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SONIC BOOMS RESULTING FROM EXTREMELY LOW-ALTITUDE SUPERSONIC FLIGHT: MEASUREMENTS AND OBSERVATIONS ON HOUSES, LIVESTOCK AND PEOPLE

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Foreword

This study was accomplished by the Biomedical Laboratory of the Aerospace Medical Division, Wright-Patterson Air Force Base in cooperation with the Joint Task Force II, Sandia Base, New Mexico. Research was conducted by Lt. Col. (ret.) E. Guild, H. K. Hille, C. W. Nixon, and H. C. Sommer of the Biodynamics and Bionics Division under Project 7231, "Biomechanics of Aerospace Environments," Task 723103, "Biological Acoustics in Aerospace Environments" and Task 723104, "Biodynamic Environments of Aerospace Flight Operations."

A significant contribution to this effort was provided by Captain Jack M. Heinemann, VC, Regional Environmental Health Laboratory, USAF, Kelly AFB, Texas. Acknowledgment is made of the excellent assistance and cooperation provided by personnel of JTF II, Sandia Base, New Mexico and personnel of the Sandia Test Range, Tonopah, Nevada.

This technical report has been reviewed, and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
Aerospace Medical Research Laboratories

Abstract

Sonic booms generated by F-4C aircraft flying low-level terrain-following profiles during Joint Task Force II operations near Tonopah, Nevada, were recorded under and near the flight tracks, and responses of structures, animals, and people were observed. Recorded overpressures up to 144 psf were analyzed, correlated with available aircraft operations data, and compared with data from different aircraft flying similar profiles. Observations of structures, animals, and people were correlated with the measured overpressures. Results include acquisition of near-field recordings of overpressures generated by the F-4C, the finding that some window glass fragments were propelled a short distance rather than falling directly below the window, an instance in which the measured overpressure of a sonic boom 1 mile to the side of the track far exceeded the predicted value, the finding that livestock (undetermined prior exposure to acoustic stimuli in this situation) did not respond adversely to the sonic booms, confirmation that very intense sonic booms do not harm people directly and the reaffirmation that the selection of site locations for low-level supersonic training missions will continue to pose a problem.

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Section I.
INTRODUCTION

Sonic boom is an important consideration for military air power since most fighter and many bomber aircraft are capable of routine sustained supersonic flight. High performance vehicles must be operated at supersonic speeds during training and national defense missions to insure maximum crew-vehicle efficiency during actual hostilities. Information and data are needed to aid operations and training planners in the selection of test sites and of training conditions to minimize adverse effects of the sonic boom exposures on structures, animals, and people. A considerable amount of both theoretical and experimental information is available in the rapidly growing literature on sonic booms from different aircraft under a variety of operating conditions (refs 1, 2, 3, 4). Of particular interest is the sonic boom generated by low-level supersonic flights, for which few physical measurements, subjective evaluations and observations have been described (ref 5).

The Joint Task Force II, a unit formed by the Joint Chiefs of Staff to investigate special problems of importance to the military services, was directed to conduct field evaluations of low-level penetration capabilities of various United States aircraft. One phase of the flight test program involved low-level supersonic flights conducted in the vicinity of Tonopah, Nevada, at the Sandia Corporation Test Range. This test area is partly inhabited. Therefore, unfavorable effects on people, livestock, and structures were considered a possible consequence of the sonic booms to be generated by the supersonic flights. For this reason our Laboratory was requested

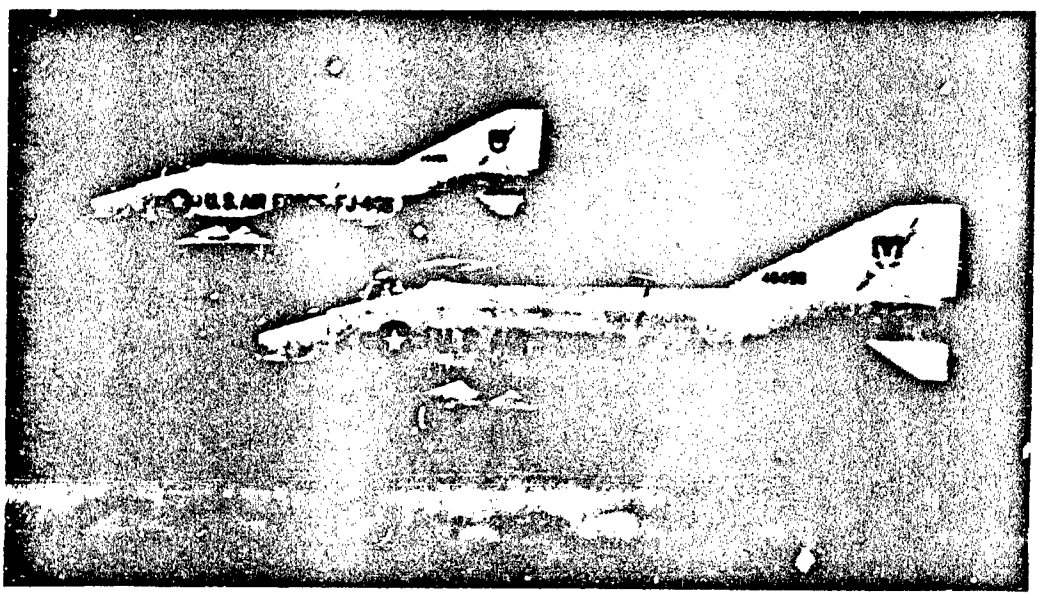

Fig. 1. F-4C Fighter Aircraft Used to Generate Sonic Booms

to consider detailed information on proposed flight profiles, to predict the nominal levels of the sonic booms that would be generated, and to estimate possible adverse consequences of the supersonic testing over the selected program location. As a result of this effort, personnel from the Laboratory participated on-site in the supersonic flight phase of the program. A Bioacoustics team accomplished measurements and observations of sonic booms generated by fighter aircraft flying low-level terrain-following profiles and their effects on structures, animals, and people.

