

Iterative Design of a High-Altitude Balloon Payload for Interplanetary Dust Particle Collection

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High-altitude weather balloons offer a low-cost, reliable platform for reaching the stratosphere, where extraterrestrial material can be collected before significant terrestrial contamination. CATITO (Cosmic-Atmospheric Terrestrial Identification of Trapped Objects) is a balloon payload designed to collect Interplanetary Dust Particles (IDPs) on such high-altitude balloon (HAB) platforms. This paper presents the design and performance of two different flown iterations of CATITO. Following the engineering design analysis, this paper briefly discusses the implications of the collected samples.

I. Introduction

Extraterrestrial particles provide valuable insight into the composition of the solar system and other planetary bodies at discrete moments in time. Most of these particles were formed during the creation of the solar system [1] and have the potential to be scientifically valuable if collected under proper conditions. Only 10-20% of extraterrestrial particles that arrive to Earth survive and become micrometeorites, which are approximately 0.01-2 mm in size [2]. Numerous sampling efforts have contributed significantly to micrometeorite collections [3] such as mounted collectors on high-altitude aircraft [4], manual collection of magnetic particles from urban rooftops [5], aerogel collectors on spacecraft [6], and bulk melting of ice in polar regions [7]. Each method presents unique challenges in terms of cost, labor, and logistical complexity, which are summarized in Table 1.

Collection Technique	Benefits	Limitations
Airborne Collection [4]	Many particles through large filtering of air	High cost, energy/labor/time intensive
Rooftop Collection [5]	Low cost, readily accessible	Time/labor intensive, only collects magnetic particles
Bulk ice melting [7]	Largest collection, most pristine terrestrial samples	Energy intensive, high-cost, labor-intensive, chemical alteration is possible
Spacecraft [6]	Highest fidelity samples	High cost and risk

Table 1: Benefits and limitations of existing micrometeorite collection techniques.

A major challenge for micrometeorite collection is the alteration that samples experience upon atmospheric entry. Micrometeorites enter the atmosphere at velocities as high as 15 km/s [8], during which atmospheric drag may melt, differentiate, and/or chemically transform the particles. In the stratosphere, there is a chance of collecting micrometeorites in a less altered or unaltered state due to atmospheric entry. Collection methods also skew the bulk chemical composition of micrometeorite collections, since iron-rich micrometeorites are more likely to survive atmospheric entry than chondritic micrometeorites.

Consequently, there is growing demand for technologies capable of collecting pristine extraterrestrial material in the stratosphere prior to atmospheric modification, defined as interplanetary dust particles (IDPs) [9]. The collection of IDPs implies that the recovered particles are minimally altered by atmospheric heating and terrestrial weathering.

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Such pristine material is especially valuable because it is more representative of original interplanetary matter and therefore provides greater scientific insight into early solar system processes.

HAB platforms enable small payloads to access the stratosphere, allowing for a low-cost method of collecting IDPs. Previous attempts have shown promise of collecting micrometeorites on HABs. After a 1.5-hour flight, a HAB payload was able to collect three potential micrometeorite samples with a maximum collection area of $\sim 0.018 \text{ m}^2$ [10].

The University of Maryland (UMD) Balloon Payload Program (BPP) is an undergraduate research group that regularly launches HABs throughout the semester, providing ready access to altitudes of 25,000 to 32,000 m. Higher altitudes are possible depending on the number of payloads and amount of lift available in the balloon. The BPP also has the unique capability of allowing latex balloons to reach neutral buoyancy at high altitude [11], allowing for a prolonged flight at an altitude favorable for micrometeorite collection. This paper details the iterative design, flight-testing, and post-flight analysis of CATITO, a payload designed to improve upon previously presented micrometeorite collection payloads for HAB flights. The approach is straightforward: samples are collected using an adhesive surface which are deployed at sufficiently high altitudes and retracted at the start of descent to prevent terrestrial contamination. This system was designed around the HAB mission architecture, which heavily influences many key design aspects, and thus mission results.

II. Design Considerations

The goal of CATITO is to collect as many particles as possible in the stratosphere using tape. Development began in August 2025 and has continued up until the time of writing. Hardware costs were limited to \$500 and the resources readily available through UMD BPP and Terrapin Works facilities, which includes many spare parts, laser cutter, and 3D printer. In order to collect high-fidelity samples, CATITO has three major payload requirements:

1. The payload shall use tape as a collection surface.
2. The payload shall be able to protect the collection surface against terrestrial particle contamination.
3. The payload shall be able to expose the collection surface to the environment at specified altitudes.

To meet these requirements, CATITO must employ a deployment and retraction system. Possible mechanism designs were inspired by deployable solar panels on spacecraft. Table 2 shows the limitations of various designs considered.

Design	Benefits	Limitations
Tape mounted on outside of payload	Simplest design	Does not protect against contamination
Panel with one hinge	Only requires servo to activate hinge, simple mechanism	Servo must have enough torque to resist drag forces
Accordion-style panels	Could be accomplished with one motor	Many moving hinges, requires guiding rails to guide deployment
Origami deployment mechanism	Extremely compact for large surface area	Complex mechanism with many moving hinges, difficult to get a geometry that would prevent tape-on-tape adhesion
DART inspired roll-out solar array mechanism [12]	Only requires one motor, large surface area for compact storage	Complex and expensive material geometry
Conveyer belt system	Only requires one motor, no moving parts besides sheet of tape	Payload would have to be last on the flight line, collection area would require supports along full collection area
Fan deployment	Simple mechanism	Surface area, mass
Panels on linear slides	Takes advantage of maximum surface area that can be contained within payload	Mass

Table 2: List of deployment and retraction mechanisms considered for payload design.

