A FLIGHT RESEARCH OVERVIEW OF WSPR, A PILOT PROJECT FOR SONIC BOOM COMMUNITY RESPONSE

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Jacobs Technology

WAVEFORMS AND SONICBOOM PERCEPTION AND RESPONSE (WSPR)

PENNSTATE ARL
Noise exposure design
Statistical data analysis

Sonic boom monitors

Fidell Associates
Smartphone study

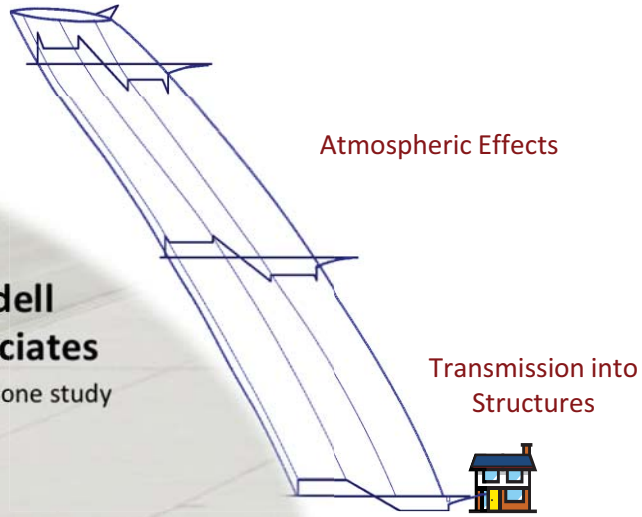
wyle laboratories
NRA leadership & integration
Sonic boom data analysis

Armstrong Langley

95th AIR BASE WING
Recruitment coordination

TETRA TECH
Subject Recruitment
Coordination with EAFB
Subjective data collection

Gulfstream
A GENERAL DYNAMICS COMPANY
Sonic boom monitors



Aeronautics Flight Research

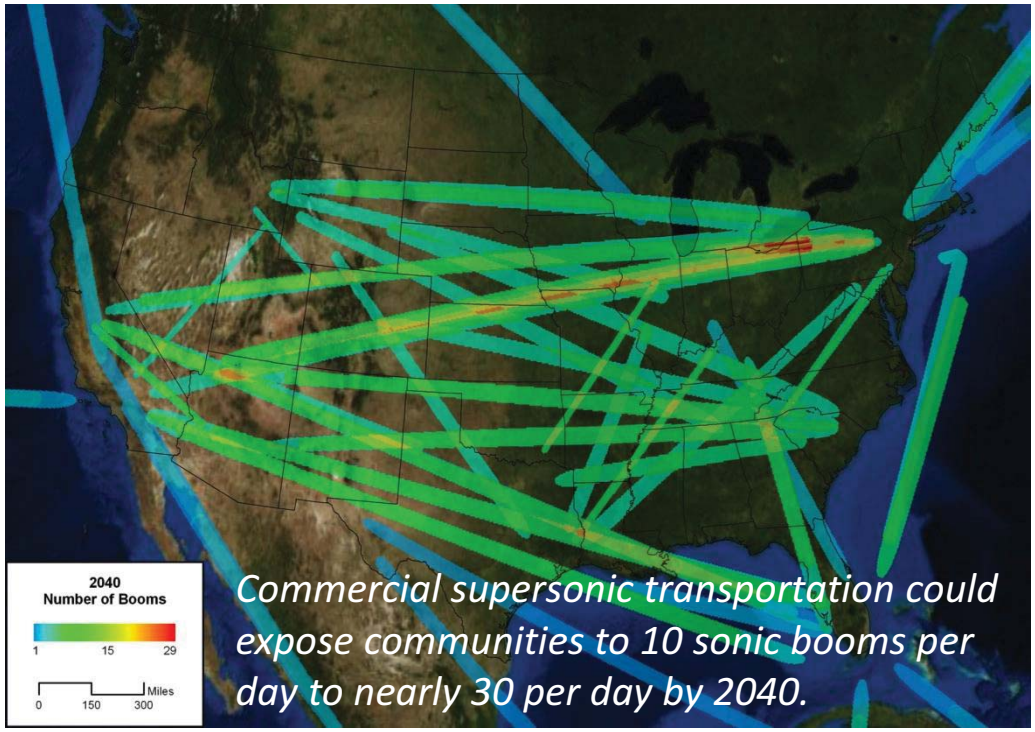
- Over 60 years of flight research (NACA Muroc Flight Test Unit)
- Edwards Air Force Base (EAFB)
- Remote Location
- Varied Topography
- 350 Testable Days Per Year
- Extensive Range Airspace
- 29,000 Ft Concrete Runways
- 68 Miles of Lakebed Runways
- Supersonic Corridor