This report describes the field recording and subsequent laboratory analysis of sonic boom overpressures experienced directly along the flight path underneath the airplane and at other distances at selected locations lateral to the ground track. Pressure sensitive instrumentation recorded the sonic boom signatures at ground level and at a height of six (6) feet above the ground. Overpressures were recorded and analyzed for an F-4C fighter aircraft (fig. 1) on which no previous sonic boom data had been measured.

Analyzed overpressure data were also used for correlation with responses of people, livestock, and structures located in this area. On-site inspections of effects of exposures on local residents and their belongings are described. In addition, an Air Force veterinarian accompanied the Bioacoustics team to provide expert counsel and to independently collect documentary data on responses of animals to the sonic booms that occurred in the areas.

Section II.

PHYSICAL MEASUREMENTS

TEST CONDITIONS AND PROCEDURES

The Sandia Test Range consists of highly irregular mountainous terrain at altitudes varying from about 5000 feet to 8000 feet above sea level. Three flight tracks each fifty miles in length and varying greatly in type of mountainous terrain were designated as supersonic corridors in the restricted area shown in figure 2. Corridor B was selected to be flat with fewest sudden or extreme variations in elevation, corridor A was moderately variable, and corridor C was extremely variable in elevation. The main observation and recording site of the biological acoustics team was located at station 1 (Sandia Tower) on corridor B. This location was selected because minimum aircraft ground clearances and maximum sonic boom overpressures were expected to occur at that site. A portable instrumentation unit was used to obtain some ground overpressure measurements at stations 2 (Belmont) and 3 (Stone Cabin Ranch) both occupied by local residents.

Four supersonic flights from north to south were scheduled daily over each of the three supersonic corridors beginning on the first track at sunrise plus 30 minutes. All sorties were flown early in the morning when air turbulence was low thereby minimizing possible atmospheric effects on propagation of the sonic booms to the ground. On each pass the aircraft entered the gate (start of track) at the designated time and the courses were flown by visual reference only. Large red markers clearly visible from the air were positioned at 1000 feet intervals along the length of the corridors. A voice communication system between the bioacoustics station and test flight operations was used to alert the recording crew that the aircraft was approaching so that the recording instrumentation could be activated at the proper time. At stations 2 and 3 only a time schedule of the individual sorties and visual sighting down range were used to advise the recording crew of the approaching supersonic flights.

Enlisted personnel with radio communication equipment were posted at the beginning and end of each track to report time of entry and exit for each aircraft. Automotive traffic on highway 6 was stopped one-half mile from each track when aircraft entered the gate and was allowed to proceed only after the sonic boom was heard at that location. No special provisions were made for dirt roads that crossed the tracks. The entire area is open cattle range and wild horses are seen occasionally.

INSTRUMENTATION

Ground overpressure instrumentation consisted of conventional commercially available equipment normally used for the measurement of high intensity noise. Two identical and independent recording stations were employed as shown in figure 3-A, each consisting of a multichannel tape recording system and three condenser microphones with associated microphone complements. Simultaneous recordings of the individual sonic booms were obtained at various locations at the main recording station: one microphone was located at ground level and the other two were shock mounted side-by-side at a height of 6 feet above the ground (fig. 4).

The ground microphone and one microphone mounted at the 6-foot level were connected to FM modulated record amplifiers (frequency range 0 10,000 Hz) and the other microphone was conected to an AM modulated record amplifier (frequency range 100 to 25,000 Hz). The latter channel recorded the higher frequency energy contained in the overpressure signature

