

## **A NASA-funded CubeSat Program**

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### **Executive Summary**

We propose an augmentation of the Suborbital and Special Orbital Projects (SSOPD) program to include CubeSats as an available science and technology platform, to complement the existing sounding rocket and balloon platforms. A relatively modest increase in the SSOPD budget of ~ \$12.5M would allow for a vibrant CubeSat program of up to 4 launches per year, enabling flight demonstrations of new instrument concepts and opportunities for students to develop the specialized scientific, engineering and management skills required to maintain NASA as a preeminent space agency. The program could be managed at Wallops Flight Facility (WFF), paralleling the highly successful suborbital program, and could leverage the existing WFF contract with NSF to provide technical support for the NSF CubeSat program.

### **Motivation**

For decades the NASA sounding rocket and balloon programs have, and continue to be, indispensable platforms for developing and nurturing the next generation of scientists and engineers, for testing and validating new technologies and instrumentation, and for offering rapid access to space for cutting-edge science experiments. The success and wide community support for the NSF CubeSat Program combined with the increasing number of NASA Explorer proposals that utilize CubeSats demonstrates the maturation of the CubeSat platform. The addition of CubeSats to the NASA portfolio of science mission platforms would enable significant new experiments for all branches of heliospheric and Earth science.

The current manifest of NSF CubeSat missions demonstrates that CubeSats can address a broad array of cutting edge science questions using state-of-the-art instrumentation:

**Radio Aurora Explorer (RAX)** / Hasan Bahcivan (SRI), James Cutler (University of Michigan) - Understanding the microphysics of plasma instabilities that lead to field-aligned irregularities (FAI) of electron density in the polar lower (80-300 km) ionosphere.

**Dynamic Ionosphere CubeSat Experiment (DICE)** / Geoff Crowley (ASTRA), Charles Swenson (USU) - Studying storm-time features of ionospheric plasma.

**Firefly** / Doug Rowland (GSFC), Allan Weatherwax (Siena College) - Determining the source of terrestrial gamma ray flashes.

**Colorado Student Space Weather Experiment (CSSWE)** / Xinlin Li (University of Colorado, Boulder) - Investigating the relationship between solar energetic particles, flares, coronal mass ejections, and Earth's radiation belts.

**Focused Investigations of Relativistic Electron Burst Intensity, Range and Dynamics (FIREBIRD)** / Dave Klumpar (Montana State), Harlan Spence (University of New Hampshire) - Resolving the spatial scale size and energy dependence of electron microbursts.

**CubeSat for Ions, Neutrals, Electrons and Magnetic fields (CINEMA); TRIO** / Bob Lin (UCB), Kyung-Hee University (Korea) - Providing critical space weather measurements of Energetic Neutral Atom (ENA) and in situ suprathermal particles.

Each mission is funded at ~\$900k over three years, a relatively small investment that provides for technology and instrument development and training a new generation of scientists and engineers, while simultaneously addressing compelling science questions. Given the continued and growing community support for CubeSats, the maturation of the necessary technology, and the demonstrated benefits to NASA and the heliophysics community, we believe it is time for NASA to include CubeSats as an option in the Suborbital and Special Orbital Projects program. For a small yearly investment NASA would enable:

- A) **Instrument & technology test beds.** A major impediment to instrument development is the lack of flight opportunities in which to test and validate new designs. This problem is particularly acute for university researchers who often do not have the access to programs, such as Space Test Program (STP), that the labs do. The lack of inexpensive flight opportunities limits innovation, as new instruments are rarely able to improve the TRL level to the point they could be proposed. For certain types of instrumentation, sounding rockets provide flights of too short duration to test long term instrument or hardware performance, while balloons do not provide the necessary altitudes. CubeSats fill this void, opening a new realm of low-cost investigations, with instrumentation not appropriate for sounding rockets or balloons.
- B) **Training the next generation of scientists and engineers.** The sounding rocket and balloon programs have been a primary means by which NASA has trained scientists and engineers for more expensive flight hardware development. Developing a vibrant, well-trained workforce is vital for the long-term health of NASA and the overall space program within the United States. A CubeSat program within the auspices of NASA would expand the explorable regimes of near-Earth space and open up a new realm of instrument development, including solar and terrestrial imaging, thermospheric and ionospheric in situ measurements, and remote sounding. Further, while the sounding rocket and balloon programs allow for often substantial student involvement in designing and building instrumentation, there are comparatively few opportunities to train component or systems engineers within an operational context. Space physics missions often require close collaboration between the scientists, instrument designers, and spacecraft engineers to achieve mission success. Spacecraft charging and magnetic cleanliness are just two examples where choices made in systems designs could adversely affect the ability to produce accurate scientific

measurements. The field would be well served by bringing systems engineers through flights embedded in a space physics program. Because of their small size and low cost, CubeSats offer the ideal platform for student engineers to design, build and fly not just spacecraft subsystems but an entire integrated spacecraft.