Through this analysis of various deployment mechanisms, additional design constraints were followed. Firstly, the mechanism would be actuated by a motor to allow for maximum range of motion as opposed to a servo or linear actuator, which unless modified, have mechanical limits on movement. Unlimited range of motion allows for easier adaptability to various designs, which is particularly important to the current and future iterations of CATITO. A 410 RPM DC motor from ServoCity with a stall torque 3.0 kgf-cm and mass of 40 g was chosen because of mass, ease of use, cost, and high torque output.

Any mechanism that requires a supporting structure expanding the full range of motion of deployment (such as guiding rails) were immediately eliminated as design options due to mass constraints. High material or mechanism complexity were also eliminated due to lack of control and limitation of material behavior in the stratosphere and to minimize potential mechanical points of failure.

Most of the payload was created using 3D printed parts and laser-cut bass wood since these materials are cheap and speed up the manufacturing and iterative design of the payload. Bass wood was most used for mounting plates. Structural foam (poster board) and plastic foam are used to insulate and provide lightweight structural integrity to the payload.

Two kinds of tape were considered for collection of samples. First, scanning electron microprobe (carbon) tape was used so samples can directly land onto the tape and be put directly into the SEM with no sample transfer. However, the tape is expensive and was used sparingly and not until adequate engineering testing was conducted. The primary alternative to SEM tape was clear packaging tape, where samples could land directly onto the tape and be investigated under an optical microscope with or without sample transfer.

HAB platforms are convenient and cheap, but they impose many constraints on the systems they carry into the stratosphere. On a typical HAB flight, payloads can reach a temperature of -60°C , a minimum pressure of 0.81 kPa, and a maximum altitude of around 32 km. A typical latex HAB setup is shown in Fig. 1, with payloads hanging from a balloon inflated with helium. Such flights must adhere to certain FAA regulations outlined in unmanned balloon flights in 14 CFR Part 101 Subpart D depending on flight and payload parameters.

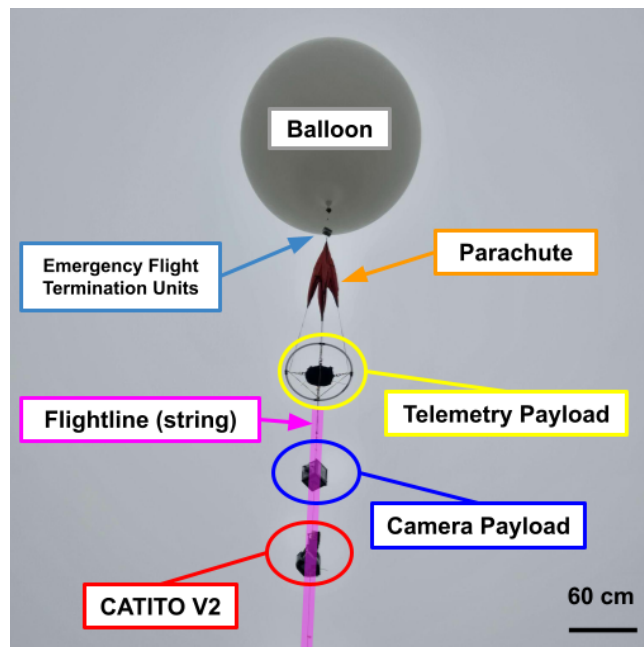


Fig. 1: Anatomy of a flight line.

The weight of any single payload is constrained to 2.72 kg (6 lbs); this imposes constraints on many desirable design features for a system collecting IDPs. For example, the surface-area of a collection apparatus and the complexity of any sample-sealing mechanism are constrained by this maximum weight. Additionally, the total assemblage of payloads carried by the balloon must not exceed 5.44 kg (12 lbs); this limits the accompanying infrastructure which may aid in the operation of a sampling payload, such as cameras, telemetry/tracking modules, and flight-termination modules. Since latex balloons often ascend until they burst, which can produce sudden contamination by spreading synthetic particulates, the sampling system must be placed sufficiently far below the balloon. This ensures sufficient time for sampling to cease before balloon-borne contaminants land on the collection surface. Upon landing, the payload must be strong enough to ensure that collection surfaces remain uncontaminated while being weak enough that in a hazardous landing situation, such as on a road or unlikely collision with an airborne vehicle, it will break.

Since the flightline, from which all payloads hang, must remain continuous, CATITO must include a tube roughly through its center of mass. This complicates the deployment of adhesive surfaces, since the top of the payload cannot open to begin sampling if a rigid tube runs through its center. For example, if a flap is deployed from the side, the

payload weight may shift, causing CATITO to fly askew, which would limit its effective cross-sectional area facing directly up. Thus, an approach that deploys adhesive surfaces radially, around the central tube, was eventually chosen.

