LOWERING THE BOOM

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Recently there has been substantial renewed interest by ASA members and others regarding the transient sounds of supersonic airplanes, called sonic booms. In fact, during July 21-22, 2005 an International Sonic Boom Forum was held in State College, PA, organized by the present author and Francois Coulouvrat of the French National Center for Scientific Research (CNRS) at Pierre and Marie Curie University (Paris VI). This Forum was a set of special sessions of the 17th International Symposium on Nonlinear Acoustics, co-sponsored by the ASA. There were 30 technical papers as well as panel discussions from industry and government. Participants were from seven countries, and included presentations by the National Aeronautics and Space Administration (NASA), the Federal Aviation Administration (FAA), industry, and university researchers. Clearly there has been recent resurgence of interest in sonic boom, including new funded research. Where is all this new interest coming from? This article will try to answer this question and provide some highlights of recent sonic boom research.

The need for speed

In our busy, daily lives we try to find ways to save time in many ways. Technology can help us save time. A good example, pointed out by Sam Bruner of Raytheon Aircraft Co., is the cell phone. The cell phone links us to others with immediacy and convenience in a way unheard of in previous generations. Twenty years ago mobile telephones were bulky, and only used by a few. They were expensive, but they did lay the groundwork for the personal communication system available today.

Another way we can save time involves personal transportation. People who have jobs involving substantial travel have a strong desire to minimize the actual travel time. Our global airline network is at capacity and is limited by the fleet of existing aircraft. Current aircraft fly at speeds less than the speed of sound in air, nominally 340 m/s (767 mph). It seems a reasonable way to save travel time is to simply fly faster, i.e., supersonically.

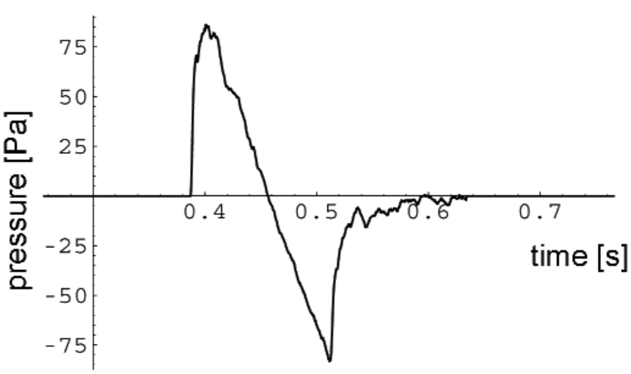

Fig. 1. Example measured waveform of F-15 aircraft. This particular waveform is somewhat rounded in shape.

Commercial supersonic travel was possible on a handful of airline routes during the 1980s and 1990s on the French/British airplane, *Concorde. Concorde* was a technical success, but economically and environmentally it was a failure[1]. *Concorde* created substantial sonic boom noise while in supersonic flight, limiting its utility. In fact, until recently, all supersonic flight created objectionable sonic boom noise. But aircraft designers now have tools they believe will reduce or eliminate objectionable sonic boom noise.

A snapshot of a sonic boom

What is a sonic boom? It is a pressure disturbance created by the passage of an aircraft, or any other object, traveling faster than the speed of sound. A typical non-minimized sonic boom time trace measured at the ground is given in Fig. 1. The vertical axis is pressure in pascals and the horizontal axis is time in seconds. This particular graph is an example of a rounded sonic boom waveform produced by an F-15 aircraft taken from the BoomFile database[2]. Notice that the pressure versus time waveform roughly looks like the letter "N." Most conventional sonic boom waveforms look similar to this, although the atmosphere and aircraft maneuvers can alter the shape. Notice there is a distinct beginning and ending to a sonic boom waveform. This is because the aircraft has a finite length.

The peak pressure of this sonic boom is about 85 pascals. One poundforce per square foot (psf) is about 48 pascals, giving this boom a peak pressure of 1.77 psf. This is a very small fraction of 1 atmosphere (about 101,325 Pa), but most people would consider this a loud boom. In the U.S., units of psf are still used to describe sonic boom amplitudes instead of pascals as used by everyone else.

The most important point to gain from this article is that the **sonic boom is made continuously during the entire time that the aircraft is moving supersonically**. This means that the sonic boom is present everywhere along and adjacent to the aircraft supersonic flight path. This acoustically impacted area along the aircraft flight path on the ground is called the primary sonic boom carpet, and it may be on the order of 75 km wide (40 miles wide) or larger depending on the aircraft altitude and the meteorological conditions. The sonic boom wave sweeps out a conical shape as it propagates. The ground is impacted by the boom in the shape of a truncated hyperbola. An overall picture, suggested by the work of Carlson[3], given in Fig. 2 shows this cone being swept over the ground behind the aircraft.

