Rascal Request For Proposal
Saint Louis University
Rascal

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Revisions Summary

Revision	Description	Date	Prepared by	Approved by
-	Initial Release	9/12/2013	Tom Moline	Tyler Olson
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1. Introduction

Before describing the Rascal mission in detail, it is important to establish the meanings of various terms that are associated with any given CubeSat mission, such as Rascal, since most of such terms are not used outside of the small-satellite industry. Firstly, 1U, or one standard unit, is defined as a cube of a uniform edge length of 10 cm. A CubeSat-Class satellite (aka a "nanosatellite") is a satellite whose dimensions derive from 1 or more of these standard units, a designation that was created by California Polytechnic University in the early 2000's for describing the satellites being developed by various universities that met this definition. The reason for creating such satellites is twofold: it greatly reduces the time and monetary investment associated with developing custom satellite shapes and structures, while allowing the development of standard satellite deployers (such as the P-POD) for integration into any rocket configuration, thus allowing greater access to launch opportunities for university missions, such as Rascal. The largest deployer volume currently available is for 6U satellites, thus putting a design constraint on the Rascal structure as a whole.

The actual Rascal mission consists of two separate 3U spacecraft that will be mounted to a common base plate for flight-integration and early on-orbit operations. Both 3U spacecraft will have identical hardware and external structures, as to simplify development time and cost. Thus, each satellite will have its own infrared and visual-based navigation tools, six-degree-of-freedom propulsive control from 6 or more thrusters, image processing capabilities for navigation, Commercial of the Shelf (COTS) power, command and data handling, radio, and solar cell systems, and satellite-to-satellite GPS communication.

The ultimate goal of the Rascal mission is to demonstrate proximity operations technologies on a CubeSat class spacecraft: infrared/visible navigation, six-degree-of-freedom propulsive control, and navigation algorithms to use these capabilities. This will be accomplished by having one of the two 3U satellites eject from Rascal's common baseplate, achieve stability, move out some distance from the remaining satellite, and return within a short distance of the remaining satellite, at which point the remaining satellite will go through the same process. If enough propellant is left in each satellite after this process, a docking maneuver between the two may then take place.

The parameters imposed upon this mission are listed in Table 1-1 below:

Table 1-1. Rascal Mission Parameters

Mass	Cube Size	Desired Orbit		Acceptable Orbit Range	Desired Mission Life
8 kg	6U	Altitude	400 km	300-900 km 40º-100º	6 Months
		Inclination	40º		

Along with the listed parameters, an initial study has been conducted into the maximum relative separation between each satellite that can be achieved in-orbit, provided a propulsion unit that can provide a ΔV of 12 m/s. This was accomplished through the use linear orbit theory[1], and assumes that the initial relative displacement and velocity vectors between each satellite are known. For the case of an initial displacement vector of [0.1,0.1,0.1] meters and an initial velocity vector ranging linearly between [0.001, 0.001, 0.001] and [0.01,0.01,0.01] km/s, the following plot of Total ΔV vs. Number of Orbits until Rendezvous is obtained:

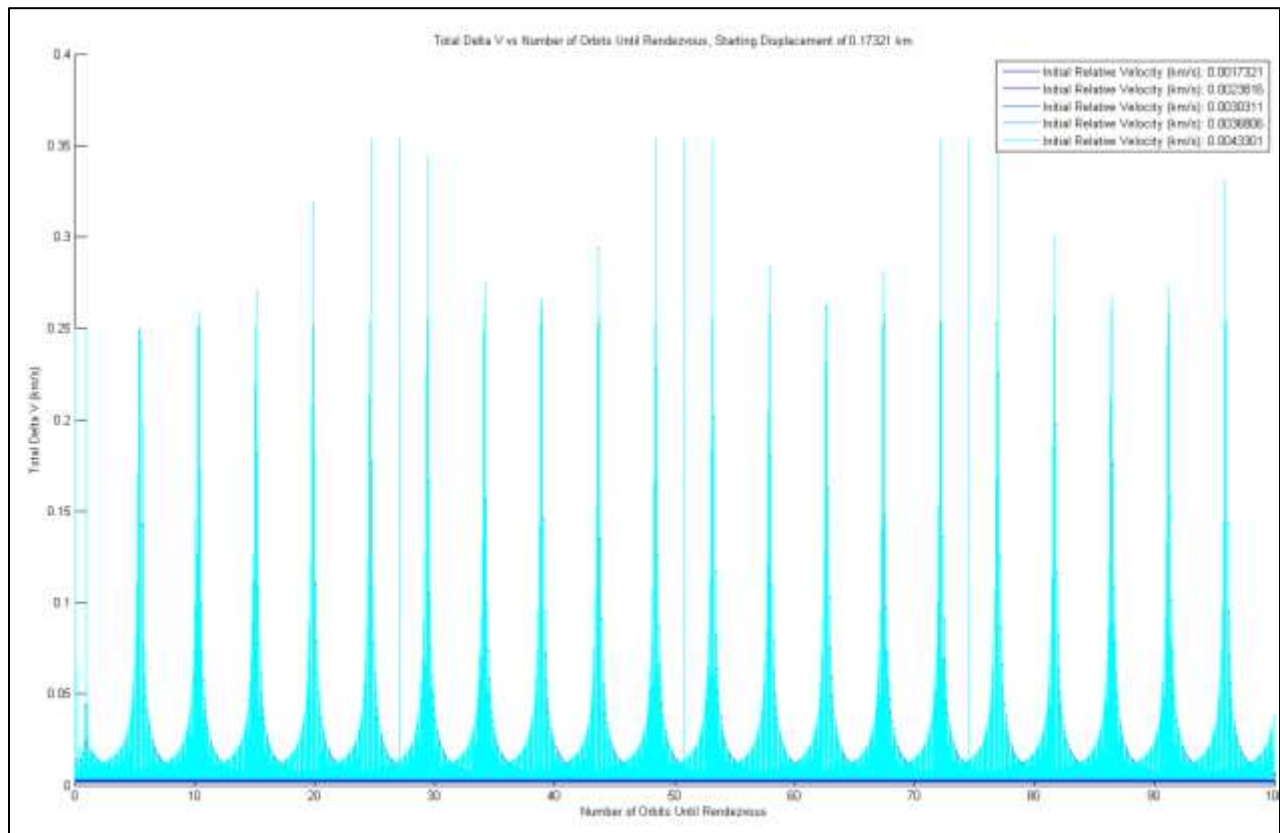[1] As discussed in Chapter 8 of *Orbital Mechanics, Prussing, Conway*

Figure 1-1. Total ΔV vs. Number of Orbits Until Rendezvous for Initial Separation of 0.17321 km and Various Initial Relative Velocity Values in km/s

When looking at the above graph in detail that is not shown, one finds that the minimum ΔV associated with the maximum initial relative velocity case is on the order of 17.5 km/s for just half of the total orbital maneuver, assuming no corrections and impulsive thrusting. This clearly is not possible for a 12 km/s propulsion unit to attain, thus a smaller initial relative velocity would be required for a return journey from this particular initial distance to be achievable (with further analysis, this value ends up being 0.0025 km/s in each axial direction, which gives a total ΔV of around 5 km/s, if each thrust maneuver is executed at the correct time in each satellites' orbit). With this analysis in mind, it is unlikely that rendezvous would be able to occur at a starting relative distance of more than 100 m, putting another constraint on the execution of the mission as a whole.

Based on these parameters, and the time that has been allotted for work to be done on this mission, the focus of this senior design project will rest in two key areas: fully defining the Rascal Mission and the requirements that indicate its success and preliminary design and fabrication of the subsystems associated with the meeting of these requirements. The actual payload design and navigation protocols are beyond the scope of this particular project and are more suited for an electrical engineering or computer science design project.