III. CATITO v1.

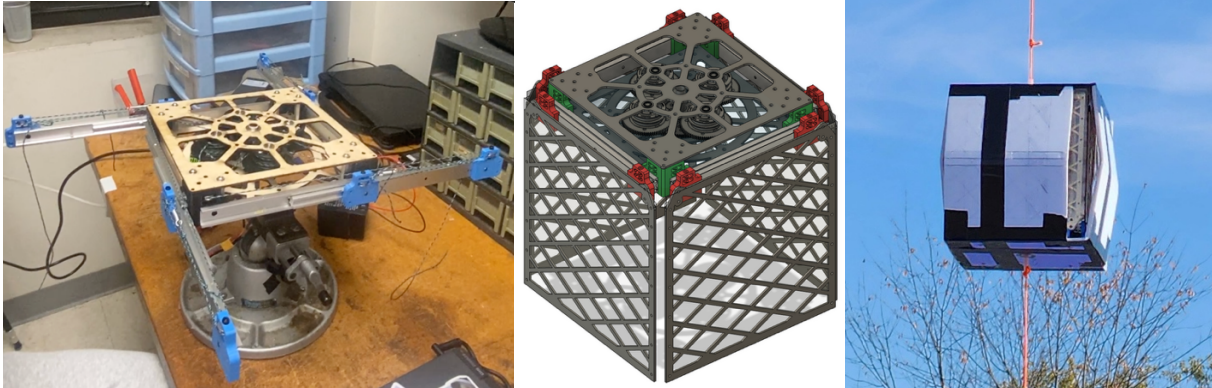


Fig. 2 (left to right): 1) Deployed linear slides without panels attached. 2) CAD model of internal structure of CATITO v1. 3) First flight of CATITO v1 on the flight line.

A. Mechanical Design

CATITO v1 attempted to maximize collection area while satisfying payload requirements. The 410 RPM motor was attached to a 15T pinion gear that interfaced with a 105T gear. The 105T gear was mounted on a tubular shaft with a 12 mm outer diameter (OD) and 10 mm inner diameter (ID) to allow the flight line to pass through the center of the payload. A 46T gear was also mounted to this shaft and was interfaced with four 74T gears, each mounted to a spool. This results in a final gear ratio of 11.26:1 between the pinion gear and the spool. This gearing was designed to maximize torque output. Each spool retracted and unraveled string that was used to deploy and retract a three-stage Misumi SAR320 linear rail (200 mm long). The outermost stages of the linear slide were outfitted with 3D-printed adapters that allowed for the string to be channeled through bearings. The retraction/deployment string was held in tension with tension springs that were tied to each end of the deployment string to ensure the payload closed entirely. The laser-cut sample collection plates were mounted to these adapters, as well as the slides to the main assembly. The main assembly had two (top and bottom) laser-cut bass wood mounting panels that ensured that the payload and gear system could be securely held in place. Flange bearings were placed in the mounting panels to ensure each rotating axle be aligned while rotating with minimal friction. The top and bottom mounting plates were separated by a 35mm standoff.

To prevent contamination, the mechanical system was placed upside-down in a box made of foam. A curvature was maintained near the center of the walls of the box to minimize interaction with the tape on the collection panel. Slots were cut out of the box to allow for smooth deployment and retraction, though these slots were much bigger than originally thought, presenting issues with contamination.

The maximum collection area of this payload was around 0.5 m² and had a total mass of ~2 kg. In summary, by using one motor, this payload could simultaneously deploy and retract four panels, each with two large sample collection surfaces.

B. Electrical and Software System

CATITO is powered by a Turnigy Nano-Tech 3S 1200mAh 11.1V 50C LiPo battery, which was chosen due to high current output, price, low mass (80g), and energy capacity. This battery would allow for the motor to be moving a load throughout the entire 1.5-hour flight duration, even though the design only requires the motor to be moving during deployment and retraction.

In addition to the motor, the system was controlled using a Teensy 4.1 microcontroller with an onboard SD card reader for datalogging. CATITO was also equipped with a pressure-temperature-humidity sensor (MS5607), real-time clock (DS1307), heater, and a temperature probe (DS18B20). The heater and the temperature probe worked in a feedback loop to monitor the temperature of the motor to ensure that it would stay above -20° C. The system was also equipped with a small control panel with two buttons that would allow for manual deployment and retraction of the system. Telemetry for the payloads are provided a separate BPP payload, which downlinks location, temperature, ascent rate, and altitude data over 144.390 MHz on APRS (Automatic Packet Reporting System). This capability

means that payloads do not have to be equipped with their own tracking units, and live telemetry allows the team to recover payloads safely and quickly.

C. Sample Handling Procedure

Sample handling proved to be a critical step for mission success. Even though the payload was designed to prevent contamination, payload accessibility to prepare, remove, and replace protection of the and the collection surfaces themselves before and after the launch while minimizing exposure is vital to ensuring the payload collects pristine samples. The collection surface preparation procedure was as follows, where the steps that would have to be repeated for every launch are recorded. Steps 1-4 were completed in a relatively clean environment after disinfecting the tables, and steps 5-7 were completed at specified points during launch day operations:

1. Lay down two sheets of nylon fabric 30 cm x 30 cm in size approximately 5 mm separated from each other.
2. Place ~80 cm lengths of tape next to each other across the nylon fabric until the sheet of tape is just over the width of the panel (~25 cm) is accomplished.
3. Fold the sheets of tape over the sample panel with the nylon fabric away from the panel.
4. Secure the tape by screwing the tape onto the panel.
5. Screw the panels into the linear slides.
6. ~10 minutes before launch, manually deploy the panels, remove the nylon fabric, and retract.
7. Upon recovery, tape up any exposed slots to prevent further contamination.