The reader can also see the analogy between a supersonic airplane and a fast moving speedboat in the water. The speedboat creates a V-shaped wake that spreads out behind

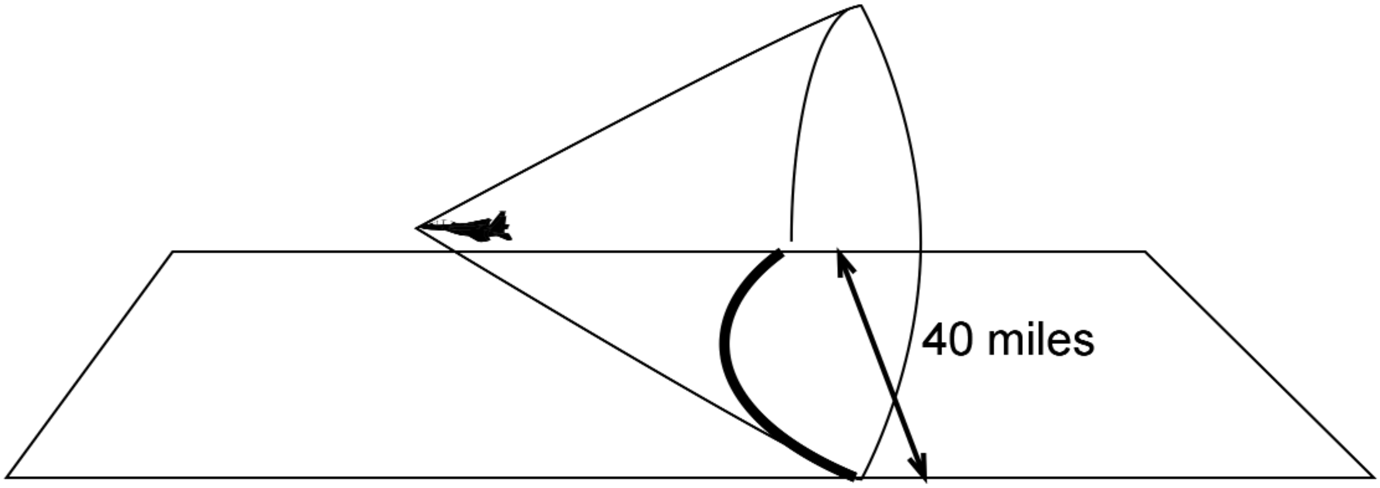

Fig. 2. Primary sonic boom carpet swept over the ground.

the boat and splashes into the nearby shoreline after traveling some distance. The sonic boom is an analogous conically-shaped wake created in three dimensions by the supersonic aircraft.

One can easily see that because the sonic boom noise is made continuously along the flight path, millions of U.S. residents will regularly hear sonic boom noise on a daily basis if supersonic civil aircraft become popular and fly overland. The good thing to know about this picture is that while conventional sonic booms are known be obtrusive to the public, the only sonic booms being considered for overland flights are sonic booms which have been tailored to minimize annoyance.

Aircraft manufacturers believe they can build small supersonic jets which have a "low-boom" sonic boom signature which will barely be noticeable. What are some advantages of such "low-boom" small supersonic jets?

Current and future regulations and the advantages of overland flight

One distinct advantage of "low-boom" designs is that overland flight would be possible. The law in the United States since 1973 assumes that any and all sonic boom noise is unacceptable[4]. The Code of Federal Regulations, 14CFR91.817, currently prohibits civil aircraft from exceeding Mach 1. It also prohibits any sonic boom from reaching the ground. This regulation was developed and enacted in a technical environment where boom shaping was considered either impossible or too technically risky. Similar, but not identical, international laws are also effective worldwide[5].

However, if "low-boom" flight were deemed acceptable, the door would be open to overland flight[6]. For example, for a cross-US round trip between New York, New York (NY) and Los Angeles, California (LA) one would depart NY at 8:00 a.m. fly to LA in 2.5 hrs. One could then conduct a six hour business meeting and then fly back to NY in 2.5 hours. No overnight layover would be required.

Similarly, a trans-Atlantic round trip between London, England and New York with a 3.5 hour flight time could be completed in one day with no overnight stay needed. One can clearly see the time savings by not staying overnight between departure and return flights for each round trip scenario.

On November 13, 2003 the Federal Aviation Administration held a Civil Supersonic Aircraft Technical Workshop[7] to gather information that might be used to reassess 14CFR91.817. Unfortunately, this workshop was held at the same time as the Fall 2003 ASA meeting in Austin, TX, so there was little input from or recognition by ASA members. There were a number of presentations at this workshop by industry indicating the tremendous strides that have been made toward building aircraft with substantially reduced sonic boom[8]. Many of these same companies have urged the FAA to revise their regulations to allow overland supersonic flight so long as those flights are quiet enough to be acceptable to the public.

Boom minimization

In the late 1960s and early 1970s, Seebass and George[9] were the first to put forward workable ideas on how aircraft could be designed to produce minimal sonic booms. The basic idea was to carefully control the cross-sectional area and lift of the aircraft, as functions of distance from the aircraft nose. These ideas were expanded upon by Mack and Darden[10] in the 1980s. Linear theory was used, at best an approximation with the nonlinear flows present around a supersonic body.

