Lessons Learned from Sonic Boom Flight Research Projects conducted by NASA Armstrong Flight Research Center

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2 Abstract

Over the course of four years, a team of aerospace engineers at the National Aeronautics and Space Administration Armstrong Flight Research Center completed four projects, each with the objective to research sonic boom signatures from a ground- and building-level perspective. The relatively compressed timeline of these projects resulted in the team amassing a large number of lessons learned. With each successive project, these lessons have been more relied upon and referenced. This report serves as a written record of the team's tribal knowledge capturing the relevant lessons learned and their importance for future projects.

3 Acknowledgments

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4 Nomenclature

AADC	Airborne Acoustic Data Collection
AFRC	Armstrong Flight Research Center
AGL	Above Ground Level
ATC	Air Traffic Control
B&K	Brüel & Kjær
CST	Commercial Supersonic Technology
DATR	Dryden Aeronautical Test Range
EAFB	Edwards Air Force Base
EMI	Electromagnetic Interference
FaINT	Farfield Investigation of No-boom Thresholds
FLDL	Flight Line Driver's License
ft	Feet

FTE	Flight Test Engineer
GPS	Global Positioning System
LFA	Low Frequency Adapter
LMR	Land Mobile Radio
LaRC	Langley Research Center
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NOTAM	NOtice To AirMen
PC	Personal Computer
PI	Principle Investigator
POC	Point of Contact
psf	Pounds per Square Foot
SCAMP	Superboom Caustic Analysis and Measurement Project
SonicBOBS	Sonic Booms On Big Structures
SAA	Space Act Agreement
VHF	Very High Frequency
WSPR	Waveforms and Sonicboom Perception and Response

5 Introduction

Due to the steady progression of sonic boom flight research projects over a four year period, the sonic boom team at the National Aeronautics and Space Administration (NASA) Armstrong Flight Research Center (AFRC) (Edwards Air Force Base, CA) rapidly amassed a large number of lessons learned. For the purposes of this report sonic boom tests are defined as tests conducted for the purpose of researching sonic boom signatures on a ground and building level. The aforementioned lessons learned span the entire typical project lifecycle, beginning at the planning phase and ending with data analysis and reporting phases. The most pertinent lessons learned from the four projects will be discussed within this report, including lessons concerning the pre-flight phase, methods of data collection, the flight phase, mishaps and close calls, and the post flight phase.

In order to provide context to the reader, a brief summary of each of the four projects has been included. All of the projects discussed in this report were funded by the Commercial

Supersonic Technology (CST) project within NASA's Aeronautics Research Mission Directorate. The ultimate goal of CST is to provide a comprehensive set of sonic boom human response data to the International Civil Aviation Organization and the Federal Aviation Administration. The human response data would likely be used to make an informed decision concerning the future of over-land supersonic flight. The four projects discussed in this report are steps towards acquiring the aforementioned data set. A more expansive overview of sonic boom flight research projects can be found in "Sonic Boom: Six Decades of Research" book by Domenic J. Maglieri, et al [1].

5.1 Sonic Booms on Big Structures[2]

Sonic Booms on Big Structures (SonicBOBS) was a two-phase project that took place in 2009 and 2010. The objective was to measure the structural response of buildings to sonic booms. The sonic booms were produced by an F-18, and the resulting N-waves varied in strength from 0.1 to 2.0 pounds per square foot (psf). The test was executed on Edwards Air Force Base (EAFB), California where an empty house in a neighborhood setting and two large office buildings were instrumented. The acoustic instrumentation array included recording stations internal to the structures; external instrumentation was used to provide a frame of reference. This project included NASA AFRC in collaboration with: NASA Langley Research Center (LaRC) (Hampton, VA); Gulfstream Aerospace Corporation (Gulfstream) (Savannah, GA); Japan Aerospace Exploration Agency (JAXA) (Chofu, Japan); Pennsylvania State University (State College, PA); and Purdue University (West Lafayette, IN). The project successfully recorded internal and external acoustics associated with building response to sonic booms. An example of the SonicBOBS instrumentation array is shown in Figure 1.

5.2 Superboom Caustic Analysis and Measurement Project[3]

The Superboom Caustic Analysis and Measurement Project (SCAMP) was executed in the spring of 2011. Primary objectives included assessing the focus of shaped sonic booms, developing models of focused sonic boom propagation, and validating models with the gathered focused boom data. Secondary objectives included gathering airborne acoustic measurements and recording the seismic effects of focused sonic booms. Ground acoustical data were recorded using a 10,000 foot (ft) ground instrumentation array, which consisted of eighty-one microphones spaced at 125ft intervals. An airborne array was used to help the researchers study the propagation of sonic booms through the atmosphere and included three microphones: one on a TG-14 motorglider and two affixed to a tethered blimp. Weather sensors, seismometers, and cameras supplemented the airborne and ground-based instrumentation. The project was conducted near Cuddeback Lake in San Bernardino County, California and lasted two weeks. Organizations that NASA AFRC worked with on SCAMP include: NASA LaRC; NASA Marshall Space Flight Center (Huntsville, AL); Eagle Aeronautics (Newport News, VA); Gulfstream Aerospace Corporation; Boeing (Chicago, IL); Wyle Laboratories, Incorporated (El Segundo, CA); Cessna (Wichita, KS); Northrop Grumman (Falls Church, VA); Central Washington University (Ellensburg, WA); MetroLaser Incorporated (Laguna Hills, CA); the Air Force Research Laboratory (Wright-Patterson Air Force Base, Ohio); Seismic Warning Systems (Scotts Valley, CA); and Pennsylvania State University. SCAMP successfully recorded 5,880 sonic boom events over the course of thirteen flights. A notional diagram of the SCAMP measurement site is shown in Figure 2.

5.3 Waveforms and Sonicboom Perception and Response[4]

In the fall of 2011, NASA AFRC conducted a flight research experiment to identify the methods, tools, and best practices for a future large-scale quiet sonic boom (or low boom) community human response test. This project was called Waveforms and Sonicboom Perception and Response (WSPR). A primary objective of this effort was to expose a community to the sonic boom magnitudes and occurrences that would be anticipated to occur in high-air traffic regions having a network of supersonic commercial aircraft in place, and gather human response data as a result of the exposure. Low-level sonic booms designed to simulate those produced by the next generation of commercial supersonic aircraft were generated over a residential community on EAFB, population 2,063. The sonic boom footprint was recorded with a wireless microphone array that spanned the entire community. Human response data were collected using multiple survey methods, including pen and paper, internet surveys, and survey applications installed on smartphones. The research focused on several essential elements of community response testing including subject recruitment, survey methods, instrumentation systems, flight planning and operations, and data analysis methods. Collaborating organizations included NASA LaRC; Wyle Laboratories, Incorporated; Gulfstream Aerospace Corporation; Pennsylvania State University; Tetra Tech, Incorporated (Pasadena, CA); and Fidell Associates, Incorporated (Woodland Hills, CA). During the successful test, the community was exposed to eighty-nine sonic booms, seventy-six percent of which were within an acceptable range of the target and many lessons were learned regarding survey fulfillment. The WSPR microphone and survey participant locations are shown in Figure 3.

5.4 Farfield Investigation of No-boom Thresholds[5,6]

The Farfield Investigation of No-boom Thresholds (FaINT) project took place in the fall of 2012 on the south shore of Roger's Dry Lakebed on EAFB. The intent of the project was to

investigate lateral and Mach cutoff phenomena. Primary objectives included producing and measuring wave profiles due to lateral and Mach cutoff at the ground and aloft. The ground array consisted of a primary microphone array and a secondary microphone array. The primary microphone array was a linear array consisting of sixty microphones spaced every 125 feet, spanning approximately 1.4 miles (mi). The secondary microphone array was a spiral array comprised of sixty-two microphones, approximately 2000 feet in diameter. Ground based weather instrumentation and an airborne array consisting of a TG-14 motorized glider with a wingtip mounted microphone and a tethered blimp lofting two microphones was used to supplement the primary and secondary arrays. During this project NASA AFRC collaborated with NASA LaRC; Wyle Laboratories, Incorporated; Cessna; Boeing; Gulfstream Aerospace Corporation; Dassault Aviation (Paris, France); Pennsylvania State University; and JAXA. The team successfully captured seventy-three acoustic events, thus meeting the objectives of the project; the data has been and will continue to be used to validate future analytical predictions. The FaINT Mach cutoff ground microphone arrays are shown in Figure 4.

6 Pre-Flight Phase

Detailed attention within the formulation phase on any project is critical to increasing the likelihood of success. During project formulation, a project's concepts and technologies are identified and developed, team structure is determined, and preliminary design is completed. Figure 5 shows the model life cycle of projects at NASA. The formulation phase within each project helps to establish the groundwork and scope of a project and defines the project in sufficient detail to form an initial baseline capable of meeting mission needs.

For the sonic boom flight research projects at NASA, these phases tend to differ from most projects, but their purpose and importance is still the same. Sonic boom flight research formulation anchors itself on four primary components: project planning (pre-phase A), test deployment planning (phase A), project coordination (phase B), and logistics and test scheduling (phase B).

6.1 Project Planning

The key components of project planning focus on defining clear objectives and requirements. Project planning also includes test site selection and extensive collaboration with inter-agency and industry partners.

6.1.1 Definition of Test Objectives and Requirements

The Objectives and Requirements Document should be the basis for determining and documenting all sonic boom research project requirements. An Objectives and Requirements Document defines the goals of the project, what is needed to achieve the defined goals, and how the project can show that the goals were met. While there is a well-documented process for defining NASA project requirements, there are particular lessons that have been learned concerning the application of this process to sonic boom research.

What are typically defined as requirements on other projects have been divided into two categories on sonic boom team projects: requirements and desirements. A requirement is a minimum needed capability or asset necessary to complete all of the project's objectives. A desirement is a wanted/desired capability or asset that will, in some way, improve the research. Note that if a desirement is not fulfilled, all project objectives can still be met without such capability. The distinction between a requirement and a desirement has allowed for the planning

of higher-fidelity projects while maintaining focus on stakeholder expectations. In project planning documentation, shall and should statements are used to differentiate between requirements and desirements, respectively. For example, the only microphone requirement for the FaINT project was a 40 microphone linear array on the ground. However, by establishing desirements, the project fielded over 120 microphones total, including an airborne microphone and a 3,000ft vertical array. A secondary benefit of defining desirements in addition to requirements, and a lesson learned, is that sometimes it is advantageous for a project to establish a desirement based on a possible requirement for a future project, especially if the resource has a long lead time. Doing this helps to assure that those assets are available at the later date because experience has shown that the need for new resources does not get enough attention until a project requires (or strongly desires) it. The key lesson is that the team can help ensure that critical assets are given the adequate attention and consideration by incorporating the need for these assets into requirements and desirements early in the project. For example, sonic boom flight research depends on accurate knowledge of an airplane's position. Often many of the Global Positioning System (GPS) recorders used for recent sonic boom team projects had utilized obsolete technology with data storage capacities that are small by today's standards. As the recorders continued to meet the minimum requirements for providing positional data, upgrading to a more modern system was continuously deprioritized. Deprioritizing the GPS upgrade has resulted in several instances where data was corrupted, or data was inadvertently overwritten. A new GPS system would require long procurement times and extensive verification and validation. Had any of these projects identified a new GPS system as a current desirement or future requirement, there would have been a greater likelihood of having one in place for later efforts.

Similarly, lessons learned have shown that fully understanding the distinction between a desirement and a requirement and the severity of each requirement is vital. For example, when planning SCAMP, the project did not realize how important it was to have a display in the rear cockpit seat of the boom producing airplane to display the first time derivative of both flight path angle and Mach number. At first the display was considered a desirement, however, further into the project planning it became obvious that it was a crucial requirement needed to meet project objectives, and one that would take a lot of time and resources to develop. The development of this display ultimately delayed the entire project schedule.

Another important lesson learned is for the project to not only establish requirements early, but to avoid scope creep by closely critiquing all revisions and additions to existing requirements. Such critique is important for all requirements, but is particularly important for airplane test point requirements. Sonic boom research requires a comprehensive airplane waypoint planning process, typically utilizing computer code written specifically for the project.[7] If an additional test point requirement is added after the waypoint planning procedure has been designed, it is time and resource intensive to make the necessary changes to the computer code and procedures. For instance, during WSPR the initial test point requirements consisted of only low boom dives after the first day,[8] but in the middle of the flight phase, a need arose for straight-and-level test points. The shift in requirements from low boom dives to straight-and-level passes caused a last minute computer code re-write that could have caused project delays. Fortunately, in this case, reworking similar pre-flight planning code from previous projects prevented such delays.

Previous sonic boom flight research has also shown that setting a realistic schedule early in the planning phase should be a requirement, especially when external industry partners are

involved. While a vast majority of aerospace projects identify a test date with the understanding that delays could push the date back, this is less acceptable with any project that involves partners and/or test site coordination; such is the case for sonic boom research-focused projects. A requirement must be made to set a test date as early as possible in the planning phase of the project. While projects may be wary of date driven deadlines, setting a test date allows the project to make arrangements with partners and coordinate assets, and thus is paramount to the project's success.

6.1.2 Test Site Selection

The emphasis of sonic boom flight research projects is not limited to the airplane and flight operations, as nominally the objective is ground-operation centric, often focusing on recording sonic booms on the ground and/or structural building response to sonic booms. Thus, a large part of project planning is choosing a test site. In general, test sites shall have the airspace restrictions that allow the required airplane maneuvers (such as supersonic flight over land) while providing adequate terrain and area on the ground to deploy any required instrumentation. Test sites must also to be accessible to the project team and located such that acoustic disturbances are minimized. The result of all of the aforementioned test site requirements is that the test site is often located in a remote location.

Some lessons learned for the pre-flight phase test site selection process include going to each prospective test location to identify potential sources of extra noise and determining if there is a way to mitigate such noises. Ideally, a test site would be completely silent, however no such site exists. "The quieter the better" is the simple rule of thumb. For example, the 2006 NASA Low Boom/No Boom project required a very silent test site because the sonic booms being produced were generated by low boom dives[7] and Mach cutoff conditions[9], both predicted to

produce sonic booms quieter than 0.50 psf. Unfortunately, several test points were negatively affected by the noise generated by unexpected, non-project related aircraft in the area. The negative impact on the acoustic data might have been avoided with a more prudent test site selection or by pre-coordinating with other aircraft operations in the vicinity.

