High Altitude Infrasound Operations for the DAG Experiment

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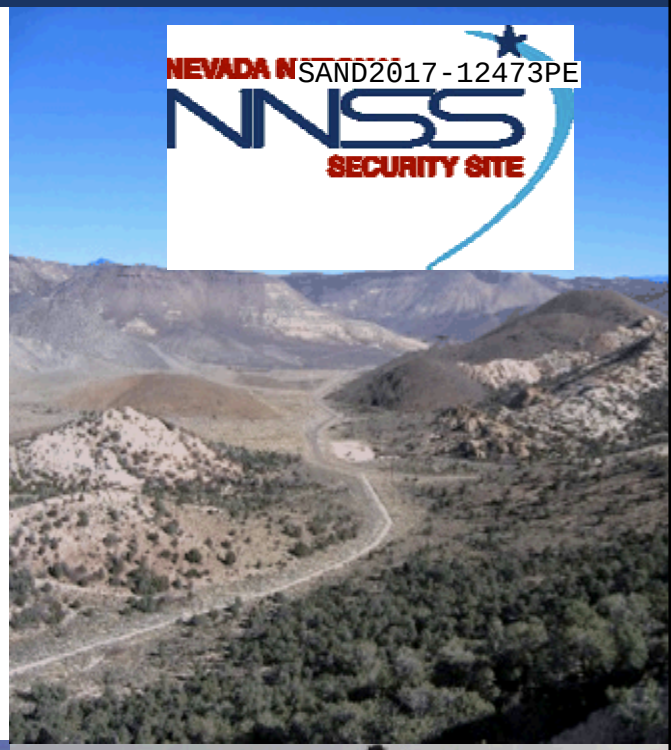
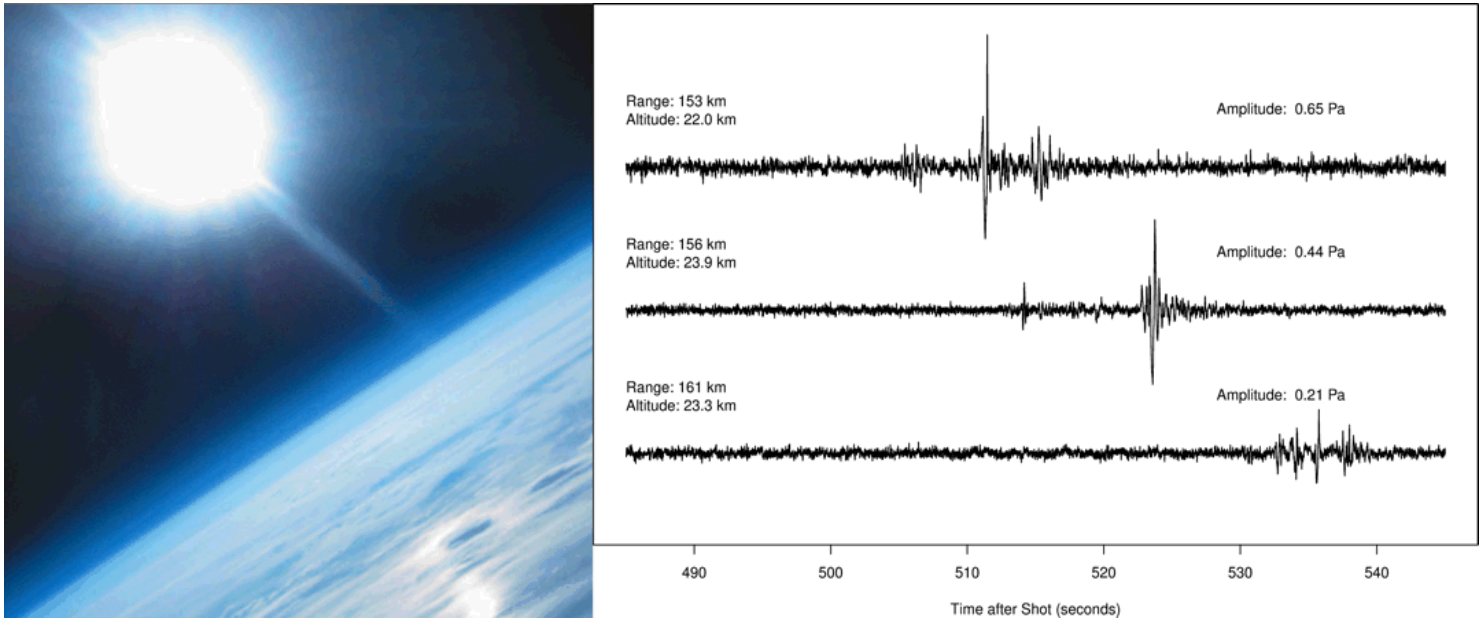


