

RocketPod™: A Method for Launching CubeSat-Class Payloads on ELVs and Spacecraft

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RocketPod™ is a novel approach for carrying CubeSat-class secondary payloads to orbit aboard rockets and spacecraft at very low cost. The idea employs architectural features and mechanical, electrical and operational interfaces that are similar to Ecliptic's RocketCam™ family of onboard video systems, which have been used successfully since 1997 on dozens of space missions. The most notable feature of the system is its ability to carry payloads on the exterior of a launch vehicle, outside the primary fairing and away from the primary payload.

For rocket launches, both externally mounted (on the exterior skin of the host rocket) and internally mounted (inside the volume enclosed by the main payload fairing) pod carriers have been assessed. Payloads could be deployable free-flyer satellites or non-deployable attached experiments. Potential RocketPod applications on spacecraft include deploying inspector satellites, sub-satellites, other sensors or piggyback technology experiments. All payloads would be required to meet CubeSat-like interfaces and weigh 1 to 2 kg.

A RocketPod-based program could start in early 2006 that would enable a cost-effective series of secondary payload launches with relatively short payload integration cycle times (much less than one year) and a variety of flexible mission options.

CONCEPT OVERVIEW

The RocketPod launch concept was conceived by one of the authors, Doug Caldwell, at Ecliptic in late 2001. The primary insight was that the mechanical, electrical and operational interface standards used by Ecliptic's RocketCam™ family of onboard video systems could be used to carry a secondary payload aloft. RocketCam has been used successfully since 1997 on dozens of space missions, including launches of Delta II, III and IV; Atlas 2, 3 and 5; Titan IV and Shuttle/External Tank. A typical view is shown in Figure 1.

Aerodynamic RocketCam camera pods are attached to the exterior of these vehicles, thus placing them outside the primary payload's fairing envelope. Carrying a payload aloft in this fashion would thus isolate the secondary payload from the primary, presumably simplifying the launch accommodation process. Moreover, because RocketCam cameras are often procured late in the mission cycle and installed only shortly before launch, an external payload carrier would offer similar benefits.

The concept originated as a means of providing RocketCam product line with the capability to do

standoff imaging by ejecting very small free-flying payloads from pods about the same size as the existing RocketCam camera pods. The concept was matured on Ecliptic IRAD funding during 2002-2003 and developed further for Boeing Delta II applications on other funding during 2004.



Figure 1. RocketCam View of Delta II SRM Sep.

Early in the 2004 effort, the team realized that yet another nano-sat payload form-factor was not desirable. A specification would have to be developed and users would have to become familiar with it. Instead, the CubeSat standard was adopted, although this necessitated a pod that would be about twice the size originally envisioned. The prototype that was built as a result of this effort is shown in Figure 2.

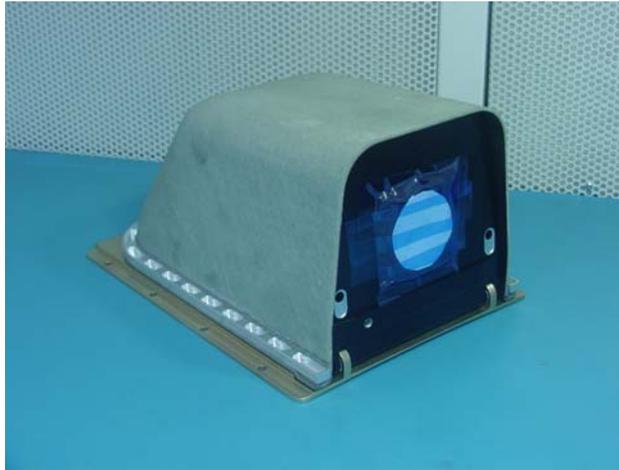


Figure 2. RocketPod Prototype.

The first public RocketPod discussion and hardware display was at the 2004 CubeSat User's Workshop and Conference on Small Satellites held in Logan, Utah, in August. RocketPod payload ejection experiments were successfully conducted onboard Zero Gravity Corporation's new *G Force One* aircraft in Fall 2004. These experiments demonstrated that payloads would be ejected cleanly and without significant tip-off rotation.

A joint Boeing-Ecliptic assessment during 2004 concluded that there were no technical showstoppers to using such RocketPods on Delta II (baselined at four RocketPods per launch) and that prospects were excellent for low recurring launch costs (much less than \$1M per CubeSat). A more thorough and definitive RocketPod assessment of Delta II applications started this Spring and is nearing completion. Assessment of options other than Delta II may begin in late 2005, to include U.S. expendable launch vehicles of interest such as Delta IV, Atlas 5, Taurus and the SpaceX Falcon 1 and Falcon 5. At the completion of this work, preparations for one or more RocketPod launches are expected to begin.

