Coordination of Multiple CubeSats on the Dnepr Launch Vehicle

A Thesis

Presented to

The Faculty of

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science in Aerospace Engineering

By

Simon Lee

December 2006

AUTHORIZATION

Coordination of Multiple CubeSats on the Dnepr Launch Vehicle

By

Simon Lee

I grant permission for the reproduction of this thesis in its entirety or any of its parts, without further authorization from me.

Signature   Date

APPROVAL

TITLE:	Coordination of Multiple CubeSats on the Dnepr Launch Vehicle
AUTHOR:	Simon Lee
DATE SUBMITTED:	December 2006

____

Dr. Jordi Puig-Suari Date

____

Dr. Eric Mehiel Date

____

Dr. Robert Crockett Date

ABSTRACT

Coordination of Multiple CubeSats on the Dnepr Launch Vehicle

Simon Lee

Picosatellites (CubeSats) have become a source of training for students in a multidisciplinary environment. Students experience the satellite development life-cycle from design, manufacture, integration, and test. However, a critical component in the life-cycle is on-orbit operation. As CubeSats begin to mature, the CubeSat Program needed frequent launch opportunities to provide students with this component of the life-cycle.

After the successful launch of CubeSats on the Eurockot launch vehicle, coordinated by the University of Toronto on June 30, 2003, it became apparent to Cal Poly that in order for The CubeSat Program to obtain frequent launch opportunities it could not rely on connections with a primary satellite. Cal Poly assumed a central role to pursue launch opportunities through a joint-effort approach to fund a launch campaign. To support the launch campaign a launch coordinator was needed to develop processes and system engineering tools that can be used for future launch campaigns. These tools must focus on maintaining a high level of safety to the vehicle and other satellites while maintaining the highest degree of success for all CubeSats.

This thesis outlines the program flow, government regulations, and issues encountered during the launch campaign; including the processes, methodology, and systems engineering tools that were developed to maintain the program and resolving

issues. Various methodologies and items that drove the decisions are outlined. In addition, recommendations and lessons learned for further refinement from the results of completing each milestone in the launch campaign are included.

ACKNOWLEDGMENTS

Dr. Jordi Puig-Suari has continued to provide interesting and unique challenges to students since the inception of the CubeSat Program. He continues to provide invaluable insight and guidance to the everyday challenges presented by the Dnepr launch campaign.

Through the partnership of Armen Toorian and Roland Coelho in the CubeSat Program at Cal Poly they have provided invaluable assistance in working with customers and launch providers. With their practical viewpoints and professional standards we have established procedures, training, and tools for the future launch campaigns organized by Cal Poly.

If tacking governmental regulations were not hard enough dealing with students and changing logistics may be equally difficult. Jill Keezer in her patience and mentorship have not only tackled ITAR and import and export issues but trained a new generation in another aspect of becoming responsible engineers.

To my friends that have helped me deal with the stress of the everyday struggle of the program by focusing on issues not related to the CubeSat Program. They continue to challenge me in other aspects beyond the work of which to them I am grateful.

Lastly, I would like to acknowledge God and my family's continued support through my extended stay at Cal Poly as they continue to provide for me and show their love for me. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

1.1 The CubeSat Program

The CubeSat Program began in 1999 at Stanford University by Professor Bob Twiggs and California Polytechnic State University with Professor Jordi Puig-Suari [18] The vision of the CubeSat Program is to provide a low-cost platform, rapid development, to train students as responsible engineers in industry's multidisciplinary environment. Since its inception, the CubeSat Program has become a worldwide program that is comprised of over 80 universities, government organizations, and private companies. All of the institutions developing CubeSats must follow the CubeSat Design Specification (CDS) set by Stanford University and Cal Poly State University [18].

The program enables rapid satellite development, usually within two years. This responsive schedule allows students to be involved in the entire life-cycle of satellite development as follows:

- Determine mission requirements
- Design, analysis, and testing
- Manufacture, assembly, and quality control
- System level integration and testing
- Launch vehicle integration and launch
- Satellite tracking and operations

1.2 The CubeSat Design Specification & Poly-Picosatellite Orbital Deployer

The CubeSat Programs vision of providing a platform for all universities to access space affordably and achieve responsive satellite programs requires a different approach to develop satellites. The CDS was developed as a way for any university to develop CubeSats for educational and research purposes. The CDS provides basic external and internal standards for a satellite to be recognized as a CubeSat.

A CubeSat fundamentally is a structural cube with 10cm on each side and a maximum mass of 1kg as described in Appendix A. Other CubeSat requirements include but are not limited to center of mass requirements, restrictions (i.e. pyrotechnics), machining tolerances, specific component placements (i.e. switches and spring plungers), and minimum activation and deployment times. These basic requirements are used to increase mission success of all CubeSats. These requirements offset the risk of inexperienced satellite developers while making access to space affordable for any university. Figure 1 illustrates a typical isometric of a cubesat along with a CubeSat developed by Cal Poly.

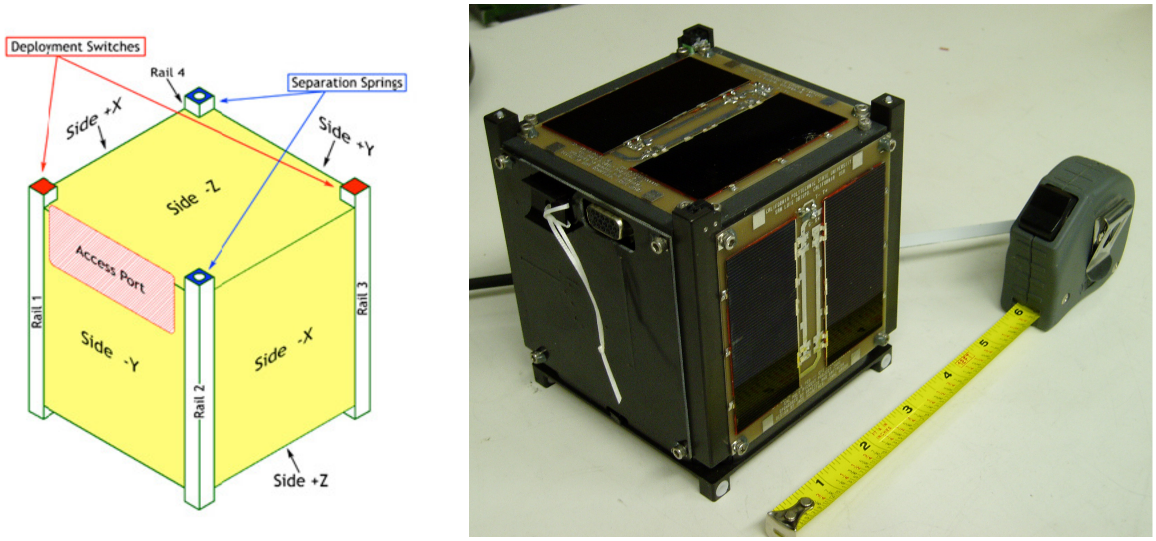


Figure 1: Isometric CubeSat (Left), Cal Poly CubeSat - CP1 (Right)

The Poly-Picosatellite Orbital Deployer (P-POD), illustrated in Figure 3, was designed to be safe and reliable method to deploy three CubeSats from a launch vehicle. The driving metrics in the design was the safety of the vehicle and satellites, simplicity of interface, adhering to the CDS, and optimizing mass. The overall design makes the P-POD versatile in its placement and seamless in its interface to the vehicle. The following design decisions were implemented to follow these drivers.

- **Enclosed Aluminum Structure:** An enclosed design serves two purposes. The first purpose is to protect the vehicle and satellites from any CubeSat structural failures or deployments. The second purpose is to act as a faraday cage to protect the vehicle from accidental transmissions from the CubeSats.

- **Space Qualified Release Mechanism:** The release mechanism is a critical area of concern not only for mission success but for the safety of the launch vehicle and satellites. This high risk single point failure is reduced significantly by using release mechanisms with significant flight heritage and built-in redundancy.

- **Standard Interface to the Vehicle:** Six interface bolts are used to interface with the vehicle. These interface bolts can vary in size and locations on the P-POD, increasing the mounting configurations. A simple interface reduces the time needed for safety analysis and manufacturing complex fixtures for a vehicle.

- **Smooth Flat Internal Surface:** The interior of the P-POD reduces the probability of a CubeSat seizing onto interior protrusions. This is a safety concern for the vehicle; otherwise, a CubeSat may find itself attached to the P-POD or create debris.

- **Extensive Testing of the P-POD Engineering Units:** P-POD Engineering units are identical to Flight P-POD units. Engineering units are not considered for flight status due to the extensive battery of testing. All modifications are qualified through the development and testing of an engineering unit. A P-POD Engineering unit must satisfy inspection after completing NASA GEVS Qualification random vibration profile illustrated in Figure 2 [2].

Frequency (Hz)	ASD Level (G^2/Hz)	
	Qualification	Acceptance
20	0.026	0.013
20-50	+6 dB/oct	+6 dB/oct
50-800	0.16	0.08
800-2000	-6 dB/oct	-6 dB/oct
2000	0.026	0.013
Overall	14.1 G_{rms}	10.0 G_{rms}

Figure 2: NASA GEVs Qualification Level profile

- ♦ **Extensive Testing of the Integrated System:** A rigorous testing plan is completed on the Flight P-POD pre and post CubeSat integration. Prior to integration the P-POD undergoes vibration testing at 150% launch environment profile for the Dnepr vehicle. Post integration the P-POD undergoes vibration testing at 100% launch environment profile. The launch provider can be assured that the entire package can safely withstand the environment of the launch.

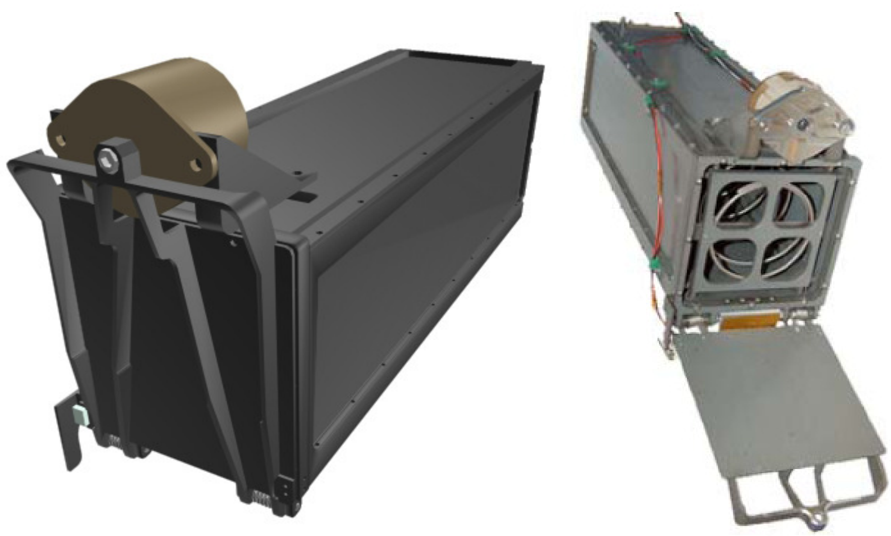


Figure 3: Solid Model of P-POD MKII (Left), Manufactured P-POD MKII (Right)

1.3 *History of Launch Opportunities*

There are a variety of launch opportunities available for large satellite programs. For the fledgling CubeSat Program, limited funding, inexperience in arranging launch opportunities coupled with government regulations create a difficult environment to materialize a launch in the early years. Experience was gained as the CubeSat Program tried different avenues to procure launch opportunities. These avenues of experience ultimately led to Cal Poly coordinating a launch for multiple CubeSats to obtain a self-sufficient option of launch CubeSats.

1.3.1 Launch Broker: One Stop Satellite Solutions (OSSS)

Coordinating multiple universities and overcoming the bureaucracy in exporting satellites is a daunting task for any university to take on, therefore, a launch broker was a logical solution to the problem. One Stop Satellite Solutions (OSSS) was a private company founded in 1996 and its headquarters was located in Ogden, Utah with 15 years of experience at the Center for AeroSpace Technology (CAST) located at Weber State University [14]. The company was noted for its successful launch of a cluster of satellites JAWSAT on a US Minuteman in January 2000 [14]. Their mission was to provide their customers with a low cost and high quality small satellite platform for an effective access to space. The CubeSat Program levied on the experience of OSSS in launching clusters of small satellites in 2000. OSSS provided the CubeSat Program with resources and experience:

- An affordable launch cost for each CubeSat
- Years of satellite design and manufacturing experience

- Experience with university satellites
- Organizing small satellites in the relatively new realm of cluster launches
- Provide launch capability into Low-Earth-Orbits (LEO)
- Facilities that universities could use to test satellite hardware
- Experience with governmental regulations in regards to satellite import and export issues

Over the next few years overhead costs and universities inability to meet additional funding needs caused OSSS to fall into financial difficulties leading to bankruptcy.

What worked:

- Invaluable connections and promotion of the CubeSat Program to universities and launch companies
- Launch contracts were signed
- Satellites were ready to be delivered

What didn't:

- The CubeSat Program cannot support a launch broker that relies on most of their funding from university programs
- The overhead of a company in addition to the employees

1.3.2 University Coordination: Eurockot Launch

Due to frustration of disappearing launch opportunities another approach to obtain a launch opportunity was enacted by the University of Toronto Institute for Aerospace Studies, Space Flight Laboratory (UTIAS/SFL). They began coordinating a CubeSat launch opportunity to ride as a secondary with a larger satellite. UTIAS/SFL had already arranged a launch by the Canadian Space Authority on the Eurockot vehicle, an SS-19, due to its development and manifested microsatellite, MOST (Microvariability and Oscillations of Stars) [13].

To move forward on this opportunity UTIAS/SFL arranged CubeSat launch partners with Aalborg University, Denmark Technical University, University of Tokyo, Technical Institute of Technology of Japan, and Stanford University/Quakefinder Corporation. Cal Poly provided two P-PODs and technical assistance. Figure 4 illustrates the foreign CubeSats ready to be integrated into Flight P-POD MKI provided by Cal Poly.

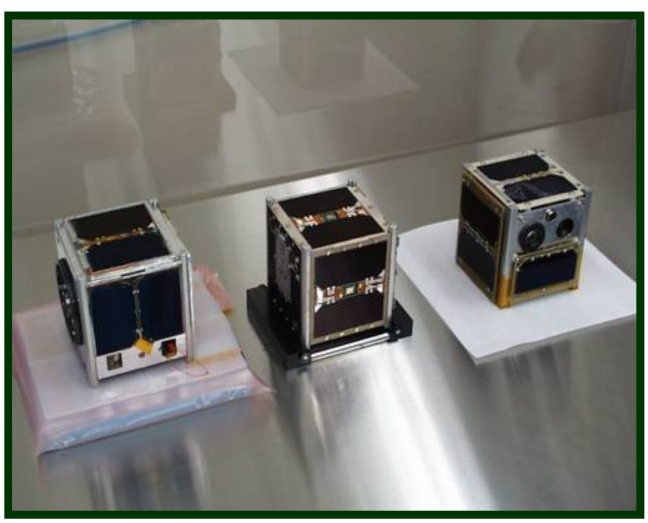


Figure 4: Three CubeSats at University of Toronto to be integrated into P-PODs MKI

The launch occurred on June 30, 2003. The coordination and launch were a success and the P-PODs successfully deployed all four satellites. Though three out of six CubeSats were not operational in orbit this first launch of the CubeSat Program proved many things:

- CubeSats can be designed and manufactured within two years
- Scientific experiments can be performed in this standard form factor
- Rapid coordination and launch of multiple universities can be done with CubeSats
- The P-PODs gained flight heritage

With this first launch for the CubeSat Program another question now loomed. When is the next available launch? For one of the lessons that was learned by UTIAS/SFL is that you need to "Make it Real" for all universities [13]. However, since one of the factors for success was due to a prearranged launch this begs the question can a university coordinate another launch without a prearranged launch?

1.4 Launch Opportunities are a Necessity: Dnepr Launch Campaign

Organizing the launch campaign by Cal Poly came out of necessity rather than an experiment due to the failure of the OSSS effort. This failure stripped many universities out of tens of thousands of dollars hindering their programs. Another need focused on the maturing U.S. CubeSat institutions that needed a material launch. The June 2003 launch was a success but to continue the growth of the CubeSat Program launch opportunities were needed in one to two years.

The launch coordinator, a Cal Poly CubeSat Personnel, officially began coordinating the Dnepr launch campaign on May 15, 2003 after a teleconference with most of the participating customers. The universities that participated at the time were:

- University of Arizona
- University of Hawaii
- University of Kansas
- University of Illinois
- Cornell University
- Nihon University
- Norwegian University of Science and Technology
- Montana State University
- Taylor University
- Cal Poly

After the teleconference it was agreed that Cal Poly would pursue the launch and coordinate all participating universities for the Dnepr Launch campaign. The launch coordinator advised Cal Poly Corporation of the contractual responsibilities of the customer and Cal Poly Corporation. Memorandums of Understanding (MOU) were drafted and subsequently provided to all customers seen in Appendix C.

Cal Poly Corporations Responsibilities:

- Enter into a contract with various institutions to make a launch opportunity economically feasible
- Register with the Office of Defense Trade Controls (ODTC) and adhere to International Traffic in Arms Regulations (ITAR)
- Obtain professional legal advice for ITAR compliance
- Enter into contracts with ISC Kosmotras for launch services
- Coordinate various meetings for CubeSat developers
- Manufacture P-PODs to be used for the launch
- Provide testing hardware and technical requirements for each participant
- Send personnel to integrate P-PODs to the launch vehicle
- Coordinate logistics and requirements between customers and ISC Kosmotras.

Customer Responsibilities:

- Deliver CubeSats on specific date to be determined as the launch date is finalized
- Foreign participants must provide appropriate approvals and documentation for temporary import into the US and the permanent export to the launch site
- Participants must adhere to all ITAR requirements
- Provide information to Cal Poly Corporation as requested
- Execute appropriate documentation required by the US Government for the launch of CubeSats.

2 Limiting Factors to Maintaining a Satellite Program

Various limiting factors hinder universities from beginning and maintaining a satellite program beyond the materialization of a launch opportunity. This section highlights some of the internal hurdles that universities must overcome. A central coordinator can provide services that can overcome some of the external and internal limiting factors the CubeSat Program by providing options not stumbling blocks.

2.1 Launch Vehicles

2.1.1 Availability

Launch opportunities are always available; however, there are hindrances for all universities in obtaining the right launch opportunity.

1. The ability to contact the right launch provider to manifest on a vehicle
2. Desired orbit parameters in altitude and inclination
3. Desired launch window
4. Mechanical and electrical interface with different vehicles
5. Environmental testing to meet safety requirement for different vehicles
6. Possible export licensing and controlling technology and information for foreign vehicles

The issues above must be taken into consideration when determining the best option for a launch opportunity. Many of the issues require time beyond the development of a CubeSat. With future launch campaigns accessible through the CubeSat Program it moves some of the issues from the institutions to the launch coordinator. This allows institutions to focus on the development of a robust CubeSat.

2.1.2 Launch Cost

Launch cost is one of the largest limiting factors to a university. Dnepr launch costs are at a minimum of $10,000 per kilogram, which means for a 10kg satellite the baseline cost is $100,000. This baseline does not take into account the cost of weight and manufacturing time of an interface adapter, separation mechanisms, shipping, import taxes, lawyer fees, hiring students and staff, and foreign and domestic travel costs. These items can double or triple the baseline cost.

Many items above the baseline have the same cost when dealing with one or a cluster of satellites. Through the principal of a joint effort program, such as the Dnepr launch campaign, those items above the baseline are minimized and the overall cost is distributed to all the customers. As an example the overhead above the baseline can cost $200,000 for one satellite. However if ten other customers with standard designs join together for a cluster launch, the overhead can be shared and spread to each university with a price tag of $20,000 each.

The Dnepr launch campaign provides a strategic factor by centralizing the coordination effort to a Cal Poly launch coordinator. Universities do not need to focus on all the additional tasks beyond satellite development. The launch coordinator interfaces with the launch provider, determines requirements for the interface hardware (i.e. P-PODs), and submission of the legal requirements for all customers, effectively lowering the overall cost for each individual university. Launch providers interface with one individual and not a dozen. This is favorable to the launch provider as it provides exposure in assisting many universities while the logistics and cost of interfacing with multiple customers is minimized.

2.2 University Setting

Beyond the limiting factors of launch availability and cost a university may not be able to support a satellite program. Factors may include lack of environmental testing facilities, turn over of students, lack of interest, or expertise in satellite development.

2.2.1 Students

Students that enter a satellite program on average need six months of maturation before they become reliable enough to be given any tasks of importance, which include critical path items. As seasoned students leave, it is up to them to pass their knowledge and instill the quality of work to the next generation. This constant influx of generations presents an interesting challenge to ensure that a university program obtain new students into the project and train them to meet specific standards and mindset. New students into the project must be committed individuals with at least 2 years availability prior to graduation.

The CubeSat Program enables students to experience the life-cycle of a CubeSat within 2 years. This fosters new students to be involved in the beginnings of a new mission. The new generation can take ownership while gaining the previous generation's knowledge and experience. As the older generation ends their satellite mission through a launch they can provide mentorship and ideas to the new generation.

2.2.2 Facilities

A university may lack the necessary facilities to manufacture, perform environmental tests, and lack groundstations to identify and track their satellites. The launch coordinator can work with the customer to provide testing facilities as one of its services. This reduces the time and cost for the customer. The launch coordinator must also prepare a plan to enable a coordinated effort in identification and tracking of the

CubeSats after initial deployment. Efficiency of satellite identification is increased due to the worldwide locations of groundstations participating in identification versus one university at a particular latitude and longitude.

2.3 Options for Satellite Programs and Funding

There are various avenues for a university to gain funding and maintain a satellite program. In general the benefits and drawbacks for each type of program are listed below. Ultimately, it depends on the situation and status of the university in determining which avenue to take.

1. **Armed Forces Training:** Satellite programs developed for training students of the armed forces and other U.S. personnel.

   Example: United States Air Force Academy provides academy graduates the experience of satellite development through its FalconSat satellites that began in October 1997 with FalconGold launched on the Atlas vehicle. The FalconSat series includes FalconGold, FalonSat-1, FalconSat-2, and FalconSat-3 [19].

   Pros:

   - ♦ Satellite is developed for training armed forces. Students experience the entire life-cycle including launch and operations.
   - ♦ Military officials can have the student built satellite be a secondary payload for a prearranged launch vehicle.

Cons:

- ♦ This approach limits the access to space to students only in military training.

2. **Government sponsored competitions:** University satellite programs can be entered into a competition sponsored by the government. At each milestone of the competition universities defend their design with a selected industry panel. Universities are eliminated while others are provided funding to further satellite design and manufacturing.

   Example: An existing program includes the University Nanosat Competition (UNC) which is a joint program between *Air Force Research Laboratory's Space Vehicles Directorate (AFRL/VS), the Air Force Office of Scientific Research (AFOSR), and the American Institute of Aeronautics and Astronautics (AIAA) [20].*

   Pros:

   - ♦ Multiple universities begin a satellite program.
   - ♦ Funding is provided by the government
   - ♦ Launch opportunity is available for the final participants

Cons:

- ♦ The selection process prohibits students in the competition from experiencing the life-cycle of a satellite program beyond the conceptual and preliminary design phase.
- ♦ The launch is available but universities can find themselves manifested to US launch vehicles not scheduled to launch for the next few years or with an undetermined launch date.
- ♦ Limits new entries to the program
- ♦ Most universities do not gain operational experience.

3. **Independent Program:** University can begin their own satellite program through various grants and industry sponsorship.

Example: Stanford University Orbital Picosatellite Automated Launcher (OPAL) was an independent program along with many others developed at the Stanford Space Systems Development Laboratory. This program enables graduate students to experience the life-cycle of satellite development. OPAL began in April 1995 and was launched on January 26, 2000 [4].

Pros:

- ♦ This approach allows the university satellite program to remove itself from a competitive selection process.
- ♦ Ability to design their own mission requirements and research goals.

Cons:

- ♦ Limited funding and continued search for more funding.
- ♦ Search for the right launch opportunity.
- ♦ Launch costs are substantial and usually not affordable with the limited amount of funding.

4. **Inter-Satellite Development:** Satellite subsystems are assigned to different universities to design and manufacture. The individual subsystems are integrated together by a systems integrator. This program is sponsored by a government agency and funding is provided to each participating university. A launch is prearranged through the government or agency.

   Example: The Student Space Exploration and Technology Initiative (SSETI) is a conglomerate of over 500 students from 15 universities located in Europe and Canada. Each university contributed to the development of SSETI Express, a microsatellite [16]. SSETI Express in conjunction contained and ejected three CubeSats into orbit. SSETI Express and the three CubeSats were launched on October 2005. SSETI Express ceased to function after depleting its batteries. The batteries could not be recharged from the solar cells due to a design flaw in the Electrical Power System (EPS). A detailed failure analysis report is located on the SSETI website [1].

Pros:

- This approach allows many institutions to participate in the design.
- Universities build satellite hardware and subsystem components.
- Students learn and understand importance of mission requirements
- A launch is prearranged
- Funding is provided to all university programs

Cons:

- Universities develop only part of the satellite. They do not see the entire life-cycle of the satellite.
- Satellite programs develop but are dependent on more funds and projects from the government agency.
- Satellite failure affects all universities.

5. **Joint Effort:** A university can develop a satellite and join with other university satellite programs in a joint effort to share the launch cost.

   Example: An example is the coordinated effort by the University of Toronto on the first CubeSat launch in June 30, 2003. Three of the six cubesats were not functional in orbit; however, the functional CubeSats have been in operation for over three years.

