INITIAL FLIGHT TESTS OF UAT ADS-B UNIT FOR SUBORBITAL REUSABLE LAUNCH VEHICLES

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Abstract

To support the periodic launch and recovery of sub-orbital reusable launch vehicles (sRLV), some sterilization of airspace surrounding the launch and recovery sites is required to ensure safe ascent and descent through the national airspace system. To reduce the necessary airspace to restrict, tracking technologies such as ADS-B can be employed. The MITRE Corporation has developed the UAT Beacon Radio – Transmit Only (UBR-TX) as a miniaturized ADS-B unit, which was initially intended for unmanned aircraft and General Aviation aircraft. This paper presents the adaptation of the MITRE technology into the UBR-ERAU, a position broadcasting technology capable of operating during sub-orbital space flight.

This paper begins with a discussion of some background on the UBR payloads and their flight history. Next, the requirements and goals of the system's upgrades will be discussed followed by the detailed discussion of key system upgrades including GPS selection, software adaptations, and custom hardware. The experimental design and results of evaluating the new prototype is discussed including a detailed discussion of initial high altitude balloon flights. Finally, the paper discusses future plans for the UBR-ERAU payload as its evaluation transitions from balloons to sRLVs.

Introduction

The emergence of commercial ultra-high altitude and space flight operations, both manned and unmanned, has resulted in a need in the current National Airspace System (NAS) to monitor these flights. The present NAS architecture supports relatively low speed travel (compared to space flight) below 60,000 feet.

As we move toward more frequent commercial space transportation, to support the periodic launch and recovery of sub-orbital reusable launch vehicles (sRLV), some sterilization of airspace surrounding the launch and recovery sites is required to ensure safe ascent and descent through the NAS. Some of the flight path's uncertainty exists during descent, especially while flying under parachute. To accommodate for this uncertainty, the airspace sterilized must be large enough to ensure the vehicle does not exit the designated area and pose a threat to other air traffic. With the significant increase in commercial suborbital flights expected in the near future it will be impractical to solve this problem with restricted airspace, and the use of temporary flight restrictions will produce a burden upon other users operating in the NAS.

The FAA is implementing Automatic Dependent Surveillance – Broadcast (ADS-B) as the NextGen surveillance system intended to augment the current air traffic management (ATM) infrastructure. Full deployment and integration is planned for 2020. Unfortunately, the ADS-B architecture is designed to support the current NAS with intent to support monitoring of flights below 60,000 ft. The potential application of ADS-B for the tracking of flights above 60,000 feet is promising and warrants exploration and concept development. ADS-B technology supporting high altitudes and high velocities could potentially meet the surveillance gap that must be addressed for frequent, routine commercial space flight.

An experimental ADS-B prototype was developed by collaboration between Embry-Riddle Aeronautical University (ERAU) and the Federal Aviation Administration (FAA) based upon ADS-B technologies from the MITRE Corporation (see Figure 1). ADS-B is already in use for manned aviation to provide situational awareness by

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broadcasting the GPS position and altitude (both barometric and GPS-based) of the transmitter equipped aircraft to ground-based transceivers (GBTs) and suitably equipped aircraft allowing controllers and other pilots to be aware of the precise location of the aircraft. Universal Access Transceiver (or UAT), as defined by RTCA DO-282A [1] is one of two types of ADS-B technologies being integrated into the national airspace today. The MITRE Corporation has developed the UAT Beacon Radio – Transmit Only (UBR-TX) as a miniaturized ADS-B unit, which was initially intended for UASs and General Aviation aircraft. This paper presents the adaptation of the MITRE technology into the UBR-ERAU, a position broadcasting technology for high altitude balloons and sub-orbital reusable launch vehicles, as well as the testing of the proposed new system.

Figure 1. UBR-ERAU ADS-B Prototype

Developed under a contract with the FAA's Commercial Space Transportation Office (FAA/AST), the UBR-ERAU upgrades the design of the MITRE UBR-TX in order to support the environment of space flight. The previous design's commercial GPS processor has been replaced with a high-end GPS capable of supporting space velocities, accelerations, and altitudes (which are typically restricted under International Trade in Arms Regulations (ITAR)). The firmware for the UBR's main board was upgraded to support the new GPS and its binary data protocol. A daughter board was produced in order to physically integrate the new GPS with the legacy board design. Lastly, components on the legacy board design were upgraded to their MIL-Spec equivalents to allow for the environment of space flight.

