

# NextSat On-Orbit Experiences

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## ABSTRACT

The NextSat spacecraft was designed and built by Ball Aerospace & Technologies Corp. as part of the DARPA funded Orbital Express mission. Orbital Express, launched in March of 2007, was a highly successful demonstration mission proving the capability of autonomous on-orbit refueling and servicing of spacecraft. The Orbital Express mission consisted of the Ball-built NextSat/CSC satellite and the Boeing-built ASTRO satellite. Both satellites launched mated into a 492km circular orbit on board a Lockheed-Martin Atlas V 401 launch vehicle from Cape Canaveral. The NextSat satellite acted as both the next generation “serviceable” satellite and the commodities satellite. This paper discusses the on-orbit mission experiences of the NextSat satellite. Key experiences include: launch and early orbit operations in which the NextSat satellite was called on to perform critical attitude control functions for the mated stack, functionality which was never tested or planned for, autonomous fluid transfers between ASTRO and NextSat, autonomous ORU transfers between ASTRO and NextSat, autonomous separation, free-flying, and rendezvous operations, and end-of-life operations.

**Keywords:** Orbital Express, NextSat, Ball Aerospace, Spacecraft, Mission Operations, DARPA

## 1. INTRODUCTION

A picture of the NextSat space vehicle stacked on top of the ASTRO vehicle in the mated launch configuration is shown in Figure 1. The NextSat vehicle provided agile, reliable, and dependable performance throughout the Orbital Express Demonstration mission. The vehicle, nicknamed “the little spacecraft that could” by the ground operators, performed above and even beyond its defined role in the groundbreaking mission. The wide variety of operational experiences that occurred during the short yet productive mission are discussed within this paper.

One of the principle elements of the Orbital Express mission design was the incorporation of autonomy into the performance of servicing operations. The NextSat space vehicle was designed to act as an autonomous agent to the ASTRO space vehicle throughout the entire mission, primarily guided by commands from the Mission Manager software operating on ASTRO and also in response to the feedback of select sensors within the payload elements on NextSat. The actual commanding of NextSat that was performed by the ground operators was generally confined to management of the stored state of health files and contact sequences, control over the communications security keys, the manipulation of the Orbital Replacement Unit (ORU) Battery preceding and following ORU transfer operations, and the upload of fresh ephemeris data prior to any unmated operations. All of the commands associated with the nominal execution of fluid transfers, ORU transfers, and unmated operations were provided by the ASTRO vehicle in the manner defined by its autonomy level.

To provide a reliable and predictable operational response to the commands from ASTRO and the ground, the NextSat space vehicle software incorporated a structured set of operational states and transition sequences into its Mode Manager software component. The Mode Manager operational model was simple and straightforward, acting as a state machine which performed transitions from one operational state to another based upon the detection of specified events such as the receipt of a command. Each defined operational state possessed a prioritized list of available state transitions with a specific target state and operational sequence associated with each unique set of triggering events. At a 1 Hz rate the software updated the event data (commands that had been accepted, payload sensor states, system fault states, etc.), cycled through the defined transitions, and acted on the first transition that had met its event based criteria to move to a new operational state.

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Fig. 1. Figure 1 is a picture of the NextSat vehicle atop the ASTRO vehicle in preparation for launch. The stack launched mated on an Atlas V launch vehicle on March 9, 2007.

This simple yet expandable architecture provided three key advantages to operations. First, the complex set of operations that were expected to be performed by the vehicle could be thoroughly defined and supported by expanding the operational state definitions and precisely controlling the transitional sequence functionality to encompass each unique pattern of behavior for the vehicle. Analysis of the mission profile and concept of operations ultimately led to 30 unique operational states and 183 state to state transitions being defined for the vehicle. That is a significant increase over the number of operational states employed by a typical space vehicle, yet it was key to supporting the structured autonomy requirements of the mission. Figure 2 shows a subset of the operational states associated with separation and rendezvous operations and a mapping of the available transitions between them.

The second advantage to this approach was that it simplified the commands that needed to be sent to NextSat from ASTRO or from the ground. The desired response to a particular command often varied based upon the configuration of the vehicle (mated to ASTRO, attached on the manipulator arm, free flying, etc.). Rather than require the ASTRO Mission Manager or ground operator to completely characterize the current configuration before deciding which similar yet distinct command to send to invoke a specific response, the Mode Manager software made the appropriate transition based upon its own knowledge of events. For example, there were four unique responses to the Safe command based upon the proximity of ASTRO and NextSat. The entire burden of determining which safing response to execute was embedded within the operational state definitions in Mode Manager, so all that any outside agent (including the Fault Manager component of software) needed to do at any point was identify to NextSat that a safing operation needed to be

performed. The transition logic handled all of the other decisions on whether to enable or disable sensors and attitude control components.

