

Development of a Dedicated Launch System for Nanosat-Class Payloads

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ABSTRACT

This paper addresses the objectives and preliminary development of a Nanosat Launch Vehicle, with attention given to payload accommodations and user issues. This system is intended to provide cost-effective, dedicated launch services for the very low end (10 kg or less to low Earth orbit) of the small satellite market. Such a capability would put small payload developers fully in charge of their destiny for the first time, freeing them from many of the technical, administrative and scheduling constraints associated with current secondary and offshore launch opportunities. Unlike many other proposed future launch systems, this launch vehicle project is based on an existing flight test program that is already manifesting academic payloads while also pioneering the demonstration and evaluation of advanced technologies that include composite propellant tanks and aerospike engines.

BACKGROUND / INTRODUCTION

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 primary goals are to develop, test and evaluate advanced launch vehicle technologies while also providing hardware experience to the next generation of aerospace engineers.¹ Frequent field testing is a CALVEIN hallmark. Notable accomplishments include the first-ever flight tests of a powered liquid-propellant aerospike engine.^{2,3,4}

To facilitate the process of identifying and defining requirements for such technology development, the CALVEIN team has baselined a two-stage, expendable Nanosat Launch Vehicle (NLV) as its long-term focus.^{5,6} The distinguishing feature of this NLV is that it addresses the very low-end segment of the small payload market, i.e. – delivery of nanosats and picosats of up to 10 kg to low Earth orbit (LEO). This contrasts with other small launch vehicle programs that are attempting to deliver on the order of 100's of kg to LEO, with a comparable increase in per-mission cost, or else are concentrating on flying humans to the edge of space.^{7,8,9} Another distinction is that the CALVEIN

NLV effort is based upon an active flight test program that is already manifesting payloads from representative small satellite organizations (Figures 1 and 2). Such interaction is essential to creating a launch service that is truly responsive to the needs of the small satellite user community.



Figure 1. Prospector 4 Flight Test 2
 (photo by D. Gaylord)



Figure 2. USC Payload Flown on the Prospector 4

NANOSAT LAUNCH VEHICLE DESIGN

The basic expendable, two-stage NLV configuration is presented in Figure 3, along with first-order requirements in Table 1. The vehicle has a gross lift-off mass of only 1,540 kg (3,400 lb_m), with a diameter of 65 cm (26 in.) and a length of 837 cm (330 in.).

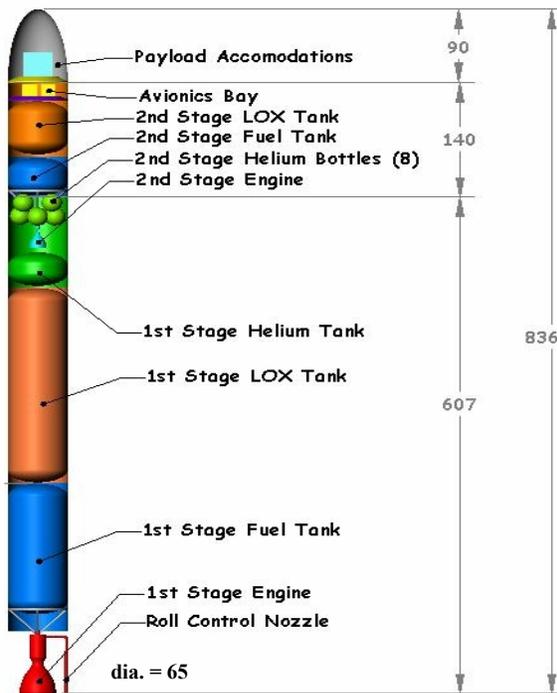


Figure 3. Pressure-fed Two-Stage NLV (dimensions in cm)

At this scale, the NLV is readily transportable. Mobility is further enhanced by the fact that the vehicle propellants are chilled industrial gases (oxygen and

propylene) that are widely available. Also, the baseline mission uses a direct insertion trajectory so that all events occur in sight of the launch complex, thus enabling telemetry, tracking and command (TT&C) functions to be accomplished from a single ground station. Combined, these features make it possible to operate the NLV with minimum investment from almost any launch site that has the appropriate range clearances.

Table 1. Top-Level Performance Requirements and Design Constraints

Deliver 10 kg to polar 250 km orbit
Use direct orbit insertion trajectory
LOX/hydrocarbon propellants*
Pressure regulated helium propellant feed systems for both stages
Single primary engine per stage
Same diameter for both stages
Both stages are expendable

* initial calculations have assumed RP-1 as the fuel. Future iterations will consider propylene instead.