However, over the past 30 years, progress has been made in the areas of computer power, computational fluid dynamics (CFD), and optimization. Computers have increased many orders of magnitude in speed and memory capacity since the 1970s, and algorithms have improved substantially. Industry now knows much more than they did during the time of *Concorde*, and they believe they can design aircraft that will have substantially quieter sonic booms via aircraft cross-sectional area and lift shaping. One can now include all fluid dynamic nonlinear effects to predict an aircraft's near-field supersonic flow pattern. The updated computer algorithms for "low boom" design have also been validated by numerous laboratory tests.

This technical advance, coupled with multivariate optimization procedures, now allows aircraft designers to design prototypes optimized to produce minimal sonic booms, and these booms might be non-obtrusive for small vehicles. Because aircraft weight is a contributing factor to the amplitude of the sonic boom, the only currently viable "low-boom" designs are for small jets. Large supersonic airliners with "low-boom" designs are not yet possible with current technology.

In addition to sonic boom there are, of course, many other considerations one must take into account for civil supersonic flight—take off and landing noise, emissions, operational issues, etc., as well as the tradeoffs one must make between the environment and the desire of humans to go faster. Many of these issues have been discussed in-depth by Fisher, et al.[11], so the reader is directed toward their work regarding such tradeoffs. However, the "main issue" of concern for civil supersonic flight is sonic boom.

Theory says "low-boom" design is possible, but does it really work in a real atmosphere?

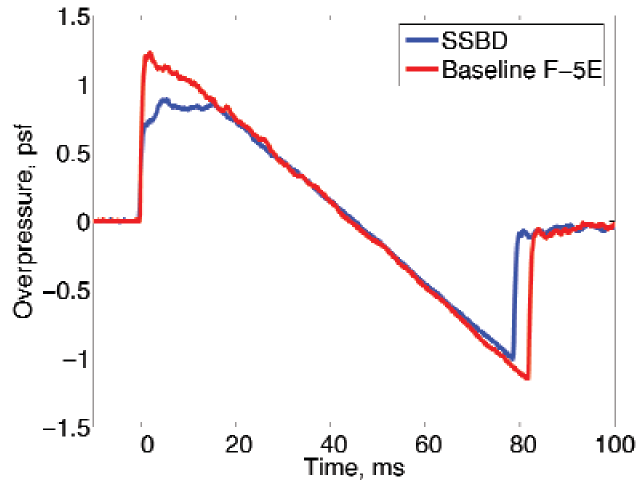

Fig. 4. First measurement of shaped sonic boom, August 27, 2003. Sonic booms compared for SSBD and F-5E. (Courtesy Northrop Grumman Corporation and Wyle Laboratories.)

Defense Advanced Research Projects Agency/National Aeronautics and Space Administration (DARPA/NASA) breakthrough

Fig. 3. F-5E (left) and SSBD (right) aircraft. (Courtesy Northrop Grumman Corporation.)

There were exciting developments in 2003 and 2004 by the DARPA/NASA Quiet Supersonic Platform Program, and this has been reported in the popular media[12] as well as in technical publications[13]. A Navy F-5E aircraft was physically retrofitted to have a nose which was especially shaped to change the aircraft's sonic boom signature (see Fig. 3). The airplane, called the Shaped Sonic Boom Demonstrator (SSBD), and an unmodified F-5E airplane were flown back to back supersonically to produce ground signatures. The intended area shaping of the SSBE did indeed produce a sonic boom pressure versus time waveform whose shape persisted all the way to the ground, validating the CFD and optimization predictions (see Fig. 4). In blue the SSBE acoustic pressure versus time signature has a "flat top" on the positive portion of the waveform. The unmodified F-5E signature in red was the usual N-wave shape. Clearly the design process followed to shape the SSBD ground signature worked well.

This breakthrough grabbed the attention of the worldwide aerospace industry as well as U.S. and foreign governments. The result has been a renaissance in sonic boom research.

Results from the International Sonic Boom Forum

As noted, the ASA co-sponsored the 17th International Symposium on Nonlinear Acoustics (ISNA17) and the International Sonic Boom Forum (ISBF) in State College, PA, USA in July 2005. This is the most recent major meeting on sonic boom in the U.S. in the last seven years[14]. Summaries of some of the technical presentations given at the ISBF appear in this article as an appendix.

Recent NASA low-boom flights

Two papers at the ISBF discussed a series of new experiments recently completed at NASA Dryden Flight Research Center. Peter Coen, of NASA Langley Research Center, provided an overview of NASA's Vehicle Systems Program efforts related to the reduction of sonic boom and explained that the purpose of the low-boom experiments is to determine the threshold of acceptability of low overpressure N waves. These low overpressure N waves, as will be described in a moment, can be created by careful maneuvering of existing aircraft. The first goal of this testing is to show the feasibility and repeatability of generating the low overpressure N waves (< 0.6 psf) within a specific geographic area with F-18 aircraft in a low-lift flight condition.