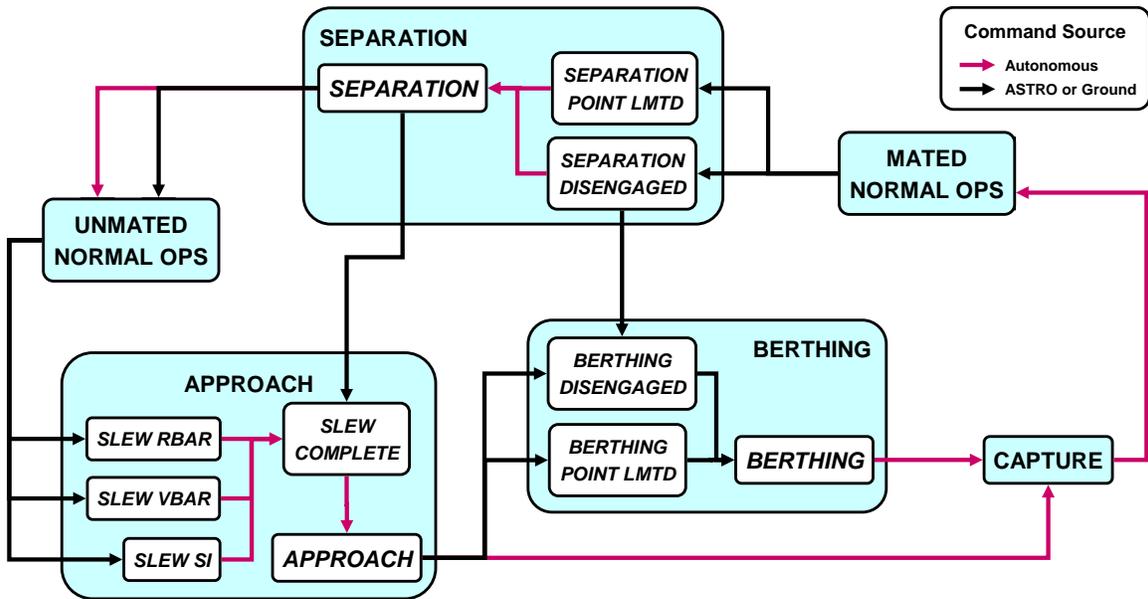


Fig. 2. Figure 2 shows a mapping of the available operational states and transitions associated with the performance of separation, free flyer capture, direct capture, berthing, and mating operations on the NextSat space vehicle.

The third advantage realized through this approach was a significant reduction in the required operator interaction with the vehicle and its telemetry. During operations, the NextSat provided a telemetry message containing key information to the ASTRO vehicle every second. While this telemetry included all of the same sensor states, fault flags, and received command summaries that were being used by Mode Manager to perform its transitions, the operators only needed to reference the operational state reported in telemetry in order to evaluate the progress of an operation since the transition logic built into Mode Manager had already evaluated the other items in order to make the transition. This large number of precisely defined onboard operational states and behaviors allowed the operator to understand the activity of the space vehicle immediately, based solely on that reported operational state. The majority of the operator's time monitoring servicing operations involved the simple recognition and announcement of state transitions, along with announcing to the other operators precisely what the characteristics of the new operational state would mean to the overall activity.

All of these design advantages resulted in an operational experience that required only simple preparation and routine activities to be performed by the “client”/“commodity” satellite operators to guide the nominal demonstration activities. Unfortunately, the mission provided significant anomaly response opportunities to keep those operators on their toes from beginning to end. The key successes and setbacks from the NextSat point of view are summarized in the remainder of this paper.

## 2. LAUNCH AND EARLY ORBIT OPERATIONS

The ATLAS V 401 launch vehicle carrying the Orbital Express mission’s ASTRO and NextSat satellites successfully launched from Cape Canaveral on March 9, 2007 at 0310 UTC, placing the Orbital Express satellites in a 492 km circular orbit inclined 46 degrees. Separation from the launch vehicle occurred approximately 20 minutes after launch.

At launch plus 32 minutes NextSat began its autonomous launch operations. All autonomous operations were initiated by the NextSat’s Mode Manager software. Mode Manager is the Computer Software Component (CSC) that configures the NextSat hardware and software systems through the recognition of events (commanded and autonomous), by dispatching command sequences specific to the recognized event, along with transitioning to a new mode.

The launch vehicle separation event started the autonomous command sequence. The first step in the sequence was the deployment of the NextSat solar array followed by a transition to the mated normal state which is a full power state for all subsystems except the Attitude Determination and Control Subsystem (ADCS). Nominal mated operations called for the larger ASTRO satellite to perform all attitude control, therefore the NextSat's ADCS was not designed to be powered on until the second day of the Orbital Express mission.

Immediately after launch an anomaly with the ASTRO vehicle's attitude control system occurred. This prevented the mated stack from achieving a power positive orientation. In order to conserve power during the anomaly resolution of the ASTRO vehicle, the NextSat satellite was commanded via the ground into its Mated Safe mode. The Mated Safe mode is a low level power state which removes power from any non-essential hardware. This occurred approximately 3 hours after launch. Over the next 20 hours the NextSat vehicle was continuously monitored for health and safety, with primary consideration given to the battery state of charge. Figure 3 is a plot of the battery health over the first 6 hours after launch vehicle separation. The plot shows the main battery voltage and current as well as the spacecraft loads and the solar array current. As shown on the plot, the NextSat main battery power was slowly being depleted starting at its maximum value of 32.0V and finishing 6 hours later at 30.5V. During this time there were periods where the NextSat solar array was swept across the sun which allowed some charging of the main battery.

