SONIC BOOM RESEARCH (1958 - 1968)

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WASHINGTON, D. C.

November 1968

23

The United States Government has been actively engaged in sonic boom research since 1958 in an effort to learn more about this phenomenon and the means of controlling it. To this end, extensive testing has been done in the field as well as in the laboratory environment.

This document is a brief history of sonic boom research. Part I presents a chronological listing of the various field research programs, identifies the Government agencies involved and provides a brief summary of the work accomplished. Part II describes some of the laboratory experiments and theoretical studies conducted under Government sponsorship. Part III contains a listing of publications resulting from these research programs and tells how these documents may be obtained.

TABLE OF CONTENTS

I. FIELD RESEARCH

1958 NASA - Ground Measurements of Shock Wave Noise from Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 feet. Tests using F-101 and F-100 at Wallops Island, Virginia; six flights, Mach number range from 1.25 to 1.4 at altitudes from 25,000 to 45,000 feet. Maximum pressure of 2.0 psf measured. First known test program to record sonic boom for steady level flight conditions. It was found that the measured and calculated values of the pressure rise across the shock wave were generally in good agreement. There was a tendency for the theory to overestimate the pressures for conditions of high tailwind at altitude.

Reference: NASA TN-D 48.

1959 NASA - Ground Measurements of Airplane Shock Wave Noise to Mach Numbers to 2.0 and at Altitudes to 60,000 Feet. Tests using F8U-3, 26 flights. First flight at 60,000 feet and Mach 2.0. Range of altitudes 20,000 to 60,000 feet. Maximum pressure, 1.5 psf. Measurements made on the flight track and laterally, structural response data obtained on buildings at Wallops Island. Two B-58 passes were also included at 41,000 feet. It was found that the measured variation of sonic boom intensity, with altitudes up to 60,000 feet, was in good agreement with the variation calculated, using the prediction methods given in TN-D 48. It was also found that level cruising flight at an altitude of 60,000 feet and a Mach number of 2.0 produced sonic booms which were considered to be tolerable, and it is reasonable to expect that cruising flight at higher altitudes will produce booms of tolerable intensity for airplanes of the size and weight of the test airplanes.

Reference: NASA TN-D 235.

1960 NASA/USAF TACTICAL AIR COMMAND - Ground Measurements of Shock Wave Pressure for Fighter Airplanes Flying at Very Low Altitudes and Comments on Associated Response Phenomena. Project Little Boom at Nellis Air Force Base, using F-104 and F-105 aircraft. Twenty-five flights at Mach 1.09 to 1.2 and altitudes from 50 to 900 feet. Maximum pressures measured were 120 psf. No F-104 flights were made at overpressure levels of 0 to 20.0 psf during the tests; however, using F-105 aircraft, no glass breakage was experienced for sonic boom levels from 0 to 20.0 psf. There were 2.4 possible breakages of small and colonial residence-type windows. Fifty-one breakages occurred within the pressure range of 20.0 to 100.0 psf. A large group of individuals was subjected to sonic booms up to 120.0 psf. No physiological or psychological reactions were noted.

Reference: NASA TMX-611.

1960 NASA/USAF/FAA - Ground Measurements of Shock Wave Noise From Supersonic Bomber Airplanes in the Altitude Range of from 30,000 to 50,000 Feet. Project Big Boom at Nellis Air Force Base. Sixteen flights at Mach 1.5 at altitudes from 30,000 to 50,000 feet. Maximum pressures 2.1 psf. Measurements made on the track and laterally. First check on lift effects weight of B-58 aircraft used varied from 82,000 to 120,000 pounds. Using the B-58, it was found that the measured overpressures were generally higher than would be predicted by the theory that accounts only for volume effects. Lift effects were verified for this type aircraft in the altitude range from 30,000 to 50,000 feet.

Reference: NASA TN-D 880.

