

## **Technical Report: Mission Design Review**

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March 8, 2025

Through the NASA Wallops Flight Facility, there have been many big strides made in space exploration using a variety of launch platforms, including sounding rockets, scientific balloons, and expendable launch vehicles. These platforms have helped develop many smaller missions, test new technologies, and collect important data to improve our understanding of space (Adkins, 2025). A key focus at Wallops is small satellites, or smallsats, which are a cheaper and more flexible way to explore space. These small satellites are commonly used for scientific research, technology testing, and Earth observation. Because they are small, they can be launched more often and allow for creative mission design. A notable project within this realm was known as the Firefly mission which helped to study natural phenomena and further improve smallsat technology (Kogut, 2024). Therefore, this report will explore the overall elements of the Firefly mission, the general role of smallsats, key instrumentation used in the mission, and observe the role of stakeholders.

As its purpose, the Firefly mission, NASA Goddard Space Flight Center's first CubeSat, was designed to investigate the connection between lightning and Terrestrial Gamma-ray Flashes (TGFs), brief bursts of high-energy radiation in the upper atmosphere. Led by Dr. Doug Rowland and funded by the National Science Foundation, Firefly's specific objectives were to determine which types of lightning produced TGFs and the frequency of weaker TGFs as it had not been previously studied (Goddard Space Flight Center, n.d.). More broadly, its science goals included improving the general understanding of high-energy electron acceleration in Earth's atmosphere, crucial for advancements in planetary science and astrophysics. To achieve this, the particular platform of Firefly's development was a 3U CubeSat, a compact, standard satellite to be used for space research within the class of nanosatellites. NASA Wallops Flight Facility played a crucial role in supporting the mission by overseeing pre-launch testing, including

vibration and mass property tests before its deployment. The spacecraft launched on November 20, 2013, aboard the Minotaur-1 rocket from the Mid-Atlantic Spaceport on Wallops Island, Virginia, was chosen as the launch site due to its capabilities and resources to deploy small satellites efficiently and allow for quick access to orbit. As a secondary payload on the Operationally Responsive Space-3 mission, the Firefly mission involved an orbital vehicle with the expectation of the satellite to operate for a year, orbiting Earth. While initial telemetry confirmed the spacecraft's health, no science data was ultimately received because of interface issues, however, this would serve as a key experience for CubeSat development and operations in future missions (Kramer, 2012).

Firefly was launched aboard the Minotaur I, an expendable launch vehicle developed by Northrop Grumman and created from decommissioned Minuteman missile stages. As a four-stage rocket, the Minotaur I is capable of delivering small payloads into low Earth orbit with very high precision, which makes it well-suited for CubeSat missions like Firefly. Firefly was deployed as a part of the Operationally Responsive Space-3 mission, a rideshare launch that carried several small satellites to orbit (Kramer, 2012). The launch took place on November 20, 2013, from the Mid-Atlantic Regional Spaceport at NASA Wallops Flight Facility in Virginia. Since Firefly was designed for an orbital mission, it was not intended for recovery as it remained in space until it naturally deorbited on November 2, 2017, because of atmospheric drag (Goddard Space Flight Center, n.d.).

The Firefly mission used a variety of specialized instruments to study the link between lightning and TGFs. The Gamma Ray Detector was the main instrument that measured the energy and time of X-ray and gamma-ray bursts alongside energetic electrons. It was selected to be used because of its ability to capture high-energy events in thunderstorms using a  $64 \text{ cm}^2 \times 1$

thick scintillator crystal with a 4mm thick plastic layer. The GRD was able to detect photons between 100 keV and 10 MeV and electrons from 100 keV to 2 MeV, however, this was capped at a maximum count rate of 100,000 per second. Other key instruments included the Optical Lightning Detector, which concerned the timing of lighting flashes using four Hamamatsu silicon PIN diodes, and the Very Low-Frequency Receiver, which measured electric field signals from lighting. All of these instruments were pre-existing and not built specifically for Firefly but were modified to fit within the small 3U CubeSat. However, the major problem and limitation involving all of these instruments was with the interface circuitry between the instruments and the spacecraft bus, which stopped Firefly from sending back scientific data even though the satellite itself was working (Goddard Space Flight Center, n.d.).