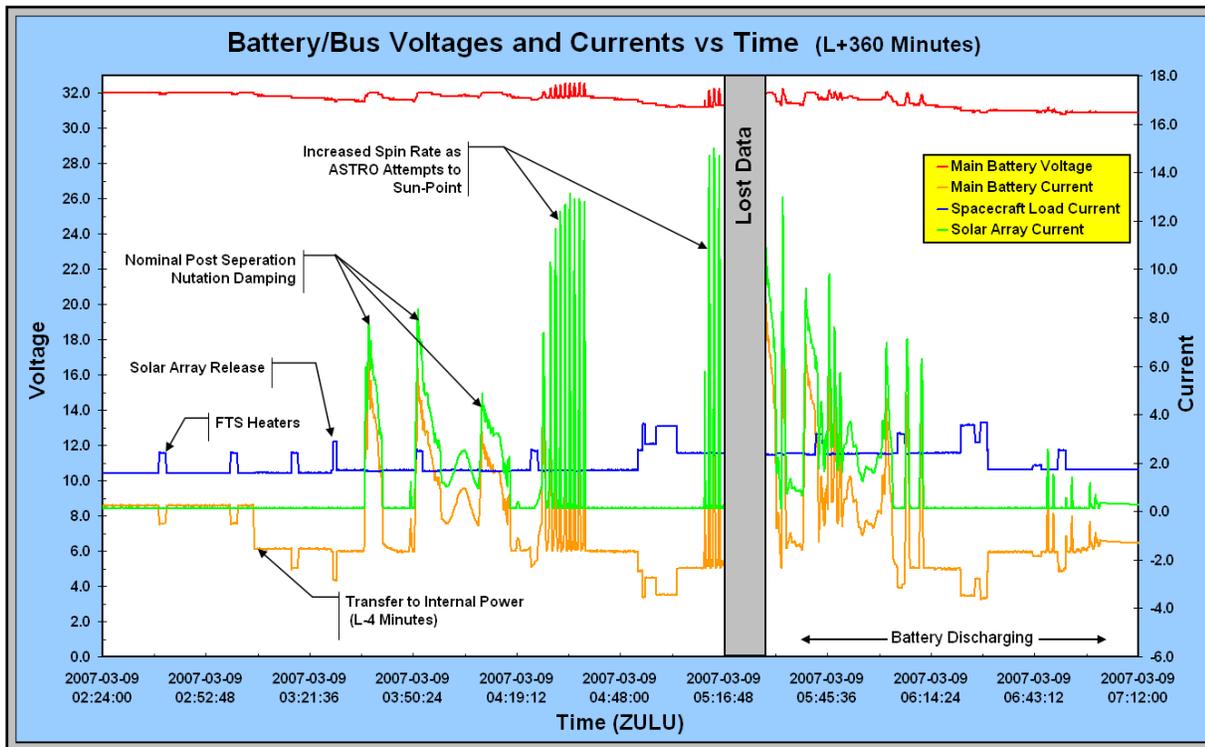


Fig. 3. Figure 3 is a plot of the NextSat battery health and status during the first 6 hours after launch vehicle separation. The plot shows the gradual decrease of the main battery voltage along with solar array current which charges the battery and indicates that the solar array was being swept across the sun.

The NextSat satellite was healthy at this point, and given the ability to charge its battery would have been able to stay in the Mated Safe mode indefinitely. The battery was continuously monitored to ensure that the battery voltage didn't drop below 27.25V which would have placed the NextSat into its Mated Emergency mode, its lowest level state. In Mated Emergency mode, the flight computer shuts down and a microprocessor residing on the Network Interface Card (NIC) is used to provide battery charge control. As in all Mated states, no attitude control functions take place in Mated Emergency mode.

At approximately 1700 UTC on March 9, 14 hours after launch, the mated stack rotated to approximately the anti-sun direction. No sunlight was shining on the NextSat solar arrays. As shown in Figure 4, this caused the NextSat battery

voltage to drop sharply. The ASTRO vehicle was also in a precarious power state, and at this time it was decided to attempt to have the NextSat control the mated vehicle stack's attitude. The NextSat had not been designed to control the mated stack, as this was not a planned on-orbit configuration. Quick calculations were done to show the feasibility of the NextSat taking control.

On March 10, 0000 UTC, approximately 21 hours after launch, the first attempt at taking control of the mated stack by NextSat occurred. Unfortunately due to problems with the ground system, commanding acquisition of the NextSat did not occur until loss of signal (LOS) minus two minutes. This did not allow sufficient time to send all of the necessary commands.

The next attempt occurred at 0250 UTC, about 3 hours after the first attempt. Unfortunately this attempt was also unsuccessfully due to a mismatch between the ground command count (GCC) and the vehicle command count (VCC). These need to be identical in order for the vehicle transponder to accept commands. The mismatch occurred because the final command sent on the previous attempt was not received by the vehicle.