TOPICS OF DISCUSSION

- Motivation & Objectives
- Test Preparation
- Test Execution
- Flight Operation Results
- Challenges & Lessons Learned
- Future Work

MOTIVATION

- Simulated next generation commercial sonic boom levels, 70-80 PLdB (database of human responses to over 100 booms)
- Provide data for FAA and ICAO to determine regulations and requirements for over-land sonic booms
- Low Boom Demonstrator shows the ability to meet sonic boom requirements



Commercial supersonic transportation could expose communities to 10 sonic booms per day to nearly 30 per day by 2040.

Source: Rachami, J., and Page, J., "Sonic Boom Modeling of Advanced Supersonic Business Jets in NextGen," AIAA-2010-1385, 2010.

- FAA and ICAO rule change allowing quiet supersonic flight
- US manufacturing of quiet supersonic aircraft
- Greatly reduced travel time for people and products worldwide

OBJECTIVES

- Key goal – Test and demonstrate the techniques for gathering data from an in-home low-level sonic boom community response test

- Project objectives
  - Investigating surveying methods, data acquisition and analysis methods, and human response subject recruitment strategies.
  - Expose 100+ volunteer human response subjects to a schedule of sonic booms with a C-weighted day-night average sound level (CDNL) of 42-58 dB
- Flight objectives – ***(First ever low boom community response test)***
  - Execute 20 – 25 flights over 2 weeks, up to 4 flights/day
  - Accurately place “low booms” on community. Produce sonic booms with peaks of 0.13 – 0.53 lb/ft^2
    - With the use of a of a unique, NASA-designed F-18 dive maneuver

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HUMAN RESPONSE SUBJECT SURVEYS

Armstrong Flight Research Center

Fidell Associates

PENNSTATE ARL

TETRA TECH

National Aeronautics and Space Administration

Daily Summary Response Form

A1 Date: _____/_____ (MM / DD) ID: _____

A2 Which parts of the day were you at home for at least one hour? (select all that apply)

1☐ Morning (7:00 AM to Noon)
2☐ Afternoon (Noon to 5:00 PM)
3☐ Evening (5:00 PM to 7:00 PM)
4☐ Not at home today *(end survey)*

A3 During the time you were at home today, how many sonic booms did you hear? (enter number below)

_____ # of sonic booms heard today *(If 0 booms heard today, go to A10)*

For the next questions, please think about the sonic booms you heard today while at home.

	(select one)	Not at all 0	1	2	3	4	5	6	7	8	9	Extremely 10
A4	How much did the sonic booms **bother, disturb,** or **annoy** you?	0☐	1☐	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐	10☐

A5 Which of the following categories best describes how much the sonic booms **bothered**, **disturbed**, or **annoyed** you? (select one)

1☐ Not at all
2☐ Slightly
3☐ Moderately
4☐ Very
5☐ Extremely

	(select one for each)	Not at all 0	1	2	3	4	5	6	7	8	9	Extremely 10
A6	How **loud** were the sonic booms?	0☐	1☐	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐	10☐
A7	How much did the sonic booms **interfere** with your activities?	0☐	1☐	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐	10☐

	(select one for each)	None 0	1	2	3	4	5	6	7	8	9	A great deal 10
A8	Vibration is a motion. The motion may be seen or felt. How much **vibration** from the sonic booms did you see or feel in your home today?	0☐	1☐	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐	10☐
A9	Rattle is a type of noise that can occur when objects move due to a vibration. How much **rattle** from the sonic booms did you experience in your home today?	0☐	1☐	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐	10☐

A10 During the time you were at home today, were your windows closed most of the time or were they open most of the time? (select one)

1☐ Closed most of the time
2☐ Open most of the time

A11 Did you hear any noises today that might have been sonic booms but you are not sure? (select one)

