

# Space: It's Not What It Used to Be.

## A Goddard Approach to This Challenge, Questions About SmallSats, a Few Answers, and the Need for Transformative Thought in a Transformative Time

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**Abstract** - *The "final frontier" is not what is used to be. Advancements in systems capabilities, easier access to orbit, a rapidly expanding spacefaring community saddled with imagination, and innovative approaches to mitigate chronic fiscal constraints are all converging to create novel spaceflight systems and mission architectures. Persons content to apply yesterday's thought to today's challenges stand the risk of finding themselves following instead of leading.*

*The Dellinger 6U CubeSat project ongoing at NASA Goddard Space Flight Center is demonstrating that while there is great potential to achieve compelling science, new systems and processes are required to fully leverage the cost and schedule efficiencies small satellites can yield. In addition, realizing the potential of these platforms in environments more challenging than benign low earth orbit requires spacecraft systems designed for reliable or resilient operation, and reliable components and subsystems.*

**Keywords:** CubeSat, SmallSat, small satellite, Dellinger

### 1 Introduction

Disruption in the aerospace sector is ongoing. Not only are missions recently considered not possible or unfeasible on orbit, but the demographics of communities deploying these missions has changed dramatically. Small innovative organizations from industry, and students from high school through elementary school with novel insights and perspectives are accomplishing missions in space—a domain once accessible to governmental organizations and large industry. Small satellites, largely CubeSats are driving this transformation. New approaches must accompany this transformation if CubeSat-based missions are to realize their full potential. Whereas some of these approaches are well understood and defined, others are a work in process.

### 2 A Transformational Platform-CubeSats

A CubeSat is a type of miniaturized spacecraft categorized as a nanosatellites or microsatellite. It is implemented from one or multiple 10 cm x 10 cm x 10 cm modules known as 1U cubes. The CubeSat Design Specification [1] defines their physical and electrical characteristics.

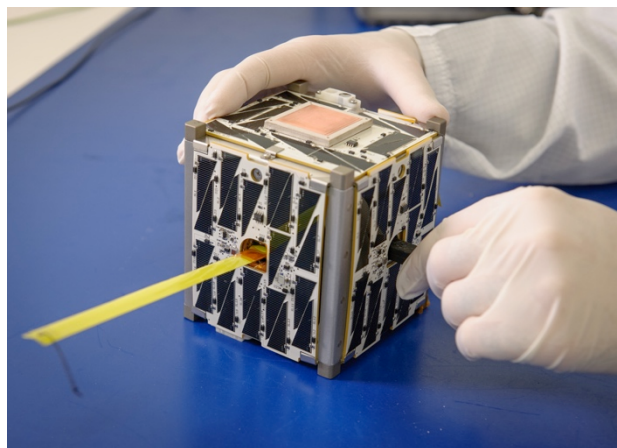


Figure 1. A 1U CubeSat

Many technology and science research missions targeted by these spacecraft can be implemented at costs significantly lower than typical spacecraft missions as CubeSat-based missions are typically implemented with commercial off-the-shelf (COTS) components and are developed using less rigorous processes. Furthermore, given they are typically deployed as secondary or rideshare payloads, costs to transport them into orbit are low as the primary mission bears most of the launch costs.

The rapid growth of these platforms and other low cost small satellites has led to the birth of what is known as “new space”, a term that defines approaches to, and use of space that differ from those of organizations such as NASA or

other government or industry entities who define the traditional or mainstream space industry.

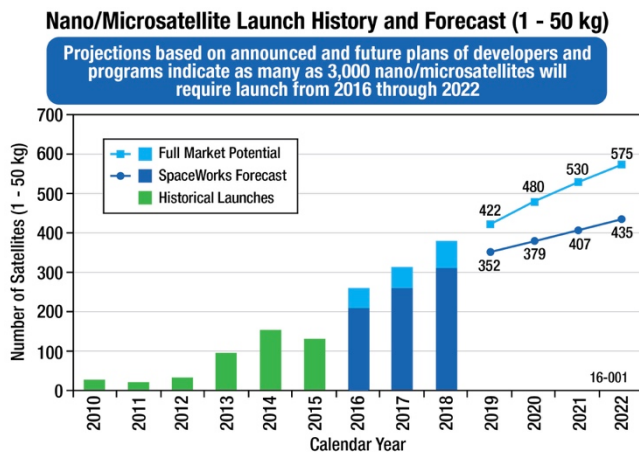


Figure 2. Growth of the small satellite sector is increasing rapidly. [2]

