A STUDY OF REFLECTED SONIC BOOMS USING AIRBORNE MEASUREMENTS

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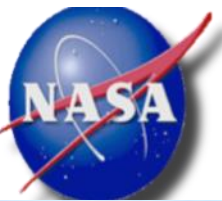*NASA Armstrong Flight Research Center*

- Background

- Research objectives

- Test architecture and execution

- Analysis and Results
  - Incident/reflected sonic boom model validation
  - Mission planning accuracy
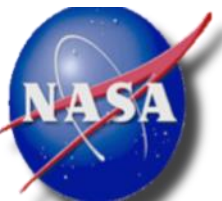
- Conclusions and future work

Aeronautics Flight Research

- Over 60 years of flight research (NACA Muroc Flight Test Unit)
- Edwards Air Force Base (EAFB)
- Remote Location
- 350 Testable Days Per Year
- Extensive Range Airspace
- Supersonic Corridor
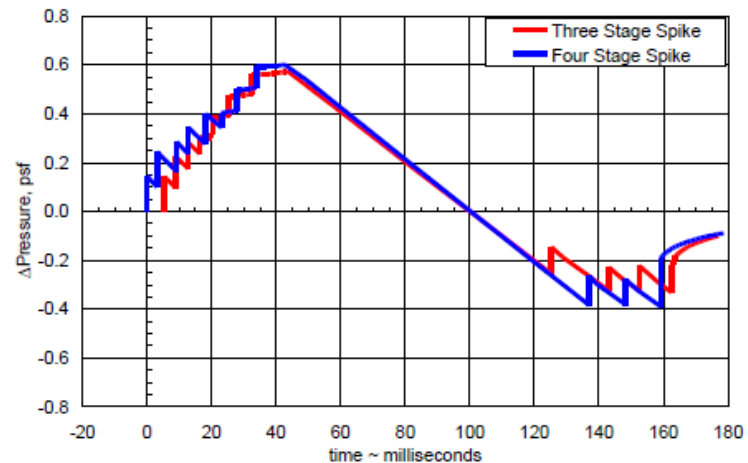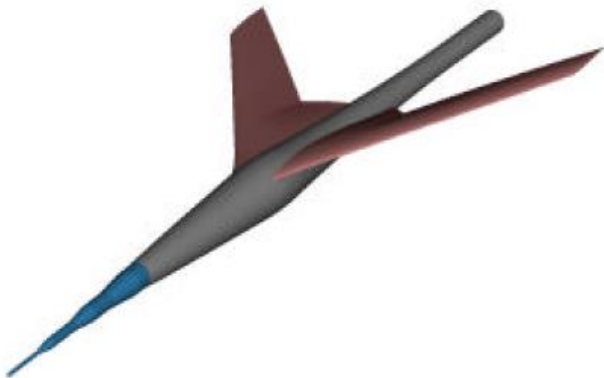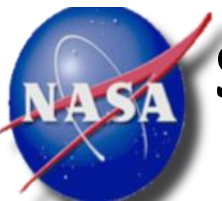
Sonic Booms in Atmospheric Turbulence (SonicBAT)

Aircraft Design

Atmospheric Effects/Propagation

Transmission into Structures

Human Response
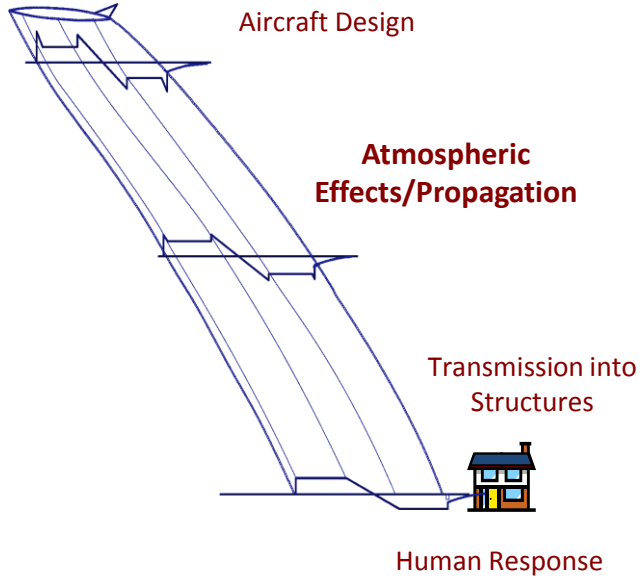
- **Need: Better understanding of sonic boom propagation**

SonicBAT Experiment Description:

The objectives of this research are to validate, via flight test measurements, models for the propagation of sonic boom signatures through atmospheric turbulence to predict the effect of turbulence on the loudness of shaped sonic booms for "low-boom" aircraft designs.