Pros:

- ♦ This approach allows a university satellite program the ability to determine their mission requirements and research goals.
- ♦ Joint funding with other programs to launch multiple satellites.
- ♦ One malfunctioning satellite does not affect other satellites on the vehicle.

Cons:

- ♦ Launch costs are formidable even with joint funding from all universities.
- ♦ One university must take the lead in coordinating launch and universities.

2.4 The CubeSat Program Approach

The Dnepr launch campaign uses a joint effort approach that alleviates the drawbacks by taking the lead in coordinating with all the participants, a need for a number of customers are needed to mitigate the launch costs. In addition to a viable launch opportunity, the launch coordinator determined other goals of the Dnepr launch campaign that were lessons learned from the first CubeSat coordination effort from University of Toronto.

Goals of the Dnepr Launch Campaign

- ♦ Universities need to focus on the development of their CubeSat
- ♦ Make it affordable for the universities/customers while breaking even at Cal Poly.
- ♦ Provide facilities and hardware for universities/customers to perform testing.
- ♦ Find launch opportunities so customers don't have to.
- ♦ Cal Poly handles contracts and requirements with the launch provider.

- Increase communication between all universities
- Be a barrier for the universities/customer against government regulations
- Enable processes that maintain levels of standards for CubeSat safety.

Implementing the above mentioned goals enables universities to develop a robust CubeSat design while opening the doors for universities to perform space research and provide hands-on experience in satellite development.

3 Government Regulations

Before the launch coordinator can contact each university to participate in a launch campaign the void in the knowledge of government regulations needed to be filled. Questions remained as to how Cal Poly could correspond with foreign institutions and launch providers? What security precautions and procedures are needed? How long is required to get approval from the government? Can Cal Poly do all the legal work alone or hire consultants that have experience? These questions and more were explored through the Dnepr launch campaign.

3.1 International Traffic in Arms Regulation (ITAR)

The International Trade and Arms Regulation (ITAR) govern all items that are covered under the U.S. Munitions List described in 22 CFR Part 121.1. Spacecraft Systems and Associated Equipment fall under Category XV of the Munitions List [10]. The articles, services, and technical data determined in the U.S. Munitions List are designated as defense articles, which are under the umbrella of the Office of Defense Trade Controls management. The import and export of hardware determined in the munitions list is considered a defense item and must be approved by the Office of Defense Trade and Controls management prior to hardware and software transfer to foreign entities [10]. However, there are exemptions from the approval process for universities performing fundamental research.

3.1.1 Fundamental Research

Under the aegis of ITAR there is a restriction on information dissemination to foreign nations and individuals. U.S. accredited institutions have exemptions that do not require approval from the Office of Defense Trade and Controls (ODTC) management on any logistical and technical transfers when discussing with foreign institutions. In order to use university exemptions all university activities at Cal Poly and the foreign institutions must fall under fundamental research.

Fundamental research is defined in 22 CFR 120.11(a)(8) *to mean the basic and applied research in science and engineering where the resulting information is ordinarily published and shared broadly within the scientific community, as distinguished from research the results of which are restricted for proprietary reasons or specific U.S. Government access and dissemination controls [10]*.

Fundamental research is negated when any of the following applies [10]:

1. The university accepts restrictions on publication of the results generated to he scientific community.
2. The funding is from the U.S. Government and resulting information is specifically restricted from publication.

3.1.2 Consequences of Violations

There are various exemptions for U.S. institutions to transfer technical information and export hardware to foreign institutions that do not require a license. Several universities have taken the stance that they do not need to register with ODTC to export satellites and satellite related hardware since they are performing fundamental research. However, Cal Poly Corporation decided to register with ODTC due to the ambiguity of certain aspects of the exemptions to ensure that Cal Poly would not be in any future violation due to the launch campaign.

Violations can be any misrepresentation and omission of facts or any attempt of illegal exports. The penalties of these violations can vary from the following:

- Fines can be up to $1,000,000 [12].
- Seizures of exported hardware: Hardware that is illegally exported maybe detained and seized [10].
- Future Denials: Licenses and other approvals are not granted to persons who have been convicted of violating any of the U.S. criminal statues enumerated in 22 CFR 120 [10]
- Imprisonment of up to 10 years [12].

3.2 Technical Assistance Agreement (TAA)

After registering with ODTC a Technical Assistance Agreement (TAA) was written by the launch coordinator and the Sponsored Programs Director and submitted to the ODTC for approval. A TAA allows defense services to be disclosed like technical data and a right to manufacture defense articles. The agreement is formed between a registered U.S. exporter and a foreign entity.

Establishment of Parties Roles

The TAA establishes the roles and responsibilities of the parties involved. In respect to the Dnepr launch campaign there were four entities. The fourth entity was not on the original submission and an amendment was filed during the launch campaign:

- **Cal Poly Corporation:** Acts as central launch coordinator for institutions developing CubeSats and manufacturer of a standard CubeSat deployer, the P-POD.
- **ISC Kosmotras:** Provides low-cost launch services to the satellite community through the use of the Dnepr Launch Vehicle.

- **SDO Yuzhnoye:** Provides the primary design and development of all launch vehicle interfaces.
- **Khartron-Arkos:** A sublicense of which was amended after the original TAA submission. Khartron-Arkos provides electrical services to the launch vehicle.

Establishment of Definitions

The launch coordinator established the definitions, responsibilities, and commodities for each of the parties that will be transferred in the TAA. In respect to the Dnepr launch campaign there were three commodities that were to be transferred and manufactured:

- The P-POD is designed and manufactured by Cal Poly and is reliable, low cost launcher for deploying CubeSats.
- Picosatellites (CubeSats) are delivered to Cal Poly to be integrated into the P-POD which is secured to prevent the tampering of CubeSats.
- Launch Vehicle Interface (LVI) adapter will be manufactured by SDO Yuzhnoye to conform to the bolt pattern on the P-POD.

Beyond establishing the roles and responsibilities of the parties the TAA promotes assistance and technical data exchange between the foreign entities to ensure that certain goals are met. In respect to the Dnepr launch campaign the TAA allowed the transfer of information to promote the success of the following goals as outlined in the TAA:

- To ensure the successful integration of the P-POD(s) containing the satellites and attachment to the LVI onto a satellite cluster payload at the launch facility,

- To ensure that ISC Kosmotras and SDO Yuzhnoye will provide the bolt patterns for the P-PODs. The P-PODs will attach to the LVI of which will be integrated to the launch vehicle.
- To ensure the P-POD(s) and CubeSats are able to withstand the harsh launch flight environments for insertion into Low-Earth-Orbit (LEO).
- To ensure that all electrical and mechanical interfaces are in operational order prior to launch.
- To ensure the CubeSats contained in the P-PODs successfully separate from the Dnepr launch vehicle into LEO.

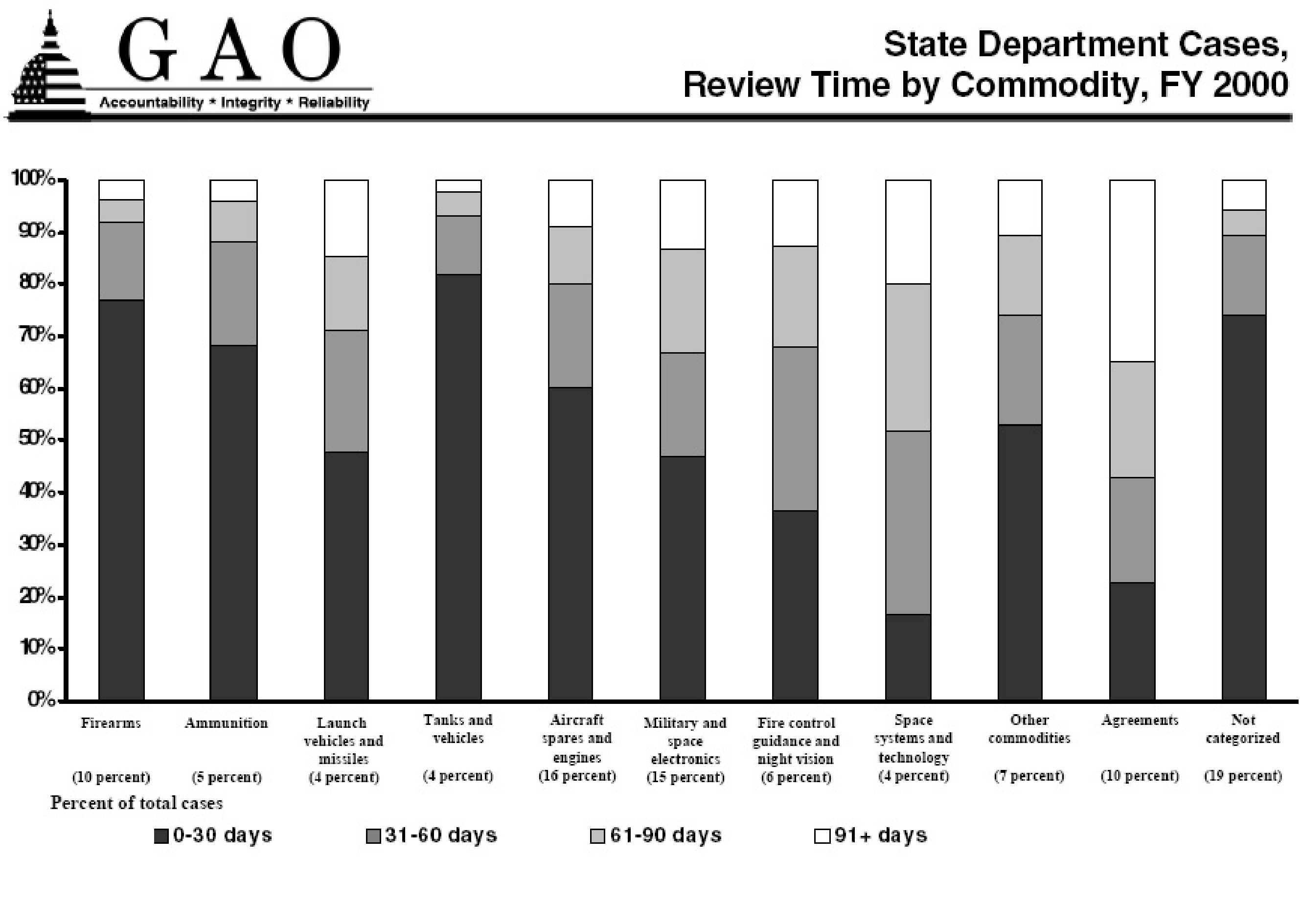
The transfer of technical data is limited to the areas of compatibility, integration and processing of the P-POD and LVI onto the Dnepr launch vehicle. Beyond these areas the TAA places restrictions on technical data and hardware that cannot be transferred in addition to attached provisos to the TAA:

- Manufacturing technology, systems optimization/integration know-how or design know-how
- Detailed engineering design data for the components and manufacturing and production processes or know-how
- Design philosophies or explanations for engineering changes
- Detailed design data or manufacturing know-how
- Information pertaining to the design, production or manufacture of the Cal Poly Corporation P-POD that is not in the public domain

- Software source code or documentation of on-board systems
- Any technical assistance that might assist in the design, development, or enhancement of the performance of any of ISC Kosmotras current of future existing space launch vehicles, missiles, or facilities.

3.2.1 Processing Time

Upon completion of the TAA the agreement must be submitted and approved by the Office of Defense Trade Controls. According to the U.S. Government Accountability Office (GAO) reviews of license applications in fiscal year 2000 took on average 46 days [7]. Figure 5 illustrates 64% of the applications submitted to the state department and note that agreements on average take more than 30 days to complete. In some cases reviews can be indefinite due to past violations. After the TAA has been approved provisos will be attached to the approval letter. Provisos may indicate that a Technology Transfer Control Plan (TTCP) be submitted and approved prior to authorizing the transfer of technical information. A sample format can be obtained by contacting the state department at ttcp.review@osd.mil.



Source: GAO analysis of State Department data.

Figure 5: Processing time for the 2000 fiscal year of 64% of the submittals [7]

3.3 Technology Transfer Control Plan (TTCP)

The Technology Transfer Control Plan (TTCP) is prepared by the launch coordinator and provided to the Sponsored Programs Director after the review and approval of the TAA. The TTCP is developed only if it is requested in the attached provisos to the TAA approval letter. The TTCP details various events between the U.S. exporter and the foreign entity approved by the TAA. For the Dnepr launch campaign the TTCP is between Cal Poly and ISC Kosmotras, Yuzhnoye SDO and a sublicense Khartron-Arkos.

The TTCP detailed procedures on data control and dissemination to the launch provider during scheduled events (i.e. integration with the launch vehicle) and teleconferences. In addition, the TTCP can cover but is not limited to security, training of personnel, responsibilities of officials, facility layout, monitoring and waivers, required meeting information, and document markings for later audits. Review and subsequent approval of the TTCP can be completed within 30 days of submission.

3.4 Export Licenses

After approval of the TAA from the ODTC, export licenses need to be written and submitted by the launch coordinator and export control officer. An export license permits the export and import of specific defense articles. Export license can be permanent or temporary for import or export of defense articles. The value of each satellite, related hardware, and technical data must be represented in the submission of the export license. Figure 6 illustrates the ODTC process to review an export license submission. Submitters should take note that applications are deferred to Congress only for Significant Military Equipment (SME) which is defined as equipment valued over $14,000,000 or services that are over $50,000,000 [10]. A deferment typically adds an additional 15 days if the receiving country is NATO or 30 days for non-NATO [7].

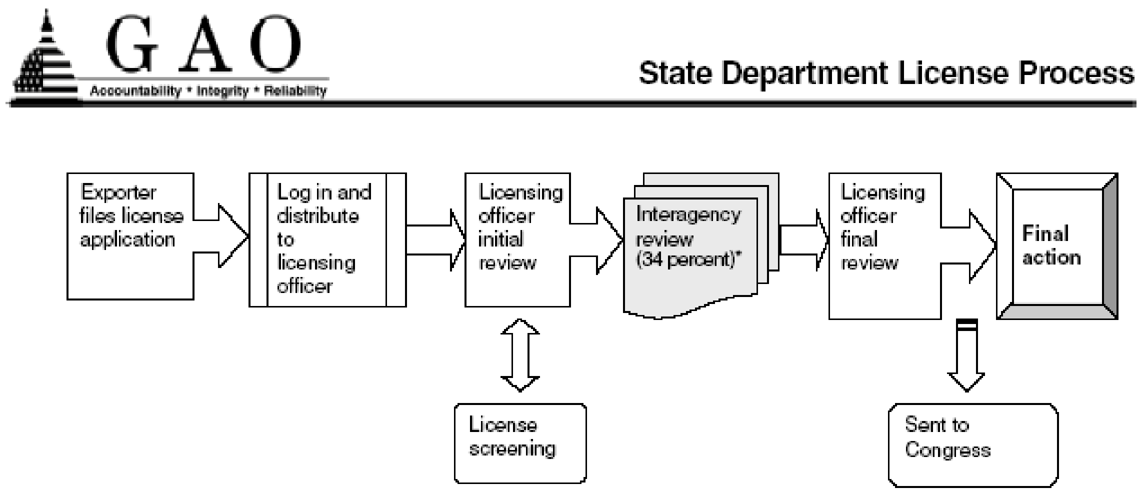


Figure 6: The export license application processing [7]

Figure 7 illustrates the total application submittals in the Fiscal Year 2000 and the time in days of reviewing the submittals. It is clear that license amendments have a fast review time since it pertains to minor changes to an approved TAA. In the same manner temporary import and permanent licenses have quick return time since it pertains to hardware that is developed by a foreign entity where the US is an intermediate location.

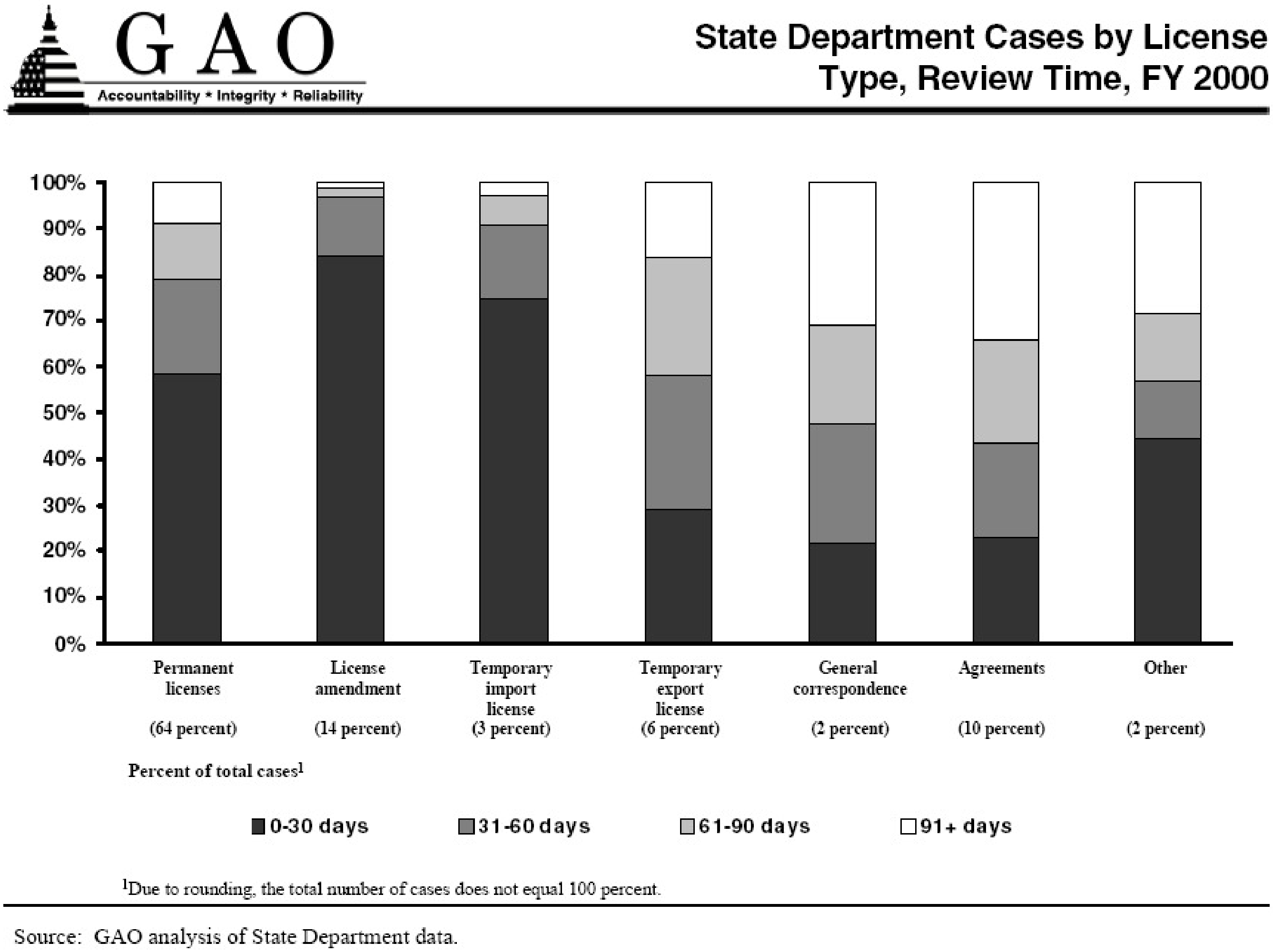


Figure 7: Turn around time for various license submissions [7]

3.4.1 Temporary export license (DSP-73)

A temporary export (DSP-73) is used to export US institution's CubeSats and/or software to a foreign entity. CubeSats were exported under a DSP-73 because the CubeSats are temporarily in a foreign country, in this case Russia, but when it is delivered into orbit it will be registered with the US Space registry and rights return to the US. The review time is 30 to 60 days as illustrated in Figure 7.

3.4.2 Temporary Import license (DSP-61)

A temporary import (DSP-61) is used to import foreign CubeSats into the US. A temporary import is used since the US is an intermediate location and not the final destination. Once the CubeSat is deployed into orbit the rights return back to its respective country. In the case of the Dnepr launch campaign foreign participating institutions must provide documentation that their CubeSat will be registered with their countries space registry. The review time for DSP-61 is typically within 30 days as illustrated in Figure 7.

3.4.3 Permanent Export license (DSP-5)

A permanent export (DSP-5) is used to permanently export the foreign CubeSats to a foreign launch site. In addition, a DSP-5 includes P-POD hardware since all will be destroyed upon atmospheric reentry of the upperstage. The review and approval time for DSP-5 is typically within 30 days as illustrated in Figure 7.

3.5 Satellite Post-Mission Lifetime

The launch coordinator must handle regulations regarding the mitigation of satellite orbital debris. Orbital debris is an ever increasing problem for popular orbits such as Low-Earth-Orbits (LEO). The task of mitigating orbital debris in the U.S. has been delegated to the Federal Communication Commission (FCC) according to FCC, 47 CFR parts 5, 25 and 97 on the “Mitigation of Orbital Debris” effective October 12, 2004. The current guidelines define orbital altitudes for Low-Earth-Orbits (LEO) as below 2,000km and Geostationary-Earth-Orbits (GEO) at altitudes approximately 35,786km. In addition, the orbit life of satellites in LEO must have a maximum post-mission life of 25 years.

Submissions for FCC licensing must include disposal and mitigation plans that address satellite design and operation that will minimize the amount of orbit debris, orbital collision avoidance, quantity of fuel for post-mission disposal (if applicable), and the use of Inter Agency Space Debris Coordination Committee's guidelines on "U.S. Government Orbital Debris Mitigation Standard Practices" published in 1997. The guidelines have four main objectives [8]:

1. *Control of Debris Released During Normal Operations*
    a. *Satellites must minimize or limit orbital debris of 5mm in any dimension.*
2. *Minimizing Debris Generated by Accidental Explosions*
    a. *Demonstrate that there is no mode for an accidental explosion.*
    b. *All stored energy including propellant must be depleted to minimize accidental explosions.*
3. *Selection of Safe Flight Profile and Operational Configuration*
    a. *Mission profile for the satellite will minimize the probability of collision with known objects.*
    b. *Minimize the probability of the loss of post-mission disposal due to collisions with objects smaller than 1cm in diameter.*
    c. *Tether systems must be analyzed for intact and severed conditions.*
4. *Postmission Disposal of Space Structures*
    a. *Atmospheric reentry option with the risk of human causality that is less than 1 in 10,000.*
    b. *Maneuver to storage orbit.*
    c. *Perform a direct retrieval.*
    d. *Tether systems must be analyzed for intact and severed conditions.*

The U.S. Government Orbital Debris Mitigation Standard Practices guidelines do not all directly apply to CubeSats in that most do not have propellant to perform maneuvers. CubeSats must rely on atmospheric reentry to mitigate space debris. In addition, due to its relatively low density the risk of human casualty is much less than 1 in 10,000.

Amateur stations, of which most CubeSats fall under, must provide various statements which are highlighted in the ruling to attach to the submission to the FCC. The Radio Amateur Satellite Corporation has filed a petition to reconsider amateur satellites in the filing process for orbital debris on May 4, 2005. As of yet there is no final ruling on amateur radio satellites to submit to orbital debris mitigation plans to the FCC.

3.6 Frequency Allocation

Prior to the Dnepr launch campaign, frequencies were unofficially coordinated by professor Bob Twiggs. CubeSat institutions were provided frequencies in the UHF Band ranging from 436.500MHz to 437.500MHz. This method expedited the lead-time in obtaining a frequency for a university but was difficult to determine if the frequencies assigned conflict with other amateur satellites in development. At the time this was the best option due to long lead-times for coordinated frequencies from the central authority on amateur radio International Amateur Radio Union (IARU).

A parallel track was taken by Cal Poly during the Dnepr launch campaign to obtain an experimental license through the FCC. After completing a submission to the FCC there was no response for the approval of the submission for over six months. In addition to the submission a request to waive the FCC's requirements of §97.207(g) was submitted. This requirement applies to the rules and regulations that normally require applicants to notify the International Bureau at 27-months and 5-months before initiating space station transmissions. This ruling is difficult to apply to CubeSat launch opportunities of which CubeSats are notified as soon as a viable launch opportunity appears, typically within 24 to 18 months.

In both cases the official method of obtaining frequencies subjected all CubeSat institutions to lead-times up to 18 months. In addition, both methods require the compliance of different sets of rules and regulations depending on the chosen method. Regulations that are of specific concern to CubeSats include but not limited to:

IARU – Amateur Frequency

- **Contribution to the Amateur Radio Community:** Provide a useful tool for amateur radio community in post-mission phase of life (i.e. Transponder)
- **End of Life Termination:** Positive termination of satellite transmission if requested
- **Public Disclosure of data transmission:** Proprietary or restrictive information is not allowed.

FCC – Experimental Frequency

- **FCC Orbital Debris Mitigation:** Meet post-mission deorbit guidelines in affect on October 2004.
- **Waiver of §97.207(g):** Notification to the FCC 27-months and 5-months before initiating space station transmissions

4 Cal Poly Solutions to the Regulations

4.1 International Traffic in Arms Regulation (ITAR)

Since any satellite hardware is deemed as defense articles under 22 CFR Part 121 there are two directions that the CubeSat Program can take in dealing with ITAR. Cal Poly can undertake the task themselves or hire a consultant. In either case future measures of how Cal Poly will handle ITAR related issues need to be done. The launch coordinator weighed the benefits of both positions and the overall affect on the launch schedule. The benefits of both positions are listed below:

1. Cal Poly State University will take on the task of learning the regulations.

Benefits:

- Cal Poly can reduce costs by not investing in third party consultant(s) and use in-house resources and legal experts.
- Cal Poly does not need to depend on intermediary consultants to track & complete paperwork.
- Through the lessons learned on this first experience Cal Poly can reuse the knowledge for future launch campaigns.