Other previous sonic boom flight research projects have encountered test site noises produced by flagpoles with lanyards that slapped in the wind, nearby street traffic, occupants in nearby buildings, and systems with audible machinery such water fountains and air conditioners. Other noise sources that have been encountered are wildlife deterrent speakers that play the calls of various birds of prey to ward off nuisance animals. After visiting a potential test site it is wise to discuss the possibility of reducing extraneous noise with the site owner. Past interactions have taught the team that people are often willing to make such accommodations.

Other topics to consider when selecting a test site include the presence and use of irrigation systems and restrictions concerning equipment installation. For outdoor test sites, project-required equipment is often staked in place, but some landowners and jurisdictions require permits for stakes of a certain length. For example, digging and staking deeper than 11 inches below the ground surface on EAFB property requires a permit and approval from the environmental department.

For test sites involving structural response data, similar concerns apply. Additional considerations include determining what doors and windows can be propped open to allow instrumentation cable routing, checking to see if loud appliances can be turned off before testing, and making sure there are accessible electrical outlets.

Accessibility is an issue as well. When selecting a test site, the project should be aware of any potential obstacles or hazards that might be encountered when traveling to the site. FaINT, in

addition to the primary test site, had six potential remote test sites, called sentinel locations, which would each accommodate single microphones. Two of the remote sites proved to be too difficult to access without a high chance of a vehicle getting stuck in deep sand. Therefore, any project should make sure that there are multiple routes to and from the test site and consider the implications of transporting heavy equipment to the site.

As there are many concerns when selecting a test site, projects should be advised that site visits are critical to mission success and that one site visit is not sufficient. Thus, when selecting a test site, projects should visit prospective test sites at least twice, preferably during the predicted testing hours; upon site selection, more visits should be conducted to determine if any changes have taken place. Ultimately, the lessons learned regarding test site selection can be summed up as follows: (1) selection of the test site must be meticulously thought out, and (2) multiple visits to the test site reduce the number of acoustical and logistical unknowns.

6.1.3 Collaborating with Partners

NASA sonic boom flight research projects typically involve a number of partners. SCAMP and FaINT were two of the most recent highly collaborative projects, with both projects including at least six partners. Partnering with outside organizations and communities is facilitated and governed by Space Act Agreements (SAAs). While SAAs allow NASA to enter into partnerships with organizations that give NASA access to a wider range of technologies and capabilities that are not part of NASA's core competency, it does take time to set up such legal agreements up. Early sonic boom flight research projects, predating SonicBOBS, created partnerships through invited contributions, in which partners are involved in projects through voluntary participation; such arrangements are still used by the sonic boom team on a project-by-project basis. In these instances any assets from partners cannot be mission critical or a

requirement. Such assets are the responsibility of the owner and enhance the project and data set collected. Note that if data is to be exchanged as a part of the agreement then a formal agreement – such as an SAA – must be established as early as possible to ensure that no misunderstandings result in schedule delays to the project.

Because partnership is usually done on a voluntary basis, there are no contractual deadlines for the partners to meet. A lack of such deadlines can result in difficulty identifying which partners will be participating, and what assets (both in terms of workforce and equipment) they will be providing. This uncertainty makes planning projects problematic. For example, without knowing how many microphones the project can expect from partners, it is not possible to finalize a microphone array design. Therefore, future projects should implement a hard deadline for potential partners to decide if they will be participating, and a similar deadline for identifying what assets they will contribute; both of these deadlines should be determined early in the planning phase, noted in project documentation, and communicated to prospective partners accordingly.

It is important to define the expectations of each organization participating in the test. Setting such expectations is especially important regarding partners of whose influence and authority is a requirement. For example during WSPR, an unforeseen challenge was getting the human response subject solicitation letters officially endorsed by NASA. EAFB would only allow the letters to be distributed if NASA AFRC endorsed them. However AFRC would not endorse such a letter without approval from the highest levels at EAFB. The project saw a two-week delay as it coordinated approval between AFRC management and the EAFB Installation Commander due to a lack of documentation outlining each stakeholder's understanding and expectations of the project. Similar future tests should establish approval and agreements

between partners early in the project, document all stakeholder expectations, and communicate such expectations to all remaining stakeholders.

For sonic boom human response research, a major partnership is with the human response subjects themselves. The public's participation as test subjects is a requirement, and therefore an established partnership is vital. There are two lessons learned from the WSPR project regarding partnership with human subjects: the first is that recruitment of volunteers requires a significant amount of time, effort, and incentive; the second is that continued contribution throughout the test by the volunteers is not guaranteed and providing the incentive at the end of the test mitigates volunteer dropout. During the early stages of recruitment and outreach planning for WSPR, it was thought that incentives would not be needed to attract human response subjects due to the great working partnership with and interest from the EAFB community. While there was strong interest within the community after the initial outreach actions, the project failed to meet its target of 100 human response subjects by about 30%. The target of 100 subjects was out of approximately 650 households on EAFB, and thus the determination was made to offer $50 pre-paid debit cards as an incentive for all human response subjects who participated through the end of the test – regardless of when they initially signed up. It should be noted that an incentive had to be offered to each participant as opposed to a raffle-like system because a raffle would be perceived as gambling on a military base. Six weeks before testing, a second phase of electronic outreach and another newspaper post were distributed to reflect the incentive. The incentive received great response and the project easily recruited the remaining required volunteers. The volunteers received their incentive at the conclusion of the test. To avoid possible legal complications, the incentives were funded through the project's primary contractor.

6.2 Test Deployment Planning

Sonic boom flight research nominally puts most of its emphasis on personnel, instrumentation, and equipment on the ground. The ground assets are required to measure the sonic booms produced by the airplane, and are therefore vital to the project's success. Due to the unique requirements concerning the ground assets, project teams often deployed to a remote test site. For NASA's sonic boom flight research projects a remote deployment is generally considered to be any ground test site outside of Edwards Air Force Base. A test located on EAFB but not near NASA AFRC is considered a local deployment due to the complexities that are added to the project concerning transportation of personnel and equipment, as well as the need to coordinate basic amenities for the field crew. Concerning any type of deployment, some of the aspects that have garnered the most lessons learned involve understanding the reasons for test deployment, the financial impact of test deployment, and the complexity a deployment adds to a project.

6.2.1 Reasons for Test Deployment

Some of the rationale for utilizing a deployed test location for a sonic boom flight research project include avoiding local noise sources, having enough area to fit the desired instrumentation arrays, and avoiding placing booms on populated regions. Most NASA AFRC involved sonic boom flight research efforts have been fortunate that EAFB has enough real estate to accommodate a variety of instrumentation array designs. While EAFB has various extraneous noise sources, it is typically not enough of an issue to cause the test site to be relocated off-base. Additionally, EAFB is expansive enough to allow the test site to be located away from major noise sources while still accommodating large instrumentation arrays. In instances where the test site is located on a remote section of EAFB the project considers this as a local deployment due to the added complexity of setting up a functioning test site away from the usual amenities.

SCAMP was one of the few sonic boom flight research projects in the last 20 years to be remotely deployed, near Cuddeback Dry Lake, CA. SCAMP was originally planned to be a local deployment test, but early analysis revealed that the project would be expecting sonic booms with levels above 12 psf over a large portion of the sonic boom footprint, which is exceptionally loud. Sonic booms at such levels can be harmful to human hearing and the sonic boom carpet was too large and unpredictable to consistently keep away from populated areas, thus the remote deployment.

Referring back to site selection (Section 6.1.2) as it pertains to the above discussion, the lesson learned is that it is just as important to understand why proposed test site location can't be selected as to why a test site can be selected. Such an understanding will help clarify to all stakeholders why the project must work with the added cost and complexity if the project is to be successful.

6.2.2 Cost Impact and Added Project Complexity

The remote deployment of a project has a significant cost impact on the project. For SCAMP, the major additional costs included truck operations to transport equipment, personnel lodging, meals and incidental expenses, as well as security guards. Security was required because SCAMP was located on a publically accessible site over 11 miles from the nearest well-traveled road which caused equipment integrity concerns. Therefore, the project employed 24-hour security personnel. These major expenses accounted for a significant percentage of the total flight operations budget.

A remote deployment also adds other considerations that would not be necessary for a test site located on EAFB, near NASA AFRC. These considerations significantly increase the amount of planning and coordination required. For a test deployment – local or remote – the

project must plan on how to get any equipment to the test site. SCAMP required the transport of an 80-microphone array, including miles of cabling, electrical components, and data acquisition systems. Transportation of equipment may not be trivial, for example, one of the flatbed trailers transporting equipment got stuck in the sand while heading to the off-road site at Cuddeback Dry Lake. In addition to ground equipment, a remote deployment may be located such that it is not possible to use the Dryden Aeronautical Test Range (DATR) for flight operations, or it may be impractical to use Armstrong's aircraft maintenance facilities. If that were the case, such capabilities would need to be identified and acquired at a test deployment site.

Other complexities due to test deployment might include the need for amenities such as portable toilets, plenty of drinking water for the field crew, automobile jumper cables, shelter and eating areas for the crew, a way to charge batteries, etc. There should be more than one option for restroom facilities. During FaINT the project depended on the bathroom inside of a small trailer generally used for flight support. When this bathroom became inoperable after only a couple of days of testing, an emergency order was placed to get portable toilets to the test site. Fortunately, the FaINT test site was still on EAFB and relatively close to main base. Had FaINT been a remote deployment, or more remotely located on EAFB, the lack of restroom facilities would have proven to be dire. Adequate water and crew rest are also critical for the field crew, and need to be accounted for. In all deployments, remote and local, AFRC purchases a large quantity of water for the field crew. Crew rest is complicated by the long travel time usually associated with deployed test sites and by the fact that equipment batteries usually need to be charged in another location, lengthening the duty day.

The lesson learned is that the complexity of basic logistics – transporting equipment and essential amenities, for example – dramatically increases as a function of how remote the test site

is and whether or not access to the test site is limited. A remote or publically accessible test site requires the project to look at all logistics with a greater amount of scrutiny.

6.3 Project Coordination

Due to the sheer amount of work involved in coordinating a large test, it is necessary to assign each team member a coordination task – or set of tasks – to spearhead. A key lesson learned is that it is critical that the team make time to sit down and work out a plan of action for each part of the test – from the receipt and set-up of test equipment to tear down and equipment return shipping. Taking the time to work out such a plan allows the team to present a unified front throughout each phase of the test. Creating a plan of action requires a discussion of each person's roles and responsibilities, and greatly reduces the likelihood that a task will be overlooked. Such a discussion eliminates confusion as to who is the Point of Contact (POC) for various coordination tasks, thus minimizing potential confusion with coordinating organizations. Furthermore, working through the process of creating a plan of action will force the team to look at the big picture of the project, which is essential to identifying any requirements for additional workforce and/or the need for skill sets not found within the core team. Once the need for resources external to the team has been identified, it is critical to communicate these needs and coordinate the additional equipment and staffing as soon as possible, as freeing up such resources is rarely a quick and simple task.

During the coordination effort, the project must begin interacting with the aircrew, with added emphasis on discussions regarding flight profiles. During the FaINT practice flights there was confusion from the aircrew as to what they were being asked to do and when the waypoints were going to be communicated to them. This lead to a lengthy practice flight brief and a several questions from management during the technical brief concerning flight planning and flight

profiles. The lesson learned here is that coordination with the aircrew is crucial during project planning, especially for a uniform understanding of the mission profile and daily schedule; such interaction and subsequent buy-in from the aircrew will present a united front to management during practice flights, technical briefs, and other project reviews.

6.3.1 Coordinating with Government Entities

All of the aforementioned tests, with the exception of SCAMP, occurred on EAFB, but it should be noted that many of these lessons are relevant to coordination with other military bases and government agencies.

In working with external organizations, one of the biggest lessons learned is that reducing the required direct oversight from external organizations during the test window is highly desirable. Mitigation of these logistics requires extra effort in the coordination phase but significantly eases the workload on the field crew during the test phase. For example, working on Rogers Dry Lakebed, EAFB requires a great amount of oversight from both EAFB's Tower and Airfield Management. However, working closely with these organizations well ahead of the test window has historically allowed the field crew the freedom to request the tower to activate the test area for an entire day, rather than call the tower each time a person or a vehicle entered or exited Roger's Dry Lakebed.

While the lessons discussed in this section and section 6.3 are valuable and applicable to all coordination with government organizations, there are five general groups that will need to be involved in the coordination and execution of most tests that involve government assets. These organizations are Environmental, Air Traffic Control, Airfield Management, Frequency Management, and Security.

6.3.1.1 Environmental

Site selection of primary and backup test locations should be completed as early as possible, as an environmental survey is required prior to the use of any government land for testing purposes. This survey often requires considerable time due to the heavy workload of these environmental organizations, the paperwork required to start the process, and the implications that it may place on the test. For example, during FaINT, the team learned through the environmental survey that if spray paint was used to mark microphone locations, the paint either needed to be biodegradable or cleaned up and treated as hazardous waste at the completion of the test. Luckily, the team discovered this early enough that there was time to locate and procure biodegradable spray paint. As previously mentioned, staking items to the ground may be regulated or prohibited; these requirements are easier to incorporate into the test setup plan early in the project lifecycle.

Another reason to complete the environmental survey as soon as possible is to accommodate any concerns discovered during the survey process, such as wildlife or undetonated munitions precautions. In the case of wildlife concerns, it is necessary for all field crewmembers to complete training on how to handle various wildlife encounters. Historically speaking, any test executed on government controlled land outside of business or residential areas required each field crewmember to formally complete Desert Tortoise Training and carry a card indicating the completion of such training during the test. SCAMP required that all field personnel remain clear of burrowing owls and their nests, and thus it necessitated that personnel were able to correctly identify both the owls and their nests; this requirement was fulfilled with informal training. As previously mentioned, sometimes the environmental survey will warn the team to be aware of the possibility of finding unexploded ordnance. Any test on a remotely

located section of an active or inactive military base should warrant awareness of how to react to undetonated munitions. This awareness includes communicating the possibility of finding undetonated munitions to all field personnel, having a plan of what to do in the event that a suspect object is encountered, and briefing this plan to all crewmembers prior to deployment. For instance, during SCAMP, a crewmember from a partner organization found a suspicious looking device in the field, and correctly took action by placing cones around a wide perimeter of the object and notifying the rest of the team.

The key lesson learned regarding coordinating with any environmental department is that it is critical to get the environmental survey performed as early as possible, as the results of the survey could delay the project schedule by requiring a change to equipment set-up procedures, crew training requirements, or even the test site location.