In a separate paper providing details of the effort, Ed Haering of NASA Dryden presented a paper with coauthors James Smolka and James Murray of NASA Dryden and Ken Plotkin of Wyle Laboratories. Haering indicated that these low amplitude N-waves have been produced from the top of an F-18 in a supersonic dive. This boom from the upper portion of the aircraft does not include lift, and thus has a lower boom amplitude that the usual boom off a supersonic aircraft's lower side. Maximizing the aircraft altitude and the sonic boom propagation distance also minimizes the overpressure.

Figure 5 shows the path of a typical flight experiment to measure low overpressure booms. The aircraft does a 180° roll, then a supersonic dive, then another 180° roll. This puts the airplane in a steep enough dive so that one can measure the signature from the top of the aircraft. The aircraft then

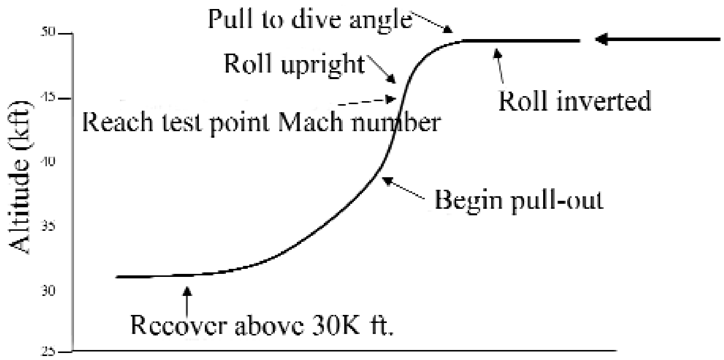

Fig. 5. Aircraft maneuver for F-18 generation of low overpressure N waves. (Courtesy NASA Dryden Flight Research Center.)

pulls out of the dive at a safe altitude. This interesting aircraft maneuver necessary for this supersonic dive was shown to the ISBF attendees via playback of a cockpit video.

The work so far has been successful, with all of the measurements producing low boom N waves in the desired geographical area. Example low-overpressure N waves are shown in Fig. 6. Haering reported that the resulting waves had rise times which greatly increased with decreasing maximum pressure amplitude.

The importance of this work cannot be overstated. Given the ability to place low amplitude sonic booms in a specific geographic area should allow for future performance of subjective testing of these waves both indoors and outdoors. It would be very useful to know how people react to such low amplitude sonic booms. Such tests are not yet planned, but they likely will be very useful in assessing the acceptability of the low-boom designs that industry would like to build.

Ongoing work by the PARTNER Center of Excellence

Since no aircraft designed for low-boom currently exists, substantial research is underway using artificially reproduced sonic booms. There is much research being conducted in this area in Project 8 (sonic boom mitigation) of the FAA/NASA/Transport Canada Center of Excellence (CoE) PARTNER[15] (Partnership for AiR Transportation Noise and Emissions Reduction). PARTNER was established in September 2003, but funding for the sonic boom mitigation aspect was received by the participating universities in April 2005. Since Project 8 was funded much later than the other projects in PARTNER, the work is still in its infancy at the time of this writing.

One of the major purposes of Project 8 is to determine the acceptability of low-boom sonic boom noise to the general population. What signatures will be acceptable to the public for overland supersonic flight?

Project 8 consists of a number of research tasks that are interconnected. Potential aircraft manufacturers are supplying baseline supersonic signatures at the ground from their designs, but rarely will individuals actually hear these signatures. During supersonic cruise people most often will instead hear the signatures after they have been distorted by propagating through the atmosphere. During other portions of the flight when the aircraft is climbing, turning, or descending, the aircraft will produce other signatures on the ground, and these waveforms also will be needed. Hence some of the tasks in Project 8 are to take the baseline signatures and produce synthesized signatures, similar to the ones that will be actually heard by the public. It is these signatures that will be jury tested for acceptability. After subjective testing, recommendations then can be made for use by the FAA and NASA.