Outline

- Objectives
- FAA Regulatory Framework
- System Description
- System Theory of Operation
- Normal Operation
- Trajectory Planning
- Failure Modes and Mitigation
- Single Point Failure Analysis
- Unacceptable Consequences
- Launch Safety
- Qualification Flights

Objective: Capture infrasound in the upper troposphere/lower stratosphere

- Secondary Diagnostic
- Target DAG – 2 through DAG – 4
- Based on experience gained during 2017 LDRD express project



Operates Under the FAR 101 Exemption:

- any unmanned free balloon that—
- (i) Carries a payload package that weighs less than four pounds and has a weight/size ratio of less than three ounces per square inch on any surface of the package, determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface;
- (ii) Carries a payload package that weighs less than six pounds;
- (iii) Carries a payload, of two or more packages, that weighs less than 12 pounds; and
- (iv) Uses a rope or other device for suspension of the payload that requires an impact force of less than 50 pounds to separate the suspended payload from the balloon.

Examples: Weather balloons, small scientific balloons

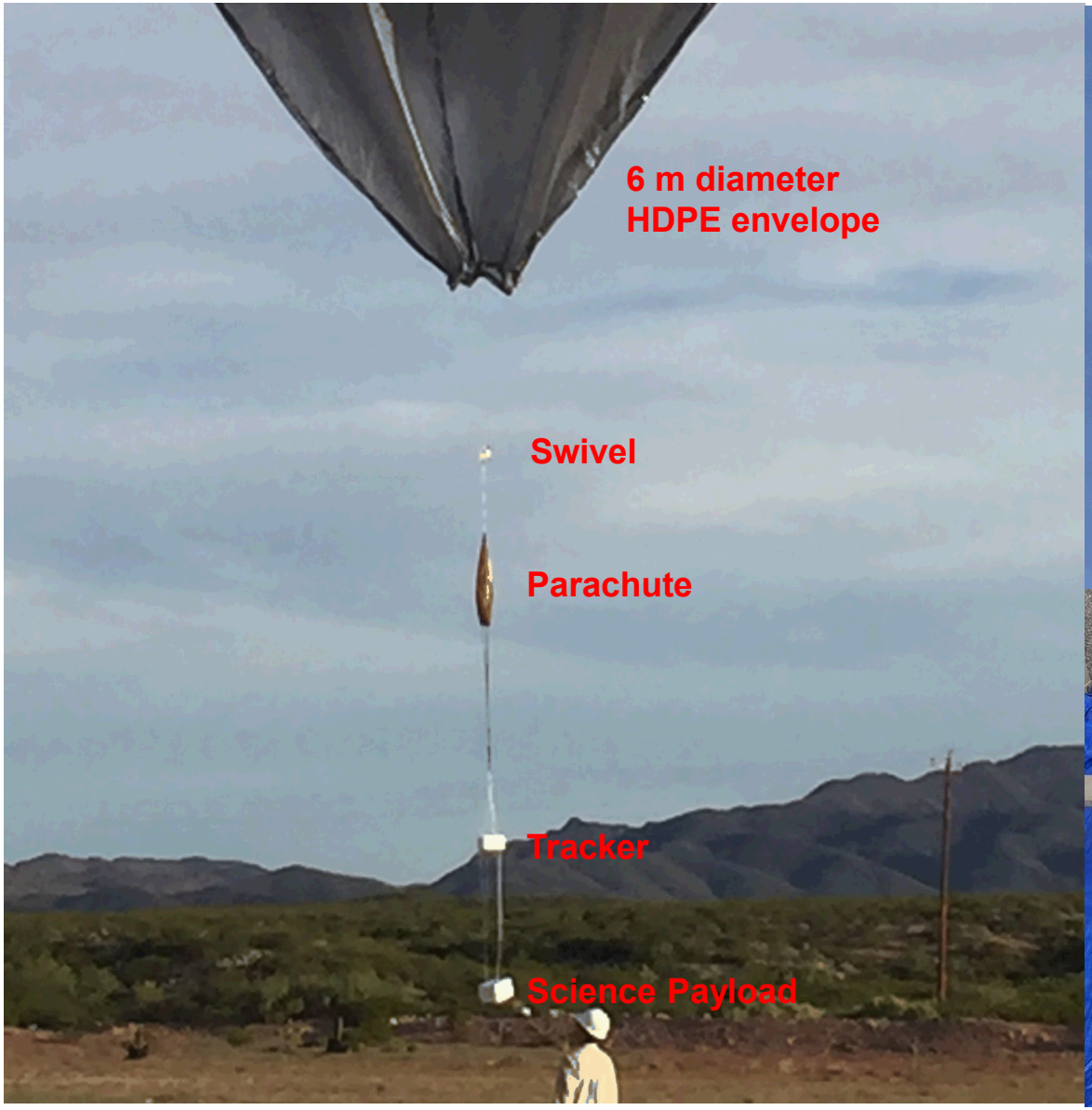
Electronic Code of Federal Regulations: https://www.ecfr.gov/cgi-bin/ECFR?page=browse

