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Bento Box - Modular Stratospheric Balloon Payload to Enable Artificial Intelligence for Small Unit Maneuver

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NPS NRP Executive Summary

Bento Box – Modular/Recoverable Stratospheric Balloon Payload to
Enable Artificial Intelligence for Small Unit Maneuver (AISUM)
Period of Performance: 10/25/2020 – 10/23/2021
Report Date: 10/19/2021 | Project Number: NPS-21-N105-E
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NAVAL RESEARCH PROGRAM
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MONTEREY, CALIFORNIA

BENTO BOX – MODULAR/RECOVERABLE STRATOSPHERIC BALLOON PAYLOAD TO ENABLE ARTIFICIAL INTELLIGENCE FOR SMALL UNIT MANEUVER (AISUM) EXECUTIVE SUMMARY

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Project Summary

The research that was conducted on the use of a modular stratospheric balloon system to enable artificial intelligence for small unit maneuver (AISUM) combines the work of two master's theses and a payload design effort conducted by Space Systems Engineering, Space Systems Operations, and Defense Analysis students and interns. By examining the barriers to operationalizing the stratosphere (Gallegos, 2021) and developing a high-altitude balloon (HAB) bus that can accommodate up to three payloads (Hansen, 2021), a suitable infrastructure that can potentially support AISUM concepts of operations (CONOPs) was identified. A software-defined radio (SDR) payload was configured to simulate a real-time video feed from multiple sources, including a remotely operated drone and ground forces, back to a joint operations center (JOC) location. This serves as one example of how a near-space platform can be used as a low-cost, disposable asset that supports AISUM and augments existing capabilities for operating in hostile, contested environments.

Additional feasibility testing was conducted to demonstrate the utility of such a system in the 3D battlespace as an independent operation with precision recovery capabilities. Building on previous work on autonomously steered parafoils deployed from a HAB bus, student interns researched parafoil deployment methods and used radio-controlled servos to characterize the flight dynamics of a CubeSat form factor carried by a parafoil. Flight times were limited due to the use of tethered balloons, but this testing demonstrated the feasibility for a parafoil to guide an asset to a targeted location.

The results of this effort indicate that a low-cost, simple solution like the Bento Box can support AISUM objectives. Commercial small satellite bus vendors have similar mechanical, electrical, and data interfaces as the Bento Box. The reliable and robust nature of these space-worthy systems with high technological readiness levels can be leveraged and adapted for successful use in the stratosphere.

Keywords: *high-altitude balloons, HAB, over-the-horizon communications, unmanned systems, space systems, CubeSat, artificial intelligence, small unit maneuver*

Background

Operating in hostile, contested environments against technological peers is a growing concern across the Department of Defense, but the tactical advantages against future adversaries for Special Operations Forces (SOF) is especially important. The use of alternate means to maintain continuous airborne surveillance, uninterrupted communication, and accurate navigation inputs are critical for tactical maneuver elements to perform basic combat tasks and maintain situational awareness. The widespread use of unmanned, autonomous vehicles to offload dirty, dull, and dangerous tasks from manned systems speaks to the benefits of such systems; using HABs would provide this capability in the airspace between traditional air-breathing systems and space systems outside of the Earth's atmosphere. As the SOF community looks to incorporate artificial intelligence (AI) and machine learning (ML), a potential low-cost system that increases force protection across domains could provide infrastructure to support Navy Special Warfare tactical maneuvers.

The CubeSat form factor, a small satellite based on a 10-cm cube (1U) weighing no more than 1.33 kg, has had a profound influence in low-Earth orbit for both commercial and government entities. Since its inception in 1999 for educational purposes, the CubeSat has matured as a global market within the satellite industry with a projected compound annual growth rate of 15.1% (Allied Market Research, 2021). However, obtaining and funding launch opportunities to space still presents a challenge to operational responsiveness. Despite efforts by the Operationally Responsive Space Office to pursue critical or enabling technology (Davis, 2015), satellites are not assets that are organic to, and deployable at, the squad level, which leaves SOF units competing for access to mission-support assets. The Space Systems Academic Group (SSAG) at the Naval Postgraduate School (NPS) has developed a HAB bus that conforms to the CubeSat form factor for educational and research purposes. By leveraging the CubeSat form factor, the HAB bus facilitates the adaptation of space technology that can be flown on small satellites to use in the stratosphere. Meanwhile, the mission life cycle can be reduced from the nominal two-year timeline for CubeSats (Lan, 2006) down to as short as three months. This HAB bus, which uses standard data communication protocols and power input levels for commercial-off-the-shelf (COTS) technology, has been used for student projects and theses to conduct near-space testing for spacecraft payload development (Correa de Souza, 2018) and perform CONOP feasibility testing for space-to-ground, beyond-line-of-sight (BLOS) voice communication relays in very-high frequency (VHF) with PRC-152 radios for a SOF use case (Swintek, 2018). Additional research was performed by Space Systems students in 2019 to investigate targeted recovery techniques, including an autonomously steered parafoil.