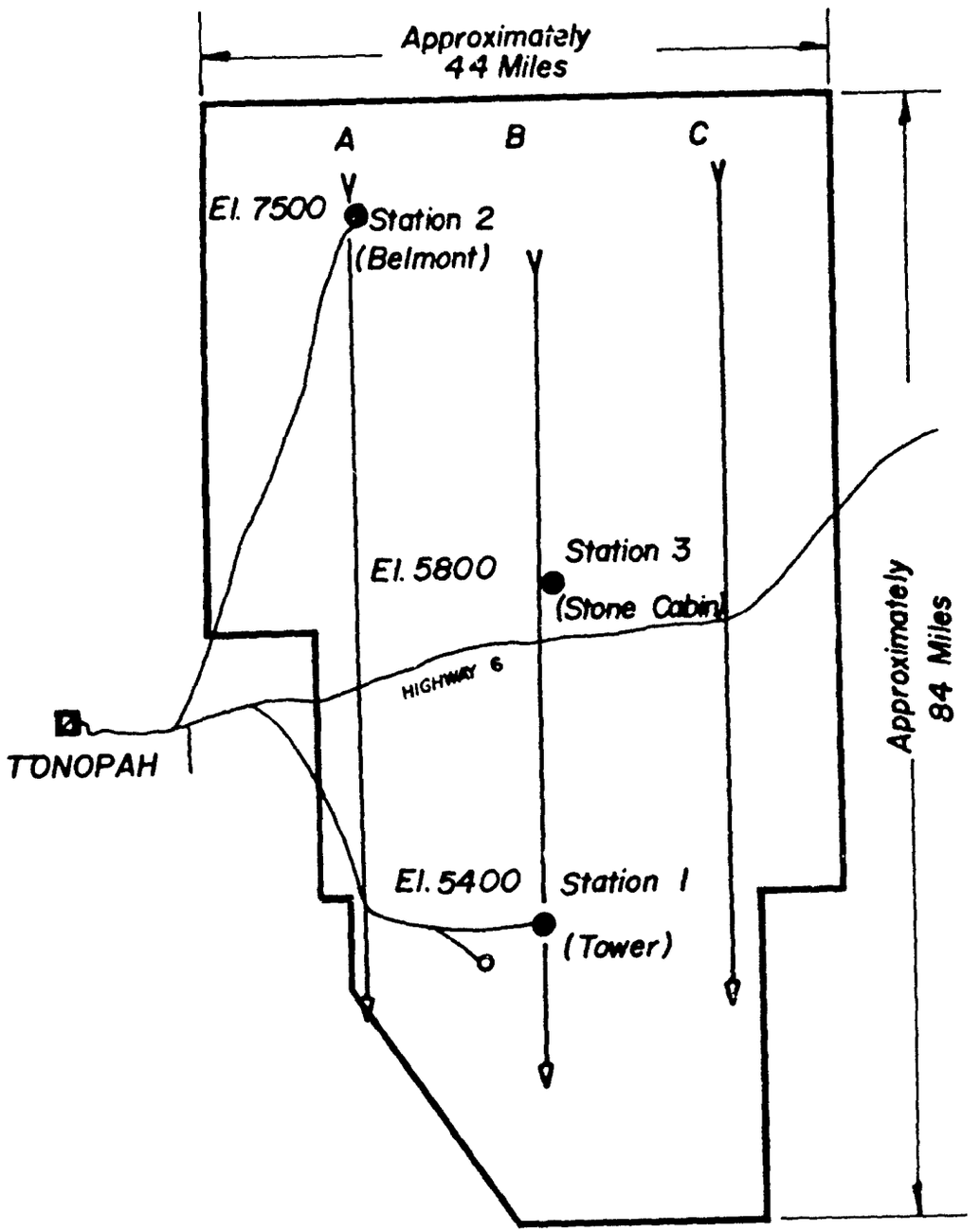

Fig. 2. Schematic Map of Sandia Test Range and Measurement Sites

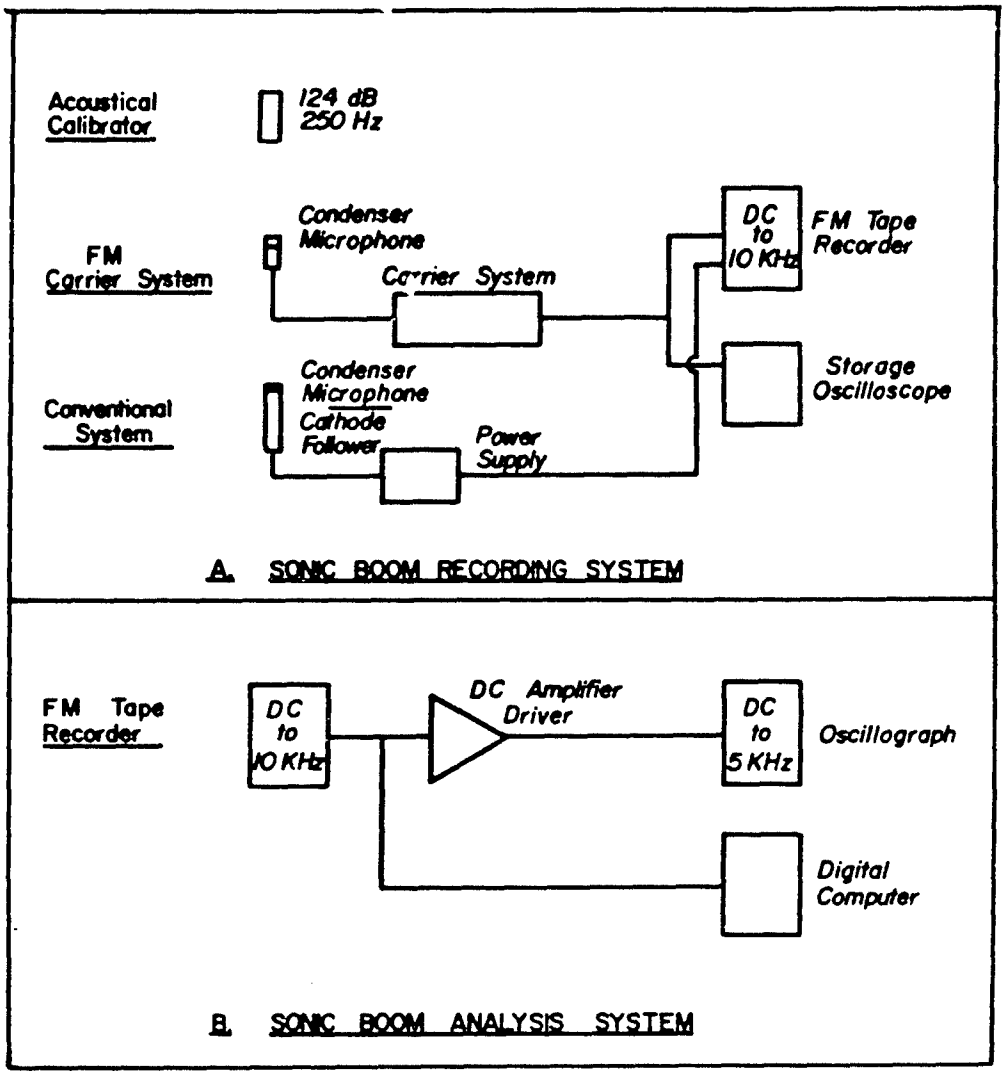

Fig. 3. Block Diagram of Instrumentation System

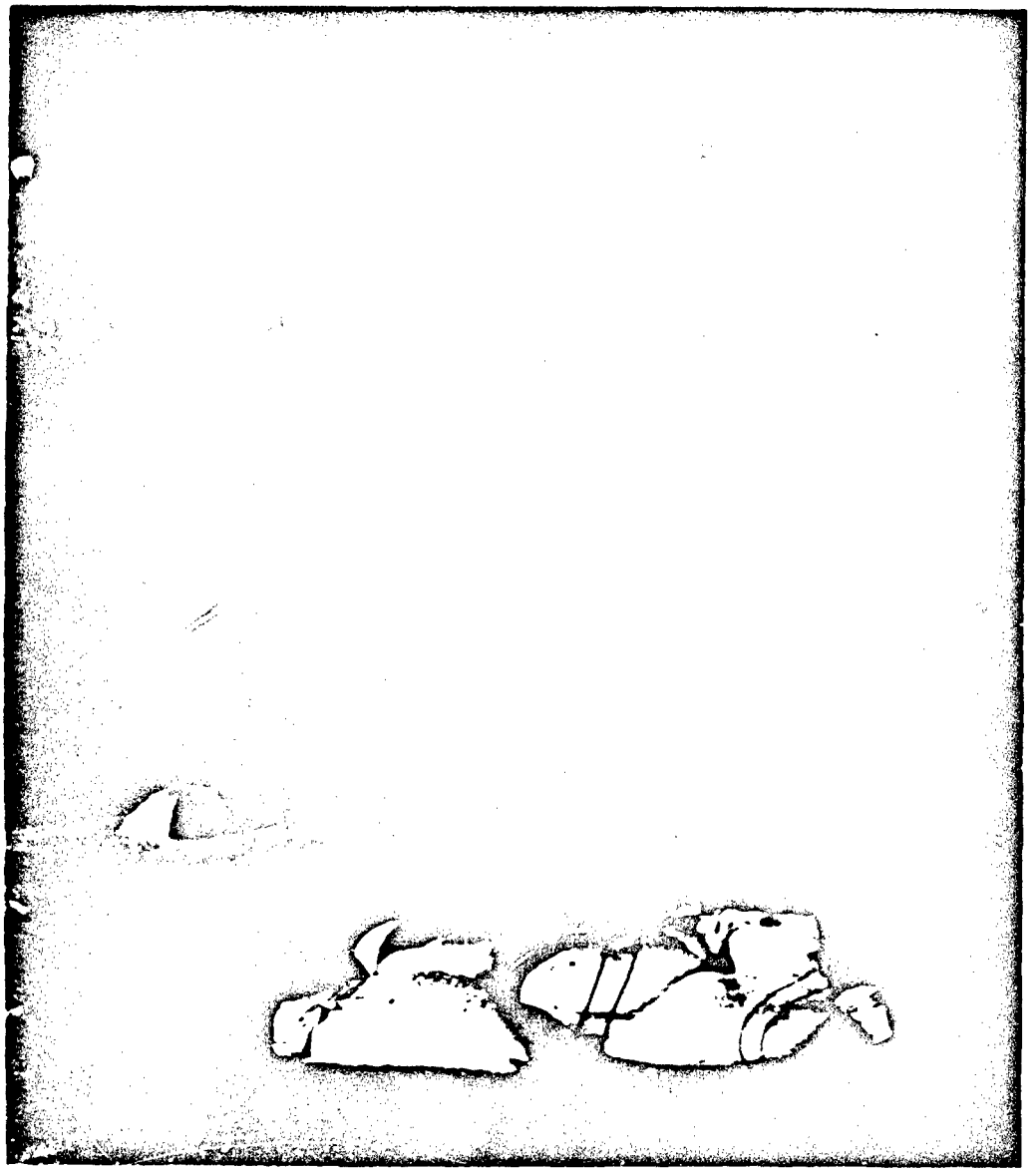

Fig. 4. Microphones Mounted at 6' Height Above Ground

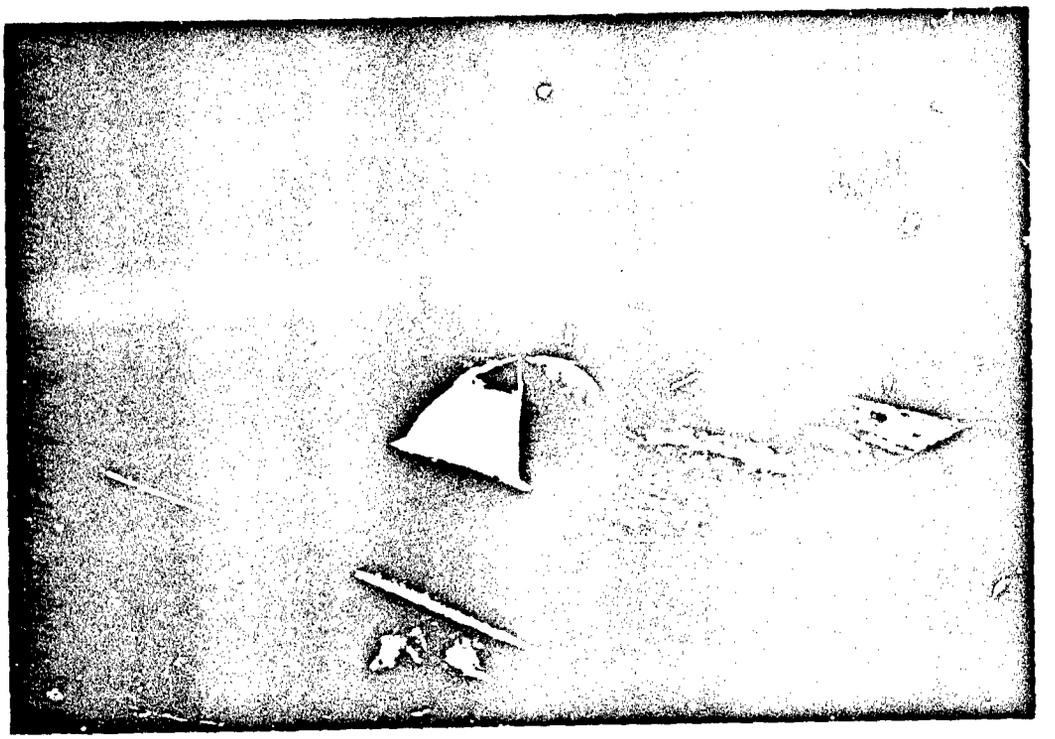

Fig. 5. Microphone Mounting Board with Wind Screen for Ground Level Measurements

and in combination with the FM System resulting in an AM-FM frequency response from 0 to 25,000 Hz. In addition to these two channels, a microphone measuring system specially modified to record sonic booms and supplied by the Acoustics Branch, NASA, Langley Research Center was also mounted at the 6-foot position (ref 6). This served as a known control microphone system with which responses of the other system were compared.

