Rascal Concept of Operations Overview

Saint Louis University

Rascal



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Copper Operational

Test Plan

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# Introduction

## Background

This document serves to outline the proposed concept of operations (CONOPS) associated with the Rascal mission.

## Rascal Mission Statement and Overall Mission Architecture

Rascal’s mission can be summed up as:

**The Rascal mission seeks to incrementally demonstrate the capability of a small-spacecraft in performing proximity operations, rendezvous, and inspection of both a cooperating and non-cooperating resident space object.**

Though there are many other missions attempting to demonstrate similar or greater capabilities as those outlined above (Such as Tyvak’s PONSFD, Surrey’s STraND-2, and Embry-Riddle’s ARAPAIMA), Rascal is the only mission that has taken seriously the challenges associated with conducting rendezvous and proximity operation (RPO) missions of any scale and actually integrated a realistic assessment of program capability directly into its mission design.

It is from this assessment where the “incremental” part of the mission statement comes in. As opposed to seeking out another spacecraft on the same launch or going after a decommissioned spacecraft that is already in orbit, hoping that spacecraft acquisition and checkout occurs fast enough for the mission to actually be performed, Rascal will bring with it the target it seeks to perform its mission relative to. This alleviates the many risks associated with the “initial conditions” problem of orbital analysis and planning. Instead of attempting to account for the impact of perturbation forces (mainly, aerodynamic drag, third-body influences, solar-radiation pressure) on two spacecraft released at slightly different times in slightly different locations, and hoping that these initial conditions match up in a way that allow for the mission to be quickly executed, one can eliminate all the uncertainty and not start the mission until contact has been confirmed between each mission spacecraft and the ground. This allows for a more precise understanding of both where and when the mission is actually starting, which greatly increases the odds of its ultimate success.

As such, regardless of the way in which the mission will be executed, several components of the overall mission architecture will be fixed, mainly:

* **The Target spacecraft will be brought with the Interceptor**: this removes the risk of securing permission to go and inspect either another organization’s spacecraft or a company’s rocket body (as has been done in the past), as well as that of finding an object to perform inspection of.
* **The Target and Interceptor will be conjoined up until mission commencement**: this removes the problem of “initial conditions”, giving the mission operators greater control over the mission as a whole.
* **The mission will be conducted “incrementally”**: this attests to the difficulties that past RPO missions have encountered over the course of their mission life, as well as realistically assesses the risks associated with RPO missions of any scale.

# Concept of Operations



## General CONOPS Overview and Definitions

With the discussion in the previous section in mind, a CONOPS has been drafted that is capable of demonstrating mission success:

* **RPO Demonstration**

The mission will demonstrate key RPO maneuvers, such as the ability to stationkeep at various distances from a resident space object, to rendezvous with said object, and to inspect said object using image processing, thus warranting its launch.

The mission CONOPS will use the terminology and mission phases, as described below:

* **Target Spacecraft:** spacecraft about which all RPO maneuvers would be performed.
* **Interceptor Spacecraft**: spacecraft with which all RPO maneuvers would be executed.
* **Cooperative State**: target spacecraft state in which all interceptor RPO aids are active.
* **Uncooperative State**: target spacecraft state in which no interceptor RPO aids are active.
* **Stationkeeping**: keeping a set relative distance between the target and interceptor spacecraft while maintaining as small a relative velocity as possible.
* **Inspection Stationkeeping (ISK)**: stationkeeping within 10 meters of the target spacecraft.
* **Remote Stationkeeping (RSK)**: stationkeeping at least 100 meters away from the target spacecraft.
* **Rendezvous**: the act of reducing the relative distance between the target and interceptor spacecraft.
* **Separation**: the act of increasing the relative distance between the target and interceptor spacecraft.
* **Uncooperative Mission Timer**: timer that is set prior to the uncooperative portions of the mission that, upon running down, forces the target spacecraft into its cooperative state.

## CONOPS

Figure 2-1 shows a general overview of CONOPS-1. The defining feature of this CONOPS is that it is done in a very incremental fashion, allowing at various points for payload performance assessment, as well as for mission alteration (such as the ability to update RPO algorithms based on in-orbit observation, as opposed to relying solely on ground testing and predictions).

Thus, after initial launch, launch vehicle ejection, and checkout, the mission can be broken down into three primary phases. Mission success would be defined by meeting the first phase of the mission (RPO and Inspection Performance relative to a Cooperating Target Spacecraft), with the completion of the remaining two mission phases being contributing to secondary mission success.