Figure 1

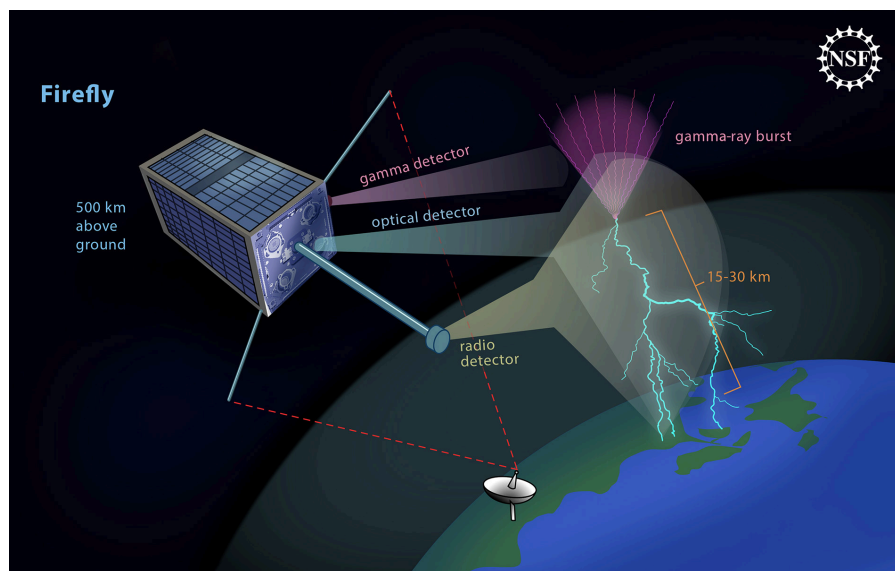


*Diagram of Firefly Detector Instrumentation in Action*

Zina, D. (2012). *Firefly* [Photograph]. National Science Foundation.

<https://www.nsf.gov/news/tiny-firefly-satellite-set-flash-straight#image-caption-credit-block>

While scientific data was not retrieved from the Firefly mission, the results would have been beneficial for various important stakeholders, especially NASA scientists and engineers alongside the general scientific community. NASA scientists were directly involved in this mission's designs and goals in regards to understanding the mechanisms of TGFs and their relation to lightning. The gathered data would have helped to improve models of space weather and atmospheric phenomena, crucial for understanding and predicting space weather events that could affect satellite operations. Without being able to send back scientific data from the mission due to interface circuit problems, this helps to serve as a basis for NASA engineers to improve from their creation errors and prevent such technical problems in future CubeSat Problems. Additionally, industry partners, like the Universities of Space Research Association and the University of Maryland Eastern Shore, would have used the research data to advance their own studies in atmospheric science and space technology to improve the development of future missions and technologies (Goddard Space Flight Center, n.d.). Through an indirect relationship, the general public would also benefit from the data because there would be more knowledge gained from studying the relationship between TGFs and lightning, which could help improve weather forecasting and prepare for similar natural disasters due to understanding the impact of extreme weather on Earth's atmosphere.

In conclusion, the Firefly mission, even though it faced issues with data collection, played a crucial role in contributing to NASA's current research into space weather, lighting phenomena, and atmospheric science. In an attempt to help increase our understanding of high-energy processes in Earth's atmosphere, the mission design, technology used, and provided valuable experience with integration, testing, and communication of such systems. The Firefly mission was a valuable learning opportunity to make improvements and have more successful future CubeSat missions that collected important data. The mission's objectives aligned with NASA's strategic goals of expanding scientific knowledge and advancing space technology, specifically representing goals of expanding human knowledge through new scientific discoveries on Earth's system and climate. Firefly also showed the potential of smaller and more cost-effective CubeSats, which aligns with NASA's strategic goal of catalyzing economic growth, driving innovation, and advancing transformational space technologies (Keeter, 2024). Overall, while the mission was unable to directly uncover scientific data due to technical issues, Firefly helped to push NASA's boundaries of discovery and innovation by providing a basis to pioneer new satellite technology, reinforcing its mission to explore space for the benefit of humanity.

## References

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