System Description: The Heliotrope
A passive solar powered hot air balloon

- Payload Capacity: up to 1.8 kg (tested) up to 2 kg (expected)
- Altitude Ceiling: 16.5-24 km (tested) 15-30 km (expected)
- Flight Duration: Deployment to sunset
- Climbout: approximately 3 hours
- Descent: approximately 1 hour

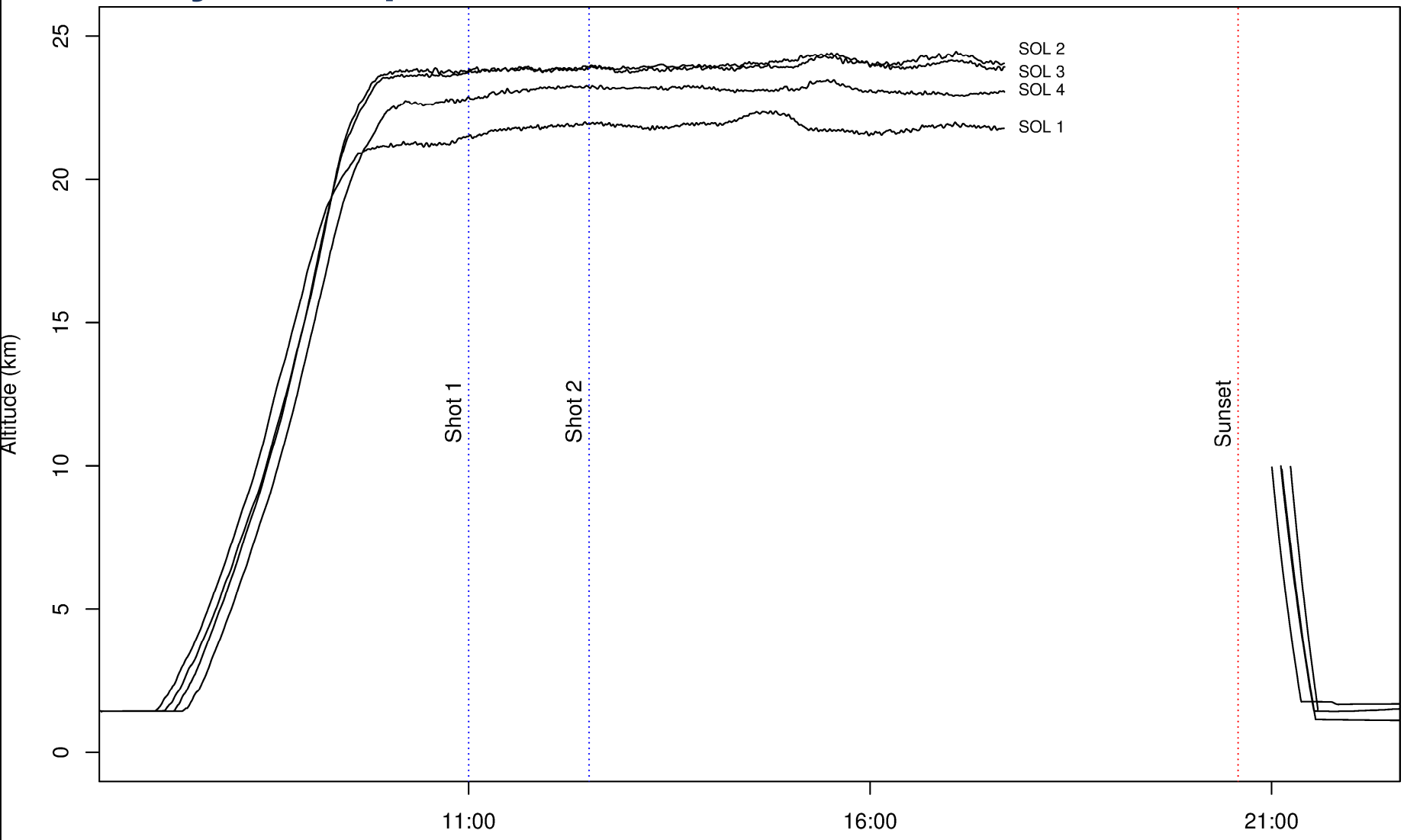
System Description

- 6-10 m diameter solar envelope (0.31 mil HDPE darkened with carbon powder)
- <50 lb test fishing swivel (for FAR 101 compliance)
- 4 ft. diameter Rocketman parachute
- SPOT TRACE Asset Tracker (for recovery)
- Scientific Payload (Infrasound sensors, digitizer, and batteries)