6.3.1.2 Air Traffic Control

If instrumentation is going to be in an air traffic controlled (ATC) limited-access area, the team should meet with ATC personnel during the project coordination phase. It is ideal to discuss and/or develop standard operating procedures concerning access, entry and exit, emergency procedures, nominal communications, and the deployment of any unusual equipment (for example, tethered blimps, which will be discussed in greater detail later) early in the pre-flight planning phase of the project. As test windows approached, ATC entities have been open to receiving a phone call to clarify the aforementioned operating procedures, if needed. Furthermore, often a new and test specific call sign will be given to groups operating in unique locations or situations. Usually the first time this call sign is used the controller will confirm that this call sign is indeed a real call sign, resulting in a short wait. Therefore it is recommended that the lead field controller call the tower on the phone prior to contacting the tower via radio when a

new call sign will be used. This is particularly pertinent to cases where a short response time is highly desired or critical.

The sonic boom team had positive interactions with ATC concerning ground operations and the operation of unusual equipment during the FaINT project test window, due largely to the pre-coordination and communication with ATC personnel prior to test execution. The lesson learned being that establishing detailed communication with ATC early in the pre-flight planning phase will increase the likelihood that day-to-day operations run smoothly throughout the flight phase.

Another consideration concerning interactions with ATC has to do with planning the flight path of the test airplane(s). While airspace constraints on flight paths are addressed during mission planning, it is also important to consider what artificial effect instrumentation error has on the airplane trajectory displayed to ATC. For instance, in the past, known pitot-static calibration issues near Mach 1.0 falsely reported that the airplane was climbing dramatically during transition through Mach 1.0, which caused ATC to become concerned and relay these concerns to the aircrew during critical moments of the test. The lesson learned for future projects is to communicate this issue to ATC in advance of the test, and prepare for these possibilities in flight path planning.

6.3.1.3 Airfield Management

If the project will require instrumentation and/or personnel to be placed anywhere on an airfield – including flight lines, Roger's Dry Lakebed, and fly-by towers – airfield management must be aware of and approve of all such activities. While the need to contact governing and partnering organizations early in the planning and coordination of a project has been discussed, airfield management is one of the most critical organizations to establish communication with

early in a project's life cycle, and initial coordination with airfield management should begin at the same time coordination with environmental has been initiated.

Early interaction with this group is critical because they are the scheduling authority for airfield assets. Airfield Management can inform the team if there are any conflicts with scheduling of the physical space, if any other tests have the potential to delay the test due to priority, or if there are any other conflicts that could arise during the test window that would require additional planning from the test team. During FaINT, the team was informed that the planned test area was also designated for emergency aircraft landing use. As such, the team developed an emergency evacuation plan to allow for this contingency. *It should also be noted that non-mission essential activities sometime sometimes require the airfield over the weekend.* Thus, it is worth specifically asking airfield management if any of these events are planned over the course of the test window, especially if any equipment will remain in place over the weekend. If so, airfield management can help de-conflict the schedule. Additionally, airfield management may place restrictions on the team concerning the layout, set-up, and tear down of equipment. In particular it is usually required that no material from the test be left on the airfield or in the ground around the airfield, including items such as t-posts, stakes, and nails. Finally, airfield management has complete control over access to all airfield assets, meaning that the airfield can be shut down with little notice, particularly in the event of an emergency or severe weather. The lesson learned is that the project needs to communicate all desires and expectations with airfield management upfront, while being aware of all of the expectations airfield management has concerning the project and the general operation of the airfield.

The impact of seasonal effects on the testing site combined with such controlled access should be considered. If the test site is located on a controlled-access lakebed, any amount of rain

can cause the lakebed to be shut down for ground operations. While lakebeds are not commonly closed due to sprinkles, it is technically possible. Rain causes the surface of lakebeds to become silty and sludge-like, which means that the flat surface can be easily marred by foot traffic or vehicle traffic, especially if there is standing water on the lakebed. Therefore, once the lakebed has been closed due to rain, it can be closed for quite a long time – sometimes up to several months during the winter. As such, it is wise to avoid scheduling a test on the lakebed during the rainy winter season. In all cases, project consultation from the meteorological team at AFRC is critical – especially during the flight phase when the team can be alerted if likelihood of precipitation is high, so that the test site can be evacuated of equipment and personnel accordingly. The lesson learned here is that test site selection can also be weather-dependent and that the time of year that the site will be used can impact project risk. Discussion with the organization in control of the site in question will give the project the best idea of how weather-dependent the site is, and how much risk the project is assuming.

6.3.1.4 Frequency Management

The use of radio frequencies for transmission of data or communication is well regulated on military bases and government installations. Therefore, it is necessary to gain approval to operate any wireless sensors or equipment equipped with a transmit and/or receive function from the installation's Frequency Management group prior to operation of such equipment. Previous sonic boom team projects have required the use of wireless instrumentation that transmitted from the recording station back to a central location and a GPS sensor for test site surveying; both of these instruments were required to go through a one-time approval process. Future test teams should be aware that the process of gaining approval to use a wireless device on a government property can be lengthy, and plan to submit the requisite documentation several months in

advance of the test. Note that even if the test takes place off of a federal installation, if the organization leading the test is government sponsored, then it is likely that all equipment capable of transmitting and/or receiving a signal will be required to go through a frequency management process.

Concerning field communications, which will be discussed in greater detail later, it is also advised that future test teams be aware that Very High Frequency (VHF) and Land Mobile Radios (LMRs) have already been approved for use on military bases, but a frequency request must be submitted prior to their usage. Commercially available camping-style walkie-talkies or family radios are not approved for use on military bases, nor are they approved for use by government personnel during a government-led test.

The lesson learned is that it is important to ensure that all equipment has been approved for use by the government well before it is used on government land. This is accomplished by discussing restrictions with a frequency management group and is best done before the test setup design is finalized.

6.3.1.5 Access to Military Bases

As indicated in Sections 5.1 through 5.4, NASA AFRC collaborates with several outside organizations to complete sonic boom flight research projects. While this collaboration is highly beneficial to gathering a larger, more unique data set, it also means that the logistics of getting off-base personnel access to the installation and physically onto the test site becomes a bigger, more time consuming task. The key lessons learned concerning base access are first to designate a person to serve as the POC for base access with the understanding that they will essentially be on call for the duration of the test, and second, the base access POC should not be a member of the field crew to avoid overtasking or crew rest issues. The sonic boom team has found that the

project manager is a good fit for the base access POC role. During the test window, the POC might be contacted if any issues arise with sponsored personnel already on base at any time. If there are Foreign Nationals – non-US citizens – traveling to join the test team, access should be addressed several months in advance of their arrival, as gathering the required information from foreign team members, submitting the paperwork, and gaining approval is a long process. Access for all visiting members of the test team who are United States citizens should be addressed simultaneously, roughly two months before the test to allow for the time it takes to gather the information from the personnel, complete all the required forms, and ensure their access is granted through by base security. The base access POC should contact base security to discuss current procedure for granting base access to a large group. If the test requires that base access be granted for more than ten days in duration, security may require that all of the visitors renew their base passes. Renewing a group of visitor passes is best accomplished when the whole visiting team goes with the POC to the gate, or the base security entry point. Thus, the final lesson learned concerning base access is that the POC should plan to meet arriving/visiting personnel at the gate when they first arrive, and accompany them to the gate when the visitors renew their passes.

6.3.1.6 Facilities Use

As previously mentioned, some of the prior tests focused on or included building response data, which presents its own unique coordination challenges. Lessons learned regarding site selection have taught the sonic boom team that selecting a building to instrument and gaining permission to do so early in the pre-flight planning phase is essential to project success. One unique hurdle to instrumenting a building is that if the building is occupied the test team may have to coordinate with the owners and/or tenants of the building. Usually this involves

requesting occupants to not open doors, windows, operate heavy machinery, or perform other tasks that could alter the data during the test time. Making these requests early in the coordination or site selection process helps the team eliminate test sites that are not ideal due to the increased possibility of erroneous measurements. Making operational requests early also provides the building residents enough time to plan for such accommodations so that these constraints are not a limiting factor. Additional consideration should be given to the security of the hardware, including how many people have access to the building and if it is acceptable to leave equipment in the building overnight. Finally, facilities owners usually want to approve any equipment installation; in this case it is best to know the exact size, amount, and installation technique of the equipment in question as early as possible.

6.3.2 Coordination of Land and Airspace

While most of the projects discussed in this paper took place on EAFB, it is reasonable to assume that similar tests conducted out in the public would require, at a minimum, the same level of coordination. In fact, it may take much more time than anticipated to determine which organizations need to be involved in the coordination effort. For example, in the planning of SCAMP the team had to determine who the governing authority was over Cuddeback Lake, CA. The process of discussing this issue with the Bureau of Land Management, the California Department of Fish and Wildlife, and the United States Air Force to determine the answer required as much time as did the following planning efforts. It should be noted that approval from an environmental authority may still be required, depending on what organization has authority over the test site. As with all other tests sites, storage of the equipment overnight and/or over weekends needs to be discussed early, as this may or may not be allowed. Tests in communities will be accessible to the public, and thus present a greater concern for the security

of hardware. Similar to building response tests, the organization in control of the test site will likely want to know details concerning how equipment will be installed and how much equipment will be used; as usual, it is best to provide as accurate of an answer as possible early in the project's lifecycle to prevent confusion and misunderstanding leading to work-arounds during the set-up stage. The lesson learned is that coordination tasks often take more time than initially assumed, thus projects should begin the coordination early in the pre-flight phase.

6.3.3 Coordination with Partners

While exchanging the appropriate technical details with partners is critical to test success, it is important to begin coordinating non-technical logistics while the test setup is being designed. Of particular interest is the number of people who will be traveling to the test and how many of those people will be working in the field. This will provide the team with an idea of how much workforce will be available for set-up, test execution, and tear down and whether or not additional staffing from personnel outside of the sonic boom team is needed. Furthermore, the number of field crewmembers will drive how much vehicle support is needed, which is especially critical if the test site is in a remote location or on a controlled access area. It is important to discuss vehicle support requirements with each partner prior to the test to ensure that the expectations of all involved parties are well understood. The lesson learned in this case is to create a detailed ground operations plan that covers all of the daily operations and a detailed list of what personnel will be assigned to each task, and when the task will take place.

During the test window crew rest is crucial to ensure safe and efficient operation of the team. Therefore, if the test is located in a remote area – including someplace on EAFB that is a great distance from AFRC – it is highly recommended that both the local and visiting team members utilize lodging near the test site. Doing so reduces the commute time, allows the team

to get more sleep, and promotes camaraderie among team members, even across sorganizations. Thus, it is not surprising that when the option to stay at the EAFB Hotel during WSPR and FaINT was presented, every visiting individual indicated a desire to do so. This lodging arrangement greatly improved test team morale and alertness by increasing crew rest.

Working on a military base or other similarly regulated site requires the team to follow a specific set of standard operating procedures and regulations, which are often unfamiliar to external partners. In previous tests these expectations and rules were communicated in an email or verbally, but the most successful method of communication is to send out one document outlining all of the base rules and expectations. Each participant is then required to read the document and return the back page of the document signed and dated to indicate their understanding of, and agreement to operate under the aforementioned terms. It is also recommended that a comprehensive email with the general test schedule and other pertinent information be sent to the partner organizations a couple of weeks prior to the test window. This lesson learned was applied prior to FaINT and resulted in fewer questions about base procedures and regulations from visiting partners.

Finally, it is important that each partner knows and understands what the daily schedule is during the test window. During morning setup, many activities occur simultaneously. If access to the test site is controlled, ferrying vehicles and equipment can require a complicated series of logistics that takes longer than it would if everyone could merely drive their rental car out to the test site. This process, while lengthy and possibly frustrating to those not used to operating under such rules, is essential and runs smoothest if everyone is waiting in place to be transported out to the test site. This means that it is not always immediately obvious to crewmembers (especially new crewmembers or visitors), why the morning arrival time is so early. Therefore it is

recommended that the test team explain the morning timeline to the entire field crew during the Day One briefing so that team members understand how they fit into the bigger picture of the daily activities. Further, the Day One briefing is the perfect time to disseminate and explain the previously discussed daily, detailed ground operations schedule.

6.3.4 Navigating Potential Roadblocks

Despite the number of sonic boom ground measurement tests NASA AFRC has performed, and how well versed the team is with coordinating such tests, there are a few commonly encountered roadblocks. Some of these challenges have to do with the perception of sonic booms and being involved in a test focused on them; being involved with an on-going test; equipment integrity and security; and avoiding superfluous noises.

6.3.4.1 Sonic Boom Related Stigmas

First and foremost, it needs to be stated that the term "sonic boom" carries a specific connotation to most people. Some people do not mind sonic booms, while aviation enthusiasts often like them. However there is a segment of the population that has strong negative reactions to the term. These perceptions may be based on previous personal experiences and dislikes. Alternatively, some people may have never heard a sonic boom, but believe sonic booms are always a violent event, due to information gleaned from news stories, anecdotes, and historical accounts. Essentially, there exists a great deal of misinformation and negative perceptions surrounding sonic booms. Therefore, the key lesson learned is that future tests involving communities unfamiliar with sonic booms will need to educate the public prior to executing the test. Topics that should be addressed include sonic boom carpets and how sonic boom carpets can be strategically placed to lower human exposure.

The stigma that all sonic booms are loud and likely to cause property damage coupled with media coverage of sonic boom flight research tends to lead people to file damage claims with NASA AFRC. When operating in an area where other organizations are flying supersonically it is common that all sonic booms produced during the publicized test window are attributed to the publicized project. This phenomena is also associated with people familiar with flight test, as EAFB personnel have asked NASA to rearrange flight schedules to no longer coincide with all-hands meetings in the past. The lesson learned here is that tests involving the public may need to be sensitive to community events in the creation and execution of the flight schedule.

When the ground measurement tests move into the realm of collecting human response data, the situation becomes more complicated. Because of the history of human response sonic boom testing, the stigmas attached to sonic booms, and the previous press resulting from sonic boom tests, some within NASA AFRC expressed concerns with the planned tests. These issues centered on whether NASA should perform this type of test and/or endorse this type of test. Given these common apprehensions, the lesson is that the team should clearly communicate the justification for human response testing and test details with all project stakeholders, especially those with the authority to halt the project due to such concerns. This communication must start in the earliest project formulation activities in order to ensure a successful project.

6.3.4.2 Use of Land and Facilities for Instrumentation

Sonic boom stigmas aside, it is possible that test site selection could be challenging because some people are reluctant to participate – actively or inactively – in an on-going test. This is particularly true if requests are made of residents or occupants to avoid certain locations or activities during the test.