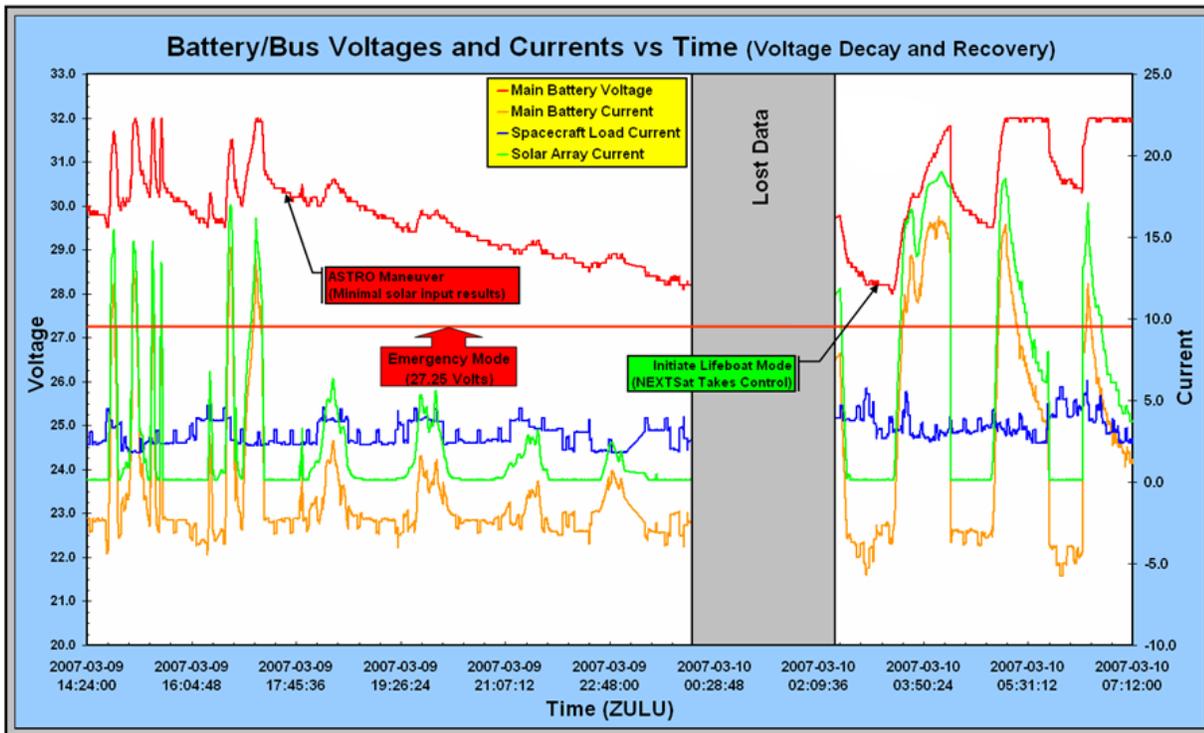


Fig. 4. Figure 4 is a plot of the NextSat battery health and status prior to and just after the NextSat vehicle taking over attitude control of the mated stack. The plot shows the NextSat battery voltage dropping rapidly prior to taking control and the subsequent maximum charging of 32V after taking control. The charging and discharging shown after attitude control was resumed was due to the spacecraft orbiting in and out of eclipse.

The next attempt at transferring attitude control to the NextSat satellite occurred at 0331 UTC, approximately 24 hours after launch. The correct GCC was determined, and commands were sent to disable all on board autonomous fault protection, and to trick the spacecraft into thinking it was free flying by overriding its internal mated latch states. The latch states define whether the ASTRO vehicle is mated to the NextSat. Overriding the mated latch states caused the Mode Manager to autonomously transition the NextSat from Mated Safe mode to the Unmated Safe mode.

The transition to Unmated Safe mode powered on the NextSat's attitude control system. The NextSat's attitude control system is a zero-net-momentum 3-axis stabilized control system which utilizes 3 orthogonal reaction wheels for attitude control and 3 orthogonal torque rods from momentum control. Attitude determination is provided by coarse sun sensors, a magnetometer, a rate gyro, and two star trackers. The NextSat's attitude control system successfully maneuvered the

mated stack into a power positive orientation immediately upon sunrise. Figure 4 shows the NextSat battery voltage increasing rapidly after sun acquisition. The troughs in the battery voltage after taking over control are due to the NextSat orbiting in and out of eclipse.

Over the next 24 hours, additional higher level attitude control was commanded in order to provide enhanced pointing during eclipse. This included loading an initial condition vector which allowed the use of a modeled sun vector while in eclipse, and the powering on of the NextSat star trackers. By modeling the sun vector in eclipse and having the star trackers powered, the NextSat was able to point the mated stack within 7 degrees of the desired sun vector during the entire orbit. This was an improvement from the initial transfer of control which drifted up to 70 degrees in eclipse and had to reacquire at sun rise. The inertia parameters used by the NextSat attitude control system were not updated to account for the inertia of both vehicles. The mated inertia was approximately 15 times greater than that of the NextSat alone. The reason the NextSat attitude control system was able to control the attitude of the mated stack was that it used a low gain ultra-stable bandwidth with sufficient gain and phase margin to point accurately with an inaccurate inertia tensor.