The frequency range of the conventional microphone complements was extended down to 0.2 Hz with a signal-to-noise ratio of –68 dB by modifying the screen coupling circuit of the microphone power supplies. The microphones were dynamically calibrated in the Laboratory with a mechanical pistonphone down to 0.1 Hz and selected for use on the basis of their overall frequency response characteristics and sensitivity. The microphones were not provided with a small hole (airbleed) to allow compensation for the temperature and atmospheric pressure changes during the field measurements. The venting rate of these microphones was judged sufficient to compensate for the expansion and not cause a distortion in the pressure reading. The microphones and their associated complements were acoustically field calibrated with a known 250 Hz signal of 124 dB which was applied to the microphones and recorded before and after each sonic boom was recorded.

The microphone positioned at ground level was shock mounted in the surface of a 4 by 4 feet, ¾-inch-thick plywood board. This board was firmly attached to the ground. A silk screen was placed over the microphone to protect it from dirt and sand and to reduce possible effects of the wind (fig. 5). This mounting arrangement was adopted from the method utilized by the NASA, Langley Research Center in their sonic boom measurement programs.

The overpressures as recorded by the FM system were later analyzed in the laboratory using a conventional multichannel recording oscillograph and the associated instrumentation shown in figure 3-B. The galvanometer type recording elements had a flat response from 0 to 3000 cps. A special driver amplifier was used to match the low input impedance of the oscillograph with the output impedance of the tape recorder. Calibration and check of the frequency characteristics of the playback system were accomplished before the analysis. The recorded calibration signal was played-back with the data and reproduced on the oscillograph. This signal along with the signature of the overpressure was then used to calculate the peak overpressure (ΔP) in pounds per square foot (PSF). The energy density spectrum analysis was accomplished by digitizing the analog tapes and using a digital computer.

DATA ACQUISITION AND ANALYSIS

Aircraft operation data of flight profiles for which overpressures were recorded are summarized in table I. This information was provided by JTF II and derived from automatic data recordings collected during the supersonic flights. Airborne radar and other data retrieval systems employed as part of the basic penetration study generated the data that was later made available for use in the bioacoustic portion of the sonic boom project.

Ground overpressure values for the F-4C fighter aircraft are summarized in table II as a function of altitude and Mach number. Ground clearance ranged from about 85 feet to 125 feet at Station 1 while Mach numbers ranged from 1.11 to 1.30. The highest positive peak overpressures were measured at Station 1 (Flights 1 thru 7) where aircraft passed at minimum altitudes. The terrain was reasonably flat at this location as can be seen in figures 6 and 7.

RUN	GROUND CLEARANCE	MACH NUMBER	MEASURED ΔP		ΔT		COMMENTS
			GROUND LEVEL	6 FEET LEVEL	GND.	6 FT.	
1	90	1.23		57.0		.064	MIKE 50 FT TO SIDE OF GND TRK
2	90	1.22	118.2	79.2	.057	.036	MIKE ON GND TRK
3	100	1.11	108.0	86.5	.066	.067	"
4	95	1.26	144.0	100.9	.054	.053	"
5	85	1.25	129.1	77.8	.063	.064	"
6	125	1.30	61.9	61.9	.059	.056	MIKE 150 FT TO SIDE OF GND TRK
7	110	1.23	51.8	50.5	.058	.058	"
8				33.1		.114	
9				24.5		.115	
10	210	1.27		50.1		.115	MIKE 1 MILE TO SIDE OF GND TRK

TABLE I.

SUMMARY OF MEASURED SIGNATURE OVERPRESSURES AND DURATIONS

		DATE	TIME	ALTITUDE	GROUND CLEARANCE	MACH	VELOCITY (ft/sec)
1	STATION 1	6/17	0748	5490	90	1.23	1267
2	"	6/18	0817	5490	90	1.22	1256
3	"	6/18	0904	5500	100	1.11	1145
4	"	6/18	0947	5495	95	1.26	1290
5	"	6/18	1025	5485	85	1.25	1281
6	"	6/21	0553	5525	125	1.30	1333
7	"	6/21	0728	5510	110	1.23	1261
3	STATION 2	6/18	0904	Estimated 7600	NO DATA →		
5	"	6/18	1023	"			
6	STATION 3	6/21	0551	6010	210	1.27	1292

TABLE II.

AIRCRAFT OPERATION DATA: FLIGHTS FOR WHICH OVERPRESSURES WERE RECORDED

Examination of the detailed tracking data shows that the aircraft were essentially "straight and level" over this station so that measured sonic booms are interpreted as not influenced by aircraft maneuver. Peak overpressure levels ranged from about 80 psf to 144 psf directly under the flight track and from 50 psf to 118 psf at various distances to the side of the ground track at Station 1. In general, higher overpressures corresponded to lower altitudes and higher Mach numbers as would be predicted from theoretical and experimental data. However, the extremely low ground clearance as well as the numerous irregularities in the configuration of this aircraft resulted in highly irregular near-field signatures and as a result interpretation of positive peak overpressure was not always a clear and easy determination. Some representative near-field pressure-time histories from the F-4C are presented in figure 8.