1961 NASA/USAF/FAA - Ground Measurements of Sonic Boom Pressures for the Altitude of 10,000 to 75,000 feet. At Edwards Air Force Base, thirty-eight F-104 flights were made from 10,000 to 50,000 feet and Mach numbers from 1.2 to 2.0 and twenty-five B-58 flights were conducted at altitudes from 30,000 to 75,000 feet and Mach numbers from 1.5 to 2.0. Lateral measurements of overpressure extended out to 20 miles. This was the first very high altitude, large lateral spread and first good atmospheric effects research flights. Super booms were generated by linear acceleration and turning maneuvers and measurements made using the F-104. It was found that the shape of the pressure signature from a supersonic airplane is a function of atmospheric conditions, altitude, Mach number, flight path, configuration of the airplane, and relative position of the observer. It was also found that turbulent atmospheric conditions resulted in erratic wave shapes and in considerable variation in the measured peak overpressures for given flight conditions.

Reference: NASA TMX-633
NASA TN-D 2021.

<u>1961</u> NASA/USAF - In-Flight Shock Wave Measurements Above and Below a Bomber Airplane at Mach Numbers from 1.42 to 1.69. Tests were made with an F-106, flying under and over B-58 at altitudes from 30,000 to 50,000 feet. The probe aircraft flew from 1,600 to 10,000 feet from B-58. There were 7 flights at Edwards Air Force Base. It was found that as the distance from the airplane increases, the wave length (distance between the bow and tail waves) increases and the number of individual shock waves diminishes until the classical N-wave shape is approximated at a distance of 50 to 90 body lengths for the conditions of these tests. These tests also further verified lift effects and provide a check on the lift-volume theory.

Reference: NASA TN-D 1968.

<u>1961/1962</u> NASA/FAA/USAF - Community and Structural Response Program at St. Louis, Missouri. Seventy-six flights were made with B-58 aircraft at altitudes from 30,000 to 41,000 feet, but measurements were obtained on only 66 flights. Maximum pressure measured was 3.2 psf. The result of personal-interview studies indicated that about 90 per cent of those contacted experienced some interferences as a result of sonic booms, about 35 per cent were annoyed by them, less than 10 per cent had contemplated complaint action, and less than 1 per cent had actually filed a formal complaint. From field investigations and analysis, it was apparent that reported damage to structures normally occurs at stress points within a structure. The overpressures from supersonic test flights of B-58 and F-106 aircraft to overpressures of 2.6 psf were not sufficient magnitude to cause damage to sound plaster and good quality glass to break.

Reference: NASA TN-D 2705.

<u>December-1962</u> NASA/USAF/USN - Program to Obtain Response Data of Buildings. Building response data was obtained at Wallops Island, using F-104, F4H, and B-58 aircraft, at altitudes from 32,000 and 62,000 feet. It was found that, as a result of overpressures to 3 psf, sonic boom damage consisted mainly of cracks in brittle construction materials, such as plaster, glass masonry, tile, etc. This type of damage is believed to result from the triggering action of sonic booms in instances where prior stress concentrations existed in the buildings.

<u>February-1963</u> NASA/FAA/USAF - Sonic Boom Effects on Light Aircraft - Project Littleman - Light aircraft on the ground and in the air were overflown by F-104 aircraft at supersonic speeds. Twenty-three passes were made by F-104 aircraft at distances from 3,600 to 36,000 feet. Light aircraft carried NASA flight instrumentation. No significant sonic boom effects on light aircraft on the ground

and in flight, were found at sonic boom overpressures up to 16.0 psf.

Reference: NASA TN-D 1941.

1964 FAA/NASA/USAF - Oklahoma City, Oklahoma Public Reaction Study. Conducted February 3 through July 31, 1964. This six month program was designed to determine public reaction to the sonic boom at nominal overpressure levels of 1.5 and 2.0 psf. Boom runs were conducted on a precise time schedule during daylight hours, for a total of eight flights a day, seven days per week. A total of 1,253 booms were included in the program. Nine "control" houses, in various geographic locations throughout the city, were included in the program. These houses were used as a means of identifying any structural component damage. This was to ensure that the overpressures generated would not exceed the damage threshold, although prior research, as previously summarized, indicated that no structural damage should be anticipated at programmed overpressure levels. Two of the test houses were extensively instrumented for structural response identification. Two additional test houses were selected, outside of the boom area, to afford comparison of house deterioration due to natural causes as compared with that observed in the boom exposed test houses. Also, included in the program was an investigation of the influence of meteorological effects on the sonic boom and an analysis of wave pattern characteristics as observed at ground level.

