ICA 2013 Montreal  
Montreal, Canada  
2 - 7 June 2013  

Noise  
Session 2aNSc: International Aviation Noise Standards  

2aNSc2. Developing noise standards for future supersonic civil aircraft  
Robbie Cowart*  

*Corresponding author's address: Program Management, Gulfstream Aerospace Corporation, POB 2206, M/S R-07, Savannah, Georgia 31402, robbie.cowart@gulfstream.com 

With renewed interest in civil supersonics, NASA and industry researchers continue to make progress toward enabling quiet civil supersonic aircraft. Gulfstream Aerospace has long been interested in the development of an economically viable supersonic business jet, however many regulatory challenges still remain for routine supersonic operation. Gulfstream's approach includes unrestricted supersonic flight over land to enable the same operational flexibility of its subsonic fleet. The largest technical barrier to achieving this end is mitigating the sonic boom created by flying at cruise speeds greater than Mach 1.2. At present, the United States and many other countries prohibit supersonic flight over land due to the loudness and public annoyance associated with sonic boom noise. In the U.S., the FAA prohibits supersonic flight over land under FAR 91.817. Although the FAA has shown interest in reconsidering its position, the agency supports the noise and emissions standards setting process through the International Civil Aviation Organization and its Committee on Aviation Environmental Protection. Development of future standards for sonic boom noise is a key component to enabling continued investment in civil supersonic research. This paper will outline the steps currently underway to assess the viability of defining low amplitude supersonic signature acceptability.
OVERVIEW

Steady progress in low boom research over the last decade remains encouraging. As a result, aircraft manufacturers are advocating for new noise regulation on sonic boom, the remaining technical barrier to the elusive civil supersonic transport aircraft. Both domestic and foreign research agencies have sponsored fundamental and system-level noise research including recent flight programs conducted by the National Aeronautics and Space Administration (NASA). At present, the United States and many countries prohibit supersonic flight over land due to public annoyance associated with sonic boom noise. The Federal Aviation Administration (FAA) has shown interest in reconsidering this position; however, the agency supports the noise and emissions standards setting process through the International Civil Aviation Organization (ICAO) and its Committee on Aviation Environmental Protection (CAEP). Development of future standards for sonic boom noise is a key component to enabling continued investment in civil supersonic research. This paper outlines the steps currently underway to assess the viability of defining low amplitude supersonic signature acceptability.

BACKGROUND

The aerospace industry has long been interested in the development of an economically-viable, civil supersonic transport category aircraft, however many regulatory challenges remain for routine low boom supersonic operation. The long and sorted history of past supersonic transport (SST) programs and the retirement of Concorde and Tu-144 are haunted by stories of excessive jet noise, engine emissions, and sonic boom. Moreover, high fuel burn and prohibitive maintenance costs followed by limited market opportunities due to loud and startling sonic booms are just a few of the reasons skeptics hold out little hope for an environmentally responsible and economically successful civil supersonic aircraft.

Over the last 40 years, significant technical advancements have been made in aircraft and engines; ongoing environmental aviation research now indicates that jet noise and engine emissions are more likely to attain levels needed for future civil supersonic operation. Regarding sonic boom, renewed industry focus on smaller aircraft size and weight rather than large passenger transports makes achieving publicly-acceptable low amplitude ground signature levels (sometimes referred to as “low booms”) within reach, a requirement necessary for routine overland supersonic flight and what many believe is the key to economic viability. At present, the United States and many countries prohibit supersonic flight over land due to public annoyance associated with sonic boom noise. FAA and ICAO have followed the issue of sonic boom for decades. Their harmonized position, contained in ICAO Assembly Resolution A37-18 Appendix G issued in 2010, reaffirms the importance of “ensuring that no unacceptable situation for the public is created by sonic boom from…commercial service.” The resolution goes on with a charge to the ICAO Council to “achieve international agreement on (sonic boom) measurement”, define “unacceptable situations for the public”, and establish “corresponding limits” for sonic boom.

SONIC BOOM

Low boom research has its roots in the late 1960’s & early 1970’s where linearized sonic boom theory aimed for ramp and flat-top sonic boom ground signatures. Figure 1 shows the extent of ground exposure for a typical sonic boom generated by an aircraft flying at supersonic speed. The boom exposure consists of 1) the primary carpet, or direct ground impingement of acoustic rays from the supersonic aircraft; 2) secondary carpet, or indirect ground impingement of reflected or refracted acoustic rays; 3) focus boom, the transonic acceleration region where acoustic rays converge on each other; & 4) lateral cutoff, or the edge of the primary carpet. The resulting ground signature across most of the primary carpet is generally referred to as an N-wave, since the pressure versus time trace resembles the capital letter “N” as indicated in Figure 1.