- Comprehensive dataset of sonic booms that have propagated through turbulent atmosphere at elevations anticipated by future low sonic boom aircraft to validate computer models
    - Aircraft, meteorological, acoustic data
    - Statistically significant variations can be observed

- **Ground level**
    - Instrumentation provided by NASA AFRC, Wyle, Boeing, and Gulfstream
    - Three microphone arrays
    - High-fidelity atmospheric instrumentation to measure turbulence parameters and general weather data

- **4,500 ft. to 10,000 ft. MSL**
    - Airborne Acoustic Measurement Platform (AAMP) to measure sonic boom pressure signatures just above turbulent boundary layer
    - AAMP may also measure sonic boom pressure signatures that have been reflected off of the ground, therefore heavily "turbulized" due to passing through the turbulent boundary layer twice

- SonicBAT provided an unexpected dataset :
  - For most test points the Airborne Acoustic Measurement Platform (AAMP) recorded both an **incident** and **ground-reflected** sonic boom
  - This provided the unique research opportunity to analyze the propagation of sonic booms that have been reflected off of the ground

F-18

AAMP aboard the
TG-14 motorized sailplane
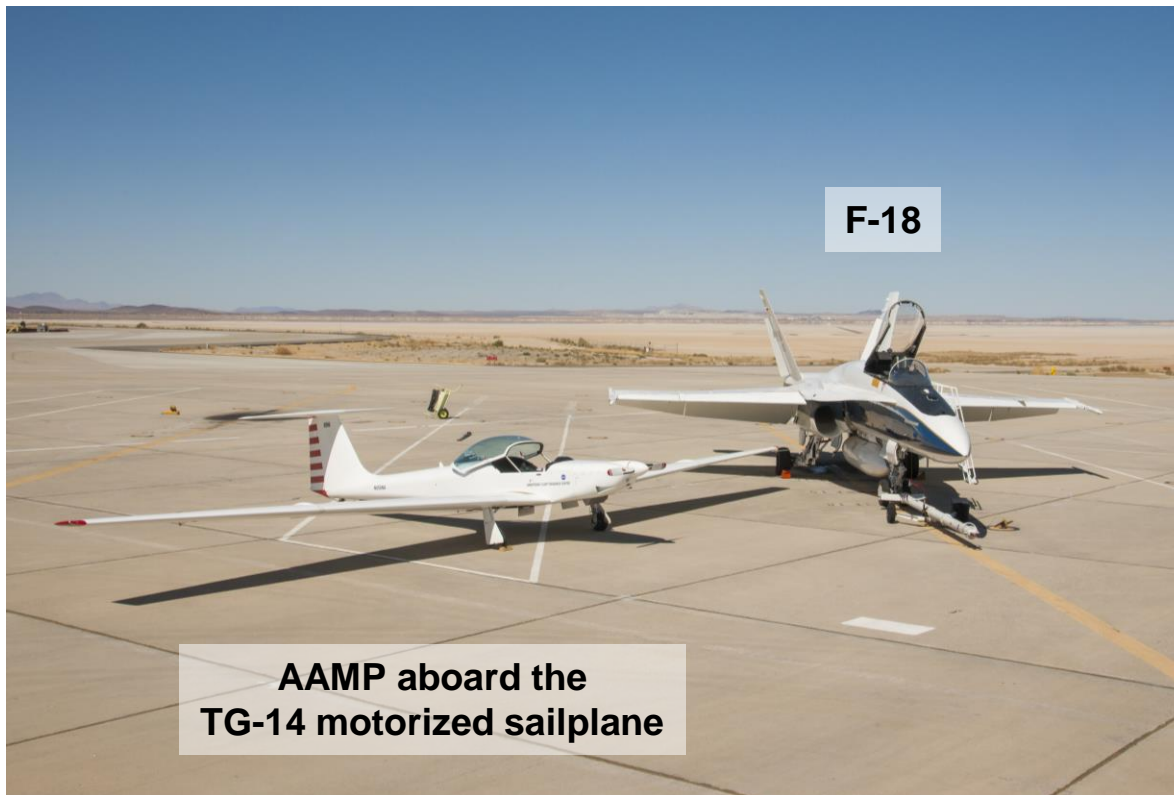
- Flight conditions
  - F-18B airplane
    - Mach 1.38 and 32,000 ft. pressure altitude
- Primary microphone array
  - 1,500 ft. linear array of 16 microphones
  - Brüel & Kjaer 4193 microphones
- Airborne Acoustic Measurement Platform (AAMP)
  - Capable of measuring sonic booms in flight
  - TG-14 motorglider
  - 4,000 – 12.500 ft. MSL
- PCBoom[1] used for initial flight planning

[1] PCBoom was developed by KBRwyle
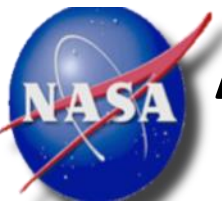
AAMP SYSTEM DESCRIPTION

- **AAMP Instrumentation Pallet**
  - Brüel & Kjaer LAN-XI Data Acquisition Unit
  - ITS 6155E IRIG-B GPS Timecode Generator
  - Tapped into ship's intercom with audio transformer
  - Ashtech Z-Xtreme GPS
  - UBI-2590 Ultra Life Battery
  - Accelerometer

- **Microphone Boom & Microphone**
  - Modified Wing-tip & Wing-tip Spacer
  - Brüel & Kjaer 4193 microphone