**C:\Users\MR LEO\Documents\GitHub\Preliminary-Design\CMQA\ConOps\CONOPS Cases\Rascal ConOps NO Docking.tif**

**Figure 2-1: Rascal CONOPS Illustration.** The Concept of Operations for the Rascal mission consists of several distinct phases, mainly: Initial Separation, Imaging Payload Checkout, Continued Separation, Remote Stationkeeping, Rendezvous, and Inspection Stationkeeping. It also has two overlying states: Cooperative and Uncooperative.

### Phase 0: Launch to Checkout

Phase 0 of the mission consists of all of the standard processes that define the beginning of any spacecraft mission: Launch, Launch Vehicle Ejection, Spacecraft Power-On, Ground Acquisition, and Checkout. Each of these stages is laid out in detail in the following sections.

#### Phase 0-A: Flight Vehicle Integration and Launch

This phase begins with Rascal’s integration into the flight vehicle and ends upon the flight vehicle reaching its target orbit. The main requirements associated with this phase would be ensuring that Rascal can survive the launch vehicle environment (Random Vibration Testing), as well as actually integrate into the launch vehicle (Following CubeSat deployer interface control document).

#### Phase 0-B: Ejection

This phase begins with the opening of Rascal’s CubeSat deployer and ends with Rascal’s exit from its launch vehicle. The only requirement during this stage is that no deployables (such as solar panels, antennas, etc.) are released for a specified period of time (as dictated by the launch provider).

#### Phase 0-C: Power-On

This phase begins the moment that Rascal is ejected from its CubeSat deployer. It consists of the powering on interceptor spacecraft, which would include initiating satellite beaconing and attitude determination and control (ADC) systems.

#### Phase 0-D: Acquisition and Checkout

This phase is initiated on the ground and begins during the first pass of the Rascal spacecraft over any of its ground-based radio stations. Once satellite acquisition has been achieved, a checkout of the systems on both the target and interceptor spacecraft would be performed. This would consist of verifying battery telemetry data, solar panel, ADC, payload, and communications functionality prior to full mission commencement. Once this has been completed, Phase-0 would be considered complete and the mission would then enter Phase-1.

### Phase 1: Cooperating Mission Phase

Phase 1of the mission consists of the main portion of the mission, such as the separation of the target and interceptor spacecraft, the first testing of the image processing payload, and the performance of key RPO and inspection maneuvers. Mission success is defined by the ability to perform each of sub-sections of this mission phase, which are described in detail in the following sections.

#### Phase 1-A: Orient for Separation

This phase begins with a command from the ground for the interceptor-target spacecraft combination to orient itself such that separation can occur with the optimal initial conditions determined before launch. This would help alleviate the risk associated with expending too much delta-V prior to mission execution. This phase ends when the proper spacecraft orientation has been verified from the ground.

#### Phase 1-B: Command Separation

This phase begins with a command from the ground for the target and interceptor spacecraft to separate. This would occur near the beginning of a pass over Rascal’s ground network, such that successful separation could be verified. This phase would end with this verification.

#### Phase 1-C: Move to Inspection Stationkeeping (ISK) Distance

This phase commences upon the initiation of separation. The interceptor spacecraft will enter its search mode, in which it orients itself in such a way that the target spacecraft enters the imaging payloads field of vision. Once the target spacecraft has been acquired, the interceptor will thrust out to its ISK distance (~10 meters) and stationkeep there until it can be verified on the ground that ISK is being performed.

#### Phase 1-D: Verify ISK

Once the interceptor spacecraft has reached its ISK distance, it will perform thrust maneuvers to stay at said distance until verification of ISK has been made on the ground. This will be accomplished by either decoding beacon data that is being emitted by the interceptor at all times or by specifically querying for imaging/relative distance data during a pass over the Rascal ground station. This step helps alleviate the risks associated with rapidly separating the target and interceptor spacecraft, which could result in a rapid divergence in the relative displacement between each of them, making it impossible for each to rendezvous later in the mission.

#### Phase 1-E: Command Continued Separation

After ISK has been verified, the interceptor spacecraft will be commanded to increase the relative distance between it and the target spacecraft from ~10 meters to ~100 meters, its remote stationkeeping (RSK) distance. This RSK distance constitutes a sphere of constant radius surrounding the target spacecraft, as shown in Figure 2-2.

#### Phase 1-F: Verify RSK

Max Separation Distance.tif

**Figure 2‑2 Remote Stationkeeping distance illustration.** This image shows the maximum allowable separation distance between the target and interceptor. This distance is visualized as a sphere of constant radius surrounding the target spacecraft.