New Space approaches are enabling visionary opportunities as diverse as weather forecasting, land imaging, fundamental Earth and space science, technology demonstration, and even asteroid mining [3]. This “space renaissance” is changing the rules of space exploration.

This renaissance can be traced to the advancements in terrestrial systems. Advancements such as electronics systems miniaturization, low power systems, additive manufacturing, and other 21<sup>st</sup> century developments are not limited to terrestrial applications, but can also be applied to space systems. Accordingly, the systems that comprise satellites are growing in capability while shrinking in resource load—mass, volume, and power.

NASA investments are advancing the capabilities of small spacecraft. The Space Technology and Mission Directorate (STMD) Small Satellite Technology Program (SSTP) is sponsoring initiatives that strategically address capability gaps in propulsion, communication, attitude determination and control, and other critical areas that allow these platforms to meet increasingly challenging mission requirements [4]. SSTP also invests in “intellectual capital” at universities via technology partnerships that leverage novel ideas and perspectives from university populations with fresh and innovative ideas [5]. Furthermore, the NASA Venture Class Launch Services, which offers dedicated launches of small payloads as an alternative to rideshare addresses an additional barrier—cost-effective primary launch opportunities [6].

Meanwhile, the fiscal environment is constraining science budget and requiring science to be accomplished with fewer available resources. The confluence of growing capabilities of small platforms, their lower cost relative to traditional spacecraft, and science budget pressures is

fostering innovation and the use of alternative approaches and technologies to address challenges and expand the range of what is possible.

## 2.1 NASA Relevance

Whereas these developments are exciting, there were unanswered questions regarding their relevance to NASA science. To answer these questions, NASA and the National Science Foundation requested in 2014 that the National Academies of Sciences (NAS) conduct an ad hoc review of the scientific potential of the CubeSat platform and make recommendations to improve the capabilities of the platform to enable its use by the scientific community.

Findings of the Academies [7] are aligned with perspectives shared within the small satellite community at Goddard. Specifically, while large spacecraft can accomplish certain science objectives, CubeSats offer opportunities to complement large science missions and to achieve science in targeted areas more feasibly than large spacecraft, opening new areas of science and exploration. They can be deployed as probes to venues and environments considered to risky or impractical for larger more costly space assets. The distributed architectures they facilitate can reveal new science by virtue of the increased temporal, spatial, and angular measurement resolution enabled by simultaneous multi-point observations as conveyed in Figure 3.

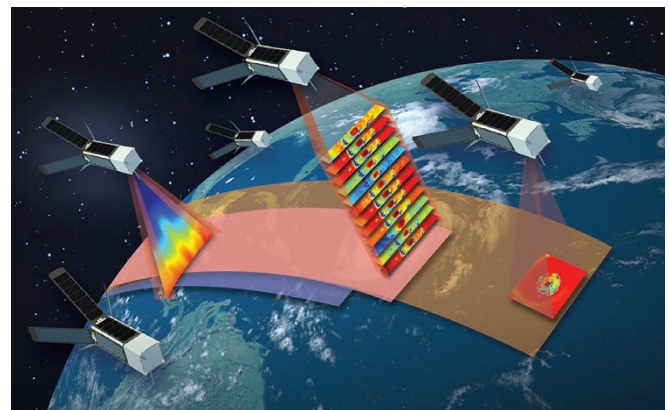


Figure 3. Conceptual rendering of the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats investigation. [8]

New Space offers great potential. Definitive and intentional effort is required however, to fully realize this potential. The Dellinger project addresses this challenge.