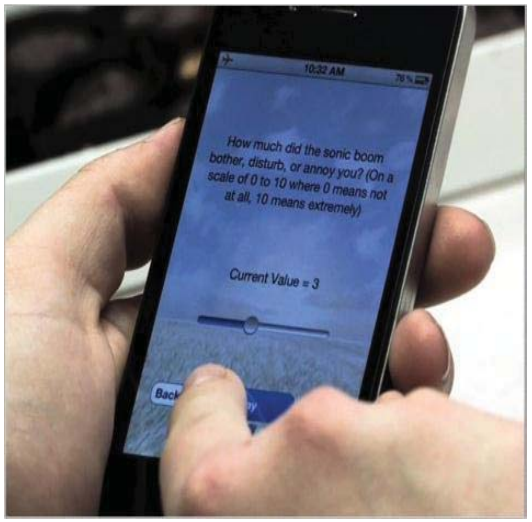
1☐ Yes ------- A12 Please describe what that noise sounded like. _____
2☐ No

A13 Please enter any additional comments.

_____

Source: Hodgdon, K. K., and Page, J. A., "Low Amplitude Sonic Boom Noise Exposure and Social Survey Design," Proceedings of Meetings on Acoustics, Vol. 19, ICA Montreal, Canada, 2013, pp. 1-6.

- Web-based surveys
  - Instruction via emails and phone calls
- Paper/Pencil surveys
  - Instructions and materials mailed via postal service
- Smartphone application surveys
  - Door-to-door installations for Apple® iOS application on subject-owned devices
  - Centralized meetings for distribution of Android™ phones with application pre-installed (to be returned after the project)

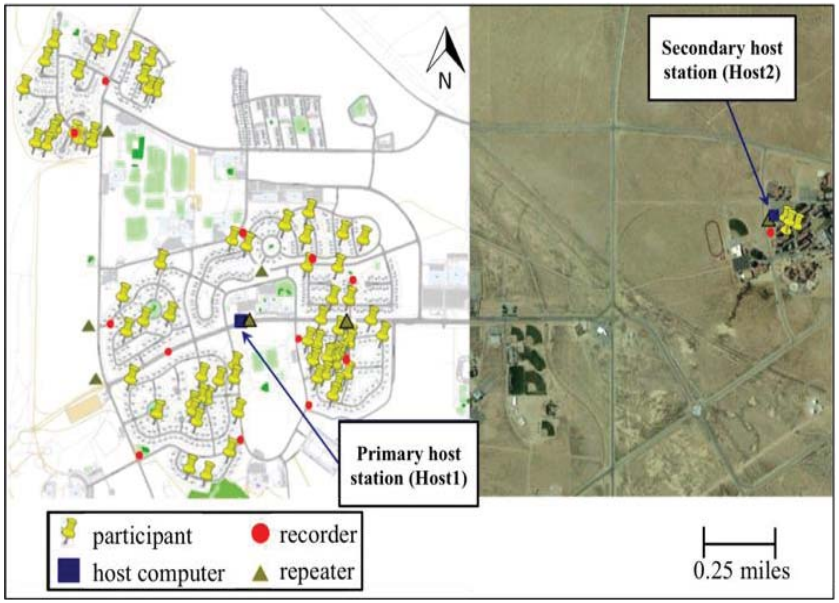


RECRUITMENT AND OUTREACH

- Military-controlled community constraints
  - High resident turnover rate
  - Approval of outreach methods
  - No door-to-door solicitation
- Knowledge of housing types
- Confident projections of occupancy and turnover rate
- EAFB allowed exclusive communication channels
  - EAFB newspaper
  - Base-wide emails
  - Facebook, Twitter, EAFB website
- Recruitment letters
  - Endorsed by NASA and EAFB
  - Could not be mailed by non-military parties

