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Ongoing Nanosat Launch Vehicle Development for Providing Regular and Predictable Access to Space for Small Spacecraft

John Garvey
Garvey Spacecraft Corporation
389 Haines Avenue
Long Beach, CA 90814-1841; (562) 498-2984
jmgarvey@garvspace.com

Eric Besnard
Department of Mechanical and Aerospace Engineering
1250 Bellflower Blvd
California State University, Long Beach
Long Beach, CA 90840; (562) 985-5442
besnarde@csulb.edu

ABSTRACT

One candidate approach for providing regular access to space for very small satellites is through the use of a Nanosat Launch Vehicle (NLV) that is designed and dedicated specifically to this purpose. Accordingly, a joint academic-industry team, working together through the California Launch Vehicle Education Initiative, has defined such an NLV that is scaled to deliver up to 10 kg of payload to a reference 250 km circular polar orbit.

During the past year this team has achieved several milestones towards implementing such an NLV. Most significant has been the start of flight testing with full-scale, low-fidelity NLV prototypes. These tests are helping to drive the NLV design process while also pathfinding associated field site operations. At the same time, the experiences from manifesting multiple academic payloads are providing insights on what will be required to optimize NLV payload accommodations. Furthermore, while not baselined for the operational system, successful vehicle recoveries have expedited project turn-around times between flights and enabled significant cost savings.

Future testing will focus on improving the performance and fidelity of these development vehicles. To conduct high altitude suborbital development flights, such activities will eventually have to re-locate to a new launch range that is free of the altitude ceiling constraints that characterize the present site in the Mojave desert.

BACKGROUND

California Launch Vehicle Educataion Initiative

The California Launch Vehicle Education Initiative (CALVEIN) is a joint university-industry partnership between California State University, Long Beach (CSULB) and Garvey Spacecraft Corporation (GSC). The initiative's original goals were to develop, test and evaluate advanced launch vehicle technologies while also providing hardware experience to the next generation of aerospace engineers.[1] Since getting underway in 2001, this activity has provided students the opportunity to participate in the development of six liquid-propulsion test vehicles and the performance of ten flight tests. Significant technical milestones include the first two-ever powered flight tests of a liquid propulsion aerospike engine.[2]

Nanosat Launch Vehicle

During the last several years, the CALVEIN team has also established the development of a Nanosat Launch Vehicle (NLV) as an additional top-level objective. Such a specific goal has proven useful for prioritzing technology R&D tasks and came in part as a response to inputs from representatives of the small sat community on the need for such a dedicated capability.

As presently envisioned, the all-liquid, two-stage, expendable NLV (Figure 1 and Table 1) would deliver up to 10 kg to a 250 km polar orbit. The basic vehicle requirements, design concept and associated philosophies towards operations and mission integration were addressed in a presentation at the 18th Small Satellite Conference and subsequently updated in several Space 2004 papers.[3,4,5]

