Progress and Future Development toward a UAT ADS-B Transmitter for Space Operations

Richard Stansbury Ph.D.
Embry-Riddle Aeronautical University, stansbur@erau.edu

EMBRY-RIDDLE Aeronautical University

Progress and Future Development toward a UAT ADS-B Transmitter for Space Operations

Space Congress 2018

Presenter: Richard S. Stansbury
College of Engineering
Embry-Riddle Aeronautical University, Daytona Beach, FL

March 1, 2018

Acknowledgements

- NASA Flight Opportunities Program
- Up Aerospace, Inc
- Near Space Corporation
- Terminal Velocity Aerospace
- FAA Office of Commercial Space Transportation (AST) and sponsor Nickolas Demidovich
- FAA William J. Hughes Technical Center
  - Chuck Greenlow and John Dinofrio
- MITRE Corporation

Resources, support and cooperation from all were vital for this opportunity to flight test the payload!

This presentation presents a work in progress funded by the FAA, but does not reflect any official views/conclusions from the sponsor.

Lecture Outline

EMBRY-RIDDLE Aeronautical University

- Background
  - ADS-B Overview
  - MITRE UBR-TX
- UBR-ERAU ADS-B Payload
  - Requirements
  - Design and Implementation
- System Qualification
  - Ground tests
  - Near Space Corporation's Nano Balloon System
  - Terminal Velocity Aerospace's RED-4U prototype spacecraft
- Path Forward
- Conclusion

Background

- ADS-B Overview
- MITRE UBR-TX

Automatic Dependent Surveillance - Broadcast

EMBRY-RIDDLE Aeronautical University

- Also known as ADS-B
- Utilizes GPS position instead of Radar-based interrogation to identify location
- Additional information:
  - Aircraft ID (callsign and ICAO address)
  - Altitude (geodetic and/or pressure)
  - Velocity
  - Emergency
  - Climb rate
  - Quality and integrity of data
- Two standards:
  - Universal Access Transceiver
    - Frequency: 978 MHz
    - Common for general aviation
    - < 17,999 ft.
  - 1090 MHz Extended Squitter (ES) Mode-S transponder
    - More common for transport category aircraft
    - > 18,000 ft.

2020 mandate for all aircraft equipped with mode C transponder to be upgraded to ADS-B out

FAA ADS-B Deployment

EMBRY-RIDDLE Aeronautical University

- Baseline deployment of 634 radio stations is complete
- Each radio station has a minimum line-of-sight range requirement (i.e., radius) of 250 NM based on latitude/ longitude distance (altitude is not limiting factor)
  - Actual coverage may be up to 300 NM radius (currently limited by radio station software configuration)

•Source: MITRE

Slide courtesy of Nickolas Demidovich, FAA AST (project sponsor)

ADS-B Operations

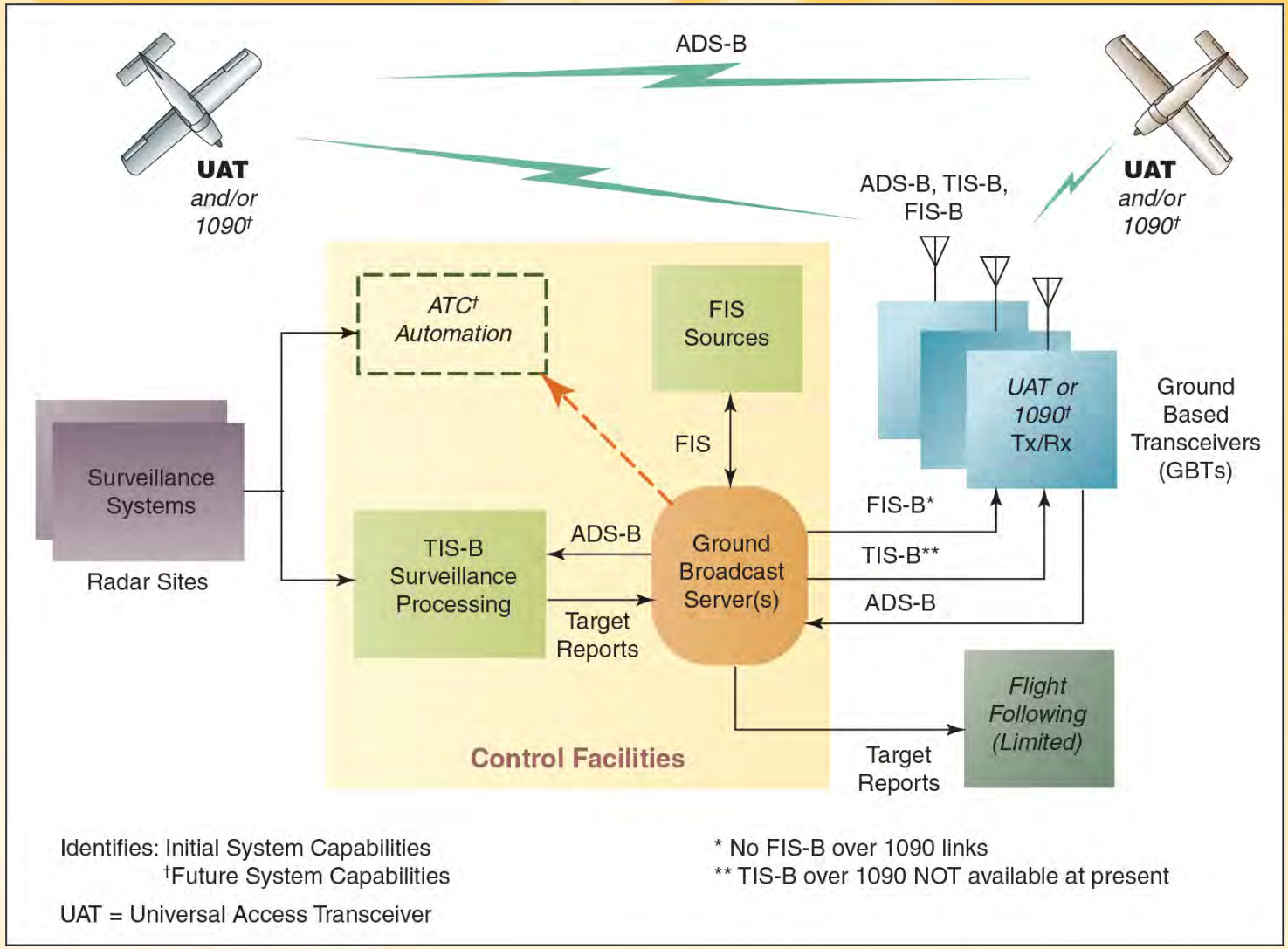


Image Source: learntoflyblog.com

Source: Aviation Week

UAT Message Specification

EMBRY-RIDDLE Aeronautical University

Byte	Bit 1	2	3	4	5	6	7	8
1	Payload Type					Address Qualifier		
2	ICAO Address							
3								
4								
5	Lattitude							
6								
7	Longitude							
8								
9								
10								Alt Type
11	Altitude							
12					NIC			
13	A/G State							
14	Horizontal Velocity							
15								
16	Vertical Velocity or A/V Size							
17					UTC	Uplink Feedback		
18	Emitter Category and Call Sign / Flight Plan ID Characters #1 and #2							
19								
20	Call Sign / Flight Plan ID Characters #3, #4, #5							
21								
22	Call Sign / Flight Plan ID Characters #6, #7, #8							
23								
24	Emergency/Priority Status			UAT MOPS Version			SIL	
25	Transmit MSO						SDA	
26	NACp				NACv			NICbaro
27	Capability Codes			Operational Modes		CSID		SILsup
28	Geo Vert Acc	SA Flag	NICsup					
29	Reserved							
30	Secondary Altitude							
31								
32	Reserved							
33								
34								

Primary and Auxiliary Message Payload shown

Message Broadcast once per second

Defined in:

RTCA DO-282B: Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance – Broadcast