2. Cal Poly will hire consultants that have previous experience.

Benefits:

- Consultants have previous experience and knowledge in government regulations and possible university exemptions.
- Cal Poly can focus on other issues on the launch campaign.

- ♦ Contacts within the government can expedite the application process.

After evaluating the two options it became clear that Cal Poly's inexperience with ITAR posed a great deal of risk to the success of the launch campaign due to the learning curve of understanding the regulations and processes. Ultimately, the consultant's experience and potential time-savings over their cost were more beneficial to the overall project. Therefore, a consultant was hired to provide legal advice and outline the necessary paper work. They were also hired to outline a program for current and future Cal Poly projects that fall under ITAR.

4.1.1 A Lesson Learned – ITAR Consultants

The consultant over the first few months of the launch campaign provided valuable insight into the processes of ITAR. The consultant described processes and whom to contact. However, after the first few months there was little progress in submitting approvals to the U.S. government even with constant contact and submission of technical documents from the launch coordinator. Ultimately, due to the lack of progress on submitting the necessary paperwork and no progress on outlining a program for future submissions and procedures for following ITAR the consultant was let go.

This was a major hindrance to the progress of completing the export licenses. There were insufficient funds to hire a consultant whose main focus was solely on the launch campaign. Dealing with procedures and regulations is too important and time critical to not have a consultant working full time on ITAR. Submitting documents and obtaining all necessary approvals can take anywhere from three months to a year. In addition, obtaining technical information from participating universities to complete a submission to the state department can also impact the schedule. Having a full time consultant is essential. The project must support a consultant for approximately one to two years as they will be needed through the life of the launch campaign.

To hire a full time consultant is costly but to make the launch campaign affordable to all the participating universities a full time consultant is unrealistic and therefore Cal Poly's Sponsored Programs Director and the launch coordinator took on the task of completing the submissions to the U.S. government. The lack of knowledge and experience were offset by the focus of the Sponsored Programs Director and launch coordinator to understand and act according to the regulations.

4.2 Work Environments

4.2.1 Working with Cal Poly Corporation

Once the launch campaign became a sponsored program the launch coordinator worked with the Sponsored programs office in detailing and reviewing contracts, legal issues, and compliance with regulations. The Sponsored Programs Director was the main point of contact and designated as the empowered official. From the Dnepr launch campaign several factors enabled a closer interface between launch coordinator and the export control officer.

- The export control officer must also have the ability to sign and approve TAA, TTCP, licenses, etc… as the empowered official. This mitigates one level of bureaucracy within Cal Poly for approval to directly submit to ODTC.
- The launch coordinator must assist in creating and reviewing submissions as the export control officer must devote a majority of focus on other sponsored programs.

- The export control officer may not understand all the technical issues. The launch coordinator must work closely with the export control officer to coordinate events such as fit-check with universities and launch providers, technical discussions, integration of satellites, attending the launch, flight hardware shipments, contracts, teleconferences, etc.

4.2.2 Laboratory Environment - Students

Due to the launch campaign and the project as a whole the students need to change their mentality of the normal atmosphere of a university setting. Students now need to work in an environment where regulations, proprietary information, and non-disclosure agreements are the norm. The launch coordinator in conjunction with the Cal Poly CubeSat senior members must train and inform students to be aware of what information can or cannot be communicated when in discussions with visitors at conferences even with students that are training in the laboratory.

Students that are training in the project are given limited access to computers, laboratory keycard access, and proprietary meetings and information is not disclosed. Under the discretion of the project manager and senior members full access is given to the student. Laboratory safety and internal rules, proprietary agreements, computer and keycard access are disclosed by the project manager with the necessary training. Students are notified not to provide information to outside sources and visitors without the approval of the project manager or senior member. In addition, non-Cal Poly personnel cannot be left unattended including students that are under training and do not have access to the lab.

Students must also control the documentation whether it is proprietary information or ITAR controlled. The launch coordinator must explain and disclose the proper documentation, secured storage, and disposal of documents as written in the approved TTCP. Proprietary items must not be left in the laboratory on tables when not in use. If not in use must be stored properly or shredded. In addition, students must adhere to proper procedures in order to mitigate human errors in manufacture, assembly, and testing of hardware all of which can greatly impact schedule, cost, and success of the launch. Proper traceability and documentation is equally important to provide future generations with a reference of precedents and methodology.

4.3 Technical Assistance Agreement (TAA)

4.3.1 Cal Poly Corporations Responsibility

It is the responsibility of the Cal Poly Corporation as an exporter of defense articles as classified in 22 CFR 121.1 to provide technical assistance to foreign entities after a TAA has been approved in writing by the Office of Defense Trade Controls. Prior to an approved TAA contractual agreements with the foreign entity is under the discretion of the exporter. The TAA must be written and submitted to the Office of Defense Trade Controls well in advance once a proposal with a foreign entity is determined.

The Cal Poly Corporation must appoint an empowered official that will be responsible for complying with all regulations. The empowered official must be in a position for having the authority to make policy or management decisions within the organization. The empowered information must be legally empowered in writing to sign license applications. The empowered official must have independent authority to enquire on the proposed export or import, verify the accuracy of the information that is going to be submitted, and able to refuse to sign any license application without consequence. With these criteria the empowered official was designated as Frank Mumford but in later months the Sponsored Programs Director was given authority to sign as an empowered official in addition to the role of export control officer.

4.3.2 Launch Coordinator Responsibility

The launch coordinator is the single point of contact with the launch provider, all customers, Cal Poly CubeSat personnel, and the Cal Poly Export Control Officer. The launch coordinator must disseminate and obtain technical and logistical information between all contacts as necessary. Figure 8 illustrates that the launch coordinator is the main point of contact for the four entities in disseminating information.

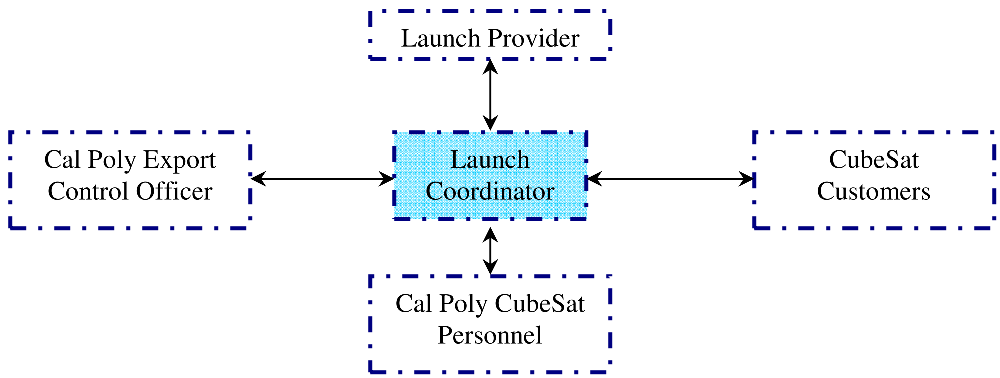


Figure 8: Transfer of information dissemination through the launch coordinator

Cal Poly Export Control Officer: The launch coordinator must provide technical information about CubeSat hardware and the participants that are involved. Assist in the development and review of the TAA, Technology Transfer Control Plan (TTCP), and all contracts. Inform the Cal Poly Export Control Officer of when CubeSat and related personnel will be arriving for scheduled events and assist in the necessary paperwork for compliance. This also includes when Cal Poly CubeSat personnel need to depart with hardware or technical information to various meetings with the launch provider.

Launch provider: The launch coordinator must obtain logistical information such as but not limited to orbit parameters, launch windows, payload weight, and cost. Obtain required technical information such as satellite frequencies and transmission levels, summary of satellite descriptions, safety documentation. Prepare any items listed in contractual agreements.

Cal Poly CubeSat Personnel: The launch coordinator must inform the internal group of incoming foreign entities so that they can perform integration, fit-checks, and environmental testing. This scheduling needs to be coordinated with the internal personnel so that they do not disrupt the Cal Poly CubeSat development and testing. Any shipment of hardware for fit-checks and launch must also be coordinated with the team.

CubeSat Customers: The launch coordinator must provide updates to the date of the launch which corresponds to delivery of CubeSats for integration. Ensure that the CubeSat meet the standard and safely integrates with the other CubeSat neighbors within the P-POD. Ensure that all CubeSats have performed environmental testing prior to delivery to Cal Poly for integration. Documentation they need to provide includes: battery charging procedures, safety documentation, CubeSat subsystem summary, P-POD Allocation, non-military documentation, coordinated frequency and communication information, orbital debris mitigation (optional).

4.4 Technology Transfer Control Plan (TTCP)

The TTCP details several events that the launch coordinator and other Cal Poly CubeSat personnel must attend when working with the launch provider. These events are scheduled face to face meetings. The launch coordinator must inform the export controls officer of the content of the meeting. During the meeting the launch coordinator must provide direction to the Cal Poly CubeSat team on what information is ITAR controlled. In addition, assist in contractual requirements, and prepare the necessary paper work for the shipment of the hardware and personnel attending the location. The written TTCP dictates procedures that govern the security for future launch campaigns.

Below describes the events attended with the launch provider as written by the launch coordinator in the TTCP. During each event the technology that was presented was strictly on the P-POD interface and the deployment mechanism which was shared publicly at conferences and on Cal Poly's website. Other items are logistical in nature and include orbital parameters, completion of contractual agreements, deployment sequence, etc…

Dnepr Initial Meeting (May 2003): In attendance were ISC Kosmotras and Yuzhnoye SDO representatives and four Cal Poly CubeSat representatives. Discussions pertained strictly to interfacing with the launch vehicle. The overall dimensions of the P-POD were clarified. The launch provider informed of us of needed requirements such as grounding bolts on the P-PODs, the maximum velocity of each CubeSat when deployed, required documentation of safety and non-military purpose of each satellite. Other items of a non-technical nature included the total mass range of our payload, issues with the contract, the deployment sequence of the CubeSats, etc.

Dnepr Fit-Check (February 2005): The fit-check was located at Dnepropetrovsk, Ukraine. In attendance were various engineers from Yuzhnoye SDO, ISC Kosmotras, other satellite customers, and two Cal Poly CubeSat personnel and the export control officer. This fit-check was used as a dimensional and mass check of P-POD Engineering and mass simulators to the interface adapter. In addition, other satellite mass simulators were integrated to the Space Head Module (SHM) for visual interface and clearance. The SHM under went vibration testing with all mass equivalent payloads. Cal Poly arrived with four mass and dimensional equivalents and one engineering P-POD. Beyond the technical aspects other items to discuss were contractual and schedules.

Arrival to Launch Site (July 2006): In attendance were personnel from Yuzhnoye SDO, ISC Kosmotras, and customers from other countries to view the launch of their hardware including three Cal Poly CubeSat personnel and the export control officer. All integrated flight hardware was shipped to the launch site including one spare P-POD Unit and various tools all packaged in a wooden crate. Upon arrival the hardware would then be inspected and integrated to the Dnepr vehicle by Yuzhnoye SDO engineers. Other items of a contractual nature were included in the discussion.

Beyond external meetings the TTCP must also cover the internal procedures of the Cal Poly laboratory in the Advance Technology Building in Room 15. The following highlights internal procedures with visitors and placement of flight hardware (i.e. P-POD).

Internal Laboratory Procedures:

- **Flight Hardware:** The Advanced Technology Laboratory (ATL) at Cal Poly is a secure facility. ATL access is provided by keycards which are given to Cal Poly CubeSat Personnel. Within the ATL the flight P-PODs and delivered CubeSats are located in a secure cabinet in the cleanroom. Only senior members can authorize access to the flight hardware.

- **Escorting Visitors:** All walk-ins will be escorted by Cal Poly CubeSat Personnel at all times in the ATL. No more than four visitors may be escorted by each Cal Poly CubeSat Personnel.

4.5 Export Licenses

The export licenses were completed by the export control officer with supplement information from the launch coordinator in regards to CubeSat and P-POD logistics and schedules. In addition the launch coordinator provided the cost and USML category of each hardware item.

4.5.1 Temporary export (DSP-73)

A temporary export (DSP-73) was used to export US CubeSat institutions satellites to be shipped to the launch site. Figure 9 illustrates the corresponding value of the satellites along with the license. The CubeSats that are itemized under the DSP-73 are all US institution CubeSats with an additional P-POD that is used as an emergency backup unit that maybe used at the launch site. The value and the US Munitions List Category are cited for each commodity.

PART A - ALL ARTICLES ON THE MUNITIONS LIST			
12. QUANTITY	13. COMMODITY	14. USML CAT.	15. VALUE
Lot as per attached	Satellites, and Launch Deployer per attached	XV(a) & IV(h)	$63,000.00
		16. TOTAL VALUE:	$63,000

Figure 9: CubeSats and P-PODs temporarily exported on a DSP-73

The approval process for a DSP-73 is typically 30 to 60 days according to the GAO briefing in the Fiscal Year 2000 [7]. The DSP-73 for the Dnepr launch campaign was submitted and returned with approval in 120 days. This discrepancy for the typical review time could be due to limited staff at the state department by an increasing number of retirees thereby increasing the review time for the submissions in Fiscal Year 2004.

4.5.2 Permanent Export (DSP-5)

A permanent export (DSP-5) is used to permanently export the foreign CubeSats to the launch site and clear customs in the US. Figure 10 illustrates the commodities and their USML categories and values for the DSP-5. In addition, five P-PODs are listed since the P-PODs are not returning to the US as they will be permanently destroyed when the launch vehicle upperstage reenters the atmosphere.

9. QUANTITY	10. COMMODITY ☒ Hardware ☐ Technical Data	11. USML CAT.	12. VALUE
1	Satellite, Hausat-1	XV (a)	$5,000.00
1	Satellite, SEEDS	XV (a)	$5,000.00
1	Satellite, NCUBE	XV (a)	$5,000.00
5	Launch Deployers (P-POD Deployer Units)	IV (h)	$40,000.00
	LICENSE SUBJECT TO ATTACHED DEPARTMENT OF STATE LETTER		
		13. TOTAL VALUE:	$55,000.00

14. Name and address of foreign end-user   15. ☒ Source or ☐ Manufacturer of Commodity

Figure 10: CubeSats and P-PODs permanently exported on the DSP-5

4.6 CubeSat Post Mission Lifetime

According to the guidelines of the Federal Ruling regarding the Orbital Debris Mitigation the orbital lifetime of satellites in LEO must have a maximum post-mission life of up to 25 years. Since the designed mission length of most CubeSats is approximately one year, a CubeSat must deorbit within 25 years. The launch coordinator needs to determine altitude ranges that satisfy the FCC regulation and in addition the needs of the customer.

A NASA Debris Assessment Software (DAS) provided by NASA Orbital Debris Program Office provides a preliminary tool to determine orbit lifetime of a CubeSat. Since the CubeSats on the launch campaign do not have active control to deorbit, Cubesats rely on atmospheric drag. The DAS only requires the input of area to mass ratio to affect atmospheric drag.

An estimate of $0.012m^2$ was used for the surface area. This estimate assumes that only one face of the CubeSat facing the direction of the velocity vector, therefore, a conservative estimate. In addition, the estimate accounts for a typical dipole antenna deployed from most CubeSats adding to the surface area. The mass is an ideal CubeSat at 1kg. Figure 11 illustrates what appears to be a ceiling altitude less than 650 km circular orbit for CubeSats to meet with the guidelines.

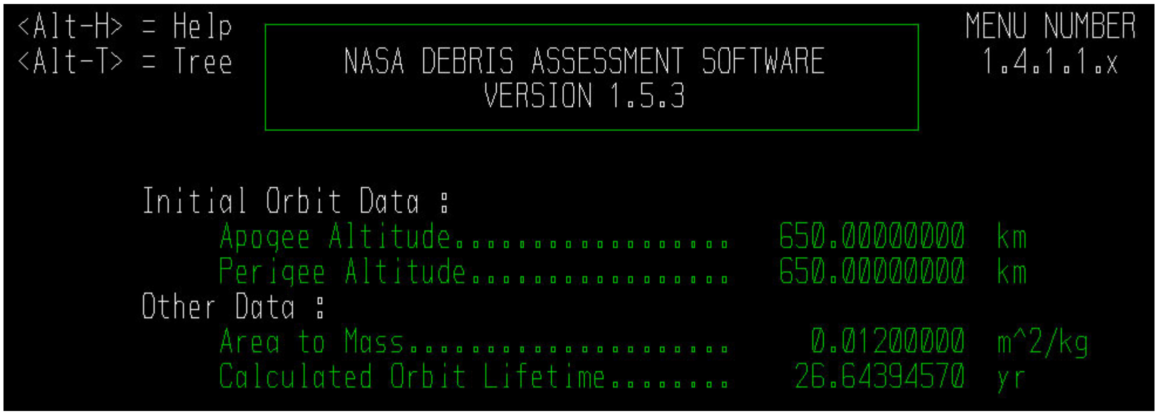


Figure 11: Ceiling altitude for CubeSats in an ideal circular orbit.

This result assumes an ideal circular orbit in reality launch vehicles will have eccentricity at a minimum of .001 which produces about a 20km difference between apogee and perigee. On the other hand, launch vehicles near the end of their satellite deployment sequence can increase their eccentricity as much as 0.01 which can produce as much as 150km difference between apogee and perigee. Figure 12 illustrates this point in varying apogee and perigee values. Note that the orbit lifetime still meets the deorbit guidelines. It is important that the actual values of perigee and apogee be determined for each CubeSat when carrying out the orbital debris requirement, however, these values are not given immediately from the launch provider. In the initial stages to determine a viable launch the launch coordinator used an ideal circular orbit but it is recommended for future launch campaigns to obtain perigee and apogee from the launch provider. Later orbital analysis studies should consult the launch vehicle Interface Control Document (ICD) for more accurate apogee and perigee values.

Figure 12: Varying apogee and perigee we still meet the deorbit guidelines.

CubeSat developers that have applied for an experimental license through the FCC have undergone the submittal procedure to prove that their CubeSat will have a post-mission life of 25 years. This added procedure has yet to affect the CubeSats that apply for amateur radio frequencies. Through the launch campaign, Cal Poly and several other universities have spearheaded in contacting the FCC for clear submittal procedures to comply with the regulations whenever it comes into affect for amateur stations. As of 2006 there continues to be a lack of official processes for amateur radio satellite to submit Orbital Debris Plans to the FCC. It is recommended that the CubeSat Program continue to spearhead and create guidelines and procedures to prove that the CubeSats comply with the regulations, similar to submissions for FCC experimental licenses, before the regulation comes into affect for amateur radio satellites.

4.7 Frequency Allocation

The Dnepr launch campaign demonstrated that current processes in obtaining either amateur radio frequency or an experimental frequency require lead-times over18 months for review and approval. The launch coordinator informed IARU of the Dnepr launch campaign and the needs of the CubeSat community. The Dnepr launch campaign needed IARU to reduce the typical review time for a submission and provide regular updates to the frequency coordination status. Since subsequent discussion during the Dnepr launch campaign IARU streamlined its process to within 30 to 60 days and the IARU website contains regular frequency coordination status [9].

The FCC in parallel streamlined its application process by implementing the Office of Engineering Technology (OET) Experimental Licensing System, an e-filing system [6]. Applicants can now submit Form 442 for an experimental license in addition view the status of the submission after the user logs in. Typical lead-times are still maintained at 90 days. All additional changes require lead-times of an additional 90 days for processing.

Since the streamlining of the frequency processes CubeSat institutions can opt for either process to apply for one or multiple frequencies. There are pros and cons for either method.

Amateur License:

Pro:

- Application process is simplified
- Website provides updates to informally requested, formally requested, and coordinated frequencies.
- Turn around time within three months.

Con:

- Limited frequency range
- Must follow the requirements of IARU on publicly disclosing information

Experimental License:

Pro:

- ♦ Application for a multitude of frequency ranges.

Con:

- ♦ Application and processing time is extensive and can be up to 2 years.
- ♦ Submission of applications must be completed 27 months prior to the launch date.

CubeSats participating in the Dnepr launch campaign opted for amateur frequencies for their CubeSats. With an influx of 14 CubeSats requesting amateur frequencies and a limited amateur radio frequency in the 400MHz range as shown in Figure 13 it was determined by IARU that future CubeSats would be assigned in the 437 MHz frequency range. Due to the spectrum limitation this posed two potential issues which need to be mitigated by the launch coordinator.

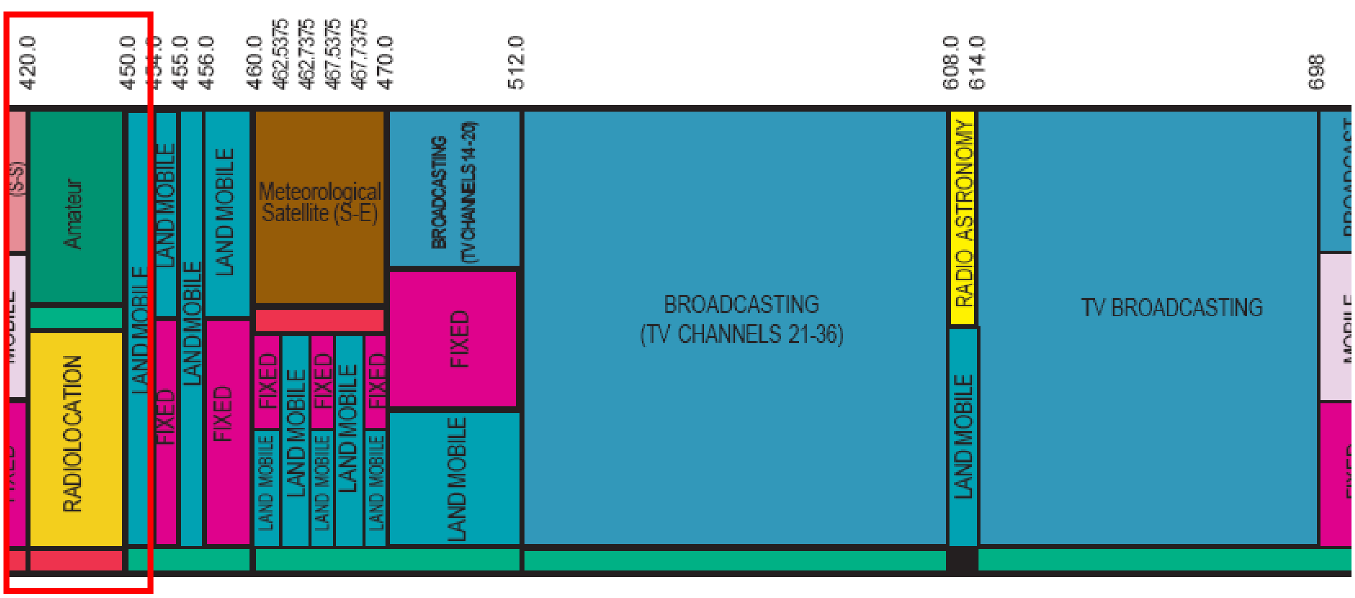


Figure 13: Amateur frequency range in the 400 MHz region

- **Issue 1:** CubeSats on a coordinated launch are assigned the same frequency.

- **Issue 2:** Due to adjacent frequencies between CubeSats subsequent transmission can cause damage to receivers to nearby CubeSats.

The first issue did occur during the launch campaign. IARU assigned identical frequencies for a foreign and domestic CubeSat assuming that transmission will only occur over their respective country of origin. This assumption is correct in the steady-state mode of operations when all CubeSats are identified. This is not the case in the transient mode of operations where it is critical to communicate and identify all CubeSats immediately after orbit insertion. The launch coordinator discussed with customers and IARU to determine possible options. It was determined that Cal Poly's CubeSat can be coordinated on another frequency. The launch coordinator must maintain a list of frequencies for all CubeSats on the launch to mitigate this risk.

The second issue did not occur on orbit but in the laboratory. This issue became apparent during the diagnostic testing and transmission of a CubeSat that was in storage. The adjacent frequency and transmission damaged the transceiver of another CubeSat that was undergoing performance tests in the laboratory. Subsequently, no transmissions are allowed in the laboratory without prior notification.

To mitigate the second issue the launch coordinator implemented transmission delays on the Dnepr launch campaign CubeSats and future CubeSats. CubeSats deployed from the P-POD under ideal conditions can expect a velocity difference of 0.03m/s between CubeSats. This equates to a 1.8m of CubeSat separation per minute. Low Power Transmissions (i.e. Beacons) are delayed at 15 minutes after deployment from the P-POD equating to 27m of separation. High Power Transmissions are delayed at 30 minutes equating to 54m of separation. This separation allows for enough free space pathloss to protect receivers from neighboring transmissions.

5 Program Flow

The schematic model illustrated in Figure 14 demonstrates the program flow of the launch campaign. An enlarged version of the schematic model can be found in Appendix B. The schematic model illustrates the top-level processes for the life-cycle of the launch campaign from initial contact to operations and tracking. This section details the methodology and processes developed at different paths critical to the success and safety of the CubeSats and the vehicle.

In the schematic model, the darkened items are critical path items to the launch campaign; supportive items are lighter in color. Note that P-POD Allocation and Monthly Status Reports items and not essential to the launch campaign since they are monitoring tools. Dotted lines indicate supportive information that is needed from a previous item.

Two areas highlighted in the schematic model from existing processes either by the launch provider or Cal Poly Corporation. They are highlighted in Area 1 and Area 2. Area 1 indicates the standard processes of the launch provider that include an initial meeting and Dnepr Fit-Check prior to launch site delivery. Area 2 illustrates Cal Poly Corporation's standard practices in approving a program. A Scope of Work (SOW) and preliminary budget are submitted to Cal Poly's Grants Development office for approval. Note that the TAA and TTCP are not part of the Cal Poly Corporations standard practices and was developed by the launch coordinator for the Dnepr launch campaign. The rest of the schematic model represents the processes developed to work with CubeSat customers and handling government regulations.