- **Handheld Tablet PC with LAN-XI Software**

- **Handheld Garmin GPSMap 496**

AAMP Instrumentation Pallet – Aft Baggage Compartment

Microphone & Microphone Boom – Left Wing Tip

TG-14 Motorglider

- Sonic Anemometer
  - 10m tower
  - 140ft tower
  - 3 component winds, 30 sps
  - Ct^2 and Cv^2
- SODAR
  - Model 4000 Mini-SODAR (250m)
  - 3 component winds
  - Ct^2 and Cv^2
- GPSsonde
  - One for each takeoff time to 40K ft
  - Was EAFB or local launch
- 10 ft weather tower
  - Temp., Press., Humidity, Wind Speed & Dir
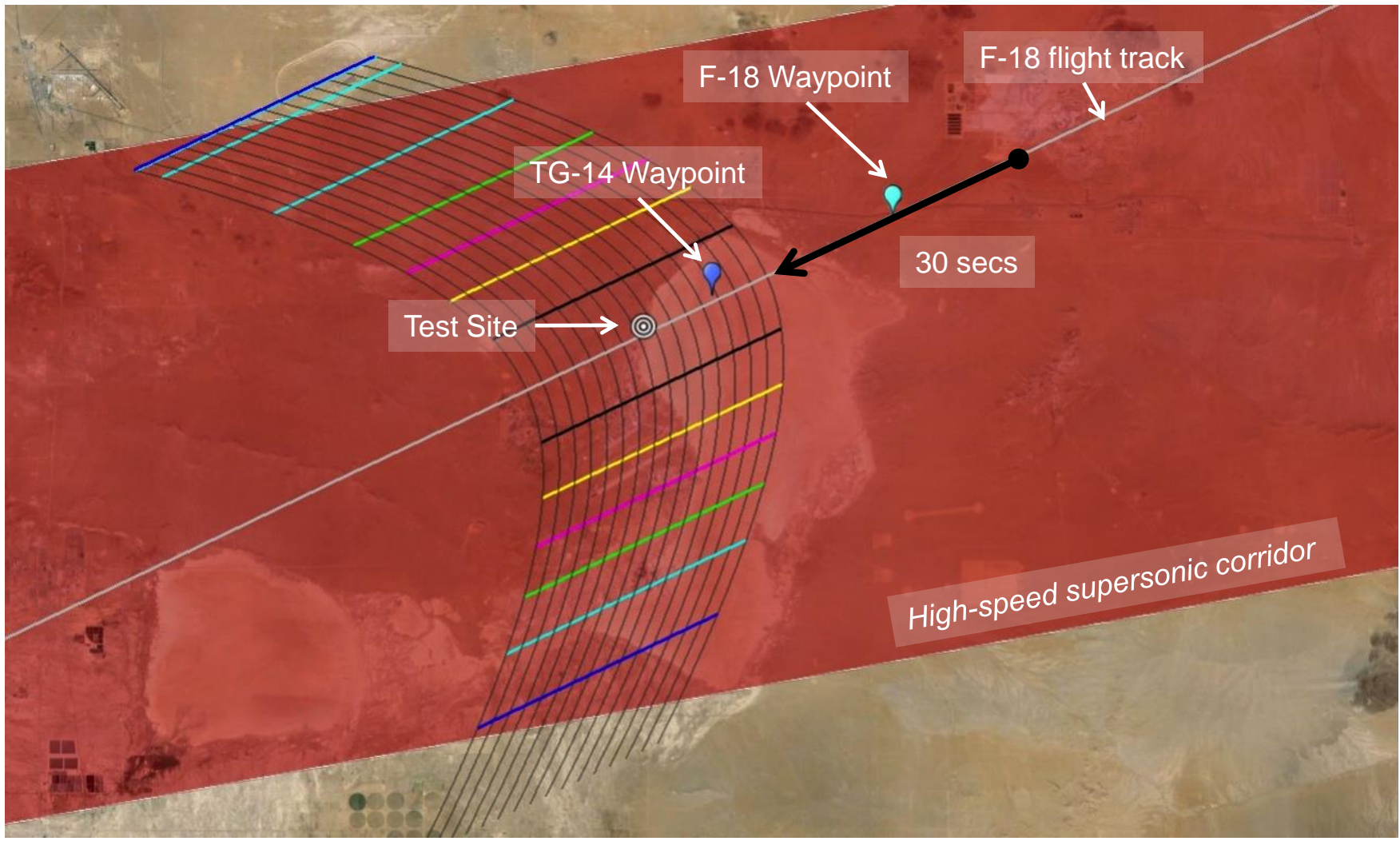

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Primary test point: On-track, 32,000 Hp, Mach 1.40, 245-deg true course

- **PCBoom** is a sonic boom propagation model developed by **KBRwyle**

- **POTRay** (Propagate Over the Top Rays) is a PCBoom module which traces ray paths in all directions and outputs raypaths and ground intercept data, including reflected booms and over the top booms.