This paper provides a background discussion regarding the UBR-TX and its flight history. Key system upgrades including GPS selection, software adaptations, and custom hardware are discussed in detail. The experimental design and results of evaluating the new prototype is discussed. Flight tests of the payload onboard high altitude balloons are discussed including integration, flight details, and lessons learned. Finally, the paper discusses future plans for the UBR-ERAU payload as its evaluation transitions from balloons to sRLVs.

Background

Prior to discussing the UBR-ERAU, it is necessary to provide some background. First, current procedures for rocket and balloon launch are discussed. A brief history of the UBR-TX being flown onboard balloons and rockets is presented, where the current limitations were verified and clearly evident. Next, a discussion of current GPS limits is presented as the motivation for the upgrades discussed in this paper. Lastly, a summary of relevant experience from the team is presented.

UBR-TX and New GPS Flight History

The UBR-ERAU is an upgrade to the MITRE produced UBR-TX and reuses a number of major components namely the primary circuit board's design and the software design (both of which have undergone some upgrades to support space velocities and altitudes). The MITRE UBR-TX and its successor the UBR-TVR (UAT ADS-B with transceiver) have been flown under the support of MITRE and the FAA on a number of platforms. Past flights with one of these units include [2, 3]: 2009 Red Glare VII amateur rocket launch, 2010 Air Force Research Laboratory High Altitude Balloon, and 2010 NASA Wallops Sounding Rocket Flight. A fit and function test has been performed onboard the Masten Space Systems Xaero rocket – this flight on the Xaero is expected in late 2013. In 2012, it was integrated onto SpaceLoft-6 and flight-tested. To some degree, all flights experienced the impact of ITAR restrictions when exceeding the altitude, acceleration, or velocity limits.

The second major component of the proposed system that has undergone flight testing is the payload's new GPS receiver, the Javad TR-G2 [4, 5]. The TR-G2 was purchased with space velocities enabled, which is a firmware update and accompanying export license that removes the COCOM/ITAR GPS restrictions for maximum velocities and altitude. NASA has evaluated this particular unit in a number of instances including 39.009 Bernhard sounding rocket flight in 2009 [5].

ITAR/COCOM Limits

The UBR-ERAU is based upon the UBR-TX, a MITRE product. While this unit has not met the FAA standards to receive a Technical Standard Order, it has undergone extensive flight testing. It has flown on a number of general aviation flights, unmanned aircraft flights, high altitude balloons, and also sounding rockets [3]. With the exception of the GPS limitations, the UBR-TX has been demonstrated reliable. Unfortunately, the GPS limitations have prevented the UBR-TX from being functional at higher altitudes, accelerations and velocities.

The current ITAR/COCOM limits for commercial GPS prevent the units from operating at accelerations greater than 4Gs, velocities greater than 1,000 knots and/or altitudes in excess of 60,000 ft. MSL [6]. The interpretation by GPS manufactures is fairly broad, but for commercial receivers when these limits are exceeded the unit will become disabled, or will output only zeros for position and altitude.

Relevant Experience

The development of the UBR-ERAU is a multi-institutional collaboration. Briefly, relevant experience of the research team is described.

ERAU Experience

ERAU's Next Generation Embry-Riddle Advanced Research (NEAR) Laboratory [7] has a history of developing and demonstrating FAA NextGen technologies (hardware and software) including ADS-B. The laboratory is equipped with a Sensis GBT for receipt of local ADS-B data as well as a subscription to ITT Exelis's real-time data feed from ADS-B GBTs nationwide.

The ERAU College of Engineering has a history of supporting commercial space transportation research projects as well as amateur rocketry. Embry-Riddle Future Space Explorers' and Developers' Society (ERFSED), a student organization, has developed a fleet of student built rockets with the capability of supporting a variety of payloads under faculty guidance. The college is also actively involved in Cubesat payload projects.

Collaborator Experience (MITRE and FAA)

This project is also receiving technical support from both the MITRE Corporation and the FAA. MITRE is responsible for the development of the UBR-TX and UBR-TVR ADS-B units. Both of these devices have flown as payloads on high altitude balloons and/or sounding rockets. This team has provided ERAU with the full intellectual property package for the MITRE UBR-TX under a non-commercial research and development license. The MITRE team has also provided data collection technologies and capabilities to support the flight testing of the UBR-ERAU, as described later in this paper.

This project is sponsored by the FAA's Office of Commercial Space Transportation office, which provides technical information on past flights, design requirements for the new UBR-ERAU, and overall project oversight. The Office of Commercial Space Transportation also works with the NASA Flight Opportunities Program (FOP) and other flight providers to obtain flight test opportunities for the UBR-ERAU. This project also is supported by researchers at the William J. Hughes Technical Center[1] in order to have access to their equipment.