A key design strategy for reducing cost and improving reliability is the elimination of the need for expensive turbopumps through the use of lightweight composite propellant tanks, higher performance propellants and/or an aerospike engine on the first stage that could potentially provide superior performance relative to standard bell-shaped nozzles. Furthermore, liquid propellants enable a non-hazardous work environment around the vehicle right up until the time of the final countdown. Their higher specific impulse is also an advantage over other propellant combinations that feature nitrous oxide or hydrogen peroxide as the oxidizer. Additional details regarding major design approaches can be found in Reference 6.

PAYLOAD ACCOMMODATIONS

The CALVEIN team recognizes that payload accommodations is a critical area in the implementation of a viable operational NLV. Consequently, a preliminary NLV User's Guide is in development that documents and communicates important user-related requirements, performance parameters and standard offerings and options. Present plans call for initial release during the fall of 2004. Potential NLV users are encouraged to become engaged in the preparation of this document. The status of several of these major hardware-related payload accommodations items are discussed below.

Payload Fairing

The NLV's biconic composite fairing has a length of 90 cm (35 in.) and a 66 cm (26 in.) diameter at the mating interface with the NLV second stage. Upcoming design tasks will assess whether a low-shock fairing separation and jettison system is feasible at this scale of vehicle. CSULB students have completed a lay-up plug for fabricating such fairings (Figure 4) that will be flown on upcoming NLV test vehicles and are on schedule to finish the first prototype unit later this summer.



Figure 4. CSULB Students with Fairing Lay-up Plug

Mechanical and Electrical Interfaces

The design approaches for the payload-to-vehicle mechanical and electrical interfaces are still evolving (Figure 5). At present, the leading options for the former are the nine-inch V-clampband design that represents a traditional default industry standard, as well as the Lightband separation systems now available from Planetary Systems Corporation.¹⁰ Attention is also being given to hosting the Cal Poly P-POD deployment system for CubeSat-class payloads.¹¹



Figure 5. Initial Mockup of Payload, Payload Adapter and 9-in. Attachment Clamp

For electrical interfaces, the present philosophy is to provide a minimum number of power and serial data

circuits through umbilicals that connect to the base of the first stage and run up through the interstage, second stage and payload adapter. Optional fiberglass fairing panels would enable RF operations after the spacecraft has been encapsulated.

Payload Encapsulation

The two NLV stages will undergo integration and in-depth system checkout testing at the vehicle production facility and are delivered to a designated launch site on a mobile transporter-erector-launcher.

In parallel, the payload accommodations hardware (payload adapter, attachment assembly and fairing) are delivered to the user's facility, where payload encapsulation actually occurs. The encapsulated payload unit is then delivered directly to the launch site under controlled environmental conditions for final mating with the NLV second stage.

MISSION INTEGRATION

Mission integration represents one of the best opportunities for innovation in launch services. The enabling factor is the low relative total cost of both the per-mission NLV hardware and the payloads themselves. Whereas a commercial communications satellite operator will not tolerate having their \$150 million spacecraft sit in storage while awaiting for an uncertain launch date on a vehicle of which they have had not had direct project oversight, university researchers might readily accept such a fate if it associated with a 50% price reduction. Consequently, the working assumption is that such flexible pricing will lead to a large number of "payload of opportunities," which in turn will enable frequent launches on a standard schedule.

Under this scenario, nanosat mission integration will more resemble those of a transportation service (i.e. – airlines) as opposed to today's hardware-oriented procurement culture. At present, three distinct classes of launch services are envisioned:

- premium
- standard
- payloads of opportunity

Premium or first-class launch services will involve extensive engineering support and assignment of a specific vehicle as soon as the procurement contract is implemented. This option serves customers whose requirements mandate unique mission parameters, launch sites, quality and configuration control, management oversight, security precautions and/or

scheduling constraints. Responsiveness will be a second-order priority, since mission-specific licensing and range safety requirements compliance are expected to dominate the mission integration process.

By contrast, standard launch services will consist of a narrow set of pre-defined trajectories and range services. To the extent possible, these will have been addressed in pre-approved licenses with the FAA, range safety and related regulatory authorities, thereby reducing or even eliminating mission-specific submittals. To streamline such processes and reduce mission-specific engineering, these users will comply with standard offering design and operational constraints. The nominal launch date would still be a customer-specified parameter. It is still to be determined whether a specific launch vehicle would be assigned to standard-class customers at the start of the mission integration process.