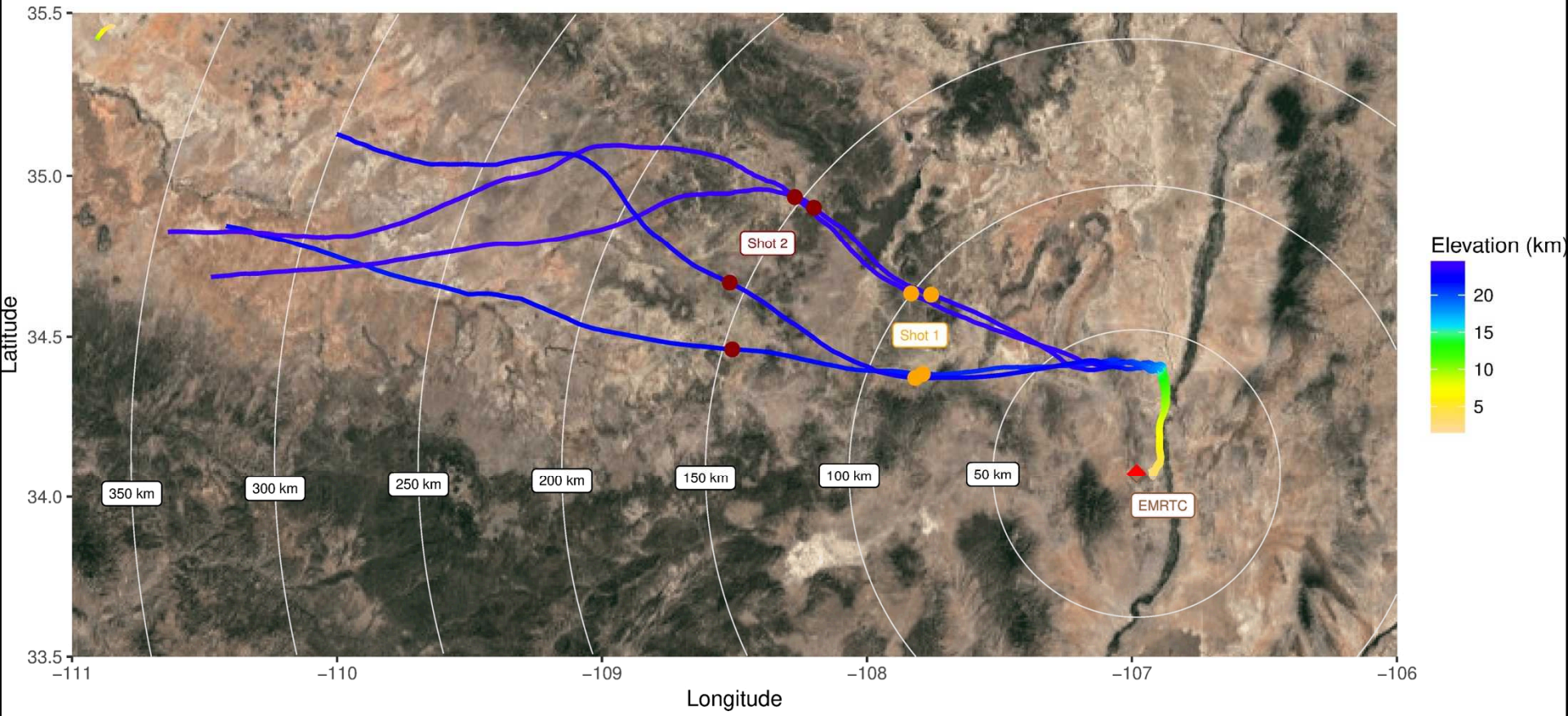

6 m diameter
HDPE envelope
Swivel
Parachute
Tracker
Science Payload

Landing Site Photos

System Operation: Time/Altitude Plot

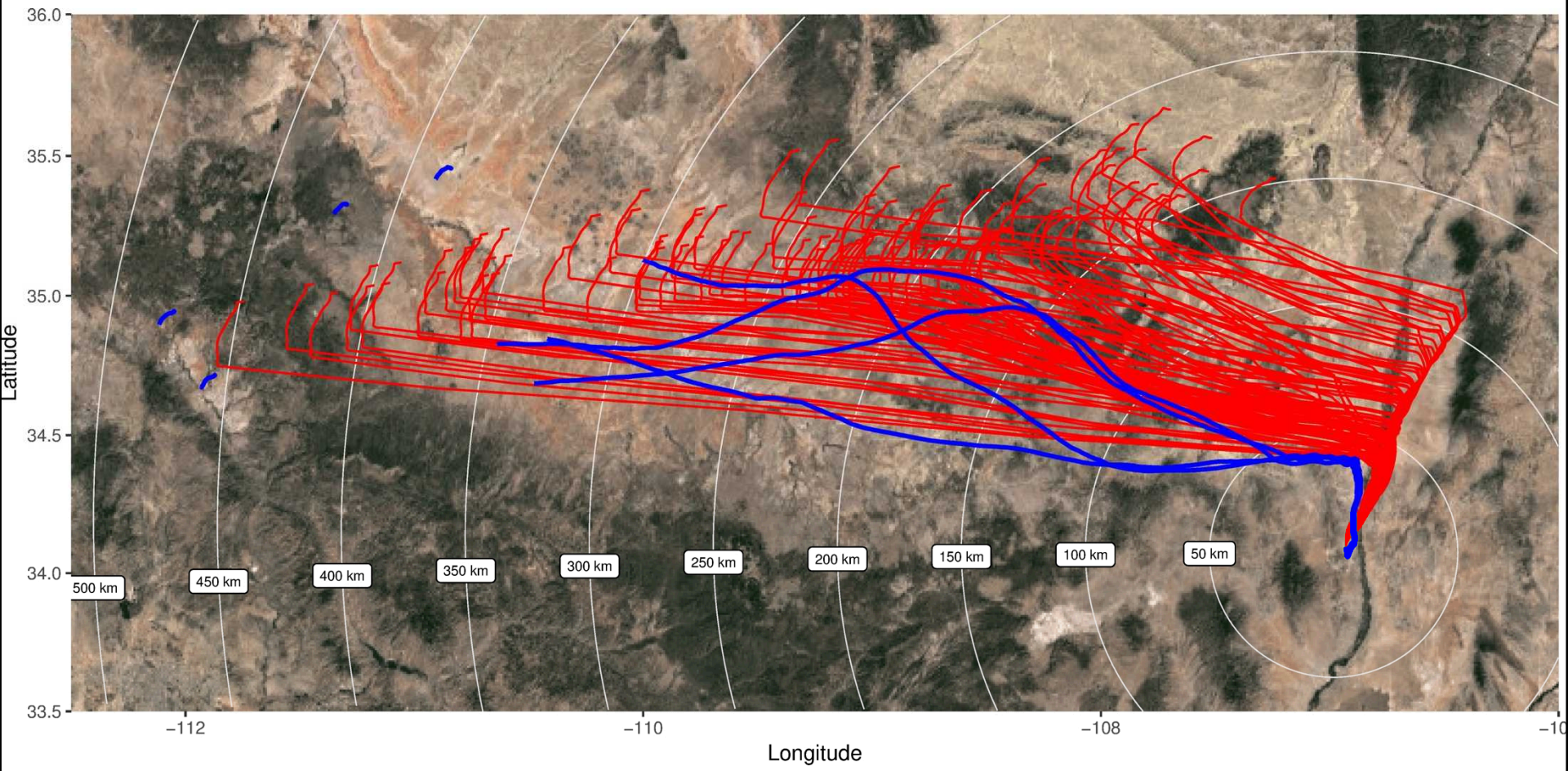


System Operation: Distance Traveled
(LDRD Express Flights: July 25, 2017)



This is dependent on atmospheric conditions, ascent rate, and float altitude.

Trajectory Predictions: July 25, 2017



A stochastic realization of 100 solar balloon flight trajectories based on Global Forecast Model data and ascent rate model based on a 2015 test flight (red) vs. actual trajectories (blue).

Two Options for Launch

1. Ground Inflation and Release
    - Proven (9 successful launches in 2016-2017, 0 failures)
    - Simple, only requires vehicle power inverter and box fan
    - Slow ascent (3 hours to float)
    - Requires low ground winds at launch and minimal cloud cover for 1 hour post launch
    - Usually too windy after midmorning
    - Sensors may be far away from DAG GZ at shot time

2. Helium Tow Balloon
    - Uses standard meteorological balloon to deploy Heliotrope above the clouds
    - Much less dependent on ground conditions
    - Rapid ascent rate
    - Place sensors closer to DAG GZ at shot time
    - Needs validation (JPL proved concept in 1990s but no SNL experience with method)
    - More complicated

Option 2 will be tested at least once in New Mexico prior to DAG 2.