Due to practicality and budget, CATITO v1 was mounted with clear packaging tape, which is significantly cheaper than SEM tape, due to the large amount of surface area. The primary goal of these flights was primarily to perform an engineering and procedure test. While we would not be able to analyze the samples to their full extend, clear packaging tape presents the opportunity for the collected samples to be analyzed under an optical microscope.

D. Launch and Design analysis

There were two opportunities to fly CATITO v1. The first attempt occurred on October 5th, 2025, and the lift of the balloon was lower than expected due to suspected impure helium. This resulted in CATITO v1 not flying in exchange for additional lift. The second attempt occurred on October 26, 2025, where BPP launched from Hancock, MD and landed on a farm in Jarrettsville, MD. The recorded flight profile is shown in Appendix 1.



Fig. 3: CATITO v1 in flight retracted and deployed.

CATITO v1 was programmed to deploy at 1000 m and retract upon sensing a vertical velocity of -5 m/s. However, this trigger failed, and the payload retracted based on an altitude trigger at 1000 m. The motor would run for a set duration of 7 seconds to deploy, a value that was determined through ground testing based on how long it took for CATITO v1 to fully deploy. In the flight footage in Fig. 3, the linear rails only extended ~5 cm of length at an altitude greater than 1000 m.

Post-flight analysis of the payload showed that the failure to deploy was likely due to the tape on the outer-facing panels getting stuck to the walls of the payload enclosure. The force outputted by the motor was so strong that the tape ripped and got stuck to itself, rendering it useless for sample analysis. This shows that the attempt to prevent this sticking by putting a non-adhesive surface onto the interior and curving the walls of the enclosure were ineffective. Additionally, the weight of CATITO v1 made it difficult to guarantee a flight, as evidenced by the first failed attempt.

No sample analysis was conducted for this iteration due to contamination, lack of deployment, and compromised tape. Overall, CATITO v1 was unsuccessful and major modifications were required to collect pristine samples within

payload constraints. However, the flight of CATITO v1 provided key insight into engineering and procedural improvements necessary for its next iteration.

IV. CATITO v2.

CATITO v2, the second iteration of CATITO, is a redesign of the first iteration that addresses all the challenges of the first system. This section discusses how the problems of the first iteration are resolved with CATITO v2. This design is made from components and stock material (3D printing filament, wood panels) bought from the initial iteration. The only new components of this system include two limit switches and a longer 12 OD 10 ID tubular aluminum shaft.

The mass of CATITO v1 was 2000g limited the number of flight opportunities. The mass of the linear slides made up the greatest proportion of CATITO v1's mass, in addition to the foam enclosure. CATITO v2 addresses this by getting rid of the need for linear slides and a foam enclosure by using rotational motion to deploy panels in a fan shape. The panels are self-containing, and retracting the panels will immediately close off the tape from environmental exposure. With the deployment, retraction, and contamination protection system built into one mechanism, accessing the electronics and attaching the payload to the flight line could be done without exposing the collection surface to the environment. This also ensured that upon landing, the payload would be protected from contaminants, which is important since the payload may have to spend an extended time outdoors in the case that a swift recovery is not possible.

The focus of CATITO v1 on surface area was not as important of a design consideration as initially thought. The number of particles collected is dependent on the volume that the collection surface is exposed to, which can be simply accomplished by having the sample collection area face in the primary direction of motion of the balloon (up). This was thought to be impossible due the flight line constraints, but CATITO v2 navigates this challenge by having the flight line go through the tubular shaft and having the panels deploy around the flight line. Additionally, analyzing such a large sampling area is extremely time-consuming and impractical; instead, a reliable payload should be flown multiple times to increase sample density on a small sampling area.

The procedure for preparing and removing protection from the sample collection area before launch and protecting the payload from contaminants upon recovery was difficult and risked extended exposure. This procedure is significantly simplified and faster in CATITO v2.

The avionics were not significantly modified. The control panel that allowed for motorized deployment and retraction was replaced with two limit switches that could sense when the payload was open and closed. The heater and temperature probe were removed since the temperature recorded inside the payload never dipped below 0° C, the listed operating temperature for the motor.



Fig. 4 (left to right): 1) CATITO v2 in deployed position after payload recovery. 2) CATITO v2 in retracted position after payload recovery. (Beef broth for scale)

A. Mechanical Design

CATITO v2 employs a fan-like deployment mechanism with 12 panels. The bottom-most panel is referred to as panel 1 and the top-most panel is referred to as panel 12. Panel 1 is mounted to the 105T gear that is directly driven by the 15T pinion gear on the motor; this results in a gear ratio of 7:1, a decrease from the gear ratio of the first iteration. Sample collection occurs on panels 1-11, and the panels are connected using string. Each panel has a black 3D-printed brim that is 5mm tall that allows for the panels to be self-containing with respect to contamination. Alternate panels have alternate brim designs that allow for the panels to get caught on each other to retract. Panel 12 is held static using standoffs to allow for tensioning of the system during deployment and a physical barrier during

retraction. It also acts as a lid when the panels are retracted to prevent sample contamination. Each panel can accommodate a 50x140mm piece of tape for sample collection. Thin plastic folder dividers from target were cut to a size of 50x140mm and superglued onto the panels to allow for a continuous surface for the sampling tape to be mounted to and to ensure easy removal for analysis.