The FAA Tech Center is exploring the integration and adaptation of NextGen systems (ADS-B) for performing surveillance of commercial space vehicles as they transition through the NAS. The center has a history of ADS-B research and was suitably equipped with technology and personnel to support this project. One resource available is the NextGen Surveillance Laboratories (NSL), which pursues NextGen harmonization across various stakeholders including commercial space transportation. NSL has access to and utilizes data from the nationwide network of ADS-B GBTs, and supports technologies dependent upon or investing in the ADS-B systems.

[1] Known herein as the "FAA Tech Center"

The FAA Tech Center has provided engineering and data processing support throughout this process. During early development stages, this team provided the ERAU team with data collected from ITT Exelis unavailable to ERAU via its subscription (near surface). Prior to its first test flights, the FAA Tech Center's GPS simulator was utilized to operate the UBR-ERAU under a number of simulated missions including a high-altitude balloon profile and a rocket balloon profile based upon past flight data. The FAA Technical Center's software tools (developed specifically for ADS-B testing/analysis) provided proof that the UBR-ERAU would broadcast the correct Geometric Altitude.

UBR-ERAU Payload Design

To address the ITAR restrictions, ERAU researched GPS receivers that could be purchased without these ITAR limits with an appropriate export license. The Javad TR-G2 GPS was identified as new GPS receiver to be integrated with the UBR's processing board for the new UBR-ERAU prototype. This particular GPS is sold with the option to enable space velocities and altitudes. NASA also has evaluated the TR-G2 on sounding rocket flights as discussed later in this paper [4, 5]. This receiver has deemed suitable to meet the performance needs of this balloon launch and future launches on solid and liquid fueled rockets.

To integrate the new GPS, several upgrades were required. The UBR-TX data processing board was upgraded to meet the environmental needs of the rocket flight, and several components were upgraded to their MIL-STD 810 (mil-spec) [8] equivalents. The firmware onboard the data process board was upgraded so that it processed the Javad GREIS [9] protocol messages format versus the previous GPS's SiRF [10] protocol messages. Lastly, a daughterboard was constructed to 1) address the TR-G2 without changing the original PCB design of the UBR data processing board, and 2) to provide regulated power to the TR-G2. Figure 2 presents the UBR-ERAU integrated package as a block diagram.

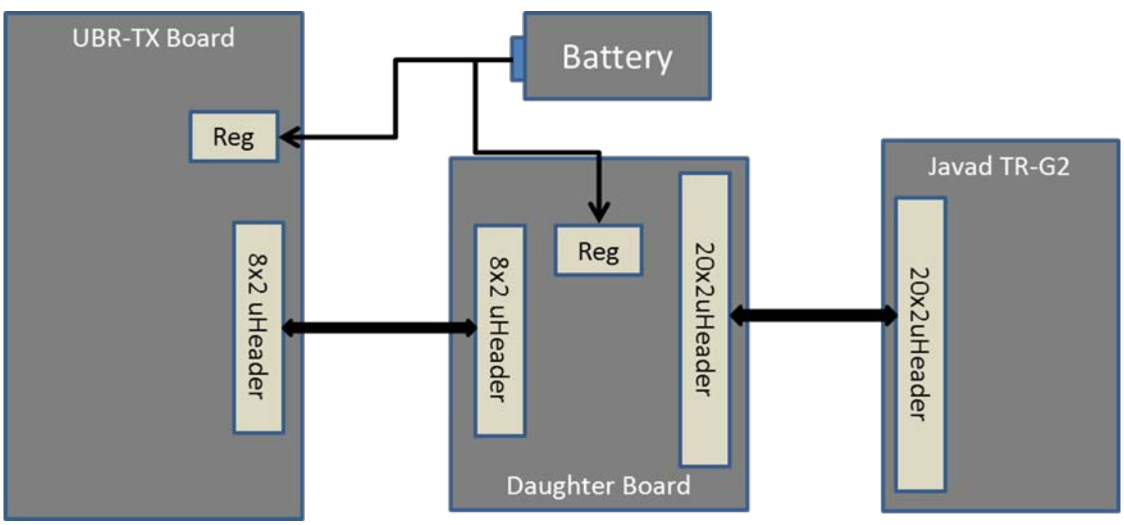

Figure 2. UBR-ERAU Prototype Configuration

The firmware upgrades required careful adaptation of the existing firmware to ensure compliance with the RTCA DO-282a [1] specification was maintained. In addition to transitioning between GPS binary data protocols, a major limitation of the UAT messaging protocol was identified and addressed.