- **FOBoom** is the Pcboom module which traces ray tubes to the ground, and outputs ground intercept and waveform data.
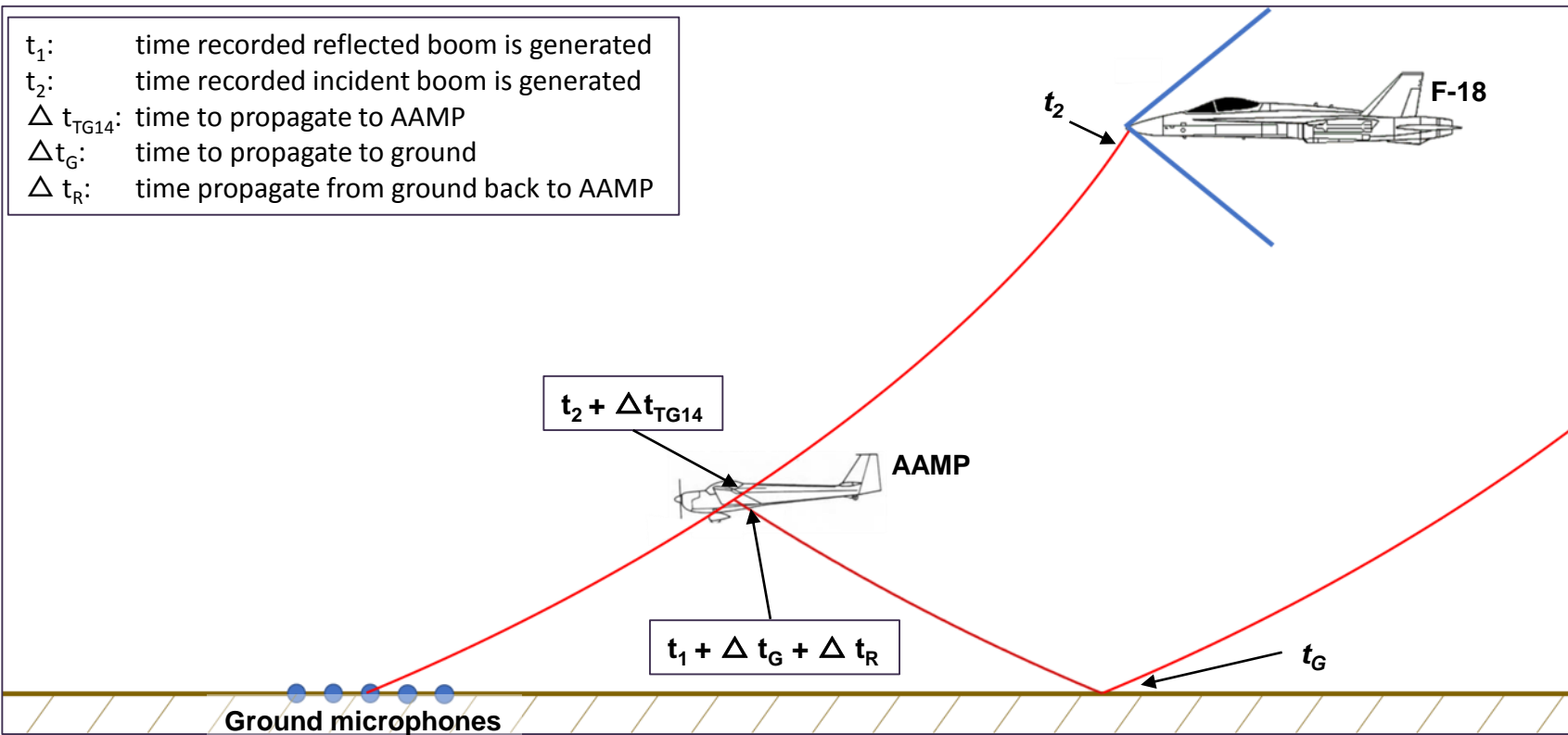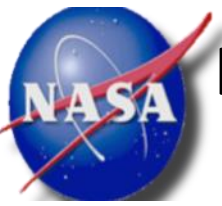
- Validate mid-field sonic boom predictions

  - Use POTRay to when an incident boom intercepted the AAMP

- Validate reflected sonic boom predictions

  - Use POTRay to predict when a reflected boom intercepted the AAMP

- Analyze the ability to record the same sonic boom ray in the mid-field and on the ground

  - Use PCBoom to predict where the ray recorded by AAMP hit the ground

- AAMP measures two N-waves:
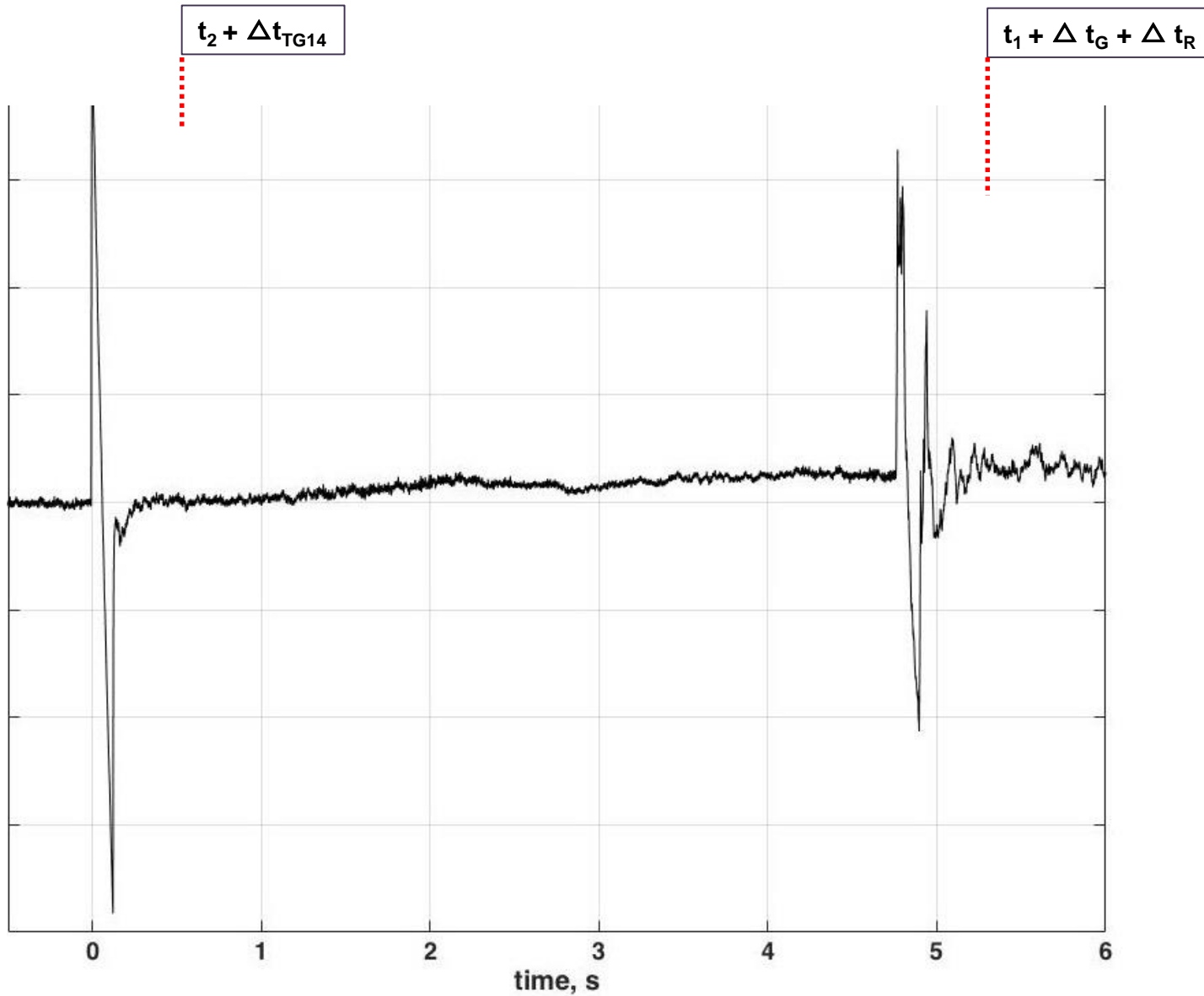
    1. Incident boom at: $t_2 + \triangle t_{TG14}$