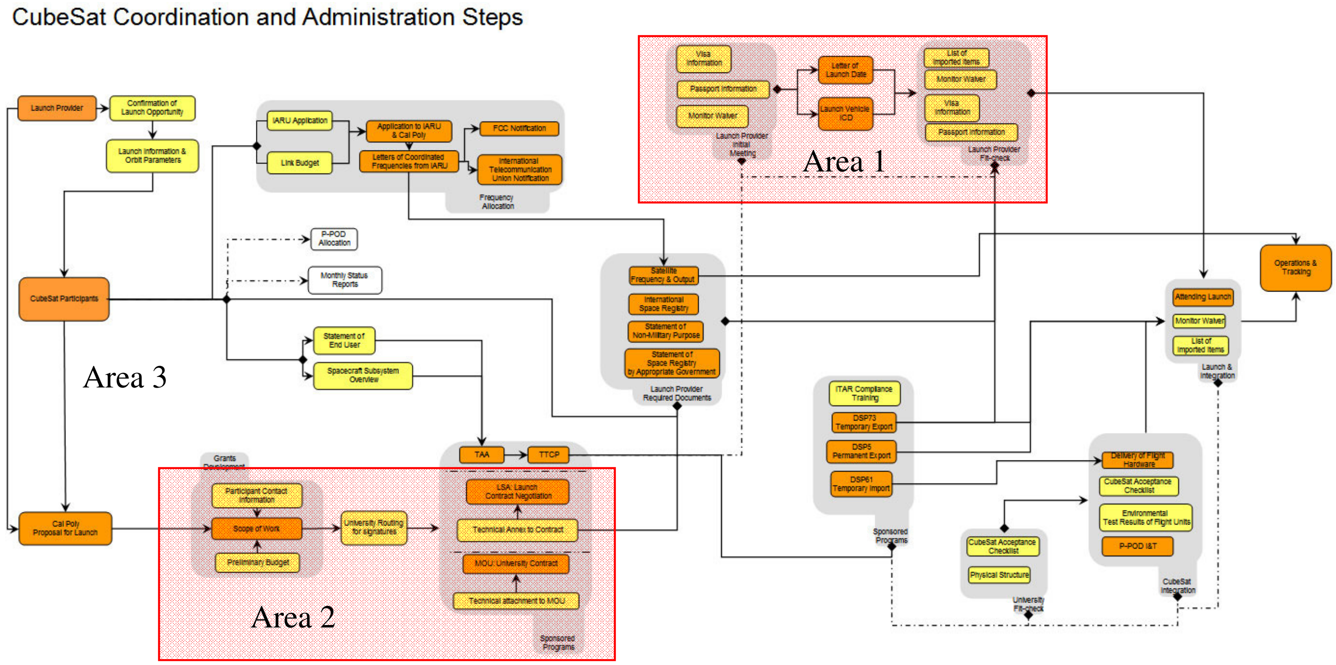


Figure 14: Schematic Model of the Dnepr Launch Campaign

5.1 Initial Contact

Figure 15 illustrates the parties contacted by the launch coordinator. For the customer, the launch coordinator must determine the nominal orbit parameters, the expected mass of the payload, and the nominal cost that will make the launch campaign affordable. The launch coordinator can then contact launch providers and determine if a launch opportunity is viable. From a viable launch opportunity the launch coordinator can begin the process of submissions and approvals for the program to be sponsored through Cal Poly.

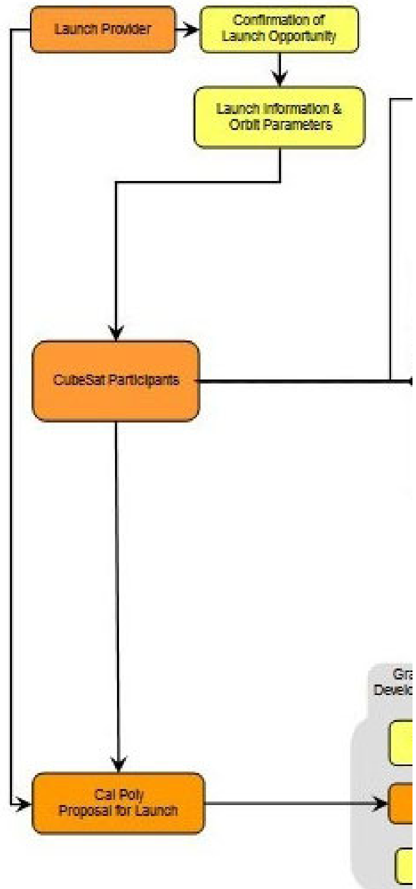


Figure 15: Schematic (Initial Contact)

5.1.1 Launch Provider: Determining a Viable Launch Opportunity

There are various launch providers around the world that have the potential to accommodate CubeSats. A compiled directory of vehicles and contacts can be found in the *International Reference Guide to Space Launch Systems* written by Steven Isakowitz. By understanding the general needs of CubeSats and their limitations the search for a launch provider can be focused. The launch coordinator used the metrics of launch window, launch cost, and orbit parameters to determine a viable launch; however, with increasing industry interest in launching CubeSats these factors may not apply in the future.

<u>Metrics in determining a viable launch:</u>

Launch window (Expected quarter/month and year): To determine a valid launch window the launch coordinator needed to determine the stage of development of interested customers. Two general items were considered for an acceptable launch window.

1. Customers provide their schedule of CubeSat completion where in reality CubeSats will need an additional one to three months to be ready for delivery as issues come after testing the final integrated system.
2. The launch provider provides a best-case launch window. This window, unless there are extenuating circumstances, is likely to be delayed several months, if not longer.

Institutions that were on schedule to meet the launch window were manifested. The second item allowed the launch coordinator to broaden the scope of potential customers to participate in a launch. Universities that may not be on schedule for the preliminary launch window were placed on standby in the event the launch window is delayed or other customers dropout early in the launch campaign.

Total Cost (Launch Cost + NRE + internal costs): Another factor to consider is the total budgetary cost. The right price for CubeSats is not necessarily free. A free launch opportunity may occur only once and have various restrictions which may not be desired.

However, if a launch cost is affordable and occurs regularly with little or no restrictions then that type of launch is more appealing.

- **Launch Cost:** The most affordable launch costs have been provided by foreign launch providers (i.e. ISC Kosmotras) at approximately $10,000 per kg. This price is highly affordable but maybe offset by the expense of exporting to foreign countries and the overhead of complying with government regulations.

- **Non-Reoccurring-Engineering (NRE):** NRE are costs that are required only once such as analyses, research, performance characteristics, etc. Launch providers may require NRE for performing safety analysis and design of interfacing the P-POD to the vehicle. NRE costs are not usually covered by the launch provider and will be distributed to all CubeSat customers. Past NRE costs, quoted by US launch companies, range from $500,000 to $1,000,000. Unless these costs can be subsidized The CubeSat Program cannot afford the initial NRE costs. The Dnepr did not require NRE, though they designed and manufactured the Launch Vehicle Interface (LVI) adapter as part of their service.

- **Internal costs:** These costs include student assistance, equipment and supplies, export and import costs, indirect costs, and travel. The impact of the budget for internal costs varies with each item and the number of CubeSats that is coordinated for the launch campaign.

- **Student Assistance:** The internal cost of hiring students does not change in regards to the number of CubeSats that are coordinated.
- **Equipment and Supplies:** The cost of purchasing separation mechanisms is spread evenly to the customers regardless of the number coordinated customers. The separation mechanism is purchased from an outside vendor. The release mechanisms for Dnepr launch campaign cost approximately $6000 each. This value is subject to change with different release mechanisms.
- **Export and Import Costs**: These costs include but are not limited to shipping, custom duties, and licenses. Custom duties and shipping costs change due to the weight of the package and value of the shipment which is directly related to the number of CubeSats. Licenses are impacted by increasing the written value of the license but the monetary value for completing the license is not affected.
- **Indirect Costs**: Federal negotiated administrative costs for a Cal Poly sponsored program are deducted from the total budget of the launch campaign. The indirect cost is calculated by taking 40% of the total budget. Line items in the budget that are over $25,000 are partially excluded. Only 40% of the first $25,000 can be deducted for administrative costs. Equipment above $5000 are excluded from indirect. Note that during the Dnepr launch campaign the overhead was 35%.
- **Travel**: Travel costs include but are not limited to hotel, airfare, visas, ground transportation, and food. Travel can be to domestic or foreign locations. The

Dnepr launch campaign requires travel at a minimum to an initial face-to-face meeting, Dnepr Fit-Check, and the launch site.

Orbit parameters (Altitude and Inclination): The launch coordinator used CubeSat limitations and the goal of attracting a large customer base drove to drive the selection of nominal orbit parameters in respect to altitude and inclination.

- **Inclination:** The location of a several potential customers is illustrated in Figure 16. In order to increase the customer base customers must be able to communicate with their CubeSat from their groundstation. This driver places a lower limit on the inclination of approximately 70 degrees. In general, inclinations below 20 degrees are undesirable since the target of customers is limited to several institutions in the equatorial region as illustrated in Figure 17. As a guideline, inclinations above 70 degrees are desirable, 20-70 degrees are nominal, and inclinations below 20 degrees are not recommended. With the development of networked groundstations this particular concern may disappear in future years.

Figure 16: Location of various CubeSat developers

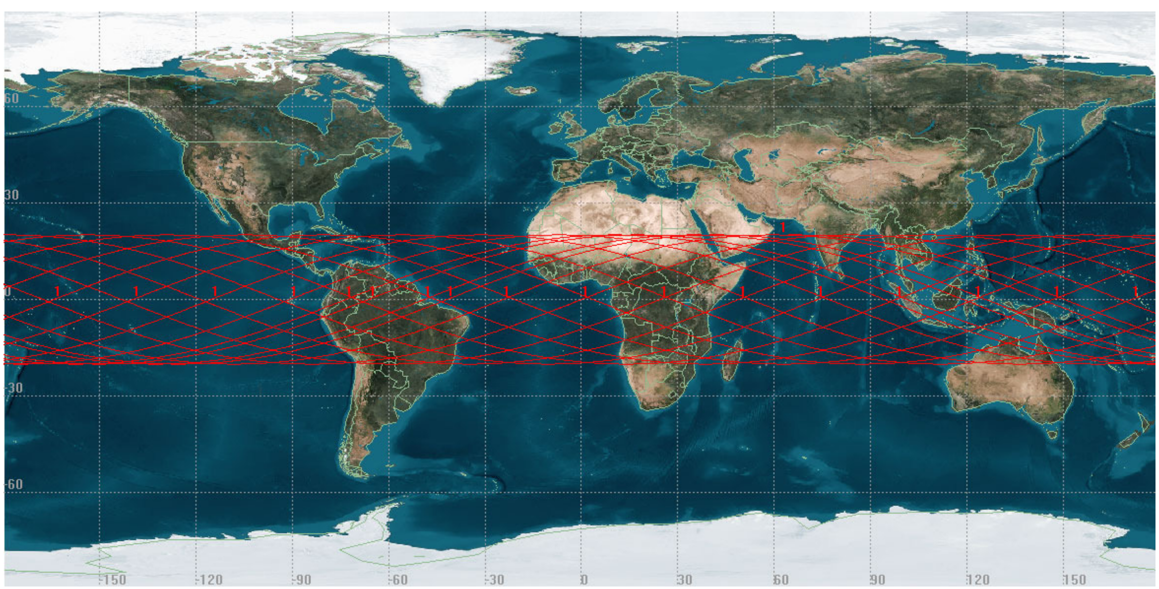


Figure 17: Inclination below 20 degrees eliminates most CubeSat developers

- **Altitude:** CubeSats have a typical mission life of 3 to 6 months which drives a lower limit altitude of approximately 300 km. The maximum altitude a CubeSat can be in LEO must meet the guidelines of the FCC ruling on orbital debris mitigation for a post-mission life up to 25 years [5]. In using an ideal circular orbit altitudes at or higher than 650 km require a deorbiting device on the CubeSat. However, it is recommended to use a preliminary apogee and perigee value from the launch provider if available. Therefore, a nominal altitude range is approximately 300 to 650 km.

5.1.2 Universities Developing CubeSats

At the initial stages of the launch campaign, universities that were on schedule to complete their CubeSat two months before the launch window were contacted through email to determine their interest in a launch. This method meant that some individuals may not receive the launch opportunity information and a potential customer could be lost. Though this method was inefficient, it was the only available option for the Dnepr launch campaign at the time. Different methods have since been established to disseminate information such as but not limited to launch opportunities, conferences and workshops, and CubeSat Program updates.

Customers that were contacted by the launch coordinator were provided with the information in Table 1. The information is enough for a customer to make a decision on the launch opportunity. The basic information was provided by the launch provider ISC Kosmotras.

Table 1: Basic Launch Opportunity Information

Launch Vehicle:	Dnepr
Launch Provider:	ISC Kosmotras
Orbit Parameters	
Altitude:	700 km
Inclination:	98 degrees
LTAN:	TBD
Launch Window:	December 2005
Delivery of CubeSat to Cal Poly:	October 2005

With the above information the universities were given a month to respond. An initial teleconference with the interested customers was held on May 15, 2003. From this point the standard Cal Poly practice of sponsoring a program was started as shown in Figure 14 in Area 2. The launch coordinator developed a scope of work which was provided to Cal Poly's Grants Developments Office. Once the SOW and budget had been approved it was up to Cal Poly Sponsored Programs Office to draft a Memorandum of Understanding (MOU). The MOU was sent to each university. A sample MOU is illustrated in Appendix C.

Different methods have since been established to disseminate information regarding launch opportunities through the use of a launch preference form, conferences and workshops, and CubeSat Program updates.

Disseminating Information:

- **Method 1:** A general mailing list that enables immediate dissemination of information to the entire community. Any parties interested in CubeSat developments can signup to the mailing list at www.CubeSat.org.

♦ **Method 2:** The CubeSat Website is being used as a tool to provide past, present, and future launch opportunities. Another section of the website is devoted to providing essential documents for CubeSat developers and launch providers.

Launch Preference Form: Figure 18, illustrates a tool developed by the launch coordinator to determine the needs of the institution and their viability. In addition, the form determines other types of possible restrictions such as available funding for launch and political issues. Using this form allows the launch coordinator to determine the needs of the majority and focus towards a target launch date and orbit parameters. The universities are removed from the processes of searching for a launch opportunity and can now devote more resources (i.e. students) on satellite development.

CubeSat Launch Preference Form

The information you provide on this form will be added to the CubeSat database
This information will allow Cal Poly to notify you of upcoming launch opportunities that fit your parameters
Send all forms to the CubeSat Coordinator at STLee@calpoly.edu

1 Satellite Name:
2 Satellite Call Sign:
3 University Name:
4 Main Contact:

Project Advisor
Phone 1:
Phone 2:
Email:
Project Manager
Phone 1:
Phone 2:
Email:

5 Satellite size (1U/2U/3U) (i.e. 1U = standard 1kg cubesat):
6 Brief mission description:
7 Satellite Date of completion (Qtr/Year):
8 Launch Date Preference (Qtr/Year):
9 Funding available for launch (Yes or No):
10 Orbit Preference:
11 Launch site preference or issues:

Figure 18: Launch Preference Form to be filled out by universities

5.2 Monitoring University CubeSat Progress

Once an acceptable number of CubeSats agreed to the MOU it was up to the launch coordinator to determine the customers CubeSat progress. CubeSat progress was monitored to provide a cautionary indicator that a customer may not meet milestones such as fit-check and delivery of their flight hardware. CubeSat progress reports can be posted publicly for CubeSat neighbors to review and alleviate any concerns. This method will add confidence in neighboring CubeSats design and reliability since they themselves can track a CubeSats progress. Figure 19 illustrates two monitoring tools developed by the launch coordinator "P-POD Allocation" and "Monthly Status Reports."

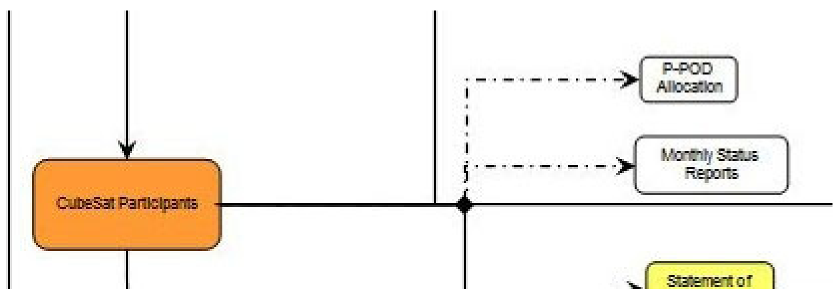


Figure 19: Schematic (Monitoring Tools)

5.2.1 Monthly Status Reports

To monitor a CubeSats development, a simple form was completed by each customer monthly. The form condenses approximately two years of development time onto a single page as illustrated in Figure 20. The form provides a top-level outline of different stages of development component and system level progress for mechanical, electrical, software, and integration and testing. The basic questions posed enable the customer's program manager to consider future events such as redesign into their schedule if they have not already done so. Overall, the status reports should provide insight to the coordinator and the customer's project manager if they are on track for cubesat delivery.

CubeSat Progress Questionnaire

Please answer this questionnaire with "Yes" or "No" answers unless otherwise specified.
Return the questionnaire to Simon Lee at Cal Poly, (STLee@calpoly.edu).

University name: ___
Advisor/Project Manager: ___
Satellite name: ___

Testing Facilities
Do you know where you will conduct Vibration testing? ___
    If yes, specify location: ___

Do you know where you will conduct Thermal Vacuum testing? ___
    If yes, specify location: ___

Structure
Have you completed your design for the structure? ___
Have you performed F.E.A.s and other structural analysis? ___
Have you built a Prototype model of your structure? ___
Have you built your structure using your final material? ___

Electrical Subsystems
Have you completed your design for the subsystems? ___
Have you tested all of your subsystems individually? ___
    With a breadboard? ___
    With PCBs? ___
Have you tested all of your subsystems working together? ___
    With a breadboard? ___
    With PCBs? ___

Software Complexity
Do you have an OS for your CubeSat? ___
Have you fully accessed all of your individual components through software? ___
Have you tested/debugged your software? ___
Have you frozen your software? ___

Integration and Testing
Have you integrated your subsystems into your structure? ___
How many weeks have you allotted for redesign after vibration and thermal vacuum testing? ___
Have you completed vibration qualification testing on your prototype? ___
Have you completed thermal vacuum testing on your prototype? ___
Have you completed vibration acceptance testing on your flight build? ___
Have you completed thermal vacuum testing on your flight build to 10^{-4} Torr? ___

Additional Items
What is your scheduled date to have your picosatellite complete? ___
Do you know who your Neighbors are in your P-POD? ___
Have you contacted the Neighbors in your P-POD? ___

Figure 20: Monthly Status Report that CubeSats customers must complete

5.2.2 P-POD Allocation

P-POD Allocation tool was developed by the launch coordinator to ensure that CubeSats were organized into an optimal arrangement to safely deploy CubeSats from the P-PODs. There can be components and issues that can pose a risk to neighboring CubeSats once deployed which include but are not limited to deployables and passive magnets. A preliminary P-POD allocation should be determined after the launch order of the satellites on the vehicle is known, pending that customers have completed the P-POD Allocation template illustrated in Figure 21. Any customers unable to provide all the necessary information may indicate that design decisions have not been finalized posing a potential schedule impact.

P-POD Allocation Questionnaire

This questionnaire will provide Cal Poly data on your CubeSat. The data will be used to determine the safest arrangement for you and your neighbors in the P-POD. If you have any questions or concerns please contact Simon Lee at STLee@calpoly.edu

University name: ______________________________
Advisor/Project Manager: ___________________________________
Satellite name ________________________________

1. Do you have deployables on your CubeSat? _____
   If yes, please provide an image demonstrating all deployables on your CubeSat.

2. Do you have permanent magnets?
   If yes, please provide an image, demonstrating the location on your CubeSat. Please note **magnitude** and **polarity**.

3. What is the cleanliness requirement for your CubeSat? (i.e. class 100,000)
   ____

4. Do you have more than one CubeSat for the DNEPR 2004 launch? ______
   If yes, do you require that both Cubesats be in close proximity to one another in orbit? ______

Comments:

Figure 21: P-POD Allocation Questionnaire

With the information gathered from the P-POD Allocation Questionnaires five different metrics were used to determine the location of each CubeSat, which is illustrated in Table 2. The highest priority metric is given a 1 and the lowest priority metric is 5. With each metric there is an accompanying action or restriction for the CubeSat. The optimal configuration is illustrated in Figure 22 after the P-POD Allocation metrics have been applied.

Table 2: P-POD Allocation Metrics

Priority	**Drivers**
1	Redundancy of university CubeSats that are from the same university
	-CubeSats from the same customer must be separated into an individual P-POD in the event of a P-POD failure.
4	Customer preference
	-Customers may have certain preferences or design issues that limit their location in the P-PODs
2	Passive magnets
	-A potential risk in neighboring CubeSats with passive magnets attracting each other as it exits the P-POD. These CubeSats must be separated with at least one CubeSat in between the two.
3	Complexity of the CubeSat
	-Deployable(s) pose a risk in that accidental deployments can occur causing damage.
5	Level of CubeSat development
	- CubeSat in advance stage of development have a higher priority to exit the P-POD since they have additional time to properly test the unit.

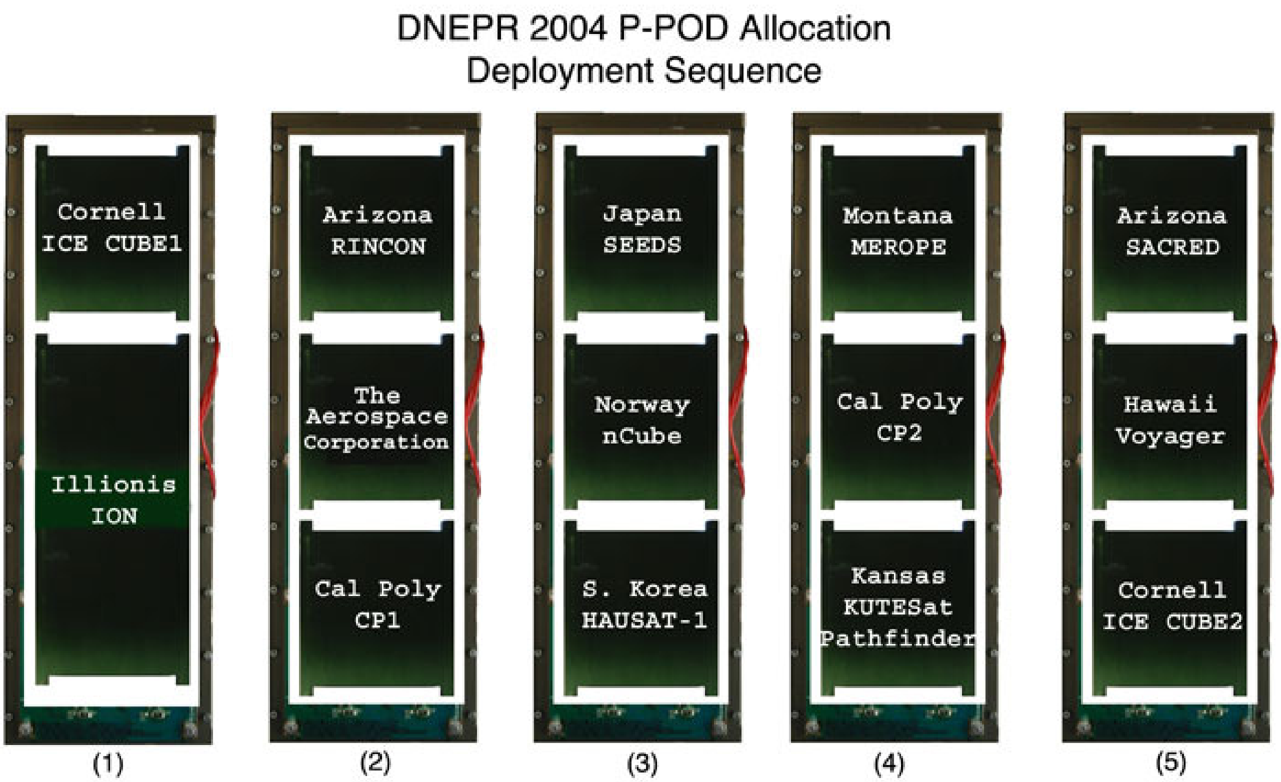


Figure 22: Optimized P-POD allocation

5.3 Fit-Checks

A fit-check is a milestone of the launch campaign between the customer and the vehicle. At this stage the design of interfaces and CubeSats are nearing completion. A proper examination and initial interface of separately manufactured hardware is examined by both parties. In respect to the vehicle, the fit-check examines the mechanical and electrical interface of the P-POD to the interface adapter built by the launch provider. In respect to the customer, the fit-check examines the interface of the CubeSats to the P-POD. After examination both parties can provide recommendations before finalizing the design and subsequent production. In addition, a fit-check indicates to all parties that the hardware will be completed as dictated by the schedule, pending that modifications with the design are minor. During the launch campaign two fit-checks occurred between the customer and the vehicle.

5.3.1 Dnepr Fit-Check

A fit-check is a necessary standard operating procedure for the launch provider with all of its customers as illustrated in Figure 23. The mechanical and electrical assessment was held 6 months prior to the launch date and was held in Dnepropetrovsk, Ukraine at the SDO Yuzhnoye facilities where the Dnepr launch vehicle is developed and manufactured. This subsequent face-to-face interface with the launch provider ensured that all parties manufactured hardware agreed with previous discussions on interface requirements.

As illustrated in Figure 23 the launch coordinator must coordinate with the launch provider and export control officer. The launch coordinator must provide logistical and technical information to obtain waivers to export the hardware and transfer of information.