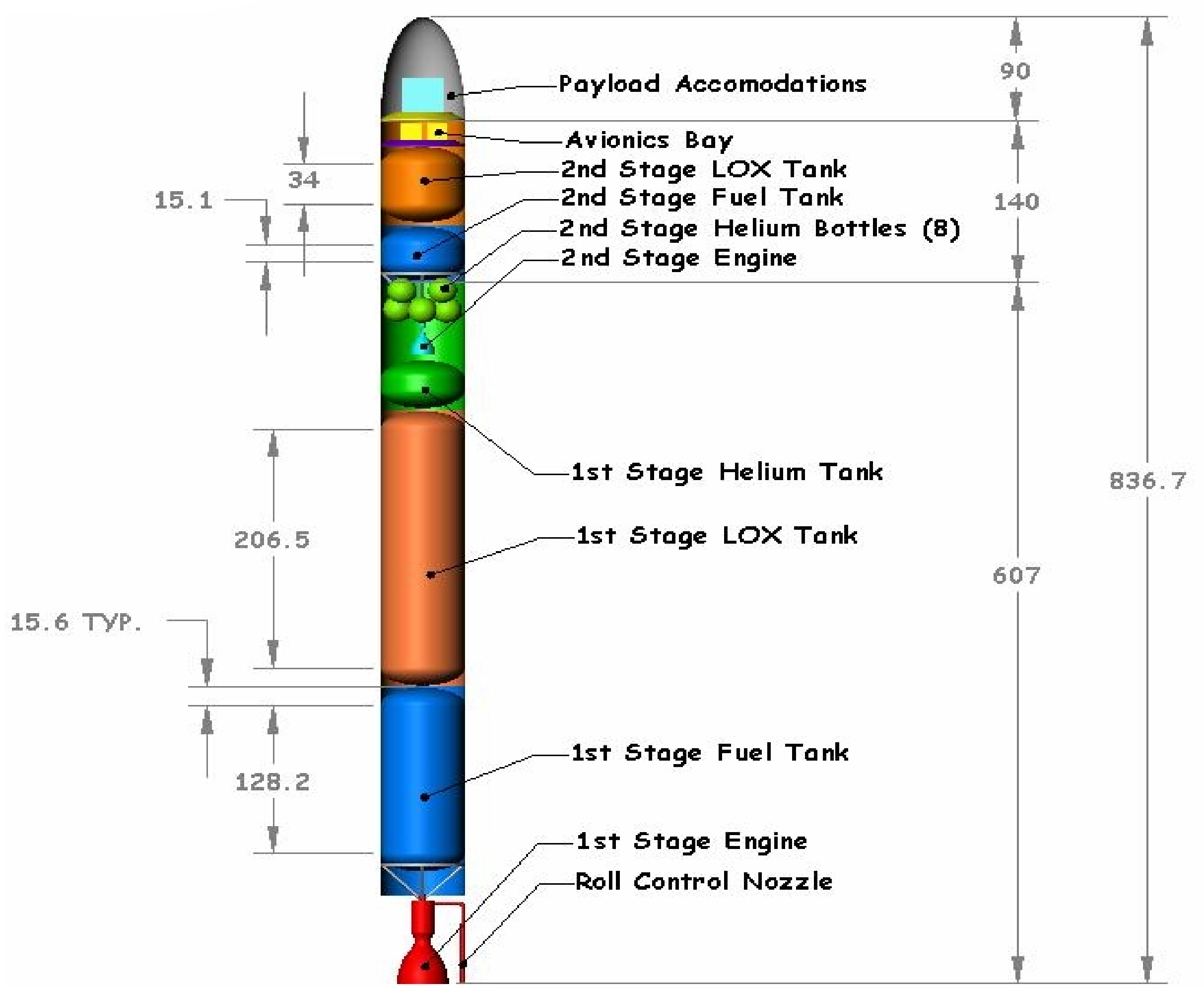


Figure 1. Pressure-fed Two-Stage NLV
(dimensions in cm)

Table 1. Basic NLV Characteristics

10 kg (22 lbm) to polar 250 km orbit
manifest either a single nanosat or multiple picosats and CubeSats
direct orbit insertion trajectory
two expendable stages
Gross Lift-Off Weight = 1540 kg (3394 lbm)
LOX / propylene propellants for both stages
pressure-regulated Helium for propellant feed on both stages
ablative first stage engine chamber, high-temp ceramic chamber for the second stage engine
maximum axial load = 7.3 g

PROSPECTOR 5

The Prospector 5 (P-5) was developed to initiate the GSC/CSULB team's transition to full-scale NLV class vehicles. Previously, all flight testing had utilized vehicles featuring a much smaller airframe (typically 25.4 cm in diameter) and a LOX/ethanol liquid propulsion system that had evolved through a dozen previous flight tests and a comparable number of static fire tests, all of which took place at the Mojave Test Area (MTA). By comparison, the P-5 diameter was 65 cm and at 136 kg, twice as heavy as previous test vehicles.