Conclusions resulting from the Oklahoma City Public Reaction Study were as follows:

1. Public reaction data indicates that an overwhelming majority (73%) of the public felt they could live with the numbers and kinds of booms experienced during the six month period. However, a large percentage (40%) of the public polled during the program believed that the sonic boom causes structural damage. This finding accentuated the need to establish sonic boom overpressure damage index levels for various types of structural materials. This index should be established through practical tests rather than laboratory experimentation to assure public acceptance.

2. Structural reaction data obtained from the test houses indicates no significant damage resulted from 1,253 sonic booms.

3. Wave pattern analysis of the sonic booms recorded at various geographic locations in the boom area, shows a significant overpressure scatter characteristic. One per cent of the measured overpressures equaled or

exceeded the predicted values by a factor of approximately 1.5 to 3.0 depending on the distance relative to the ground track; the greater factor is associated with the larger distances and with the lower predicted value.

Meteorological conditions have a significant effect on sonic boom overpressure scatter. Low altitude turbulence is suspected as the primary causal factor.

References: NASA TN-D 2539

Final Report "Structural Response to Sonic Booms" - Vol I - AD610822 (FAA Sponsored)
Vol II - AD610823 (FAA Sponsored)

"Community Reactions to Sonic Booms in the Oklahoma City Area" Vol I - AD613620 (FAA Sponsored)
Vol II - AD625332 (FAA Sponsored)
Vol III - AD637563 (FAA Sponsored)

Final Report "Meteorological Aspects of the Sonic Boom" - The Boeing Company - AD610463 - (FAA Sponsored)

1964/1965 FAA/USAF - White Sands Missile Range, New Mexico - Conducted November 18, 1964, through February 15, 1965. This program was designed to determine structural response characteristics through a measured overpressure range from 2.0 through 28.0 psf, with a flight frequency of 30 per day. This study was conducted at the White Sands Missile Range, New Mexico, and consisted of two phases.

The first phase began on November 18 and ran through December 15, 1964, and generated a total of 615 sonic booms over the instrumented test site. The nominal overpressure ranged from 2.0 psf through 16.0 psf progressing at scheduled increments of 2.0 psf. Thirty flights were scheduled for each overpressure level. The second phase began January 15, 1965, and ended February 15, 1965. A total of 879 booms were generated during this period. The cumulative effect of sonic boom was explored by exposing structures to 680 sonic booms at a nominal overpressure of 5.0 psf. Damage index data was obtained from 123 sonic booms ranging in overpressures of 7.0 psf to 19.0 psf. A total of 76 flights were conducted to obtain data on the effects of focusing of sonic booms due to aircraft maneuvers.

Sixteen types of structures were included in the test, seven of which were built specifically for this program. Five types of plaster, interior finishings and a variety of commercial glass installations were studied during the two phases. Prior to program initiation, a thorough engineering inspection was conducted for each structure to establish a state of repair and over-all condition. This included marking of existing plaster cracks and photographing any structural component deficiency found in the structures. Daily inspections were conducted at 30 minute intervals on each of the structures by a 22-man engineering team. This team included representatives from the National Bureau of Standards, Boeing and Lockheed Aircraft companies, United States Air Force, England, France, FAA and engineering personnel provided by the contractor. Additional technical assistance was provided by a team from the National Academy of Sciences.

Subsidiary test objectives included the determination of the effect of sonic booms on the hatchability of chicken eggs; human hearing impairment or adverse physiological effects caused by sonic boom at high overpressure levels; and sonic boom characteristics associated with certain aircraft maneuvers.

Conclusions:

1. Plaster. Plaster on metal lath, concrete block or on gypsum lath was not observed to crack under any of the booms during the program.

2. Plasterboard. New plasterboard tested was not damaged by any sonic booms generated during the program. Crack extensions occurred in predamaged plasterboard at designed overpressures of 7.9 psf. Incipient damage to plasterboard is characterized more by slight nail popping. This condition, normal in houses using this material, begins to be accelerated by booms at an average overpressure of 8.0 psf. Suspended plasterboard ceilings may experience minor paint chipping along the edges by repeated booms at a design overpressure of 5.0 psf.

3. Bathroom Tile. Booms at a designed overpressure of 7.9 psf may begin to extend cracks in predamaged bathroom tile. These crack extensions were very difficult to see.