Mounting plates were redesigned and laser-cut to accommodate the new mechanism and so that electronics could be mounted securely. Foam was used as insulation for the electronics, and there was no insulation for the fan mechanism. CATITO v2 had a mass of 840 g and a maximum sample collection area of 0.077 m². During ground tests in ambient room temperature with the payload hanging on a line, CATITO v2 never failed to fully deploy. While CATITO v2 never failed to retract, it sometimes failed to fully retract since it got caught on the string connecting the panels. Gluing the string in place seemed to prevent this failure.

B. Sample Preparation

CATITO v2 greatly improved and simplified sample preparation and handling. The SEM tape conveniently came with its own protective covering, as do most double-sided adhesives. Similar to the sample procedure outlined for CATITO v1, a table was disinfected and cleaned, and all tape was handled with gloves. Thus, this procedure assumes that protection comes with the roll of tape.

1. Cut the sampling tape to a length of 140 mm and adhere to the plastic on the panel.
2. Repeat this step for the ten other panels.
3. 5 minutes prior to launch, manually open each leaf of the system and remove the protection on each sampling tape.

Due to time constraints, two pieces of 20 mm wide double-side adhesive SEM tape was used instead of the planned 50 mm wide SEM tape, and two strips were used on each panel. This simple preparation method ensured that sample collection area exposure to the environment was limited while reducing the chances of human error and imperfection in a high-stress launch environment.

C. Launch and Design analysis

CATITO v2 launched on March 7, 2026 from Clear Spring, MD and landed on a farm in Brogue, PA. This launch was delayed from the week prior and the weather was very misty with a light sprinkle. These weather conditions are important to consider when analyzing the engineering performance of the payload and the samples collected. The recorded flight profile is provided in Appendix 1.

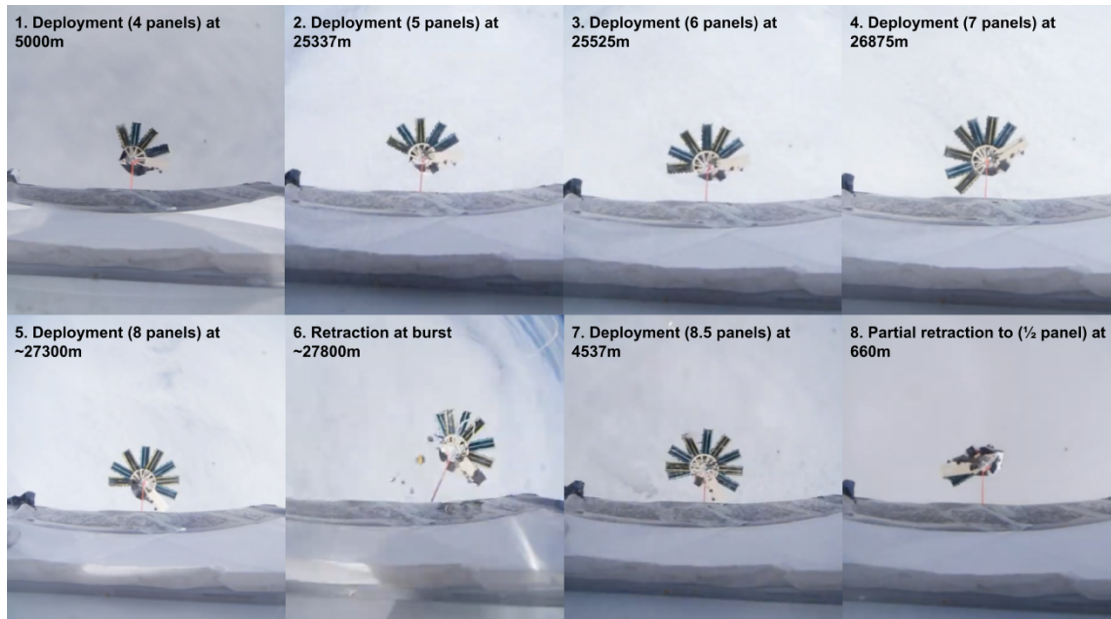


Fig. 5: CATITO v2 deployment throughout HAB flight.

As shown in Fig. 5, CATITO v2 deployed four panels at its pre-programmed deployment altitude of 5000m. At around 25 km in altitude, the payload slowly started deploying more panels until it reached its maximum deployment of 8 panels shortly before the balloon burst. Upon burst, the payload immediately retracts, where only three panels are

exposed (not pictured). There is an unintended deployment at around 4500 m to 8.5 panels, and the payload retracts to half a panel shortly before landing.