The pressure signature shown in figure 9 reflects the basic features of the N-wave, however the general configuration is quite ragged. In view of the near vicinity of the aircraft to the

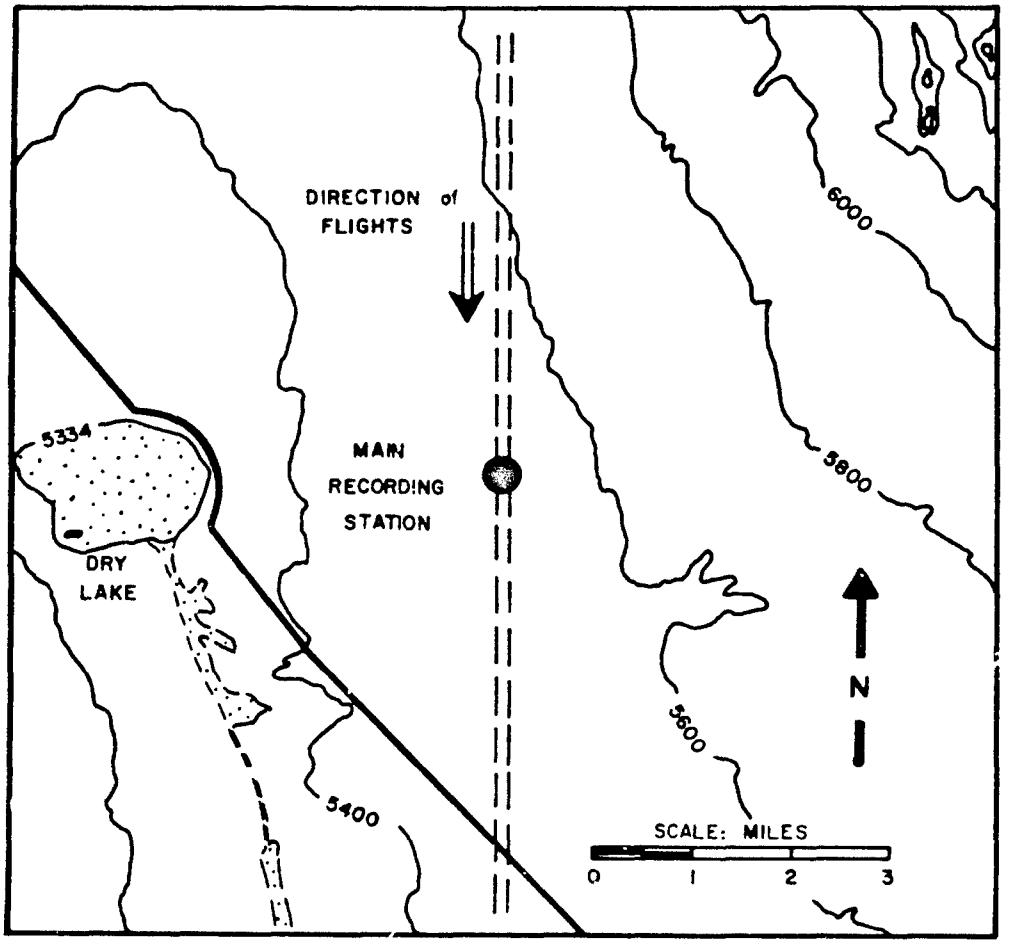

Fig. 6. Contour Map Showing Terrain at Main Recording Station on Track 8

measuring station the effects of atmosphere on propagation are considered to be quite small or even negligible. Signature irregularities are attributed primarily to the irregular surface configurations of the aircraft with the numerous individual leading edge shock waves being propagated to the ground. The relationship of some of these individual peaks in the signatures to

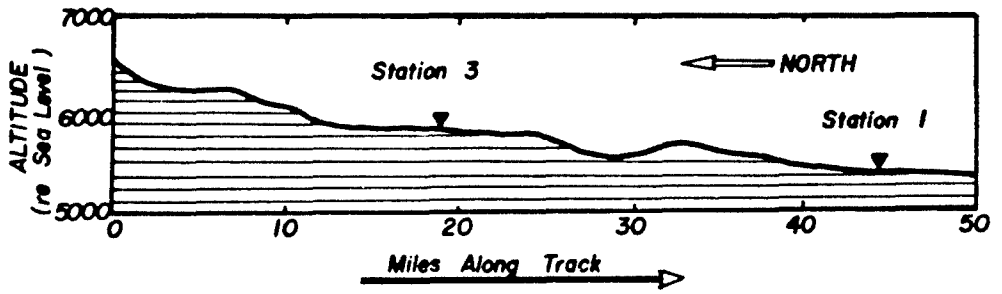

Fig. 7. Terrain Profile of Center Track (B) Flights Traveled from North to South

irregularities in the aircraft body surfaces are evident. The fact that the signature actually trails behind the aircraft with the shock waves bending to the rear is ignored for this pictorial presentation.

The sonic boom time history of signature A was recorded at ground level and signature B was recorded at a height of 6 feet above the ground (fig. 10). Signature B clearly displays both the incident shock wave as it was propagated from the aircraft to the ground and the reflected wave as bounced off the surface of the ground. Since the incident and reflected waves are identical at ground level no reflected element is present in signature A (ground level). Peak overpressures measured at ground level were equal to or greater than at the 6-foot level due to the ground reflection factor.

In addition to measurements taken at Station 1, overpressures were recorded at two other geographical areas occupied by local residents (fig. 2). Accurate aircraft operations data as shown in tables I and II could not be obtained for these flights. In one location (at the nearly abandoned town of Belmont, Nevada) aircraft over the track were an estimated 2800 feet from the center of town (the location of the measuring station) and less than 2000 feet from the nearest building. The flight track was located just inside the crest of a mountain peak situated about 1000 feet above and 2000 feet west of town. Peak overpressures of 24 psf and 33 psf were measured for two flights over this station (Station 2).