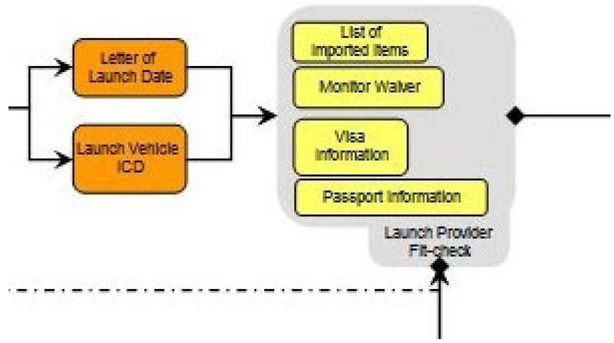


Figure 23: Schematic (Launch Provider Fit-Check)

The launch provider is responsible for manufacturing the interface adapter using the dimensions prescribed in the P-POD Interface Control Document (ICD). The P-POD is bolted to the Launch Vehicle Interface (LVI) adapter of which is attached to the launch vehicle. Cal Poly was responsible for providing 10 electrical simulators and five P-POD mass simulators to the fit-check. The mass simulators are required to maintain the P-POD external dimensions. The mass simulators must have a center of mass within 5% of a filly integrated P-POD. The aforementioned hardware was attached to the upper stage of launch vehicle along with other customer satellite mass simulators. The upper stage with all attachments underwent vibration, shock, and electrical testing.

Other issues of discussion during the fit-check included but not limited to cable lengths, the P-POD stopper bracket, and contractual issues.

5.3.2 CubeSat Fit-Check – Methodology

The fit-check is a milestone for the Dnepr launch campaign as it the first time hardware is displayed for all parties. The goal of the fit-check is to ensure that each design of the CubeSat integrates safely with the P-POD and neighboring CubeSats. Subsequent, discussion on modifications and recommendations of each individual CubeSat design is promoted through this face-to-face interaction.

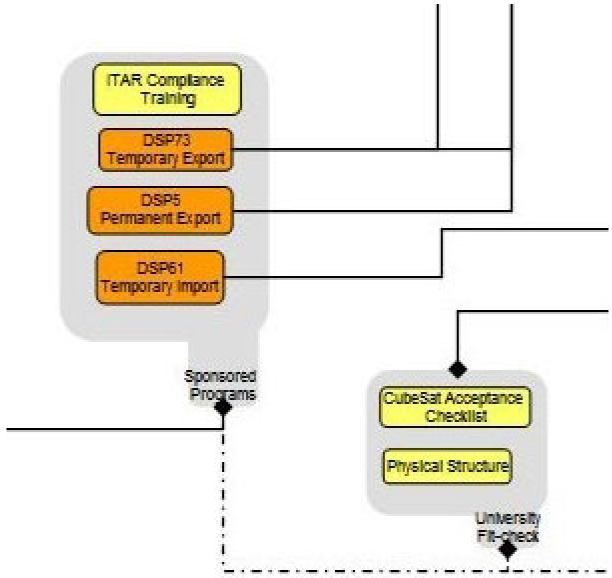


Figure 24: Schematic (CubeSat Fit-Check)

The launch coordinator determines the delivery date of the CubeSat fit-check after consulting with the Cal Poly CubeSat personnel, internal schedule, and the customer CubeSat development status. The CubeSat fit-check is scheduled to occur four to six months prior to the launch date. Less than four months prior to the launch date would not allow enough time for a CubeSat redesign and only allow for minor modifications in addition to environmental testing. The launch coordinator informed all customers that they are required to bring an external mockup of their CubeSat. This can be a structural mockup and does not need to be electrically functional. It is recommended that all external protrusions and deployables be completed or modeled in its stowed configuration. The customer is not required to bring any other types of documentation.

The launch coordinator and Cal Poly CubeSat Personnel developed the fit-check flow and examination documentations. The Cal Poly CubeSat Personnel are required to examine the mockup following the CubeSat Acceptance Checklist (CAC) (See Appendix D).

The launch coordinator outlined items that must be checked during the fit-check: as shown below:

- Protrusions that exceed 6.5mm from the CubeSat rail surface.
- Functional Spring Plungers
- Location of kill switches to shutoff current
- Location of RBF and diagnostic port
- Note all deployables located on the CubeSat and address their level of risk for accidental deployment or damage to neighboring CubeSats.
- Note all other issues with the CubeSat in complying with the CubeSat Specification Document

After examination and review of the structural mock-up and interface with a P-POD recommendations and modifications are discussed with each customer. All parties are encouraged to ask questions to alleviate any concerns in regards to the P-POD and CubeSats.

5.3.3 CubeSat Fit-Check – The Event

The CubeSat Fit-Check event occurred in the Advance technology Building 007 in laboratory room 15. Cal Poly CubeSat Personnel supported one group of customers that were allocated together as neighbors in the P-POD; therefore, a maximum of three customers and a maximum of six persons from the customers were in the laboratory at any one time. All groups were informed of when to arrive to the laboratory and were notified of changes in the schedule as necessary. The agenda items below were covered for each customer during their scheduled fit-check.

1. **Examination of Mockups**

   Two Cal Poly CubeSat Personnel performed the examination of the mockup. The Cal Poly CubeSat Personnel used the CAC as a guide to examining the CubeSat structural mockups. Items that were scrutinized included protrusions that exceed 6.5mm from the CubeSat rail surface, location of Remove-Before-Flight (RBF) Pins, data access port, separation springs, and kill switches. Cal Poly CubeSat personnel must note all deployables located on the CubeSat and address their level of risk for accidental deployment or damage to neighboring CubeSats.

2. **Environmental Testing**

   All customers were informed of the different levels of testing. The CubeSat must undergo random vibration and thermal vacuum testing with an optional sine sweep. Cal Poly CubeSat Personnel ensured that all customers have a facility to perform environmental testing. The customer could use Cal Poly as a backup location for environmental testing.

3. **Summarize Action Items**

   The Cal Poly CubeSat Personnel provided recommendations for needed modifications for the CubeSat design. Delivery schedule and documentation was also discussed.

5.4 System Level Testing

According to the test flow developed by the launch coordinator the P-POD and CubeSats must complete a battery of tests prior to CubeSat integration. After delivery, all hardware will undergo a final battery of environmental testing.

5.4.1 Testing Flow – P-POD MKII

The testing flow of hardware designed for on orbit use at Cal Poly must follow a testing regiment developed by the Cal Poly CubeSat personnel. The P-POD MKII was designed and manufactured during the launch campaign.

- P-POD MKII is manufactured and the quality of each piece is examined
- P-POD MKII is assembled following the P-POD Mechanical Assembly Procedures, which is an internal Cal Poly CubeSat procedure.
- P-POD MKII undergoes testing at 150% of the launch vehicle environment and 100% of the duration for each axis as illustrated in Figure 25. The P-PODs are then qualified for flight.

5.4.2 Testing Flow – CubeSat

This testing flow is required as a minimum for all customers on the launch campaign. This regiment of testing ensures that the design of the CubeSat can withstand the harsh environment of the launch vehicle. There is different stages of testing pre and post delivery of the CubeSats to Cal Poly for integration.

- Prior to shipment to Cal Poly the CubeSats are required to perform random vibration and thermal vacuum bakeout according to the Dnepr Safety Compliance Document [17].
- Test reports and results are given to Cal Poly for review.

5.4.3 Testing Flow – Integrated P-POD MKII

After all CubeSats are delivered to Cal Poly a final integration of hardware occurs. This final integration is done at 100% launch vehicle environment.

- Once the CubeSat is delivered to Cal Poly it will be inspected by two Cal Poly CubeSat Personnel following the same procedures as that of the fit-check. If for any reasons a CubeSat is not accepted it will be noted and further discussed with the customer to resolve the issue.
- After acceptance the CubeSats will be integrated into the P-POD to go through a final acceptance test.
- After the test the customers can perform diagnostics on their CubeSat using the data ports on the P-POD. CubeSats are not allowed to be removed after acceptance testing. If after inspection there is an issue that poses a risk to the launch vehicle, primary satellite, and/or CubeSats deintegration of the P-POD will be required. Depending on the extensiveness of the CubeSat modifications a retest at launch vehicle levels maybe required to satisfy all safety concerns.

5.4.4 Environmental Testing

LV Qualification Testing: Stage 2 testing requires that the CubeSat is ready for a full system level testing. LV Qualification testing is 150% of the launch vehicle environment and 100% of the duration for each axis as illustrated in Figure 25. The testing is required for random vibration; sine sweep, acoustic, and shock testing is optional. The random vibration profile can be found in the Dnepr Safety Compliance Document [17]. Note that testing levels may vary between launch vehicles.

DNEPR High Level Qualification Profile:

LOWER FREQ. (Hz)	20	40	80	160	320	640	1280
HIGHER FREQ. (Hz)	40	80	160	320	640	1280	2000
SPECTRAL DENSITY	0.011	0.011	0.033	0.053	0.053	0.053	0.026

DNEPR Low Level Qualification Profile:

LOWER FREQ. (Hz)	20	40	80	160	320	640	1280
HIGHER FREQ. (Hz)	40	80	160	320	640	1280	2000
SPECTRAL DENSITY	0.011	0.011	0.011	0.014	0.014	0.007	0.007

Figure 25: Random Vibration level testing from Dnepr Safety Compliance Document

Thermal Vacuum Bakeout: Stage 2 testing includes a Thermal Vacuum Bakeout of the CubeSat after completing the LV Qualification testing and is ready to be delivered to be integrated into the P-POD. Thermal Vacuum Bakeout is done to remove any volatiles and outgassing materials that have remained due to assembly. The Thermal Vacuum Bakeout minimum standard must be at a high vacuum of 1×10^{-4} Torr and the CubeSat must soak at a temperature of 70°C for one hour for two cycles illustrated in Figure 26. Figure 26 also illustrates an alternate temperature of 60°C for a two hour soak for two cycles.

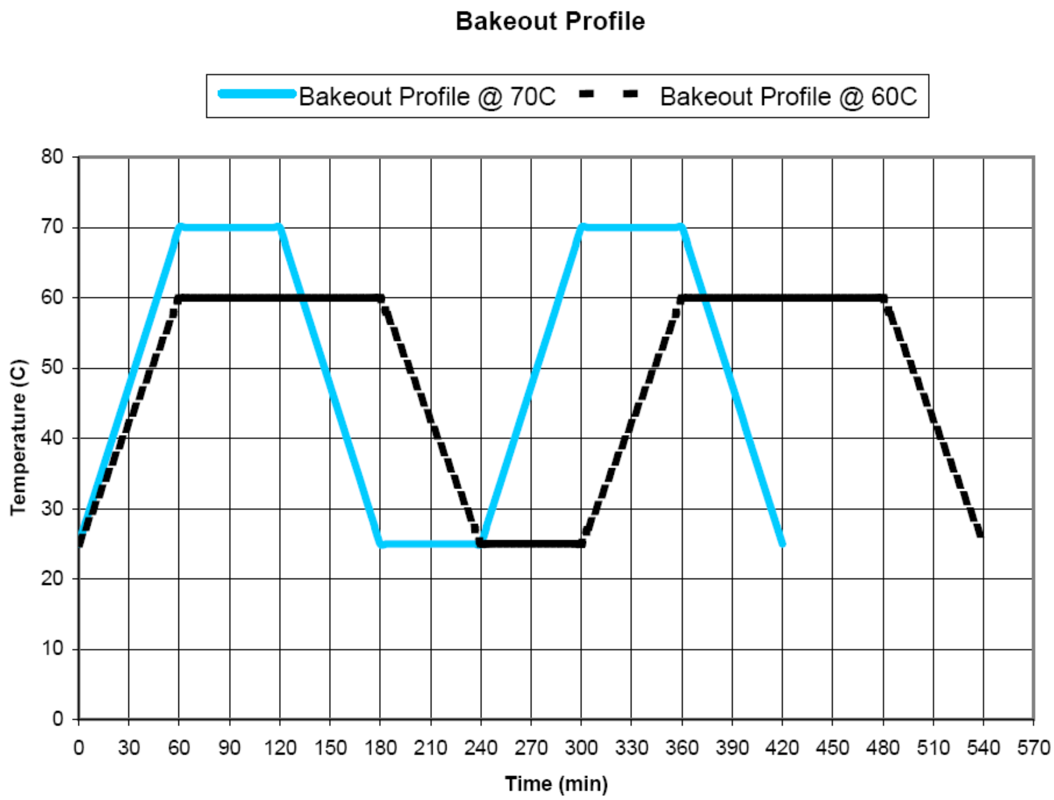


Figure 26: Thermal Vacuum Bakeout Profile

LV Acceptance Testing: Stage 3 testing requires that all CubeSat have been checked and accepted by Cal Poly CubeSat Personnel and integrated into the P-POD for the final testing prior to shipment to the launch site. The LV Acceptance test is at 100% launch vehicle levels and 100% of the duration for each axis as illustrated in Figure 27. The testing is required for random vibration; sine sweep, acoustic, and optional shock testing.

Table 9.3-3 Spectral Density of Vibro-accelerations at SC/LV Interface

Frequency sub-band, Hz	Load Source	
	Liftoff, LV flight segment where M=1, q_{max}	1st stage burn (except for LV flight segment where M=1, q_{max}), 2nd stage burn, 3rd stage burn
	Spectral Density, g^2/Hz	
20-40	0.007	0.007
40-80	0.007	0.007
80-160	0.007-0.022	0.007
160-320	0.022-0.035	0.007-0.009
320-640	0.035	0.009
640-1280	0.035-0.017	0.009-0.0045
1280-2000	0.017-0.005	0.0045
Root Mean Square Value, σ, g	6.5	3.6
Duration, sec.	35	831

Figure 27: 100% of the launch vehicle environment located in Dnepr LV Users Guide

5.5 CubeSat Integration

5.5.1 Methodology

CubeSat integration milestone requires the delivery of the flight CubeSats to Cal Poly after it has successfully completed the testing as required by the Dnepr Safety Compliance Document with the subsequent changes since fit-check as illustrated in Figure 28 [17]. Environmental reports and procedures are required from the customer. CubeSats must then undergo an examination by Cal Poly CubeSat Personnel using the CubeSat Acceptance Checklist as a guide (see Appendix C).

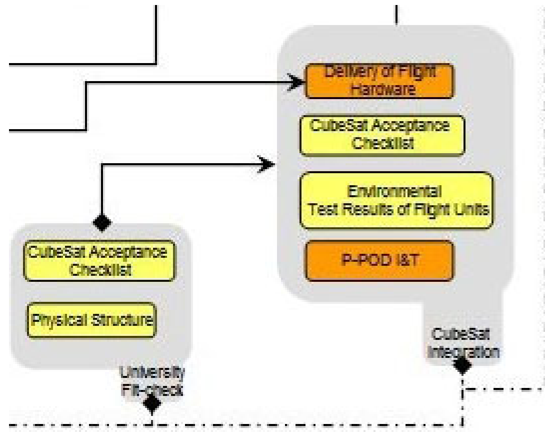


Figure 28: Schematic Model (CubeSat Integration)

After inspection, customers are apprized of integration procedures. Final testing is performed on the integrated system and tested in three axes at 100% launch vehicle environment profile. The CubeSats cannot be removed from the P-POD after testing unless there is a potential danger to satellites and the launch vehicle. Post-test diagnostics can be performed through the data access ports on the P-POD.

Post-diagnostics and inspection after environmental testing may uncover CubeSat malfunction(s). Physical removals of CubeSats are not allowed as it will compromise the final system level test. However, if the malfunction poses potential harm to the launch vehicle, other satellites, and CubeSats then this is a dominant issue that requires the deintegration of the P-POD. The extent of the repairs will be assessed with the customer. If the repairs are not extensive then the plan of action will be disclosed to all neighboring CubeSats in the P-POD. Testing may be required after repairs depending on the consensus of the neighbors in the P-POD. If repairs are too extensive and impact the overall schedule then a mass model will replace the CubeSat. Future launch opportunities with the customer can be discussed at a later date. This method is illustrated in the decision tree in Figure 29.

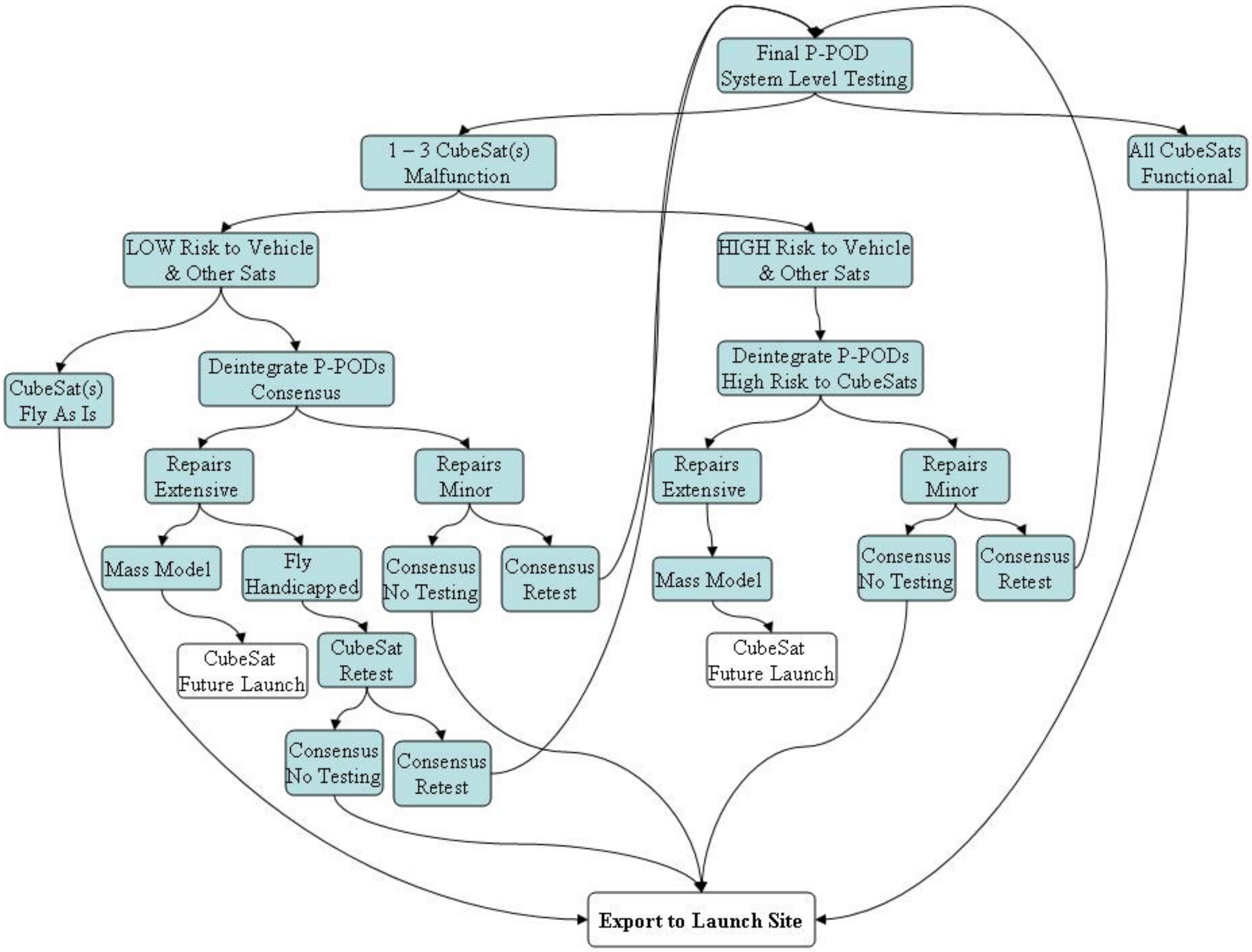


Figure 29: Decision tree after testing of Integrated P-PODs.

5.5.2 Theory

CubeSat integration is the final step prior to delivery of the integrated hardware to the launch site. There are various items that the coordinator needs to consider for the integration process, which can be broken into three general categories: Logistics, Hardware, and Procedures. Each category is dependent of each other but the coordinator must first understand the logistics/events for the CubeSat integration then what hardware will be needed for the event and what procedures will be used or developed from this event.

CubeSat Integration Logistics/Events:

- Delivery to the launch site
- Arrival of CubeSat personnel
- Flight CubeSat unpacking and GSE
- Availability of vibration testing facility
- Availability of thermal vacuum facility
- Availability of cleanroom facility
- Availability of internal Cal Poly CubeSat personnel
- Charging of CubeSats
- Diagnostic schedule of CubeSats
- CubeSat integration
- Include margin in the event repairs are needed

Hardware (Needed):

1. Flight CubeSat
2. GSE
3. General Tools
4. Power Supply
5. Multimeter
6. Testing Adapters

Procedures:

1. Battery Charging Procedures
2. Diagnostic Procedures
3. CAC (CubeSat Acceptance Checklist)
4. Integration Procedures
5. Vibration Standard Operation Procedures
6. Thermal Vacuum Standard Operating Procedures

Taking the above items into consideration a preliminary schedule is illustrated in Figure 30 to Figure 32. The CubeSat Integration is scheduled to be approximately two weeks and allows little margin in the schedule for changes and contains overlaps of differing P-POD events in one day. This integration schedule was presented to customers and other CubeSat developers at the AIAA 18^{th} Annual Small Satellite Conference where a CubeSat Workshop was held prior to the Small Satellite Conference.

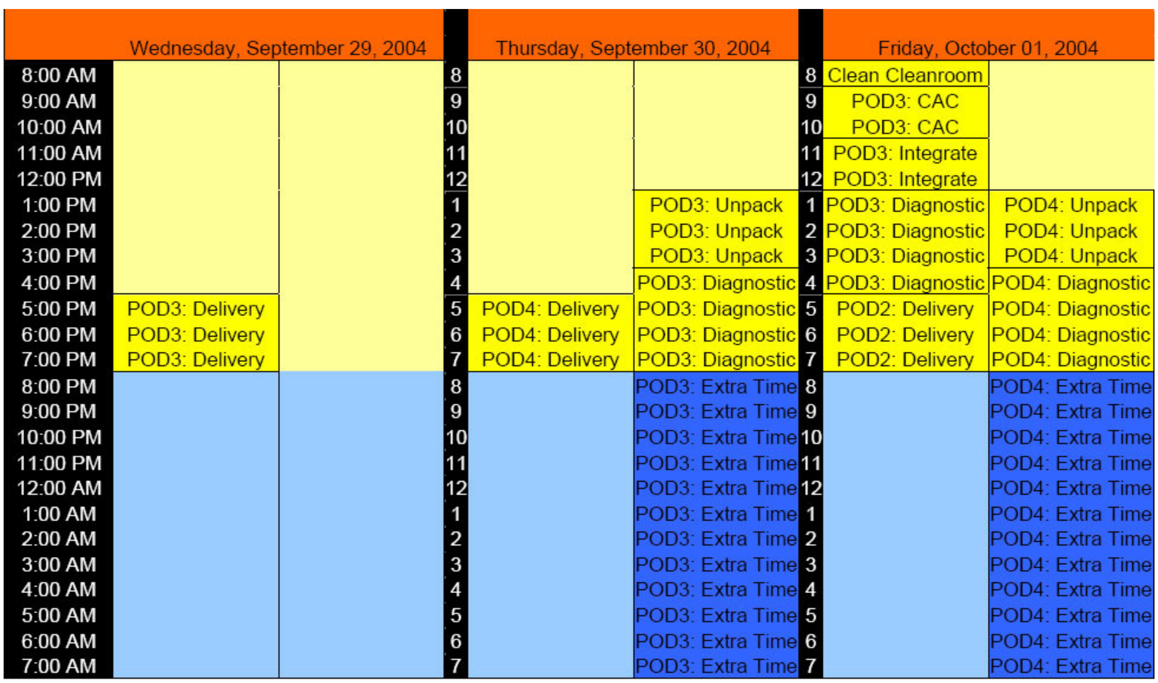
The CubeSat integration schedule was driven by several major factors:

- **Launch Date:** The most important driver to the integration schedule is the launch date. The Dnepr launch provider requires that all integrated P-PODs be delivered to the launch facility 3 to 4 weeks prior to the launch. This was driven by the assembly and integration of the upper stage of which the P-PODs are installed in the early stages and larger satellites are installed above and around the integrated P-PODs. If the launch dates are delayed the integration schedule dates can be changed to give more time for the flight CubeSats to be completed and tested properly. An integration date change is an option pending on the condition of all CubeSats and customer needs.

- **Vibration Facility:** Another major driver includes scheduling time for vibration testing. This is a major driver if the vibration facility is outsourced. The facility may have limited time for testing, therefore, subject to their schedule. The ability to retest will be difficult since it may require weeks of prior notice. It is recommended that testing be done in-house as this creates more flexibility in the testing schedule and use of equipment. In Figure 32, the acceptance vibration test was completed by the Raytheon Company in El Segundo. This decision was made to ensure that the integrated P-PODs were tested by technicians with years of experience running vibration tests. This minimized a potential risk variable of damaging the CubeSats because of improper testing.

- **Logistical Cost of Customers:** Customers have a fixed budget and for some customers international and domestics travel is expensive which restricts the number of arrivals and visitation time at Cal Poly. The trade off was the cost of travel for the customers or the needed margin in the schedule in the event of a failure. It was determined that any minor failures could be repaired in one to two days well within the allotted time prior to delivery to environmental testing. On the other hand, major repairs could take well over several weeks to correct and shipment back to the original facility. The decision was made to have a compact schedule with minimum margin.

♦ **Complexity of events:** The final driver was the level of complexity of different events during the integration sequence that allowed for a staggered approach seen in Figure 30 to Figure 32. For example, the delivery of P-PODs and unpacking have a low risk of complexity and schedule impact as it requires that developers arrive with their CubeSat and move it in the cleanroom. On the other hand, the CAC, integration, and diagnostics can be complex. These three events have a high risk of impacting the schedule if issues occur.