These previous research efforts served as building blocks for the Space Systems and Defense Analysis students who modified the existing HAB bus structure, named the Bento Box, to support multiple payloads and maintain flexibility for integration with marsupial vehicles with a "plug-and-play" mindset for mechanical, electrical, and software integration. Standard mission architecture and spacecraft design processes, along with agile principles, were used to develop the Bento Box, a payload, and a CONOP for this study.

Findings and Conclusions

The CONOP developed and tested for this study, which enables the exploitation of AI that can be used by SOF, consisted of a COTS software-defined radio (SDR) payload, which was used for a real-time, BLOS video relay. The Bento Box consisted of a payload mounting plate that facilitated mechanical assembly and integration, and the 2U CubeSat form factor from previous missions was maintained. Two balloon flights were conducted by the students using tethered weather balloons at an altitude of just under 500 ft to simulate the station-keeping capability of a large stratospheric balloon, like the Raven Aerostar, while complying with Federal Aviation Administration (FAA) regulations for systems weighing under four pounds. For both flights, there was no direct line-of-sight between a hexacopter drone and the user terminal; the ground distance separation between the ground station terminal and either the drone or user terminal was under 1 km. The ground station terminal served as the JOC, and the user terminal simulated ground partner forces (PF).

The first flight served as the initial field test for the SDR payload with a single video source from the hexacopter relayed to a user terminal. The maximum ground distance between the drone and the JOC was 853 m, and the ground PF terminal was 480 m from the JOC. This bent-pipe relay was successful, but adjustments in filters, amplifiers, and antenna components were made for the second flight, which incorporated three video sources; all video feeds operated on separate channels. In addition to the drone feed, ground PF were outfitted with a plate carrier camera, and both video feeds were relayed in real-time back to the JOC. A third camera was placed on the Bento Box itself, providing additional aerial coverage of the simulated PF patrol operation. The PF carried a receiver and six-inch display to receive target updates provided by the video feeds from both the drone and HAB (Hansen, 2021).

Targeted, autonomous recovery of low-cost, low-observable systems was also investigated by student interns as part of this study. As the autonomous steering had been previously tested, this part of the study focused on flight control and deployment testing of a parafoil with a Bento Box mass simulator, culminating in five deployments from a tethered balloon. Due to the small size of the parafoil and the low-release altitude (below 500 ft), the total flight time was approximately one minute. Although the lessons learned from these tests have not yet been integrated with the Bento Box, the results indicate that a larger parafoil and a separate, modular control system are likely needed to meet AISUM requirements.

These proof-of-concept tests showed that HAB assets can be a valuable addition in SOF operations (i.e., by enabling a remote advise/assist operation of a PF). The stratosphere has been identified as an underutilized regime that can augment existing operations, especially for SOF (Gallegos, 2021), but this system allows for rapid development of platforms that are AI-ready across multiple battlespace domains for operational use.

Recommendations for Further Research

The results of this effort indicate that while a low-cost, simple solution like the Bento Box is useful to study the feasibility of relevant concepts of operation (CONOPs), the current system has a low technology readiness level (TRL). By comparison, commercial small satellite buses are at TRL 9 and can be adapted for operational use in the stratosphere. Many have extensive space flight heritage, making these systems ideal candidates for use on near-space platforms. They also use commercial off-the-shelf technology, which drives the cost down and facilitates interoperability between subsystems and payloads. As on-board processing becomes an essential capability to utilize artificial intelligence (AI) and machine learning (ML) to affect the kill chain, systems and payloads that can accommodate and meet the necessary performance requirements become critical infrastructure as well.

A demonstration with a network of large balloons such as the Raven Aerostar, with adapted CubeSat buses implementing AI and ML algorithms on sensor data, could potentially provide meaningful results that would further inform the problem set for artificial intelligence for small unit maneuver. The inclusion of operational drones such as the Scan Eagle would be needed to validate the CONOP used for this study. Commercial products that are compatible with these types of drones already exist and could be integrated with a small satellite bus for such a test.

Future work on targeted autonomous recovery from a balloon system is needed to better understand the feasibility of possible solutions. Unmanned aerial recovery vehicles such as the Ronin and Night Fury developed by Sierra Nevada Company and the United States Air Force Academy, respectively, are included in the current trade space, but integration and testing with the Bento Box or similar system has yet been completed. Additional research into the use of an autonomously steered parafoil system as a possible solution includes investigating the use of larger parafoils, reliable deployment, and improving the flight algorithm to incorporate AI and ML.

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Acronyms

AI	artificial intelligence
AISUM	artificial intelligence for small unit maneuver
BLOS	beyond-line-of-sight
CONOP	concept of operations
COTS	commercial off-the-shelf
FAA	Federal Aviation Administration
HAB	high-altitude balloon
JOC	joint operations center
ML	machine learning
NPS	Naval Postgraduate School
PF	partner forces
SDR	software-defined radio
SOF	Special Operations Forces
SSAG	Space Systems Academic Group
TRL	technology readiness level
VHF	very-high frequency