There are three tasks initially funded in Project 8. Task 8.1 is to incorporate

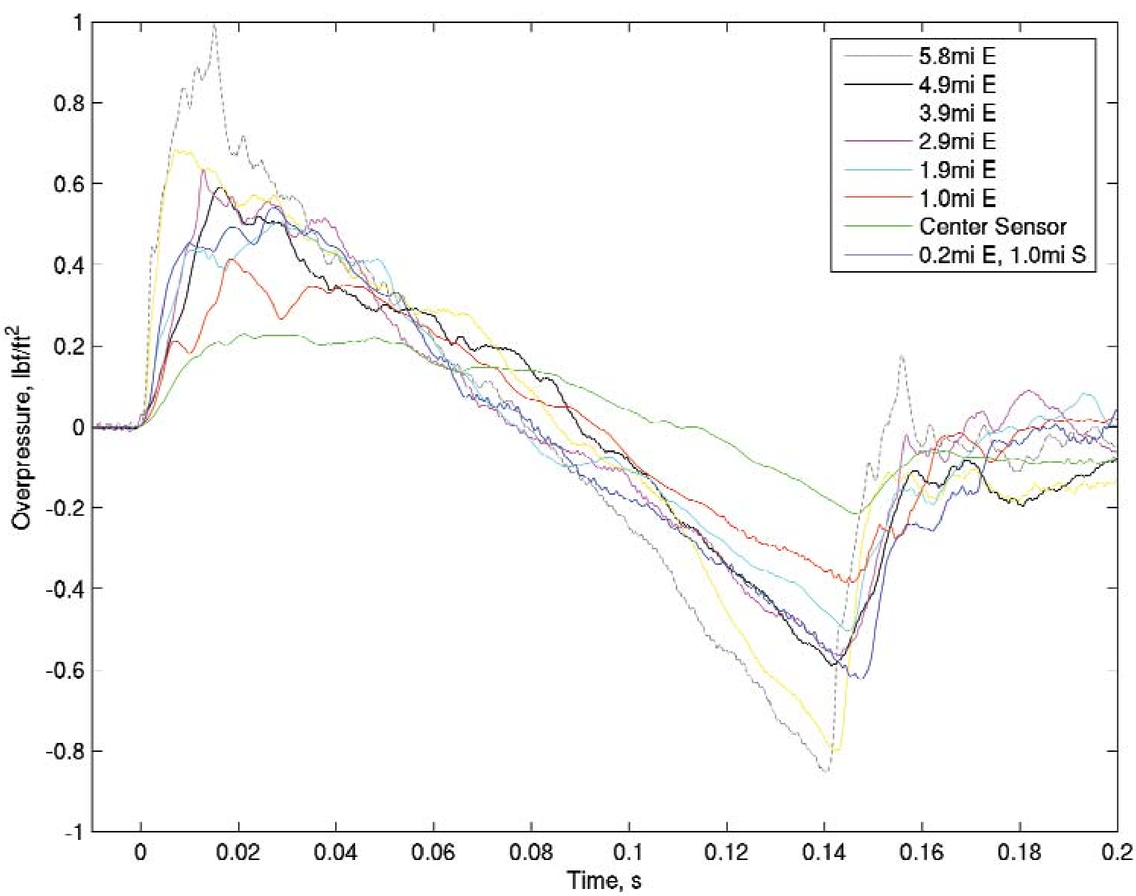

Fig. 6. Example low overpressure N waves. (Courtesy NASA Dryden Flight Research Center.)

atmospheric turbulence into waveforms provided by industry and NASA. This task will then feed in to the perception and subjective testing part of the work which includes two tasks, 8.6 and 8.7. Task 8.6 is entitled *Determine Annoyance of Low Boom Waveforms*, and Task 8.7 is entitled *Noise Metrics*.

The primary goal of Task 8.1 during the first year will be to generate waveforms of a shaped boom design that have been propagated through realistic atmospheric effects. Task 8.1 is being carried out at The Pennsylvania State University, with the present author as Principal Investigator.

"…sonic boom is made continuously during the entire time that the aircraft is moving supersonically."

The effort has begun by employing the large database of recorded waveforms from the shaped sonic boom demonstrator (SSBD) aircraft flights of August 2003 and January 2004. Those flights were for a modified F-5E aircraft with flat-top front shock shaping only. The waveforms collected in those studies have been carefully analyzed in collaboration with industrial partners. The approach has been to develop filter functions for different realizations of atmospheric turbulence, and this has been achieved for first pass filter functions. The work is now at the point where one can convolve "clean" sonic boom waveforms with the inverse Fourier transform of the filter function to "turbulize" them. Future work will use a more physics-based model by exploiting existing models for propagation through atmospheric turbulence.

Subjective studies in PARTNER

Both The Pennsylvania State University and Purdue University are working on both Tasks 8.6 and 8.7. It is assumed that supersonic aircraft signatures outdoors will be studied first, as this is much easier than indoor signatures. Indoor signatures will be discussed below.

Shaped sonic boom waveforms have not undergone extensive subjective testing to the extent that traditional N waves have. The purposes of Task 8.6 are to more fully understand the human response to realistic low-boom sonic boom waveforms and to compare listener reactions between shaped sonic booms and other natural sounds such as distant thunder.

Since no low-boom aircraft exist at this time, all subjective testing at the outset of Project 8 will take place in sonic boom simulators. Three simulators are currently involved in the research: (1) a simulator developed by and residing at NASA Langley Research Center, Hampton, VA, (2) a simulator similar in construction to the Langley simulator at Lockheed-Martin Aeronautics, Palmdale, CA, and (3) a portable simulator built by Gulfstream Aerospace Corp. described by Salamone at the July 2005 ISBF.

In Task 8.7 the applicability of both traditional and very recently developed noise metrics to shaped sonic boom sounds will be determined. The repeatability of human subject testing results across the three different sonic boom simulators will also be assessed.

There are many metrics one could try to apply to sonic boom signatures. However, some have already been determined to be more successful than others in predicting annoyance. A leading contender, showing the best correlation to annoyance is the Stevens' Mark VII Perceived Loudness (PLdB)[16]. Any new metrics will have to be compared to this baseline metric which seems to be quite robust in terms of its applicability across a wide range of boom shapes and amplitudes.