NASA flight research over the last decade has collected high-fidelity acoustic signatures for nearly all of these regions, making acoustic propagation code validation & future turbulence studies feasible. Much attention is now being placed on research to achieve primary carpet ground signature levels, or low booms, that are no longer loud and startling or cause one to be concerned over personal property or structural damage. Additionally, consideration must be given to minor annoyance concerns like window or bric-a-brac rattle in one’s home. In order to make unrestricted supersonic flight overland acceptable to the general public these concerns must be addressed by researchers. A position held by many is that once an acceptable primary carpet signature is achieved – the secondary carpet and lateral cutoff signatures become a “non-problem”. Further study into signature characteristics that
influence loudness metrics and startle is outside the scope of this paper, but more information can be found through a literature search of industry & NASA’s current work.

![Figure 1](image-url)

**FIGURE 1.** Maglieri’s depiction of the extent of sonic boom ground exposure carpets and waveforms associated with supersonic aircraft operations.9

## RECENT LOW BOOM PROGRESS

Today’s advanced computing resources and analytical computational fluid dynamics (CFD) tools have spawned a rapid acceleration in aerodynamic and acoustic research knowledge. Discoveries that once took days and weeks in wind tunnels are now accomplished in a matter of minutes, or even seconds, using current computing technology. New insights into supersonic flowfields have enabled full-scale flight tests like the DARPA/NASA Shaped Sonic Boom Demonstrator (SSBD)10 and the Gulfstream/NASA Quiet Spike.11 These tests have validated both near-field pressure and ground signature boom shaping progress in the forward part of shaped sonic boom signatures. More recently, CFD studies and wind tunnel test campaigns on N+2 configurations, e.g. aircraft feasible for entering service in the 2020 timeframe, claim “break-through progress” in low boom design validation, specifically near the aft part of shaped signatures.12 NASA & industry are now achieving near-field pressure signatures from scaled aircraft models that when propagated to ground signature levels are markedly lower than current supersonic designs. These levels, while not quite low enough to be publicly-acceptable for unrestricted operations, give confidence that engineers and researchers are nearing a solution.

Other recent NASA NRA-funded work has gained insight into focus boom signatures (sometimes referred to as “superbooms”) which occur during the transonic acceleration phase of flight, the region where an aircraft transitions from the subsonic to supersonic flight regime. The Superboom Caustic Analysis and Measurement Program (SCAMP) collected recordings of focus boom signatures from a NASA F-18B which were later used to validate new computational codes for predicting signatures at and near the focus caustic ground intercept.13 This focused ground signature is generally held as being the loudest location within the sonic boom carpet. SCAMP also gave a first look at focus signatures for low boom, cruise-optimized aircraft configurations; results that again appear promising.14

## NOISE REGULATION

In the U.S., the FAA defines certification requirements for engine emissions and landing/takeoff (LTO) community noise in 14CFR Parts 34 and 36, respectively. In 2008, the FAA issued a policy statement regarding LTO noise that any future supersonic airplane will be expected to “produce no greater impact on a community than a subsonic airplane.” This action reaffirmed previous ICAO guidance that any future supersonic aircraft will need to comply with LTO noise certification criteria current at that time. However, reasonable discussions within industry and regulatory groups may consider alternate means of compliance to meet such requirements, i.e. test procedures,
aircraft configuration, etc. To be more specific, it is envisioned that future supersonic aircraft may have transonic thrust requirements that are higher than those required for takeoff. The higher transonic thrust would be utilized during acceleration to supersonic speed at flight levels above 30,000 feet, well above and away from airport infrastructure and their surrounding communities. Current FAA/ICAO criteria require aircraft noise levels to be established using maximum takeoff thrust levels and allow no use of variable geometry on the engine or nacelle. Future supersonic aircraft may employ variable noise suppression features and takeoff/climb thrust levels rather than maximum thrust levels to successfully achieve noise certification requirements. While no official guidance is yet given or guaranteed, it is encouraging that options might be available for aircraft and engine manufacturers to help meet future supersonic LTO noise certification requirements.

Supersonic flight over the continental U.S. and its territories is prohibited under FAA’s 14CFR Part 91.817, established in 1973 as a result of Concorde flights into the northeastern U.S. FAA and ICAO/CAEP are currently monitoring international research programs and are actively engaged in the findings and validity of truly achieving low boom flight over land. It is with this regard that advocates pose the more significant question – “What will be required to set a new noise standard for an acceptable sonic boom level?” This question can be viewed as having two parts: 1) how quiet must the ground signature be for public-acceptability, and 2) what data is needed to validate and instill confidence that a sonic boom standard can be successfully established and implemented?