Purpose of Task

EMBRY-RIDDLE Aeronautical University

- Support of suborbital reusable launch vehicles (sRLVs) for commercial space transportation requires considerations for safe integration into the national airspace system (NAS)
- ADS-B technology is used for surveillance by air traffic control and situational awareness for pilots
- This research presents the potential for adaptation of existing ADS-B technology to support operations for sRLVs operations exceeding current technology limits (primarily altitude, velocity and acceleration)

US Commercial Space Transportation

Diversity of Vehicles and Operations

EMBRY-RIDDLE Aeronautical University

Air Launch

Stratospheric Manned Balloons*

Sea Launch

Ground Launch

Reusable Launch Vehicles

Suborbital Rockets

Over 200 licensed commercial launches safely conducted since 1987

* **With Environmental Control and Life Support System (ECLSS)**

Slide courtesy of Nickolas Demidovich, FAA AST (project sponsor)

Research Goals

EMBRY-RIDDLE Aeronautical University

Enhance tracking of vehicles as they traverse through the national airspace system to mitigate the impact of commercial space operations on routine aviation operations by leveraging existing FAA infrastructure

- **Sub-goals:**
  - Determine suitability for ADS-B for commercial space
  - Determine boundary conditions of system performance
  - Assess performance of prototypes on space vehicles and suitable analogues
  - Identify areas of improvement in ADS-B standard to accommodate suborbital space operations
  - Provide stakeholders with information regarding suitability of ADS-B as a primary or secondary tracking source

MITRE UBR-TX

EMBRY-RIDDLE Aeronautical University

- UAT Beacon Radio – Transmit Only (UBR-TX)
  - Broadcasts state vector once per second
  - Supports both barometric and GPS-based altitudes
- Balloon / Rocket Flight Tests
  - 2008 Red Glare V (amateur rocket)
  - 2009 Red Glare VII (amateur rocket)
  - 2010 AFRL research balloon
  - 2010 NASA Wallops sounding rocket
  - 2012 Up Aerospace Spaceloft 6
  - 2012 Team America Rocket Challenge
  - 2013 Up Aerospace Spaceloft 7
  - 2013 Masten Xombie

MITRE® TECHNOLOGY APPLIED

Limitations for space missions based upon altitude and velocity limits of GPS and limitations of ADS-B message, but not built for this purpose.

UBR-ERAU ADS-B Payload

- Requirements
- Design and Implementation

High-Level Requirements

EMBRY-RIDDLE Aeronautical University

- The enhanced ADS-B prototype shall:
  - Build upon the hardware and software firmware provided by MITRE for UBR-TX payload,
  - Support altitudes in excess of 60,000 ft **and** velocities greater than 1000 knots (i.e. in excess of COCOM/Export Control Limits),
  - Address altitude limits of UAT ADS-B standard (101,337.5 ft MSL),
  - Address climb rate limits of UAT ADS-B standard (roughly 320 knots), and
  - Be configured to support integration onto a variety of suborbital space vehicles / space vehicle surrogates with only minimal customization.

The project team shall:

- Design and implement the enhanced UBR payload (UBR-ERAU), and
- Produce nine (9) UBR-ERAU prototypes,
- Support validation and demonstration through flight test onboard a variety of suborbital space vehicles and space vehicle surrogates.

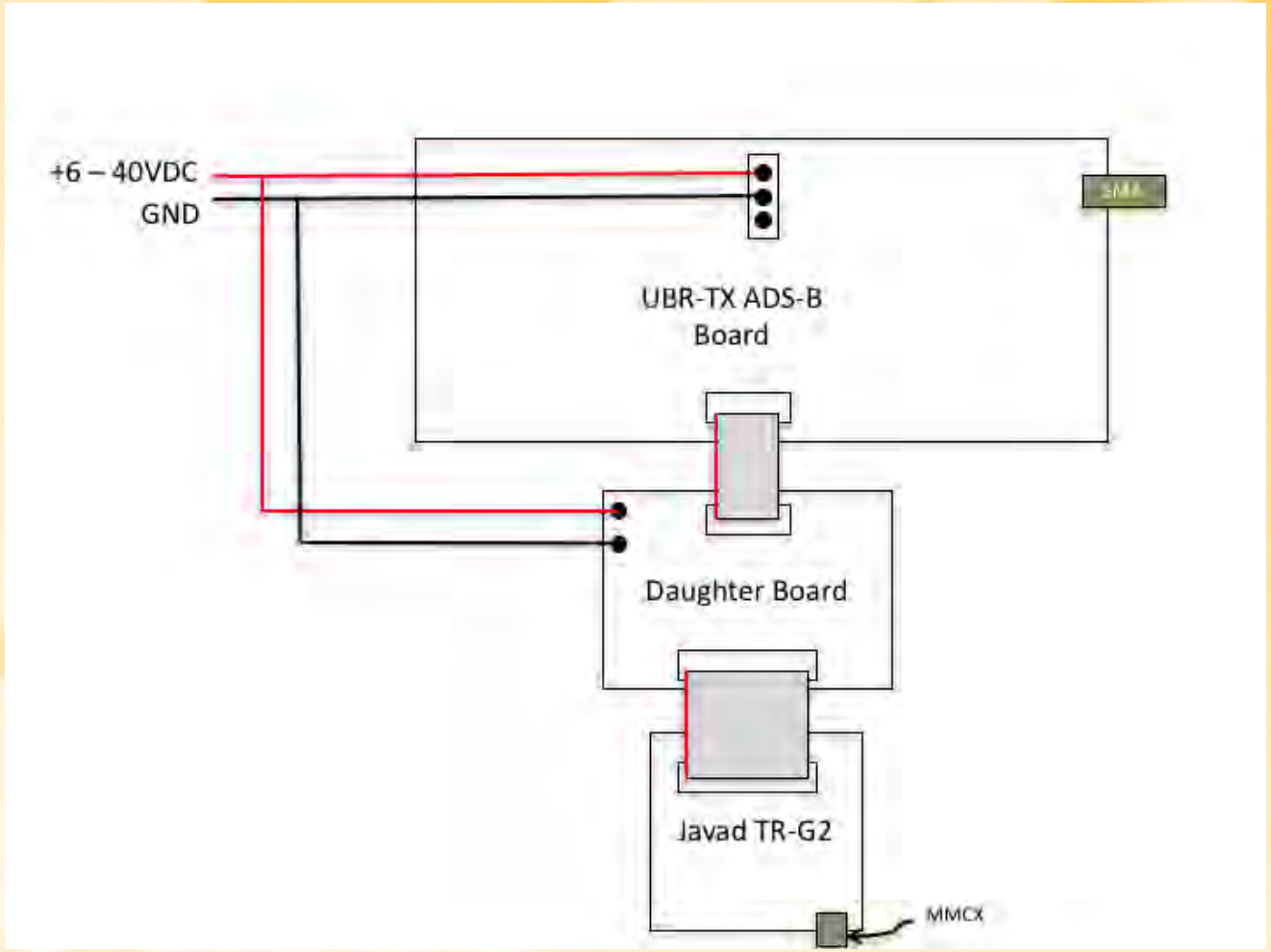
Hardware Upgrades

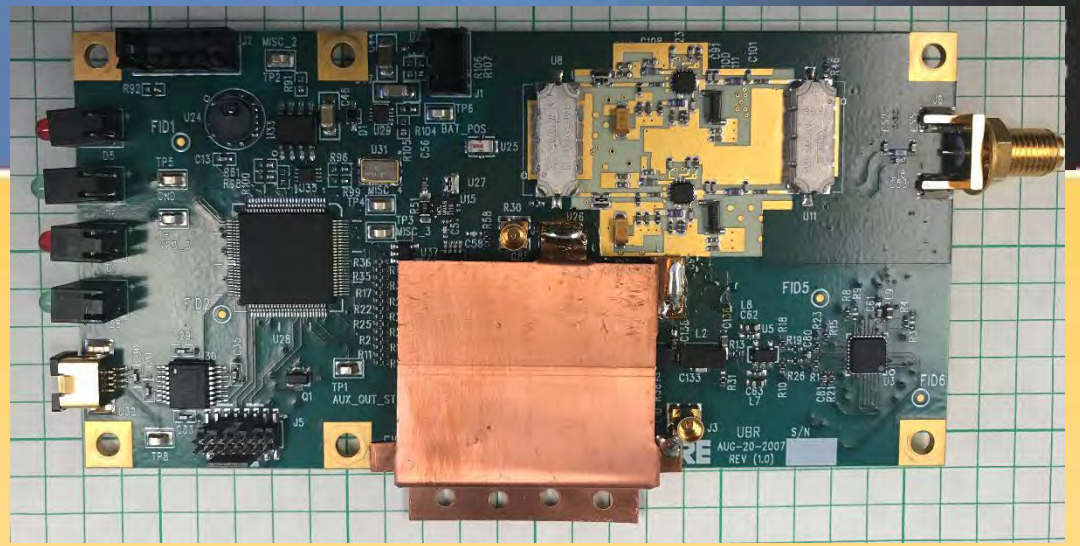
Parameter	Specification
Length	5.75” (14.6 cm)
Width	2.5” (6.35 cm)
Height	2.5” (6.35 cm)
Weight (UBR board, daughter board, GPS, battery, and enclosure)	790 g
Weight (cables, antennas, etc.)	85-300g est.
Nominal power Consumption	110mA @ 26 VDC