The current UAT ADS-B message set defined in RTCA SC-203 accommodates altitude values between -1,000 to 101,337 ft., i.e. altitude is capped at 101,337 ft. Because sRLVs can exceed this limit, this altitude limit must be addressed. The first approach considered would be the utilization of *reserved* space within the UAT message set to include an altitude with more allocated bits. For this phase of this project, this option was discounted because available GBTs would likely not parse and could potentially filter out the data within the reserved message space. As an interim solution, a rollover capability was implemented. The altitude will count upward and roll over to zero whenever the altitude limit is exceeded. By tracking the number of roll-overs, the actual altitude can be derived. This capability is designated only for experimental purposes at this time.

An aluminum enclosure was selected to integrate the payload. In addition to the addition of bulkhead connectors for power enable, GPS antenna, and UAT antenna, a window was milled into the enclosure to permit pre-flight monitoring of the unit's status to ensure it is not operating within an error mode. The enclosure was lined with an RFI/EMI blocking ecosorb material. A ground-plane was installed between the primary UBR circuit board and the GPS receiver board to mitigate the RFI noise. Without this ground plane, the GPS frequently failed to maintain sufficient lock to output position, altitude, and velocity. Integration of the payload into the high-altitude balloon is discussed later in this document. A SAFT Lithium Sulfur Dioxide, D-Cell configuration, 7800 mAH, was used to provide internal power to the unit. The final dimensions of the unit are 14.61 cm x 7.62 cm x 7.62 cm with a weight of 790 g including battery (excluding GPS and transmit antennas)

Evaluation and Demonstration Plan

This section describes the development plan of the UBR-ERAU as the team systematically raises the technical readiness level (TRL) of the payload. A step-by-step demonstration plan is presented.

First, the use of high-altitude balloons will assess the viability of the new ADS-B payload. Balloons permit the payload to operate at the altitude and environment comparable to that encountered onboard a sub-orbital reusable launch vehicle without shock, vibration, axial rotation, and velocity. The Near Space Corporation (NSC)'s Nano Balloon System (NBS) has been identified as the balloon launch provider through the NASA FOP.

The second series of flight tests will be onboard NSC's High-Altitude Shuttle System (HASS). The payload would be loaded onto the HASS shuttle platform and lifted to near-space altitudes via high altitude balloon. Once the shuttle is released from the balloon, the shuttle emulates a winged sRLV re-entry. It can support zero-G maneuvers as well as a spiral descent similar to those planned for winged sRLVs such as Virgin Galactic's Space Ship 2 and XCORs Lynx. This flight has been selected by NASA FOP for the second quarter of 2013.

Next, a series of rocket flights has been approved by NASA FOP including a flight onboard Up Aerospace's Space Loft VIII (SL-8). Prior to flight on SL-8, a more benign amateur rocket will likely be used as an intermediate test. The goal of the SL-8 flight will be to perform a full demonstration of the system with high-Gs, high altitude (much greater than the UAT's 101,337 ft. default limit).

Upon completion of these tests, the payload will be demonstrated viable for continued flight testing on a variety of commercial sRLVs as part of developing new procedures and capabilities for their flight from commercial spaceports.

Balloon Flight Demonstration

This section discusses the two high-altitude balloon test flights performed in January and February 2013 with the support of NSC and NASA FOP. The goals of the high-altitude balloon flight tests were as follows:

Launch UBR-ERAU UAT ADS-B Payload onboard a NSC Nano-Balloon System (NBS).

Payload would broadcast ADS-B message following UAT specification approximately once per second from launch to apogee to recovery.

Payload would be tracked using FAA and ITT live-data feeds throughout the flight using a local "mobile GBT" to fill in data gaps near takeoff and landing.

Payload would achieve an altitude of no-less than 90,000 ft. MSL (mean sea level) in order to demonstrate:

Successful operation in near space environment (temperatures and atmosphere).

Demonstrate operation of ADS-B unit at altitudes in excess of the GPS ITAR/COCOM limit of 60,000 ft. MSL.

Platform Overview

The NSC Nano Balloon System (NBS) is a high-altitude helium balloon system. It typically supports payloads up to 1 kg and 1U Cubesat sized payloads [11]. Several alternative dimension enclosures are also available to house payloads such as the UBR-ERAU, which fall outside the 1U Cubesat configuration.

The payload is housed in a foam enclosure, as described below. The enclosure is fastened such that it is a gondola for the balloon system. Also fastened are an onboard telemetry system, and a system capable of deploying the parachute when specified by the operator.