In the future, the desire to not be in close proximity to an ongoing test could present a challenge to sonic boom response testing. This is especially true if quantitative data would be gathered in community and residential areas to use as a reference against the qualitative response data. The concerns in this case would likely revolve around the use of microphones to record sonic booms in neighborhoods and the perceived privacy implications; these issues were in fact brought up at the last minute during WSPR. Utilizing a manual push button to record sonic booms, only using auto-triggers during flight windows, or obtaining approval from each neighborhood to continuously use auto-trigger settings are all potential ways to mitigate this issue in the future.

6.3.4.3 Equipment Integrity and Security

In an effort to reduce the workload on the field crew by decreasing daily set-up and tear down requirements, some equipment is usually left set-up for the duration of the test window; usually around two weeks. Often, cabling is left in place, while microphones, recording hardware, and signal processing hardware are picked up and stored near the recording site at the end of each day. This approach is optimal for a more reliable morning set-up and advantageous from a crew rest standpoint, but it does present issues concerning the integrity of the hardware via interference from people and wildlife.

A constant problem to both the test team and the cabling are rodents. Rabbits and mice love to chew on the cables overnight. Unfortunately, the more expensive seven-conductor cables between the microphones and amplifiers tend to experience more damage than the less expensive coaxial cables between the amplifiers and the recorders. Overnight storage, other wildlife concerns, and prevention of rodent chew-throughs are discussed in Section 7.1.2.

As previously mentioned, leaving equipment at the test site overnight poses security issues. In controlled access locations leaving equipment in water tight, incredibly durable cases (such as Pelican Cases) stacked up near each recording location has sufficed. During WSPR the equipment was secured via locking cable or a locked chain looped around a telephone pole or other permanent fixture, and none of the equipment was tampered with. During SCAMP, the remote off-base test site was publically accessible, and thus a night-patrol of NASA security guards was added to the field crew. The lesson learned is to always consider the logistics of the entire day and to plan to secure all equipment against all threats: people, weather, mishandling, and wildlife.

6.4 Logistics and Test Scheduling

Planning the test schedule and detailed coordination of test operations for recent NASA sonic boom flight research projects has provided many valuable lessons learned. Routine parts of sonic boom flight research include determining the schedule for the overall flight phase of a project, designing the test day schedules, and pre-test preparations.

6.4.1 Setting the Research Flight Phase Schedule

Time is always a lacking commodity during the flight phase of a project, but the biggest lesson previous sonic boom flight research projects have illustrated is that the project must allow for as much time in the flight phase as possible. SCAMP (12 mission flights spanning nine business days), WSPR (21 mission flights spanning 11 business days), and FaINT (13 mission flights spanning eight business days) all consisted of very aggressive flight phases – usually with multiple flights a day. Regardless of the reasons to this approach, it is highly suggested that more time be worked into the schedule to allow time to review data between flights, pick up ground

equipment, remove equipment from the test site, and give the crew adequate rest. Future teams should plan for this time in their schedule, and this requires the team to be realistic about how much time each task will take and to set the expectations of all stakeholders.

A lesson learned from previous tests is that time should be made to look at all data between flights. In cases where there are multiple flights in a day, the data should be looked at between each flight day. This allows the project to find problems with instrumentation systems or data collection methods. It also provides the opportunity to plan future test points, which may include repeating test points based on data that has already been collected and viewed. A team member could serve as a dedicated data reviewer, allowing the rest of the team to focus on flight and ground operations. An example of how this practice would have been beneficial was experienced during SCAMP when the data acquisition system settings for a blimp-supported vertical microphone array were incorrectly set. This resulted in poor data. A single data review after the first flight would have caught this error; instead, no such time was considered and all of the blimp system's data for SCAMP was unsatisfactory – spanning all 12 flights.

Planned non-flight days within the flight phase are highly advised, and the sonic boom team will be implementing this strategy in future tests. These days could be dedicated to data review but would also allow time to inspect equipment and make any necessary repairs. Non-flight days also provide the opportunity to re-train equipment operators if the data review shows apparent data collection errors or other operational mistakes were noted. Non-flight days after the flight phase are suggested to better facilitate picking up any equipment. These lessons learned are discussed in Section 8.1.3.

6.4.2 Planning the Daily Test Schedule

Most NASA AFRC sonic boom flight research projects have aggressive flight phases, often including multiple flights per day. For example, the WSPR project had as many as three flights in a day. Armstrong flight operation policies typically prohibit flights before dawn and after dusk due to EAFB airfield's operational hours. The ideal time of day for most sonic boom research flights is early in the morning, when wind levels are low, and the wind noise on any ground instrumentation is at a minimum. These limitations result in a relatively small window of time to execute multiple flights. Therefore, a carefully planned and orchestrated daily schedule is necessary.

6.4.2.1 Radio Frequency Scheduling and Daily Meetings

Radio frequencies are required for communicating with airplane pilots and for telemetering any airplane data. The frequencies need to be scheduled and designated for each flight to prevent radio interference. Due to various circumstances (for example, weather delays or maintenance issues), flight times can be volatile. Sonic boom flight research projects have experienced extended delays and complications due to the need to reschedule airplane radio frequencies. The lesson learned is that projects should schedule the necessary frequencies for the entire day when possible. The sonic boom team has experienced fewer frequency-scheduling related delays by employing this strategy.

An aggressive flight day can lend itself to confusion amongst personnel, especially when plans change or operative adjustments need to be made. Projects must have mandatory morning meetings with the entire field crew each test day prior to morning setup. These meeting should be brief and provide an overview of the day's activities. Daily meetings also allow any updates or vital information to be communicated and may also offer the opportunity for crewmembers to voice any concerns or questions they may have. This lesson was learned in some of the early

sonic boom flight research projects and implemented in later tests. This change in operations resulted in less chaos and fewer delays during the daily equipment setups, resulting in an overall shorter duty day for the field crew.

6.4.2.2 Crew Rest

An aggressive flight day can also mean a very long workday for ground grew. The planned daily test schedule for SCAMP, which is typical of an aggressive sonic boom flight research flight phase, is shown in Table 1.

Usually test days are 11.5-hour workdays (including two one-hour crew breaks). While an 11.5 hour day would be strenuous, the crew breaks are typically spent working, and common flight operations issues often cause an extended test day. Thus, the resulting workday has historically been often 14+ hours. The reader should note that the extended day was not due to project expectations, but rather due to the field crew's high work ethic. During a project with these long days, and a two-week flight campaign filled with back-to-back test days (as SCAMP was), field crew exhaustion became an alarming, but real, issue. The key lesson: to avoid exhaustion, crew rest must be a priority when planning the daily flight schedule. This must include adding more breaks and making them mandatory, having more field crew personnel so that tasks can be staggered, or by simply making the flight schedule less aggressive.

• Set-up/calibration of ground instrumentation	(0400)
• Airplane instrumentation checks	(0600)
– Preflight at beginning of flight week	
– Day of flight each flight day	
• Compute waypoints and deliver to pilots	(0615)

•	1st research flight takeoff		(0700)
	– Flight	(1 hr)	
	– Field crew break	(1 hr)	
	– F-18 turn-around	(2 hrs)	
	– TG-14 turn-around	(2 hrs)	
•	2nd research flight takeoff		(1000)
	– Flight	(1 hr)	
	– Field crew break	(1 hr)	
	– F-18 turn-around	(2.5 hrs)	
	– TG-14 turn-around	(2 hrs)	
•	3rd research flight takeoff		(1330)
	– Flight	(1 hr)	
•	Airplane shutdown and GPS downloads		(1430)
•	Crew de-brief		(1530)
•	Crew brief for next day		(1600)
•	End of duty day		(1730)

Table 1. Planned Daily Schedule for SCAMP

Planning a less aggressive schedule can be difficult when working with external partners. Many times, external partners have set budgets that limit participation. This has historically been one of the primary reasons that the test schedule was so aggressive. It should be noted that some other agencies and non-government companies have significantly different duty day policies than NASA. In previous projects, these policy differences led partners to lobby for longer work days and many more airplane flights over the course of the flight campaign. Again, the core lesson

learned is that sonic boom flight research projects must establish crew rest requirements early in the project-planning phase, and communicate these requirements to any potential partners.

6.4.3 Pre-Test Preparations

As with any flight research project there are a number of activities that take place after initial planning in preparation for the flight campaign. For NASA sonic boom flight research projects, the typical pre-test preparations that garner the most lessons learned are inspecting the ground test site, receiving equipment from external partners, and the training of project personnel.

6.4.3.1 Test Site Checkout and Receiving Equipment

After selection of a test site, the entire – or at least the local – field crew need to visit the test site prior to equipment setup. Such a trip assures familiarity, reduces surprises, and is especially beneficial to the personnel who will be delivering equipment to the test site. The site visit also allows the project to figure out exactly how equipment will be mounted on buildings, if a structure is to be instrumented; stucco and tall buildings add a challenge. An early trip to the site provides the opportunity to check out the quality of radio communications as well as internet connectivity (mobile hotspots) and allows time for the team to consider back-up options. Test site reconnaissance is also used to generate high-fidelity maps that can be provided to all field crew personnel. The routes and any back-up routes test site(s) should also be adequately marked; to include reflectors if access during the dark is anticipated. It is recommended that signs be distributed at least every 1,000 ft. along the route. The SCAMP project utilized signs along the way to its test site, but they were so widely spaced that often times the crew would make a wrong turn, resulting in traveling an uncharted, potentially hazardous route.

Partners often contribute to projects by offering technical expertise during planning and execution phases, and by providing field crew personnel. All partner contributions are extremely valuable and fill a wide variety of project needs. The most common method of support is loaning ground instrumentation and equipment to NASA AFRC during the flight phase of a project. Thus, it is highly recommended that there be a staging and equipment storage area when expecting large quantities of equipment. The FaINT project used a 122-microphone, approximately 9,000 ft. long instrumentation array on the ground. An array of this size would not have been possible without partners, as supporting instrumentation and over 105 microphones were loaned by external partners. The project used a climate-controlled room with a roll-up door and drive-up vehicle accessibility as an equipment storage and staging area. It was located outside of NASA Armstrong's security gate, which allowed shipping companies and external partners to easily access the facility. This room was an extraordinary asset, and served as a place to store equipment as it arrived and provided space to organize, check-out, and test equipment before it was taken out to the test site. During the test, this facility was used to charge batteries overnight. The reason this particular location was chosen for the staging area was due to all of the lessons learned regarding the amount of physical space required, accessibility, and power availability. The lesson for future projects that that even the smallest details in pre-test logistics make a vast difference in how the beginning of the test phase performs, and thus even small details in pre-test logistics deserve a methodical approach. Another lesson regarding loaned equipment is that projects should set a firm equipment delivery date. This deadline should allow for complications, including international customs delays. Without an equipment delivery deadline, projects could risk not having time to perform a full system check before deployment.

6.4.3.2 Personnel Training

Another pre-test preparation that has yielded important lessons learned is personnel training, which includes location-specific training and equipment-operation training. Examples of previously encountered location-specific training courses include desert tortoise precautions, unexploded ordinance identification and precautions, and heat stress instructions. It is imperative that the project work diligently to identify any training that will be required well in advance of field crew deployment. Some of these training courses can be taken online, but for projects including a lot of ground personnel, verifying that each person has taken the appropriate training can be tedious. The lesson for future projects is that projects need to organize an initial team training session after all ground personnel have reported for duty. If this is not possible, training via video conference or teleconference is a reasonable alternative.

Other things to consider when deploying include access to first aid and medical facilities in the event on an emergency. If the test site is remote, at least one team member needs to have some basic first aid training. Note that a part of the location-specific training should consider the unique medical needs of its crewmembers, and whether the deployment plan or test site can accommodate them.

In addition to location-specific training, there must be an introductory briefing before equipment is deployed. This briefing serves as an orientation and should include detailed information and documentation on how to deploy, set-up, calibrate, and tear down all ground equipment. During the meeting any guidelines or location-specific rules need to be clearly stated. Guidance for sonic boom recording etiquette should be provided. Specifically, NASA sonic boom research requires that all ground personnel be silent for a pre-determined amount of time prior to and after the sonic boom. Typically, silence should begin approximately two minutes before the estimated sonic boom arrival and end 15 seconds after the sonic boom has been

recorded. The meeting should also provide hands-on instruction over the use of any radios and other communication devices. While this demonstration requires little time, it can immensely benefit the project. For instance WSPR experienced several user-error related radio communication issues that could have resulted in a loss of data by creating background noise during a critical acoustic data gathering time or by causing the field crew to miss ques to record the sonic boom. However, when hands-on radio operation instruction was provided prior to FaINT, it virtually eliminated all user-related radio communication issues. The introductory briefing is also the opportune time to distribute a one page document containing all crucial test information to all personnel. The one-pager should include a summary of everything covered in the meeting, specifically any rules that must be followed. Such a document would have been helpful during FaINT, as there was a restriction against the use of non-government vehicles of any kind on the dry lakebed test site. Despite the restriction, personnel tried to use bicycles on multiple occasions. Each team member should sign a roster stating that they have attended the briefing and received the one-pager.

During the introductory briefing, all field crew need to be educated on expected sonic booms sounds, especially personnel who will be recording data or providing feedback during testing. SCAMP required ground personnel to report what sonic boom sounds they heard along the microphone array. Four or five people would tell the ground test coordinator what they heard, and based on their feedback, the test coordinator would determine where the sonic boom caustic was placed and make any necessary airplane waypoint adjustments. FaINT required a similar process for its lateral cutoff test points. An uneducated ear could result in poor feedback and, therefore, inaccurate airplane waypoints. Ideally, test phase introductory briefings would include sample clips of the different sonic boom classifications that are expected.

A similar briefing should be held for volunteer test subjects used for sonic boom human response testing. The briefing should provide all volunteers with any information needed, what is required of the volunteers, and any training necessary. The meeting should provide volunteers training on how to properly submit their responses. As it is important that all volunteers receive the same information, the number of times this briefing is held should be kept to a minimum.

7 Methods of Data Collection

The main thrust of each of these sonic boom flight research projects was to collect useful acoustic data to aid in the understanding of sonic booms. To collect this data, NASA and partners used a variety of methods to capture the acoustic and pressure signatures of the sonic boom at different locations and in different environments. There are two main types of arrays: the ground instrumentation, which captures the acoustic and pressure signatures of the booms at ground level; and the airborne instrumentation. The airborne array consists of a tethered blimp raising a vertical array which captures acoustic data at various points vertically from a point on the ground and a motor glider equipped with a microphone, which can capture data at higher altitudes. While overall data collection was successful in the vast majority of runs for these tests, there were several lessons that were learned during the operation of these data acquisition systems throughout these campaigns.