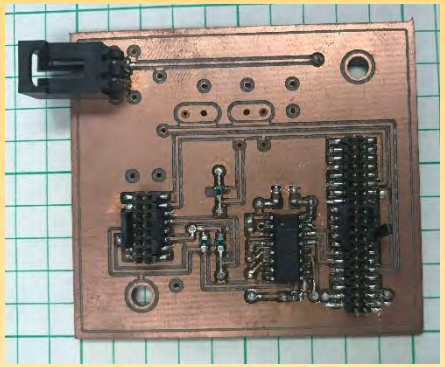
Hardware Upgrades

- **GPS Upgrade:**
  - Old GPS: SiRF GPS chipset
  - New GPS: Javad TR-G2 L1 with space altitude/velocity enabled
- **GPS Integration Daughter Board:**
  - Power regulation
  - Logic conversion
- **UBR Board**
  - Replaced components with milspec equivalents (when possible)
- **UAT (978 MHz) Antennas:**
  - Balloon: omnidirectional monopole antenna aimed nadir (Antcom)
  - Rocket: blade antenna (UB Corp)
  - Window placed: patch (Antcom)
- **Ruggedization:**
  - New enclosure
  - Epoxy
  - Neoprene
  - Ecosorb EMI/RFI

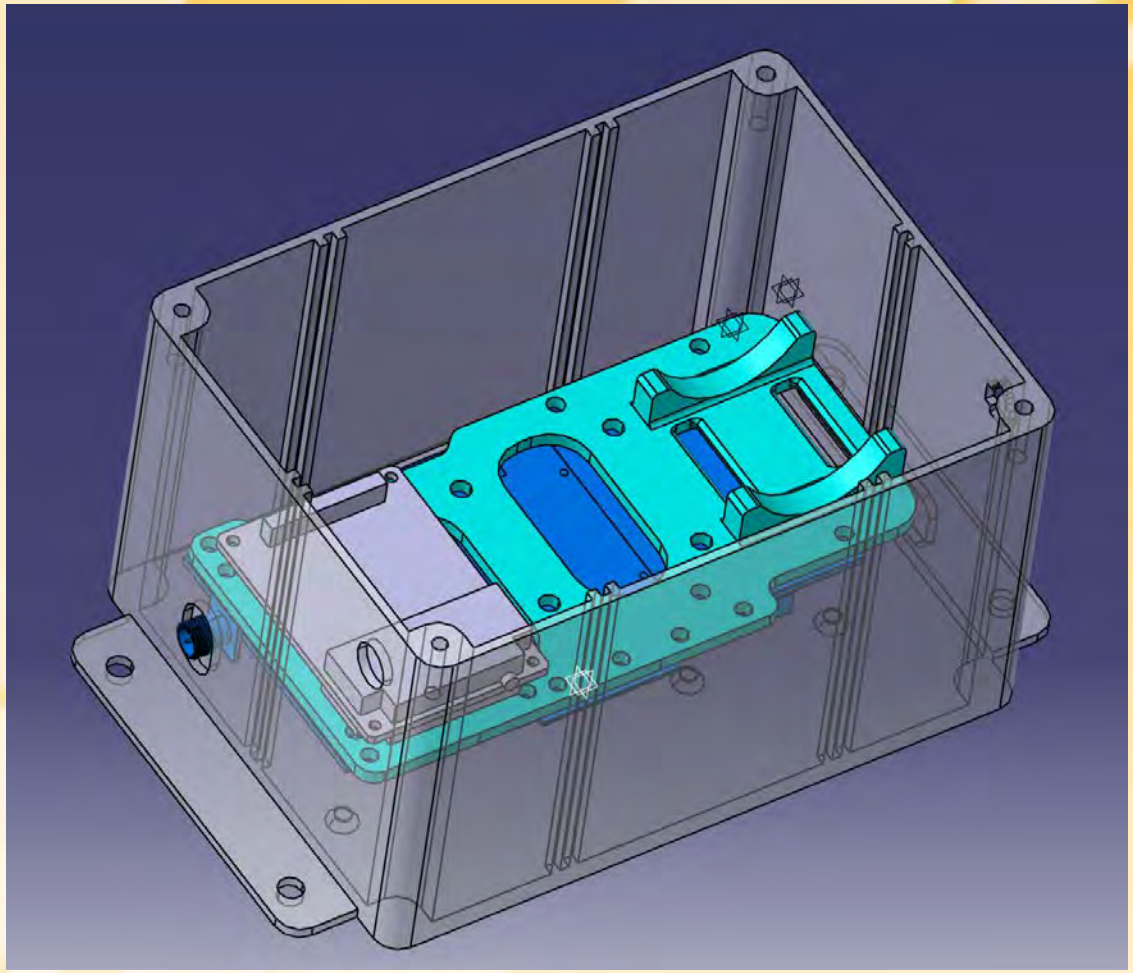
UBR-ERAU Hardware







UBR-ERAU Enclosure



Software Upgrades

Parameter	Specification
Length	5.75” (14.6 cm)
Width	2.5” (6.35 cm)
Height	2.5” (6.35 cm)
Weight (UBR board, daughter board, GPS, battery, and enclosure)	790 g
Weight (cables, antennas, etc.)	85-300g est.
Nominal power Consumption	110mA @ 26 VDC
Nominal battery capacity	7.75 Ah

Software Upgrades

- **Reuse of MITRE developed software:**
  - Message assembly
  - Transmission of message
- **GPS Parser:**
  - Old: SiRF binary protocol
  - New: Javad GREIS binary protocol
- **Addressing maximum altitude and climb rate limits of UAT message format:**
  - Implemented “roll-over” over feature wherein modulo of value with limit is used
  - Temporary solution to permit continued use of GBT network
- Provided general debugging of legacy code

System Qualification

- Near Space Corporation's Nano Balloon System
- Up Aerospace SpaceLoft XL
- Terminal Velocity Aerospace RED4U Prototype Spacecraft

Technology maturation plan

EMBRY-RIDDLE Aeronautical University

- System tested at WJH Technical Center for verification and validation using GNSS simulator on high-altitude balloon and rocket flight path simulations
  - Verification of valid ADS-B message reflecting current state of simulated trajectory
- Project goal to demonstrate viability and test functional envelope of experimental ADS-B payload for sub-orbital commercial space operations
  - TRL-7, proven within its operational environment
  - Initial flights are summarized within this presentation
- Additional flights needed before transition to TRL-8 (i.e. move out of prototype phase)
- Diversity of new vehicles is desirable to get operator feedback

NSC NBS Balloon Flight

EMBRY-RIDDLE Aeronautical University

Provider: Near Space Corporation

Vehicle: Nano Balloon System (NBS)