The NextSat continued to control the mated stack for approximately one week after launch during which time the ASTRO vehicle anomaly was resolved.

### **3. FLUID TRANSFERS**

The performance of fluid transfer scenarios required the least amount of active monitoring by the NextSat operators. In order to manipulate the isolation valves within the Fluid Transfer Module, the NextSat space vehicle was placed in the Fluid Transfer mode. Once in that mode, the command and telemetry interface between the NextSat and ASTRO allowed the software running the autonomous demonstration sequence on ASTRO to control the state of those valves on the NextSat with six simple configuration commands. All of the valve state, fluid pressure, and temperature information key to monitoring the operation in progress was transmitted to ASTRO every second and was monitored by the autonomous software for fault indications. In this architecture, the NextSat operator often acted as the third layer of verification during fluid transfer operations, after the sequence verifications performed by the Mission Manager and the Fluid Transfer Technical Advisor monitoring the ASTRO telemetry. This design and operational approach freed the “client” operator to monitor all other aspects of vehicle operation independently of the fluid transfer activity, without the responsibility for making critical decisions associated with the transfer operations.

### **4. ORBITAL REPLACEMENT UNIT TRANSFERS**

The primary challenge for the NextSat ground operators associated with the transfer of the ORU Battery was the incorporation or removal of the ORU Battery from the active power subsystem. For the removal process, charge control was disabled to the ORU Battery by ground command, with the ORU Battery still connected and providing power to the vehicle. It operated in this configuration until a 1 volt differential was reached between the main spacecraft battery (which remained under charge control) and the ORU Battery. At this stage, the monitoring software removed the battery completely from the power subsystem, finalizing its preparation for transfer. Short eclipse periods would have greatly increased the number of orbits required for this differential to develop; however, all of the transfers occurred during periods where the eclipse was at or near the maximum duration. This enabled the ASTRO-guided transfer activities to be scheduled to occur within a few orbits of the client operations to ready the spacecraft components for transfer, reducing the operational impact of performing the complex servicing operation.

On the other side of the operation, a single command from the ground placed the software in a mode where it was watching for the voltage differential between the two batteries to return to 0 or 1 volt or less, at which point the software engaged the necessary relays to activate the ORU Battery in the power subsystem. Due to the built-in discharge process that was followed prior to the ORU Battery removal, this differential was achieved within the first 5 minutes of the sunlit portion of the orbit. This allowed the activation of the ORU Battery to be monitored directly during any ground contact in which the spacecraft was in full sun.

For the actual transfers of the ORU component between the two space vehicles, NextSat largely acted as a data conduit to ASTRO for the feedback from the sensors within the ORU Interface Assembly (OIA). The Orbital Express

Demonstration Manipulator Subsystem (OEDMS, or robotic arm) was driven by this data, which included the states of latches in the OIA and the internal temperature sensor data from within the ORU. As with the execution of the fluid transfers, the NextSat operators were free to monitor other spacecraft health and status information since the autonomy of the command and telemetry exchange between the vehicles controlled the performance of the transfer operation. With this architecture, the client satellite and commodity satellite participate minimally in the servicing operation, even for the highly complex operation of physically removing or installing a hardware component.

## 5. UNMATED OPERATIONS

The Orbital Express mission demonstrated the feasibility of autonomous separation and rendezvous. Throughout the mission, the ASTRO and NextSat vehicles separated and rendezvoused a total of five times. The NextSat vehicle did not have any thrusters or ability to change its orbit position. The ASTRO vehicle completed all orbit maneuvers, including separation, formation flying and rendezvous. The NextSat's primary role was to provide a stable fixed platform for separation and rendezvous in the presence of disturbing forces such as ASTRO thruster plumes and capture and separation induced forces and torques. The next two sections describe two of the unmated operations. The first is a 120m direct capture in the Local Vertical Local Horizontal (LVLH) –R bar orientation, and the second is a 4km free-flyer capture in the solar-inertial orientation. These were chosen because they encompass all of the autonomous NextSat free-flyer operations.

### 5.1 Scenario 5-1 120m Separation, LVLH Direct Capture

Scenario 5-1 was the third of five unmated operations that occurred during the Orbital Express mission. This scenario consisted of a separation distance of 120m followed by a direct capture. (as opposed to a free-flyer capture using the robotic arm, see Section 5.2).

Scenario 5-1 occurred on June 16, 2007. For the NextSat, the start of the separation began with the ASTRO vehicle sending a command via the 1553 communications link between the two vehicles. The command caused the NextSat to begin the onboard separation sequence. The sequence first recorded a snapshot of the current estimated attitude and used it to build a maneuver target table. This made the current attitude the desired attitude for the entire separation event. The sequence also kept the NextSat reaction wheels in their disengaged state, meaning that attitude control torques were computed by the control algorithms but not sent to the reaction wheels. The sequence also powered on the NextSat capture sensors. The capture sensors consist of three optical beams which detect the presence of the ASTRO capture mechanism. The state of these capture sensors tells the NextSat software whether or not it is captured by ASTRO.