Payload Integration

In December 2013, the UBR-ERAU payload was integrated onboard the NBS. A foam enclosure was used to house carry the payload. The UAT antenna protrudes through the bottom of the enclosure. An antenna ground plane is placed at the base of the UAT antenna providing isolation between the UBR-ERAU and the antenna.

The UBR-ERAU was installed on top of the ground-plan. Foam inserts were used to hold the unit in place. The GPS antenna is then placed on top of the UBR-ERAU unit with an aluminum ground plane providing RF isolation and boosting the performance of the GPS antenna. The final assembly of the payload is shown in Figure 3.

An RFI/EMI test was performed during this initial integration ensuring that there were no issues between the UBR-ERAU and the NBS's telemetry system (which provides remote on-off, altitude, position, and temperature).

The unit was returned to ERAU to make some final preparations prior to the launch, and the unit was returned to NSC on January 21, 2013.

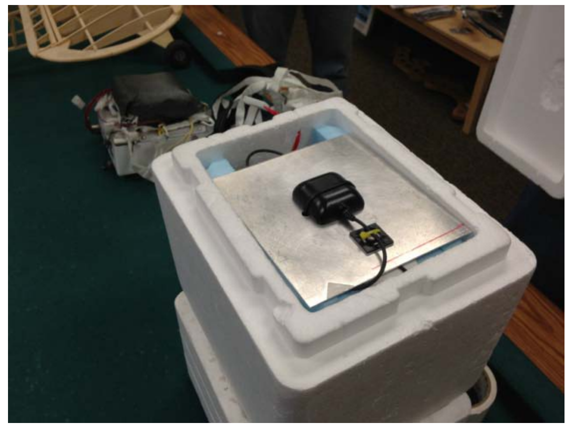

Figure 3. UBR-ERAU Prototype in Balloon Payload Enclosure

Flight Test #1, January 2013, Madras OR

In mid-January 2013, the payload underwent the first proof-of-concept flight in which it flew to an altitude of 60,000 ft. The ground track is shown in Figure 4. Flight details are as follows.

