CubeSat Launch Vehicle - CSLV

1) Abstract

The recent proliferation of very small satellites with significant capabilities due to advanced miniaturization has created a strong and quantitatively large market for a very small launch vehicle. A launch vehicle made up of many, small, simple, and identical parts has distinct advantages in scalability, flexibility, development, and assembly line production. We have many of the components on hand or partly developed, with radical simplification making the development cost much smaller than a conventional vehicle.

2) Emerging Cubesat launch market

The design specification for 10cm cube shaped satellites was produced by faculty at Stanford and Cal Poly Universities in the early 2000's. This was for the expressed purpose to give educational institutes a vehicle to teach student the arts of satellite building. The standard included a launch interface with deployment mechanisms and a encapsulation system (PPOD) to protect and prevent the enclosed satellites from interfering with other payloads on a large launch vehicle. In 2004 the Cal Poly Cubesat program offered their pre-flight testing, coordination and launch services for only $40,000 per satellite! Today the price, when available, is over $80,000. The price has risen due to scarcity of secondary payload opportunities. Their PPOD enclosure will accommodate 3 cube shaped satellites or a double or triple tall versions with associated larger capabilities and proportional costs. The standard became a success with over 100 groups developing satellites and currently (April 2009) 27 Cubesats in orbit, another 24 awaiting launch, and at least an additional 30 looking for launch opportunities. The National Science Foundation alone has announced funding for two to three triple sized satellite projects each year, each requiring a full PPOD launch. Other commercial interests, such as Boeing, have or are trying to launch Cubesats to develop and flight test components for larger satellites. All of these missions need launches, yet there isn't much 'Space Available' on larger launch vehicles and even then, there are severe restrictions on missions. The limitations on what a Cubesat may contain (eg. propulsion), where it will go (available orbits), and when it will fly (primary payload scheduling) have proven to add significant additional costs, or stop missions altogether. A very small launch vehicle, that can service a single PPOD, can deliver each set to a prescribed orbit, on a prescribed schedule, with whatever payload desired, has a definite market and can be profitable if the cost of the system can be kept down.

3) Development costs

A major cost of every launch vehicle is the amortization of the initial development costs. In some cases the costs can be written off because of external factors such as government sponsorship (military) or financial maneuvering (limited bankruptcy) but in most cases the costs are real and shall be accounted. Our plan is to minimize development costs by ruthless simplicity and using a common module approach to multiple stages. A typical launch vehicle has 2 to 4 stages. Each stage being , in effect, an individually developed vehicle in itself. Our design is to build a single simple vehicle, and parallel cluster several of them to produce lower stages. Cluster designs have been used before, specifically in strap-on boosters, Saturn vehicles, Otrag sounding rockets and many early solid upper stages. According to current FAA amateur rocket regulations, a common rocket launch waiver will allow all systems to be tested in flight, including propulsion (full duration), guidance, and staging. Only a full up orbital stack will exceed the hobbyist level of regulation. The development process is expected to have several short iterations with destructive testing, but simple small modules lead to inexpensive rebuilds and redesigns. These are some of the factors that will limit our design expenses.

4) Launch handling costs

Handling the payloads and vehicles should not be underestimated. Launch vehicle gantries, lifts, towers, pads, and transporters get very unwieldy when the vehicles are large. Vehicles, or at least there component parts, should fit on conventional transportation such as trucks and trailers. This limits the dimensions of any component, but our system has been designed to easily fit on a light trailer. Our initial modules are able to be carried empty and positioned by only two people. Similarly, the launch pad with hold-down devices will be portable to allow relatively unimproved launch sites. The complete lack of heavy equipment in favor of man-portability and over the road transport will keep launch campaigns and fabrication cost low. Similarly, the standards of the Cubesat concept severely limit the costs associated with clean-room payload shroud integrations.

5) Mass production

One factor, also partly related to amortization of development costs, is production rate. Launch vehicles have been chronically under produced. Keeping the entire staff and facilities fully operational, while only putting out a fraction of their capability, pushes costs per delivered unit higher. We have two methods of increasing unit production rates. First, don't use multiple payload manifested launches. Keep each payload on it's own launcher. This is primarily done by having an initial small launch vehicle designed to launch only one PPOD set. Each customer gets their own launch vehicle so we build more launch vehicles. This also adds value to the customer in the forms of schedule and destination. Secondly, our inherent design uses common modules for the entire vehicle and clusters them for the larger stages. Instead of building one first stage, one second stage, one ...etc., we will build a dozen or so identical modules. Assembly line fabrication cuts costs. And larger production runs allow outsourcing when economical.

6) Configuration flexibility

The ability to add or remove modules offers considerable flexibility in operations and design. If there is a problem with the development of a component in the vehicle, say overweight or underpowered, then the vehicle configuration can be adjusted by adding modules to make up the performance shortfalls until corrective actions can be developed in the assembly. This may prove invaluable in keeping initial development and first flight schedules. Additionally, higher orbits, heavier payloads, or both can similarly be accommodated by adding modules. An added benefits of more modules is the flexibility in staging. The modules can be staged off in different steps to give a 4 stage vehicle in stead of the initial 3 stage. There can be considerable performance gained by breaking a vehicle up into more stages. The parallel staged configuration of the our common module approach allows for staging based on when you run and eject spent modules. The initial configuration is at a minimum with three stages, but any growth will allow more. Similarly, modules and associated run times can be stretched or shortened with a little modification of the tank fabrication procedure. Another growth path is, after initial operation, to develop a larger engine and module to take the place of a 3 or 4 module cluster. Another capability is in restarting the upper stage. Because of the attitude control system on the final module, propellant settling and engine restart is available giving the option for a two impulse launch trajectory. This can give higher precision and accuracy, with higher perigee orbits. The focus of the initial project is to get a working microsat launcher, but flexibility and growth are inherent to this design.