7.1 Ground Instrumentation

NASA AFRC uses a wide variety of ground instrumentation in each of its sonic boom flight research tests. As a standard, this instrumentation includes multiple microphones and pressure transducers, signal amplifiers, analog to digital converters, time code generators, and

several laptops. While there are several lessons learned specific to NASA AFRC's equipment, the general lessons related to operator error, environmental considerations, and hardware considerations will be of the greatest interest to the reader and have thus been provided below.

7.1.1 Operator Error

The ground instrumentation used by NASA AFRC consists of multiple ground microphones and pressure sensors distributed over large distances, which means that there are multiple operators of the recording equipment during a given test. Since multiple operators are needed, each operator is not equally experienced in using the equipment. A recurring problem that has spanned multiple tests is the lack of data acquisition system operator training. Some data has been lost during several efforts because operators were not briefed or did not understand specific nuances of the equipment. While experienced users tend to be familiar with common problems and work-arounds for the systems they operate, new users are usually unaware that anything is wrong until the opportunity to collect the data has already passed. The lesson learned is that prior to the day of flight, new users must not only be briefed on how to use the system they are assigned, but need to practice using it. A list of common problems and idiosyncrasies with the equipment, as well as their solutions, must also be produced by experienced users and kept with the equipment. This would mitigate the risk of failure to record the data during a flight, when the new operator would not have a chance to ask questions to someone with more experience. An example of where this would have been beneficial in the field occurred when a piece of software being used had a bug which would occasionally require the record button to be pushed twice, instead of the normal one time to start recording. Since the relatively new operator was not looking for this odd error, it was missed and data was not recorded during a critical part of the test.

Error in using the equipment is not the only problem that can occur with less experienced operators. The users must also be briefed on proper conduct while running the data acquisition equipment. During past campaigns some data has been corrupted by users making noise or talking while data was being taken. Large data recording systems can also be complex to operate, especially when running on battery power which requires hardware to be routinely powered down to lengthen battery life. On several occasions equipment has been inadvertently left off. The use of checklists for determining if the equipment is ready to record greatly reduces the risk of leaving hardware powered off during a test.

Failure to obtain data caused by operator error leads into the next lesson learned when collecting the data. Multiple times when data were collected incorrectly, it was done so for multiple flights. Having a method to quickly look at the data from each recorder and confirm it was collected correctly would prevent incorrect data collection during multiple flights in a campaign. Ensuring that each recorder was working and that the recorded data was useful at the end of each flight would also catch problems early and allow for possible rectification. Looking at the data as soon as possible is helpful not only for the acoustic data, but for any type of recorded data. Precise, surveyed locations of instruments have been lost because location markers were removed before the survey data were examined. Looking over data as soon as possible after it is collected is crucial to catching errors before more data is lost or before it is too late to re-collect the data. The lesson regarding the need to look at the data quickly between flights will be incorporated into future projects via building time into the flight schedule; however, developing a method to quickly determine the quality of the data in the field would also be exceptionally useful.

7.1.2 Environmental Considerations

Lessons about the environment in which the sonic boom team operates in have been learned throughout the aforementioned projects. Instrumentation cabling is very prone to be damaged by wildlife. Stowing any outdoor cables overnight is an essential practice when instrumentation is in a place where wildlife has access to it. It was discovered that when operating on Rogers Dry Lakebed, a distance of 500 feet or greater from the edge of the vegetation would eliminate cable damage from wildlife. A commercial environmentally safe and biodegradable rabbit repellent was used to spray cables to attempt to reduce wildlife damage, but had little effect. Cables with the repellent continued to suffer from chew-throughs. It should also be noted that coyotes occasionally explore the equipment and, occasionally, leave gifts for the test team overnight. The lesson learned is that highly durable, water tight storage methods are crucial to protecting equipment from wildlife-related damage when storing equipment outdoors overnight.

Easily attached, removable dust covers for sensitive electronic connectors are also needed for connections that are left unplugged overnight. Other less obvious environmental hazards include lawn sprinklers.

Sonic boom team projects have implemented methods to decrease the likelihood that environmental limits on instrumentation are exceeded. Future projects should implement this lesson learned. To do so, the team must understand how the instrumentation will behave in different weather conditions. On one occasion an automated sensor that was programmed to record sonic booms via a pre-set overpressure trigger experienced multiple false triggers. This was due to the high winds of the day, in which gusts routinely exceeded the overpressure of the trigger. Midday heat also causes problems that can lead to equipment shutting down and behaving incorrectly. Furthermore, temperature swings can cause significant shifts in the

calibration of instrumentation – including the frequency response of microphones. To mitigate these effects, reflective sun shields have been employed, and microphones are calibrated at the beginning and end of each day to account for the temperature swing.

7.1.3 Hardware Considerations

The configuration of the ground recording equipment requires careful consideration. By the nature of the sonic boom test, there is only one chance to record the data, since it is very expensive to try to repeat a test when the data are not recorded properly. Thus any personal computer (PC) being used to record data should have a minimum amount of software besides the data recording software. Problems have occurred in the past when an unrelated piece of software attempted to update during a critical time in the test. Furthermore, any security features, power saving options, or other system settings that could cause problems at inopportune times should be turned off.

With the schedule-driven nature of these flight projects, new equipment that has previously not been used should not be counted on, and keeping the old equipment as back up is highly desirable. There have been close calls in the past when new equipment was delayed in the procurement process and did not arrive until the last minute, which was made worse by issues using the new hardware. Having the old system to use just in case such problems arise can be critical in many situations. Each piece of hardware should a have replacement available in the inevitable case of hardware failure during the test. Repair is usually not an option in the time available during the flight phase of the project, so it is important to have a plan of action if a piece of equipment fails. This plan of action could be anything from having a spare available for replacement, to adjusting the entire configuration of the equipment to compensate for a missing piece of equipment.

For large recording arrays containing many microphones, it is also important to have a plan for where each piece of hardware will be deployed and to label all hardware accordingly. Since the hardware is used repeatedly during multiple tests, labels can tend to accumulate on equipment and cables, causing confusion. Using a strong but non-residue label such as gaffers tape is recommended. Appropriate cable management is also of the upmost importance, as it mitigates cable wear and failure. Cable reels that are too small, or cable that is rolled up incorrectly can waste a great deal of valuable time, as the cables have to be untangled during deployment.

Batteries have been the source of many issues during sonic boom flight research projects; for instance, batteries have failed or prematurely drained during tests. Thus, it is extremely important to have multiple backups for batteries. Using equipment that operates on 12 volts, direct current is very desirable, as vehicles can be used as a motor-generator when batteries fail. Having the same amount of battery chargers as batteries is strongly recommended, since many batteries take multiple hours to charge, and would allow all batteries to be charged overnight after a day of operation.

7.2 Airborne Instrumentation

In addition to the previously mentioned ground-based recording systems, NASA AFRC often utilizes an airborne instrumentation array. This array can include a TG-14 motorized glider and a small tethered blimp deployed from the back of a truck. Both are equipped with a small number of microphones and the data collected from these platforms serves to supplement the data collected at the ground.

7.2.1 TG-14

NASA AFRC a TG-14 airplane equipped with a wingtip mounted microphone, call the Airborne Acoustic Recording Measurement Platform, or AAMP, to record sonic booms at pre-determined altitudes. The TG-14 is a two-place, side-by-side, motorized glider of a low wing, T-tail configuration, equipped with spoilers and retractable gear. A Garmin 496 GPS with manually programmed test waypoints assists in navigation.

The airplane is outfitted with a slightly modified version of the ground equipment: the analog to digital converter, the time code generator, and the signal amplifier are all mounted to a removable pallet behind the co-pilot's/Flight Test Engineer's (FTE's) seat. The microphone has been mounted on the tip of the left wing, and is outfitted with a bullet-shaped nose cone cover. A tablet PC is used in place of a laptop and allows the FTE to start and stop recording while in flight. Figures 6 and 7 show the wingtip mounted microphone and the instrumentation pallet.

The typical mission profile for the TG-14 includes climbing to slightly higher than the initial test point altitude, aligning with the appropriate heading, shutting off the motor when the F-18 pilot calls "60 seconds out," powering up the tablet PC, recording the event, shutting the tablet PC down, turning the aircraft around while powering up the engine, climbing slightly higher than the next test point altitude, and repeating this process until all of the test points are complete.

As the TG-14 takes a considerable amount of time to climb to the initial test point altitude, it usually takes off fifteen minutes prior to the F-18. It should also be noted that the TG-14 must wait until sunrise to takeoff as it must operate in VFR conditions, thus affecting the takeoff times of early morning flights.

Further considerations concerning the TG-14's performance require that the test team determine whether the TG-14 data is a requirement or a desirement. This is attributed to the fact

that the F-18 is capable of a quick turnaround between passes, while the TG-14 requires a long time to get back into position to begin run-in for the next test point. This time is dictated not only by the airspeed of the vehicle, but also because the engine must remain off for the entire duration of the recording to decrease noise. This causes the TG-14 to travel quite far from the run-in point and lose a significant amount of altitude over the duration of a single test point. This time can be shortened by setting the test waypoints to start at the highest altitude and progress to the lowest altitude and by avoiding large shifts in the coordinates of the run-in points. These optimizations will ease the issue of the F-18/TG-14 timing disparity, but will not eliminate it, so it is important to decide if the F-18 will proceed without the TG-14 being in position. This decision needs to be communicated to the entire flight crew and addressed during crew briefs.

Another issue related to the airspeed of the TG-14 became apparent during mission turnaround throughout the SCAMP project. The remote location of the test site resulted in the TG-14 spending a great deal of time flying from EAFB to the test site, which limited the number of flights that could occur in a day. In the future, it would be ideal to have two TG-14s so that one airplane could fly one mission while the other was traveling to the remote test site. Regardless, if the ideal test site is remotely located, this location must be evaluated along with the decreased data gathering capability, and also weighed against the data gathering requirements and desirements of the project.

An issue that has routinely resulted in data loss is operator error. The instrumentation is operated by the FTE while the pilot flies the test point profile. The best results have been obtained when the operator was well acquainted with the system, usually from extensive use of the equipment on the ground, as the equipment tends to require troubleshooting at least once a flight. A very good understanding of how the system works and a familiarity with the common

issues can speed up the troubleshooting process, providing a better chance of gathering all of the data. The value of equipment operating experience was evidenced on SCAMP when FTEs with limited experience with the instrumentation recorded more data during flights at the end of the test than earlier flights.

Troubleshooting research instrumentation on the TG-14 often requires restarting the instrumentation system, which is difficult because the switch is located behind the seat of the FTE. Additionally, neither crewmember can see the screens on the instrumentation or the pallet on/off switch while inflight. Furthermore, to reduce pilot workload the FTE must be prepared to do all troubleshooting without any assistance. NASA AFRC has redesigned the TG-14 instrumentation pallet based on these lessons. Some of the improvements include relocating switches to more accessible locations, installing indicator lights for some of the switches, and moving equipment so that the screen is easily readable to the aircrew. Furthermore, the system was redesigned so that each piece of equipment could be power cycled individually without disrupting the remaining system components.

Usually the TG-14 will not operate directly over the ground array, due to the desire to record the boom as it propagates towards the ground array and/or the need to remain clear of other airborne instrumentation, such as the tethered blimp. The ground array can barely be seen from the air, but only if the flight crew already knows where to look and the airplane is at a relatively low altitude. If it is critical to the mission or mission safety that the TG-14 crew be able to see the ground array, it is highly advisable that the assigned aircrew take time during a proficiency flight to locate the array on the ground in advance. Even if it is not critical to the mission, it would serve the aircrew well to do such scouting, as this is useful in terms of visual reference and flight safety. In the event that this scouting was not accomplished prior to the test,

it is worth noting that vehicles – and the paths that they eventually create – are the easiest things to see from the air when the array is located on a lakebed. The ground boards can barely be seen, but only if the TG-14 is nearly directly over them and a crewmember is tasked solely with looking for them; spray paint markings near the ground boards are not visible from the air at the TG-14 operating altitudes.

Finally, the TG-14 whistles in flight, as do all gliders. To reduce the impact of the whistle on data quality all port and windows on the canopy are closed prior to recording and all wing seams are taped.

7.2.1.1 Electromagnetic interference Issues

The TG-14 causes electromagnetic interference (EMI) issues with the tablet PC, such that the propeller must be completely stopped before the tablet will function properly. If the tablet is on for any period of time while the propeller is spinning the tablet will freeze and stay frozen until restarted. Therefore, the tablet cannot remain on for the duration of the flight, and the FTE must wait to power on the tablet until the propeller is no longer moving, otherwise the tablet will not boot correctly. It is suspected that this EMI issue is caused by the magnetos but has yet to be confirmed due to time and workforce constraints. The lesson learned for future programs is to fully investigate the possibility for EMI with all instrumentation for all new configurations. NASA AFRC has recently updated the TG-14 instrumentation for future projects and completed thorough tests to ensure that no EMI issues were present, resulting in a system that requires very little troubleshooting during operation.

7.2.2 Tethered Blimp

The Airborne Acoustic Data Collection (AADC) system is owned and operated by Cessna Aircraft Company and was used for the SCAMP and FaINT campaigns. The system

consists of a 32ft long, 8ft diameter helium balloon with directional fins attached to a 3500ft long steel tether truck-mounted winch capable. The tether has a 1300 pound minimum tensile strength and the winch is capable of a 300 feet per minute retraction rate. The AADC is also equipped with a radio controlled flight termination system and can hoist up to three Brüel & Kjær (B&K) microphone recorders and GPS receivers.

Between flight days the blimp was partially deflated and stored in a rented moving truck. Operating wind limits were 20 knots while moored, and 6 knots during transition to different altitudes. The blimp has been used around Kansas with three B&K model 2250 microphone data recording systems, and GPS data loggers. It was discovered during SCAMP's flight phase that the higher density altitudes of the High Desert near NASA AFRC lowered the lifting capability, so only two microphone recorders could be lofted. The decreased lifting capacity combined with the weight of the tether and the two microphone recorders caused the tether be horizontal quite a distance from the anchoring truck and then gently arc skyward toward the blimp. As winds would change direction the tether would swing around across the ground and ground personnel would need to be mindful of its location. The lesson learned from tethered blimp operations is that equipment functionality can vary with location, especially when optimal operation relies on specific weather conditions. Such equipment should be tested on-site prior to use and designed conservatively.