PLdB does not account for many things one would want in an appropriate low-boom metric. It does not account for startle, whole-body response, or a nighttime penalty. Clearly, additional work needs to be done.

Subjective studies underway

The initial work in tasks 8.6 and 8.7 is centered on showing the realism of the sonic boom simulators and on the mutual reproducibility between those simulators. Brenda Sullivan of NASA Langley, Kathleen Hodgdon of Penn State, and Patricia Davies of Purdue have been working during 2005 on the planning and execution of three human subject experiments.

Sullivan has led the effort to compare the NASA Langley simulator with the portable simulator of Gulfstream. Comparison tests by "expert ears" from the East Coast of the United States took place in May and early June 2005. These experts are individuals who have heard many real sonic booms previously, and they were asked to rate the realism of the playback of recorded sonic boom waveforms in both simulators.

A second, similar comparison test between the Gulfstream simulator and the simulator at Lockheed-Martin in Palmdale, CA is being led by Davies using experts from the U.S. West Coast. That test occurred in late August and early September 2005. Combined and coordinated with the earlier work led by Sullivan, it should be possible to have a three-way comparison between the simulators regarding realism and mutual reproducibility.

A third test, conceived by Peter Coen of NASA Langley, was designed and executed by Hodgdon to compare real sonic boom noise by military supersonic overflights with playback reproduction in the Gulfstream sonic boom simulator. F-18 aircraft were flown supersonically seventeen times over a group of subjects for them to become familiar with real sonic boom noise on the morning of June 15, 2005 at NASA Dryden Flight Research Center (see Fig. 7). Simultaneous 24-bit recordings were made which were played back for those subjects later that afternoon in the Gulfstream simulator. Results from this and the other subjective experiments are expected sometime within the next year.

During the June 15, 2005 experiment, measurements of the seventeen supersonic flights were also made with new, high-bandwidth recording equipment. Further, acoustic measurements were made inside and immediately outside a nearby house on-site at Edwards Air Force Base. Vibration measurements were also carefully recorded inside the house. Although there are no plans to analyze this data right

Fig. 7. Jury testing participants listen to sonic booms from F-18 aircraft out in the desert at NASA Dryden Flight Research Center. The subjects later listened to reproduced sonic booms in a simulator to tell if the simulator sounded realistic. To protect the identities of the participants, their faces have been obscured. (Photo by Kathleen Hodgdon.)

away, it is available for PARTNER Project 8 activity envisioned for the future.

PARTNER Project 8 aims to provide a knowledge base of signatures and the relative acceptability of those signatures, indoors and outdoors, by the population. By including information from atmospheric turbulence, aircraft operations, and human perceptual response, good information will be available for FAA and NASA decision making. At the end of the day, Project 8 will have attempted to provide the best information possible so that regulatory policy decisions are well-informed decisions.

Future plans

There are currently no plans to have another International Sonic Boom Forum anytime soon. The organizers of the ISBF have indicated interest in having a *sonic boom themed* special session at an upcoming ASA meeting, and this is now planned for the Fall 2006 joint meeting of the ASA and the Acoustical Society of Japan in Honolulu. It does seem that with its many technical committees, but especially noise, physical acoustics, and psychological and physiological acoustics, the appropriate home for sonic boomers is the Acoustical Society of America.

There are a number of major ways in which the various university and government researchers, including those involved with PARTNER Project 8, are likely to proceed in the next several years. Firstly, all subjective testing is currently focused on outdoor sonic boom waveforms. But without question an assessment of the reaction of people indoors to low-boom sonic boom waveforms should be attempted as soon as it is practicable. It is just that it is difficult to perform such testing. One challenge is that people very well may react differently in their own homes than they would in a laboratory environment designed to look like a home. One technique that already has been tried successfully is to place in people's own homes computer-controlled loudspeaker boxes that periodically play waveforms intended to sound like sonic booms indoors[17]. It is unclear if the results would have been the same if the residents had been exposed to real supersonic overflights. There have been a few recent studies of subjective reaction to sonic booms heard indoors from overflights[18, 19] but that research will not answer the questions we are seeking since low-boom sonic boom waveforms were not used.

In a few years it may be possible that indoor studies can be initiated using overflights of a real low-boom aircraft. The low amplitude N-wave flights at NASA Dryden have already been mentioned. Further, early in 2005 NASA announced that their Vehicle Systems Program was working on developing a low-boom flight demonstrator. However, changing priorities have delayed that initiative until some later time. If it is constructed, a low-boom demonstration aircraft would be very useful for testing the reactions of people in their own homes. Many researchers would then participate in in-home overflight studies in conjunction with the FAA, NASA, and industry. That is the acid test. We all will really know then whether overland supersonic flight of civil aircraft will be acceptable.