GROUND INSTRUMENTATION

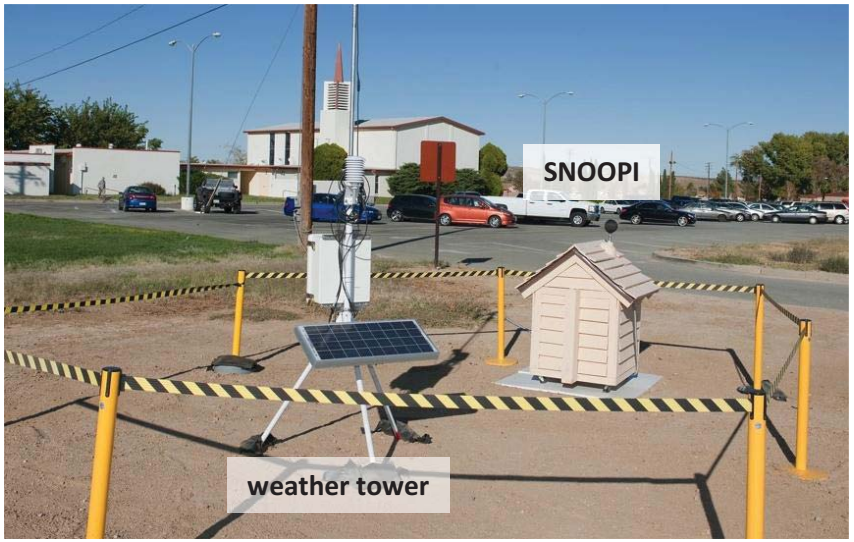
- Remote sonic boom recording
  - Sonic Boom Unattended Data Acquisition System (SBUDAS)
  - Contributed and operated by Gulfstream Aerospace Corporation (Savannah, Georgia, USA) and Pennsylvania State University (University Park, Pennsylvania, USA)
  - 13 recorders distributed throughout the community
  - GRAS Type 41AO-S2 microphones
  - Remotely triggered over a Wi-Fi network from a host station
  - Solar powered
  - Hardware concealed in National Electrical Manufacturers Association-rated (NEMA) box



Source: Cook, B., Hobbs, C. M., Page, J., and Salamone, J., "Objective Data Collection and Analysis for the Waveform and Sonic Boom Perception and Response Program (WSPR)," *Proceedings of Meetings on Acoustics*, Vol. 19, ICA Montreal, Canada, 2013, pp. 1-8.

GROUND INSTRUMENTATION, CONT.

- Autonomous sonic boom recording
  - Supersonic Notification Of Overpressure Instrumentation (SNOOPI)
  - All-weather enclosure (dog house)
  - Automatically records events greater than a preset overpressure threshold
    - Continuous ring-buffer technique
    - SenSym SCXL004DN pressure transducer: +/- 20.8 lb/ft^2 range, at 0.00304 lb/ft^2 per count resolution

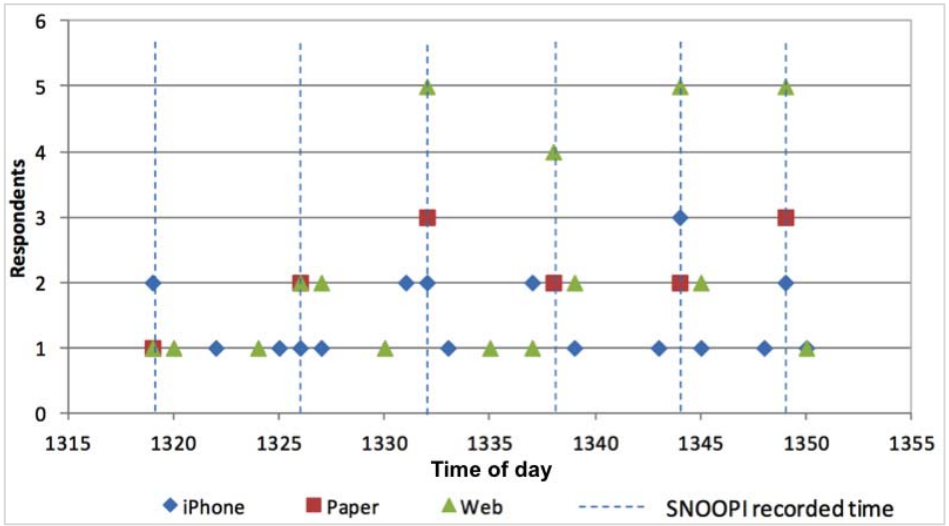


Underside of SNOOPI

- Meteorology
  - Sonic boom propagation is extremely sensitive to atmospheric conditions
  - Meteorological data was required for both pre-flight planning and post-flight analysis
    - Surface weather towers placed within the community
    - GPS radiosonde weather balloons