- C) **Focused science investigations.** As the NSF CubeSat program has demonstrated, the platform is fully capable of a range of science implementations across heliophysics, including ionosphere/thermosphere/mesosphere (ITM), solar and magnetospheric science. The flexibility of the CubeSat platform to be three-axis stabilized or spinning, for example, enables the full-breadth of heliophysics science to be explored. The low cost and complexity allows rapid turn-around from inception to launch, enabling rapid study of focused science questions and also valuable second-tier science that does not justify an Explorer class mission. For example, the NSF Firefly mission is designed to answer very specific questions about energetic electron acceleration over thunderstorms. Despite its small size, its instrumentation is focused to answer new questions that larger satellites, not expressly designed for this mission, could not answer. In a similar fashion to existing suborbital programs, a CubeSat program would allow relatively short concept-to-flight times. Typically, payloads can be flight ready in less than three years from concept and much less than that for existing science.

NASA has typically required closure or significant progress on science questions as a measure of the success of a space flight mission. We believe it would be a mistake to implement a CubeSat program with the same standards of science closure as, for example, the Explorer program. Instead, A NASA sponsored CubeSat program should be implemented to promote flight validation of new advancements, early cutting edges science results, and effective post graduate research, with the acceptance of some risk. A CubeSat experiment that fails early in orbit, for example, has still provided important technical, scientific and engineering development.

### **Technical Implementation**

NASA could implement and manage a CubeSat program in a number of different ways. One option would be to mimic the sounding rocket approach, where much of the technical engineering infrastructure (e.g., communication, attitude control system (ACS), power, mechanical design, and deployment) lies at WFF, leaving the Principal Investigator (PI) responsible for the instrumentation. Another option is to mimic the current NSF implementation, where the PI is largely responsible for all aspects of the CubeSat. Each option carries distinctly different sets of advantages and disadvantages. Relying on WFF for engineering infrastructure frees the PI to focus on their instrument and science, without needing to “reinvent the wheel.” It allows for shared engineering designs and access to flight for small groups that do not have the engineering resources or expertise necessary to design, engineer and build a complete flight system. On the other hand, there is often tremendous value in having the PI and their team design and build a complete system. It allows for the training of systems and subsystem engineers, and can allow for greater flexibility and innovation in spacecraft design.

We describe below the details of implementing a CubeSat program under the auspices of the Suborbital and Special Orbital Projects Directorate (SSOPD) at WFF. This is but one example of an implementation of a NASA-funded CubeSat program, and we encourage the survey panel to examine others, including partnering directly with NSF on the existing program and implementing the NSF-style program within NASA. Regardless of implementation, the program should adhere to the spirit of the CubeSat platform, which is engineering and technical training combined with high science return on a small but powerful platform.

### **A CubeSat Program office at WFF**

The Goddard Space Flight Center Suborbital and Special Orbital Projects Directorate (SSOPD) at WFF could manage the CubeSat Program for a relatively modest investment. SSOPD currently supports the National Science Foundation (NSF) CubeSat Program, manages the Advanced Technologies Program (ATP) for CubeSat and Unmanned Aerial Vehicle (UAV) Applications, the NASA Sounding Rocket (SR) Program and the NASA Balloon Program. SSOPD would manage the overall CubeSat program in a manner similar to the services currently provided in support of the NSF CubeSat Program. This will include coordination with NASA sponsors, interfacing with launch services, offering use of existing test, evaluation, and ground support infrastructure, management of CubeSat bus services, and coordination with selected CubeSat developers. The CubeSat Program would build on SSOPD's long history of successful implementation of NASA's sounding rocket and balloon programs with a culture of responsive schedules, low-cost methods, and miniature payload accommodations. It will also draw from the recent development of CubeSat systems, through the ATP for CubeSat and UAV Applications.

Today, the sounding rocket and balloon programs provide ease of integration for the science instrument developer. The CubeSat Program would be designed in the same fashion to make available to developers CubeSat technologies from the SSOPD ATP, although the proposer would have the option of pursuing their own spacecraft bus solutions. SSOPD has integration and test facilities tailored for small satellites, which will support CubeSat development and testing. These facilities include labs, clean rooms, thermal-vacuum chambers, vibration test stands, Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) facilities, antenna pattern test facilities, and spin-balance test facilities. WFF could also provide ground station services.