Figure 5 is a plot of the NextSat body frame angular rates during the separation event. Upon starting separation, the ASTRO vehicle transitioned into free drift and began freeing NextSat by releasing the three capture mechanism linkages. Figure 5 shows the increase of the NextSat angular rates during the time that the linkages are deploying. NextSat is considered fully released and unmated when the three capture sensor loopback signals on the NextSat vehicle indicate a cleared state, showing that the ASTRO capture system linkage mechanisms are no longer holding onto the NextSat vehicle. This occurred approximately 120 seconds after the start of the separation event. The NextSat vehicle began its autonomous attitude control as soon as it recognized that it was unmated via the capture sensor beams. This is shown in Figure 5 at time 132 seconds. Immediately after being released, the NextSat vehicle began to damp out all of the separation induced torques and maneuvered back to the initial separation attitude. The recovery maneuver was completed within 20 seconds.

The NextSat vehicle was design to stay in the separation attitude and mode until either commanded into its Unmated Normal mode or until a 3 hour timer expires. During scenario 5-1 the NextSat was commanded by the ASTRO vehicle into its Unmated Normal mode approximately 60 minutes after separation. The mode change from Separation mode to Unmated Normal mode started a 15 minute attitude maneuver into a solar inertial orientation and powered off the NextSat capture mechanism sensors. The solar inertial orientation aligned the NextSat solar arrays towards the sun and placed the long end of the solar arrays along the inertial z-axis.

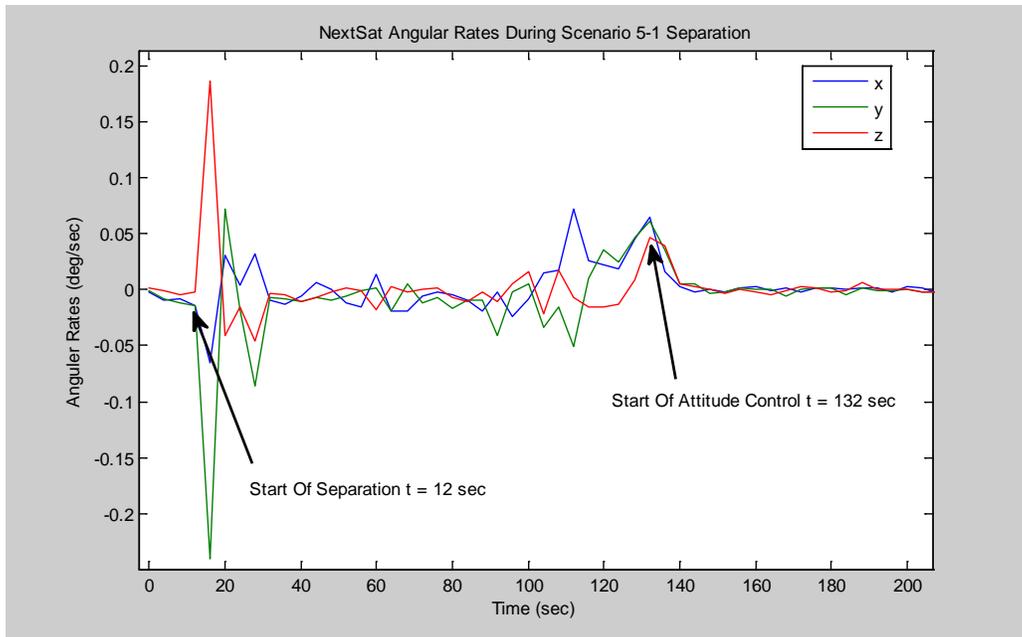


Fig. 5. Figure 5 is a plot of the NextSat angular rates during Scenario 5-1 separation.

Approximately 200 minutes after separation, the ASTRO vehicle commanded the NextSat vehicle into a  $-Rbar$  approach. After receipt of the command from ASTRO, the NextSat's Mode Manager transitioned NextSat into its Approach mode which started a 15 minute maneuver into the  $-Rbar$  orientation. The  $-Rbar$  orientation places the NextSat docking mechanism outward along the spacecraft zenith direction and rotates the  $-z$  axis at orbit rate. Figure 6 shows the maneuver into the  $-Rbar$  orientation. At the completion of the maneuver the NextSat Mode Manager autonomously powered on its capture sensor electronics in preparation of the capture event.

During the ASTRO approach the ASTRO thrusters impinged on the NextSat solar array causing disturbance torques, which were compensated for by the NextSat reaction wheels. Figure 6 shows the effects of the thruster impingement torques on the NextSat body rates. As can be seen in Figure 6, the ASTRO thruster impingement torques did not cause any appreciable change in the NextSat body rates or momentum state.