2. Mission Overview

2.1.   Mission Statement and Mission Success Requirements

The Rascal mission shall demonstrate two main objectives over the course of its mission life:

1. **The use of image-based navigation in the execution of orbital maneuvers associated with three key types of proximity operations:**
    - Low-Delta-V Stationkeeping,
    - Collision Avoidance,
    - And Long-Distance Satellite-to-Satellite Rendezvous.

2. **The execution of each of these types of proximity operations through the use of a cheap, small-scale, cold-gas propulsion unit that is able to fit within the volume and size specifications of a CubeSat-Class satellite and that could be used for future on-orbit service/inspection missions.**

The success of the Rascal spacecraft in meeting this mission statement will be determined by several mission objectives, four of which are listed below.

Each spacecraft within the Rascal mission shall be able to:

1. Capture an image of the other and calculate the relative displacement between each.

2. Demonstrate stationkeeping at a distance between 5 and 20 meters of the other using image-based navigation.

3. Demonstrate collision avoidance by performing an orbital maneuver that intentionally increases the final relative displacement between each.

4. Demonstrate rendezvous by performing an orbital maneuver that decreases the final relative displacement between each.

2.2.   Concept of Operations

The Rascal mission can be broken down into four discrete stages, as discussed in the following paragraphs and shown in Figure 2-1.

Phase 1: Launch Vehicle Ejection/Checkout

This phase will commence upon ejection of Rascal from its rocket. After forty-five minutes has passed, any deployables the spacecraft has on board (such as antennas, solar panels, etc.) will be deployed, and radio beacons down to the ground will commence. Once radio communication has been made with Rascal, a ground crew will perform a full checkout of each subsystem of the spacecraft, as to ensure that Rascal survived launch and ejection. This process will likely take 2 to 4 weeks, depending on how long it takes to initially make contact with the spacecraft. Once this full functional checkout has been completed, Phase 2 can commence.

Phase 2: Controlled Separation/Minimum Mission Success

This phase is initiated by the release of one of the two separate 3U spacecraft from their common baseplate. Upon release, said spacecraft will drift away from the secured spacecraft at a controlled rate (a few centimeters a second). During this process, each spacecraft will orient itself such that their image navigation tools are pointed in the other's general direction. Each spacecraft will continue to point at the other until a stable separation gap has been attained. This process will likely take 3-4 orbits and will occur

autonomously. Also during this process, zero-net thrust bursts will be issued by each spacecraft for observation by the other.

Phase 3: Rendezvous/Complete Mission Success

Once this stable distance has been reached, a command will be sent to the released satellite to begin the process of returning within a short distance of the secured spacecraft. The same processes that took place during separation will also occur during this phase. Once a less than 10 meter separation has been attained for at least one orbit, the process will be repeated with the secured spacecraft. As a note, in order to mitigate the risk of one satellite losing the other in orbit, GPS receivers and communications crosslinks could be included on each spacecraft, as to keep track of each satellite if too large a separation was attained or in the event of a failure of the propulsion or navigation systems of either spacecraft. This entire process will likely take 2-4 weeks.