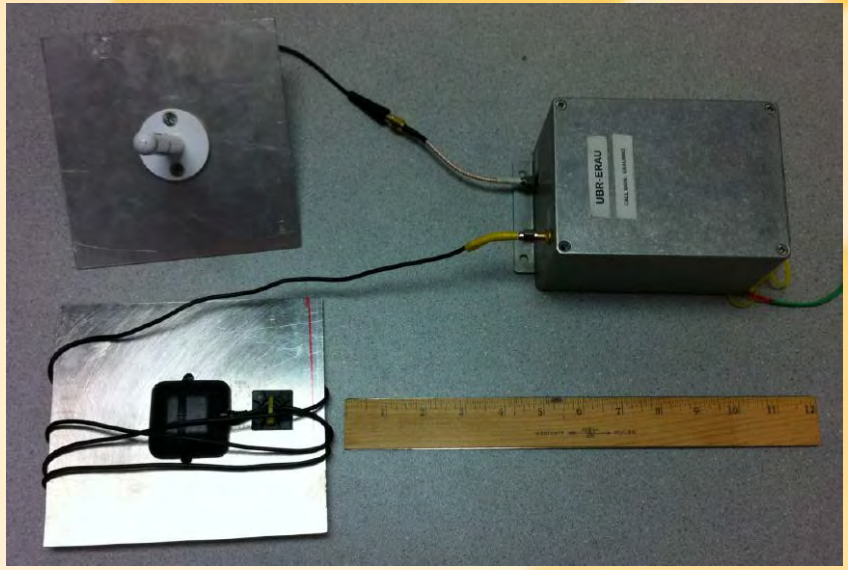
Flown under NASA Flight Opportunities Program

Milestones:

- Flights funded under NASA Flight Opportunities Program AFO1 and AFO5
- Near Space Corporation Nano Balloon System (NBS), 22 Jan 2013
  - Achieved altitude near 59,000 ft
- NSC NBS Flight #2, 15 Feb 2013
  - Achieved altitude near 94,000 ft

NSC NBS Payload Integration

EMBRY-RIDDLE Aeronautical University



- Foam enclosure houses payload for NBS
- Internal power via onboard batteries
- Netting material used to secure payload enclosure to balloon and its telemetry unit
- Cable from NBS telemetry unit routed to payload for remote enable/disable capability
  - Telemetry unit also provides position, altitude, and pressure data

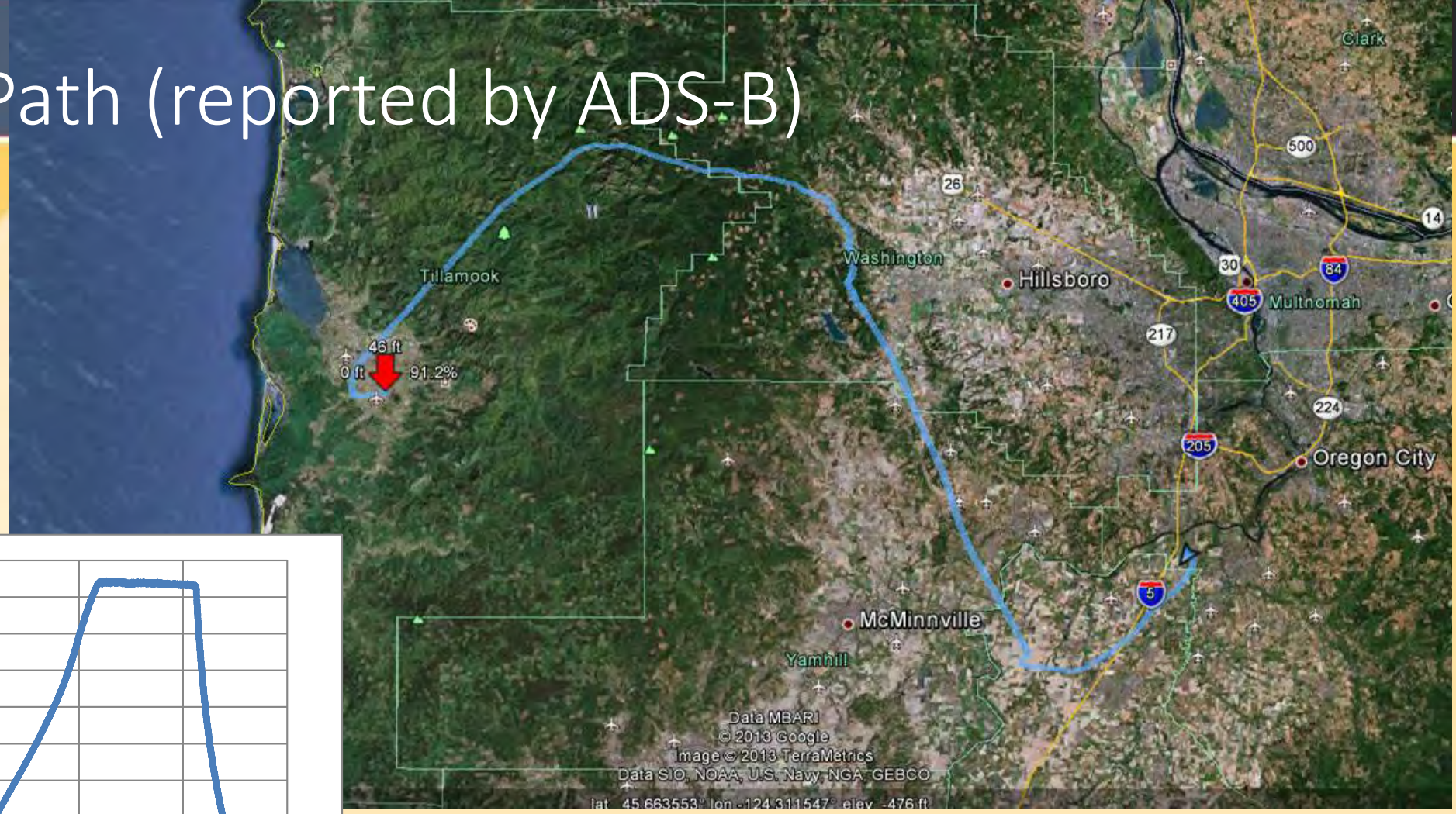
NSC NBS Flight Details

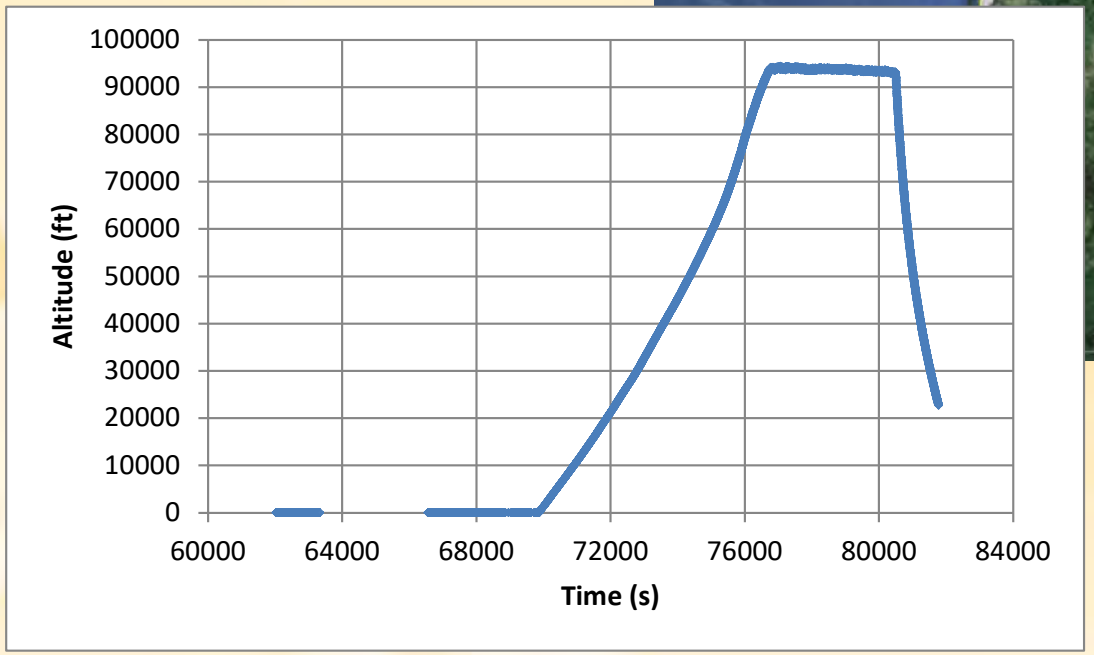
EMBRY-RIDDLE Aeronautical University

Flight: 15 February 2013

Maximum Altitude	
Geometric, MSL	94,025 ft.
Pressure, MSL	94,200 ft.
Flight Time	
Ascent	116 min
Float	58 min
Descent	38 min
Total	212 min
Tracking	
Total Number of Unique GBTs Receiving Data	31 (available in post-processing)
Number of GBTs Receiving at Float	11 (available in post-processing)