4. Glass. Poorly mounted, undamaged glass in the greenhouse was chipped by impact against nail holding points at a sonic boom overpressure of 12.1 psf. The same type of glass, which was already damaged, was further damaged at a designed overpressure of 7.9 psf. A large one-ninth of an inch thick window, intentionally precracked from corner to corner, was further damaged by booms of an average 6.5 psf overpressure.

5. Bric-a-brac. Of several pieces of bric-a-brac observed during the program, some bric-a-brac fell and broke at a designed overpressure of 10.4 psf.

6. Stucco. Cracks that existed in stucco prior to booms, extended under a designed overpressure of 7.9 psf. No new cracks were identified as caused by booms.

Observations made during the cumulative-effect portion of the structural response test indicate no significant structural component damage in any of the sixteen structures that were exposed to 680 sonic booms at a 5.0 psf nominal overpressure level.

Several thousand chicken eggs were also used in this program to study sonic boom effects in regard to hatchability. The technical report issued by the Regional Environmental Health Laboratory at Kelly Air Force Base, Texas, concluded that sonic booms do not lower or adversely affect hatchability of chicken eggs incubated in forced-air or convective-air-type incubators.

A flight surgeon was on duty during the test program. No adverse physiological effects were identified for any of the more than 20 personnel involved in the daily program operation.

Continuous audiometric examination of twenty subjects throughout the duration of the test program indicated no hearing impairment caused by sonic booms at very high overpressures.

References: "Structural Reaction Program - Summary, Conclusions and Analysis" - Vol I - AD474778 - (FAA Sponsored)

"Structural Reaction Program - Appendicies" - Vol II - AD474779 - (FAA Sponsored)

"Effects of Sonic Boom on Structural Behavior-Supplementary Analysis Report" - AD475662 - (FAA Sponsored)

"Effect of Sonic Booms on the Hatchability of Chicken Eggs - USAF" - AD619720 - (FAA Sponsored)

1965 FAA/NASA/FAA/USFC - Effect of Sonic Booms of Varying Overpressures on Snow Avalanches. This study, conducted March 18 - 20, 1965, was to determine the effects of sonic boom overpressures ranging from 1.5 to 5.0 psf on potential snow "slab" avalanches during periods of high hazard. No avalanche was observed as a direct result of sonic booms at these overpressures.

Reference: SST 65-9 - AD468794.

1966/1967 NATIONAL SONIC BOOM EVALUATION OFFICE (NSBEO) - Sonic Boom Experiments at Edwards Air Force Base, California. This study, conducted June 3 - 23, 1966, and October 31, 1966, through January 17, 1967, was to determine the subjective/structural response of people, animals, and structures to sonic booms of varying intensities and subsonic noises of varying PNdB levels. An interim report, "Sonic Boom Experiments at Edwards Air Force Base," dated 28 July 1967, has been released to the public as of 2 August 1967, and is obtainable through the Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Springfield, Virginia, 22151. Additional reports of this experiment have since been released and are listed below

Reference: NSBEO-1-67 - AD655310
NSBEO-2-67 - AD662003
NASA-6-67 - LWP-428
USDA-6-68 - ARS 44-200

II. LABORATORY RESEARCH AND THEORETICAL STUDIES

1966 Theoretical Study of Structural Response to Near-field and Far-field Sonic Booms.

Datacraft, Inc.

Investigators: John H. Wiggins, Jr. and Bruce Kennedy

Objective: This study investigates the difference between near-field and far-field sonic boom intensities. To do so, it defines a new intensity standard, effective static load which depends on load waveform as well as magnitude. Many sonic boom loading waveforms are computed for 19 structural elements of various types produced by two SST designs as well as F-104, B-58, and XB-70 aircraft. It is concluded that near-field booms are less intense than far-field booms, the magnitude of the difference depending on the character of the waveform. The more the waveform is distorted from a symetrical far-field (N-wave) wave shape, the lower the near-field intensity. (Report No.: AD 662-893)

Funds: National Sonic Boom Evaluation Office (NSBEO)

1967 University Research on the Generation and Propagation of Sonic Booms.

Columbia University -

Investigators: M. B. Friedman and M. K. Myers

Objective: To understand the basic mechanism of the superbooms caused by non-uniform motions of the aircraft and refractive effects of temperature gradients in the atmosphere.