Test Plan (Option 1): Normal Operations

- Trajectory and weather predictions: 24 hour and 0-12 hour prior to launch time – go/no go declared
- Launch day weather evaluated onsite three times: 1) at arrival 2) at decision to inflate 3) before release; go/no go each time.
- Launch between half hour after sunrise to T-3
- Climb to float altitude: 2-3 hours
- Remain at 15-30 km for 5-12 hours
- Lands 1-2 hours after sunset at 1-2 m/s (3 - 5 mph)
- Landing location transmitted via Globalstar satellite system
- Retrieval team recovers payload and envelope

Test Plan (Option 2): Normal Operations

- Trajectory and weather predictions: 24 hour and 0-12 hour prior to launch time – go/no go declared
- Launch day weather evaluated onsite three times: 1) at arrival 2) at decision to inflate 3) before release; go/no go each time.
- Launch between sunrise and T-1
- Climb to release altitude: 1 hour
- Tow balloon cut at 20-30 km elevation
- Solar balloon floats at 15-30 km elevation for 3-12 hours
- Lands 1-2 hours after sunset at 1-2 m/s (3 - 5 mph)
- Landing location transmitted via Globalstar satellite system
- Retrieval team recovers payload and envelope

Normal Operations/Failure Modes (Options 1 and 2)

	MODE		RESULT
1.	Payload descends under fully inflated balloon envelope after sunset	1.	Normal operations
2.	Loss of lift during ascent due to clouds (ground launch only)	2.	Payload descends under parachute and fully inflated balloon envelope