NBS Flight Path (reported by ADS-B)





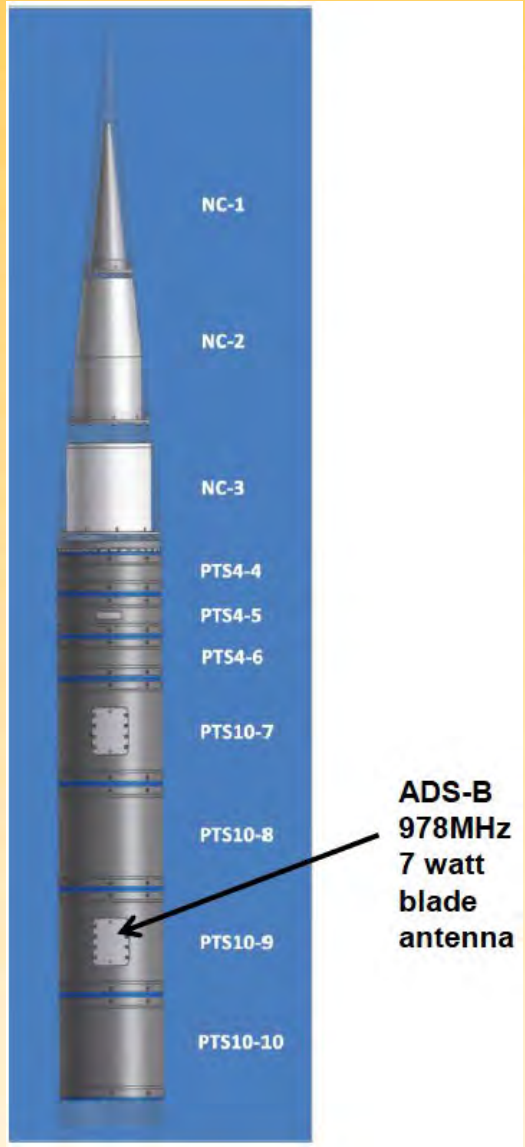
NSC NBS –Lessons Learned

EMBRY-RIDDLE Aeronautical University

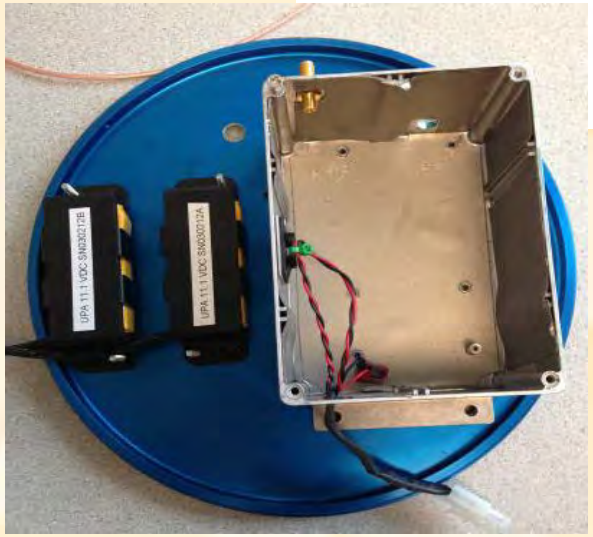
- Successful demonstration of payload
- Terrain had a major impact on ability to track unit at launch and recovery sites
- Minimum temperature (courtesy of NSC): -20.6 degrees C
  - Inside foam container
- Timing accuracy indicated no uncompensated clock drift
  - Most data points fall within +/- 1us of UAT specs
- Emitter category 15 (space/trans-atmospheric vehicle) data is not smoothed resulting in “noisy” vertical rate information
- Exelis GBT systems currently filter out targets with a ground distance of 300 nautical miles from the receiver.
  - Prevented an adequate analysis of achievable range