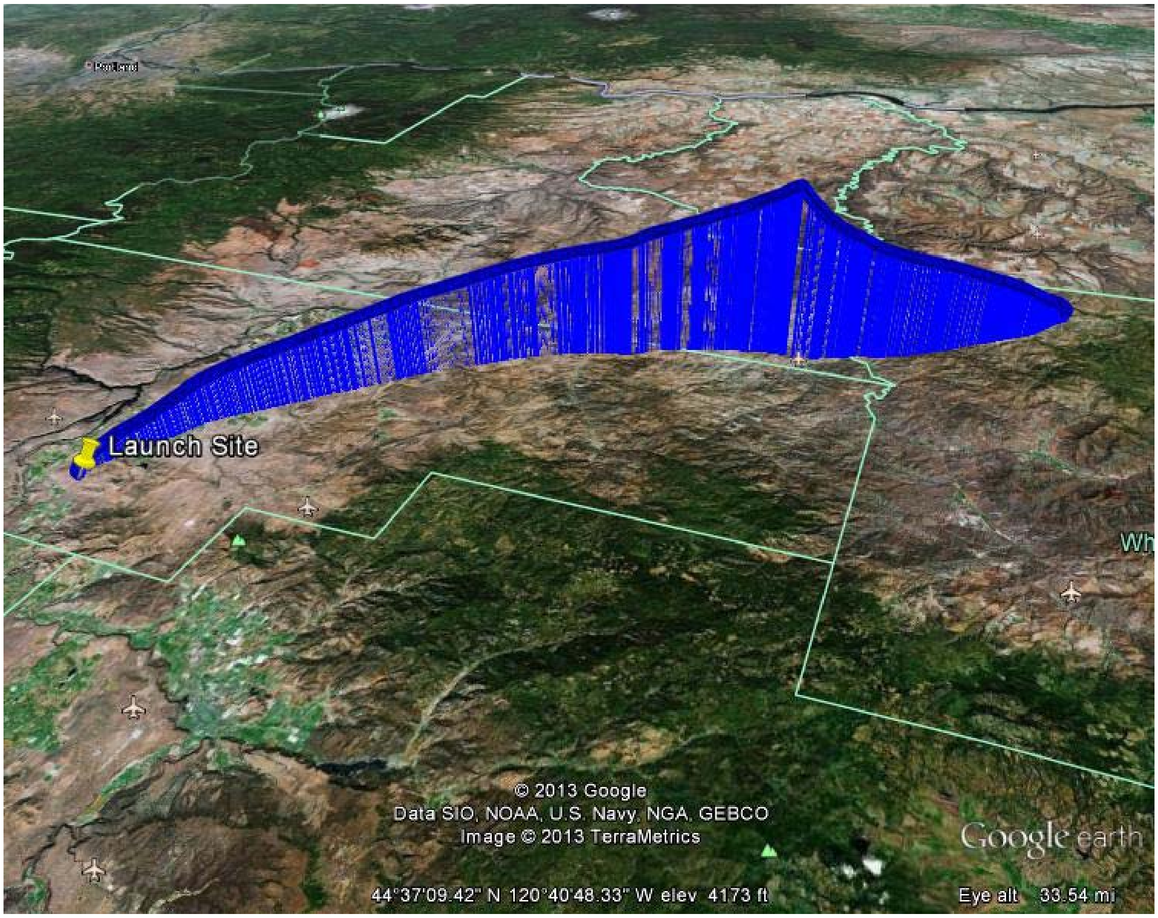

Figure 4. Flight Track of Flight #1using Geometric Altitude

On Friday, January 18, 2013, it was determined that due to weather the flight team including personnel from NSC, FAA AST, FAA Tech Center, NASA, and ERAU would launch the UBR-ERAU payload from Madras, OR. On Monday January 21, 2013, payload integration for flight was performed to re-integrate the payload onboard the balloon. Ground-based receivers both on site and ITT GBTs were used to verify successful broadcast of ADS-B data from the integrated payload. On that same day, a flight readiness review was performed by NSC with the support of the team.

On Tuesday, January 22, 2013, due to freezing fog at the Madras Municipal Airport, the launch site was moved to approximately 15 miles south of Madras OR. The chase aircraft could not fly due to icing conditions, but was not required given launch site. The launch site provided a clear RF line of sight to a GBT located in Bend, OR. Prior to launch, data reception on multiple ground-based receivers was confirmed. Launch took place at approximately 11:30 PST. Figure 5 shows the balloon prior to launch. Table 1 presents details regarding the flight.

Figure 5. NSC NBS Prior to Launch

Table 1. Results from Preliminary Data Analysis

Maximum Altitude (geometric), MSL	59,575 ft.
Maximum Altitude (pressure), MSL	59,325 ft.
Flight Time – Ascent	63.07 minutes
Flight Time – Descent	29.33 minutes
Flight Time – Total	92.40 minutes
Total Number of Unique GBTs Receiving Data	14
Number of GBTs Tracking at Apogee	8

Flight Test #2, February 2013, Tillamook OR

The second launch of the balloon with ADS-B payload occurred on February 15, 2013 at 11:24am PST at the Tillamook Airport located near Tillamook, OR. A MITRE provided Garmin GDL 90 unit was set up at the Tillamook airport and configured to act as a ground-based receiver. At 11:26 PST, NSC reported that payload tracking has been maintained from pre-launch through post-launch phases of flight. By 11:27 PST, the first ITT Exelis GBT reported the unit at 1,700 ft. At 13:20 PST, the balloon and payload achieved a float altitude of approximately 94,000 ft. (maximum altitude reported at 94,025 ft.). The total float time was 58 minutes followed by 38 minutes of descent. The flight concluded at 2:59pm PST. Key details are summarized in Table 2.

Table 2. Results from Preliminary Data Analysis

Maximum Altitude (geometric), MSL	94,025 ft.
Maximum Altitude (pressure), MSL	94,200 ft.
Flight Time – Ascent	116 minutes
Flight Time – Float	58 minutes
Flight Time – Descent	38 minutes
Flight Time – Total	212 minutes
Total Number of Unique GBTs Receiving Data	31 (available in post-process)
Number of GBTs Tracking at Apogee	11 (available in post-process)

The flight was a success. However, some unexpected technical limitations with the ITT/FAA ground-based terminal network were experienced. Live/real-time data was not available once the balloon exceeded 60,000 feet. Additionally, a 300 mile limit did exist on area GBTs, which limited the number of simultaneously tracking ground-based terminals. The complete flight track ground track is shown in Figure 6. Figure 7 shows the altitude versus time starting at the moment that the GDL 90 began logging data. The payload was not tracked to surface by the GDL 90 due to terrain occlusions of the 978 MHz UAT signal.