PRE-TEST

- Three day test to identify possible problems with survey questionnaires or data collection procedures
- 21 volunteer human response subjects from NASA Armstrong
  - Instructed to treat workspace as their home
- Six full sonic booms were generated on second day
  - Adventitious sonic booms were expected on other days
- Select lessons learned:
  - Update Apple® iOS smartphone survey to require manual entry of date & time
  - Poor connectivity can result in data transmission delays for smartphone surveys
  - More frequent follow-up telephone calls required with paper/pencil method
  - Greater latency was expected with web survey method
  - Ensure ID numbers for respondents are easy to remember (Web and Paper/pencil)



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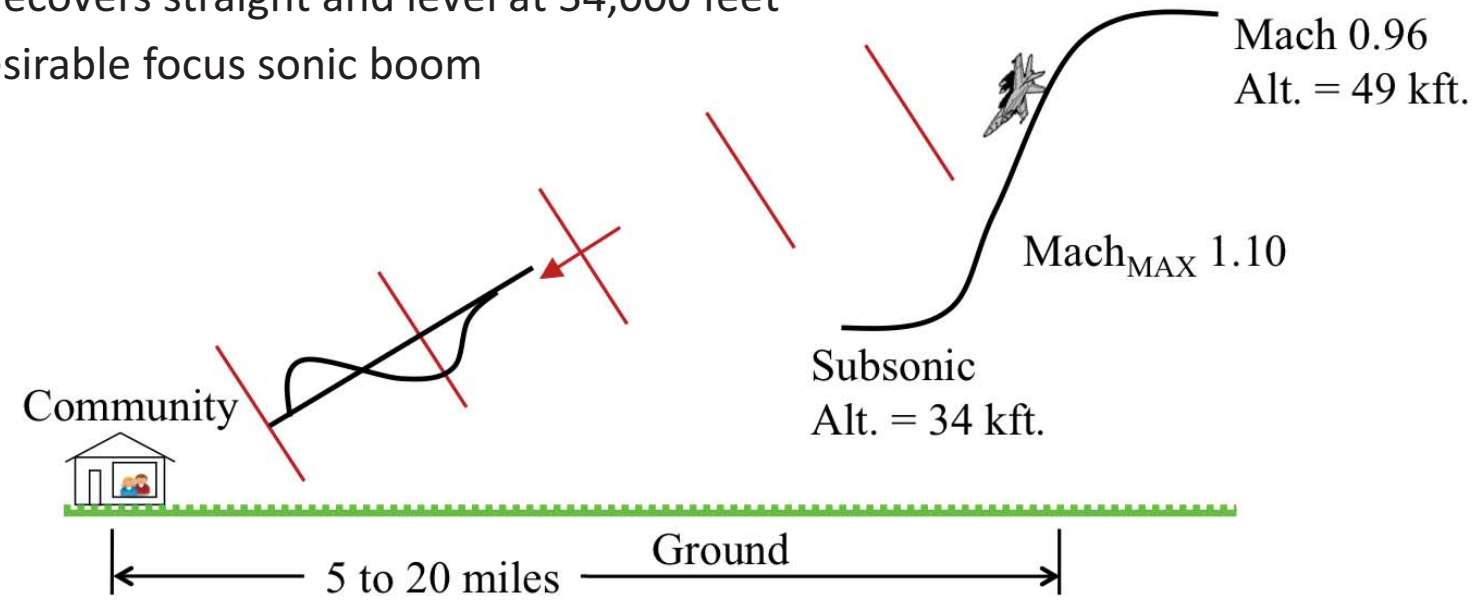
"Low Boom Dive" Maneuver

- Unique, NASA-designed maneuver to simulate the sound of future civil supersonic aircraft's sonic booms
  - Requires intricate pre-flight planning
    - Pre-flight weather data, canned F-18 trajectory, sonic boom propagation simulation software
    - Produced a waypoint (Latitude/Longitude) for the pilot to begin "low boom dive" maneuver
  - 49,000 ft. altitude, Mach 0.96. Upon reaching waypoint
    ➔ Roll to inverted, -53° flight path angle accelerated dive to Mach 1.10
    ➔ Airplane recovers straight and level at 34,000 feet
  - Produces undesirable focus sonic boom