At Station 3 located about 1 mile to the side of the center track (Stone Cabin Ranch) only one sonic boom was recorded. There were no obstructions between the ground track and the ranch buildings situated in a cul de sac naturally formed by small hills that opened toward the ground track. The peak overpressure of 50 psf measured at a distance of about 1 mile from the flight track was considerably higher than the 5-10 psf estimated for that particular flight. This estimate was made on the basis of similar data obtained from Project Little Boom and shown in figure 11. A satisfactory explanation for the high peak overpressure measured at Stone Cabin Ranch has not been obtained. Flight operations data indicate that no change in direction or no maneuver of the aircraft occurred during its closely monitored pass over Station 3 at the time of recording.

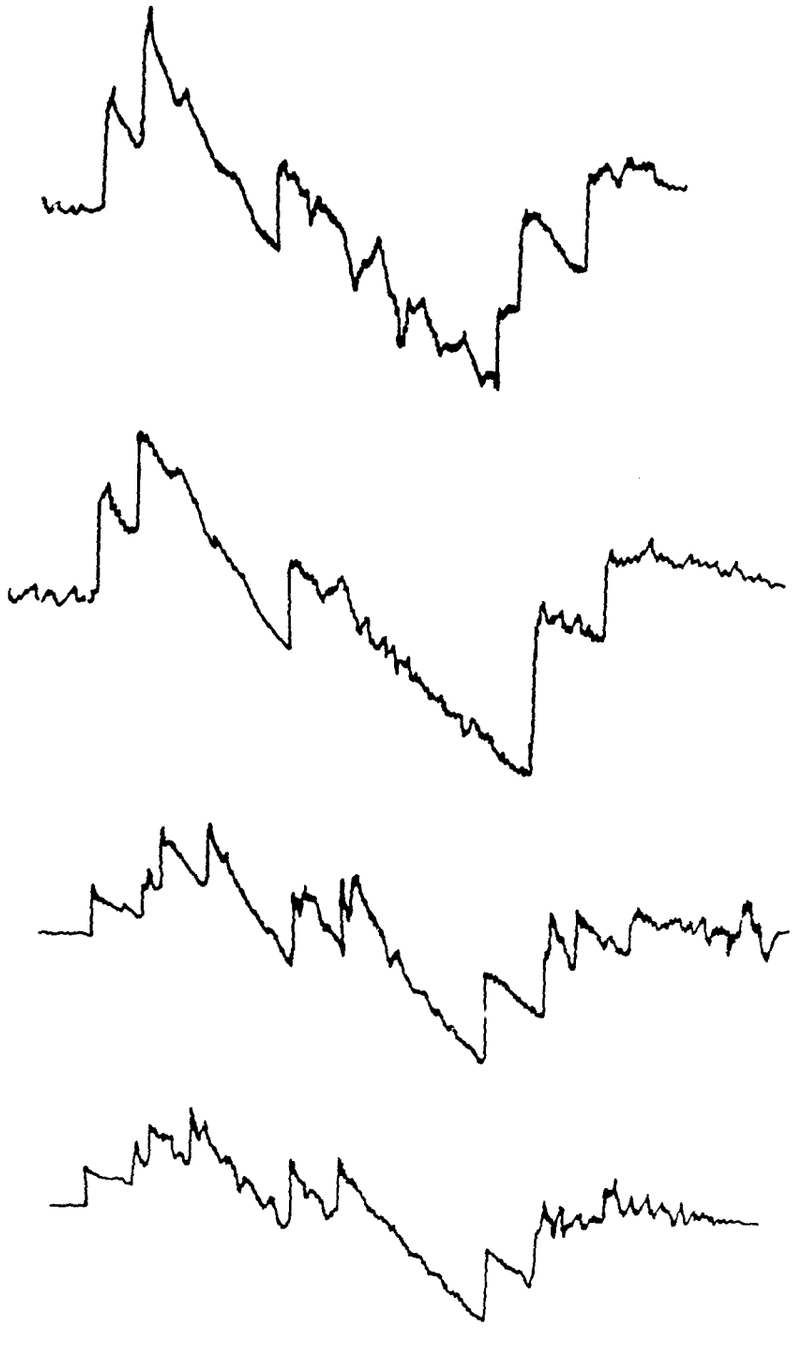

Fig. 8. Representative Pressure Time Histories Measured at 6 Feet for the F-4C at an Average Altitude of 100 Feet