Going further

Background literature on the topic of sonic booms is available[20-22]. An extensive list of references including symposia and workshops on sonic boom is given in Reference 22. Additional references should soon be available, including the ISBF proceedings that have been published as part of the proceedings for the 17th ISNA. That book should be available from the American Institute of Physics sometime in late 2006. **AT**

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Appendix: Highlights of some of the ISBF presentations

- Halvor Hobaek presented a paper with co-authors Adne Voll, Rune Fardal and Lucio Calise from the University of Bergen, Norway on laboratory scale model experiments for sound propagation in the atmosphere from 15 km to ground level. They were able to achieve a stable linear sound speed profile in a water tank by carefully mixing ethanol and water. Perhaps, surprisingly, it was found the laboratory mixture of ethanol and water made a sound speed profile which was quite stable over a period of several months. Propagation of sound in this profile was examined and will be continued in the future. This work is part of the SOBER project, a SOnic Boom European Research project.
- Francois Coulouvrat provided a summary of his recent work with Reinhard Blumrich and Dietrich Heimann, also funded by the SOBER project. Their work has shown the critical importance of meteorology (weather) on the variability of sonic booms received on the ground. Their work has shown that during supersonic cruise, weather changes the peak pressure only +/- 10 percent, but that lateral variability to either side of the flight track can be quite substantial. They have also shown that there can be measurable changes in booms received on the ground due to the season of the year and the time of day or night. Further their work has shown the importance of understanding the focusing of sonic boom, called a superboom, when an aircraft is accelerating up to cruise speed. The meteorology seems to have a substantial impact on the strength of such superbooms.
- Osama Kandil of Old Dominion University described his recent work with Xudong Zheng to model the nonlinear Tricomi equation to predict superbooms for a variety of different shaped sonic booms. Their results compared favorably to the earlier work of Auger, Marciano, and Coulouvrat, but their new scheme is more efficient by a factor of four.
- Sambadam Baskar of University Pierre and Marie Curie presented a new nonlinear ray theory including the effects of shocks, diffraction, and atmospheric effects with co-author Phoolan Prasad. The current theory is only directly applicable to the forward part of an airfoil and work is ongoing to extend the theory for the trailing part of the airfoil.
- Ken Plotkin of Wyle Laboratories gave two papers at the meeting. One described his latest work with Ed Haering and Jim Murray of NASA Dryden Research Center analyzing the sonic boom data from sounding rockets having a peak overpressure of approximately 0.2 psf, much quieter than most sonic booms. They found that current models for oxygen and nitrogen relaxation absorption in the atmosphere correctly describe the shock structure observed in their measurements. Plotkin's second paper was coauthored with Brenda Sullivan of NASA Langley Research Center and Domenic Maglieri of Eagle Engineering and described the measured effects of turbulence on and the perceived loudness of sonic booms from the SSBE experiments described earlier. Having developed a "de-turbing" process to remove the effects of turbulence from measured sonic booms, Plotkin was able to show that the root-mean-square values of the spiky fine structure near the jumps in a sonic boom agree well with the predictions of Steve Crow from 1969. The same data showed that the front-shock shaping of SSBE provided approximately a 5 dB reduction in loudness using Steven's Mark VII perceived level.
- Michael Boudoin, along with co-authors Francois Coulouvrat and Jean-Louis Thomas, presented an initial study on the effects of clouds on sonic boom propagation. Using physically based models, Boudoin showed that the absorptive effects of clouds are either comparable to or greater than traditional relaxation-based absorption mechanisms. To the present author's knowledge, this is the first time the effects of clouds have been explicitly considered along with sonic boom propagation.
- Lance Locey presented a paper on developing appropriate filter functions that can add realistic features of atmospheric turbulence to synthesized sonic booms. This work is in conjunction with the present author and is funded by the FAA/NASA/Transport Canada PARTNER Center of Excellence, described earlier. The motivation for this research is to provide the effects of a realistic atmosphere to "clean" waveforms provided by industry before playback to subjective testing participants.
- Nicholas Heron from Dassault Aviation presented a paper along with several coauthors giving an overview of the low-boom design process currently in use at Dassault. A current design on the drawing board, for example, includes canards (winglets) on the forward part of the aircraft having a backward sweep and a downward twist. Their conclusion is that sonic boom minimization requires a substantial change in the shape of the aircraft.
- Sergei Chernyshev, representing several authors of the Central Aerohydrodynamics Institute (TgAGI) in Moscow, Russia, gave an overview of sonic boom research in that country. The effects of atmospheric turbulence on the propagation of sonic booms from TU-144 aircraft were noted, as well as the notion that the accurate prediction of both primary and secondary sonic boom is challenging for a realistic atmosphere. Aircraft modification including low-boom design simultaneous with high aerodynamic efficiency was also highlighted.
- Philippe Blanc-Benon of Ecole Centrale de Lyon described some of his recent work with his colleagues on describing the rise

times of sonic booms in the presence of both kinematic and thermal turbulence in the atmosphere. Using laboratory scale measurements of N waves they showed that turbulence usually increases rise times and decreases the overpressure. However, because of random focusing, the peak pressure can be increased, and this should be accounted for in determining the loudness of sonic boom. Blanc-Benon also showed that during turbulent conditions ground roughness can substantially affect the peak pressures and rise times compared with the usual flat-ground assumption.