Mission Planning & Sonic Boom Schedule

Armstrong Flight Research Center

- Sonic Boom Schedule
  - Optimized for target daily CDNL, with different level combinations
  - Four target sonic boom levels at center of community:
    - Low booms: 0.13 lb/ft^2 (low), 0.33 lb/ft^2 (medium), 0.53 lb/ft^2 (high)
    - Full sonic booms, approximately 1.2 lb/ft^2
  - Pseudo-random sonic boom spacing
  - Two aircraft/flights required for most missions
- Sonic boom placement planning
  - Sonic boom propagation software PCBoom (developed by wyle laboratories)
  - A template, "ideal" Low Boom Dive maneuver adjusted for day-of-flight upper-atmosphere conditions

WSPR Flt. 1 (Training)		
T1- AM	2L, 1M, 1F	4
Boom #	Minutes into mission	Minutes between neighboring booms
1	0	
2	8	8
3	16	8
4	24	8

Test day – Time of day

Total booms

WSPR Flt. 2		
T2- AM	4L	4
Boom #	Minutes into mission	Minutes between neighboring booms
1	0	
2	10	10
3	24	14
4	44	20

Boom levels (1 Low, 3 Medium)

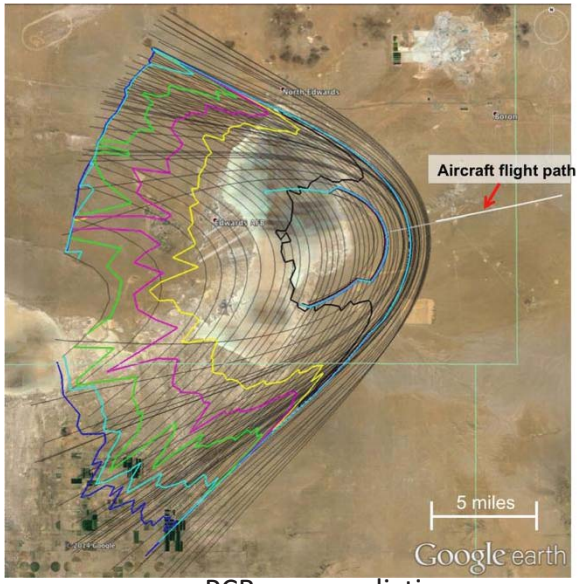
WSPR Flt. 3		
T2- PM	1L, 3M	4
Boom #	Minutes into mission	Minutes between neighboring booms
1	0	
2	12	12
3	22	10
4	42	20

WSPR Flt. 4		
T3-AM	2L, 1M, 1H	4 (Flight 1)
Boom #	Minutes into mission	Minutes between neighboring booms
1	0	
2	10	10
3	26	16
4	38	12

Flight in time-of-day sequence

WSPR Flt. 5		
T3-AM	2L, 1M, 1H	4 (Flight 2)
Boom #	Minutes into mission	Minutes between neighboring booms
1	50	
2	62	12
3	72	10
4	92	20

WSPR Flt. 6		
T3- PM	3M, 1H	4
Boom #	Minutes into mission	Minutes between neighboring booms
1	0	
2	10	10
3	26	16
4	38	12