Several lessons learned:

- The unit operated from pre-launch power on (1713 UTC) until landing for an overall operating time over 5.5 hours.
- The unit operated in near space environments at altitudes over 94,000 ft. and temperatures as low as -20.65 degrees Celsius. The full temperature profile for the flight is shown in Figure 8.
- The barometric pressure sensor provided altitude measurements consistently near the values reported by GPS, which was surprising given the total ascent altitude.
- ERAU found that they were unable to track the payload via its ITT subscription from its Daytona Beach campus.
- Ground-based receiver was capable of tracking payload throughout the flight with a brief, but permanent loss of reception on descent over terrain on the horizon.
- ITT feed to FAA Tech Center and MITRE cut out at altitudes above 60,000 ft. Local mobile ground-based receiver provided measurement coverage during this outage period.
- It appears that some ITT GBTs filter received data based upon the distance of the transmitter from the GBT. A limit of 300 miles was encountered.

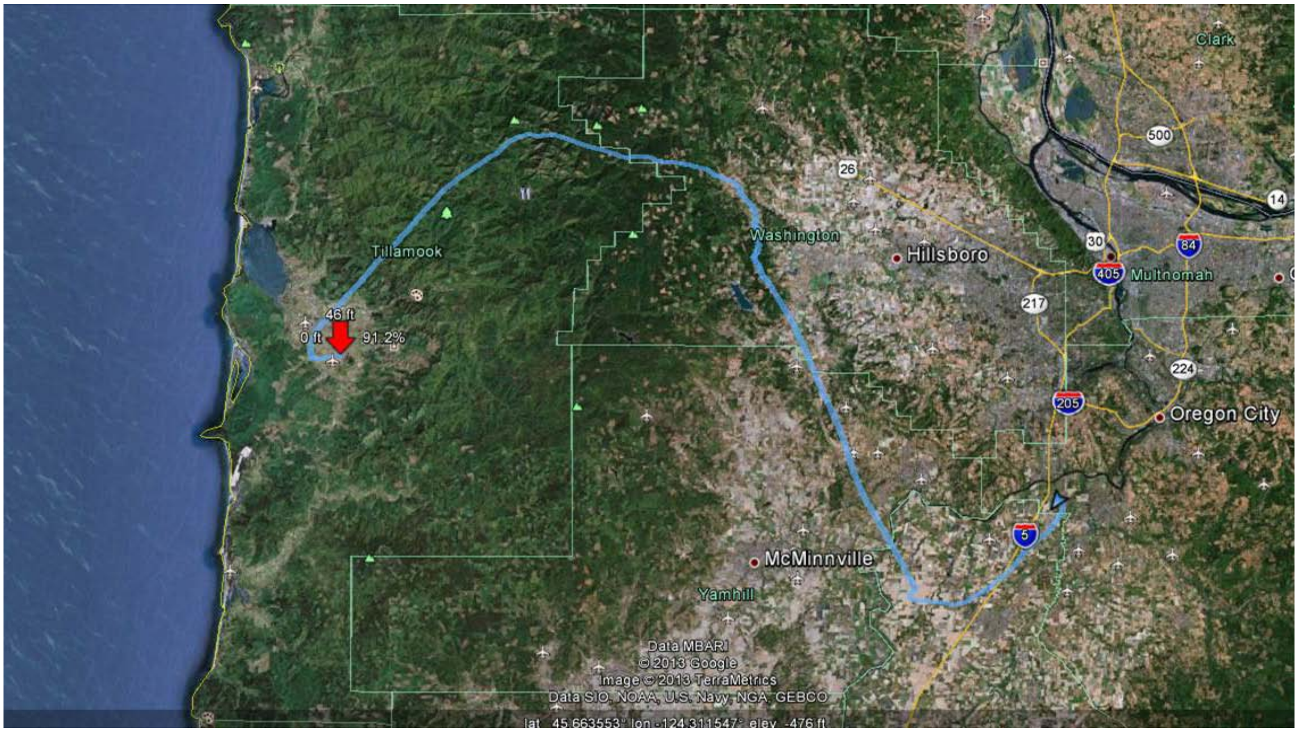

Figure 4. Flight #2 Balloon Flight Ground Track vs. Altitude.