    2. **Reflected boom generated earlier at: $t_1 + \triangle t_G + \triangle t_R$**

- Note: $t_{TG14} < (\triangle t_G + \triangle t_R)$

    - So the incident boom is recorded first, even though it is generated later (t1 > t2)

t_1:   time recorded reflected boom is generated
t_2:   time recorded incident boom is generated
$\triangle t_{TG14}$: time to propagate to AAMP
$\triangle t_G$:   time to propagate to ground
$\triangle t_R$:   time propagate from ground back to AAMP

t_2

F-18

$t_2 + \triangle t_{TG14}$

AAMP

$t_1 + \triangle t_G + \triangle t_R$

t_G

Ground microphones

$t_2 + \triangle t_{TG14}$

$t_1 + \triangle t_G + \triangle t_R$

time, s

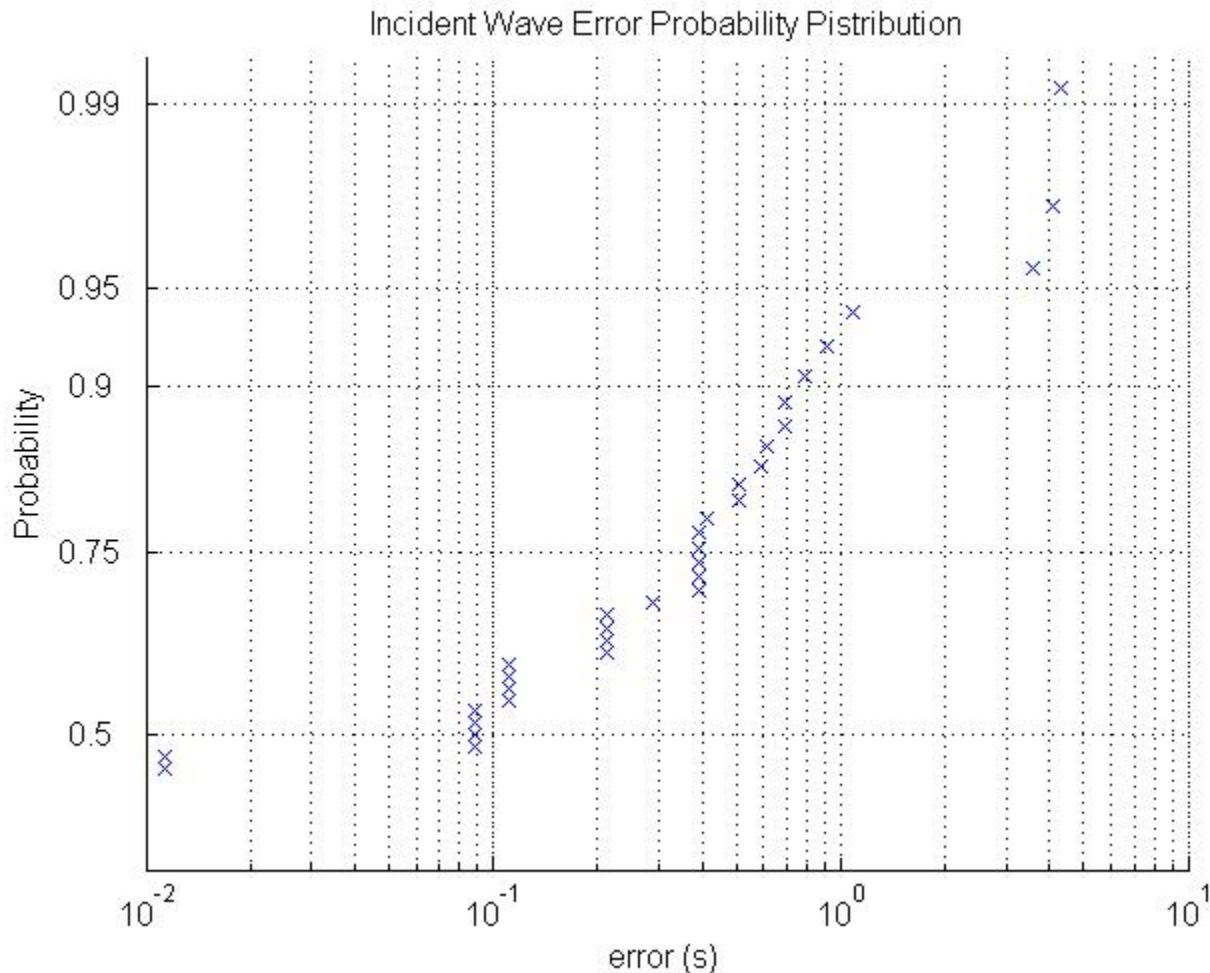# ANALYSIS AND RESULTS

Analysis methods

- Ideally we would know the complete ray from the F-18 to the TG-14

- Only the location and time the wave was intercepted is known

- The key to validating the code is the time of the intercept.