Approximately 290 minutes after separation, the ASTRO vehicle rendezvoused with and captured the NextSat vehicle. The capture dynamics are shown in Figure 6. When the ASTRO vehicle captured the NextSat vehicle, the ASTRO capture mechanism linkages blocked the NextSat capture sensor beams causing the NextSat Mode Manager to transition the NextSat vehicle from its Approach mode to its Capture mode. While in the Capture mode, the NextSat reaction wheels held their speeds constant. This kept the NextSat from applying torques to the ASTRO vehicle and kept the NextSat system momentum nearly constant. When the ASTRO capture mechanism was fully contracted the two vehicles are then mated. This event signaled the NextSat Mode Manager to transition from its Capture mode to its Mated Normal mode. During this time the ASTRO vehicle maneuvered the mated stack into the solar-inertial orientation. While in Mated Normal mode, the NextSat reaction wheels were fully disengaged, causing the wheels to spin down to zero. All NextSat reaction wheel momentum was absorbed by the ASTRO reaction wheels. The transition back into Mated Normal mode marked the end of the unmated operation for the NextSat vehicle.

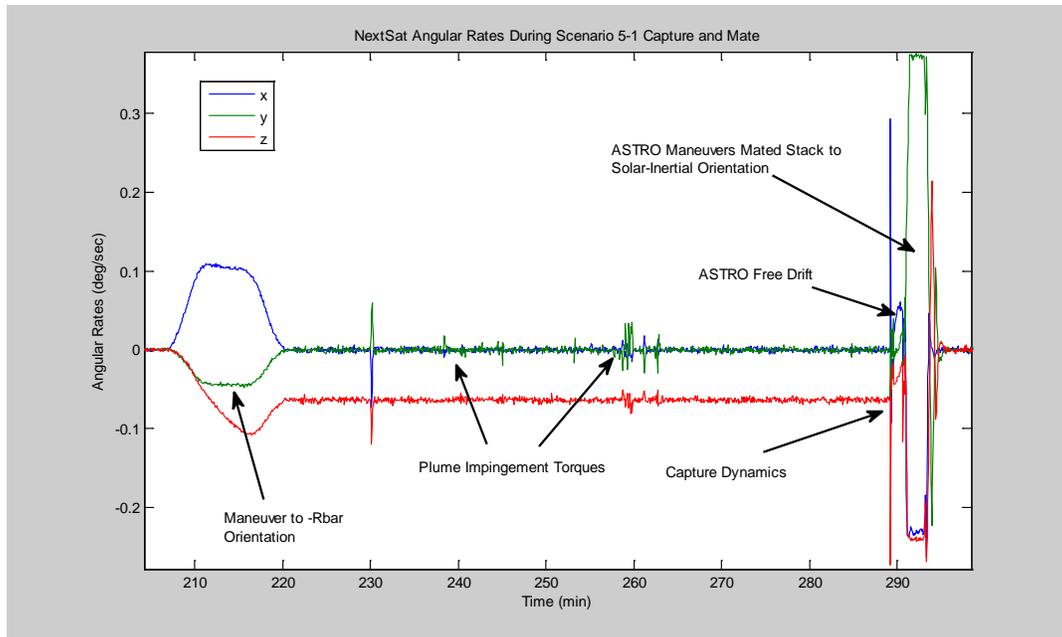


Fig. 6. Figure 6 is a plot of Scenario 5-1 capture and mate. The capture and mate began with a maneuver into the  $-Rbar$  orientation as shown. As shown in the plot during the direct capture, the NextSat body rates never exceeded 0.3 deg/sec.

## 5.2 Scenario 7-1 4.0km Separation, Free-Flyer Capture

Scenario 7-1 was the fourth of the five unmated operations that occurred during the Orbital Express mission. This scenario consisted of a separation distance of 4.0 km, followed by a free-flyer capture. A free-flyer capture was one in which the two spacecraft rendezvoused and the NextSat was captured via the ASTRO robotic arm, using a grapple fixture mounted on the side of the NextSat vehicle.

The Scenario 7-1 separation occurred on June 23, 2007. The separation event occurred in the same way as in Scenario 5-1. After being separated for nearly 16 hours, the ASTRO vehicle commanded the NextSat vehicle into its Approach mode. For Scenario 7-1 the Approach mode orientation was the solar-inertial orientation. Even though the NextSat vehicle was already in the solar-inertial it still went through the exercise of completing the maneuver. This was done so that all approach sequences would be generic; the NextSat can be commanded into Approach mode from any orientation.

Just after the approach maneuver was completed, the ASTRO vehicle commanded the NextSat vehicle into its Berthing mode via the crosslink transponder. The NextSat Berthing mode maintained the current attitude and signaled to the NextSat that it is going to be berthed by the ASTRO robotic arm. The NextSat does not have any internal indication that the ASTRO robotic arm has grappled it, therefore it must wait for positive confirmation from ASTRO.

Approximately 17 hours after the initial separation, the ASTRO vehicle commanded the NextSat into Berthing mode and successfully grappled the NextSat vehicle with its robotic arm. Immediately after ASTRO received receipt of the successful grapple from its internal sensors it sent the NextSat vehicle the Grapple command via the crosslink transponder. On receipt of the Grapple command, the NextSat transitioned into Grappled mode which held the NextSat reaction wheels constant so as to not exert external torques on the ASTRO robot arm. The NextSat stayed in this mode until the robotic arm brought the NextSat into the capture position with respect to ASTRO. Once captured the remainder of the sequence was identical to Scenario 5-1: the capture mechanism pulled NextSat into the mated position, the NextSat allowed its reaction wheels to spin down, and any NextSat momentum was transferred to the ASTRO vehicle. Figure 7 is a plot of the NextSat reaction wheels during the Scenario 7-1 grapple to capture to mate event.