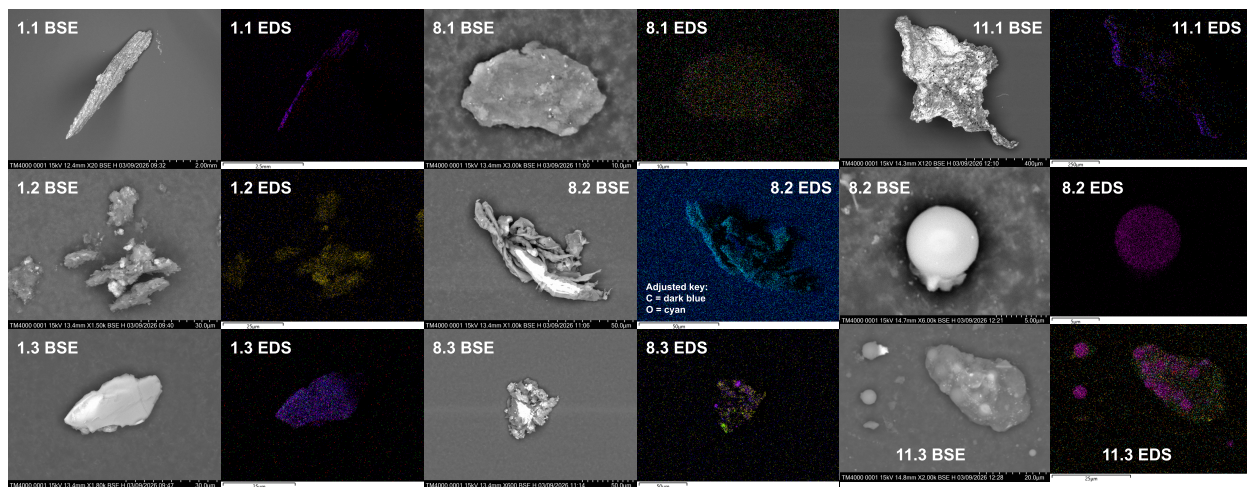
The primary hypothesis for this failure to deploy could be from a number of reasons. Upon reaching an altitude of 5000 m, the temperature recorded inside the electronics bay was less than 5° C. Considering that the interior of the payload would be warmer than the exposed part of the payload because of insulation, the water on the payload from launch and flying through the atmosphere could have frozen, interfering with the deployment mechanism. Plastic also shrinks in cold temperatures, which could have led to difficulty deploying. The failure of full deployment due to cold temperatures seems to be confirmed with the subsequent deployment sequence, which initiates as the ambient temperature increases upon reaching the stratosphere.

The effects of temperature on the structure could also explain why CATITO v2 did not fully retract upon burst. However, there was a software issue. The software continuously checks deployment and retraction triggers based on most current measurements. During this launch, the payload was set to retract if the altitude was below 5000 m or if the vertical speed was below -9 m/s. Ascent rate data is extremely noisy, so the ascent rate measurement could have been reading a vertical speed greater than -9 m/s even while descending. The solution to this software problem is to raise a software flag upon sensing descent to ensure that the payload retracts upon sensing descent, rather than checking the condition every code loop.

Upon landing, the bottom-most panel broke, and CATITO v2's panels opened up on the ground due to gravity, though only three panels were exposed. Because the bottom panel broke off, there was no way for the payload to fully retract. During post-flight evaluation of CATITO v2, the panels were successfully manually fully deployed and retracted, so the environment was almost certainly the primary cause for failure of mechanism deployment and retraction. Overall, this payload is a significant improvement from the CATITO v1, and the structure of the payload is an extremely promising method of collecting samples. Additional improvements, testing, and flights are still necessary to ensuring a robust system.

V. Preliminary Sample Analysis

SEM-EDS (Scanning electron microscopy – energy dispersive spectroscopy) analysis was performed using an TM4000Plus on fifteen points of interest (POIs) across panels 1, 8, and 11. These panels were selected because of their varying exposure to the environment: panel 1 was exposed to the ground, panel 8 was open from 5000 m on ascent to 5000 m on descent, and panel 11 was only open for a short period of time above 25000 m. Backscattered electron (BSE) images were acquired for each sample and EDS elemental maps were generated to determine major elemental compositions (Fig. 6). In total, six POIs were taken from panel 1, six POIs from panel 8, and three POIs from panel 11. The number of particles dramatically decreased as panel number increased, which is consistent with the amount of time they were exposed for. Carbon and oxygen are not included EDS maps since the SEM tape is composed of these elements. Top 5 elements by abundance and unique elements are included in the EDS maps.