ADDRESSING UNMET NEEDS

From a standards and architectural perspective, the RocketPod launch concept addresses a number of practical considerations for the frequent launch of CubeSat-class payloads and experiments that have not been solved to date.

Access to U.S. Launch Vehicles

Under current U.S. Government policy, space systems work funded by the Government (e.g., NASA, and some university work) can only be launched on U.S. launch vehicles unless special no-exchange-of-funds arrangements are struck with foreign entities. No U.S. carrier presently exists that can easily launch CubeSat-class payloads. RocketPod enables a domestic launch capability of this class, eliminating Buy American and ITAR issues.

Shorter Space Project Lifecycles

CubeSats and similar small secondary payloads are particularly valuable for technology development and research projects. The effectiveness of such investigations is substantially degraded if the time from concept to launch is more than about a year or two. A much shorter concept-to-launch project timeline is needed for U.S.-based launches of such payloads. With RocketPod, this time can be less than a year.

Streamlined Payload Integration

Since small projects can ill afford lengthy or extensive reviews (from either a cost or schedule perspective), the traditional review processes for launch accommodations (e.g., safety reviews, interface reviews) must be streamlined. A standard set of interfaces and operational constraints, defined by the RocketPod and CubeSat ICDs and payload users guides, simplifies the review and integration processes by reducing uniqueness, making it easier to accept a design by similarity with past examples or to integrate with standard procedures.

Mission Flexibility

Multiple RocketPods per rocket are supported in the current concept to reduce the launch cost per payload, to enable options for rapid deployment of satellite clusters and constellations, and to meet the demand for more than one launch slot per launch. In the baseline concept of operations RocketPods are mounted on

expendable launch vehicle (ELV) upper stages, and RocketPod payloads are placed in relatively long-life low Earth orbits. Technically a RocketPod could deploy its payload shortly after the main booster's first-stage separation, enabling some intriguing sub-orbital lofting trajectory options and interesting entry experiment possibilities.

Responsive Launch

Most secondary payloads, however small or simple, must generally be ready for integration to the host rocket many months before launch. With RocketPod, this time can be reduced to a few weeks or days before launch.

KEY ARCHITECTURAL FEATURES

Payload Types

RocketPod addresses the launch needs of CubeSat-class secondary payloads, or those having approximately 10 cm x 10 cm x 10 cm volume and 1-2 kg mass. These could be payloads designed to be free-flying nanosatellites or attached experiments designed to operate while still housed in the RocketPod. Passive attached payloads are also accommodated quite easily.

Host Platforms

Based on analyses performed for Delta II specifically and other candidate ELVs generally, it appears likely that RocketPod could be employed on various U.S. launch systems to provide a robust recurring launch capability for CubeSat-class payloads.

Location on Host Platform

As originally conceived, RocketPod's unique way of addressing issues associated with primary/secondary payload interactions is to place the secondary payload and its carrying/deployment system *outside* the main payload fairing, in the same location where RocketCam pods are now, as shown for example in Figure 3. Thus, the primary payload by and large doesn't know or care that the secondary payload is onboard the rocket. This secondary payload integration approach is now patent-pending in the U.S. and abroad.

Clearly, there are launch vehicle compatibility issues, such as structural loading and aerothermal heating. These considerations and others are part of the current accommodation feasibility study.



Figure 3. RocketCam Camera Attached to Atlas V.

Figure 4 shows the principal elements of a RocketPod. Figure 5 shows how a RocketCam camera pod appears when mounted on the Delta II mini-skirt. Figure 2 shows how the fully assembled RocketPod system (with CubeSat-class payload inside) would look, ready for mounting to essentially the same position. Figure 6 depicts the payload deployment sequence.