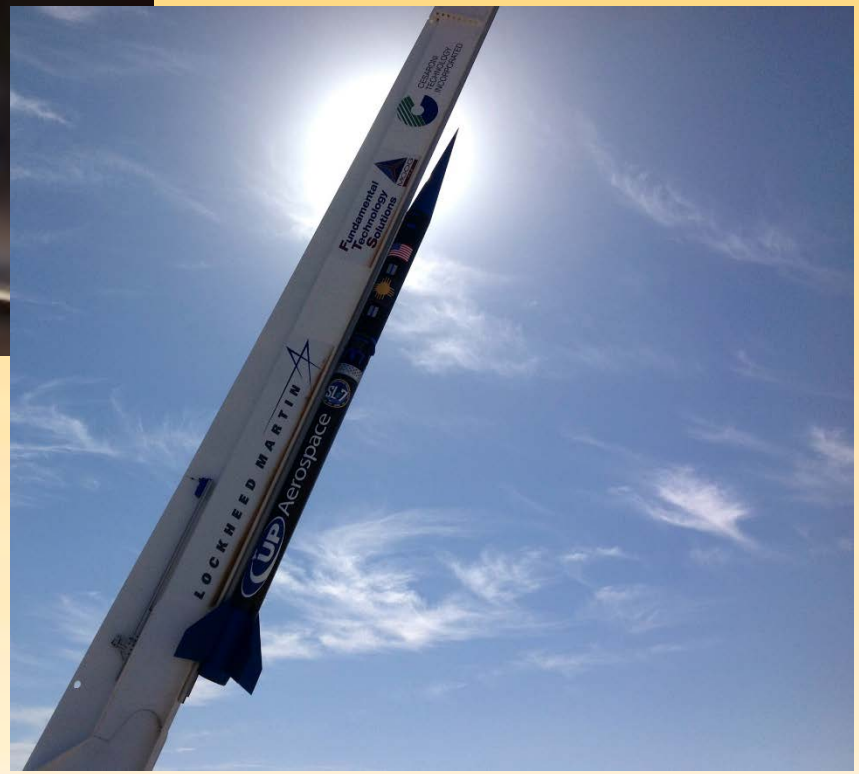
Up Aerospace SpaceLoft XL

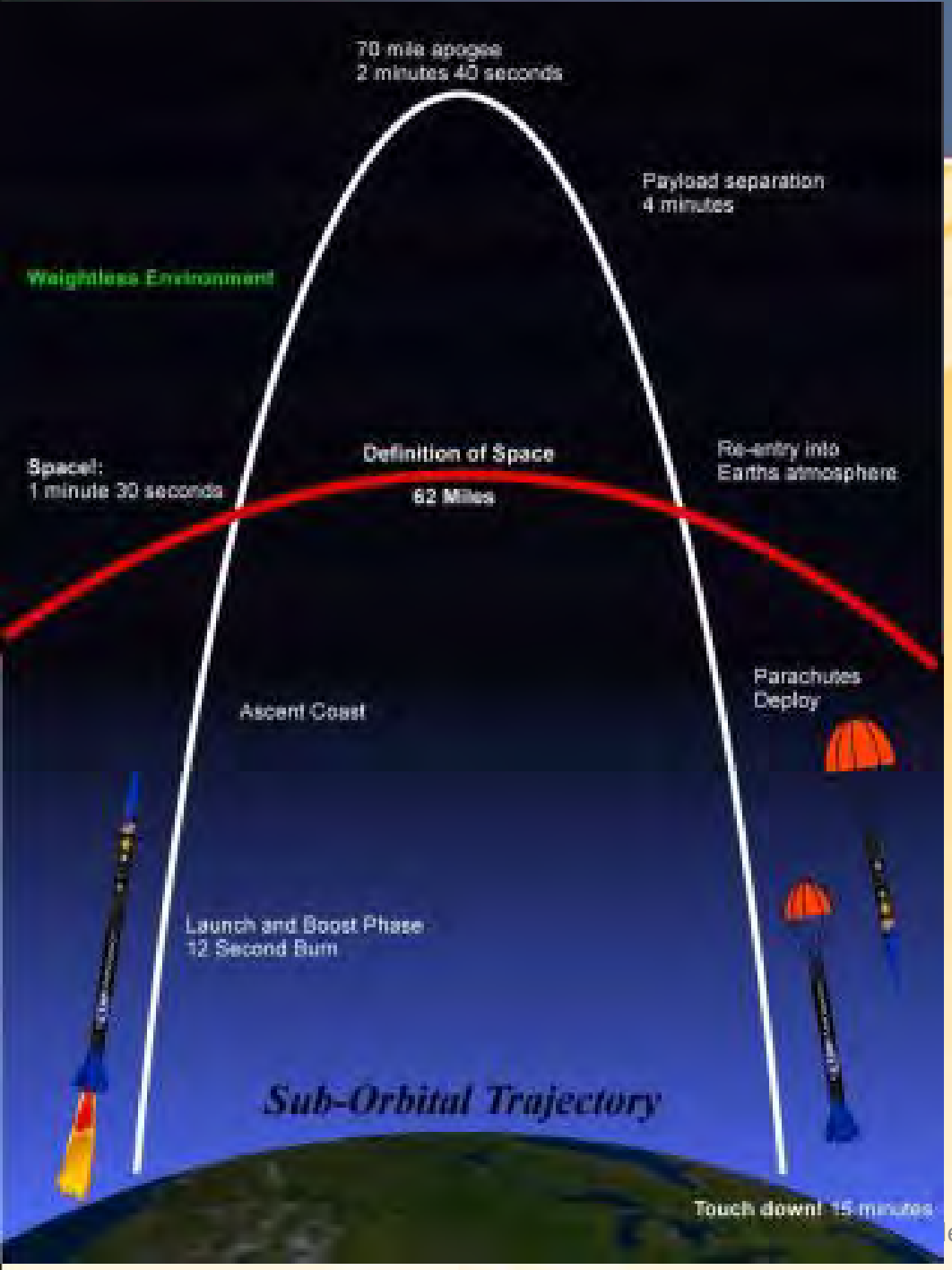
- **Provider:** Up Aerospace
- **Vehicle:** SpaceLoft XL Sounding Rocket
- Supported by NASA Flight Opportunities Program
- **Milestones:**
  - MITRE UBR-TX ADS-B flights for SL-6 and SL-7 mission
  - UBR-ERAU flight for SL-8 mission– November 2013
    - Apogee: 384,100 ft. MSL
- **Planned Flights**
  - SL-11
  - SL-12



UP Aerospace SpaceLoft XL Integration







SL-8 Flight Profile

Event	Time (seconds)
Launch	T + 0
Despin initiated	T + 55
Apogee (384,100 ft.)	T + 162
Payload separation	T + 240
Drogue deployment	T + 442
Chute Deployment	T + 452
Touchdown	T + 751

Typical Spaceloft Flight Profile

SL-8 Flight Analysis

EMBRY-RIDDLE Aeronautical University

Phase of flight	Metric	Result
Full flight	% tracked by ADS-B	73.8%
Launch to T + 62 (7 seconds post-despin initiation)	% of flight tracked by ADS-B	80.5
	Avg. time between message	1.27 s
	Max. time between message	8.00 s
	Max receivers tracking (Ground-based Transceivers GBTs only)	8
	Max receivers tracking (GBTs and portable)	10
	Avg. latitude error	16.145E-05 deg.
	Avg. longitude error	9.170E-05 deg.
	Avg. altitude error (below 101,350 ft.)	54.31 ft.
Post T+315 (descent and deceleration to less than 1000 ft./sec)	% of flight tracked by ADS-B	95.9%
	Avg. time between message	1.04 s
	Max. time between message	3.00 s

Apogee: 384,100 ft. MSL

SL-8 Performance vs. Success Criteria

EMBRY-RIDDLE Aeronautical University

Criteria	Pass / Fail	Comments
Broadcasts well-formed messages	Pass	GBTs and two portable Garmin GDL 90 successfully parsed data
Vehicle tracking for 90% of flight	Fail	73.8% of full flight, 80.5% post-despin, and 95.9% on descent.
Characterization of data loss	Pass	Primary characterization of data loss was configuration onboard spacecraft and NOT ADS-B unit itself.
Correlated with other data sources	Pass	Utilized truth data from WSMR primary radar. Position/altitude accuracy measured.

Lessons learned

EMBRY-RIDDLE Aeronautical University

- Two prior flights with “basic” MITRE ADS-B payload minimized risk of vehicle integration and site support
- Payload demonstrated to be viable for tracking sub-orbital RLV or sounding rocket of this velocity, altitude and range
  - Additional transmit antennas and transmission power desirable for longer range, higher altitude flights
  - Single transmit antenna briefly blocked by rocket body at apogee
- Current GPS antenna and amplifier may not be sufficient to maintain lock through all phases of flight
- Desirable for future missions to have onboard inertial measurement unit with payload and/or telemetry to correlate with data received (future SL missions will have telemetry)
- Desirable to equip future vehicles that host payload with GPS translator (s)
  - record raw GPS data for post-flight analysis / truth data

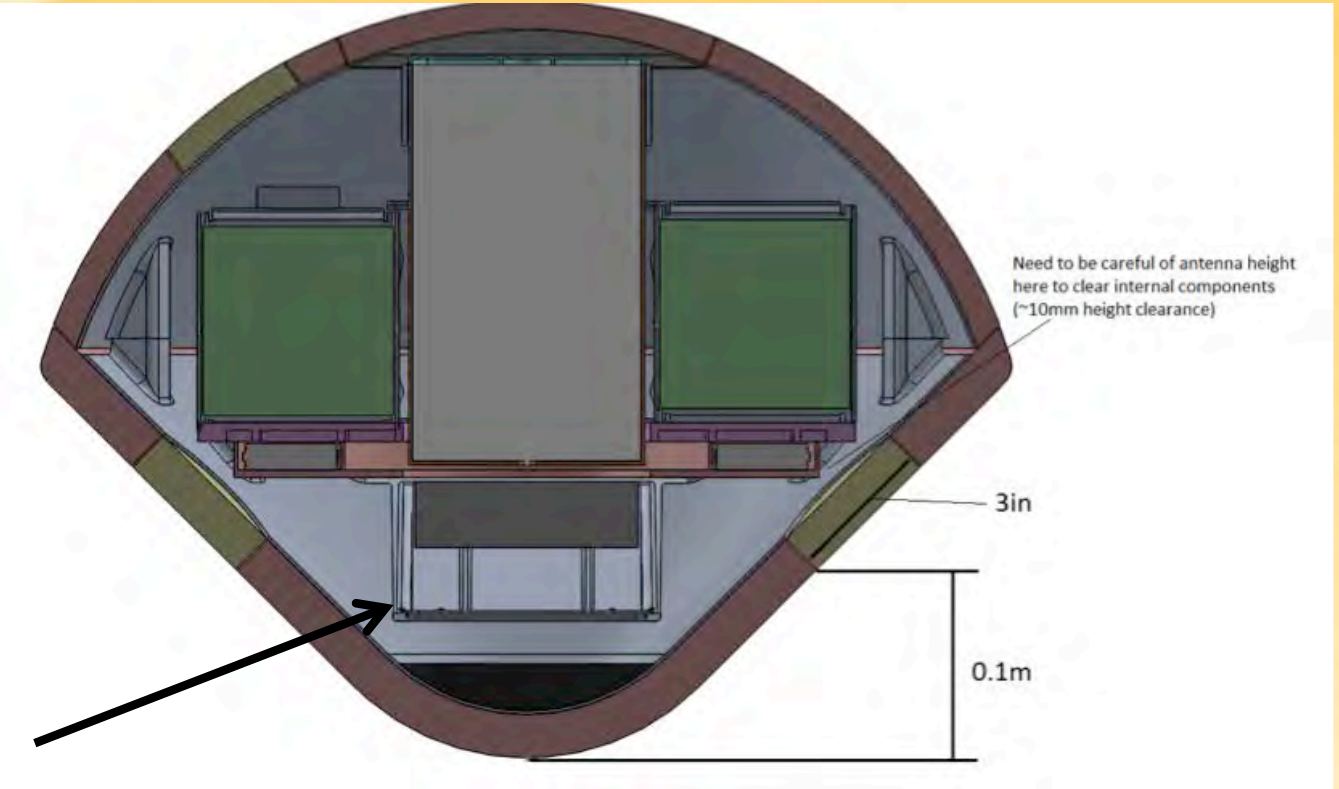
Terminal Velocity Aerospace

EMBRY-RIDDLE Aeronautical University

- **Partner:** Terminal Velocity Aerospace
- **Vehicle:** RED-4U Reentry Vehicle
- **Provider:** Near Space Corporation