	Wednesday, September 29, 2004			Thursday, September 30, 2004			Friday, October 01, 2004	
8:00 AM			8			8	Clean Cleanroom	
9:00 AM			9			9	POD3: CAC	
10:00 AM			10			10	POD3: CAC	
11:00 AM			11			11	POD3: Integrate	
12:00 PM			12			12	POD3: Integrate	
1:00 PM			1		POD3: Unpack	1	POD3: Diagnostic	POD4: Unpack
2:00 PM			2		POD3: Unpack	2	POD3: Diagnostic	POD4: Unpack
3:00 PM			3		POD3: Unpack	3	POD3: Diagnostic	POD4: Unpack
4:00 PM			4		POD3: Diagnostic	4	POD3: Diagnostic	POD4: Diagnostic
5:00 PM	POD3: Delivery		5	POD4: Delivery	POD3: Diagnostic	5	POD2: Delivery	POD4: Diagnostic
6:00 PM	POD3: Delivery		6	POD4: Delivery	POD3: Diagnostic	6	POD2: Delivery	POD4: Diagnostic
7:00 PM	POD3: Delivery		7	POD4: Delivery	POD3: Diagnostic	7	POD2: Delivery	POD4: Diagnostic
8:00 PM			8		POD3: Extra Time	8		POD4: Extra Time
9:00 PM			9		POD3: Extra Time	9		POD4: Extra Time
10:00 PM			10		POD3: Extra Time	10		POD4: Extra Time
11:00 PM			11		POD3: Extra Time	11		POD4: Extra Time
12:00 AM			12		POD3: Extra Time	12		POD4: Extra Time
1:00 AM			1		POD3: Extra Time	1		POD4: Extra Time
2:00 AM			2		POD3: Extra Time	2		POD4: Extra Time
3:00 AM			3		POD3: Extra Time	3		POD4: Extra Time
4:00 AM			4		POD3: Extra Time	4		POD4: Extra Time
5:00 AM			5		POD3: Extra Time	5		POD4: Extra Time
6:00 AM			6		POD3: Extra Time	6		POD4: Extra Time
7:00 AM			7		POD3: Extra Time	7		POD4: Extra Time

Figure 30: Preliminary integration timeline (1of3)

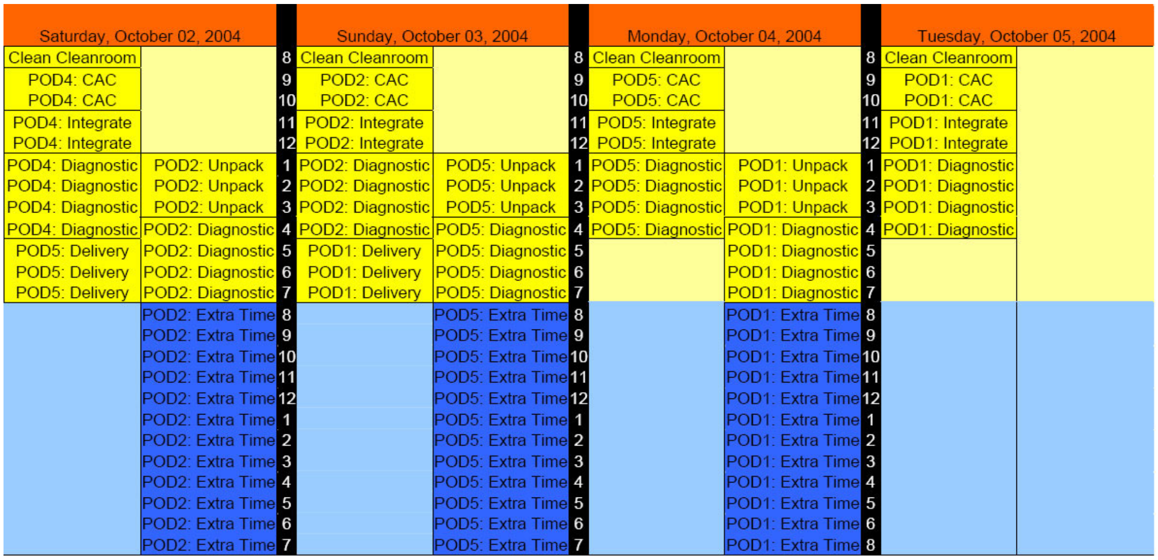


Figure 31: Preliminary integration timeline (2of3)

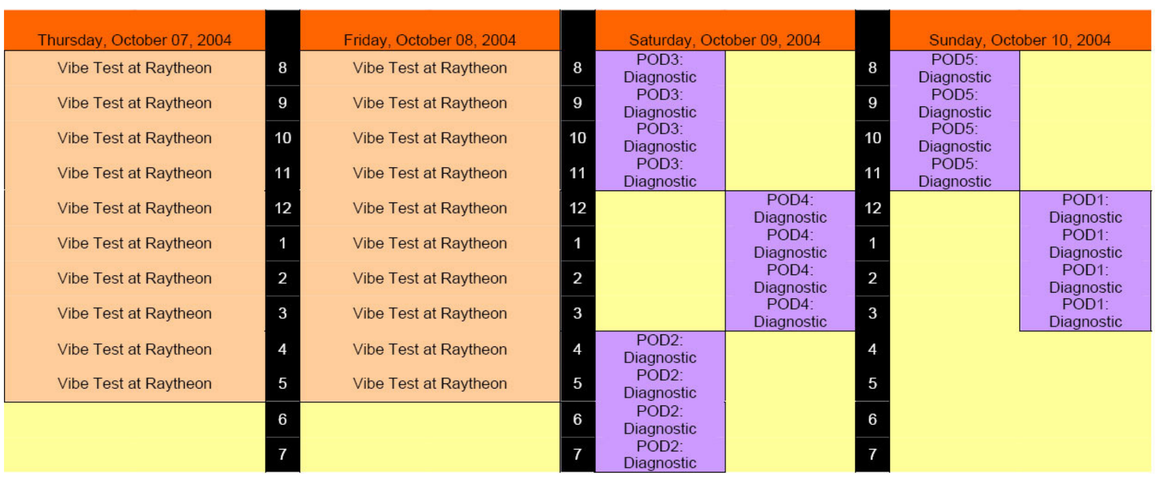


Figure 32: Preliminary integration timeline (3of3)

5.5.3 Reality

The actual integration timeline is illustrated in Figure 33 to Figure 36. These figures illustrate a differences from the theoretical model presented in Figure 30 to Figure 32. This apparent difference was driven by the changing arrival schedules of the customers when compared to their predicted arrival. This caused various delays in the integration and testing schedule which prolonged the stay for customers.

In order to decrease the overall travel cost of the customer, integration and testing was separated into two stages. Stage 1 includes the integration and testing of customers in P-POD A, B, and C. Stage 2 testing consisted of P-POD E and D. The vibration facility was notified of the change in the testing schedule of which was then determined that they could accommodate the change in the schedule. The testing facilities ability to accommodate the change in the schedule decreased the length of stay for the customers and their overall travel cost.

Other major drivers to the launch schedule include CubeSat issues that required additional time in the laboratory to repair minor issues. These issues impacted the testing schedule as later testing by the facility could not be done due to internal projects. The issues overall impact on delivery to the launch site was minimal due to a subsequent delay in the launch date.

DNEPR 2004-2005 Integration Schedule

	Monday, March 28, 2005	Tuesday, March 29, 2005	Wednesday, March 30, 2005	
8:00 AM	Clean Cleanroom		Clean Cleanroom	
9:00 AM				
10:00 AM				P-POD-A: Delivery
11:00 AM				P-POD-A: Delivery
12:00 PM				P-POD-A: Delivery
1:00 PM				
2:00 PM				
3:00 PM				
4:00 PM				
5:00 PM	P-POD-B: Delivery			
6:00 PM	P-POD-B: Delivery			
7:00 PM	P-POD-B: Delivery			
8:00 PM	P-POD-B: Diagnostic			
9:00 PM	P-POD-B: Diagnostic			
10:00 PM	P-POD-B: Diagnostic			
11:00 PM	P-POD-B: Diagnostic			
12:00 AM	P-POD-B: CAC			
1:00 AM	P-POD-B: CAC			
2:00 AM				
3:00 AM				
4:00 AM				
5:00 AM				
6:00 AM				
7:00 AM				
			Illinois arrives	3 persons
			All foreign Satellites have been delivered	

Figure 33: Actual Integration Schedule (1of4)

Thursday, March 31, 2005		Friday, April 01, 2005		Saturday, April 02, 2005	
Clean Cleanroom		Clean Cleanroom		Clean Cleanroom	
		P-POD-A: CAC		P-POD-C: CAC	
		P-POD-A: CAC	P-POD-C: Delivery	P-POD-C: CAC	
		P-POD-A: Integrate	P-POD-C: Delivery	P-POD-C: Integrate	
		P-POD-A: Integrate	P-POD-C: Delivery	P-POD-C: Integrate	
	P-POD-A: Unpack	P-POD-A: Diagnostic	P-POD-C: Unpack	P-POD-C: Diagnostic	
	P-POD-A: Unpack	P-POD-A: Diagnostic	P-POD-C: Unpack	P-POD-C: Diagnostic	
	P-POD-A: Unpack	P-POD-A: Diagnostic	P-POD-C: Unpack	P-POD-C: Diagnostic	
	P-POD-A: Diagnostic	P-POD-A: Diagnostic	P-POD-C: Diagnostic	P-POD-C: Diagnostic	
	P-POD-A: Diagnostic		P-POD-C: Diagnostic		
	P-POD-A: Diagnostic		P-POD-C: Diagnostic		
	P-POD-A: Diagnostic		P-POD-C: Diagnostic		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
	P-POD-A: Extra Time		P-POD-C: Extra Time		
		Integrate P-POD A with Arizona EM		Integrate International P-POD-C	
		Nihon Arrives	1 person		

Figure 34: Actual Integration Schedule (2of4)

	Tuesday, April 05, 2005		Wednesday, April 06, 2005		Thursday, April 07, 2005	
8:00 AM	Clean Cleanroom				Vibe Test at Raytheon	Clean Cleanroom
9:00 AM	P-POD-B: Unpack				Vibe Test at Raytheon	
10:00 AM	P-POD-B: Unpack				Vibe Test at Raytheon	
11:00 AM	P-POD-B: Unpack				Vibe Test at Raytheon	
12:00 PM	**P-POD-B: Integrate**				Vibe Test at Raytheon	
1:00 PM	**P-POD-B: Integrate**				Vibe Test at Raytheon	
2:00 PM	P-POD-B: Diagnostic				Vibe Test at Raytheon	
3:00 PM	P-POD-B: Diagnostic				Vibe Test at Raytheon	
4:00 PM	P-POD-B: Diagnostic				Vibe Test at Raytheon	
5:00 PM	P-POD-B: Diagnostic				Vibe Test at Raytheon	
6:00 PM						
7:00 PM						
8:00 PM					P-POD-C: Diagnostic	
9:00 PM					P-POD-C: Diagnostic	
10:00 PM					P-POD-C: Diagnostic	
11:00 PM					P-POD-C: Diagnostic	
12:00 AM						P-POD-B: Diagnostic
1:00 AM						P-POD-B: Diagnostic
2:00 AM						P-POD-B: Diagnostic
3:00 AM						P-POD-B: Diagnostic
4:00 AM					P-POD-A: Diagnostic	
5:00 AM					P-POD-A: Diagnostic	
6:00 AM					P-POD-A: Diagnostic	
7:00 AM					P-POD-A: Diagnostic	
	Arrives for Delivery/ Diagnostics/ Acceptance Check					
	Cornell Satellites Arrive	2 persons			Vibration test P-POD A, B, and C	
	Kansas person arrives	1 person			Diagnostic Test all satellites	
	Integrate P-POD B				Arizona Arrives with FM	2 persons

Figure 35: Actual Integration Schedule (3of4)

Sunday, April 10, 2005		Monday, April 11, 2005		Tuesday, April 12, 2005	
Clean Cleanroom				Vibe Test at Raytheon	Clean Cleanroom
P-POD-E: Unpack	P-POD-D: Unpack			Vibe Test at Raytheon	
P-POD-E: Unpack	P-POD-D: Unpack			Vibe Test at Raytheon	
P-POD-E: Unpack	P-POD-D: Unpack			Vibe Test at Raytheon	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			Vibe Test at Raytheon	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			Vibe Test at Raytheon	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			Vibe Test at Raytheon	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			Vibe Test at Raytheon	
P-POD-E: CAC	P-POD-D: CAC			Vibe Test at Raytheon	
P-POD-E: CAC	P-POD-D: CAC			Vibe Test at Raytheon	
P-POD-E: Integrate	**P-POD-D: Integrate**				
P-POD-E: Integrate	**P-POD-D: Integrate**				
P-POD-E: Diagnostic	P-POD-D: Diagnostic			P-POD-E: Diagnostic	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			P-POD-E: Diagnostic	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			P-POD-E: Diagnostic	
P-POD-E: Diagnostic	P-POD-D: Diagnostic			P-POD-E: Diagnostic	
					P-POD-D: Diagnostic
					P-POD-D: Diagnostic
					P-POD-D: Diagnostic
					P-POD-D: Diagnostic
Montana Arrives				Vibration Test	
Aerospace Corp Arrives	3 persons			Diagnostics	
Integrate P-POD E with A	3 persons			Insert Arizona FM into P-POD.	
Integrate P-POD D					

Figure 36: Actual Integration Schedule (4of4)

5.6 Launch & Operations

All integrated P-PODs must be packaged and shipped to the launch facility along with general tools as illustrated in Figure 37. An experienced satellite shipper was hired under the recommendation of ISC Kosmotras. Upon reaching the launch facility further inspection of the P-PODs and hardware was carried out. After final inspection, the integrated P-PODs were handed over to the launch provider for integration. A document stating the flight readiness of the P-POD was signed by the Cal Poly CubeSat representatives at the launch facility. Figure 38 illustrates the Dnepr integration schedule in respect to the launch date.

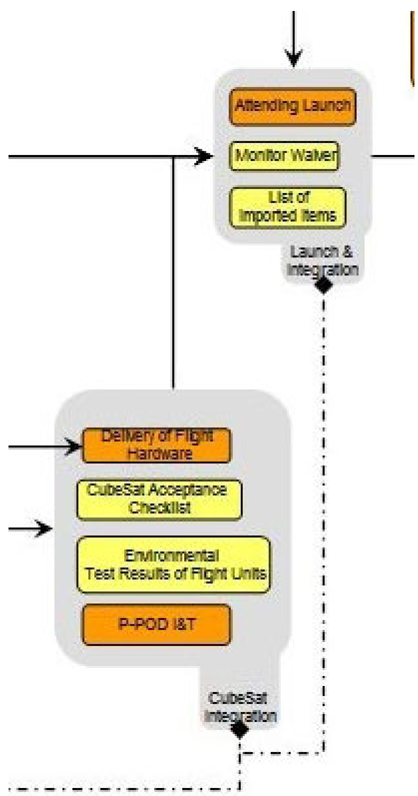


Figure 37: Schematic (Launch and Operations)

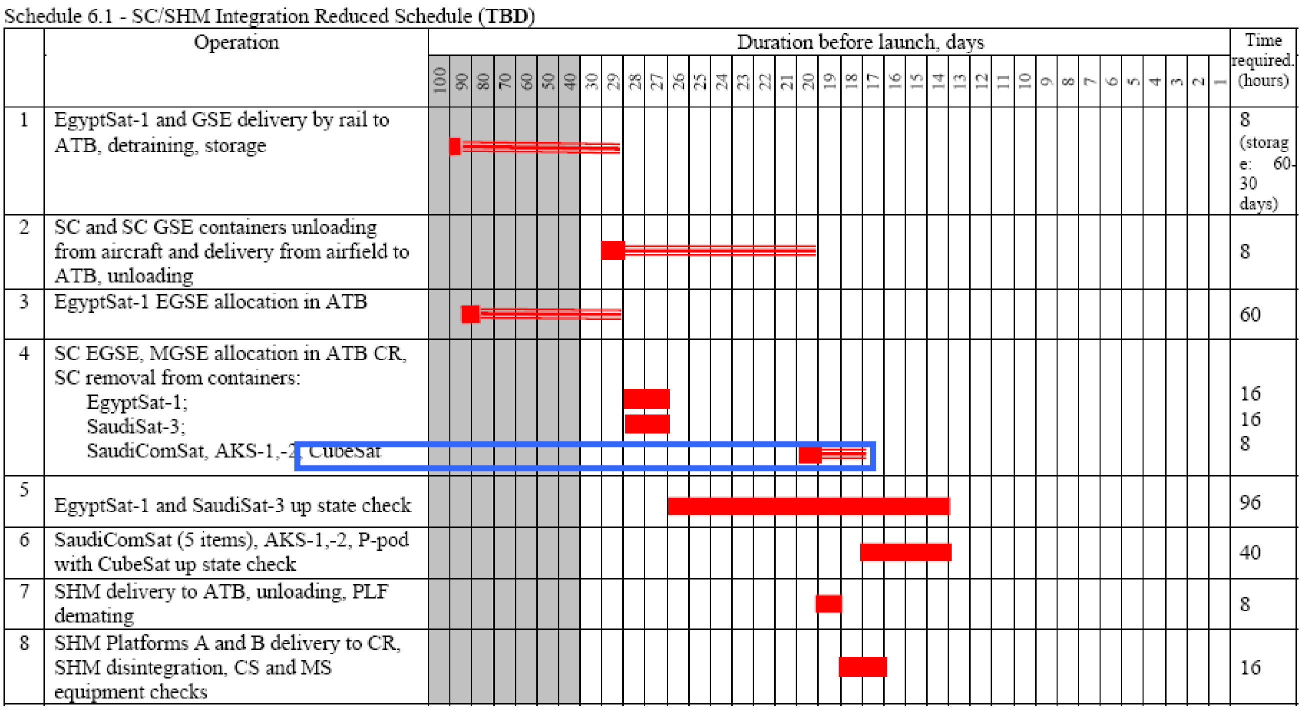


Figure 38: Integration of P-PODs to the upperstage of the launch vehicle.

5.6.1 Launch Facility – Baikonur Cosmodrome

The launch coordinator must outline security precautions at the launch facility to comply with the requirements of the ODTC. All hardware at the launch site must be secure and cannot be tampered with so that technology is transferred to a foreign entity. Subsequent negotiations were made with the launch provider to provide us with a secure cabinet, class 100,000 cleanroom, and an enclosed work area in the event that deintegration of the P-PODs was required. At least one Cal Poly employee will monitor defense items during the hours of operation at Baikonur Cosmodrome. Otherwise P-PODs will be stored in the locked cabinet provided by the launch provider.

The installation of the P-PODs will be done by the launch integrators and monitored by Cal Poly personnel. The P-POD acts as a security device by encapsulating the CubeSats. The CubeSats cannot be examined without removing the bolt closing the door. The bolt locked in place and tampering will be self evident. If the bolt is removed there could be permanent damage caused by the main spring ejecting the CubeSats. Cal Poly CubeSat personnel can immediately detect any tampering or damage to the integrated P-PODs. This procedure ensures that no information can be transferred to a foreign entity without knowledge by Cal Poly personnel.

5.6.2 Launch and Tracking

Before and after the launch CubeSats need to be identified and tracked in the first critical week after orbital deployment of CubeSats as illustrated in Figure 39. After launch a CubeSat, if damaged and on primary batteries, may only have an operational lifespan of a few days. Through the participation of amateur radio operators around the world and participating customers with groundstations, Cal Poly will direct the effort in locating and identifying the CubeSats. Tracking information will be provided directly by NORAD and subsequently posted on the Space Track website [15]. Status of CubeSats will be posted on the CubeSat Website as a central area for up-to-date information.

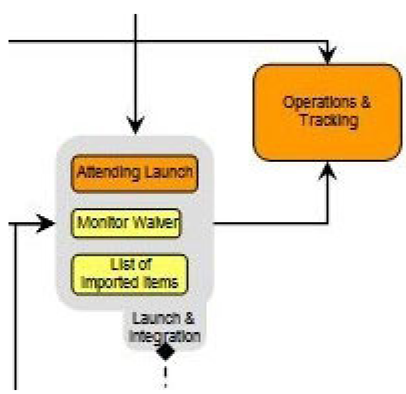


Figure 39: Schematic (Operations and Tracking)

After a user logs into the Space Track website and inputs the date of the launch, the latest 2-line elements of the currently tracked objects for that launch will be provided. A sample set of 2-line elements and descriptors is illustrated in Figure 40.

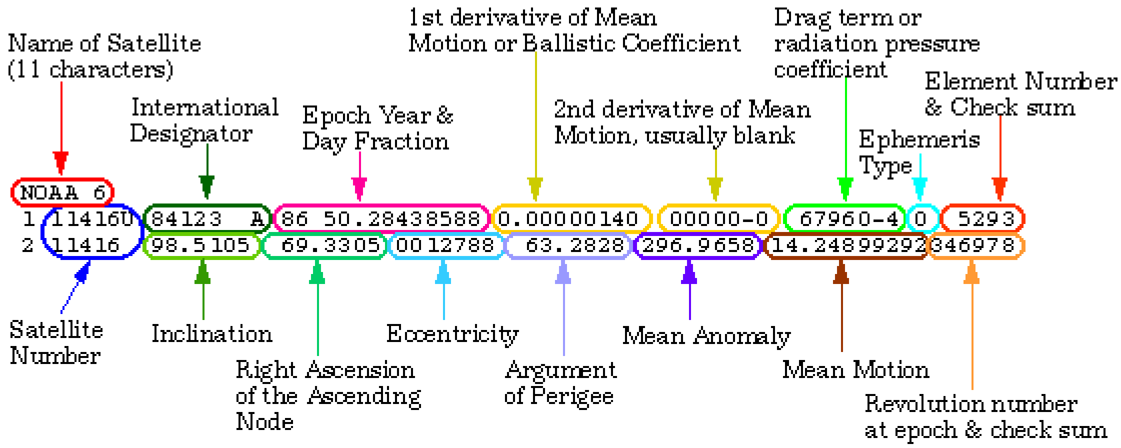


Figure 40: A sample 2-Line Element used too identify satellites

After launch, 2-line elements will be provided for each object that is tracked, however, the tracked objects can be a cluster of satellites or the vehicle, especially if the satellite cross section is small (i.e. CubeSats). It is expected that 2-line elements may in fact be a set of CubeSats. If contact with one CubeSat can be made, then the P-POD allocation can assist in determining neighboring unidentified 2-line elements. It may take up to two weeks to distinguish all the CubeSats as was the case in the June 30, 2003 Eurockot launch and the SSETI Express launch on October 27, 2005.

The launch coordinator outlined a plan for an efficient tracking and search of the CubeSats. This objective requires a centralization of information so that operators can obtain data and direct the focus of the search. The CubeSat mailing list, satellite status and info web page, discussion boards, and IRC room were developed as tools for directing the search.

- **The CubeSat mailing list:** The mailing list comprises of all individuals that are interested in CubeSats. Users can subscribe and unsubscribe at anytime. This application is used to provide a direct email of updates of the CubeSat launch status, satellite status, and to refer all interested parties in search and tracking to visit the website for more information.

- **Satellite Status and Info web page:** A CubeSat operations form was created and collected from the customers and placed on the CubeSat website for all interested operators to communicate with the CubeSat and what to expect from a CubeSat transmission. The form can be found in Appendix E. This section of the website provides up-to-date information of the status of the CubeSats. This area can focus the efforts of all who are participating in tracking to search for CubeSats that have not been identified or are malfunctioning.

- **Discussion Boards:** This area of the website is a repository where participating operators can offer their input or information on the search effort.

- **IRC Room:** A chatroom in which all parties participating in the tracking are encouraged to participate. This application provides instant access to all those that are participating in the launch and tracking efforts. Any questions, issues, information can be addressed by multiple people at one time. Information using this application is not permanently stored.

The coordinator and the Cal Poly CubeSat team must use all the information inputted into these tools to provide correct status updates of the CubeSats in orbit. Then using the information provided to determine the focus of the identification effort.

5.7 Launch Campaign Schedule(s)

Throughout the launch campaign, schedules were developed, modified, and refined at varying stages. A preliminary campaign schedule was developed in February 2003 as illustrated in Figure 41. Figure 41 illustrates lead-times for milestones and responsibilities which were then categorized for the launch provider, customers, and Cal Poly. A delay in one occurrence ripples through the schedule. Items early in the launch campaign do not offer a significant impact to the schedule. Delay on items near the end of the launch campaign (i.e. integration/testing/diagnostic) can culminate in a lost launch opportunity.

A unique advantage of the Dnepr launch campaign is the availability and flexibility of contracts and payments between Cal Poly, the customer, and the launch provider. Once a program is sponsored by Cal Poly, the full amount is allotted to the program and can be used to pay for services and materials meanwhile funding is gathered from the customers. This allows immediate use of funding to progress hardware development and procurement. Contract negotiations with the customer and launch provider continued while hardware development was continuing internally. This flexibility enabled internal development progress.

