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# PROX-1 Automated Proximity Operations

David Spencer
GEORGIA TECH RESEARCH CORPORATION

01/13/2016
Final Report



Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB1
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**14. ABSTRACT**
During 2015, the Prox-1 team completed a set of system-level tests focused on demonstrating the functionality required to meet minimum mission success criteria. The minimum mission includes on-orbit spacecraft checkout of all spacecraft subsystems, including flight qualification of the following new technologies: the Honeybee Robotics Microsatellite CMG unit, the University of Texas at Austin 3D printed cold-gas propulsion unit, and the Arizona State University visible and infrared imagers. The minimum mission also includes deployment of LightSail-B from the P-POD, and imaging of LightSail-B for 20 minutes as it recedes from Prox-1.

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*Technical Memorandum*
December 21, 2015

TO: Air Force Office of Scientific Research/Air Force Research Laboratory

FROM: David Spencer, Prox-1 Principal Investigator

SUBJECT: Prox-1 Final Performance Report

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This technical memorandum provides a summary of the Prox-1 project status as of December 2016. The project is on track to deliver the spacecraft for launch in late 2016 or early-mid 2017, with full capability to meet all mission objectives.

Current Status

During fall 2015, the Prox-1 team completed a set of system-level tests focused on demonstrating the functionality required to meet minimum mission success criteria. The minimum mission includes on-orbit spacecraft checkout of all spacecraft subsystems, including flight qualification of the following new technologies: the Honeybee Robotics Microsatellite CMG unit, the University of Texas at Austin 3D printed cold-gas propulsion unit, and the Arizona State University visible and infrared imagers (note: the JPL Advanced Micro-Sun Sensor was descoped in fall 2015, because it did not operate properly when received from JPL, and JPL could not provide troubleshooting support within the schedule constraints). The minimum mission also includes deployment of LightSail-B from the P-POD, and imaging of LightSail-B for 20 minutes as it recedes from Prox-1.

A Lifecycle Charging Test has been successfully completed that demonstrates the operation of the electrical power subsystem, including switching of the electrical inhibits, battery charging from the solar panels, a discharge/charge cycle, and behavior when full charge is reached. A Command Execution Test was performed that demonstrated the operability of all commands needed for the minimum mission. A Simulated Communications Test was performed that demonstrated long-range uplink and downlink capability, and measured the link margins for comparison with the flight telecommunications link budget. The downlink test showed performance consistent with predicts. The uplink test had a shortfall of 1.5 dB relative to predicts; additional testing will be performed to verify uplink performance. Finally, a Day in the Life Test (DITL) was performed to execute the minimum mission concept of operations in a flight-like fashion, and to show long-duration (24 hours) performance. The DITL test was successfully performed, however faults occurred during the propulsion unit checkout and instrument checkout. These faults are understood and will be resolved during the next DITL opportunity.

A fit check of a P-POD into the Prox-1 flight structure was performed in October 2015. The fit check was fully successful, with adequate clearance for mechanical systems and harnessing. Activation of the P-POD burnwire was demonstrated as part of the DITL testing.

Full mission success criteria includes rendezvous, relative orbit determination of Prox-1 with respect to LightSail-B, and automated proximity operations including station-keeping, rest-to-rest orbit transfers, and natural motion circumnavigation around LightSail-B. An internal review of the guidance algorithms needed for rendezvous and proximity operations was conducted in November 2015. The algorithms have been modeled within the Guidance, Navigation and Control subsystem 6 DOF simulation, and delivered for flight coding. Validation of the system's capability to meet full mission success criteria will be demonstrated in the next set of system-level testing beginning in January 2016.

Schedule and Milestones

The scheduled launch date for the Prox-1 mission is September 2016, however, the Prox-1 team has been advised by the University Nanosatellite Program that a delay in launch date is very likely, and the date for the Pre-Integration Review was changed from December 16, 2015 to February 5, 2016 in order to allow the project team more time to complete key system-level tests. The date for the Pre-Ship Review has not yet been established, but the project team is planning to complete this review in spring 2016.

During January 2016 the team will begin to integrate the flight unit. The team will host a workmanship review with staff from the Georgia Tech Research Institute (GTRI) to evaluate all solder joints on the flight boards. Afterwards, flight boards will be conformally coated by AFRL-approved procedures and with the support of former University of Texas-Austin graduate students who manufactured flight boards while there. In the first and second weeks of January 2016, a group of 10 students specifically trained in integration procedures will mechanically and electrically integrate all components in the satellite. This will be a staged, recurring two-step process, where a component will be physically integrated, and then a standard software unit test will be run to verify successful data and electrical connections.

Following flight unit integration, the team will run through the battery of four system-level tests run for the Pre-Integration Review, updated to include flight components and full mission success criteria. The Lifecycle Charging Test will verify the re-fabricated EPS inhibit and breakout boards. The Simulated Communications Test will verify a conformally-coated Terminal Node Controller, and verify the effect of the flight structure on the antennae radiation pattern. Both the Command Execution Test and the Day In The Life Test will build on previous iterations, ensuring that the satellite can run through 24 hours of nominal events and through the

sequence of events required to achieve minimum mission success criteria. All of these tests are scheduled to occur between the third week of January and first week of February.

A Pre-Ship Review (PSR) will be held at Georgia Tech in spring 2016, immediately preceding shipment of the spacecraft to the Air Force Research Laboratory in Albuquerque, NM. Depending upon the established date for shipment, the LightSail-B/P-POD delivery will be made to either Georgia Tech or AFRL. The LightSail-B/P-POD schedule for readiness to ship is March 16, 2016.

