth performing its mission. Here REPTAR is on standby and simply remains charged by the SmallSat provided solar panels. Phase 3 is when the de-orbit maneuver is performed and re-entry to Earth begins. Phase 4 is the re-entry process which along with Phase 3 is performed by a separate system.

Figure 3 shows the objectives performed by the REPTAR system. After the REPTAR system has identified the SmallSat has successfully performed the re-entry maneuver, the TPS is jettisoned from the rest of the bus. Now the REPTAR system begins its landing and recovery operation. First, REPTAR must identify when it is able to begin decelerating. After identifying conditions for deceleration, REPTAR begins the actually deceleration stage for a safe landing. Once landed, REPTAR will transmit its location for a ground team to recover the SmallSat.

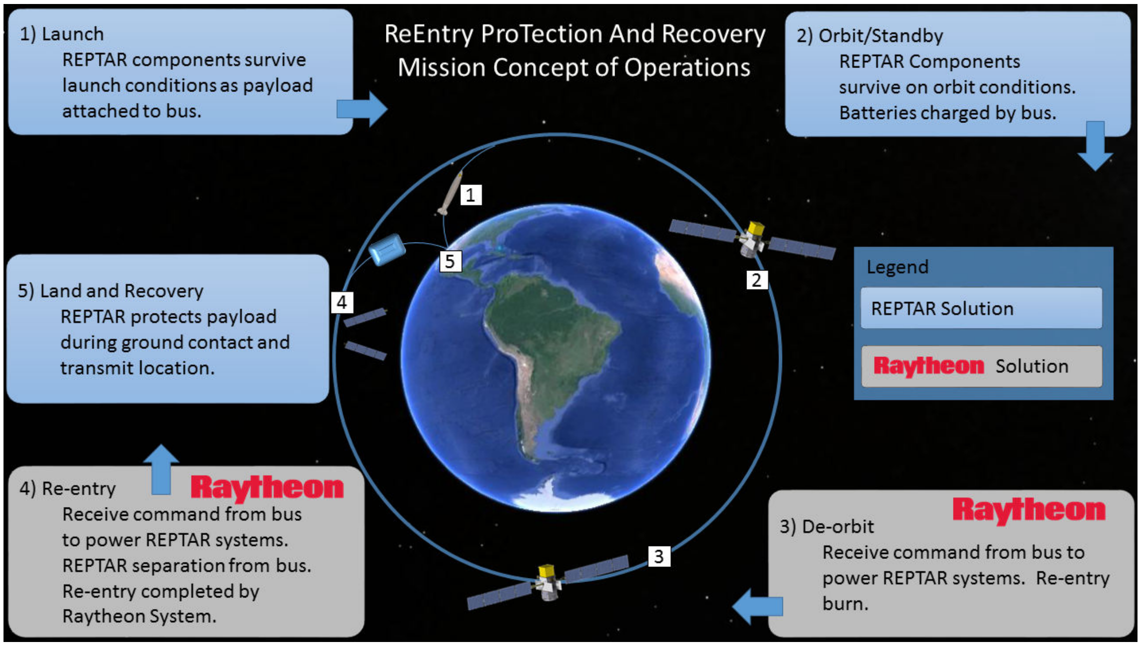

Figure 2: Concept of Operations for SmallSat mission

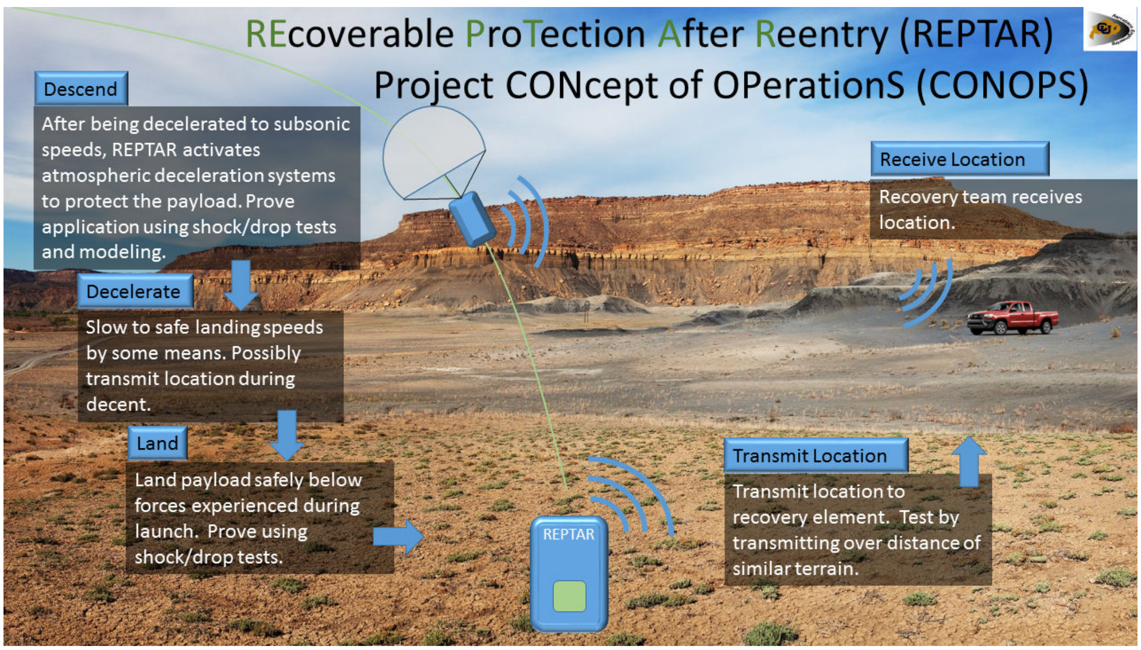

Figure 3: Concept of Operations for REPTAR

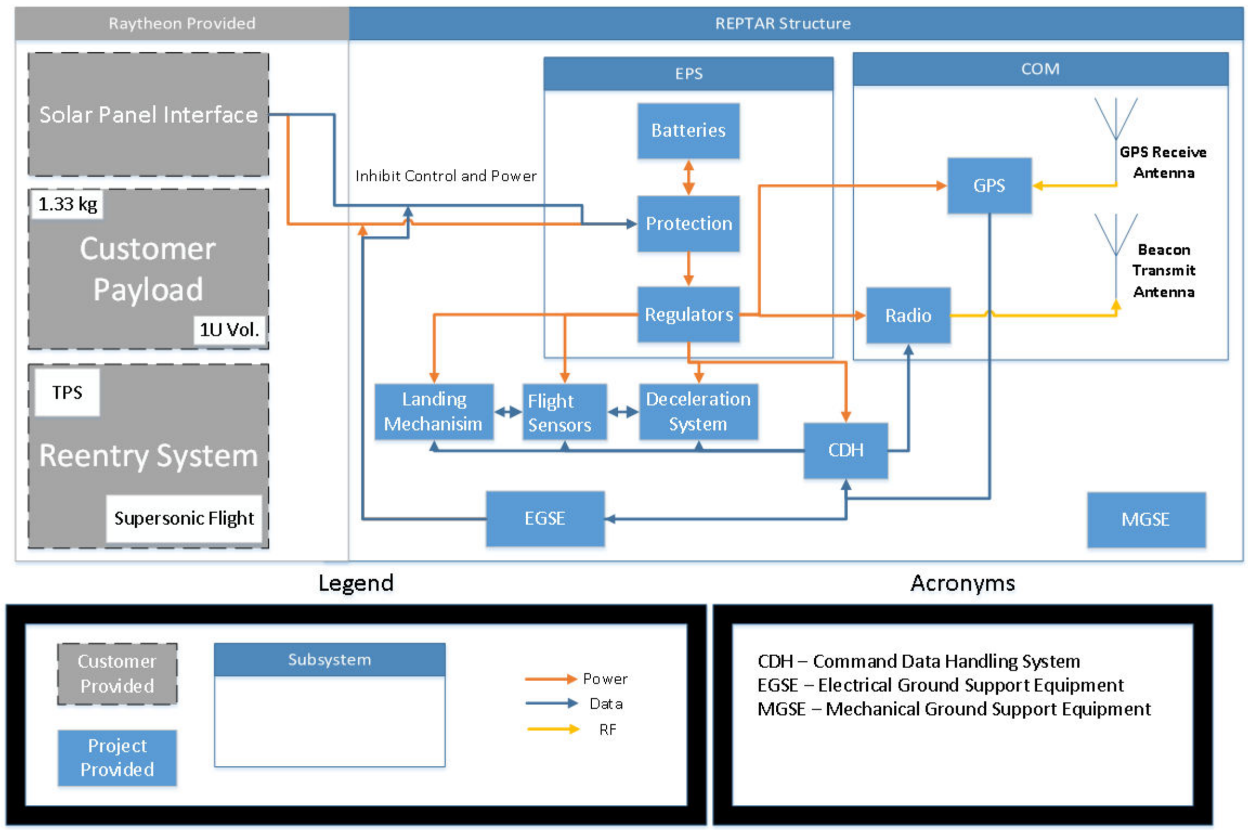

Figure 4: Functional Block Diagram

V. Critical Project Elements

Technical		
T1	Size Limitation	The entire system must not exceed an 8U size. Depending on the design this may prove inhibiting.
T2	Communication System	Must have a transmitter capable of transmitting at a range of at least 20 mi with the goal of 45 mi. A transmitter must be chosen in a way to provide adequate signal power and frequency while being constrained to the available energy
T3	Shock Limits	To ensure structural integrity of the payload, the payload must not experience a shock greater than 8.5 G's. Will have to determine types of forces the payload may experience to predict and design shock and vibration protection.
T4	Environmental Testing	Need to figure a way to determine when it is safe to start deceleration process (ie determining our altitude / speed / dynamic pressure)
T5	Space Survival Capabilities	Must ensure that all components of the design survive long term durations in orbit. This will involve ensuring all components can survive in a vacuum, and it is possible that a heating system would need to be implemented.
T6	Launch Safety Compliance	Must ensure that REPTAR adheres to all launch and range safety constraints.