For the SCAMP effort the blimp was deployed up to 6,300ft mean sea level (MSL). The TG-14 needed to be clear of the blimp visually, or above 7,000ft MSL if the blimp was not in sight. Similarly for FaINT, the blimp was deployed up to 5,300ft MSL. The TG-14 operations were supposed to occur between 4,000 to 7,000 AGL, and if the blimp was not in sight the TG-14 would need to be above 6,000ft MSL. The Alpha Corridor airspace in the DATR would be

subject to a NOtice To AirMen (NOTAM) keeping out all other traffic below 7,000ft MSL when the tethered blimp was airborne, articulated as the "Blimp Area Hot". This area was fairly close to the main runway at Edwards Air Force Base, and the Air Force Airspace Manager wanted to ensure that other air traffic (mostly high performance airplanes) would not conflict with the tethered blimp and the TG-14.

With a maximum wind limit for tethered blimp operations at 20 knots and an altitude of 6,300ft it was determined that hard hats should be worn by ground personnel within 1,750ft of the tether anchor point. This would ensure (so the team thought, see Section 9.1) that any parts that might fall off of the blimp would not hurt personnel on the ground below.

8 Flight Phase

Careful attention to detail during all previous phases of the project increases the efficiency of the flight phase. During this phase it is important to revisit and emphasize each team member's duties and POC roles. Clear and effective communication is crucial, as this phase passes quickly, but is consistently the busiest part of the program. For the purposes of this report, the flight phase is being defined as the time from when the fieldwork begins, until after the flights are complete and the supporting equipment is returned. Tasks to consider during the flight phase include test equipment deployment, operations, and retrieval; flight and field crew responsibilities; research team communications; and documentation.

8.1 Test Equipment Deployment, Operations, and Retrieval

Immediately prior to the flights, the workload of the team begins to ramp up as the remaining coordination tasks are finalized and the team begins to prepare for the test. This

section will discuss the tasks leading up to the test that must be done to ensure successful test execution and data analysis including the pre-flight campaign, equipment deployment, and equipment pick-up.

8.1.1 Pre-Flight Campaign

The preflight campaign largely consists of preparing the test site and equipment for setup in addition to deployment of the equipment. This phase is relatively short, but begins a marked increase in workload for the team.

8.1.1.1 Surveying and Marking

Prior to the test, especially in cases where knowing the exact placement of each microphone is critical to analysis, the position of each ground board and microphone should be surveyed and staked or marked. If the flags or marking will be removed when the instrumentation is installed or deployed, the survey data should be checked to ensure accuracy and completeness of the survey prior to such removal. In the past, metal templates have been used to speed up the process of spray painting the outline of the ground board locations, but on a few days this was a less than optimal solution as the template was more of an unruly object with sharp corners than helpful, especially when exposed to 60 mile per hour winds. Finally, in the event that spray paint is used in marking, water based, biodegradable spray paint is nominally acceptable to most environmental authorities and does not require any clean up.

8.1.1.2 Equipment Calibration

The acoustic recording equipment requires annual calibration. Some of the equipment can be calibrated by AFRC personnel, but some equipment must be sent to the manufacturer for calibration. When preparing for a test it is important that the team be aware of the calibration

processes and take into account the time required to complete these processes, especially when the manufacturer is involved. When arranging for the microphones to be calibrated, it is important to consider any tests expected to occur within next year, as altering the configuration of the microphone invalidates the previous calibration.

B&K microphones can include a Low Frequency Adapter (LFA) or can be used without an LFA. Low Frequency Adapters allow microphones to pick up lower frequencies, but unfortunately also attenuate the signal at higher frequencies. Therefore, if the shape of the sonic boom is more important than the data, then the LFA is acceptable or even preferable to use, depending on the frequencies being measured. If the data will be used to compute the Perceived Level of Noise in Decibels (PLdB) or played back for human testing, LFAs should not be used.

8.1.2 Equipment Deployment

Many of NASA's sonic boom flight research projects involve deploying large microphone arrays in expansive secluded areas before the flight phase. The need to maximize the number of trained people available for equipment deployment cannot be overstated. The amount of time and physical effort required to deploy instrumentation is obviously directly proportional to the amount of workforce available. As a reference, the FaINT project had adequate staffing; about 30 trained people deployed over 120 microphones.

Prior to deployment, all equipment and cables should be labeled and there should be a checklist indicating where each piece of equipment should be deployed. The project schedule should include dedicated time prior to deployment to go through each pallet or container and perform a walkthrough of the deployment plan: what piece of equipment goes where, who is responsible for it, and in what order the equipment should be deployed.

Certain test site locations may present unique challenges. In publically accessible there may be the concern of people tampering with the equipment. Therefore, if equipment will be unattended for long periods of time in such areas, equipment housing should be rugged or a security detail should be employed. Rugged housings will also help prevent animals from damaging equipment. The most successful method to prevent unattended cables from being chewed is threading cable through polyvinyl chloride piping; the reader should be advised that this is time intensive, and works best when there are only a few short cables. Animal repellents have been used, but with only minimal success.

Another thing to consider when deploying equipment is recognizing any deployment equipment limitations, such as wind limits on forklifts. When instrumentation will be left at the test site overnight, it is beneficial to mark the test site with reflectors to avoid vehicles driving over equipment and cabling. The project should also be aware of any time limitations imposed by the landowner. For example, the WSPR project was surprised to find out that Edwards Air Force Base management would only allow equipment installation during daylight hours. This limitation was realized during the first day of equipment deployment. Since the project had planned to do instrumentation installation overnight, the restriction greatly increased deployment time and could have caused project delays if the team was unable re-assign tasks to allow more personnel to help with the deployment.

8.1.3 Equipment Pick-up

Lessons learned for equipment teardown and pick-up for NASA sonic boom flight research projects are generally similar to those discussed for equipment deployment (Section 8.1.2). However, there are a couple of additional distinct considerations. While most previous projects scheduled equipment pick-up immediately after the last research flight, it is suggested

that future project schedules include days after the flight phase completion for pick-up. Such a schedule would result in shorter workdays as well as a less-rushed process with more orderly stowing. Projects with equipment deployed should expect it to get dirty. Therefore, when possible, it is also recommended that equipment be cleaned as it is retrieved. Cleaning in the field has proven easier than doing so inside a building after equipment has been relocated.

8.2 Flight and Field crew Responsibilities

A significant amount of time prior to the test should be spent thinking about what needs to be done each day and how to task team members accordingly. No single person or group should be overtasked, and each person needs to know their daily duties and how those duties fit in to the big picture. Staffing in this manner limits chaos and presents a professional, united image to the team (including external partners), any authoritative entities, and to any visitors to the test site.

Most importantly, the morning task load of the Principle Investigator (PI) needs to be managed. In the past, the PI has been responsible for calling into the morning crew brief, performing the pre-flight planning, communicating the waypoints to the flight crew, shuttling people and equipment around the test site, and assisting with instrumentation setup and calibration. This is too much for one person to handle in the span of one to two hours, especially if there are issues concerning internet access or getting the pre-flight planning code to run.

While the previous tests have all been successful, the logistics of the tests would have been much less complicated if the team had more help from people who were consistently available. Ideally these field crew members would have a background in electrical engineering and/or electronics (which is helpful if the instrumentation requires troubleshooting) and would be

well acquainted with the equipment and procedures of the sonic boom team. Thus, in the future, it is recommended that a brief equipment familiarization training is provided to all field crew members internal to AFRC.

Finally, when the test site is in a controlled access area, such as the Roger's Dry Lakebed or the EAFB Flight Line, the need for several people with Flight Line Driver's Licenses (FLDLs) is critical to efficiency. During FaINT, four people had valid FLDLs, and a significant amount of these team members' time was spent shuttling equipment and/or people around the test site. This effort would be less of an issue if the people holding FLDLs were not also the core sonic boom team members, and thus the most knowledgeable personnel on NASA AFRC's equipment. Future tests would be well served to increase the number of available drivers and to ensure that some of those drivers, likely volunteers, can be solely tasked with driving.

8.2.1 Pre-flight Planning

As mentioned previously, the PI is responsible for the pre-flight planning on a daily basis. Pre-flight planning is often performed using PCBoom, a code created and developed by Wyle. To obtain flight waypoints for the pilots, the PI runs a MATLAB code that reads a weather and a trajectory file into PCBoom. This MATLAB code is usually created by the PI. PCBoom will not run if the input file is not formatted correctly and weather files sometimes contain a random error which is not easily visually apparent, so troubleshooting the code and the inputs on the day of flight has occurred in the past. Such troubleshooting, programming, or re-programming is not easy to accomplish when crew rest is lacking. Maintaining backup copies of the code and avoiding requirements creep in the code are both encouraged. In cases where exposure levels over the duration of the test are important it is advisable to have separate, back-up pre-flight planning code ready in case louder or quieter booms are needed.

The weather files utilized in this pre-flight planning process are usually weather balloon data files. If the balloon data are unavailable for some reason, model weather data provided by NASA AFRC meteorologists are used instead. During FaINT it was discovered that PCBoom, for unknown reasons, produced an unbelievable result every time an early morning weather balloon file was used; thus model weather data was used instead of balloon data for early morning flights. While the team does save all of the weather balloon data or model data that was used, it would be helpful to save all model data that could have been used in the pre-flight planning process to allow the team to study how inputs of model data versus balloon data would affect PCBoom outputs.

8.3 Research Team Communications

One of the challenges unique to sonic boom flight research projects is that it is essential for the field crew to communicate with each other and with the control room, but the field crew may be spread out over a large area. The solution to this issue requires field radios, a communication hierarchy, and some creative thinking.

As previously mentioned, the use of family camping or hiking style walkie-talkies by the government is prohibited, and the use of such radios is also prohibited on military bases. If the test site is not on a military base and the test is headed by a non-government authority, then the use of these radios may be acceptable. This style of radio usually has several different channels, which is useful for assigning each partner or each task team a unique channel. This allows for more communication while limiting the amount of communication traffic, but has the drawback that one can only communicate with someone on the same channel.

Verizon Push-To-Talk phones have been used to facilitate field-to-field and field-to-control room communication in the past. However, the Push-To-Talk feature operates as an app that transmits data on cell networks, and are thus quite unreliable in locations where cellular coverage is at a minimum or where cellular networks are already overloaded with traffic.

VHF radios can also be utilized for field communication, however it is important to know that these radios require a clear line of sight to communicate and reflection can easily corrupt the signal. These radios are not useful when the test site is on a lakebed, a large swath of concrete, or other such hard, smooth surfaces.

The best tool for field communication and field-to-control room communication, based on past experiences, is a set of LMRs. The control room can be set up to access the LMR frequency assigned to the test team and the radios are very reliable, which allows for timely communication during the flight.

Regardless of the type of radio utilized, it is strongly encouraged to reserve and set-up a back-up set of radios. Often the backup set is a different variety than the primary set. Furthermore, it is incredibly important to test the radios in the field prior to the beginning of the test window, as it is much more seamless to swap out radio types before the test begins than in the middle of test set-up or field operations. Frequently, the test day is longer than the battery life of mobile radios, so holding back a spare radio or three is a wise idea because usually the radios that are most critical (and thus get used the most) run out of battery power first.

During the test it is critical that the field crew know when to expect the boom so that any manually triggered recording systems are activated at the correct time. The beginning of each pass is typically communicated over the field radios, but it is best to have a backup plan in the event that the radios fail. In some instances this has involved the use of a back-up

communication system such as an Ultra High Frequency (UHF) receiver, while in other instances where the F-18 was performing a low-boom dive maneuver the field team simply watched for the unique contrails. Despite the use of backup communication systems, the team always briefs the predicted propagation time of the boom during the crew brief or through email when the test points are sent to the flight crew. This helps the team guess roughly when they should hear the boom in the event that radios fail. If the radios are functional it helps the field crew know how long the expected delay is between the "mark" call (indicating that the boom generating airplane is at the proper flight conditions) and the boom, so that radio chatter does not occur during this window, causing a loss or a corruption of data.

While the hardware is important, nothing will more effectively facilitate communication during times of urgency than a well thought out protocol that is followed by all team members. The NASA AFRC team experienced the best outcome concerning communication protocol during FaINT. FaINT began with a Day One Briefing, which included a discussion of the communication protocol, as well as a hands-on demonstration of the radios. The communication protocol should be created with two considerations in mind: safety and test efficiency. There is often a very short amount of time between passes that the PI can relay trajectory changes to the pilots; doing so requires a quick survey of the qualitative field data (each field station reports what they heard) and making an assessment and decision from there. During FaINT, pre-determined arm positions were used to inform the binocular wielding PI of what each field station heard; this worked well except for when field members forgot which sign belonged to which auditory queue, so in the future it is suggested that one page reference sheets listing out such signals are produced for each field station.

On a more individual note, personnel who are operating more than one radio are encouraged to implement their own protocol to eliminate confusion regarding which radio is used for which channel. A popular and easy system to implement is to clip one radio to each hip, designating each side as only for Channel A or Channel B for the duration of the test.

Finally, participating in the pre- and post-flight crew briefs helps eliminate confusion between the pilots, the control room staff, and the field crew while providing context for any changes to operating procedures or communication protocols over the course of the test window. It is advantageous for the entire field team, or at least a few key leaders of the field team, to attend or call into the pre- and post- flight crew briefs. Furthermore, since field communications, procedures, and hardware operation are refined on a daily basis (as previously mentioned), a short all-hands meeting for the field crew at the beginning and end of each test day is a great time to communicate any new obstacles or concerns, while also allowing the team to provide input on their own concerns or obstacles. However, it should be noted that in order for these quick meetings to work, everyone needs to be present, which requires that the field team lead be firm about the arrival time.

8.4 Documentation

Documentation is an important part of every flight phase. Thorough photography and field notes, including file logs, are critical to post-flight analysis. The tasks to ensure adequate documentation were learned over the course of NASA AFRC's sonic boom flight research projects.

8.4.1 Photography

As quoted from Sarah Arnac:

"The test set-up should be extensively photographed for documentation purposes. This photography should include sensor orientations and locations and show placement of the equipment relative to any nearby stationary landmarks. The landmarks can be used to relocate equipment if GPS surveying data is not available. The photographs should also be checked before sensors are moved to ensure the detail needed for future reference is captured.