## 3 A Goddard Response- The Dellinger Project

The Dellinger 6U CubeSat project was initiated in 2014 as a Goddard effort to address three critical objectives:

- Deliver compelling science from two flagship quality instruments developed by the Goddard Heliophysics Science Division;
- Develop intelligent “lean” end-to-end systems and processes for lower-cost, scalable risk systems; and
- Derive key findings

### 3.1 The Spacecraft

The Dellinger spacecraft (figure 4) is a three-axis stabilized 6U CubeSat that targets compelling Heliophysics science from its instrument complement—a compact Ion and Neutral Mass Spectrometer (INMS), and a 3-axis science magnetometer system (DAGR or Distributed Acquisition for Geomagnetic Research) which is comprised of boom- and body-mounted sensors.

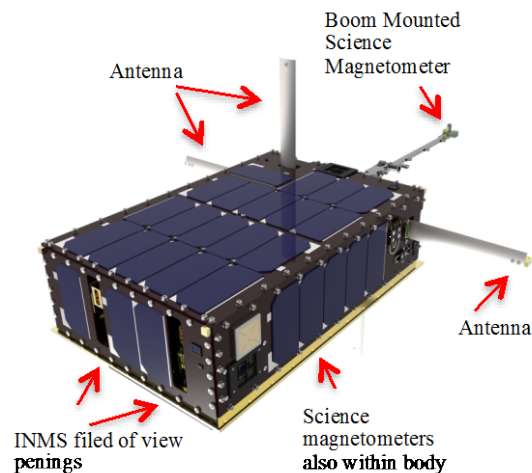


Figure 4. External rendering of the Dellinger 6U Spacecraft.

INMS will measure the composition and density of various ions and neutral elements in Earth's lower exosphere and upper ionosphere, a volatile region of the upper atmosphere that affects satellite communications and creates a drag that can degrade satellite orbits.

DAGR is a miniaturized fluxgate system with better than 0.1nT resolution at 3.5 Hz. It is comprised of a sensor mounted at the end of a 76 cm boom and three sensors mounted within the spacecraft. The sensed field is comprised of two components—one attributable to science, and the other attributable to disturbances created by bus subsystems. Algorithms created by the science team will analyze field data, identify the disturbance component, and subtract it from the total field to yield the science data.

Dellinger bus systems are partially comprised of commercial off the shelf (COTS) components (figure 5).

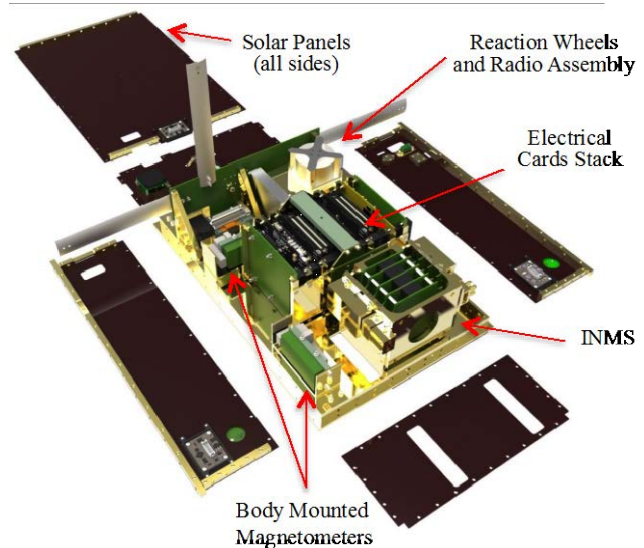


Figure 5. Rendering of the Dellinger spacecraft with solar panels removed showing internal components.

The components were selected based on their predicted compliance with mission goals over the six-month low earth orbit mission duration. Selected systems, such as the boom, the antenna, deployment mechanisms, solar panels, the attitude determination and control components, and custom electronics were developed in-house in order to meet mission performance requirements or to realize cost or implementation benefits.

Dellinger is currently undergoing spacecraft level test and is manifest for launch to the International Space Station in May 2017 (figure 6).

### 3.2 Key Findings

Dellinger development has yielded a wealth of valuable findings, several of which are documented below.