3.	Solar balloon envelope loss of integrity	3.	Payload descends under parachute
4.	Payload detaches from envelope	4.	Payload descends under parachute
5.	Destruction of payload box(es)	5.	Several <2 lb. objects descend under parachute
6.	Detachment of parachute from payload	6.	Payload descends at terminal velocity, landing at 35 m/s (78 mph) or less

Failure Modes (Option 2 only)

MODE	RESULT
1. Solar balloon released from tow balloon	1. Normal operations
2. Solar balloon fails to detach from tow balloon	2. Solar balloon descends to nominal float altitude after tow balloon burst at ~30 km altitude
3. Solar balloon fails to inflate after release	3. Payload descends under parachute
4. Solar balloon released early (>400 m agl) in clear sky	4. Solar balloon inflates and ascends
5. Solar balloon released early (<400 m agl)	5. Payload descends under parachute
6. Solar balloon released early under cloud layer	6. Payload descends under parachute

Descent Control Redundancy

The parachute is a redundant descent speed arrestor for the balloon envelope. In the event of substantial destruction of the envelope (sufficient for opening of parachute), the parachute will slow the payload to an acceptable velocity (5 m/s or less). In the event of separation of the envelope from the payload at the FAR-101 mandated 50 lb. test connection, the parachute will arrest the payload.