Phase 4: Extended Operations

After the completion of Phase 3, the secured spacecraft will be released from the common baseplate. After achieving stability, it will begin to drift away from the other spacecraft and the baseplate itself. After achieving a distance of 10-50 meters, each spacecraft will attempt to rendezvous with each other, as well as the baseplate. If possible, each satellite will dock with the other, by means of Velcro, electromagnets, or some other means, as determined by analyses that will be conducted in the upcoming semesters. This phase of the mission is not the ultimate focus of this project, but merely an objective to be attempted after the successful completion of the mission parameters, as laid out in the previous 3 phases.
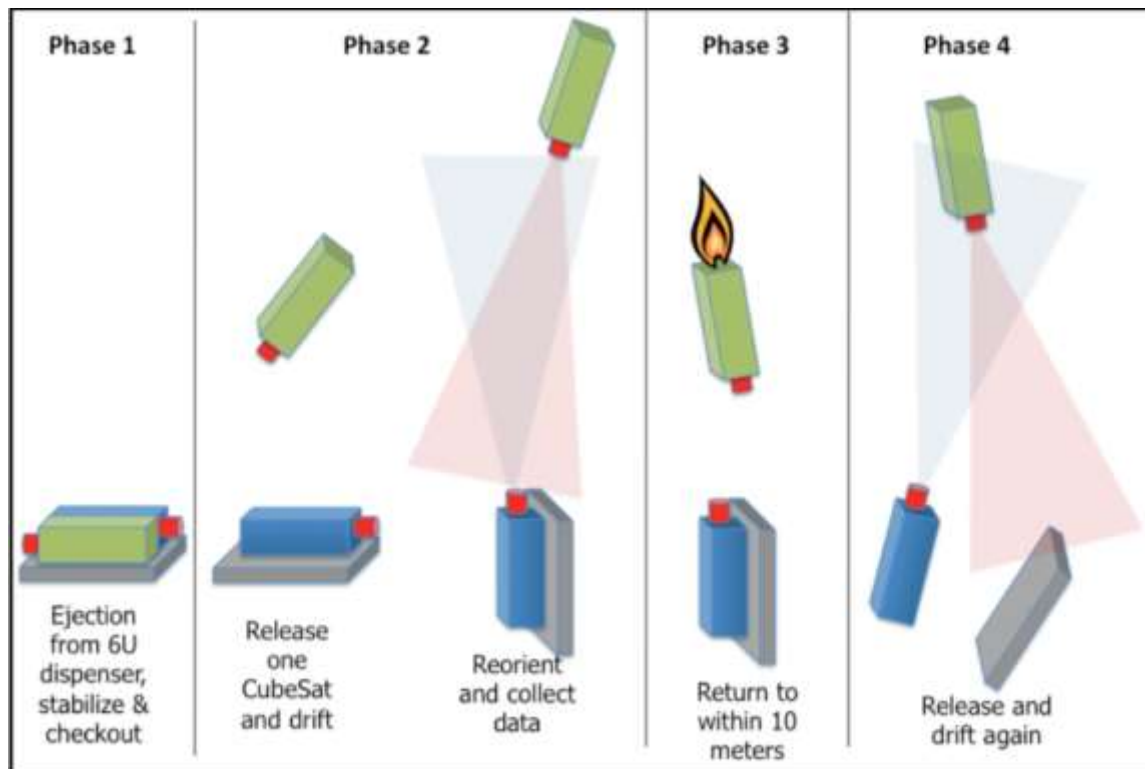

Figure 2-1. Visual Representation of Rascal's Concept of Operations

2.3.   Mission Configuration Rationale

When researching other missions that have attempted to demonstrate proximity operations, it became quite apparent that the Rascal mission is a difficult one to manage. Of the many missions that have already been launched, only a handful has seen success. The way in which each of these missions failed were many and for a variety of reasons, but could essentially be placed into two categories:

1. Achieving relative separations that were too large to overcome.

2. Encountering navigation control bugs that could not be tested on the ground.

The former problem occurred due to a simple reason: small initial relative velocities between each satellite that led to large changes in relative displacement over a small period of time. However, each mission expected each of their satellites to stay relatively close together, considering the fact that they each launched at the same time in the same orbit. These missions took for granted the chaotic nature of relative satellite motion problems, resulting in one satellite losing the location of the other, thus ending each of these missions in failure. The only exceptions to this particular mission failure that can be found are those of the Orbital Express, XSS10, and XSS11 missions, each of which cost over 100 million dollars and involved real time ground based tracking and the most advanced navigation sensors available at their times of launch. None of these missions were attempted on the CubeSat-Class satellite scale.