- *It may be small, but it's still a spacecraft.* The development effort required to deploy a *successful* CubeSat science mission such as Dellinger is significant. Though small, the spacecraft incorporates the types of subsystems one finds in large spacecraft, and requires a level of development rigor commensurate with the mission risk posture. Or concisely, “small spacecraft” does not equate to “small effort”. Of particular note is software development; it does not scale with spacecraft size since each subsystem within the spacecraft requires the same level of intelligent control whether the subsystem is large or small, and the data generated by the instruments require onboard handling irrespective of their size.

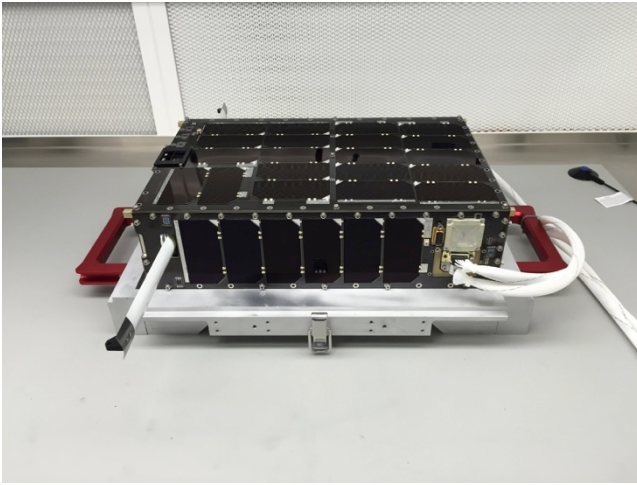


Figure 6. The Dellinger spacecraft.

- *It Is a System, Not Just a Spacecraft.* Efficiently meeting Dellinger science objectives extends beyond the science instruments and the spacecraft bus. External systems are required to achieve the end product of reliably delivering data and telemetry to end-users. These systems must communicate with the spacecraft, predict its orbit, and control spacecraft functions—both on orbit and during the “test as you fly” test program Goddard routinely implements. Cognizance of this system-level perspective should inform design of the mission and will inform mission success.
- *The Quality of Commercial Components is Largely Inconsistent with Mission Requirements.* Many of the commercial subsystems incorporated into the spacecraft required remedial efforts to improve their reliability. As delivered, they exhibited build quality inconsistent with the mission risk posture. For example, one of the systems exhibited a thermal design deficiency that would have led to overheating and likely system failure. Another vendor delivered multiple systems that were non-operational on arrival despite accompanying documents stating they had been tested. Other components exhibited signs of improper handling. Such quality is not consistent with the level of mission reliability required for Goddard science missions.
- *Intelligent Design and Development Practices Can Mitigate the Impact of Questionable CubeSat Component Quality.* The quality of commercial components strongly informs the probability of mission success. But incorporating such components in a mission or spacecraft architecture that is resilient to certain failure modes, and conducting a robust “test as you fly” test program contributes greatly towards a successful mission.

- *We are in the 1960’s.* CubeSat mission success is informed by component and subsystem reliability, the system architecture, and by systems and processes applied to mission development. Historical success metrics range between 50-70% [9]. Lessons developers are learning from mission failures are contributing to an upward trend in reliability. This is analogous to the early days of rocketry, when mission failures were frequent and expected; but knowledge acquired during that period has contributed to the high success rate observed today (figure 7).

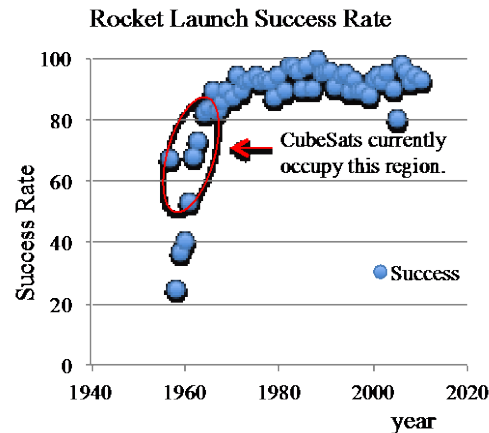


Figure 7. Current CubeSat success rate is analogous to success rate demonstrated by rockets in the early 1960s.