Approach: Extend present linear theory of the super-boom to include various atmospheric effects and to develop the appropriate non-linear corrections to the theory.

Funds: NASA Headquarters

Cornell University -

Investigators: F. K. Moore and E. L. Resler, Jr.

Objective: To study the effects of multipole distributions and configuration changes in delaying the formation of the ultimate N-wave. To explore the effects of high Mach numbers on the near-field.

Approach: Theoretical investigation using an asymptotic expansion about the ultimate N-wave for large radial distance. Utilization of hypersonic blast wave theory.

Funds: NASA Headquarters and AFOSR

Cornell University -

Investigators: A. R. Seebass and A. R. George

Objective: To further understanding of our ability to predict and minimize sonic booms of present and future generations of aircraft.

Approach: Theoretical investigation into the validity of the basic theory, the extent of the mid-field region, atmospheric effects and the sonic booms of hypersonic aircraft.

Funds: NASA Headquarters and AFOSR.

New York University -

Investigators: A. Ferri and L. Ting

Objective: To determine whether or not substantial reductions may be obtained by novel configurations. To initiate work on the modification of existing shock propagation theories and their applications. To calculate the effects of engine streamtube area changes.

Approach: Theoretical determination of the pressure signature of novel configurations, including higher-order effects. Theoretical study of shock wave propagation theories. Study of engine characteristics at supersonic speeds.

Funds: NASA Headquarters

Oklahoma State University

Investigator: G. W. Zumwalt

Objective: To develop procedures to study the diffusion of disturbances on sonic boom waves.

Approach: Numerical techniques to permit solution of equations by digital computer.

Funds: NASA Langley

Princeton University

Investigator: W. D. Hayes

Objective: To determine the appropriate analytical techniques to account for atmospheric and unsteady effects. To determine second-order wave structure and the non-linear behavior of an N-wave at a caustic.

Approach: Geometrical Acoustics. Matched asymptotic expansions.

Funds: NASA Headquarters - NASA (ERC)

Royal Institute of Technology and the Aeronautical Research Institute of Sweden

Investigators: M. T. Landahl and G. Drougge

Objective: To further understanding of non-linear effects on the generation of sonic booms.

Approach: The theoretical investigation will employ the technique of parametric differentiation which has proved useful in other phenomena governed by non-linear partial differential equations. It is anticipated that this theoretical investigation will be complimented by lateral experimental studies.

Funds: NASA Headquarters

University of Colorado

Investigator: A. Busemann

Objective: To determine the feasibility of large sonic boom reductions through a lateral redistribution of pressure intensities. To study the possibility of creating an I-wave signature with a more rapid decay than the present N-wave signature.

Approach: Theoretical investigation of these possibilities by examining appropriate combinations of singular solutions to the linear wave equation and various exotic aircraft configurations.

Funds: NASA Headquarters

1967 University Research Sponsored by NASA on Other Aspects of the Sonic Boom

City University of New York

Investigator: D. H. Cheng

Objective: To study the response of various structures to sonic booms.

Approach: Analytical investigation of the response of plates and beams with various constraints to impulsive loads.

Funds: NASA Langley

Massachusetts Institute of Technology

Investigator: S. Crandall

Objective: To obtain basic research information on the response of building structures to sonic booms, acoustic vibrations, and sonic boom induced seismic waves.

Approach: Experimental and analytical studies of the transmission of vibrational energy, effects of isolation pads, etc., on building structures subjected to acoustic and sonic boom pressure loadings.

Funds: NASA Langley

Oklahoma State University

Investigator: R. L. Lowery

Objective: To obtain detailed information on the response of structural elements of buildings to sonic booms

Approach: Analytical studies of structural elements and cavities having various acoustic coupling characteristics.

Funds: NASA Langley

University of Southampton

Investigator: B. Clarkson

Objective: More general understanding of the dynamic response of buildings to sonic booms.

Approach: Study of building response to impulsive loads, the effects of cavity coupling and window dynamics.

Funds: NASA Langley

III. SONIC BOOM RESEARCH REPORTS

In October of 1966, the Library Services Division of the Federal Aviation Administration published a bibliographic list of Aircraft Noise and Sonic Boom references. This is the most complete document of its kind available; however, since it is current only through June of 1966, a listing of the most recent reports and studies are contained on the following pages.