- Lou Sutherland presented a paper along with his colleagues Karl Kryter and Joe Czech reminding the ISBF participants that any acceptability criteria for supersonic aircraft will have to account for building vibration and startle. Sutherland indicated that previous studies have shown that building vibration and rattle are the "most annoying" aspect of traditional sonic booms, and that startle is the "most disturbing" aspect. Although industry intends that their new "low-boom" aircraft will neither be annoying nor startling, these were sobering words of wisdom for the ISBF attendees.
- Brenda Sullivan of NASA Langley Research Center reviewed some of the known results from the High Speed Civil Transport studies of the 1990s regarding the human perception of sonic boom as well as some results found recently. She noted that earlier results indicating that peak overpressure does not correlate with subjective loudness is still true. For the low-level booms now envisioned by industry, calculated loudness (Steven's Mark VII) and A-weighted metrics are quite adequate and work with complex, multi-shock waveforms as well as simple waveforms. Another of Sullivan's recent research results is that post-boom noise, the rumble after the main boom sound, seems to be very important for sonic booms to sound "realistic" upon playback in sonic boom simulator boxes. Sullivan also reported some of the subjective experiments recently carried out by members of the PARTNER Center of Excellence, described earlier.
- Joe Salamone of Gulfstream Aerospace Corporation described his company's Supersonic Acoustic Signature Simulator II (SASSII), a portable unit inside a trailer that can be towed to any desired location. It contains high-fidelity audio equipment capable of playing both recorded and synthesized sonic boom signatures. In fact, the SASSII was available throughout the ISBF and ISNA17 for participants to hear comparisons between the sonic boom of *Concorde* and that of an envisioned low-boom aircraft.
- Nicolas Epain of Laboratoire de Mechanique et d'Acoustique in Marseilles, France presented work on another sonic boom simulator, this one using 3-D sound field reproduction. They included spatial orientation of the sonic boom by arranging realistic wave front passage by the listener.

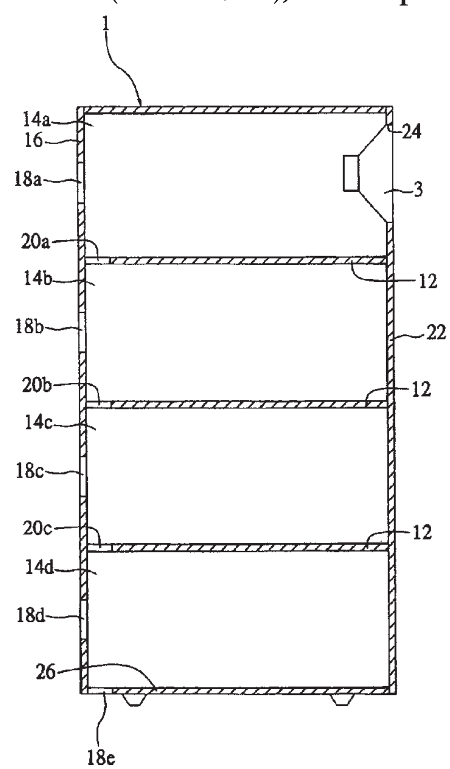
In addition, the panelists making short presentations included Laurie Fisher of the FAA, Ken Orth of Gulfstream Aerospace Corp., Akira Murakami of the Japanese Institute of Space Technology and Aeronautics (JAXA), Gerard Duval (a retired *Concorde* pilot), Thierry Auger of Airbus, Sam Bruner of Raytheon, Tom Hartmann of Lockheed-Martin Aeronautics, and Richard Smith of NetJets, Inc.

Victor W. Sparrow is Associate Professor of Acoustics at The Pennsylvania State University. He received his Ph.D. in 1990 from the University of Illinois, Urbana-Champaign, and joined Penn State's Graduate Program in Acoustics that year. In 1996 he received the ASA R. Bruce Lindsay Award, and was elected an ASA Fellow in 1998. He currently serves on the ASA Executive Council and is Project Lead for the PARTNER Center of Excellence Sonic Boom Mitigation Project. In addition to sonic booms his research interests include physical acoustics, structural acoustics, computational acoustics, virtual acoustics, and acoustic visualization.

6,862,360

43.38.Ja SPEAKER SYSTEM

Jen-Hui Tsai, Wen Shen Suburb, Taipei, Taiwan, Province of China
1 March 2005 (Class 381/351); filed 19 April 2001



A novel understanding and interpretation of the laws of physics, how electrodynamic loudspeakers and their constituent parts operate, the why and how of enclosure and port design, among other things, lead to an interesting patent that is an excellent example of wishful thinking. The patent basically describes a plurality of volumes **14** and ports **20,** each tuned to a different frequency band, that solve a multiplicity of problems, none of which are adequately described.—NAS