The payloads of opportunity option will be available for those users who can tolerate their encapsulated payloads being on standby for months while waiting for a manifest position to become available. Such users would have absolutely minimum flexibility with respect to modifying mission parameters. The predominant interest for this group is getting access to space in general, as opposed to operating in a specific orbit, for the lowest possible cost. Such users are typified by academic researchers who might want to evaluate functionality of nanotechnology components in the space environment for a period of two weeks, as opposed to remotely sensing the Earth for two years under tightly controlled altitudes and sun angles.

Generating a large backlog of such payloads of opportunity is considered to be the single most important factor in streamlining NLV operations and reducing operational costs.

NEXT STEPS

The CALVEIN team's work plans are based on serial development of selected critical technologies and operations. At present, the focus is on fabrication of a full-scale mockup of the NLV and field testing of several potentially enabling propulsion technologies

NLV Mockup Development

The development of a low-fidelity, full-scale NLV mockup (Figures 6 and 7) has two primary motivations. First, it maps well with the capabilities and interests of the CSULB undergraduate students. Our experiences are that despite all the modern CAD tools now available, a physical mockup still remains the best single tool for educating new engineers about the

design and operational intricacies of a functional aerospace system.



Figure 6. First Stage Mockup



Figure 7. Second Stage Mockup

Second, we plan to use this mockup for pathfinding transportation logistics and field site operations. Again, the CALVEIN philosophy is that first-hand empirical experience is preferred over paper studies whenever possible. Students may have to work years before getting a similar experience within industry. Of particular interest will be cooperative studies with potential nanosat providers to refine payload accommodations designs and practices.

Technology R&D

CALVEIN technology R&D is focused on those vehicle technologies that can enhance performance enough to eliminate the need for turbopumps. These include aerospike engines, alternative hydrocarbon fuels (particularly propylene) and advanced materials for lightweight cryogenic propellant tanks and engine chambers.

Aerospike Engine

The CALVEIN team successfully conducted the first two-ever powered flight tests of a liquid-propellant aerospike engine in the fall of 2003 (Figures 8 and 9). The self-compensating plume expansion characteristics of an aerospike engine promise to increase performance relative to a standard bell nozzle that is optimized to a single ambient atmospheric pressure. While this initial aerospike featured a single annular combustion chamber with an internal plug, future designs will be follow that of more traditional aerospike designs that consist of multiple chambers mounted around a central core.



Figure 8. Second Flight Test of a Liquid-Propellant Aerospike Engine on the First Launch of the Prospector 4 (photo by K. Caviezel)



Figure 9. Prospector 4 After a Successful Recovery

LOX/Propylene

With the goal of improving specific impulse over that available from LOX/RP-1, the CALVEIN team has assessed several alternative hydrocarbon fuels. This effort has led to the selection of propylene as the best candidate for further investigation because of its higher specific impulse and comparable density with RP-1 when chilled to cryogenic temperatures. In addition, propylene is relatively benign environmentally. As a bulk commodity feedstock to the plastics industry, it is available through distributors who also provide LOX.

Propylene has not received as much research attention as methane or other hydrocarbons, in part because of perceived disadvantages when used with a turbopump-fed regenerative engine (high vapor pressures and increased susceptibility to polymerization and “hard starts”). However, these issues do not apply to the NLV pressure-fed engines with ablative and radiative engine chambers. Consequently, the CALVEIN team is conducting static fire tests (Figure 10) in preparation of use of LOX/propylene in future flight test vehicles.^{12, 13}



Figure 10. Initial LOX/Propylene Static Fire Test

Silicon Carbide Composite Chamber

A cooperative effort is underway to static fire test a 500 lb_f-thrust silicon carbide radiative chamber later this year. Successful demonstration of this new chamber would be followed by a flight test using a Prospector-class test vehicle. Ultimately, the application of this material for the NLV second stage engine chamber would save significant dry mass relative to existing designs that use heavy refractory metals.

Composite Propellant Tanks

Composite propellant tanks represent the second major option for reducing overall vehicle dry mass. Prior to the CALVEIN partnership, GSC accomplished a major milestone in the advancement of this technology by conducting the first-ever flight demonstration of a composite LOX propellant tank provided by Microcosm, Inc.¹⁴ The CALVEIN team is continuing to explore opportunities for incorporating this technology into the NLV design.

Advanced Avionics and Electrical Ground Support Equipment

On-going flight tests are frequently used to evaluate the latest available off-the-shelf avionics technologies and products. In addition, CSULB has contributed to the CALVEIN program by investing in a data acquisition and command systems based on the LabVIEW graphical software environment. LabVIEW networking functions and the availability of commercial broadband services means that distributed NLV operations can be implemented with minimum investment in the command and control architecture. Much of these features are already being used on the local level during field tests at the MTA.