**Terminology**

Many of the projects mentioned earlier were aimed at defining an “acceptable” sonic boom level and validating computational tools to design and analyze aircraft configurations to reach that level. Various noise metrics have been studied, but Sullivan concluded that Stevens Mk VII Perceived Loudness correlated best for subjective human response for sonic boom noise. When one considers structural response and human annoyance due to vibration or rattle, research has been inconclusive at best, however, human perception of vibration and/or rattle must be better understood to determine whether other supersonic ground signature characteristics must be considered in a future standard.

To complicate matters, when discussing acceptability one must consider terminology by which all parties can communicate and understand. The term “acceptability” is typically replaced by “annoyance” in the context of aviation noise. It has been stated that one cannot measure “acceptability”, but “annoyance” can be measured and is generally characterized with adjectives like “slightly”, “moderately”, “highly”, or “not-at-all” annoyed. In most research, noise-response curves are labeled “Percent Highly-Annoyed (%HA).” Further, the use of noise metrics for single-event response (e.g. how one might react to a single sound) versus cumulative response (e.g. how one might react to repeated or multiple sounds) make matters even more complex. The bottom line that advocates continue to struggle with is how one might define acceptability by using commonly held terminology in aviation noise regulation. Much collaborative work remains in this area, but industry, NASA, academia, and regulatory agencies appear to be converging on common language and sonic boom terminology to clearly communicate a path forward.

**Addressing Gaps**

An important NASA NRA-funded effort to help close the terminology gap is the Waveforms and Sonic boom Perception and Response (WSPR) program, conducted at NASA’s Dryden Flight Research Center and Edwards Air Force Base (EAFB) residential housing area. The flight program was designed to begin the process of dissecting the community response data collection and post-processing problem needed to address the second part of the regulatory question above – “what data is needed for rule change?” WSPR was conducted on an acclimated community at EAFB, one in which community residents were already familiar with traditional sonic boom noise and where existing environmental impact studies are in place. The work has given insight into data collection methods for both the objective acoustic pressure signatures from NASA’s aircraft flying a unique “low boom dive” maneuver as well as the subjective human response data from base personnel while at home performing their daily routine. WSPR utilized traditional paper surveys, web-based surveys, and smart phone applications to gather the community subjective response to many low amplitude sonic boom signatures and has enabled open discussion on how one might introduce and objectively evaluate new low boom ground signatures into non-acclimated communities. The details of this program are being briefed at this Acoustical Society of America meeting in June 2013, so for more information refer to the WSPR session or conference proceedings.
As noted above, there are several international groups conducting supersonic research similar to NASA and U.S.-based aircraft manufacturers’ efforts. Most international work has been limited to computational studies, with some moderate amount of wind tunnel testing; however one program of note is managed out of the Japanese Aeronautics and Space Agency (JAXA). Over the past few years JAXA has performed a series of field tests including the collection of traditional and shaped sonic boom pressure signatures at the ground and just above the planetary boundary layer using instrumentation on a tethered blimp. The second phase of a small-scale drop test referred to as D-SEND#2 (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) is planned in 2013; more details on the D-SEND project can be found on JAXA’s website. At present, the drop testing appears to be for ground signature validation only and not human response, thus it will likely fall short of the data necessary for regulatory change on sonic boom.

AN APPROACH

NASA and industry are continuing to advance the state-of-art in low boom research. The overall objective is to enable regulatory change for a new environmentally responsible sonic boom standard, lifting the prohibition on civil supersonic flight. One widely held approach is to conduct a community-scale flight program using a purpose-built low boom research aircraft. It is believed by many, including FAA and ICAO/CAEP, that such an aircraft and flight program is needed to confidently validate low boom physics and the resulting ground signatures, since wind tunnel testing is insufficient to include complex whole airframe and propulsion effects as well as atmospheric variability. The flight program would gather real-time ground signatures and the relevant subjective human response over various geographic locations, accounting for signature variability due to atmospheric conditions, terrain, population density, and demographics (i.e. urban, suburban, rural). The combination of acoustic and human response data will help inform researchers on sonic boom, or ground signature, levels that result in low community annoyance and establish thresholds where that annoyance might change. Public outreach and community feedback would be expected from test subjects and the general public. It is also likely that such a flight program will offer guidance on how aircraft manufacturers and regulatory agencies might conduct certification testing for future civil supersonic aircraft (i.e. measurement locations, test methodology, and data analysis processes).

CONCLUSION

This paper discusses recent work in low boom supersonic research and outlines noise policy changes necessary to achieve a remarkable increase in the speed of civil air transportation. FAA and CAEP remain interested in current low boom supersonic research; however the path forward remains tentative in establishing acceptable sonic boom limits. This may be a result of priority when compared to current noise stringency and emissions standards work, but regardless of the rationale, development of future standards for sonic boom noise is a key component to enabling continued investment in civil supersonic research. The steps underway to assess the viability of low amplitude supersonic signature acceptability continue to show promise and market forces remain high for this still elusive form of future air travel.

REFERENCES