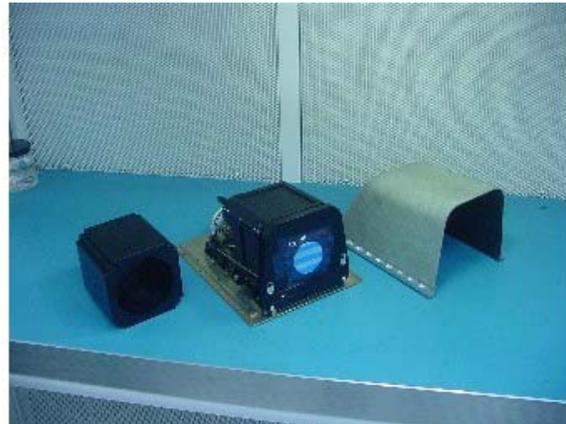


Figure 4. CubeSat Mass Model, RocketPod Carrier and Fairing.

Besides being completely outside the main payload fairing, the low mass of the RocketPod and CubeSat-class payload (less than 4 kg total) is a tiny fraction of the payload capability for a large launch vehicle. For an externally mounted RocketPod (or several), the key issue to assess is how the pod(s) respond to airflow along the rocket's body during launch and ascent and whether the aerothermal loads imposed on the RocketPod fairing(s) create any vehicle dynamic or mechanical concerns. For an internally mounted RocketPod, these issues are obviously moot.



Figure 5. RocketCam Camera Pod on Delta II Mini-Skirt.

Extended Payload Option

It became apparent during the detailed design activity that the RocketPod carrier/launcher system would have additional, nominally unused volume that could

accommodate about 30% more payload volume than the standard CubeSat, as shown in Figure 7. This “CubeSat-Plus” capability is documented in the RocketPod ICD but is considered non-standard (unlike the CubeSat definition) because it is too closely coupled with the specific implementation of the carrier.

Users adhering to the CubeSat standard would be expected to have more launch options available (e.g., Dnepr), but users committed to a RocketPod launch could make use of the extra volume. Figure 8 shows how this additional volume might be used, with a helical antenna and a deployable solar array capable of delivering about 10 W.

Low Cost

Preliminary cost estimates for Delta II indicate that the recurring launch costs for RocketPod-housed payloads should be relatively low compared to historic domestic secondary payload launches – perhaps 10% to 30% of the cost of a fully custom secondary payload (a few \$100k each versus typically \$2M to \$4M each). The actual cost of such launches is presently being studied.

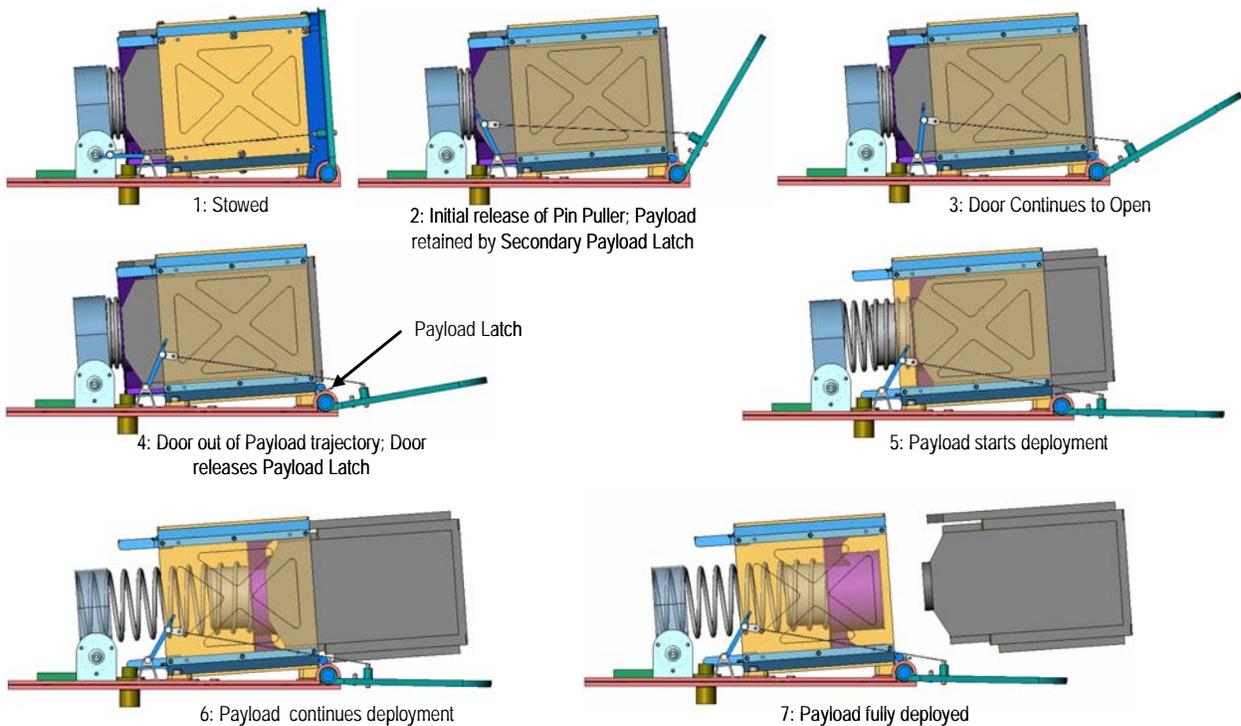


Figure 6. RocketPod Deployment Sequence.