- 90% of error was under 0.7 seconds

Incident Wave Error Probability Pistribution

- 90% of error was under 4 seconds

Reflected Wave Error Probability Distribution
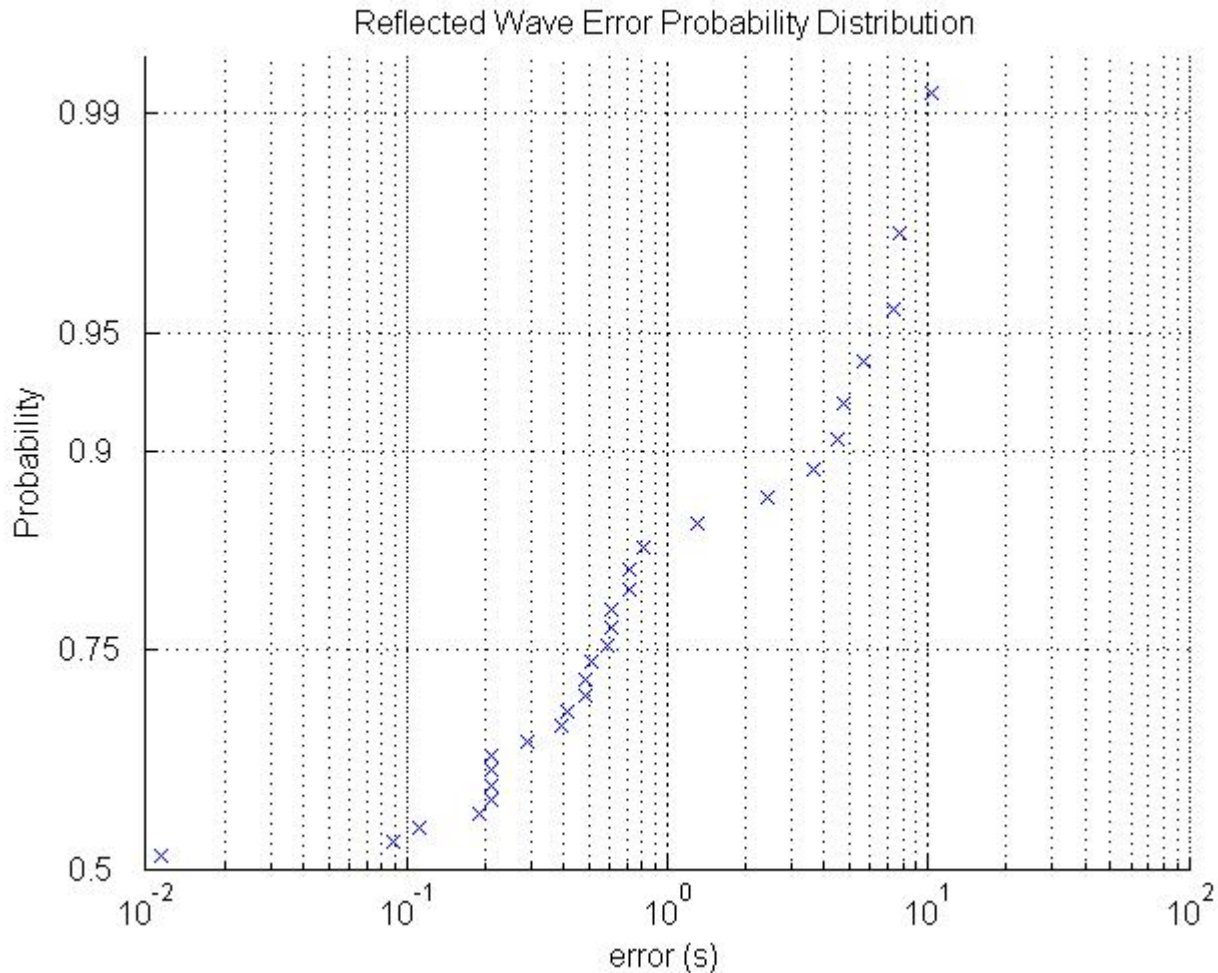