Many photographs were taken during SonicBOBS; however, none were taken with the specific purpose to document the location or orientation of the sensors. Test set-up photography had not been considered a requirement because the equipment locations had been previously surveyed with a GPS and marked with flags. Unfortunately, it was discovered after the test (and after the sensors had been moved) that the GPS data had not recorded properly. While the lesson learned here again was to check the data before the end of the test, the photographs that had been taken were a great asset and used for post processing where applicable.

With the large sensor array for FaINT, it was thought that aerial photographs would be a good way to document the test set-up. Unfortunately, the array was not visible well enough from the air to capture the equipment location, even with high-resolution digital photography. The array was documented through a series of ground photographs and the lesson learned is that aerial photography is not a sufficient means of documenting the array layout."

8.4.2 Field Notes

As quoted from Sarah Arnac:

"Copious field notes should be taken during a sonic boom ground test. These notes should be in a predetermined, organized format to reduce potential knowledge- and data-loss over time. Prior to the flight campaign, the personnel responsible for generating, disseminating,

and collecting flight test documentation should be identified well in advance. A place for file logs, lists of the file names associated with calibration, and test data should also be included in the field notes. If additional comments or ‘rough notes’ are recorded, the author should clarify the comments on the written document as soon as possible.

General lessons learned from SonicBOBS and SCAMP motivated the WSPR team to agree upon both the content and the format of field notes prior to first flight. This process worked well, however, individual field notes, although they made sense to the writer at the time, were not ‘decoded’ post-flight. This caused the flight notes to lose some of their value as time progressed due to the writer’s knowledge loss on what they meant or were referring to during the test.

Several individuals took detailed field notes during FaINT while collecting data from various sensors. However, during initial post-processing, it was a challenge to find any specific data file. This challenge was, in part, because there had not been a file naming convention established between all recording personnel ahead of the flight campaign. The lesson learned is that time stamps in the field notes and a uniform naming convention for all data files are crucial to smoothly and successfully analyzing the data.”

9 Mishaps and Close Calls

While each of the tests pertinent to this paper were successful, they were not flawlessly executed; therein lies valuable lessons learned. The sonic boom team prioritizes the safety of all crewmembers and takes any incident, no matter how minor, seriously. For these reasons, the following incidents are included, as well as lessons learned. The reader should note that the blimp incident, the T-34 incident, and the TG-14 incident are all written in a narrative style

because studies have shown that a narrative format helps the reader internalize a lesson more than a clinical format. As these incidents were among most serious lessons learned, the authors wanted the reader to understand the gravity of such lessons.

9.1 Blimp Incident

On Saturday, May 7, 2011, the blimp operators were adjusting the rigging of the blimp, which required moving the bridle of the tether with respect to the guy-wires from various parts of the blimp. At an altitude of about 1,000 ft AGL an unexpected wind shear was encountered, and the blimp exhibited an unstable bucking motion. Winds were variable in speed and direction with gusts up to 12 knots. Due to the bucking motion, a GPS receiver housing, about 6 in x 4 in x 3 in and weighing around two pounds, departed the blimp and landed on the ground. It landed 50 ft outside the 1,750 ft hard hat zone. In the original analysis it was assumed that any part falling off the blimp would drop straight down; ejection from a bucking blimp was not considered. The event resulted in no injuries and damage was less than $500, and so deemed a non-mishap, no greater than a close call. After review of the incident the hardhat zone was increased to 2,000 ft from the tether anchor point, and a better attachment than the original four sheet metal screws holding the GPS receiver housing was fabricated. The main lesson learned here is that the team should be as thorough as possible when listing project hazards and strive to include the effects of off-nominal conditions. All further NASA AFRC projects utilizing a blimp to loft instrumentation have determined the hardhat zone radius to be one seventh larger than the height of the blimp, as the guideline was revised above.

9.2 T-34 Incident

On Wednesday, November 07, 2012, during the twelfth FaINT flight, an incident occurred involving a NASA T-34 airplane in the area of the blimp operation. At the start of the test day, Edwards Ground was contacted and permission was received to make the blimp area hot. The blimp then started its ascent to 3,000ft AGL. As usual, the tether assumed its nearly horizontal orientation near the ground, then arcing up and to the north of the linear microphone array. During the blimp ascent the field crew at the blimp noticed a small airplane at an altitude of a few hundred feet flying along the microphone array toward the blimp anchor point. The ground controller on site immediately announced the airplane position, and called for an immediate retraction of the blimp.

The ground controller soon realized that there was no chance that the blimp could be retracted to the ground before the airplane passed, and ordered the descent to stop. Better to have a motionless blimp than a descending blimp with an approaching airplane.

The airplane stayed to the south of the microphone array, away from the tether, and completed his pass safely. It was the NASA T-34 airplane with an aerial photographer onboard documenting the microphone array layout. This aerial photography pass was not coordinated with the field crew. The ground controller was not on the teleconference for the preflight crew brief when this photography pass was briefed. The lesson learned here is that – at a minimum – key ground personnel need to attend or call in to the crew brief or important information will be lost, so that a similar incident never reoccurs.

9.3 TG-14 Incident

During one of the final FaINT flights there were several minor miscommunications and events that culminated in a close call. FaINT consisted of thirteen flights; the TG-14 flew in

twelve of these flights. Of the twelve flights involving the TG-14, the first eleven were flown by the same pilot, and the majority of those flights were also staffed with the same FTE. For the twelfth flight, a new pilot was assigned to fly the TG-14 along with one of the project's experienced FTEs.

During the twelfth flight, the TG-14 aircrew was not hearing the booms, but had also been briefed that the propagation times for the booms on this mission were very long. Standard operating procedure is that the TG-14 aircrew remain gliding and listening for the boom, several seconds after the predicted propagation time expires. Therefore, the nature of this flight required large amounts of time gliding, which means that a significant amount of altitude was lost on each pass. This issue was complicated by the fact that over the course of the flight the altitude of the test points was not consistently decreasing. Climbing in the TG-14 is not nearly as quick as the amount of time it takes the F-18 to return to its starting position for the next supersonic pass. As such, the TG-14 was usually slightly below the desired test point altitudes on flight twelve, increasing the propagation time for the boom to reach the TG-14 (leading to an even greater altitude loss). Furthermore, the area that the TG-14 was usually in during the FaINT missions was to the east of the instrumentation array, such that the TG-14 was well away from the blimp. During flight twelve, the long glide times brought the airplane further and further west on each pass, as the airplane did not always have enough time to return to the starting point at the east for each pass. A contributing factor to this creep was that in the past, the pilot would begin to turn the airplane around while the FTE was shutting the computer down to help reduce the amount of time it took the TG-14 to get back into place. The new pilot did not operate in the same manner as the prior pilot, and was also concerned with maintaining as much altitude as possible due to the fact that the test points were not in order of decreasing altitude.

The TG-14 aircrew also had to deal with a “high oil temperature” light in flight, which meant that the mission was ignored in favor of flight safety. During these instances, the emergency procedure checklist called for the engine to be turned off, which resulted in a further loss of altitude.

Towards the end of the flight, the TG-14 was gliding and was already quite low and close to the instrumentation array. There was a quick turnaround between the second to last and the last pass, and thus at the beginning of the last pass the airplane was nearly over the instrumentation array and at a relatively low altitude. Luckily, The FTE glanced up from the tablet PC and saw the TG-14’s course. The FTE pointed out the blimp and the cable to the pilot, who indicated that he was not able to see the cable. While the course was altered, the airplane’s proximity to the blimp and its cable was concerning to both the aircrew and the field crew. This was discussed during the post-brief, during which the pilot voiced his concern that the altitude of the blimp and its typical cable orientation need to be clearly communicated and understood by all aircrew members on each flight. One lesson learned is that key field crew members must be actively involved in the crew briefs so that critical information is communicated. Another lesson learned is that even at the very end of the flight phase, the team needs to be just as vigilant as they were on the first day of flights. This means that if a new aircrew member joins the team, even at the end of the project, they need to briefed just as the aircrew was at the beginning of the flight phase.

10 Post Flight Phase

10.1 Logistics

The first item of business after the test tear down is complete is to return borrowed equipment to the test partners. Since the test has been executed and that data is available for processing at this point in the project, it is easy to underestimate how much effort is required for this task. Partners prefer equipment to be returned as quickly as possible after the test and sending the equipment back requires coordination between NASA AFRC and shipping companies. Thus, a team member is usually required to be on call to work with shipping companies. Given the above, the return of equipment is no small effort, and the test should not be considered complete until all equipment has been sent back to the owners. Therefore, one person must be placed in charge of this task, and serve as the POC for communicating with shipping companies; ideally, the POC is the equipment owner. This would requires that tests not conclude at the end of a week so that partners are more likely to remain on site to supervise the return shipping process.

At the conclusion of a test all involved parties will want to look at, or at least acquire, all of the data. While this desire is anticipated, accumulating and distributing the data is no simple task, and the expectations for receiving the data need to be managed. The timeline for gathering the data from the partners, wrapping all of the data up into one time-synced package, getting approval from export control to send the data out, and actually sending the data out needs to be discussed with the partners well in advance. It is preferable that this timeline is discussed prior to the test – during planning and coordination – on a general or rough estimate level, while the more accurate and detailed timeline estimate should be presented to all parties during the Day One Briefing.

10.2 Recording Project Details

The project details should be collected, evaluated, and recorded directly after the flight phase. The information compiled should include flight information, personnel involved, field notes, outputs, data files and formats, incidents, if any, and lessons learned. The documentation of these project details should be completed using an organized format with specific content required, such as a ground report. Recording these project details should be considered a priority and made readily available for future tests.

Although the aspects of early sonic boom flight research projects tests that went well or could be improved upon were discussed during debriefs, they were not recorded in any formal document in 2009 or 2010. This resulted in several of the lessons being re-learned throughout other tests.

By the time FaINT was conducted, it was recognized that standard NASA flight reports were a useful historical document, but did not capture all of the information necessary to repeat any experiment. To record the supporting project details, a ground report standard was generated. This document included the test set-up documentation and field notes. After FaINT was conducted, the ground report was modified to include lessons learned, additional field notes, and the file logs.

10.3 Post Flight Data Processing

Post-flight data processing should occur as soon as practical after the flight phase. Additionally, standard challenges to timely post-flight analysis should be recorded and addressed between projects to improve efficiency. For example, during WSPR, there were instances where the weather balloon terminated early, and therefore balloon information had to be pieced together

from multiple balloons. A standardized technique for this was created after WSPR to reduce post-processing time.

The post-processing challenges encountered during FaINT concerned the data timestamps. As all equipment referenced Coordinated Universal Time (UTC), even though all individual project flights occurred during a single calendar day, some data timestamps went past midnight in UTC (a transition from 23:59:59 to 00:00:00). The standard post-processing scripts did not work with a reversion in time and a solution to this challenge is still being developed.

10.4 Communicating Thanks

As quoted by Sarah Arnac:

"Thanks and appreciation should be communicated to supporting groups in a timely manner. This correspondence should include what the project accomplished and how the supporter specifically made a difference in the project's success. In addition to being a common courtesy, this action fosters working rapport, and should not be overlooked.

WSPR set up a 'Thank You' event to pick up community surveys and phones. By passing out participation incentives at this event, the 'Thank You' event had high attendance. Despite this system, two people received their incentive before returning their phones; however, at the request of their commanding officers, the phones were returned.

A less formal post-flight party held after work hours at the conclusion of FaINT was beneficial. In addition to building comradery, this party allowed participants to discuss follow on tests with the FaINT project fresh in their memory. The team also shared lessons learned to others who had not directly participated in FaINT, were not on site for the entirety of the test, or had not previously been involved in such work."

11 Conclusion

While SonicBOBS, SCAMP, WSPR, and FaINT were all successful, it is obvious that a wealth of lessons learned were gleaned from each test. Perhaps the biggest lesson learned came from consolidating all of these lessons into one document: it is critical to reflect on the planning and execution of a test before moving on to new endeavors and to document these lessons, otherwise they may not get passed on to new team members or seem as important once time has passed. The primary lesson to be gleaned from these tests is that it is of utmost importance to plan for tasks to take significantly longer than initially predicted to allow for buffer due to process, technical difficulty, troubleshooting, equipment malfunction, and other unknown unknowns. Secondly, always try to take load away from the test window by front loading as much of the work as possible – this includes a thorough test location checkout. Third, setting up the test schedule and/or tasking to allow data to be examined between flights can reduce lost data when the team returns to the office. Fourth, there is always a need for more crewmembers, and prioritizing crew rest eliminates burnout and increases efficiency. Finally, no matter how far the test takes the team from their home base – be it South Base on EAFB or several hours away at Cuddeback – the complexity of the test increases exponentially with the distance to any deployment.