Logistic		
L1	Signal Testing	Testing the transmission range may require a large, flat area, similar to the desired landing ground.
L2	Shock Testing	Creative method of shock testing will be needed. It is unlikely that the system can be tested in design speeds and scenarios so the shocks experienced must be replicated during testing
L3	Vibration Testing	Proper testing of vibrations will require additional facilities which may prove difficult to access
L4	Drop Testing	There will be a need for the ability to perform drop tests from various heights ranging from several stories off the ground to thousands of feet in the air.
Financial		
F1	Testing Costs	Multiple tests will need to be performed which may prove expensive.
F2	Materials	Materials used may prove costly.

VI. Team Skills and Interests

Name	Skills/Interests	CPE
C. Buechler	MATLAB, STK, Dynamics, Structures, Manufacturing	T1, T3, T4, T5, L1, L2, L3, L4, F1, F2
K. Faggiano	SolidWorks, Machining, Manufacturing, MATLAB, C++	T1, T3, L1, L2, L4, F1, F2
D. Fishelman	Machining, Financial Analytics, Structures	T1, T3, T5, L2, L4, F1, F2
C. Gondek	Leadership, Logistics, Manufacturing, MATLAB, Thermodynamics, Dynamics	T1, T4, T5, L1, L2, L3, L4, F1
L. Huynh	MATLAB, C, C++, Modeling, Simulation, Numerics, SolidWorks	T1, T2, T5, L2, L3, L4, F1, F2
A. McCusker	MATLAB, Modeling, Simulation, SolidWorks, Manufacturing, Financial	T1, T3, T4, L1, L2, L3, L4, F1, F2
W. Sear	MATLAB, C, C++, Python, Fortran,,SPICE,,RF Circuit Design, Altium Designer (2-8 layer), STK, Electrical Testing, SolidWorks	T2, T4, T5, L1, L4, F1 F2
H. Singhal	C, MATLAB, STK, SATPC 32,,Modeling & Simulation, Finance, RF, Systems Testing, Program Management experience	T2, T4, T5, L1, L2, L3, L4, F1, F2
C. Wenkheimer	Helicopter mechanic, Hands-on skills, Experience with VBA, database administration, Military experience, leadership, MATLAB.	T1, T4, L2, L4, F1, F2
N. Yeo	C, MATLAB, Modeling & Simulation, Digital/Analog electronics, Mission Operations experience	T1, T2, L1, L4, F1, F2

VII. Resources

Most of the needed resources for this project will be subject matter experts, testing environments, or software. CU's aerospace department has very knowledgeable professors, and they will be able to advise the team on matters such as aerodynamics, electronics, and structures. The testing will largely be done at CU, but drop tests may need to be performed with facilities that CU does not possess. The needed software is almost all free or supplied by CU.

Critical Project Element	**Resource**
Communication	Dr. Akos, Dr. Axelrad, Dr. Zoya Popovic
Deceleration	Wind Tunnel, Dr. Argrow, Dr. Evans, Dr. Axelrad
Designing for Loading	FLUENT, SolidWorks, Dr. Felippa
Size Limitation	SolidWorks, Bobby Hodgkinson, Trudy Schwartz, Machine Shop
Space and Launch Environment	Environmental Chamber, Matt Rhode, Bobby Hodgkinson, Trudy Schwartz
Budget	EEF, Raytheon, UROP
Drop Testing	Rooftop, Balloon Sat, Crane, NOAA Platform in Boulder, Accelerometers, Load Cells

References

[1]2014. Berlin: Walter De Gruyter, 2014. SpaceWorks. Web. 9 Mar. 2016. "SpaceWorks Nano Micro satellite Market Assessment January 2014."

[2]Carendente, Valerio, and Raffaele Savino. "New Concepts of Deployable De-Orbit and Re-Entry Systems for CubeSat Miniaturized Satellites." ResearchGate. University of Naples, Apr. 2014. Web. 30 Aug. 2016. <https://www.researchgate.net/publication/262796321_New_Concepts_of_Deployable_De-Orbit_and_Re-Entry_Systems_for_CubeSat_Miniaturized_Satellites>.

[3]Andrews, Jason, Watry, Krissa, and Brown, Kevin. "Nanosat Deorbit and Recovery System to Enable New Missions." Andrews Space, Inc. Tukwila, WA. Web. 30 Aug. 2016. <http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1164&context=smallsat>

[4]Chen, Bryan, Nicole Bauer, Jessica Juneau R., Stephanie Stout, Kento Masuyama, and Dave Spencer. "Recovery of In-Space CubeSat Experiments (RICE) Project." (n.d.): n. pag. Web. 9 Sept. 2016. <https://solarsystem.nasa.gov/docs/po423.pdf>

[5]Hevner, R., and Holemans, W., "Payload Specification for 3U, 6U, 12U and 27U," Planetary Systems Corp., PCS Revision B, Silver Spring, MD, Jul 2014.

[6]Falcon 9 Launch Vehicle Payload User's Guide, Rev 2. Space Exploration Technologies Corp. (2015).

[7]Delta IV Payload Planners Guide. Huntington Beach, CA: The Boeing Company (1999).