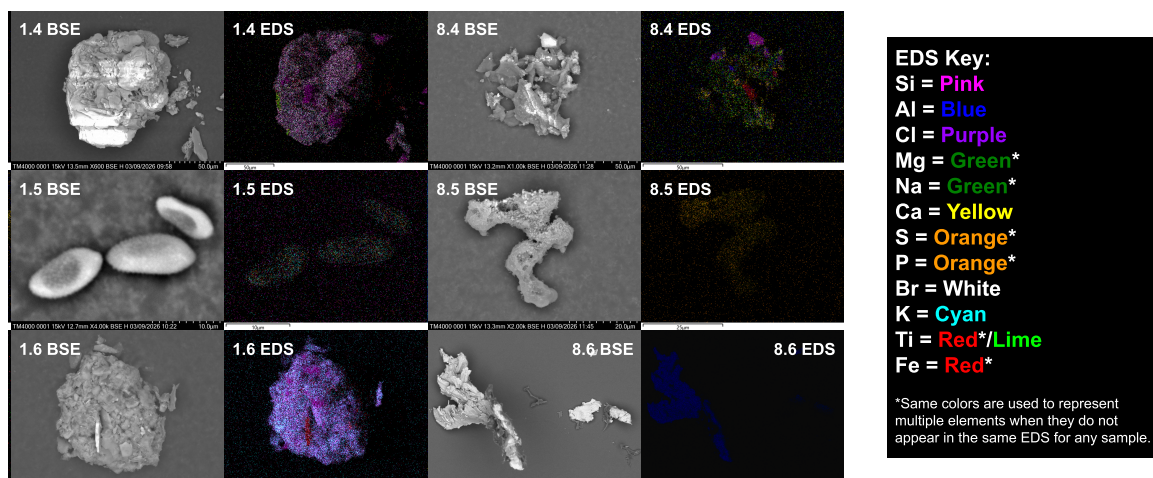


Fig. 6: BSE images and EDS maps of all samples analyzed. Sample ID is determined by the panel number followed by the spot number in order of analysis.

Analysis of the samples provides insight into the payload design, particularly regarding protection against contamination. Most of the payload was constructed from organic (carbon-bearing) materials such as plastic, wood, and superglue, while all metal components were made of aluminum. Sample 8.6 is rich in aluminum, indicating that it is almost certainly a fragment of CATITO that adhered to the SEM tape. This observation demonstrates that pieces of the payload itself can contaminate the collected samples. Several samples lack strong elemental compositions, suggesting that they are rich in carbon, and these particles could have originated from the payload itself. Visual inspection of the tape also revealed wood fragments; the fibrous morphology of sample 8.2 and dominant carbon composition could suggest it is a fragment of, though the presence of sodium would have to be further understood.

There is no direct evidence that particles from the balloon burst were deposited onto the panels. Latex particles observed in SEM images can appear spherical [13], which superficially resembles the morphology of sample 11.2. However, latex is an organic material and does not contain silicon. If balloon-derived material had contaminated the panels, talcum powder would also likely be present. Talc contains silicon and magnesium and typically exhibits a sheet-like morphology [14]. None of the analyzed samples show this morphology or the expected strong silicon and magnesium signatures.

Terrestrial rocks and micrometeorites are typically rich in silica [15], so silica abundance was used as a criterion for identifying possible naturally occurring particles and potential micrometeorites. The term micrometeorite is used here because the balloon flight did not reach the altitudes typically required to collect IDPs. Samples 1.4 and 1.6 both contain trace amounts of bromine. Although present in small quantities, the presence of a relatively heavy element is not characteristic of micrometeorites. These particles therefore likely originated from the ground, potentially related to agricultural bromine compounds, which is consistent with the balloon landing in a farm field. No bromine-bearing particles were found on panels other than Panel 1, providing some support that the other panels were not significantly exposed to ground contamination. Samples 8.3 and 8.4 are notable because they are dominated by calcium and contain a variety of inclusions. Pristine micrometeorites are expected to display angular morphologies because they have not been exposed to terrestrial weathering processes that would typically round such particles. Particles collected on panel 11 most closely match canonical expectations for micrometeorites. The rounded grain of sample 11.2 suggests that the particle experienced melting during atmospheric entry, producing the spherical morphology commonly associated with micrometeorites.

Analysis time should also be considered in payload design. Approximately four hours were required to analyze fifteen points across only 2.5 of the 22 tape strips flown. An additional ~31 hours would have been required to analyze all strips. Much of the analysis time was spent navigating across empty areas of tape. Future payload designs should prioritize improved contamination control during storage and consider flying the collection system on multiple flights before performing SEM analysis to increase particle density on the collection surfaces.

The sample analysis above is extremely preliminary and primarily serves to evaluate whether particle collection using CATITO is feasible. The results demonstrate that such collection is indeed possible. Even if micrometeorites or IDPs are not definitively identified, the collection and analysis of physical particles in the atmosphere remain valuable. Studying these particles provides important insight into the types and distribution of material present in the atmosphere and helps inform future collection and analysis efforts.

VI. Future Work

Beyond long-term future work on design iterations and sample analysis, imminent improvements can be made in the to improve CATITO's performance. Additional sensors, such as a voltage monitor on the battery and current sensor on the motor, will be added to measure the power consumed by the system while attempting to deploy and retract. Labels will be added to each of the panels to allow for easier identification during post-flight analysis.