It is this particular risk that has led the decision to begin the Rascal mission with each satellite attached to a common baseplate. This allows for direct control over time at which each satellite is released relative to the other, thus allowing for mission progress to be tracked more directly from the ground, thus alleviating the risk of one satellite losing the other.

The latter problem usually arose during the transition between the use of two separate image sensors for different relative distance values. Doing this helps increase attitude adjustment accuracy at close distances, but adds the risk of not accounting for any give approach path that one satellite could take relative to the other. Thus, if the satellite were to take one of these unaccounted for paths, it could risk passing up or even crashing into the target satellite, the latter case actually taking place on during NASA's DART mission.

This risk led to the design decision of using only one type of imager for image processing and navigation control. This reduces the risk associated with incorporating more complicated code into the navigation control software to account for the use of separate imagers at varying distances, thus reducing the risk of satellite collision or flyby. This risk could further be reduced through the use of differential GPS measurements that would help increase in the relative displacement values calculated by the on-board imager.

3. Team Organization

Work on the mission will be separated between two specific teams: one focusing on the development of the propulsion system for each spacecraft, and one focusing on the development of the external structures associated with each satellite. However, until the beginning of the second semester, most of the work associated with this project will be related to defining the mission as a whole, as opposed to designing any of its subsystems. Thus, for the first semester, it is likely that each team member will aid in the process of determining Rascal's mission, rather than work on any separate component of its development.

Of the five members of this particular team, one will be designated as project manager, whose job it will be to oversee and participate in the development of both such systems, as well as determine the placement of all components within each satellite. The project manager will also be responsible for the adherence to schedules, the setting of weekly action items/deadlines, the maintenance of version control on all documentation, and the upkeep of the team's project website, which will be running shortly. Any other specific task associated with the project (such as minutes taking, document archival, quality assurance, etc.) will be filled by each member as needed.

Table 3-1 below lists out the names of each person on the project and the teams that he or she is associated with.

Table 3-1. Team Members and Positions

Team Member	Position	Email	Phone
Tom Moline	Program Manager	tmoline@slu.edu	630-401-0791
Nate Richard	Propulsion Team	nrichar8@slu.edu	608-732-7147
Tyler Olson	Structures Team	tolson6@slu.edu	812-204-1098
Bryant Gaume	Propulsion Team	gbryant1@slu.edu	636-448-0378
Jennifer Babb	Propulsion Team	jbabb1@slu.edu	636-579-6816

4. Schedule

The major tasks expected to be completed over the coming semesters are listed in Table 4-1 below.

Table 4-1. Rascal Schedule

Preliminary Design Phase	• Refine Mission Objectives • Create Requirements Verification Matrix • Website Development • Preliminary Subsystem Drawings • Navigation Feasibility Study • Mass, Link, Power, Volume, Computing Budgets • Propulsion/Structures Trade Studies • Structural/Thermal Analyses	Completed in December 2013
Critical Design Phase	• System Drawing • Subsystem Breadboard Tests and Results • Materials List • Structures Fabrication and Testing • Propulsion Unit Fabrication and Testing • Payload Integration and Testing (EE Senior Design)	Completed in May 2013

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The prevailing focus of the first semester will be on initial trade studies associated with additive manufacturing processes (as related to propulsion units), as well as the affordability/usefulness of commercially available propulsion options. Other trade studies will also be conducted, with the vast majority focusing on the pros and cons of custom CubeSat skeleton design and manufacturing. Analyses will also be conducted into the risks associated with Phases 2-4 of Rascal's mission life, as to determine the feasibility of the current goals listed in this document, as well as to refine the processes associated with the successful completion of each phase. Other goals include completing preliminary link, mass, and power budgets, determining the exact physical layout of the Rascal structure, researching the manner in which each 3U satellite can be secured to and released from their common baseplate, etc.

The second semester will predominately focus on the refining of the designs of the propulsion unit and satellite structures, with the ultimate goal at the end of the semester being the successful fabrication of the preliminary designs associated with each system.