- Integration of Advanced ADS-B Unit onboard prototype reentry vehicle
- Funded by NASA Ames
- Proof-of-concept flight onboard high-altitude balloon

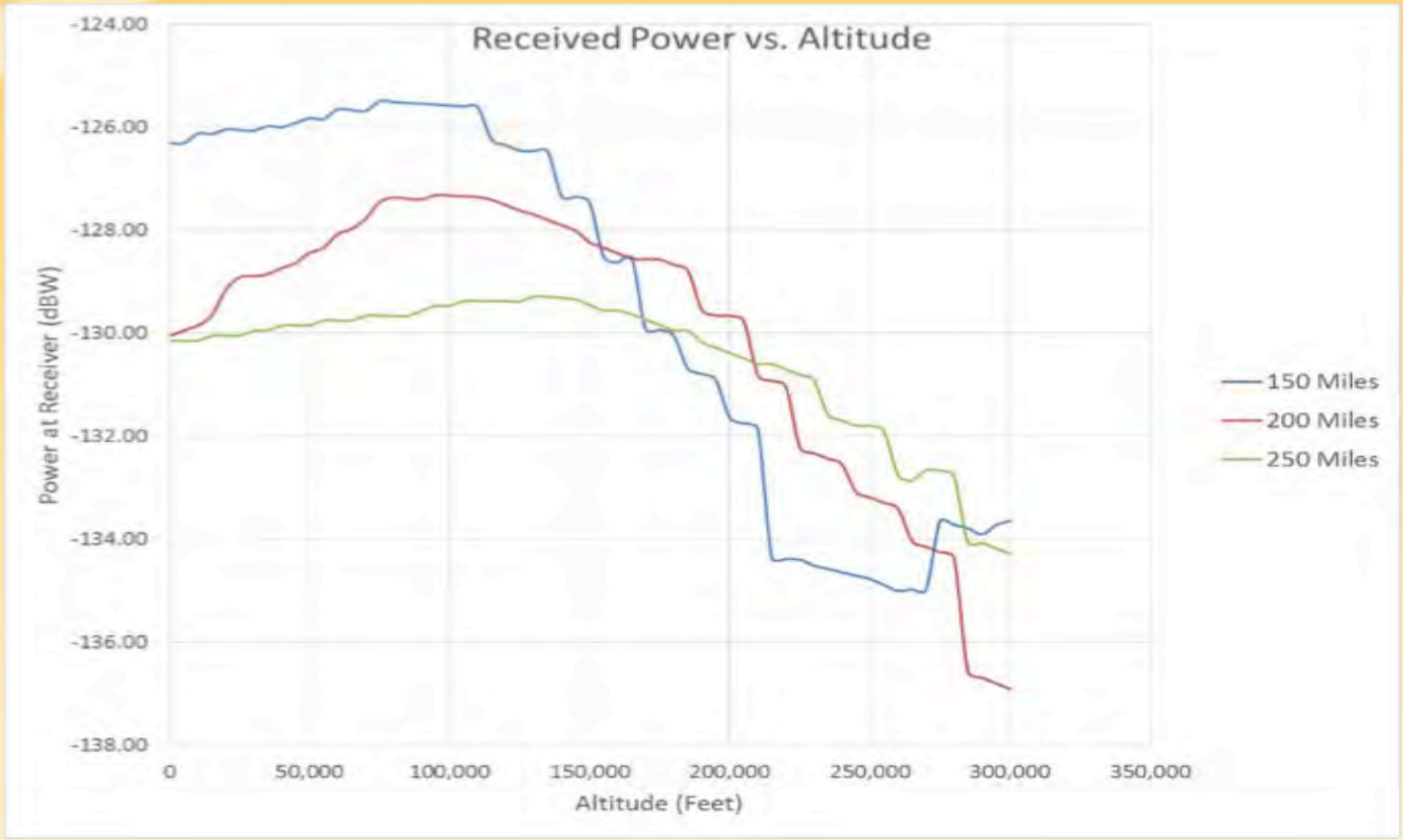
- Goals:
  - Evaluate performance of ADS-B broadcasting through experimental TPS material
  - Demonstration of UBR on new vehicle type



Antenna Options

EMBRY-RIDDLE Aeronautical University

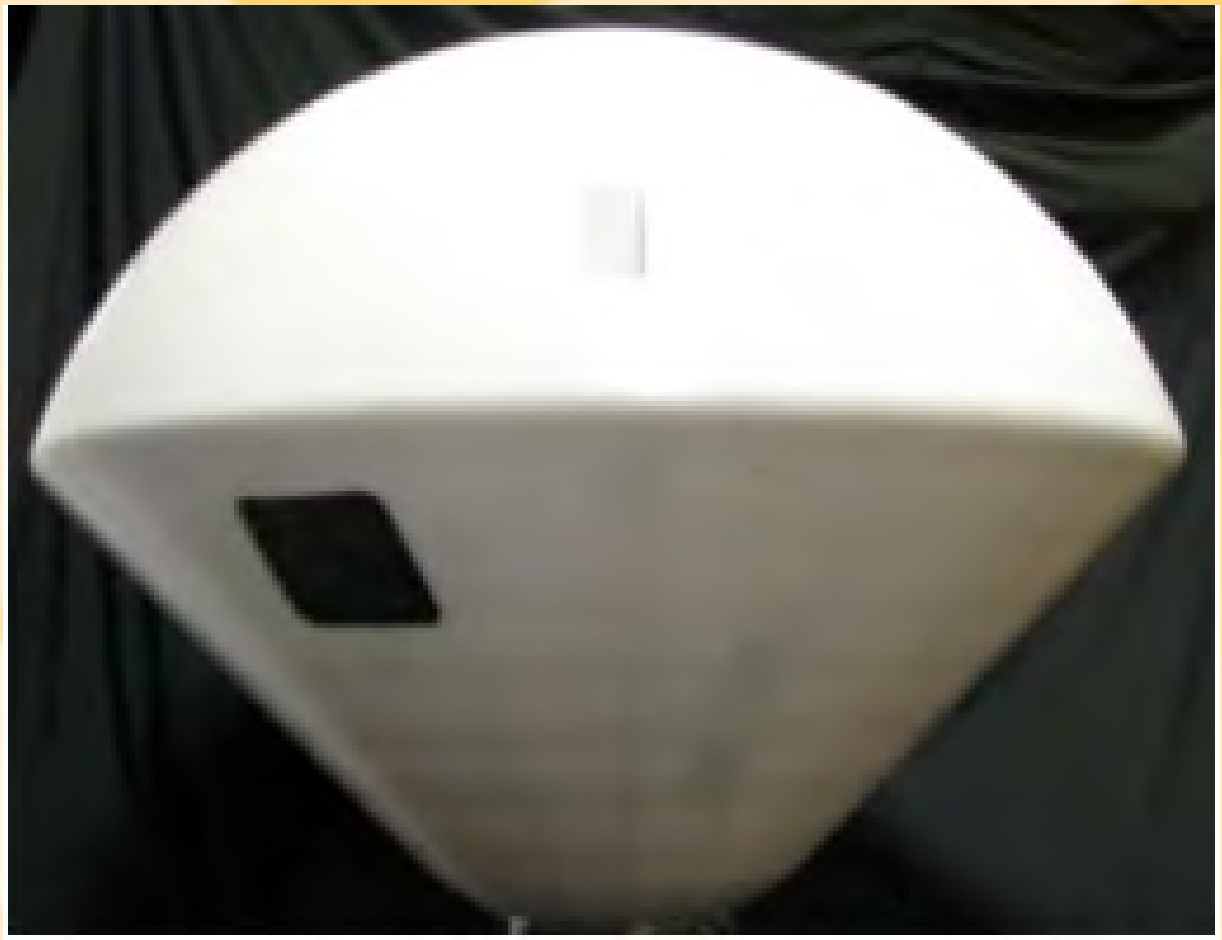
- Antenna Selection and RF Analysis
  - Limited space for antennas
  - Aluminum foreshell with windows for UAT and GPS antennas
  - Experimental RF transparent thermal protection system substrate for windows
    - NASA Ames
    - Material or its RF characteristics not available
- Option #1: Antcom off-the-shelf patch antenna tuned to 978MHz
  - Less costly
  - Faster turn around time
- Option #2: Custom patch antenna
  - Designed and tuned to RF environment of the spacecraft and the TPS materials
- Option #1 was selected given budget, scope, and time