To minimize cost, the team made extensive use of previously flown and recovered hardware (an advantage of having an active, in-place flight test program). In particular, the 5,338 N (1,200 lbf) thrust engine was the same one salvaged from the Prospector 4 that had experienced a crash landing in June 2004. In addition to the cost savings, another benefit to this approach was the reduced development time - the basic P-5 was integrated over a six-week period starting in mid-October 2004. The trade-off was that engine burn-time and peak altitude would be extremely limited - on the order of 8 seconds and 1.5 km above ground level (AGL) - relative to the operational NLV first stage. Furthermore, the vehicle would be fin-guided and require a launch rail, whereas the NLV will employ thrust vector control. Such compromises were (and still are) deemed acceptable, given that the alternative was to wait for an indefinite period for sufficient external funding to develop a higher-fidelity prototype.

Launch operations took place on 05 December 2005 under near-perfect weather conditions (Figures 2 and 3).[6] The P-5 flew well, although a wind-induced pitch maneuver resulted in a peak altitude of less than 1 km. As a bonus, a new side-ejecting parachute system that had been added only five days before launch functioned better than expected and returned the vehicle to the ground in one piece. Because the main parachute was undersized, the landing shock was still high and the airframe incurred some damage (as might be notable in Figure 5), but all of the high-value propulsion equipment was recovered intact and ready for use yet again in follow-on flight tests.

For responsive space operations advocates, it is worth noting that the entire launch campaign - including vehicle deliver, set up, site preparations, launch, recovery and return to the lab - took place in a single day.

Figure 2. P-5 During Pre-Launch Operations
(photo by D. Allday)

Figure 3. P-5 Entering Free Flight
(photo by D. Allday)

Figure 4. Successful P-5 Parachute Deployment
(photo by D. Allday)

Figure 5. CSULB Students Recovering the P-5 from the Field

Figure 6. P-5 Stowed and Ready for the Trip back to the Lab

PROSPECTOR 6

The successful recovery of the P-5 first stage enabled the GSC/CSULB team to proceed next to an attempted flight test of a full-scale development version of the entire NLV. This Prospector 6 (P-6) vehicle was intended to continue operational pathfinding, while adding stage separation as a flight test objective. As with the P-5, cost constraints dominated all design and development activities.

P-6 development began in January 2005 and the flight took place on 21 May 2005 (Figures 7 through 14).[7] To achieve NLV-scale dimensions, the team added an interstage section and a second stage simulator, resulting in a total vehicle length of 813 cm (compared to 837 cm for the current reference NLV concept). The interstage was mated in the field to the first stage and remained attached in flight. The second stage simulator and the payload fairing underwent a similar field mating procedure and also remained attached during flight. The newly-developed stage separation assembly featured a set of four springs to provide the push-off force and was activated by the same command signal as used for the first stage drogue parachute ejection.

Besides the new stage separation assembly, students also fabricated an entire set of composite bulkheads and fins that replaced the wood and aluminum versions previously used in the P-5. Consequently, despite the added stage elements, the P-6 lift-off weight was essentially the same as that of the P-5. For added thrust-to-weight margin, the engine injector (now on its fourth flight) and tank pressurization levels were modified to provide sufficient mass flow rates to enable lift-off thrust of 6,228 N (1,400 lbf) versus the previous level of 5,338 N (1,200 lbf).

As in the proceeding December test, launch conditions were ideal and the P-6 flight went smoothly. After the engine burn and coast phases, stage separation occurred, followed by parachute deployments for both the first stage/interstage and the second stage simulator/payload fairing assemblies. Peak altitude was estimated to be on the order 860 m, representing a 25% underperformance from the final pre-launch estimate. This is now attributed to under-pressurization in the LOX propellant tank due to Helium chilling, which caused the engine burn to be fuel rich and closer to 5,338 N (1,200 lbf) thrust at lift-off.

