# 3.2 Proximity Operation Mission History

Rendezvous and proximity operations (RPO) missions have a long history in human spaceflight dating back to the first Gemini missions. It was not until the previous decade did interest arise in doing RPO missions with purely robotic applications. For the most part RPO missions have been solely under the purview of NASA and the military, only recently have private companies and universities made inroads in this area. Each mission has taken a different approach to RPO and has ranged from small CubeSats to massive multi-million dollar satellites. The successes and failures of these missions helped drive the constraints in the Rascal Mission.

Many of the RPO missions have been large million dollar satellites, out of these missions three were selected for more analysis because these mission cover several different ways to approach RPO. The first spacecraft is the Demonstration for Autonomous Rendezvous Technology (DART) built by Orbital Sciences Corporation for NASA to develop and demonstrate autonomous navigation and rendezvous. It was to try to dock with an experimental communication satellite. The primary objectives of the mission were to navigate autonomously using GPS and rendezvous using the Advanced Video Guidance Sensor. Within a few hours of launch it was able to reach the target. It began to approach the target vehicle, but a malfunction occurred and caused a soft collision with the target vehicle leading NASA to end the mission to find the cause of the collision. The total cost of the mission was $98 million. The next mission was Orbital Express, built by Boeing and Ball Aerospace and managed by Defense Advanced Research Projects Agency (DARPA) and Marshall Spaceflight Center. The Orbital Express mission was meant to show several servicing operations as well as rendezvous and proximity operations. It consisted of two spacecraft, one as the target and another to perform servicing operations on it. The primary spacecraft was able to refuel and replace the batteries of the target spacecraft. The mission cost $300 million. The final large spacecraft mission analyzed was the Micro-satellite Technology Experiment (MiTEx) mission. It consisted of three spacecraft working in geostationary orbit. One was an experimental satellite and the other two which served as inspection satellites. The inspection satellites, with mass of 225 kg each, were technology demonstration satellites capable of maneuvering in relation to other satellites and providing platforms to inspect other satellites without detection. The satellites demonstrated autonomous operations, maneuvering, and station-keeping capabilities. They were built by Lockheed Martin and Orbital Sciences and managed by DARPA. They were able to complete their mission with the experimental satellite, and then moved to inspect a failed missile detection satellite to try to find what fail. The total cost of the mission was $24.6 million.

More and more private institutions are starting to move into RPO missions with smaller spacecraft. Currently the missions done by private institutions have been primarily proximity operations; they still offer technologies that could be used on future RPO missions. The first of these was SNAP-1 developed by Surrey Satellite Technology Ltd and the University of Surrey. The 6 kg nanosatellite was to approach and rendezvous with Tsinghua-1. After launch SNAP-1 ended up in an orbit below that of Tsinghua-1 and, being relatively light, suffered more from the effects of atmospheric drag than the much heavier Tsinghua-1 microsatellite. They became more separated and at maximum separation, Tsinghua-1 and SNAP-1 were about 15,000 km apart. But by means of the propulsion maneuvers, SNAP-1 brought itself to within 2000 km of its target. Thus, while a true rendezvous was not achieved, it was able to demonstrate the agility and maneuverability of SNAP-1 under automatic control. The mission cost less than $1 million. The next mission looked at was Aerocube-4 developed by the Aerospace Corporation. It consisted of 3 1U CubeSats that had solar panel wings that close and open to tune the ballistic coefficient. This enabled efficient formation flying. It includes three-axis attitude control to 1 degree absolute accuracy, a 0.3-square-meter deployable deorbit device, and sub-miniature reaction wheels. The satellite also carries a launch environment data logger that records ascent accelerations, vibration, pressure and temperature. In order to efficiently manage three CubeSats, a new three-node automated ground system network has been developed. High-precision orbit determination (OD) was made possible by a GPS receiver installed on each satellite that collected fixes on a regular basis and delivered the measurements of the satellites’ position and velocity. The mission cost around $200,000. The final mission looked at was PARADIGM, a partnership between University of Texas-Austin and Texas A&M. It consisted of two 1U spacecraft, one developed by UT Austin and the other one developed by Texas A&M. They were deployed at the same time. The objective of the mission was get two orbits worth of GPS data to determine how far apart the spacecraft traveled. The mission cost around $100,000.

# 3.3 Related Activity in Proximity Operations

Several private institutions are developing RPO missions using the CubeSat architecture. They were looked at to see what else is being currently developed and how Rascal can differentiate itself from the others. Looking at these missions might help identifying areas that will need to be focused on in the future as well as areas that need to be reviewed.

The first mission is Proximity Operations Nano-Satellite Flight Demonstration (PONSFD) under development by Tyvak Nano-Satellite Systems LLC and sponsored by NASA Ames Research Center. It consists of a set of two 3U spacecraft to demonstrate rendezvous and proximity operations. The concept of operations will consist of simultaneous deployment from the P-POD. Then there will be initial health checkout. The mission then enters its main rendezvous and proximity operations flight demonstration phase. The spacecraft enter orbit maneuvering to initial proximity distance and maintain otherwise known as formation flying. Cube-sat one will perform rendezvous and proximity operations relative to Cube-sat two. Then the rolls are reversed. The mission then enters increased and decreased range rendezvous and proximity operations scenarios. The mission ends when the spacecraft deorbit. The next mission is Application for RSO Automated Proximity Analysis and Imaging (ARAPAIMA). The spacecraft is being developed by Embry-Riddle Aeronautical University, University of Arkansas, and Red Sky Research LLC. It is a 6U spacecraft that will autonomously maneuver into close proximity to a resident space object. The concept of operations starts with the deployment of the spacecraft. The solar panels are partially deployed. Then it detumbles and acquires the sun. The solar panels are completely deployed so the payload can be exposed. The vehicle then under goes orbit and system checkouts. It approaches the selected resident space object after attitude determination and control systems and propulsion have been verified. Finally, the mission then enters science operations. The last mission analyzed was the Glint Analyzing Data Observation Satellite (GLADOS) under development by University of Buffalo. GLADOS is a satellite designed to evaluate the size of space debris. The cameras on GLADOS allow the satellite to look at the reflection of light to get the size, mass, shape, spin, and possibly its path of space debris. The spacecraft has the capability to help in predicting the path of space debris several months in advance, which might prevent orbital collisions.