PCBoom prediction

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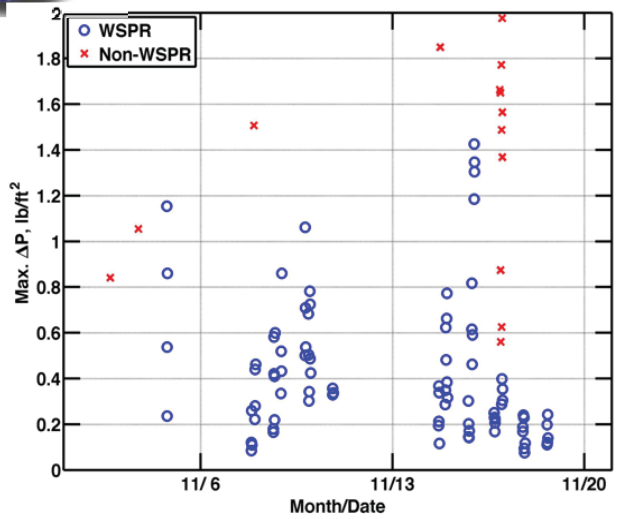
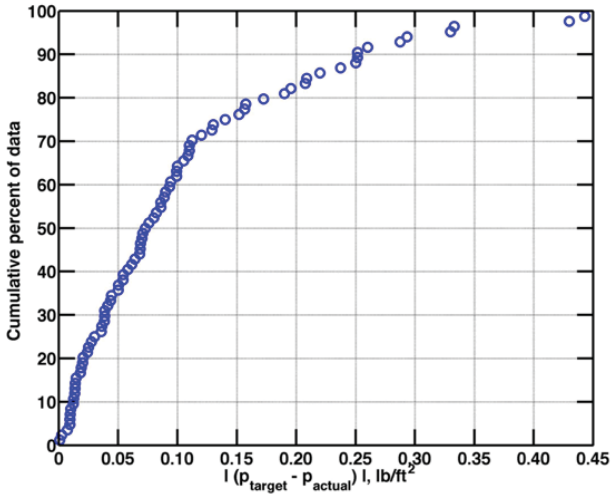
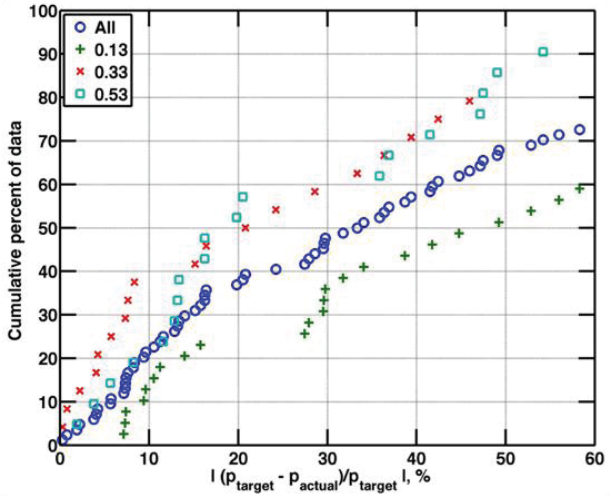
MAXIMUM OVERPRESSURES



- 89 planned sonic booms within the community
  - 84 planned low booms
    - 75 of which were actually low booms (less than 0.60 lb/ft^2)
  - 5 planned full sonic booms
- 14 additional adventitious full sonic booms

- 76% of the planned low booms were within +/- 0.15 lb/ft^2 of target
  - The lowest target attempt (0.13 lb/ft^2) was most difficult to achieve
  - 0.13 lb/ft^2 attempts were within 30% of target for only *30% of the attempts*
  - All other low boom attempts were within 30% of their targets for *60% of the attempts*