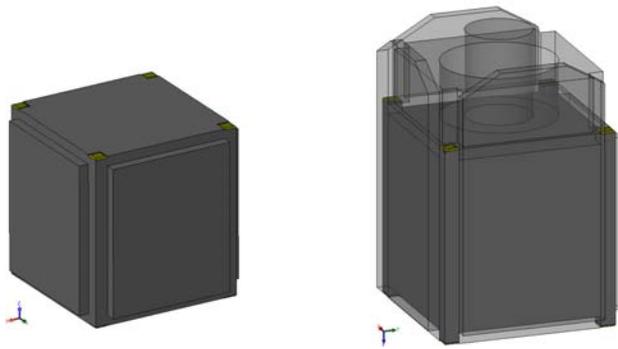


Figure 7. Standard CubeSat (l) and Allowable RocketPod Volume (r).

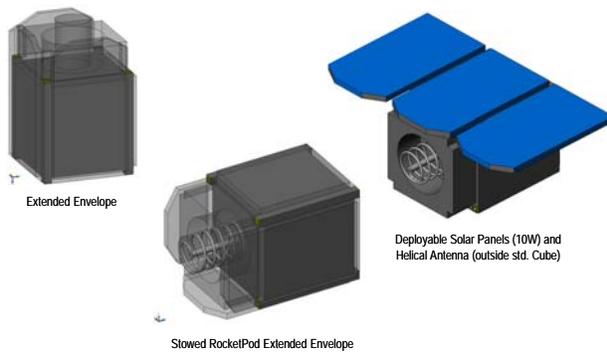


Figure 8. Extended Envelope Use Concepts.

ROCKETPOD INTEGRATION CONCEPT

RocketCam camera integration experience suggests that RocketPod payload carriers could be installed relatively late in the ELV integration cycle (a few months to weeks to days before launch). If properly planned, a RocketPod could conceivably be mated (or CubeSat swapped out) on the day immediately prior to launch, with little or no influence on the primary payload. This was actually done for a Delta II RocketCam pod on the *Mars Odyssey* launch in 2001. This integration flexibility could provide responsive launch capability for users.

The pacing item for the payload integration timeline, as is the case for RocketCam installations, is installation of the control and power harnesses on the host booster, routing from the interior of the ELV to the RocketCam camera RocketPod carrier installation locations. If the harnesses aren't installed up front, late integration timelines cannot be accommodated.

Another cost and schedule driver is the definition and verification of ELV flight software commands used to turn the RocketCam/RocketPod hardware on. These are simple discrete commands, but if they are not loaded and verified well in advance, the hardware cannot operate as planned. In the baseline RocketPod implementation for Delta II, with four RocketPod carriers and two RocketCam cameras per launch, these software functions are isolated from the launch vehicle by an Ecliptic-provided avionics unit, the Digital Video Controller. DVC operation is initiated by a single ELV-generated discrete command and then controls all aspects of RocketPod system operation.

Assuming that a standard RocketPod implementation and installation approach has been devised and analyzed for a *program* of recurring launches (e.g., for Delta II or Atlas 5), and that for each given host ELV the necessary electrical and software long-lead items are addressed, it is reasonable to envision a CubeSat-class launch program that regularly delivers on CubeSat-class secondary payload integration timelines (approval for manifesting to actual launch) of less than a year. This is nearly always the case for RocketCam on Delta and Atlas launches.

Ecliptic's baseline RocketPod integration model is to have each pre-tested CubeSat-class payload shipped to Ecliptic's Pasadena facility, where it would be integrated with a pre-tested and verified RocketPod carrier, then buttoned up with final closeouts for shipment via common carrier (e.g., FedEx) to the launch site. While awaiting final integration with the ELV, interfaces designed into each RocketPod support CubeSat payload electrical checks and battery trickle charge (if applicable) and optional dry nitrogen purge of the RocketPod interior – all without opening the RocketPod door or fairing. These activities should take no more than a month or two.