7) Sample configurations

Initially, single modules and small clusters will be flown for test flights. The first operational vehicle should consist of 13 modules arranged as 9 for the first stage, 3 for the second, and 1 for the third. (figure 1.) With adding extra modules we get a 4 stage or 5 stage version. The performance with a single Cubesat, PPOD and heavier Microsats payloads are given in Table 1.

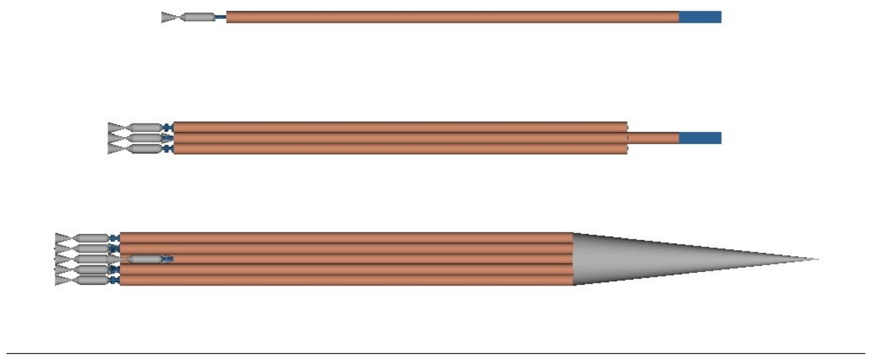

Figure 1. Small Launch Vehicle 931 showing top stage, top two stages, and launch configuration.

Configuration	Payload	Circular w/o Restart	200km Eliptical	Circ w/ Restart
931	1kg	435km	10177 km	5189 km
931	3kg	360km	4666 km	2433 km
931	6kg	246km	1030 km	615 km
961	6.9kg	200km	200 km	200 km
12331	1kg	475km	17600 km	8900 km
12331	3kg	415km	8256 km	4228 km
12331	6kg	317km	2907 km	1553.5 km
12331	9.3kg	200km	200 km	200 km

Table 1. configurations and related performance.

8) Progress to date:

There are many components even in a simplified launch vehicle. Each has it's own unique needs, and we have multiple solutions and experience to address each of them.

One obvious one is the main propulsion tanks. They form most of the structure of the vehicle and their performance, in term of volume, pressure, and weight, are a significant driver to the ultimate performance of the vehicle. In a simpler pressure fed vehicle, the tank weights become especially important because they have to carry a significant higher pressure. Tanks have been developed by using epoxy coated Kevlar cloth wrapped around a mandrel. The mandrels are removed and multiple sections are grafted together for any desired length. With end-caps of similar material and a interior coating applied, the entire tank is further wrapped in Kevlar fiber to strengthen the unit to any desired pressure rating. Our 2 pound tanks, 6' long and 4” in diameter, have been tested to 850 psi.

Another component is the avionics. Microsat, and microelectronics development in general, has spurred on advances in avionics. Consider the Unpiloted Air Vehicle market where people are putting together fully autonomous aircraft for a few hundred dollars. Similar equipment looks appropriate for the launch vehicle and is currently being tested in small sounding rocket flights.

The very important, and possibly most expensive system, is the main propulsion rocket engines. We currently have two unique propellant blends that are competing for final selection. Each has been successfully used with their own advantages. A possible blend of both is also worth investigating. The final selection will depend on several characteristics such as combustion temperature, stability, and initiation in our final engine design.

Another important section is the valving and engine gimbals. Most commercial valves are unsuitable for our vehicle due to weigh, power, or cost. We have built several piston valves that may be gas or powder actuated, but we would like the final version to integrate with a hinge with the intake on one arm and the exit on the other. This will allow the attached engine to have an angular deflection of +10 or -10 degrees. With a few degrees of motion along one axis, the thrust can be directed, giving us one axis of control. Our module arrangement has groups of three engines firing, giving us roll, pitch, and yaw control by proper mixing of the positions of the three hinged engines. This removes the need for a two axis gimbal on each engine with its inherent complexity.

The final top stage single module will only have one main engine and is attitude stabilized by a set of 4 solenoid valve cold-gas thrusters at the top of the vehicle. By firing all 4 thrusters simultaneously, a directly forward acceleration is generated causing the propellant in the main tank to settle to the bottom. This allows the engines to be efficiently restarted after a coasting period and improving the orbital insertion accuracy and altitude.

For actuators, small worm drives move the engines. An alternate back up plan is to use a small pneumatic cylinder using gas tapped off the main tanks. Similarly, thermal cutters on Spectra attached points, can cut away empty modules for staging. This techniques has been used many, many times in other payload release applications and has proven effective in weights from a few ounces to several hundred pounds.

9) Continuing Work

Low level work is continuing on the avionics systems with test launches aboard small solid propellant rockets. The development of the full vehicle is envisioned as appropriate for a multi phase approach costing about $800k in total. The first phase, engine development, should be about a $100k six month effort to design and build one good engine. The next year, and probably $350k, would put the engine in production and integrate the tanks with the hinged valve. This phase should have one to three suborbital launches. The third phase would be a series of orbital launch campaigns, probably quarterly.

Air Force Space Command specifies four basic characteristics of any launch system:
capability, reliability, affordability, and responsiveness. With this concept all these characteristics are improved.