The bibliographic listing and the reports referenced in this document are available to the general public and can be obtained from:

Chief, Input Section
Clearinghouse for Federal Scientific
and Technical Information
5285 Port Royal Road
Springfield, Virginia 22151

FAA SPONSORED RESEARCH

AD 801320 Aircraft Noise and Sonic Boom (Selected References) FAA, October 1966

AD 610822 Structural Response to Sonic Booms - Volume I - (Oklahoma City)

AD 610823 Structural Response to Sonic Booms - Volume II - (Oklahoma City)

AD 475662 The Effects of Sonic Boom on Structural Behavior (Final Report) (Analysis of Oklahoma City and White Sands Experiments)

AD 613620 Community Reactions to Sonic Booms in the Oklahoma City Area - Volume I

AD 625332 Community Reactions to Sonic Booms in the Oklahoma City Area - Volume II - (Data on Community Reactions and Interpretations)

AD 673563 Community Reactions to Sonic Booms in the Oklahoma City Area - Volume III (Questionnaires - Appendix to Volume II)

AD 474778 Structural Reaction Program, Volume 1 - Summary, Conclusions and Analysis (White Sands)

AD 474779 Structural Reaction Program, Volume 2 - Appendicies (White Sands)

AD 468794 Effects of Sonic Booms of Varying Overpressures on Snow Avalanches. SST 65-9

AD 619720 Effect of Sonic Booms on the Hatachability of Chicken Eggs. February 1965. 40 p. SST 65-12. (White Sands).

AD 610463 Meteorological Aspects of the Sonic Boom. Final Report. (Oklahoma City) September 1964. 143 p. FAA-RD-64-160.

AD 655310 Sonic Boom Experiments at Edwards AFB, California. Interim Report. July 28, 1967. NSBEO-1-67.

AD 662003 Response of Structures to Sonic Booms Produced by XB-70, B-58, and F-104 Aircraft. Final Report (Based on Sonic Boom Experiments at Edwards Air Force Base.) NSBEO-2-67.

AD 602175 Sonic Boom Effects on Light Aircraft, Helicopters and Ground Structures (June 1964).

NASA RESEARCH

NASA SP-147	Sonic Boom Research
NASA SP-180	Second Conference on Sonic Boom Research
NASA CR-57022	Community Reaction to Sonic Booms
NASA TND-2705	Result of Community Responses to Sonic Boom - St. Louis
NASA TND-2539	Sonic Boom Exposures in the Oklahoma City Area
NASA TND-3655	Sonic Boom Measurement - Chicago Area
NASA CR-187	Laboratory Tests of Subjective Reaction to Sonic Booms
NASA CR-1192	Relative Annoyance and Loudness Judgments of Various Simulated Sonic Boom Waveforms
NASA CR-1193	A Preliminary Study of the Awakening and Startle Effects of Simulated Sonic Booms
NASA CR-66169	Pressure Time History of Sonic Boom Shock Waves Acting on Glass Windows on Buildings
NASA CR-66170	Acoustical and Vibrational Studies o[illegible]c Boom Induced Damage to Window Glass in a Store F[illegible]
NASA CR-1137	Seismic Effects of Sonic Booms
NASA TND-1941	Measurement of the Response of Two Light Aircraft to Sonic Booms
NASA TND-4588	Summaries of Sonic Boom Variation Associated with Atmospheric Conditions
NASA CR-157	Computer Program Study of Atmospheric Effects of Sonic Boom
NASA TND-4890	Development of Sonic Boom Signatures in a Stratified Atmosphere
NASA TND-2370	Sonic Boom from Aircraft and Maneuvers
NASA TND-2730	Comparison of Patterns of Aircraft Maneuvers
NASA TND-3443	Ground Measurement of Fighter Airplanes
NASA TND-3520	Experiments on Refraction and Acceleration of Sonic Boom Patterns

NASA CR-358	Behavioral of Sonic Boom Shock Waves Near Sonic Cutoff Altitudes
NASA CR-1055	Shock Exposure Tube and Its Application as Sonic Boom Simulators
NASA CR-1075	Calibration for Microphones for Sonic Boom Measurements