- *Efficient Systems Development Requires New Systems and Processes.* Systems and processes Goddard has employed over the past 50 years to develop spacecraft have contributed greatly towards a history of successful missions. There are costs associated with implementing such systems and processes however. And these costs are not necessarily consistent with CubeSat mission costs, which are significantly lower than those of heritage missions. Accordingly, one of the challenges Dellinger is helping to address is to define new and novel approaches to spacecraft development that improve the “risk vs. cost” metric. Or specifically, what approaches will yield a level of reliability that approaches that associated with traditional Goddard spacecraft, yet do not incur the associated costs.

### 3.3 Next Steps at Goddard

The breadth of science questions that can be addressed with small satellite-based mission architectures is expanding. Many of these measurements are in environments beyond a relatively benign low earth orbit, but are instead in environments with more challenging radiation environments such as deep space or geosynchronous orbit. In addition, the transit time to the mission station may be years. Given the vast majority of COTS CubeSat components or subsystems were not

designed for such environments or durations, incorporating them into such missions would raise a significant risk.

Whereas it is fairly easy to implement “expensive reliable systems”, novel approaches are required to implement “reliable systems inexpensively” or at a cost vs. risk metric that is improved relative to traditional approaches. To address this need, the Applied Engineering and Technology Directorate is maturing development of the Goddard Modular Spacecraft Architecture (GMSA)—an architecture that will facilitate such efficiencies via a modular, flexible, and scalable approach, and incorporate systems that exhibit reliable operation in challenging environments and during extended missions.

Initial investments target robust radiation-tolerant Command and Data Handling and Electrical Power systems—the core of the spacecraft bus. Ongoing efforts target system architecture approaches that cost-effectively maximize mission robustness and resiliency. Subject matter experts are also engaging external technology and capability providers to increase their cognizance of Goddard performance needs, and to support their efforts to develop systems consistent with them.

## 4 What is Government’s Role in the CubeSat-SmallSat Transformation?

GMSA mitigates deficiencies relevant to Goddard science missions. On a larger scale, CubeSat systems currently available are not consistent with challenging missions targeted by other NASA centers or with operational missions targeted by other governmental organizations. Government has a role in addressing this challenge, advancing the sector “from the 1960s” (Figure 7).

This raises several questions regarding an interagency government role in the New Space transformation. Industry is moving at a pace that eclipses most governmental actions. This is creating new capabilities, opportunities, communities, and associated disruptions, yet leave unaddressed capability gaps that must be resolved if the science goals of NASA and operation missions of other agencies are to be met. The author offers the role of the government must be value added, instead of one where guidance or participation impedes innovation or the risk taking that can lead to transformational positive outcomes.

Among the questions that should be considered in defining this role are the following:

- Should a government-wide community of practice be established?
- Should a mechanism be established to facilitate sharing key findings or lessons learned among government organizations, as appropriate?

- Should a mechanism be established to share design aid tools, as appropriate?
- Should an effort be started to identify constructive standards, and to facilitate establishing them?
- Are there other actions the government should collaboratively execute in support of all stakeholders, to advance our national CubeSat-SmallSat space flight capabilities?
- How can the government incentivize the private sector to form a UL LLC-like entity to self-regulate the quality of CubeSat/SmallSat parts?

The author raised these questions to an intergovernmental audience at the 8<sup>th</sup> Government CubeSat Technical Interchange Meeting, convened 24-25 May 2016. The consensus answer to each is “yes”, with specific implementation actions ongoing.

## 5 Conclusions

Rapidly increasing small satellite capabilities and an innovative and growing community are enabling spaceflight missions unimagined a decade ago and at costs that mitigate effects of a constrained fiscal environment. Intentional efforts, such as the Dellinger project and next steps such as maturation of GMSA and other governmental actions are required to fully realize the Earth and space science potential of these small platforms.

The role of government is to facilitate this ongoing disruption. Careful consideration is being given to the questions posed above in order to bring clarity regarding this role.

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