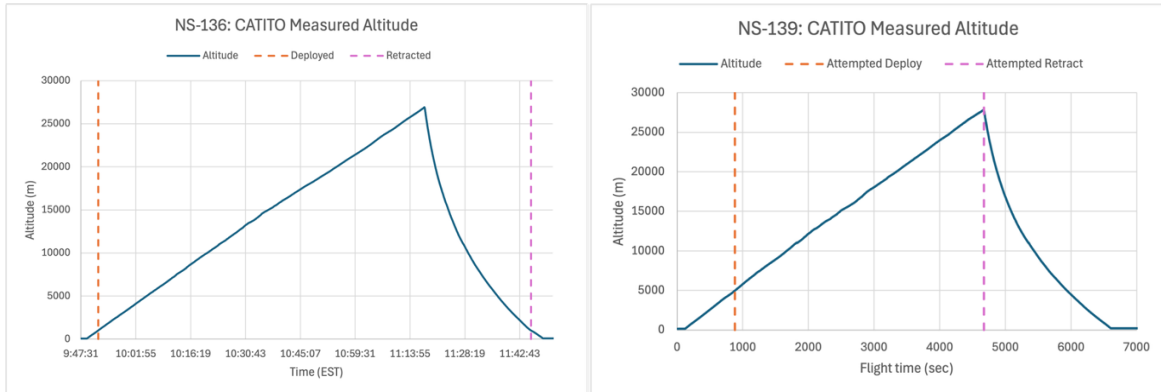
Additional tests are also planned, such as freezer tests and dry ice testing to determine payload performance in cold temperatures, and flour sprinkling to test contamination. Redesign on the brims is also imminent to allow for easier retraction and deployment, particularly to accommodate plastic shrinkage. Conducting further research and taking SEM-EDS standards of various common and expected materials is vital to identifying the origin of the collected samples. At time of writing, additional flights are planned, including a flight that would allow for an extended HAB flight beyond 1.5 hours in the stratosphere at neutral buoyancy.

VII. Conclusion

This paper provides a viable design, flight experience, and an end-to-end sampling methodology which enables the collection of micrometeorites and IDPs on HAB flights. Through these two iterations, CATITO has proven to be a promising system for micrometeorite and IDP collection, though further engineering design is required for the design to be fully robust. CATITO is modular and simple in design and could be distributed to ballooning teams across the nation to fly to gather more samples of extraterrestrial particles.

Appendix

Appendix 1. Launch profiles of CATITO v1 and v2, respectively. The abbreviation "NS-xxx" denotes the number of launches the BPP has conducted.



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References

- [1] Haenecour, P. (2016). Stardust in primitive astromaterials: Insights into the building blocks and early history of the solar system. Ph. D. Thesis.
- [2] Rubin, A. E., & Grossman, J. N. (2010). Meteorite and meteoroid: New comprehensive definitions. *Meteoritics & Planetary Science*, 45(1), 114-122.
- [3] Van Ginneken, M., Wozniakiewicz, P. J., Brownlee, D. E., Debaille, V., Della Corte, V., Delauche, L., ... & Zolensky, M. (2024). Micrometeorite collections: a review and their current status. *Philosophical Transactions A*, 382(2273), 20230195.
- [4] Brownlee, D. E. (1976). An Atlas of extraterrestrial particles collected with NASA U-2 aircraft, 1974-1976. Ames Research Center.
- [5] Genge, M. J., Larsen, J., Van Ginneken, M., & Suttle, M. D. (2017). An urban collection of modern-day large micrometeorites: Evidence for variations in the extraterrestrial dust flux through the Quaternary. *Geology*, 45(2), 119-122.

- [6] Brownlee, D. (2014). The Stardust mission: analyzing samples from the edge of the solar system. *Annual Review of Earth and Planetary Sciences*, 42, 179-205.
- [7] Maurette, M., Olinger, C., Michel-Levy, M. C., Kurat, G., Pourchet, M., Brandstätter, F., & Bourot-Denise, M. (1991). A collection of diverse micrometeorites recovered from 100 tonnes of Antarctic blue ice. *Nature*, 351(6321), 44-47.
- [8] Brownlee, D. E. (1985). Cosmic dust-Collection and research. IN: *Annual review of earth and planetary sciences*. Volume 13. Palo Alto, CA, Annual Reviews, Inc., 1985, p. 147-173., 13, 147-173.
- [9] Bradley, J. P. (2003). Interplanetary dust particles. *Treatise on geochemistry*, 1, 711.
- [10] Novakova, J., Valicek, M., Bucek, A., & Velic, D. (2021). Collection of micrometeorites in the stratosphere. *WGN, Journal of the International Meteor Organization*, 49(6), 190-194.
- [11] Kuznetsov, J. J., Takeuchi, A., Grammer, D., Kalin, M., Bhingradiya, K., & Bishop, J. (2024). Design, optimization and additive manufacture of generalized helium outflow unit for latex balloons to float. In *AIAA SCITECH 2024 Forum* (p. 0369).
- [12] Chamberlain, M. K., Kiefer, S. H., LaPointe, M., & LaCorte, P. (2021). On-orbit flight testing of the Roll-Out Solar Array. *Acta Astronautica*, 179, 407-414.
- [13] Lopez, J.F., Pelaez, G.J. & Perez, L.D. Monitoring the formation of polystyrene/silica nanocomposites from vinyl triethoxysilane containing copolymers. *Colloid Polym Sci* 291, 1143–1153 (2013). <https://doi.org/10.1007/s00396-012-2842-4>
- [14] Soriano, M., Sánchez-Marañón, M., Melgosa, M., Gámiz, E. and Delgado, R. (2002), Influence of chemical and mineralogical composition on color for commercial talcs. *Color Res. Appl.*, 27: 430-440. <https://doi.org/10.1002/col.10096>
- [15] Genge, M.J., Engrand, C., Gounelle, M. and Taylor, S. (2008), The classification of micrometeorites. *Meteoritics & Planetary Science*, 43: 497-515. <https://doi.org/10.1111/j.1945-5100.2008.tb00668.x>