Even with an improved main parachute, the first stage/interstage still experienced some structural damage (to the forward end of the interstage and the fins and thrust structure on the first stage), but as with the P-5, the key vehicle components were recovered intact, still fully capable of continued flight testing. By comparison, the second stage simulator / payload fairing assembly landed on one of the few metal structures in that region. This resulted in total loss of the fairing and some additional damage to the stage simulator, both of which can be easily rectified by the now-experienced CSULB student fabricators.

Figure 7. CSULB Students Integrating the P-6 With the Launch Rail

Figure 8. P-6 being Erected into Launch Position
(photo by D. Allday)

Figure 9. P-6 Launch Team
(photo by J. Mullin)

Figure 10. P-6 Engine Ignition
(photo by D. Allday)

Figure 11. P-6 In Flight
(photo by J. Mullin)

Figure 12. Deployed Parachutes Shortly After P-6 Stage Separation
(photo by D. Allday)

Figure 13. P-6 First Stage/Interstage Assembly Just Prior to Landing
(photo by J. Mullin)

Figure 14. P-6 First Stage/Interstage Assembly After Landing

PAYLOADS

As with all CALVEIN-sponsored flights, the Prospector development teams soliticed academic payloads for both the P-5 and P-6 flights (Table 2). Due to the short six-week development schedule of the P-5, only a single CSULB student payload - a wireless video camera mounted on one of the fins - was manifested on that flight test. In contrast, the P-6 featured four student experiments, including a data logger provided by Montana State University.

Table 2. P-5 and P-6 Student Payloads

University	Payload	Results
P-5		
CSULB	Wireless Video "Fincan"	Successful
P-6		
CSULB	Wi Fi Telemetry Experiment	Successful
CSULB	On-Board Mini-DV Camera	Successful
CSULB	On-Board Wireless Camera	Unsuccessful
MSU	Data Logger Experiment	Successful

The Wi Fi Telemetry Experiment and MSU Data Logger both provided valuable environmental data as typified by Figures 15 and 16 that is now being used to assess and characterize P-6 flight performance. With respect to on-board imaging, a discharged battery prevented operation of the wireless camera located in the second stage, whereas the on-board Mini-DV camera mounted on the first stage looking aft obtained expectional video throughout all phases of the flight.