Terminal Velocity Aerospace Reentry Vehicle

Drop from stratospheric balloon

EMBRY-RIDDLE Aeronautical University



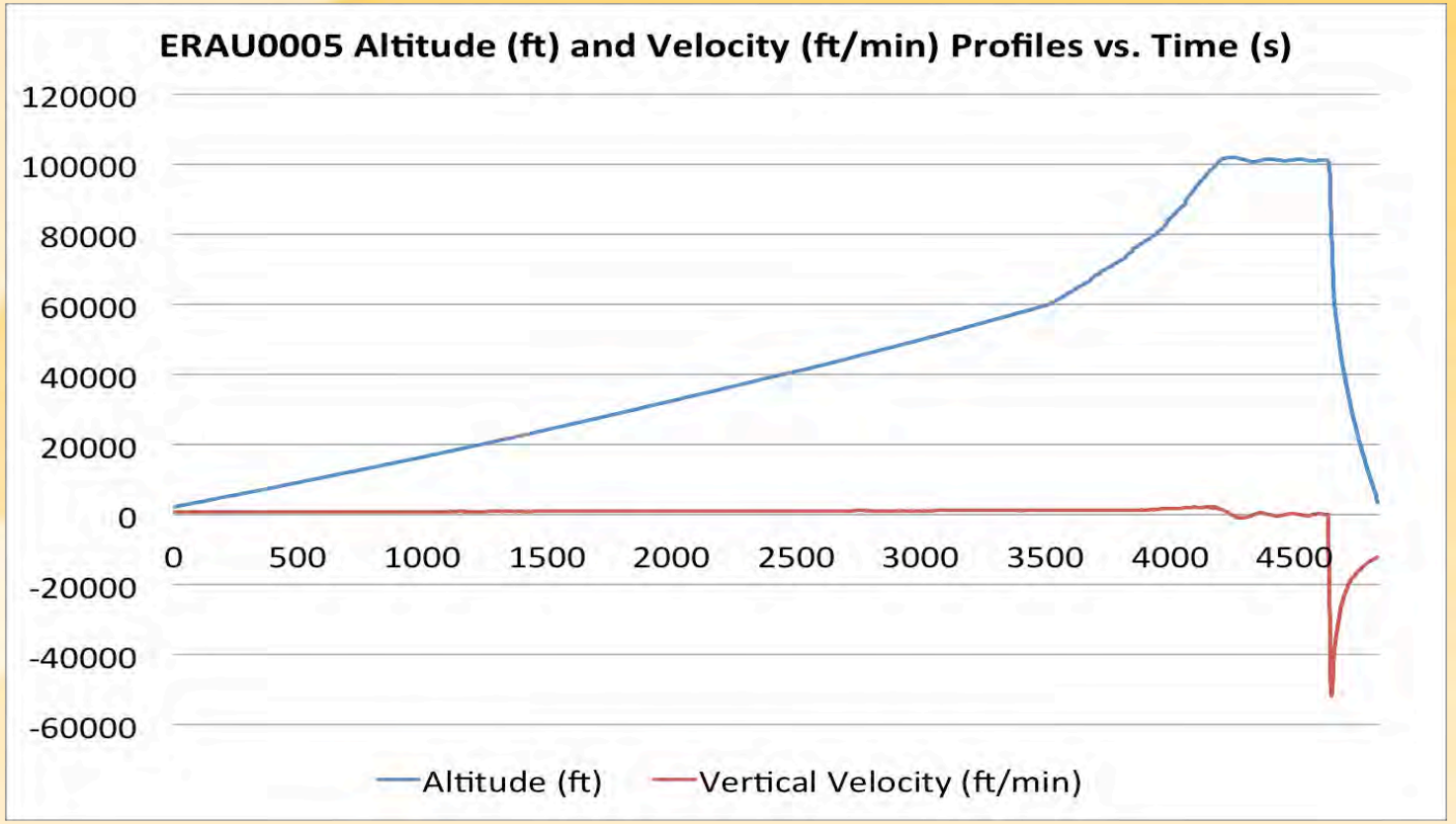
System Integration Ground Test

EMBRY-RIDDLE Aeronautical University

- Performed by ANG-33 Surveillance Branch, Engineering Development Services Development from FAA WJH Technical Center
- Location: Oregon, May 2015
  - Near Space Corporation Facility
- Integration with stratospheric balloon
  - UBR-ERAU (ERAU0002) onboard balloon gondola
  - UBR-ERAU (ERAU0005) onboard TVA RED-4U
- Hoisted by crane to replicate flight configuration
- Data received by portable Garmin GDL-88

Flight Test June 21, 2015

EMBRY-RIDDLE Aeronautical University



ERAU0002 (blue) and ERAU0005 (red) flight path captured by FAA GBTs

EMBRY-RIDDLE Aeronautical University

TVA RED-4U provided opportunity to operate two ADS-B payloads simultaneously. One tracked gondola while other tracked RED-4U spacecraft

Lessons Learned

EMBRY-RIDDLE Aeronautical University

- ERAU0005 performed well throughout flight onboard RED-4U

- RED-4U parachute did not deploy
  - Tracked ERAU0005 along ballistic descent trajectory
  - Exceeded maximum climb/descent rate of UAT standard and “rolled-over”
  - ERAU0005 was total loss

- ERAU0002 on gondola lost GPS lock for part of ascent due to faulty connector.
  - Connector damaged during Near Space Corporation High Altitude Shuttle System flight (rough landing)
  - Regained during descent under parachute.
  - ERAU0002 payload has been replaced for all future use

Path Forward

- Future upgrades
- Future Flights

Proposed Future Upgrades

EMBRY-RIDDLE Aeronautical University

- Dual antenna configuration
  - UBR-TX design supported only one antenna
- Payload hardening and size reduction
  - Unit designed as a proof-of-concept, but further hardening of payload needed for wider use in space applications
  - Payload size is a limiting factor for finding suitable test platforms
- Increase output rate of ADS-B message
- Power amplification to support future use in LEO flight opportunities
- Doppler shift impact and mitigation
  - RF modeling and radio tuning need to be investigated
- Reduce system startup time
  - Reduce 15-30 second startup time

Future Flights

- Near Space Corporation's High Altitude Shuttle System
  - Surrogate winged suborbital vehicle performing a descent into NAS (from above 60, 000 feet)
- Up Aerospace SL-11 and SL-12
  - TBD 2018
  - New GPS antenna and IMU to log vehicle acceleration and orientation
- Coordination with NASA FOP and other flight providers for future flights
  - Future announcements pending

Source: Near Space Corporation

Summary

- ADS-B provides a suitable means for the real-time tracking of commercial space vehicles to mitigate the impact to routine operations within the National Airspace System
- MITRE UBR-TX provided a sufficient platform to evaluate this opportunity through upgrades to hardware and software
- Flight demonstration has provided
  - Opportunities to further develop and refine payload
  - Address payload integration issues across flight providers
  - Receive input from future users (i.e. flight providers)

Questions

- Any questions?