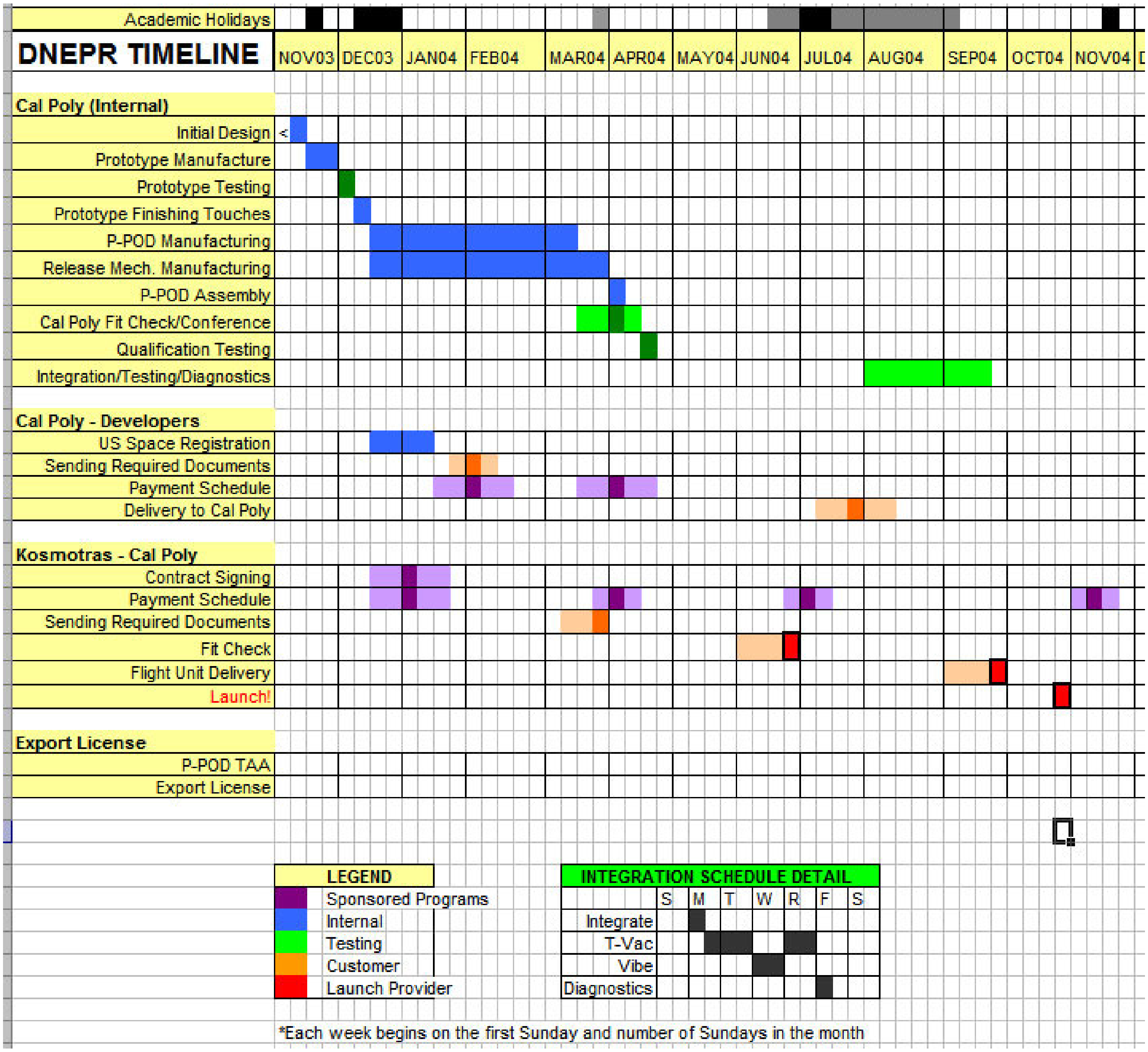


Figure 41: Preliminary Program Schedule

Though there were very little impacts to the schedule internally, externally there were numerous impacts to the schedule including launch delays. Figure 42 illustrates numerous launch delays that were presented to CubeSat developers at the 19th Annual AIAA Conference on Small Satellites. These delays initially provided additional margin to the program schedule. In later delays it became a discouragement as CubeSats were finalized and ready for delivery to Cal Poly. On April 2005, all CubeSats were delivered to Cal Poly for integration. This decision for delivery was made in order for customers to move to the next generation CubeSat development at their institutions.

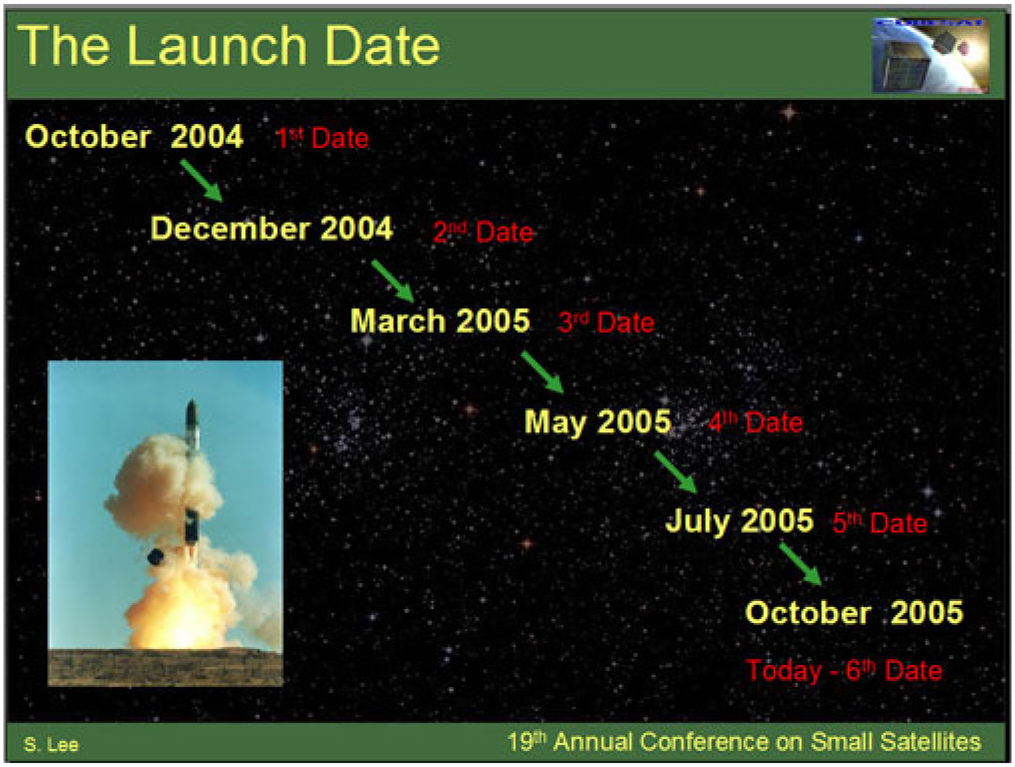


Figure 42: Dnepr Launch Campaign Delays

Delays continue past October 2005. CubeSats were in storage for over a year. As a service, customers were allowed to charge and perform diagnostics on their CubeSat during storage. Upon the request of the customer Cal Poly can perform these services. Of particular concern was the charge remaining in the batteries over the year of storage. CubeSats usually use lithium-ion batteries which have a low discharge rate. A significant depletion of a battery can be an indicator of a current leak in the system. Customers were consulted when issues arose.

Charging and diagnostics can be requested by the customer up until the delivery of the integrated unit as illustrated in Figure 43. Figure 43 demonstrates a detailed sequence schedule prior to the launch; a larger image can be viewed in Appendix F. At this stage the launch date has been confirmed. CubeSats that have been repaired at the customer facility and retested are delivered to Cal Poly for final integration and subsequent shipment to the launch site. All P-PODs undergo a final inspection prior to packaging and shipment to the launch site.

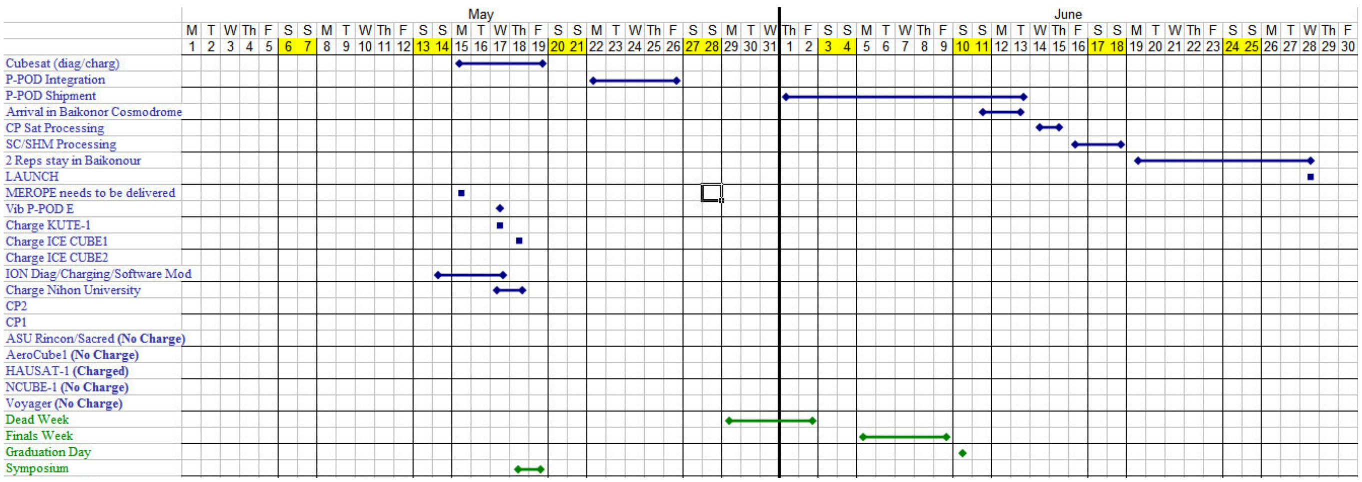


Figure 43: Detailed Delivery Sequence Schedule

6 Conclusion and Future Work

Due to the nature of a pioneering program like the Dnepr launch campaign system engineering management processes, protocols, and monitoring tools were developed. As the launch campaign moved forward, those processes, protocols, and monitoring tools were refined. A summary of the launch campaign milestones are outlined along with recommendations for future work.

6.1 Tools

6.1.1 Summary

Tools developed for the Dnepr launch campaign were to ensure the safety of the vehicle, satellites, and CubeSats. The monthly status report and P-POD allocation tools provided information on the development of the CubeSats prior to the fit-check. The tools also assisted in the development of the CubeSat integration schedule and CubeSat fit-check.

6.1.2 Lessons Learned & Recommendations

- Monthly Status Report: With the data gathered on the development of CubeSats from the Dnepr launch campaign, analysis can be done to determine a typical timeline for CubeSat development.
- Monthly Status Report: By understanding the typical timeline for CubeSat development, weights can then be added to the monthly status report to provide ideal numerical values of each stage of development. If a customer falls short of the value after returning the monthly status report then further discussions with the customer is needed.

- P-POD Allocation: CubeSat components such as spring plungers and kill switches need to be added to the form. The data should include force, stiffness of the spring, manufacturer, and part number.

6.2 Dnepr Fit-Check

6.2.1 Summary

The Dnepr Fit-check was located in Yuzhnoye SDO in Dnepropetrovsk, Ukraine. In attendance were two Cal Poly CubeSat personnel and the export control officer along with ISC Kosmotras, Yuzhnoye SDO engineers, and other satellite customers. All satellite customers provided mass simulators of their satellite. Cal Poly shipped 10 electrical simulators, four P-POD mass simulators, and one P-POD engineering unit. All mass and electrical simulators and engineering unit underwent vibration, shock, and electrical testing.

6.2.2 Lessons Learned & Recommendations

- Ukraine Customs office took several days to clear the hardware after arrival in Dnepropetrovsk, Ukraine. The launch provider stated that one day was sufficient to clear customs.
- Note that the mass simulators were removed from the packaging and handled by customs agents in an unclean environment.
- The facility is not in a clean environment and there is no temperature or humidity control. It is recommended that Cal Poly maintain levels of cleanliness and professionalism for future launch opportunities. At a minimum creates the correct professional mindset for training students.

- More accurate mass simulators are needed: The P-POD bolt interface was out of tolerance in certain areas when the SDO Yuzhnoye engineers proceed to bolt the mass simulators and the engineering unit to the interface adapter.
- Be prepared for SDO Yuzhnoye engineers to proceed without consultation in modifications. Example: The diameter of the interface adapter was increased to 0.5mm so that the P-POD Mass simulators can attach properly to the adapter.
- Increase the fidelity of mass simulators (i.e. Add stopper bracket).
- Bring at least one engineering P-POD to demonstrate clearances as the door opens.
- Testing will be performed on the integrated stack of the upper stage.
- Minor issues: Include but not limited to clarifications of cable lengths and length of the stopper bracket.

6.3 CubeSat Fit-Check

6.3.1 Summary

University Fit-Check was conducted at Cal Poly State University. It was held in conjunction with the CubeSat Workshop in April 2004. All customers were required to bring at a minimum a structural model that is externally equivalent to the actual flight hardware. The structural model did not need to be electrically functional. Customers brought structural models with exterior panels while several others that were further in development delivered their flight ready CubeSat. Both cleanroom and laboratory benches were used for the acceptance of CubeSats and structural mock-ups. The face-to-face interface proved to be useful in determining issues and recommendation in interfacing the CubeSat with the P-POD, the facilities and equipment that Cal Poly can offer to the customers, the internal procedures and level of standards (i.e. cleanliness).

6.3.2 Lessons Learned & Recommendations

- Provide a summary of action items that all parties can agree to. Include modification(s) with quantifiable numbers, test reports and results, customer required procedures, testing hardware and facilities.
- Customer's documentation: Customer CubeSat Development Schedule, which should include general topics such as but not limited to manufacturing, testing, and delivery of hardware.
- An external mockup must be dimensionally equivalent to the actual hardware. This includes mock deployables, solar cells, etc. If a fully equivalent dimensional hardware cannot be provided the customer must provide a solid model version with all protrusions and deployables in the stowed position. They can provide the solid model to Cal Poly in electronic format. For all solid models, *.iges format is recommend.

6.4 CubeSat Integration

6.4.1 Summary

CubeSat Integration began on March 28, 2005 and was completed on April 12, 2005. This was completed 2 months prior to the launch date which was still undefined during CubeSat integration. All flight CubeSats were delivered to Cal Poly and integrated into the P-PODs. During the process of integration issues arose ranging from clearance issues, tolerances, CubeSat malfunctions, accidental deployments, outgassing material, etc. these issues and resolutions are recorded in the Dnepr Issue Log. Due to the complications after the final acceptance tests of the integrated P-POD in conjunction with the continued launch delay all five P-PODs were deintegrated. Most flight CubeSats were stored in the Cal Poly cleanroom for later integration. Two CubeSats were shipped back to the manufacturing facility for repairs.

6.4.2 Lessons Learned & Recommendations

- The logistics of customer arrival to Cal Poly were difficult to minimize the customer's stay at Cal Poly and CubeSat complications hindered the schedule. It is recommended that for future integrations at Cal Poly universities prepare to stay at Cal Poly until the end of the integration schedule.
- Prepare for a launch delay, therefore obtain battery charging procedures and training from the customer.
- P-POD allocations will change constantly throughout the week of integration as complications arise. Before relocating the CubeSats consult previous drivers for the P-POD allocation in addition to the complication. Ensure that customers agree to the change.
- Vibration testing should be done in-house for flexibility in scheduling testing.
- Ensure that as the schedule of integration changes all Cal Poly CubeSat Personnel are notified as well as customers.
- Continue issue logs for future launch campaigns. This will allow future teams to understand the thought process of previous teams and precedents that have been set.

- After environmental testing (thermal vacuum bakeout and vibration) is complete on their flight CubeSat the customer needs to submit the test report prior to shipping the CubeSat to Cal Poly for integration.

6.5 Launch & Operations

The loss of the launch vehicle was unfortunate in that real operational analysis and use of identification and tracking tools could not be used. However the choice of the vehicle still is practical due to the launch cost of $10,000 per kg and large history of successful flight heritage. However the ITAR issues dealing with a foreign launch provider places the completion of TAA and export licenses as a critical path. Future launch opportunities would hopefully be moved to U.S. vehicles.

6.5.1 Baikonur Cosmodrome: Lessons Learned & Recommendations

- Customs tax and duties are a significant cost of approximately 30% of the cost of the license which was much higher estimate than initially budgeted for Russia.
- Limit the number of Cal Poly CubeSat Personnel that will attend the launch. The cost of tickets and hotel stay over three weeks greatly affects the cost at the launch site.
- Shipment of hazardous materials must be processed at least one month before delivery. Hazardous materials (i.e. lithium batteries, epoxies, etc…) these hazards may affect the type of travel and paperwork.
- Customers need to disclose a list of hazardous materials in regards to their CubeSat.

- All shipment should contain accelerometers (i.e. Hobo) to characterize and record vibration loads during transportation. It is recommended to include temperature and humidity sensors.
- Continue the report log of what occurred during the event as future teams can review what occurred at the launch site and be better prepared. It is also a requirement by the Office of Defense Trade Controls in the event of an audit.

6.5.2 Launch: Lessons Learned & Recommendations

- Develop a deorbiting propagation tool using the state vectors of each CubeSat not just the state vectors of each P-POD.
- Continue operations and use of the tools developed for tracking CubeSats from other launches not coordinated by Cal Poly.

The Dnepr launch campaign was a successful first step in organizing launch opportunities for CubeSats. The processes and tools developed are now given for future coordinators to refine and develop even better tools to make decisions and resolve issues systematically. Programmatically the processes and tools will enable future coordinators to understand the various critical paths of a typical launch program and a general timeline of the milestones. The future work and recommendations are ideas and experiences from the Dnepr launch campaign that will enable future coordinators to have more data and assurance of safety and reliability of the CubeSats and decisions that are made; greatly reducing the physical ailments that accompany the position.

LIST OF REFERENCES

1. Alminde, Lars., "SSETI Express Failure Analysis Report Phase E" Issue 2, Nov. 2005 <http://sseti.gte.tuwien.ac.at/express/mop/index.php?uri=downloads.html>

2. Baumann, Robert, "General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components," Revision A, June 1996, pg. 2.4-19

3. Blanchard, B., Fabrycky, W., "Systems Engineering and Analysis" 3rd Edition Princeton Hall, Upper Saddle River, New Jersey, 1997

4. Cutler, J., Hutchins, G., "OPAL: Smaller, Simpler, and Just Plain Luckier," Proceedings of the 14th Annual AIAA/USU Conference on Small Satellites, Logan, Utah, August 2003, pp. 1-12

5. Federal Communication Commission, 47 C.F.R. parts 5, 25 and 97, pp. 54581-54589 (2004)

6. Federal Communication Commission: Office of Engineering and Technology general website <https://gullfoss2.fcc.gov/prod/oet/cf/els/index.cfm>

7. Government Accountability Organization, "Export Controls: State and Commerce Department License Review Times Are Similar", June 2001, pp 2-27

8. Inter-Agency Space Debris Coordination Committee (IADC), "US Government Orbital Debris Mitigation Standard Practices", 1997 <http://orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html>

9. International Amateur Radio Union general website, <http://www.iaru.org/satellite/>

10. International Traffic in Arms Regulations (ITAR), 22 C.F.R. Chapter 1, Subchapter M, parts 120-130 (2005)

11. Isakowitz, S., Hopkins, J., Hopkins, J., "International Reference Guide to Space Launch Systems," 4th Edition AIAA, Reston, Virginia 2004

12. Office of the Vice President and General Counsel, "Export Controls" Oct. 2005, Yale University <http://ogc.yale.edu/legal_reference/export_controls.html>

13. Pranajaya, F., Zee, R., "An Affordable, Low Risk Approach to Launching Research Spacecraft as Tertiary Payloads" Proceedings of the 14th Annual AIAA/USU Conference on Small Satellites, Logan, Utah, August 2003, pp. 2-6

14. Space Daily, “One Stop Satellite Solutions Takes A Japanese Approach,” Ogden, Utah, Oct. 2000 <http://www.spacedaily.com/news/microsat-00y.html>

15. Space Track general website < http://www.space-track.org/perl/login.pl>

16. SSETI general website, <http://www.sseti.net/>

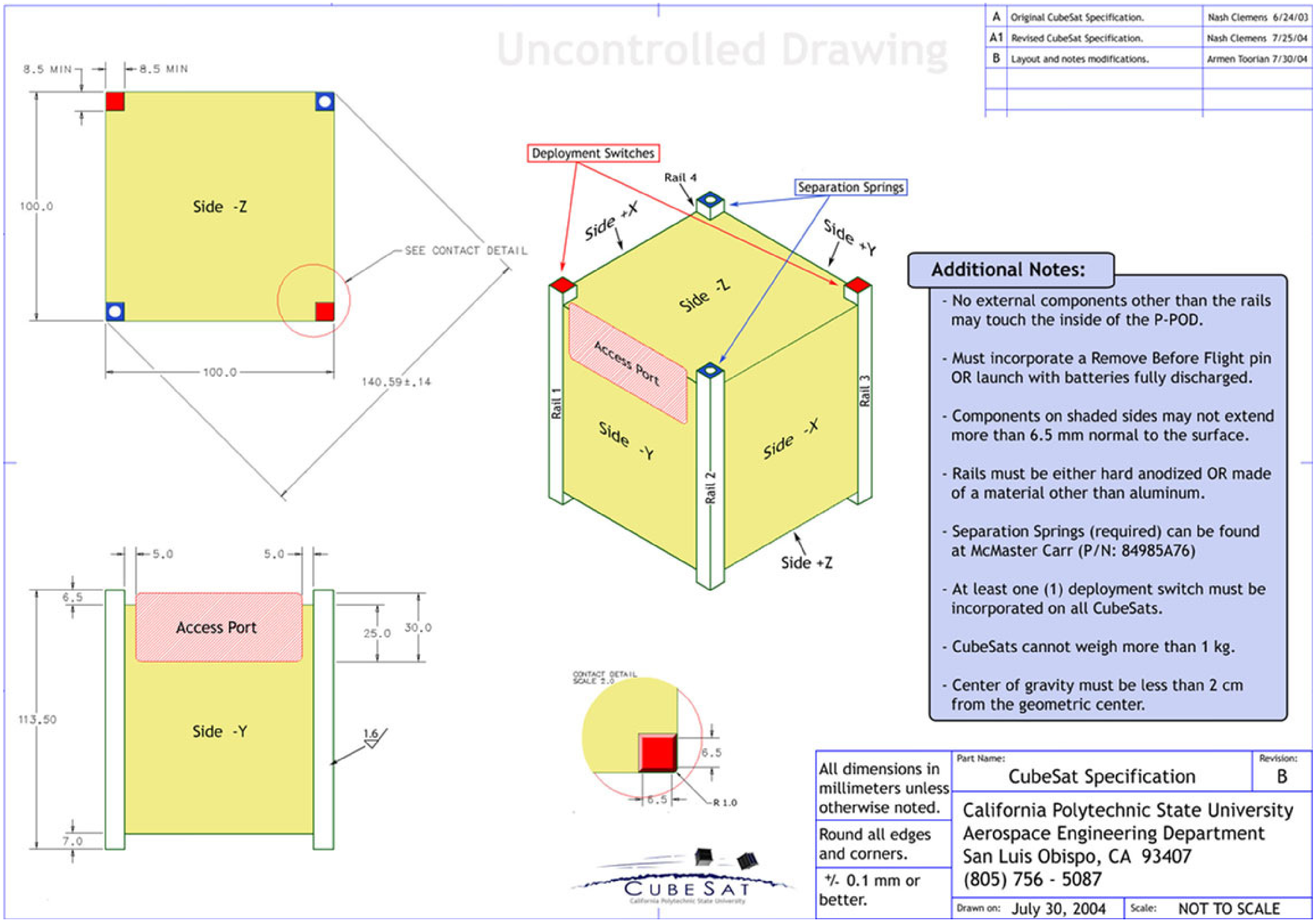
17. Toorian, A., Coelho, R., Lee, S., “Dnepr Safety Compliance Requirements,” Revision 1, Aug. 2004, pp.1-11 <http://cubesat.calpoly.edu>

18. Toorian, A., Hutputtanasin, A., “CubeSat Design Specification,” Revision 9, June 2004, pp. 1-8 <http://cubesat.calpoly.edu>

19. United States Air Force, “The Academy in the Space Age,” June 2005 <http://www.usafa.af.mil/superintendent/pa/factsheets/space.htm>

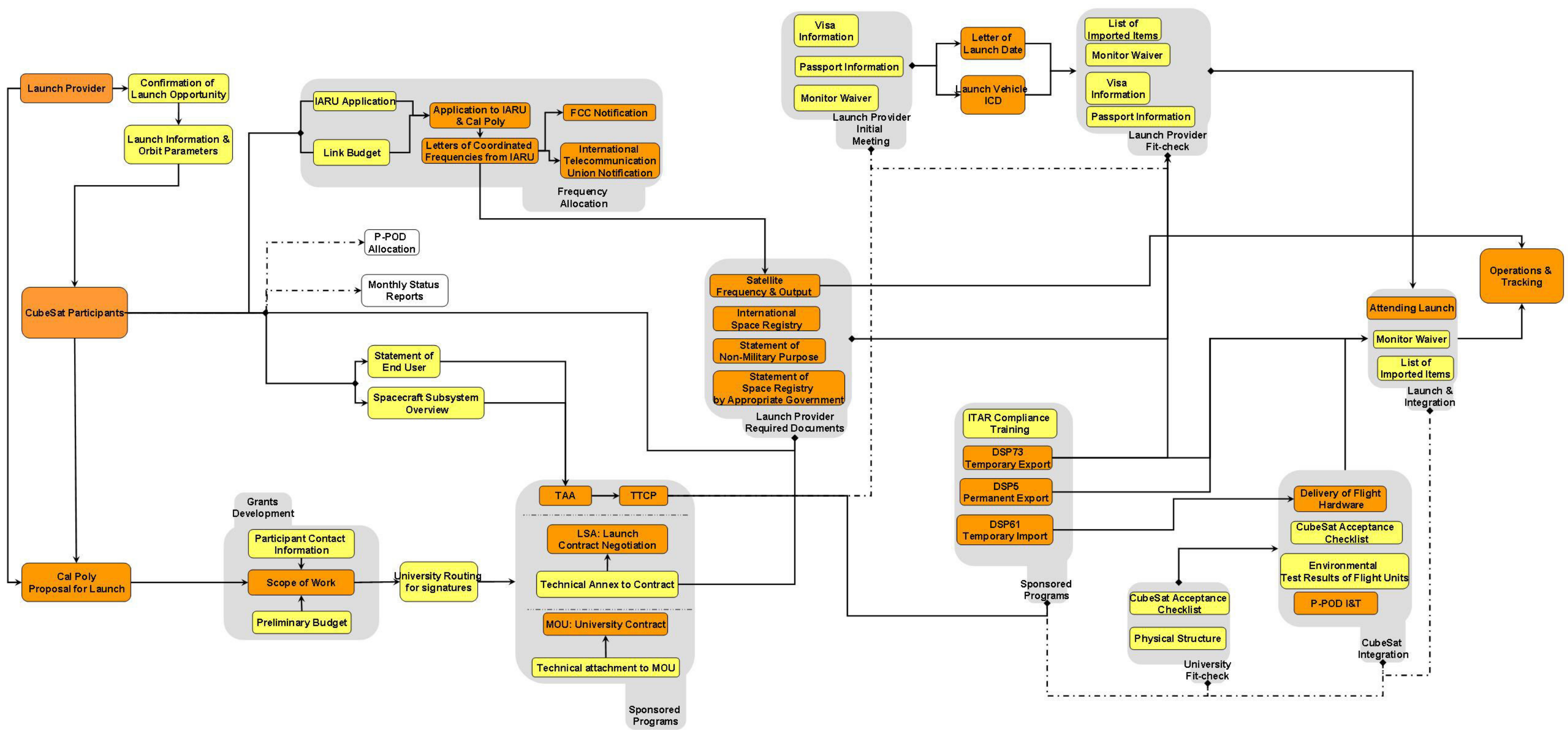
20. University Nanosatellite Program general website <*http://www.vs.afrl.af.mil/UNP/About.html*>