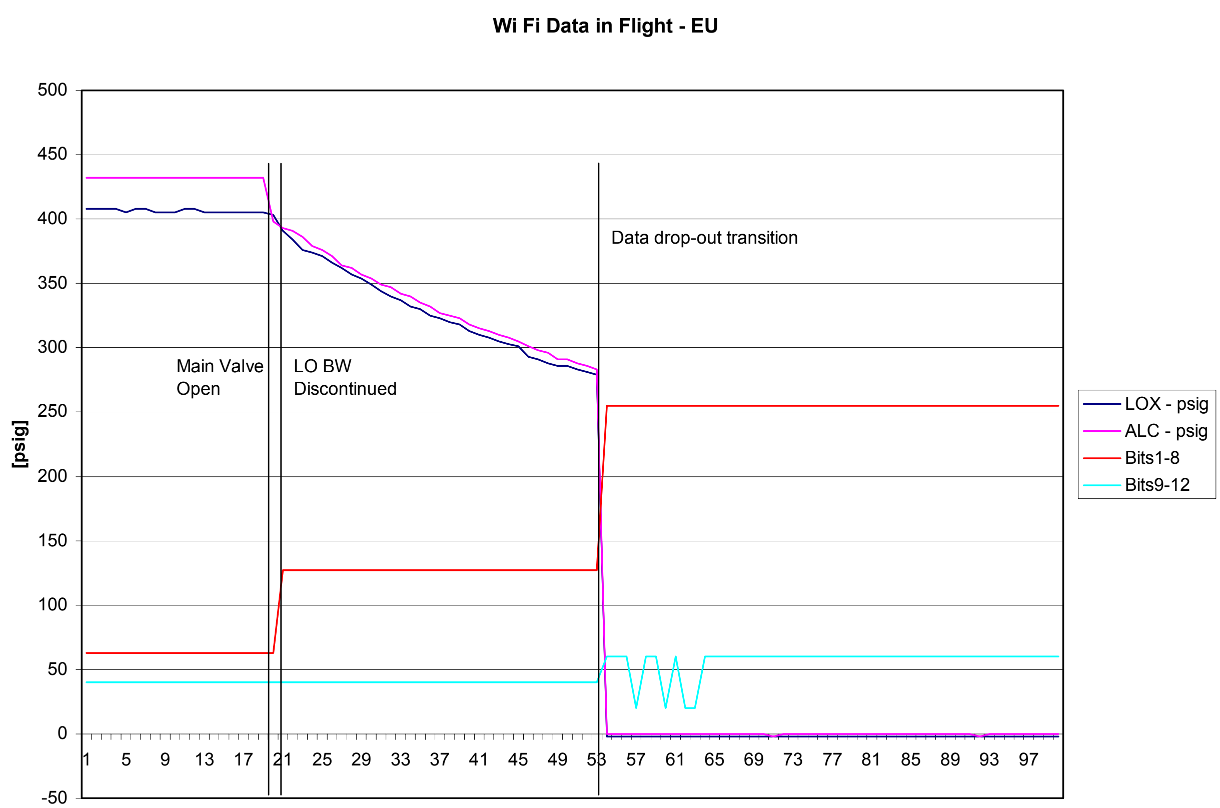
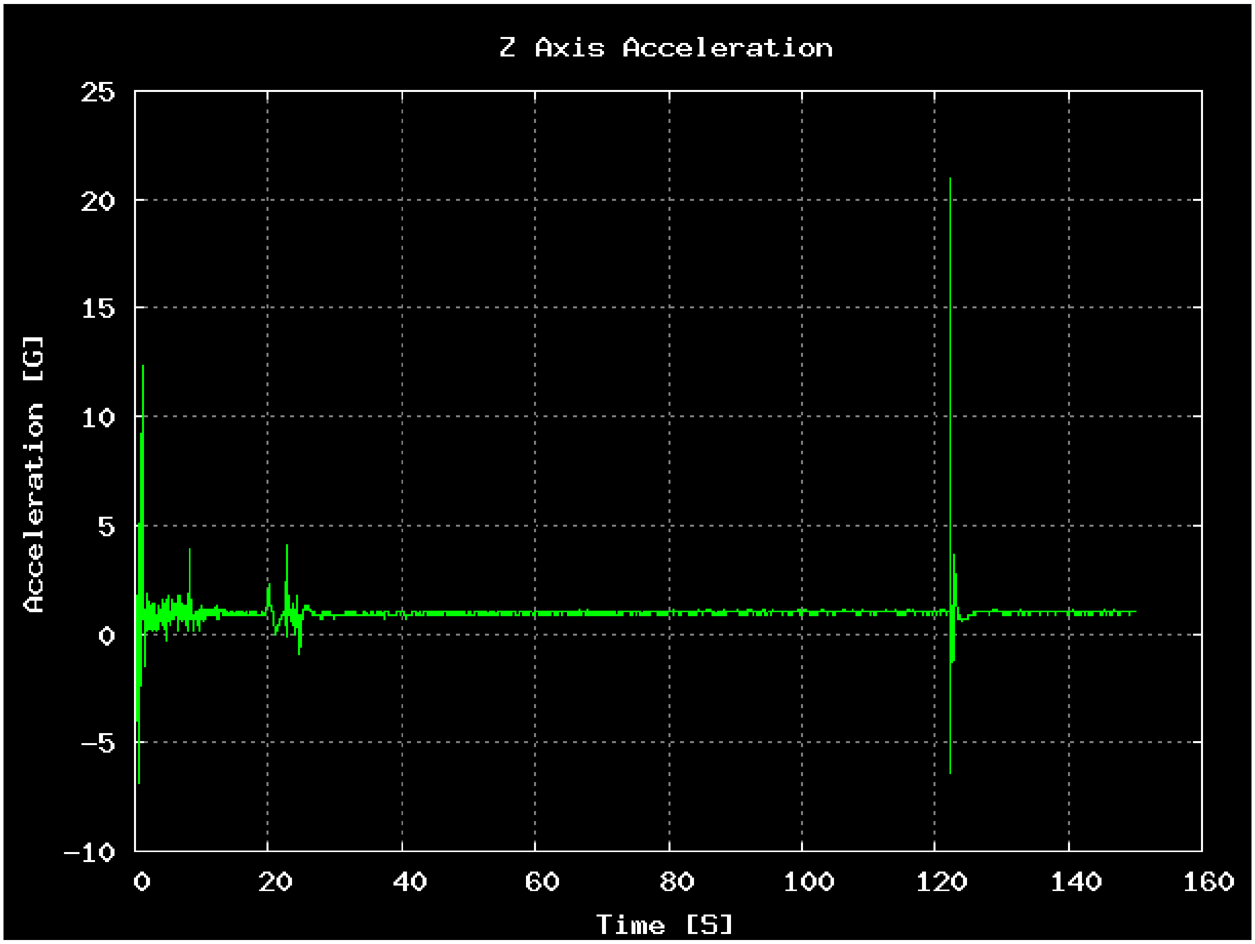