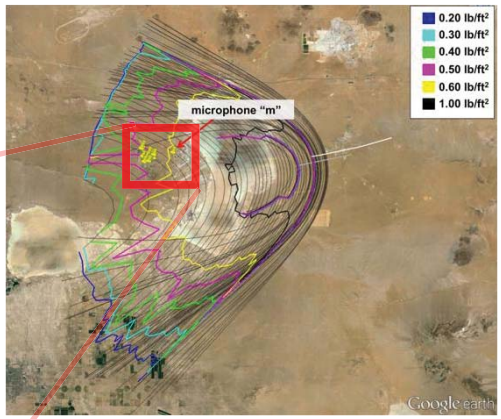


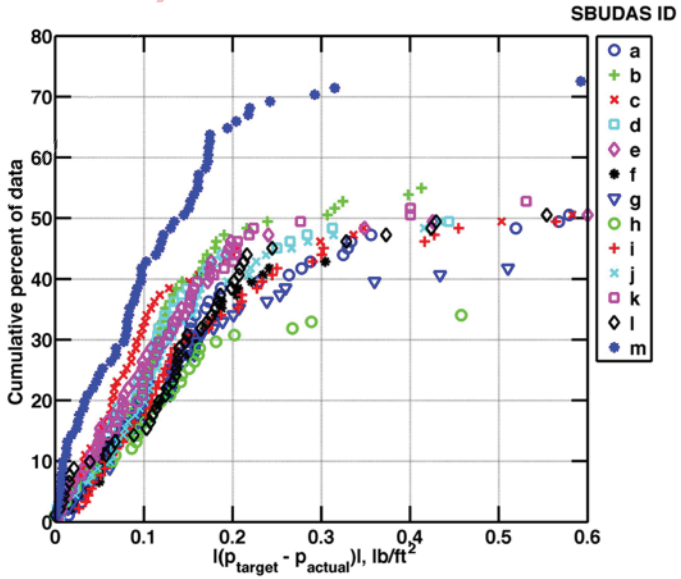


**All measurements recorded at center of community*

PCBoom versus SBUDAS

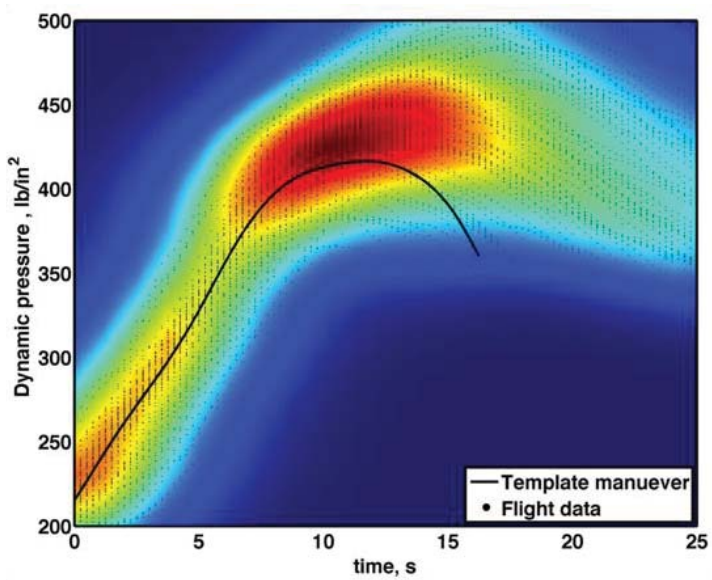
- PCBoom analysis done using real aircraft trajectory and time-of-takeoff upper atmospheric conditions
- Maximum overpressures on SBUDAS recorders within 0.15 lb/ft^2 for only approximately 35% of the low booms
- Consistent yet precision inaccuracy
- Possible reasons for poor magnitude agreement
  - Spiking and rounding due to turbulence
  - Very low overpressure levels





Low Boom Dive Repeatability

- Used extensively for previous tests – Low Boom/No Boom (2006), HouseVIBES (2007) and SonicBOBS (2010)
- Template maneuver chosen from SonicBOBS
- Heading and flight path angle were relatively consistent during test
- Dynamic pressure (Mach & pressure altitude) was much less precise and typically larger than designed
  - Yielded louder sonic booms than planned
- Possible causes for inconsistency
  - The need for a better-defined maneuver
  - Four different pilots used for WSPR
- WSPR still had overall success planning and generating low sonic booms within the residential community



Test description	Successful out of total	Success rate, %
Sonic booms successfully planned and executed	89 out of 91	98
Low booms successfully planned and executed	75 out of 83	90
Low booms within 0. 15 lb/ft^2 of planned target value	63 out of 83	76
Low boom attempts with overpressures higher than planned target values	59 out of 83	71

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CHALLENGES & LESSONS LEARNED

Recruitment

- Two-week delay (out of a 14-week recruitment effort) due to unanticipated approvals required for recruitment letters
- Failed to meet target # of subjects (76 out of 100) after initial outreach
  - $50 pre-paid debit card incentive introduced, and target was achieved

Smartphones

- Distribution/training of Android™ smartphones was tedious as it required several small meetings due to participants' varying schedules
  - Suggestion: Distribute individually, and include a tutorial video
- Due to an inadequate sign-off process, two participants received their incentives prior to returning their smartphones

Support Instrumentation

- SNOOPI had excessive false-triggers due to high winds (226 in one day)
- SBUDAS installation required unanticipated, extensive EAFB approval
- Incomplete description of SBUDAS hardware created concerns during EAFB approval process
- Installation time for SBUDAS was underestimated
- Weather balloons sometimes terminated prior to reaching the necessary altitude
  - Old data was used to fill in gaps

Mission Planning & Sonic Boom Schedule

- Confusions among civilian air traffic controllers not accustomed to supersonic aircraft
- Unanticipated need for full sonic booms to be generated
- Non-WSPR sonic booms toward the end of testing

FUTURE WORK

- Community response using low boom dives on a larger community unaccustomed to sonic booms
  - Continued methodology studies
- Community response using a large-scale shaped low-boom demonstrator vehicle on large communities
  - Data used for proposal of overland sonic boom regulations change

QUESTIONS?