Appendix A: CubeSat Standard Schematic


A Original CubeSat Specification. Nash Clemens 6/24/03
A1 Revised CubeSat Specification. Nash Clemens 7/25/04
B Layout and notes modifications. Armen Toorian 7/30/04
Uncontrolled Drawing
8.5 MIN
8.5 MIN
100.0
100.0
Side -Z
SEE CONTACT DETAIL
140.59±.14
5.0
5.0
6.5
Access Port
25.0
30.0
113.50
Side -Y
1.6
7.0
Deployment Switches
Rail 4
Separation Springs
Side +X
Side +Y
Side -Z
Access Port
Rail 1
Side -Y
Rail 2
Side -X
Rail 3
Side +Z
CONTACT DETAIL SCALE 2.0
6.5
6.5
R 1.0
CUBESAT
California Polytechnic State University
Additional Notes:
- No external components other than the rails may touch the inside of the P-POD.
- Must incorporate a Remove Before Flight pin OR launch with batteries fully discharged.
- Components on shaded sides may not extend more than 6.5 mm normal to the surface.
- Rails must be either hard anodized OR made of a material other than aluminum.
- Separation Springs (required) can be found at McMaster Carr (P/N: 84985A76)
- At least one (1) deployment switch must be incorporated on all CubeSats.
- CubeSats cannot weigh more than 1 kg.
- Center of gravity must be less than 2 cm from the geometric center.
All dimensions in millimeters unless otherwise noted.
Round all edges and corners.
+/- 0.1 mm or better.
Part Name:
CubeSat Specification
Revision:
B
California Polytechnic State University
Aerospace Engineering Department
San Luis Obispo, CA 93407
(805) 756 - 5087
Drawn on: July 30, 2004
Scale: NOT TO SCALE

Appendix B: Schematic Diagram Program Flow

CubeSat Coordination and Administration Steps



Appendix C: Memorandum of Understanding

Memorandum of Understanding
For 2004 Kosmotras Launch Project

This Memorandum of Understanding ("MOU") is effective as of the 1st day of April, 2003, by and between ____ ("University"), an educational institution and having its principal place of business at ______________________________________, and California Polytechnic State University Foundation ("Foundation"), a nonprofit corporation organized as a §501(c)(3) auxiliary organization of California Polytechnic State University, ("Cal Poly") with its principal office at Building 15, California Polytechnic State University, San Luis Obispo, CA 93407, and in support of Cal Poly of San Luis Obispo, CA.

This Agreement is for (note which option) One CubeSat Two CubeSats One Double CubeSat. All University participants agree to the same terms with Foundation for participation in the project as described herein.

Background

Cal Poly and Stanford University developed a low cost satellite launcher known as the Poly Picosat Orbital Deployer ("P-POD") that ejects pico-satellites weighing less than 1 kilogram ("CubeSats") at a specific insertion point into space orbit. Due to their standardized design features, minimal mass, and low cost, CubeSats can be developed quickly and inexpensively for research and educating space scientists and engineers. The P-POD is physically attached to the P-POD Launch Vehicle Interface ("LVI"), also manufactured by Cal Poly, is attached to a launch vehicle's upper stage. To date, Cal Poly is the only producer of the P-POD.

Numerous universities are interested in developing and obtaining launch services for their own CubeSats. ISC Kosmotras of Russia is willing to provide room for several P-PODs on a launch planned between March 31, 2004 and September 30, 2004. For various reasons there are no domestic launch providers available for this project for the foreseeable future. Due to the price of a launch with Kosmotras (about $200,000), few Universities would be able to afford the launch service by itself. However, with the economies of working with a group of universities, a launch can be accomplished. Cal Poly, through its nonprofit auxiliary Foundation, agrees to facilitate participation of multiple universities on this Kosmotras launch by being the coordinator of the University participants and the contracting party for necessary professional services, including the Kosmotras launch services. This Kosmotras launch to be coordinated by Foundation will be called the Project.

At the May 15, 2003, conference call, sufficient number of Universities agreed to participate that allows Foundation to proceed with negotiations with Kosmotras, and initiate other administrative support related to this project. The University participants that agreed to participate were:

- University of Hawaii
- University of Kansas
- University of Illinois (two as double-size CubeSat)
- Cornell University (two)
- Nihon University (Japan)
- Norwegian University of Science and Technology (Norway)
- Montana State University
- Taylor University (two as double-size CubeSat)
- Cal Poly

University of Arizona was unable to participate in the conference call.

This collaboration should lead to an in-depth understanding of the P-POD and CubeSat system as a cost-effective platform for conducting significant scientific research experiments in space. Through this experimental scientific research satellite program, the parties intend to demonstrate that utilizing commercial off-the-shelf ("COTS") parts originally developed for non-U.S. Munitions List ("USML") uses is a quick and cost effective way to construct a reliable, short-mission micro-satellite.

Agreement

1) **Foundation responsibilities.** In furtherance of research and testing of the P-POD and CubeSat systems, and for a valuable consideration, Foundation will:
   (a) Enter into agreements with each of the University participants to confirm that participation will make the service economically feasible;
   (b) Register as the manufacturer of the P-POD with the Department of Trade Controls ("DTC:")
   (c) Register as the exporter of the P-Pod with the DTC;
   (d) Comply with all ITAR regulations applicable to this project.
   (e) Obtain professional and legal advice regarding ITAR compliance, as necessary.
   (f) Obtain professional services to assist University to get proper export permission from DTC for their CubeSat(s);
   (g) Enter into an agreement with ISC Kosmotras for the launch services;
   (h) Coordinate technical, legal and logistic requirements between Cal Poly, Foundation, the University participants, DTC, Kosmotras, and others as necessary.
   (i) Coordinate meetings for CubeSat developers to be scheduled at the Small Satellite Conference in Utah in summer 2003.
   (j) Manufacture P-PODs to be used for the launch;
   (k) Manufacture and ship to each University a test P-POD;
   (l) Provide technical requirements for University's CubeSat(s) for integration into P-POD and with Kosmotras' launch vehicle.
   (m) Be responsible for physical shipment to Kosmotras of the P-PODs, including shipping charges, and any duties, import bonds, custom broker fees, and any other fees or taxes, if any, associated with this export of the University CubeSats, and any other property required for the launch;
   (n) Send appropriate personnel to the launch facility prior to the launch, as required by Kosmotras, to oversee the integration of the P-Pods with the launch vehicle;
   (o) Coordinate launch logistics between University participants and Kosmotras.

2) **University responsibilities.** In furtherance of research and testing of the P-POD and CubeSat systems and for a valuable consideration, University will
   (a) Deliver its CubeSat(s) to Cal Poly no later than Jan 1, 2004, or other date that may be mutually agreed upon due to changes related to launch requirements;
   (b) If an American University, work with the professionals retained by Foundation to timely prepare any export applications;
   (c) If a foreign University participant, provide the appropriate approvals and documentation for temporary import to the U.S., and the permanent export to the Kosmotras site;
   (d) Comply with all ITAR requirements;
   (e) Provide information and assistance to Foundation in a timely fashion, as requested;
   (f) Execute appropriate documentation needed by the U.S. government for the launch of CubeSats by the University participants with Kosmotras;

3) **Assumption of risks.** All the parties are jointly assuming the risks of contracting for launch services. Kosmotras will require significant downpayments prior to the launch, which may be unrecoverable by Foundation if the launch is cancelled by Kosmotras or Foundation. In that case, the unreimbursed costs will be prorated across the participants. Upon cancellation of the

launch, all costs borne by Foundation to date such as for export professional and legal services, and for hardware manufacturing, shall not be reimbursable to the participants. As much care as possible is being made so that monies are not spent prior to their need, particularly for the Kosmotras launch service. University participant will also bear in mind that if the Kosmotras launch were to be cancelled certain services to be provided under this Agreement such as export applications and hardware manufacturing would be re-useable for a subsequent launch

4) **Fees**. Foundation will charge a fee to each University participant that will cover the services named herein. The fees will pay for administration and other services to be provided by Foundation on behalf of all the universities and the fee to Kosmotras for the launch. Fees are estimated to be between $35,000 to $40,000 per CubeSat to be launched, which will be finalized by Foundation upon the final deadline for participation. Any increases or decreases will be shared proportionately among the participants. The final deadline for participant count by Foundation shall be at the conclusion of the Kosmotras-Foundation negotiations, but prior to final Kosmotras and-Foundation contract execution.
   (a) **Payment of Deposit.** In order to ensure firm commitments by participants a deposit of $10,000 is due to Foundation by June 24, 2003.
   (b) **Remainder of payments.** As the main financial cost will be the Kosmotras commitment, the payment schedule will be determined upon the final contract with Kosmotras. At this time it is expected that the final payment will be due no later than December 15, 2003 for this launch, but University will be expected to comply with the payment schedule as needed to support Project commitments by Foundation. Any other payment schedule must be agreed upon in writing by Foundation.

5) **Reimbursement of deposit or other fees if Project terminates**.
   (a) The deposit or fees paid will be reimbursed to the University participant under the following circumstances:
      i) If the Project is cancelled by Foundation, or Kosmotras determines that it will not allow P-PODs on the designated launch, before Foundation has contracted with Kosmotras and committed funds to it, but minus the amount for any expenses incurred by Foundation after May 15, 2003, based on the verbal commitments made by Universities, for production of P-PODs, export services, and other administration.
      ii) If the project is cancelled by Foundation or Kosmotras after Foundation has contracted with Kosmotras and committed funds, but minus a prorated amount for any expenses incurred by Foundation after May 15, 2003, based on the verbal commitments made by Universities, for unreimbursable payments made to Kosmotras, production of P-PODs, export services, and other administration.

   (b) These expenses will be reasonably prorated among the University participants. A University participant would retain rights to anything already generated by Foundation such as export applications and professional services, the test P-POD, and rights to room on the "live" P-POD if already produced that would be of use or of value to University on any launch subsequently arranged through Foundation.

   (c) **Full funding due.** If a University cannot participate in the Project after its execution of this agreement, the University will be liable for the full amount, unless the conditions named in Section 5(a) occur.

6) **CubeSat Shipping costs to Foundation.** Any costs for shipment of University's CubeSat(s) to Foundation, and any duties, import bonds, custom broker fees, and any other fees or taxes, if any, associated with this export, and any arrangements necessary will be the responsibility of the University, and not the Foundation or Cal Poly.

7) **Compliance with laws.** University and Foundation agree to comply with all state, federal, and applicable foreign laws, including compliance with all applicable sections of the International Traffic in Arms Regulations ("ITAR") of the U.S. Department of State, and with §38 and §39 of the Arms Export Control Act (22 U.S.C. 2778 and 2779).

8) **No Warranties.** Since research by its nature is unpredictable and without guarantee of successful results, the transfer to, and the subsequent use for launching its CubeSat(s) by University of the P-POD is conducted on a "best efforts" basis. No fee or profit is expected for facilitating this research service and such work is performed on a "no-profit-no-loss" basis. For these reasons, Foundation will not guarantee results, accept penalties for failure of the P-PODs to perform if University is not satisfied with the results. FOUNDATION DOES NOT MAKE ANY EXPRESS OR IMPLIED WARRANTIES OF ANY KIND TO UNIVERSITY.

9) **Indemnity.** UNIVERSITY AGREESTO PROTECT, DEFEND, INDEMNIFY, AND HOLD HARMLESS FOUNDATION AND CAL POLY FROM ANY AND ALL CLAIMS, DAMAGES, EXPENSES, EITHER DIRECT OR CONSEQUENTIAL FOR INJURIES TO PERSONS OR PROPERTY ARISING OUT OF OR IN CONSEQUENCE OF THE PERFORMANCE OF THE P-POD AND UNIVERSITY'S CUBESAT, UNLESS CAUSED BY THE SOLE NEGLIGENCE OF FOUNDATION OR CAL POLY.

10) **Insurance.** University shall be responsible for providing adequate insurance coverage, if desired, for the CubeSat(s) during transportation from University to Foundation, and before, during and after launch, including coverage for any ancillary equipment and personnel of University. In the event the insurance becomes payable, University's insurance policy shall not give the insurer any subrogation rights with respect to Foundation or Cal Poly.

11) **Publicity.** University shall not use the name of Cal Poly or Foundation, nor any of the staff of these entities, in any publicity, advertising, or news release without the prior written approval of an authorized representative of the Foundation. Except for on-campus newsletters and reports, the Foundation or Cal Poly will not use the University's name or the name of its employees, in any publicity without approval of University. At a later time, the University participants may agree in writing on the form and message of any publicity related to the Project.

12) **Non-Disclosure.** Anything in this Agreement to the contrary notwithstanding, any and all knowledge, know-how, practices, process, or other information (hereinafter referred to as "Confidential Information") disclosed in writing or in other tangible form which is designated Confidential Information or which, if initially orally disclosed, is reduced to writing within forty-five (45) days of disclosure, to either party by the other shall be received and maintained by the receiving party in strict confidence and shall not be disclosed to any third party. Furthermore, neither party shall use said Confidential Information for any purpose other than those purposes specified in this Agreement. The parties may disclose Confidential Information to those requiring access thereto for the purpose of this Agreement provided, however, that prior to making any such disclosures, such employees shall be apprised of the duty and obligation to maintain Confidential Information in confidence and not use such information for any purpose other than in accordance with the terms and conditions of this Agreement. All parties agree to use reasonable efforts not to disclose any agreed to Confidential Information.

13) **Ownership Of Research Results.** Foundation may hold Cal Poly intellectual property, and manage the rights to such intellectual property consistent with Cal Poly regulation and policy. All rights and title to Intellectual Property whether patentable or copyrightable or not, relating to the P-POD made solely by employees of Cal Poly or Foundation shall belong to Cal Poly and shall be subject to the terms and conditions of this Agreement.

14) **Publications And Copyrights.** Foundation and Cal Poly will be free to publish the results of that part of the research that is performed under this Agreement pertaining to the use and implementation of the P-POD and CubeSat system. Only University will have the right to publish any data collected by the actual CubeSat(s) belonging to University. Title to and the right to determine the disposition of any copyrights, or copyrightable material, first produced by Cal Poly or Foundation in the performance of this project shall remain with the Cal Poly, or Foundation as an agent for Cal Poly in Intellectual Property.

15) **Disputes.** Any dispute concerning a question of fact arising under terms of this agreement that is not resolved by mutual agreement of the parties shall be brought to the attention of the authorized signatories of both parties. If resolution of the dispute cannot be accomplished, either party may seek resolution employing whatever remedies exist in law or equity.

16) **Governing Law.** This Agreement will be deemed fully executed when signed by both parties. This Agreement shall be governed in accordance with the laws of the State of California.

17) **Agreement Modification**. Any changes in the terms of this Agreement in any way shall be valid only if the change is made in writing and approved by mutual agreement of authorized representatives of the parties hereto.

18)
The parties by duly authorized signatures accept the provisions of this MOU.

Frank Mumford
Executive Director
California Polytechnic State Cal Poly Foundation

____

Date: ____________________________

Name:
Title:
University:

____

Date:
____

Principal contact information
Name (Last, First, Middle Initial)

____
Title

____
Department

____
Institution

____
Mailing Address

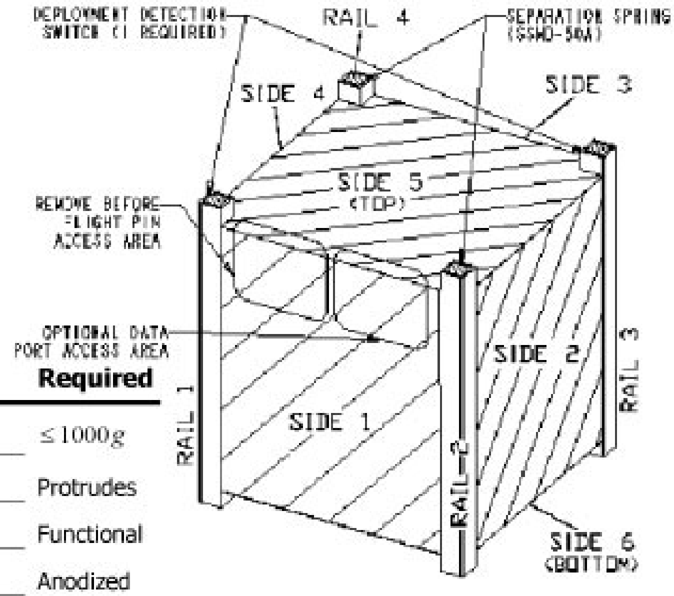
____
____
City ____________ State _________
Postal Code________ Country __________
Telephone ____________
Fax _____________
E-Mail ____________________

Appendix D: CubeSat Acceptance Checklist

Cubesat Acceptance Checklist

Revision Date: April 4, 2004
Author: Armen Toorian

This document is intended to be used concurrently with the Cubesat Integration Procedure (CIP)



List Item	Actual	Required
Mass	______	$\leq 1000g$
Remove Before Flight	______	Protrudes
Spring Plungers	______	Functional
Rails	______	Anodized
Deployment Switches	______	Functional
Width [x-y]		
Side 1	______	$100.0 \pm 0.1mm$
Side 2	______	$100.0 \pm 0.1mm$
Side 3	______	$100.0 \pm 0.1mm$
Side 4	______	$100.0 \pm 0.1mm$
Height [z]		
Rail 1	______	$113.5 \pm 0.1mm$
Rail 2	______	$113.5 \pm 0.1mm$
Rail 3	______	$113.5 \pm 0.1mm$
Rail 4	______	$113.5 \pm 0.1mm$
Diagonal [x-y]		
Top 1&3	______	$141.2^{+0}_{-1.5}mm$
Top 2&4	______	$141.2^{+0}_{-1.5}mm$
Bottom 1&3	______	$141.2^{+0}_{-1.5}mm$
Bottom 2&4	______	$141.2^{+0}_{-1.5}mm$

Authorized By:	Testing Info:
IT #1: ______	Date: ______
IT #2: ______	Passed: **Y / N**

Appendix E: CubeSat Operations Template

Operations Form: Understanding your satellite

The information you provide on this form will be added to the CubeSat website.

This information will aid in the search for your satellite in the crucial first hours/days/weeks after launch.

1 Provide an example of your beacon for search/tracking purposes (*.wav or *.mp3)

2

2	Downlink Freq 1	(i.e. 436.888)	MHz
	Output Power 1	(i.e. 500)	mW
	Downlink Freq 2	(i.e. 436.999)	MHz
	Output Power 2	(i.e. 700)	mW
	Add as necessary		

3 What is the deployment sequenence of your antenna/side panels/booms/etc...

Example	Timeline: (sec)	(min)	
	0.0	0.00	**Satellite is deployed from the P-POD**
	900.0	15.00	Antenna 1 BEGINS deployment (signal sent)
	906.0	15.10	Antenna 1 ENDS deployment (fully deployed)
	1800.0	30.00	Antenna 2 BEGINS deployment (signal sent)
	1800.6	30.01	Antenna 2 ENDS deployment (fully deployed)
	1860.0	31.00	Boom 1 BEGINS deployment (signal sent)
	1861.2	31.02	Boom 1 ENDS deployment (fully deployed)
	2100.0	35.00	Additonal 1 BEGINS deployment (signal sent)
	2160.0	36.00	Additonal 1 ENDS deployment (fully deployed)

4 What is the on/off cycle for each beacon/transmission. What is the length of the beacon/transmissions?

Example	Timeline		
Interval: (sec)	(sec)	(min)	
	0.0	0.000	**Satellite is deployed from the P-POD**
900.0	900.0	15.000	Beacon/Transmission **DELAY**
	900.0	15.000	Beacon/Transmission is on frequency **436.888**
1.0	901.0	15.016	Beacon/Transmission is on
	901.0	15.016	Beacon/Transmission is off
1.0	901.9	15.032	Beacon/Transmission is off
	901.9	15.032	Beacon/Transmission is on frequency **436.999**
1.0	902.9	15.048	Beacon/Transmission is on
	902.9	15.048	Beacon/Transmission is off
1.0	903.8	15.064	Beacon/Transmission is off
	903.8	15.064	Beacon/Transmission is on frequency **436.888**
1.0	904.8	15.080	Beacon/Transmission is on

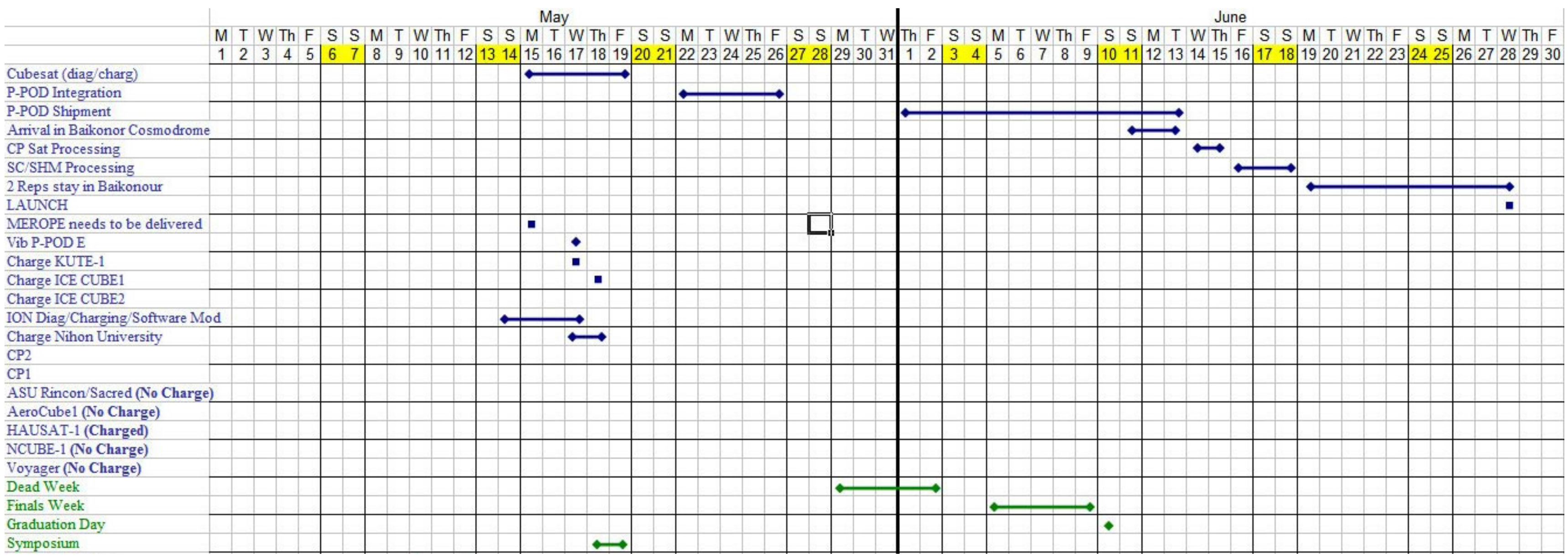
Add additional transmissions/information that should be expected from the satellite during the search.

5 What information is the beacon/transmission? Is the beacon/transmission morse code, digital data, etc...?

6 Does the satellite have alternating communication systems?
- What is the difference in the comm systems or are they identical?
- What types of deviations do you expect?

7 Will the beacon/transmission change if there is a switch in the modes of the satellite.
(Example: The beacon will turn off when the satellite is switched to normal operations mode.)

Appendix F: Delivery Sequence Schedule



May
June
M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Cubesat (diag/charg)
P-POD Integration
P-POD Shipment
Arrival in Baikonor Cosmodrome
CP Sat Processing
SC/SHM Processing
2 Reps stay in Baikonour
LAUNCH
MEROPE needs to be delivered
Vib P-POD E
Charge KUTE-1
Charge ICE CUBE1
Charge ICE CUBE2
ION Diag/Charging/Software Mod
Charge Nihon University
CP2
CP1
ASU Rincon/Sacred (No Charge)
AeroCube1 (No Charge)
HAUSAT-1 (Charged)
NCUBE-1 (No Charge)
Voyager (No Charge)
Dead Week
Finals Week
Graduation Day
Symposium