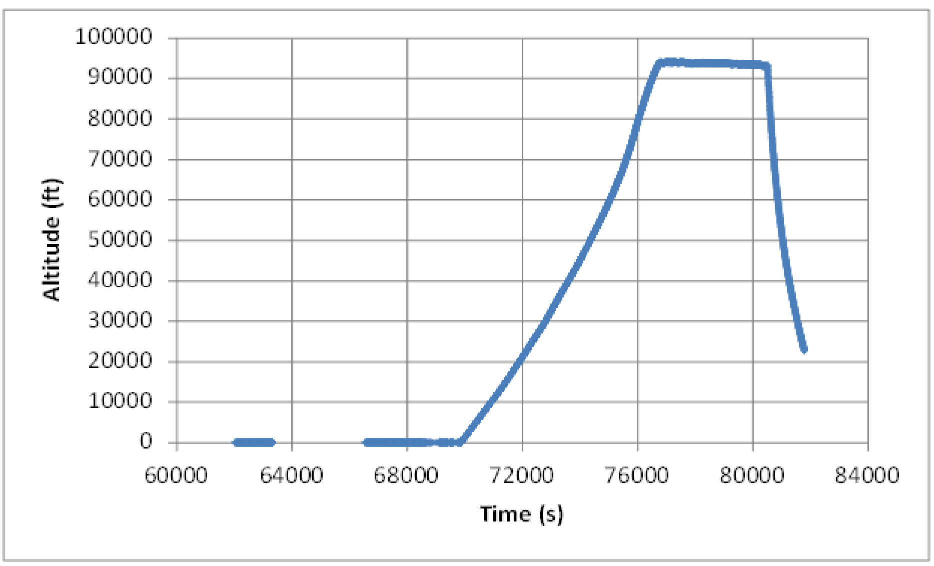

Figure 5. UBR-ERAU Altitude Profile from Flight #2 as Measured by Garmin GDL 90 at Tillamook, OR

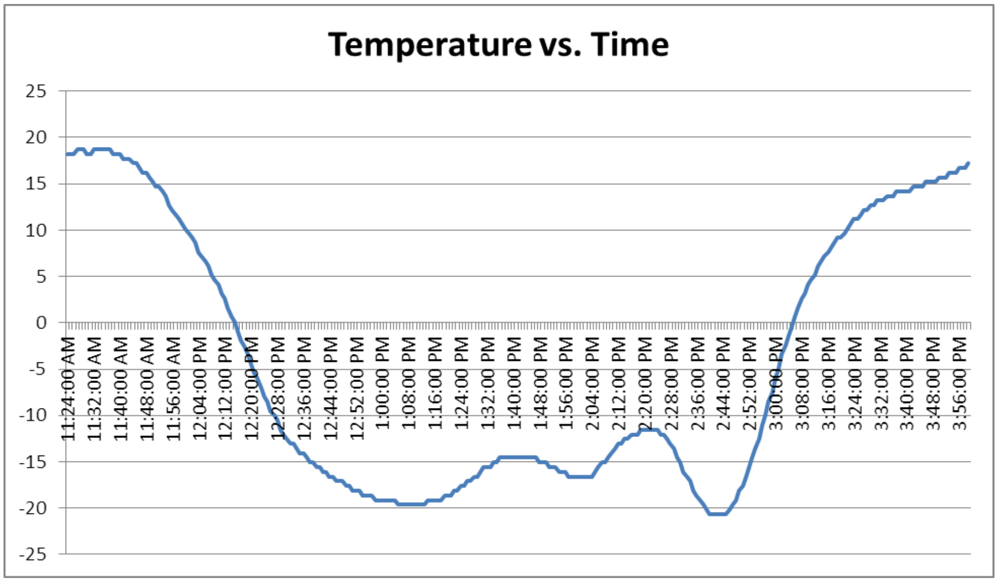

Figure 6. Plot of Payload Temperature vs. Time of Day for 2/15/2013 Flight (courtesy of NSC)

Conclusion and Future Work

From the initial round of flight tests, the UBR-ERAU payload has proven to be viable for supporting ADS-B based tracking of high altitude air vehicles. The next phase of testing will move toward demonstrations that validate its ability to support reusable launch vehicles: HASS, to demonstrate reentry maneuvers; an amateur rocket, to demonstrate performance at higher velocities, shock, and vibe; and SL-8, to demonstrate performance on a sounding rocket.

To date, only a single payload exists, and more units are required to support the test and demonstrate schedule set forth by the team and manifest by the NASA FOP office. Therefore, the next course of action is to acquire enough parts to construct a total of 10 payloads to maximize flight test opportunities on a variety of platforms, Four additional payloads will be constructed from this batch of parts to support each flight plus spares.

The current configuration of the UBR firmware does not support the ADS-B transmission to "go to glass," i.e., be visible by Air Traffic Control. An additional engineering effort will be required to incorporate the necessary software features to achieve this goal to move the product from only supporting monitored demonstrations toward regular use to support integration of reusable launch vehicles into the NAS.

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Disclaimer

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