Personnel

There are currently 40 undergraduates and graduate students supporting the Prox-1 mission. At this point, the personnel needs of the mission are predictable and stable. Subject matter experts in EPS, COMM, and FSW are required to finalize the required pre-ship testing. Personnel for the spacecraft integration team are from the Mechanical Structures sub-team who have been working on the project for more than a year. The Mission Operations team will be composed of a Mission Manager, a System Engineer, and three subteams: Spacecraft Team, Mission Planning & Sequencing Team, and Tracking Station Team. Personnel for each of these positions will be recruited from the current development staff. The primary needs for the spring semester are in the Electrical Power Subsystem and Flight Software. The team is actively recruiting in these areas.

Funding

The Prox-1 mission received four years of funding from the University Nanosatellite Program totaling $220,000. This funding has been fully expended. The project also received additional funding of $9,000 to enable hourly work by undergraduate students in summer 2015. This funding was very critical in allowing progress to be made on the electrical power subsystem design, assembly and testing which was a necessary precursor to the system-level testing in fall 2015.

Prox-1 has been fortunate to receive Georgia Institute of Technology internal funding throughout the project lifecycle. A grant of $110,000 was received in 2009 for hardware purchases needed for the Georgia Tech tracking station and mission operations center. These facilities will be utilized for Prox-1. Also, the Georgia Tech Center for Space Technology and Research (CSTAR) has provided $50,000 in funding over the past three years specifically for Prox-1 mission development.

Prof. Spencer utilized $140,000 of his start-up funds for space flight facilities and Prox-1 flight hardware. Also, $30,000 of discretionary funding received from the Aerospace Corporation has been utilized to support Prox-1.

There is a current need for $20,000 to fund the purchase and assembly of Prox-1 flight boards. The project is working with the University Nanosatellite Program office to establish the availability of funding and identify the funding mechanism. These funds are critical to the completion of the flight unit integration, and the project appreciates the willingness of UNP to attempt to address this funding issue. There are no other major funding needs anticipated at this point prior to delivery of the spacecraft to AFRL. LightSail-B and P-POD are fully funded by The Planetary Society.

Risks

The greatest risk remaining during the integration and testing phase is a hardware failure during vibration testing. The project is mitigating this risk by having a GTRI professional electronics technician perform assembly of the flight boards. An inspection of the flight boards, harnessing, and overall spacecraft assembly will be conducted by an expert from the GTRI Electronics Systems Laboratory. The Honeybee Robotics Microsatellite CMG unit has not been vibration tested at the component-level, so there is some residual risk associated with the CMG as it enters system-level vibration testing.

During mission operations, the primary risk is failure of Prox-1 to rendezvous with LightSail-B following deployment of LightSail-B from the P-POD. This risk became more likely when the JPL Advanced Micro-Sun Sensor was descoped, as Prox-1 attitude knowledge is degraded to ~30 deg/axis. The duration of the rendezvous phase is likely to be 1-2 weeks. The LightSail-B project has brought in an experienced orbit determination expert who will estimate the LightSail-B orbit using several different data sources, including radar tracking and laser ranging (LightSail-B does not have a GPS unit). The rendezvous phase will be complete when Prox-1 attains a trailing orbit 150-200 m behind LightSail-B, with LightSail-B in the field-of-view of the infrared imager.

The project has worked diligently to ensure that the minimum mission success criteria will be met. System-level testing of the CMG has been performed, and the flight team has developed an understanding of how to operate the unit and address anomalies. An external review of the electrical power subsystem, including the inhibits scheme and P-POD initiation, was performed by consultant Gordon Hardman. The design was deemed to be sound, although Mr. Hardman suggested several electrical component changes to make the design more robust. These recommendations are being incorporated into board revisions that will be tested in parallel with the prior boards to assess operability and performance.

There are no major risks that threaten Prox-1's ability to meet the minimum mission success criteria.

# AFOSR Deliverables Submission Survey

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PROX-1 Automated Proximity Operations

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David Allen Spencer

**Program Manager**

**The AFOSR Program Manager currently assigned to the award**

Julie Moses

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**Abstract**

During fall 2015, the Prox-1 team completed a set of system-level tests focused on demonstrating the functionality required to meet minimum mission success criteria. The minimum mission includes on-orbit spacecraft checkout of all spacecraft subsystems, including flight qualification of the following new technologies: the Honeybee Robotics Microsatellite CMG unit, the University of Texas at Austin 3D printed cold-gas propulsion unit, and the Arizona State University visible and infrared imagers. The minimum mission also includes deployment of LightSail-B from the P-POD, and imaging of LightSail-B for 20 minutes as it recedes from Prox-1.

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Prox1_Final_Report.pdf

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**Archival Publications (published) during reporting period:**

Spencer, D.A., Chait, S.B., Schulte, P.Z., Okseniuk, K.J., and Veto, M., "Automated Trajectory Control for On-Orbit Inspection in the Prox-1 Mission," Journal of Spacecraft and Rockets, in review.

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**Funding Summary by Cost Category (by FY, $K)**

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| Salary | | | |
| Equipment/Facilities | | | |
| Supplies | | | |
| Total | | | |

**Report Document**

**Report Document - Text Analysis**

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**Appendix Documents**

## 2. Thank You

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