Figure 15. Preliminary Data from P-6 Wi Fi Telemetry Experiment



Note: MSU data logger Z-axis is equivalent to the P-6A X-axis (i.e. - along the central axis in direction of flight)

Figure 16. Montana State University Data Logger Accel Data from P-6 Flight

NEXT STEPS

Inspection of the P-6 stage elements back in the CSULB lab (Figure 17) has confirmed initial assessments from the field that only several weeks worth of work are required to refurbish the vehicle. Range availability will drive the launch date, with several opportunities are under consideration. It is anticipated that the Prospector 6A (P-6A - so designated to reflect continuing configuration evolution) will feature at a minimum a refined wireless telemetry system and an upgraded version of the MSU data logger on its next flight.

Figure 17. The P-6 First Stage Back in the CSULB Lab after Its Initial Flight Test

In addition to P-6A re-flight, initial development is now getting started on the Prospector 7 vehicle, which will be used to attempt two flights in one day as a demonstration and evaluation of reusable launch vehicle operations under a contract with the Air Force Research Lab. The tentative launch time frame is fall 2005.[8]

Over the medium term, the next major technical advances will feature a combination of thrust vector control, expanded propellant tankage and a larger engine to implement high altitude flight testing. CSULB students are already working on the first development article of the full-thrust 20,000 N (4,500 lbf) first stage NLV engine (Figure 18).

Figure 18. Mold for First Stage Engine Chamber

To fully pursue these goals, it will be necessary to transition to a new launch site that is not constrained by the 50,000 ft maximum flight ceiling at the MTA. Consequently, discussions are now underway with several alternative ranges, including those operated by both government and civilian organizations.

SUMMARY

The GSC/CSULB CALVEIN team has made significant progress during the past year in the early phase of NLV development. In particular, it is one of the few organizations that is actually flying prototype hardware and is doing so on a frequent and repeatable basis. In the process, it is continuing to validate concepts for responsive launch operations - both of the P-5 and P-6 launch campaigns were conducted in a single day. Of potentially equal significance, the NLV program is providing very low-cost flight opportunities for academic teams that otherwise might have to wait many years for a ride opportunity with traditional launch providers.

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