The parachute will be attached to each piece of equipment in each payload box via 550 lb. test paracord.

Both the balloon, the paracord, and the parachute have been tested on multiple high altitude flights.

This is in accordance with SNL safety procedures set forth for the July 25, 2017 Heliotrope launch.

Unacceptable Consequences

It is unacceptable for:

1. Any part of the payload to land within the city limits of a municipality while descending at a speed of 13 m/s (30 mph) or greater.
2. Any portion of the flight system or payload to cause injury or property damage.
3. Injury to the launch crew.
4. Damage to the SPE program's reputation.

These consequences will be protected against by not performing a launch when predicted landing points are near urban areas such as Las Vegas, NV and by having dual means of attachment (kite string and 550 lb. test paracord) for scientific payload components. Administrative controls and PPE will ensure launch crew safety (see following slides).

Probability of Strike

The chance that an object falling from the sky will strike a person in Nevada is approximately 1 in 100,000 (0.0001%), assuming a person occupies 1 square meter and the entire state population is standing outside.

The chance that an object falling from the sky in the Las Vegas metro area will strike a person is less than 1 in 500 (0.17 %), assuming a person occupies 1 square meter and the entire city population is standing outside.

To determine the likelihood of striking features near the launch site, 435 randomly selected points in a 20 km box centered on the BEEF facility were examined. In this study, 0.91% of the points were on a paved road, 2.8% were on a dirt road, 4.8% were in or near a crater, and 20% were in areas of disturbed earth. The remainder of the points were in hilly areas (47%) and flatlands (25%). No facilities or vehicles were located at or near the simulated landing points.

Approximately 10,000 weather balloons are launched worldwide per week. There have been no reports of weather balloon aircraft strikes or injury to people.

Payload Impact to Human Head

SNL Safety has modeled the consequence of a 5 lb. object in a Styrofoam box striking a human head at 75 mph:

-Skull fracture is unlikely, since the maximum stress imposed on the skull is less than its tensile and compressive strength

Based on a 760 N impact (5 lb at 75 mph, 0.1 second impact time), I calculate:

-Assuming a small (4 kg) head, the acceleration sustained on impact would be about 20 g. **The lowest acceleration value for concussion I was able to find is 35 g.**

These conclusions are preliminary and have not been peer-reviewed. However, the analysis indicates that skull fracture and/or concussion are unlikely even if the payload box strikes a person at terminal velocity.

Single Point Failures

No single point failures were identified.

Redundancies: There are two descent speed arrestors (the balloon envelope and the parachute) and there are two attachment systems (kite string on each payload box, 550 lb. test paracord attached to each piece of equipment in each payload box, then directly to the parachute).

The kite string supports payload weight under nominal operation with a 4 point attachment system on each payload box. The paracord is attached to each object in each payload box, and does not bear weight under nominal operations.

If the kite string breaks, the paracord will support all equipment on the flight train.

Launch Safety

To mitigate risk of swinging or detached payloads during launch operations, the following will be implemented:

1. Any personnel within 100’ of the balloon location during launch operations will have hard hats.

2. Any persons within that radius without a hard hat must be either in a building or a vehicle during the inflation and release of the balloon.

3. Radio or cell phone communication will be present and tested during launch operations.

4. At least two personnel with the appropriate PPE will be present during launch operations.

5. The above conditions will remain in force until the balloon is at least 100’ from the launch location.

Demonstration Flight Schedule

At least two test flights are planned in New Mexico prior to DAG-2.

Test Flight 1 Goals: Validate the helium tow balloon concept. Onboard cameras on both the helium balloon and the solar balloon will document the release procedure.

Test Flight 2 Goals: Test new high-resolution infrasound payload on a ground launched solar balloon (if Test Flight 1 is unsuccessful) or a midair deployed solar balloon (if Test Flight 1 is successful).