CHALLENGES

Technically, the biggest vehicle design challenges are the first-ever combination of pressure-fed propellant feed systems and lightweight yet still cost-effective

structures for achieving orbit. The second major challenge will be complying with range safety requirements, particularly in the areas of TT&C and flight termination. Mature technical solutions exist for these functions, but their costs could be prohibitive.

From a programmatic perspective, the response of members of the small satellite community to the NLV program discussed herein has been very positive. However, this has not been the case among those organizations that have sufficient resources and the responsibility for development of new launch systems. Their focus is set on systems that can accommodate payloads a magnitude larger and users for whom \$5 million per launch is considered low-cost. Consequently, securing the resources for NLV development and evolution remains the single largest challenge to program implementation. In the mean time, the CALVEIN team will continue to incrementally develop and flight test important NLV subsystem components.

It is also worthwhile to note that understanding and acceptance of increased technical risk is one area that potential NLV users do have some level of control. The CALVEIN team has shown, as many others have before, that a great deal can be accomplished at very low cost if a program is organized such that it can tolerate the occasional technical failure (Figure 11). Our philosophy is that the best approach to developing launch vehicles is to fly as early and often as possible, thereby pushing the capabilities envelope while learning and refining designs and procedures on every launch, as opposed to trying to get everything right the first time into flight.



Figure 11. Prospector 4 After Its Final Flight – Another Example of the Risks Involved

SUMMARY

The proposed Nanosat Launch Vehicle addresses the needs expressed by members of the academic and small satellite research communities for a dedicated, very low cost launch vehicle that would be achieved by constraining performance to payloads with masses of 10 kg or less, which in turn enables the use of launch vehicles that are a magnitude smaller and less expensive than small launch vehicles now available or in development.

Because the CALVEIN NLV development effort is based on an ongoing suborbital flight test program, multiple opportunities exist for manifesting precursor payloads. These should be particularly attractive for university programs, for which student participation in actual launch campaigns that take place several times a year would complement the orbital missions that occur only once every few years.

Potential users and interested parties are invited to provide inputs to and participate in the NLV development program. This is the best way to assure that the resulting operational service best meets their needs for cost-effective, practical access to space.

REFERENCES

- ¹ Besnard, Eric and John Garvey, "Educating Tomorrow's Aerospace Engineers by Developing and Launching Liquid-Propelled Rockets," IAC-02-P.1.95, 53rd International Astronautical Congress, World Space Congress - 2002, Houston, TX, 10-19 October 2002.
- ² Besnard, E., Chen, H.H., and Garvey, J. "Design, Manufacturing and Test of a Plug Nozzle Rocket Engine," AIAA-2002-4038, 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Indianapolis, IN, 07-10 July 2002.
- ³ "Initiation for Engine," Aviation Week & Space Technology, 29 September 2003, p. 19.
- ⁴ Besnard, E. and Garvey, J., "Towards Flight-Testing Larger Expansion Ratio Aerospike Engines," AIAA paper no. 2004-3354, 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Fort Lauderdale, FL 11-14 July 2004.
- ⁵ Garvey, J. and Besnard, E., "A Status Report on the Development of a Nanosat Launch Vehicle and Associated Launch Vehicle Technologies," RS2-2004-7003, AIAA 2nd Responsive Space Conference, Los Angeles, CA, 19-22 April 2004.
- ⁶ Garvey, J. and Besnard, E., "Development Status of a Nanosat Launch Vehicle," AIAA-2004-4065, 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Fort Lauderdale, FL 11-14 July 2004.
- ⁷ Covault, C., "Cheaper Access to Space – Bring It On," Aviation Week and Space Technology, 29 March 2004, pp. 48-52.
- ⁸ "Force Application and Launch from CONUS," <http://www.darpa.mil/tto/programs/falcon.html>, posted 04/01/04.
- ⁹ Dornheim, M., "A New Spaceship," Aviation Week & Space Technology, 28 June 2004, pp. 28-29.
- ¹⁰ Holemans, W., "The Lightband as Enabling Technology for Responsive Space," RS-2004-7005, 2nd Responsive Space Conference, Los Angeles, CA, 19-22 April 2004.
- ¹¹ Puig-Suari, J., Twiggs, B. and Creedon, M., "CUBESAT Design Specifications Document," Revision V, November 2001.
- ¹² "Test Report – LOX / Propylene Static Fire Test 1," CALVEIN Document No. T-2004-1, rev. A, July 2004.
- ¹³ "Test Report – LOX / Propylene Static Fire Test 2," CALVEIN Document No. T-2004-2, rev. A, July 2004.
- ¹⁴ Bates, Jason, "Firms Flight Test Composite Liquid Oxygen Tank," Space News, 03 July 2000, p. 10.