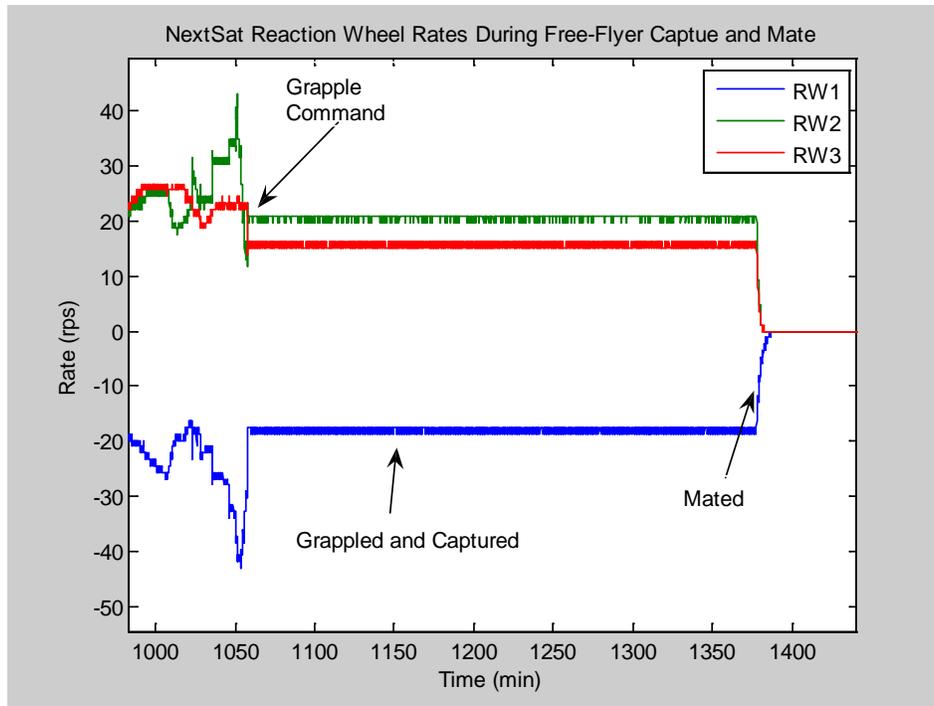


Fig. 7. Figure 7 is a plot of the NextSat reaction wheel speeds during the free-flyer grapple, and subsequent capture and mate. The NextSat reaction wheels are commanded to hold their speeds after confirmation that the NextSat was grappled by the ASTRO robotic arm. This was done so that the NextSat would not impart torques into the ASTRO robotic arm while the arm pulled the NextSat into the capture location.

## 6. END-OF-LIFE OPERATIONS

After all mission goals were successfully met, the final task for the NextSat team was to decommission the spacecraft. Decommissioning began with the NextSat and ASTRO vehicles still mated. The ORU battery was transferred to ASTRO as well as all remaining fuel. The ASTRO vehicle separated from the NextSat vehicle and performed a number of delta-V maneuvers to ensure that a future collision would not occur.

The NextSat end-of-life sequence began on Friday, July 20, 2007. At 2252 UTC, operators commanded the NextSat vehicle to execute the decommissioning commands. The sequence first disabled all autonomous fault responses. This was done so that there would be no chance that the NextSat would change states during the ensuing battery discharge. The NextSat Emergency Mode Controller was also disabled, in order to prevent it from taking control of the spacecraft and maneuvering it into a power positive orientation.

The final steps included corrupting the flight software such that if processor reset occurred it would not be able to reboot software, setting the desired spacecraft orientation such that the solar arrays would be positioned 180 deg from the sun, and turning off solar array strings to prevent battery charging.

The final NextSat contact occurred on Saturday July 21<sup>st</sup>, 2007, approximately 270 minutes after the maneuver away from the sun. At this time the NextSat battery had dropped from 32 volts to 29 volts. Based on this, the NextSat battery was expected to be fully depleted approximately 10 hours later. During this final contact, the NextSat reaction wheels were powered off, all commanding was disabled, and the transmitter was powered off.

The NextSat decommission was determined successful and complete on Sunday July 22<sup>nd</sup>, 2007 after ground operators were unable to make contact with the vehicle. This was the end of an exciting, ground breaking mission which will certainly leave a lasting impression on all of the great people who helped make it a success.

## **7. ACKNOWLEDGEMENTS**

The authors would like to thank all of the hard working engineers, mission controllers and support personnel who helped to make the Orbital Express NextSat satellite a success. Throughout every aspect of the mission, from the design, to test and finally mission operations, the teamwork and camaraderie that was exhibited by the NextSat team was unparalleled. We are very thankful to have been a part of it.