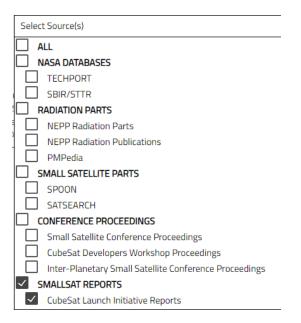**CubeSat Information and Lessons Learned**

Thank you for your interest in the CubeSat Launch Initiative (CSLI). Below is some information that will help with the development of your CubeSat and includes some lessons learned from other entities as they were designing, building, and operating their CubeSat.

The CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers document provides guidance and recommendations to assist in the development of your CubeSat. This document contains invaluable information that should be reviewed. The document walks you through the development process, requirement sources for launch, licensing procedures and more. There have been some advancements since it was originally published so it is currently being updated and will be posted once complete.

The Small Satellite Information Search includes the Final Reports from past CSLI missions. To search for lessons learned for CSLI only, click on the down arrow for Selected Source(s) and click on All to deselect, then click on SmallSat Reports and click on Search. These reports include valuable lessons learned that the teams have experienced related to the development of their CubeSat, project management, testing, etc. and may prevent similar situations from occurring and ensure mission success. In addition, if you are looking to collaborate with another university you can see who has previously participated and what their mission entailed.

In addition to the two resources identified above, below are some bulletized items that were identified by previous CubeSat developers from their experience and are items to consider when designing/developing your CubeSat.

- Be mindful of any light pollution generated by the CubeSat and state clearly the impact on ground based astronomical observations. Reach out to the American Astronomical Society (AAS) Committee on Light Pollution for advice on what is acceptable and methods to minimize the impact. Another resource is the International Astronomical

Union Center for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference Payload website https://cps.iau.org/.

- CubeSats with drag devices for de-orbit will face greater scrutiny from the regulatory community and may not be approved; design for demise and minimize the use of high melting point materials (titanium, tungsten, ceramics, glasses, tantalum, etc.).
- CubeSats with propulsion should include GPS as well as the ability to share predicted ephemeris data with the 18 SPCs and all other satellite operators. In short, know where you are in space and where you will be at all times to minimize conjunctions with other spacecraft or crewed vehicles.
- If you have any propulsion or any other means of modifying your orbit, consider encryption for your spacecraft, preventing the ability of 'bad' actors controlling your spacecraft and ramming it into another object.
- There are International Space Station (ISS) unique technical considerations/restrictions (battery testing, toxic materials, propulsion, lasers, inhibits, additive manufacturing, etc.). For the most comprehensive series of requirements that you will have to consider, please review the following page on the Nanoracks website Technical Resources - Download Nanoracks IDD & ICD Documents. Please pay close attention to the Lithium-ion battery test requirements.
- If possible, design your spacecraft to accommodate the broadest range of orbits possible. Orbit flexibility maximizes your launch opportunities while restrictive orbit requirements can limit launch opportunities, thereby potentially leading to later than desired launch dates. In short, if the bus is going to Pittsburgh, it can't take you to Seattle.
- Deployment altitudes should be in line with planned mission duration and de-orbit capability.   For example, designing a spacecraft without deorbit capability that will only last a couple of weeks or requesting a 550 km deploy when the mission will end in six months resulting in the spacecraft being a hazard to navigation for years to come.
- If you are a 3U or larger and are planning for an altitude of 540 km or higher ensure that you have considered how you will passivate your batteries and reaction wheels. Also consider the probability of explosion for all propulsion systems and reaction wheels above this altitude, ensuring that the risk is small in all instances.
- Consider how far along the CubeSat development is prior to accepting a launch assignment to avoid multiple schedule delays.
- In general, use an agile model for development so that you can get something working early and then refine it as your knowledge increases. This will reduce risks of big failures on large milestones late in the process.
- Having a team member and/or external reviewer with prior experience related to CubeSat development can be beneficial when considering options at key decision points.
- For Educational missions it is important that the Principal Investigator and Co-Principal Investigators manage expectations as to what is truly possible for a student educational mission with limited budget and schedule. Trying to do too much defeats the primary purpose of an educational mission.

- Technical and Project leadership should be carried out as two distinct roles to prevent the conflation of technical issues and project issues such as budget and schedule. Systems Engineering students can help to bridge the gap between various sub teams, technical requirements, budgets, and schedules.
- Gain a clear understanding of your mission objective(s) and the minimum functionality necessary to allow you to achieve them. Eliminate unnecessary complexity, design in easy assembly/disassembly to account for human factors and incorporate more commercial components in the design to reduce the need to design from the ground up.
- Start hardware integration as early as possible to avoid the pitfalls of development delays and last-minute integration issues. Develop strong validation and verification standards early in the project. Understanding your spacecraft and managing anomalies are effort well worth considerable time investment.
- Thermistor wires are prone to fatigue and breaking so covering them with epoxy and heat shrink tubing can help however it may cause problems with fit. Start fit checking early and do this often as it will reveal design issues.
- Plan to test early and often to reveal any design issues to prevent inoperability on orbit. Test as you fly and fly as you test so you are prepared for what you will encounter on orbit. For the aspects of the mission that cannot be "tested as you fly" should receive extra scrutiny and design margin. Simulate and test every condition the CubeSat can experience during on-orbit operations.
- Mission operations and planned duration needed to achieve mission success must account for the aggregate probability that all required aspects of the mission are functioning properly simultaneously.
- Implement back-up plans for subsystems much earlier in the design process and have clearly defined gates for making those decisions. Establish parallel path for critical item suppliers if there is evidence of an impending delay or of reduced performance.
- Close coordination with the integrator/CSLI team is crucial and don't be afraid to bring up issues early. Build an engineering unit in addition to the flight unit if possible. This would be beneficial in the event of having to perform a failure review.
- Have a robust two-way communications design and add a redundant downlink if possible. Do no rely on a single ground station for comms and ensure licenses account for multiple ground stations. Ensure there is adequate power as well to detect the beacon. Consider commercial off-the-shelf components vs in-house build.
- Team organization and continuity is vital. Long-running programs face substantial risks due to student and staff workforce transitions. Proper documentation of all satellite systems and assembly/test procedures is essential to allow rotating staff/student workforce to successfully continue and complete project work.
- Document all project activities, decisions, methods used, formats, code, lessons learned etc. Insufficient documentation contributes to the loss of experience and knowledge, and difficulty in troubleshooting especially with software. Consider turnover and the need for knowledge capture/mentoring. Configuration Management is essential; maintain your documentation so you don't have to reverse engineer if key personnel

leave the team; prevent scope creep. Someone who is not part of the project should be able to read and understand it.

- Strong management of the project schedule and mitigation plans for anticipated and unanticipated delays. Ensure experienced mentoring to provide guidance and support to meet program objectives (i.e., hardware development will be challenging, and science investigations will be difficult to achieve). When creating a schedule, set goals for larger milestones which can drive the schedule, and define smaller, achievable milestones up to two-weeks out.