Once the interceptor has reached its RSK distance, it will stationkeep until said separation has been verified, which will take place in a manner similar to that for verifying the ISK distance in Section 2.2.2.4.

#### Phase 1-G: Command Rendezvous

After RSK has been verified, a ground operator will command the interceptor to perform a rendezvous relative to the target spacecraft. This will constitute reducing the relative distance between the target and interceptor from the RSK to the ISK distance. Upon reaching its ISK distance, the interceptor will stationkeep until rendezvous verification can be made.

#### Phase 1-H: Verify Rendezvous

After the interceptor has reached its ISK distance, rendezvous will be verified in the same manner discussed in Section 2.2.2.4. Once this has been done, Phase 1 will be considered complete, and preliminary mission success will be considered achieved.

### Phase 3: Noncooperating Mission Phase

Phase 2 of the Rascal mission is not very different from Phase 1: the visual aids will be turned off either due to the batteries dying or by a command from the ground, thus transforming the target into a noncooperating space object. As such, Phase 2 will consist of the same maneuvers as those described in Phase 1, with the same mission timer in play as in that phase. Full mission success is defined as being able to complete Phase 1.

### Phase 3: Extended Operations Phase

Phase 4 of the Rascal mission consists of extended operations, which can include performing Phases 1 and 3 until the propellant in the interceptor is depleted, using the interceptor’s imaging payload for Earth observation, or for studying the relative drift between two different spacecraft when provided with initial velocity and position information. The extended operations phase would end when both spacecraft deorbit within 1-3 years of launch.

# CONOPS Risk Analysis

Table 3-1 summarizes the various risks associated with the CONOPS, each of which is discussed in detail below.

### Spacecraft Unable to Orient for Separation

Failure of the spacecraft to orient themselves properly for separation could lead to increased ΔV requirements for inspection stationkeeping. This risk can be mitigated by testing the pointing capabilities of the conjoined spacecraft on the ground prior to launch integration.

### Spacecraft Unable to Separate

**Table 3‑1 Risk Likelihood vs Consequence for the CONOPS**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Likelihood |  |  |  |  |  |
|  |  |  |  |  |
|  |  |  | **IV** |  |
|  | **I** |  | **V, VII** | **II, VI, VIII** |
|  |  | **III** |  |  |
|  | Consequence | | | | |

A failure of the separation mechanism to push the two spacecraft apart would result in mission failure. This risk can be mitigated by extensive ground testing of the separation mechanism under the expected environmental conditions in low Earth orbit.

### Initial Separation Velocity is too high

One of the main drivers between the ΔV required to execute the Rascal mission is the initial separation velocity between the target and interceptor spacecraft. If this value is too high, it can necessitate the use of more fuel to be used to execute the mission as a whole, which can negatively affect the ability of the interceptor to perform the whole Rascal mission. However, unless this high initial separation velocity is coupled with poor thrust timing in the rest of the mission, the mission can easily be executed for initial relative velocities up to 5 m/s (Two times faster than a CubeSat is shot out of a P-POD). This risk can also be mitigated through extensive ground testing and planning. As such, it is a low likelihood, mildly consequential risk.

#### Primary Spacecraft Unable to Locate Secondary Spacecraft

One of the greatest risks associated with the Rascal mission, regardless of approach, is the ability of the primary spacecraft to orient in such a manner that it can identify and determine the distance between it and the target spacecraft. If it were unable to do this early on, the target spacecraft would still be in its Cooperative State, meaning that it is powering the visual aids used to help the primary spacecraft’s payload identify its target. Though this risk has a higher likelihood of taking place, it would not be mission ending, as it allows for a “redo” of the mission using visual aid data.

#### Collision with Target Spacecraft during ISK

A collision with the quarry spacecraft during inspection stationkeeping may result in damage to solar arrays, communication antennas, and external sensors, potentially impeding further progress.

#### Unable to Rendezvous with Target Spacecraft during Cooperative Rendezvous

Failure of the primary spacecraft to rendezvous with the quarry spacecraft from maximum stationkeeping distance with visual aids active precludes any further rendezvous attempts.

#### Unable to Rendezvous with Target Spacecraft during Noncooperative Rendezvous

Failure of the primary spacecraft to rendezvous with the quarry spacecraft from maximum stationkeeping distance without visual aids precludes any further rendezvous attempts.

#### Collision with Target Spacecraft during Rendezvous from RSK Distance

A collision with the quarry spacecraft during rendezvous may result in damage to solar arrays, communication antennas, and external sensors, potentially impeding further progress.