The baseline Delta II concept mounts two pairs of RocketPod carriers on the perimeter of the Delta II second stage "mini-skirt" ring with a RocketCam camera pod observing the deployments from each pair of carriers. The RocketCam systems perform their normal duties of providing situational awareness during liftoff, ascent and orbit insertion, and then support coverage of RocketPod payload deployments.

Inside the second stage, the Ecliptic-supplied DVC controls and sequences the other RocketPod system components. It also ingests and compresses video signals and other engineering data. The system also includes the transmitter(s) and RF antennas for downlinking the compressed video and housekeeping

data, a battery pack for power, and all needed cable harnesses. This implementation is similar to that used for all RocketCam applications on Delta II.

The baseline command interface between the Delta II and the RocketPod/RocketCam complement is one or two pulse commands from the Delta II flight computer (the RIFCA) to the DVC. Sequencing is based on Delta II staging and mode-switch events, all of which are very predictable and tightly controlled for each Delta II launch. This is a straightforward evolution from the RocketCam experience. The mass for a baseline system consisting of four CubeSat payloads, four RocketPod carriers with fairings, two RocketCam cameras, system controller and cable harnessing, is estimated to be about 30 kg, or about 7 kg per payload carried.

The integration process then, with Delta II used as an example, would involve the following notional key steps:

- For a given ELV (e.g., Delta II), a baseline RocketPod system configuration is defined and approved as a standard optional launch service.
- For a given upcoming launch opportunity, the baseline RocketPod system equipment complement is approved by the primary launch customer as part of the payload for the launch. The specific RocketPod-carried secondary payloads are not identified at this time.
- The host rocket launch service provider (e.g., Boeing Launch Services for Delta II) integrates all internal support equipment onto the ELV by approximately 6 months prior to launch (L-6 months). This does not include the RocketPod carrier or its payload; these will come later.
- Specific payloads are associated with particular RocketPod slots independently of the launch vehicle flow. The final matching of payloads to RocketPod slots happens as late as possible, perhaps a year or less before launch, to provide maximum scheduling flexibility.
- RocketPod secondary payload customers deliver their ready-to-fly payloads to Ecliptic at about L-4 months for integration with RocketPod carriers that have already been separately assembled and tested. The payload is integrated with the carrier, final system functional tests are performed, and an acceptance vibration test is performed on the integrated assembly.
- At about L-2 months the integrated RocketPod carrier/payload assemblies are shipped to the launch site for final integration with the ELV.
- The RocketPod carrier/payload assemblies are integrated with the ELV at about L-1 month to L-1 week.
- Launch occurs, the DVC manages deployment activities, and the RocketPod payloads reach orbit.

ROCKETPOD CONCEPT OF OPERATIONS

In the baseline concept of operations, all RocketPod payloads end up in relatively long-life LEO orbits because this is where all Delta II second stages complete their operations before they are shut down. In most cases, RocketPod payload ejections would occur while the launch vehicle still maintains attitude control, immediately before or after a propellant depletion burn and final stage shutdown.

In principle, a RocketPod carrier could deploy its payload shortly after first stage separation, enabling some intriguing sub-orbital trajectory options and interesting entry experiment possibilities. Or, it's possible to deploy RocketPod payloads immediately after the first Delta II Second-stage Engine Cut-Off event (SECO-1), leaving them in relatively low and short-life LEO orbits – prudent for orbital debris mitigation.

Many operational scenarios can be imagined.

- On a single launch, multiple RocketPod payloads could be deployed simultaneously (e.g., to form an “instant cluster” for formation flying applications) or sequentially (e.g., to create an “instant constellation” in a single orbit plane).
- RocketPod payloads that remain attached to the carrier could be used for boom or inflatable deployment demonstrations, remote sensing sensor demonstrations, microdevice testbed applications, etc. In such scenarios, the DVC might supply power, control and telecommunications capabilities to the payloads for short-duration experiments.
- Since all RocketPod carriers are on a host stage, the spent stage could be used as a platform (like NASA's *DUVE* and *SURFSat* secondary payloads).

A ROCKETPOD-BASED LAUNCH PROGRAM

A based launch program based on RocketPod could meet user needs in the many ways.

Regular Launch Opportunities

Starting in 2006, the CubeSat community could have access to a large number of launch opportunities per year – on average perhaps four RocketPod slots a quarter for a few \$100k each.