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1 Appendix A

Lesson Learned	Section
Set test dates early in the project's lifecycle	6.1
Take time to carefully define requirements and refer back to them frequently throughout the project's lifecycle	6.1.1
Field visits - during and after site selection - are crucial to test success	6.1.2, 6.4.3
Implement commitment deadlines for potential partners	6.1.3
Set expectations of all partners and stakeholders early in the project's lifecycle	6.1.3
Deployments greatly increase the complexity and cost of a project	6.2
Together, the team must carefully create a plan of action for each part of the test and coordination effort	6.3
Determine staffing needs for the test early in the project's lifecycle	6.3
When coordinating with an outside authority, work to maximize freedom for the field crew during the test window	6.3.1
Each coordination effort should have only one POC; any hand-offs of duties need to be addressed with the external stakeholders to minimize confusion	6.3.1
Environmental factors and concerns will impact all field tests	6.3.1
Determining who to coordinate with requires a significant amount of time and effort	6.3.2
Know as much as possible about all test operations and equipment when beginning to coordinate with facilities managers	6.3.2
Continue to set expectations of visiting team members prior to the test window	6.3.3
Sonic boom-related and testing-related stigmas can complicate the planning and execution of a test	6.3.4
No matter meticulous the site selection was, there will always be extraneous noise during the test window	6.3.4
Build time into the schedule to look at data between flights	6.4.1
Crew rest must be considered and properly addressed	6.4.2, 8.1.2
Be brutally realistic when creating the schedule	6.4.2
Planning and checking out how all equipment will function at the test site is crucial to test success	6.4.3
Field crew training must include the basics of daily operations, an overview of the test, location specific training	6.4.3
All field crew operating hardware must have detailed, hardware specific training	7.1.1, 7.2.1

The environment will adversely affect hardware in many ways - try to anticipate and mitigate as many of these effects prior to equipment deployment	7.1.2
Thoroughly checkout all new hardware and software prior to deployment. Do not allow any changes after this checkout	7.1.3
Equipment in aircraft needs to be accessible to the aircrew to facilitate troubleshooting	7.2.1
Whether aircraft-captured data is required or desired will greatly impact how the test is executed	7.2.1
Hardware can operate vastly differently in different environments	7.2.2
Complete the survey and verify that the data is good before the test	8.1.1
Ensure that all equipment is properly calibrated well before the test	8.1.1
Create a deployment plan and walk through it with the entire test team prior to deployment	8.1.2
Label all equipment, and group accordingly prior to deployment	8.1.2
Many, trained people are needed during equipment deployment	8.1.2
Mark instrumentation with signs and reflectors	8.1.2
Include time in the schedule for equipment pick-up	8.1.3
Realistically task all field crew - this is especially important for critical personnel	8.2
Always have a backup copy of the preflight planning code	8.2.1
Camping radios/walkie-talkies cannot be used by the government or on government facilities	8.3
Always test all communication devices in the field and always have a backup set of radios	8.3
Create, utilize, and enforce a communication protocol for field use	8.3
Field crew members need to be part of all pre- and post-flight briefs	8.3, 9.2
Field crew briefs are essential to smooth day-to-day operations	8.3
The test set-up and layout must be extensively photographed	8.4.1
Field crew notes are invaluable	8.4.2
Carefully think through all hazards or potential hazards prior to the test	9.1
All new team members must be thoroughly briefed about the project regardless of when they join the team	9.3
Set expectations regarding data dissemination during the planning and coordination phases	10.1
Shipping equipment back to partners is time consuming and best if performed by the equipment-owners	10.1
Field reports must be created shortly after the test to fully capture all field notes	10.2
Clearly and explicitly document any time changes that occur during the test window (for example, the shift to daylight savings time)	10.3

Thank you gestures and events at the end of test are good for morale, gathering equipment, and discussions of future studies	10.4

1

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3 Figures

4

5 **Figure 1. Example of SonicBOBS instrumentation array.**

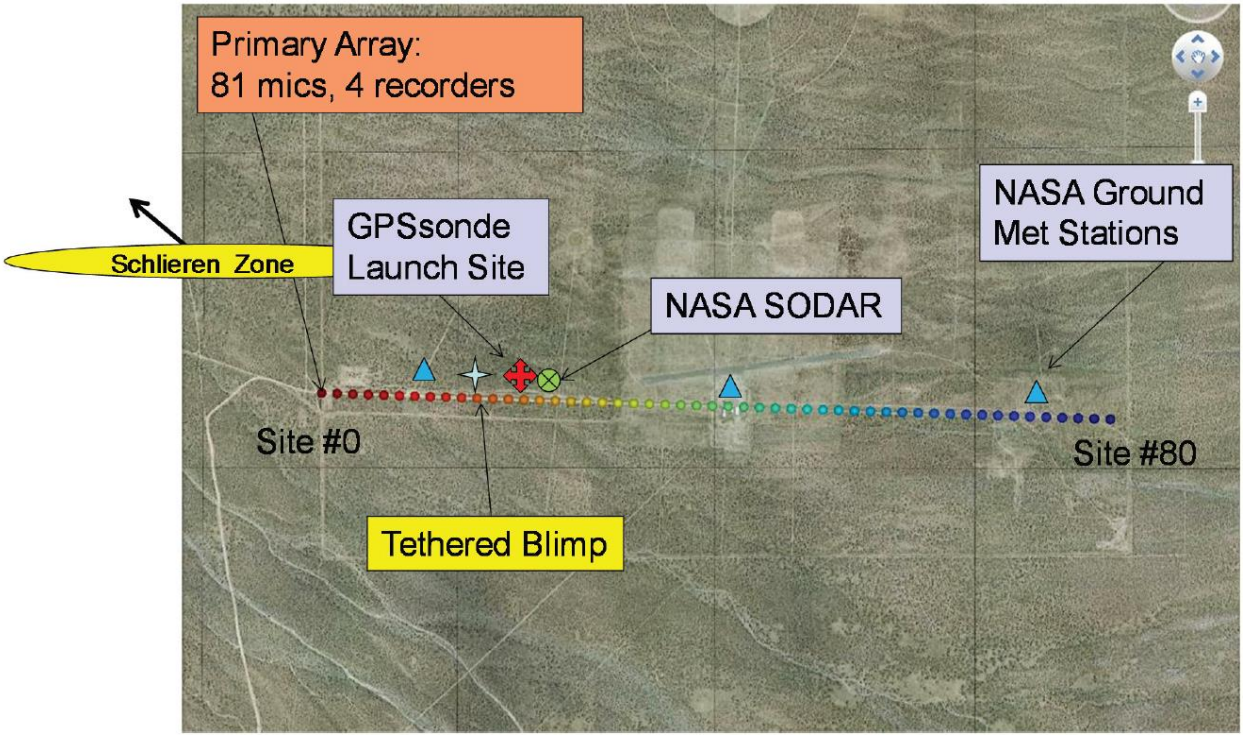

Figure 2. Notional SCAMP measurement site layout diagram.

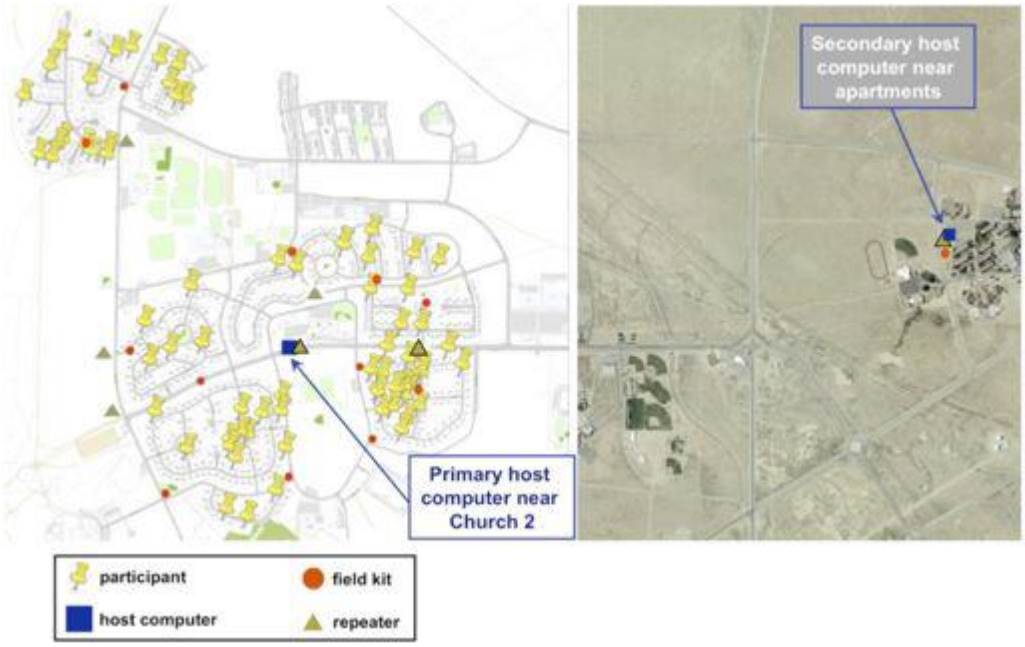

Figure 3. WSPR microphone and survey participant locations.

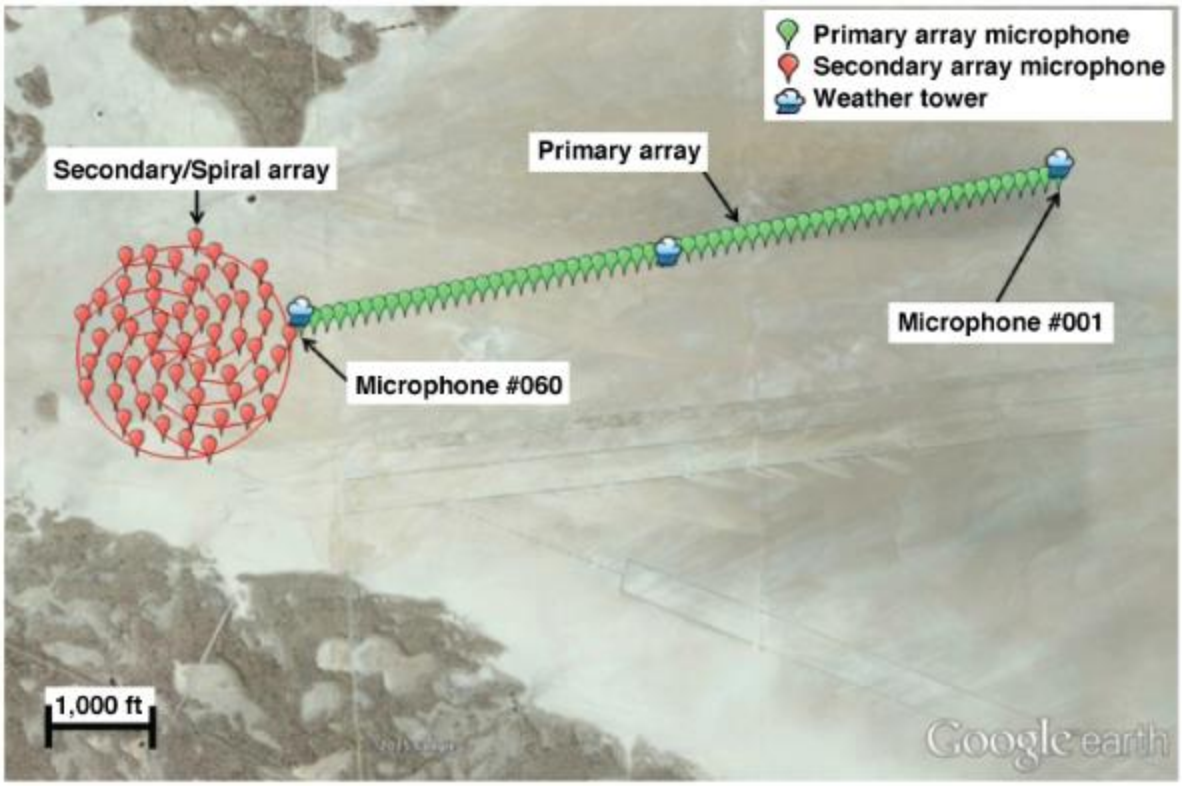

Figure 4. FaINT Mach cutoff ground microphone arrays.

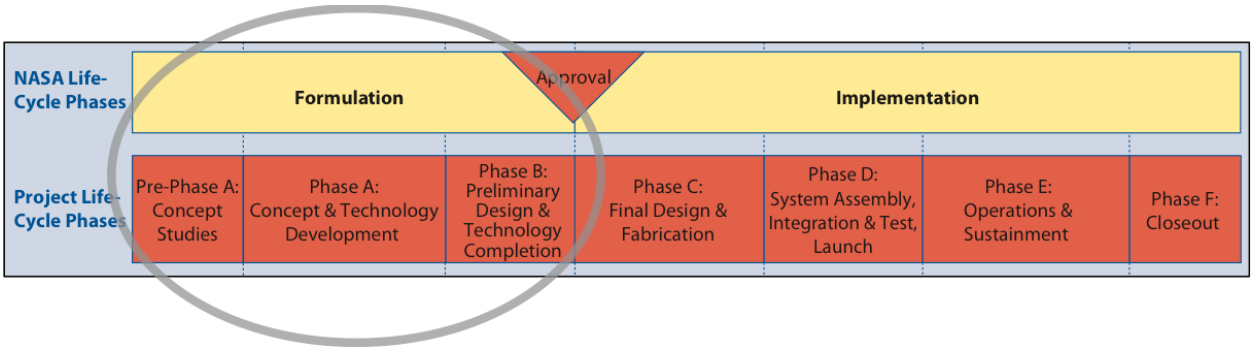

Figure 5. NASA Project Life Cycle.

Figure 6. The wingtip-mounted microphone on the TG-14 motorized glider, with inset close-up of microphone.

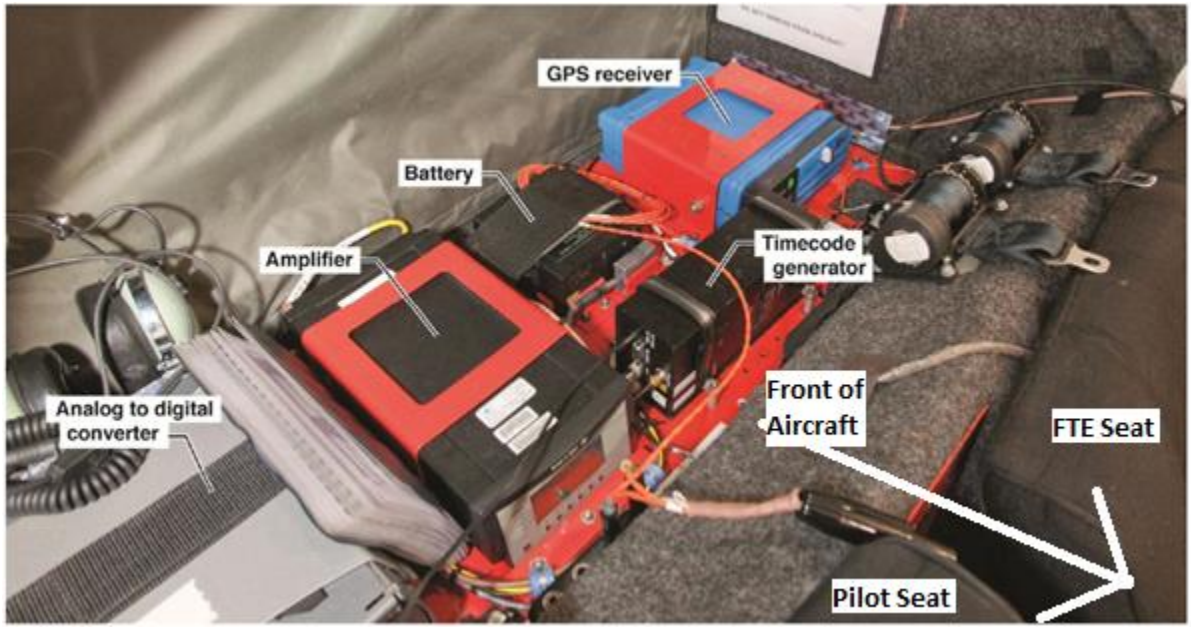

Figure 7. The TG-14 instrumentation pallet. From left to right: analog to digital converter; amplifier, battery, GPS-based IRIG-B Time Code Generator, GPS receiver.