The current balloon and sounding rocket programs enable the science community to select and prioritize mission funding through a program executive, simplifying the proposal and selection process. Program implementation management is executed through the WFF program offices that provide the integration and launch services. This allows the science PI to focus largely on the delivery of the science instrument should they choose. Typically the PI will have the option to employ extensive use of instrument support "bus" elements that can be provided by the program office. Examples of these are solar pointing for balloons or telemetry and attitude determination for sounding rockets. The CubeSat program could be implemented in very much

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the same way. This paradigm allows the proposers the flexibility, if they choose, to focus their limited resources solely on the instrumentation and science. In some cases an integrated spacecraft would be proposed.

As mentioned above, the vision is to provide a small program office at WFF that would be responsive to a program executive at HQ. Flight manifesting would be coordinated through the CubeSat Program Office. Through WFF civil servant and contract engineering, bus and ejector components, integration and test services would be arranged for and provided by the program office as desired from the PI. Current facilities exist, including environmental testing and clean rooms to support these efforts.

### Program Cost Estimation

Using the benefits of the existing contractor support organizations and on-site civil servant engineering, the CubeSat program would be able to improve on the current amortized per mission costs of the existing programs. The WFF FY10 costs (not including payloads) are \$47M for the sounding rockets, \$26.7M for balloons, \$3.2M for aircraft, and \$19.1M for the range. Each of these suborbital programs is producing approximately 15 missions apiece. Included in these costs are the actual costs of the launch vehicles and the operational costs of the launch effort. By manifesting CubeSat missions on existing host missions, most of these costs are eliminated. CubeSat launch costs are assumed to be \$50k/1U, with an additional \$100k to handle launch vehicle related documentation, interface, integration, and deployer procurement and testing. Using the numbers above and assuming a program of 12 missions a year once up and running, the per mission program execution cost would be less than \$1M.

Modeled after the sounding rocket and balloon programs, there will be a small Program office at WFF to manage the CubeSat Program. The CubeSat Program will work in cooperation with the

<b>Title</b>	<b>Function</b>	<b>Yearly Cost (\$K)</b>
Program Manager	Manages overall CubeSat Program	200
Deputy Program Manager/ Technical Manager	Manages Principal Investigator interactions and integration and test support	200
Resource Analyst	Manages Program budget	100
Grants Manager	Supports NASA HQ managed solicitations and awards	100
Safety	Prepares risk analysis and mitigation plans	100
Engineering Support	Supports integration and test and technology development	200
Contract Funding	Electro-mechanical support, integration and test, engineering support, and institutional support	7000
<b>Total</b>		<b>7900</b>

existing sounding rocket and balloon programs, using existing contract arrangements and infrastructure. The table above summarizes the yearly program office costs.

The NSF CubeSat program invests ~\$900k over three years per experiment, and we assume a similar baseline in this paper. Assuming four new CubeSat awards per year, the program could fund 12 experiments per year (four in their first year, four in their second year, and four in their third) at a yearly cost of \$300k/year, plus an additional \$250k/launch (four per year). The total yearly science payload cost is then \$4.6M. Including the WFF support, the required NASA investment would be \$12.5M/year, a relatively modest cost for such a high return-on-investment program.

## **Summary**

With a relatively modest yearly investment of \$12.5M NASA could expand the Suborbital and Special Orbital Projects Office to fund 12 simultaneous CubeSat investigations and four launches per year. The program could build upon the highly successful sounding rocket and balloon programs, and leverage existing resources for a high return on investment. We encourage the panel to examine other implementations of a NASA CubeSat program as well, such as partnering directly with the existing NSF program or implementing an NSF-style CubeSat program within NASA. Regardless of how a program is implemented, the benefits for rapid, focused science return, training the next generation of scientists and engineers, and advancing small technologies and instrumentation would be enormous, and are needed to maintain the NASA workforce. The addition of a CubeSat platform alongside the sounding rocket and balloon platforms enables a much larger range of science questions to be addressed, opening up a new area of space exploration to the next generation. Further, the NSF program has proven that the scientific opportunities enabled by CubeSats are in high demand, attracting proposers from the smallest universities to the largest labs. The CubeSat platform is also suited for Earth observing and small astrophysics missions, providing even greater breadth of science return and possible additional funding from other divisions. Finally, we note that each platform – sounding rockets, balloons and CubeSats – provide clearly differentiated science platforms, and including CubeSats in the SSOPD at the expense of funding the existing sounding rocket and balloon programs would be detrimental to the health and vibrancy of the community.