Years ago NASA took in reservations for many Get-Away Special (GAS) payloads. Based on these, university student programs, government programs, and commercial endeavors were Shuttle launches. In the current state of Shuttle operations, NASA is not in the position to fulfill these promises. A similar fate awaits ISS-based experiments. The NASA Student Flight Experiments Program, though not actively seeking GAS or ISS opportunities, lacks a supply of low-cost domestic secondary payload launch opportunities. Similarly, NASA's New Millennium Program of advanced technology demonstration missions has no ability to support individual low-cost tech-demo flights.

Domestic Launches

All launch opportunities would be on domestic ELVs and thus not subject to "Buy American" restrictions, cumbersome ITAR regulations, foreign travel, or international shipping complications.

Minimal Risk

Because the RocketPod concept is based upon the proven RocketCam system architecture, the program implementation risk is minimal. This risk is reduced further if the baseline host vehicle is a proven ELV.

Short Development and Integration Timelines

From project start to launch, a given project could be done in one to three years, depending mostly on the complexity of the payload, not the launcher. Complying with the CubeSat standards will accelerate the development schedule.

Responsiveness and Flexibility

The standard interfaces and modularity of the system allow RocketPod payloads to be swapped between RocketPod carriers and/or between launch opportunities weeks before launch. On orbit, RocketPod payloads can be standalone free-flyers or attached experiments.

Deployments can be independent or coordinated to form clusters or constellations. Deployment times during the ascent to LEO can also be varied to allow for sub-orbital trajectories or short-life orbits vs. longer-life orbits. Spacecraft-based applications are equally diverse.

Technology Forcing Function

Complying with the rather limited volume and mass limitations of the CubeSat-class standard forces payload developers to strive for miniaturization and efficiency. Though not necessarily convenient, this restriction will probably result in development of a technology base that supports ultra-miniature spacecraft, an outcome that will benefit all programs.

Matched to Student Programs

As was the case for GAS payloads, the RocketPod/CubeSat approach is well matched to the needs of student programs, where the goal is to provide an opportunity for students to experience the total project life cycle in one to three years. Students would be able to focus more effort on space system payload or experiment development rather than on the often-frustrating process of getting payloads to orbit. Of course, as the CubeSat standard is already the *de facto*, worldwide standard for student spacecraft, there is already a waiting list of worthy RocketPod payloads.

Matched to Today's Commercial Thrusts

A secondary payload launch services program offered by a commercial company would be consistent with NASA's recently stated objective of relying on commercial services whenever possible.

Outreach and Public Relations Value

The onboard RocketCam video capabilities built into the baseline system architecture provides improved situational awareness and insight from liftoff to the end of orbital operations, with inherent outreach and public relations value.

WHAT NEXT?

RocketPod provides a new approach to accommodating CubeSat-class secondary payloads. The combination of short approval-to-launch timelines, relatively low recurring launch costs, responsive integration concepts, and multiple candidate ELV platforms suggest that a RocketPod launch program could directly address

capability, performance and cost objectives of interest to a variety of users.

The flagging U.S.-based secondary payload programs could be revitalized if one or more sponsoring organizations take the following steps.

- Voice their support for a RocketPod-based launch program, that such an idea has merit and warrants further investigation. Fund short assessment efforts for each candidate platform (if not completed already).
- Support the goal of having a risk-reduction demonstration launch of the baseline RocketPod system complement in 2006, with a formal program to start immediately following successful demonstration.
- Reserve a block of RocketPod launches – say 4 to 12 – to ensure launch priority and set the tone for the RocketPod program.
- For all NASA-funded projects (for example) that are languishing because they are waiting on GAS, ISS, or Student Flight Project launch opportunities, revive them by converting their launch opportunities to RocketPod opportunities for the 2006-2010 timeframe and redirect their efforts accordingly.
- Work with Ecliptic, one or more launch service providers and other interested parties (e.g., NASA, university and commercial users) to sort out other details and agreements for this program. Help these other agencies and interests sell the program within in their own organizations.
- Once appropriate launch opportunities are reserved and assured, sponsor one or more student competitions where the “prize” is a launch to orbit. Better yet, create a competition wherein a down-selected group of competitors are all launched and the “winner” is based on which performs best in orbit against one or more specified goals (like DARPA’s *Grand Challenge*, only in LEO).

More than anything, the U.S. needs a capability that ensures a low-cost, continuing, guaranteed domestic launch capability for very small secondary payloads. The RocketPod system concept can form the basis for such a capability.

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