Data shows the location on the ground where the sonic boom recorded by AAMP hit the ground, compared to target/planned location (According to PCBoom predictions)
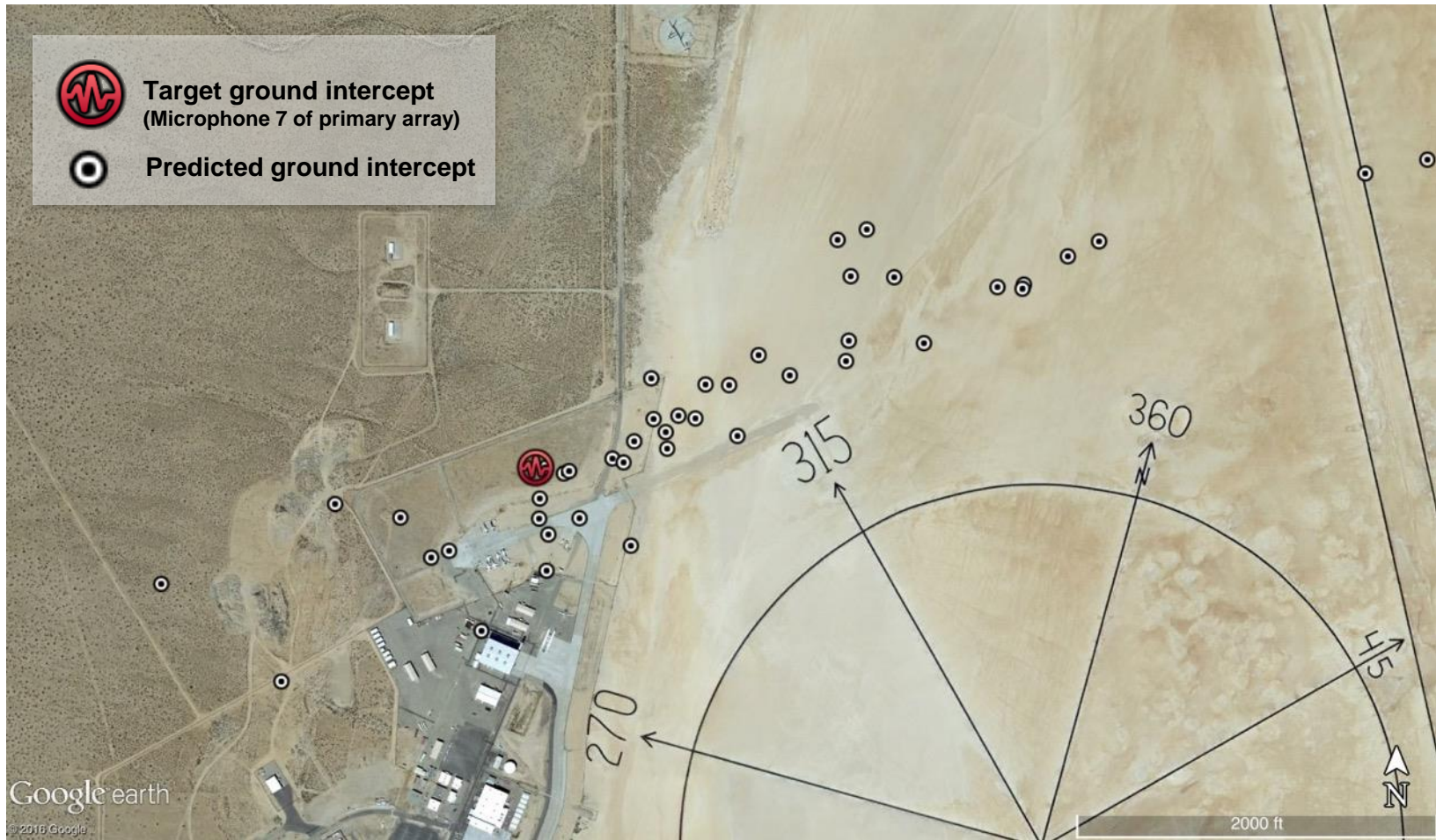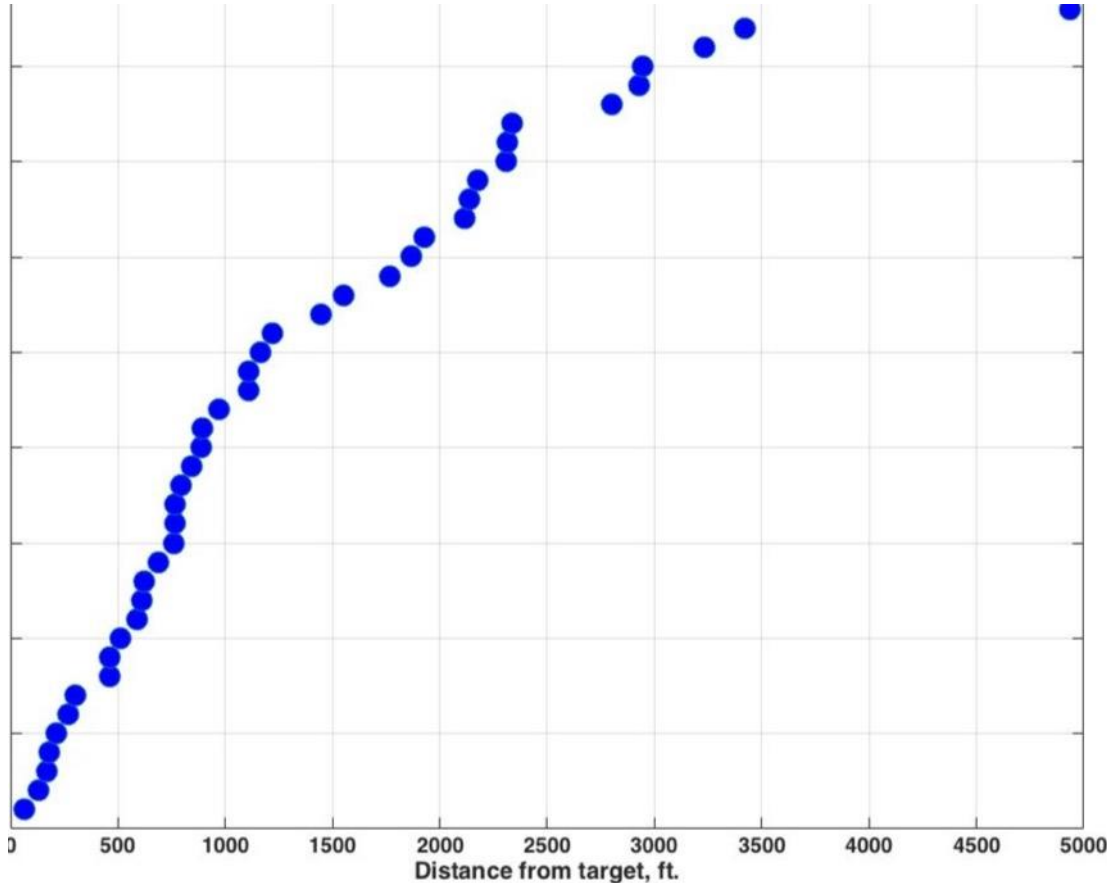
Data shows:

- **45%** of the predicted ground intercept was **within 1000 ft.** of target
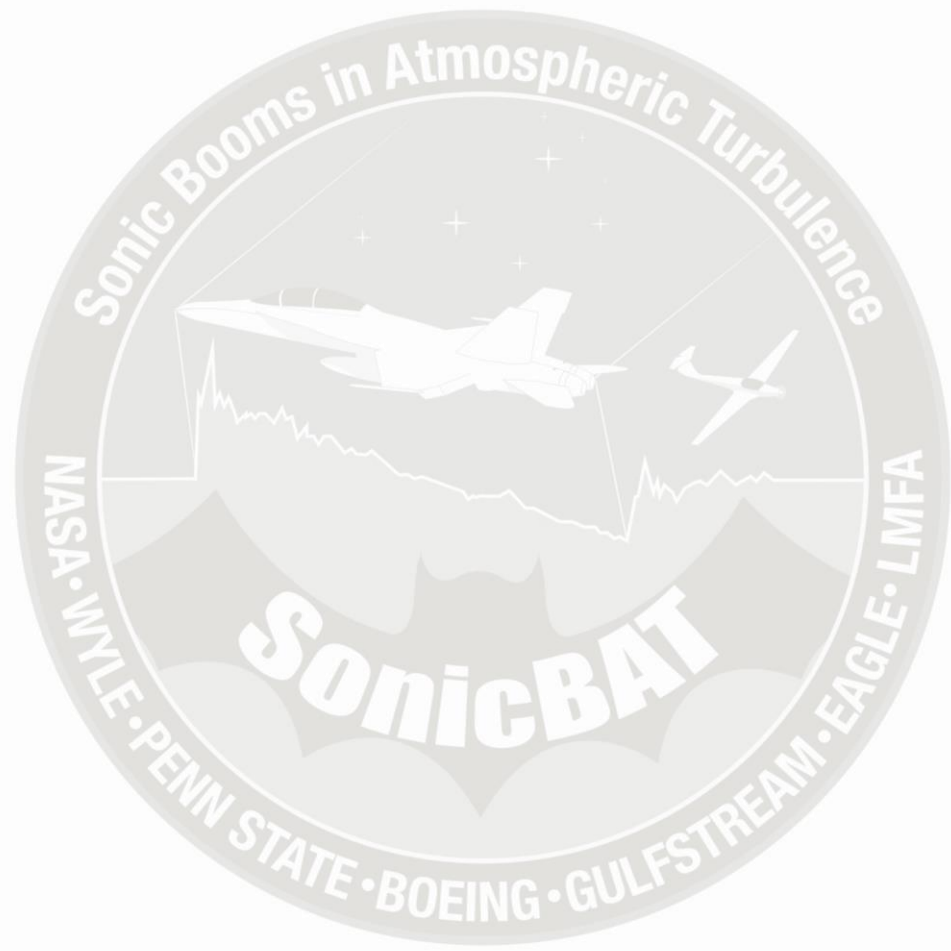- **80%** of the predicted ground intercept was **within 3000 ft.** of target
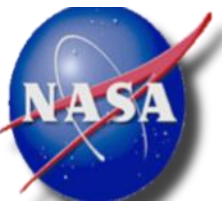

Cumulative Percentage

- POTRay provides excellent accuracy for both incident rays and reflected rays
  - Test data shows that POTRay is a validated tool to use for research in sonic boom reflection, over the top booms, and other parts of the secondary boom carpet.

- FOBoom is validated as a mission planning tool even for complex missions with multiple aircraft.

- SonicBAT II is coming to Florida this August
  - Will likely generate another database of reflected booms, this time reflected on water.

- More research can be done to quantify how much error in ground intercept is due to pilot error and how much do to error in modeling (FOBoom).

THANK YOU.