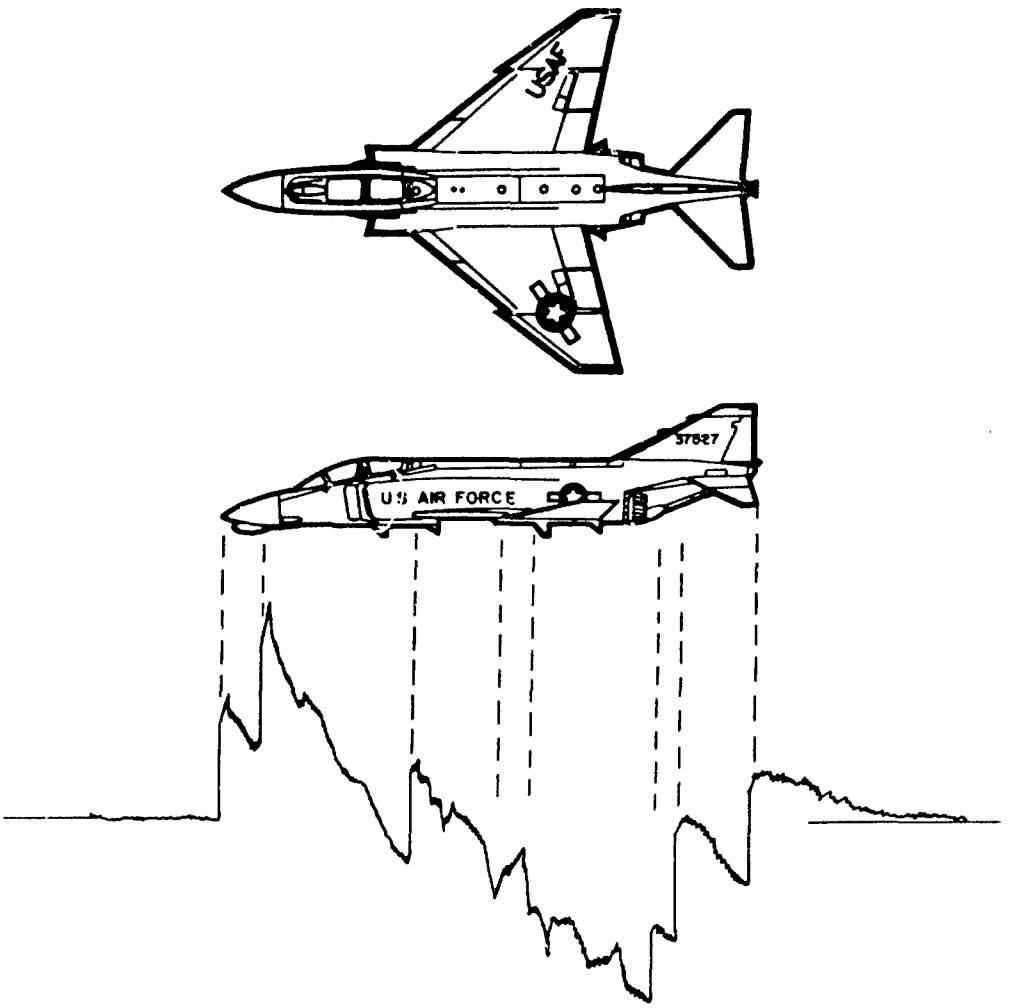

Fig. 9. Planform and Side Views of the F-4C with a Typical Pressure Time History

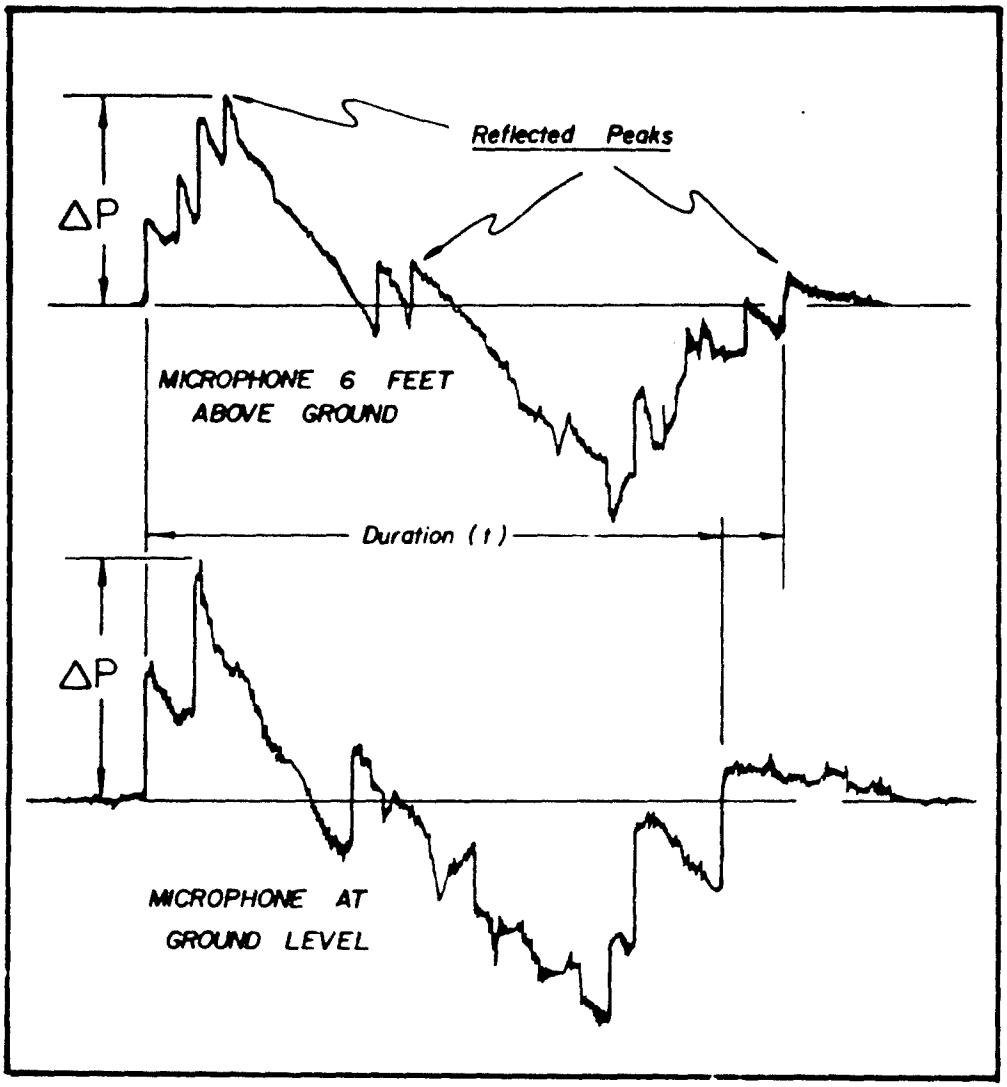

Fig. 10. Pressure Time History Measured at Ground Level and at 6 Feet

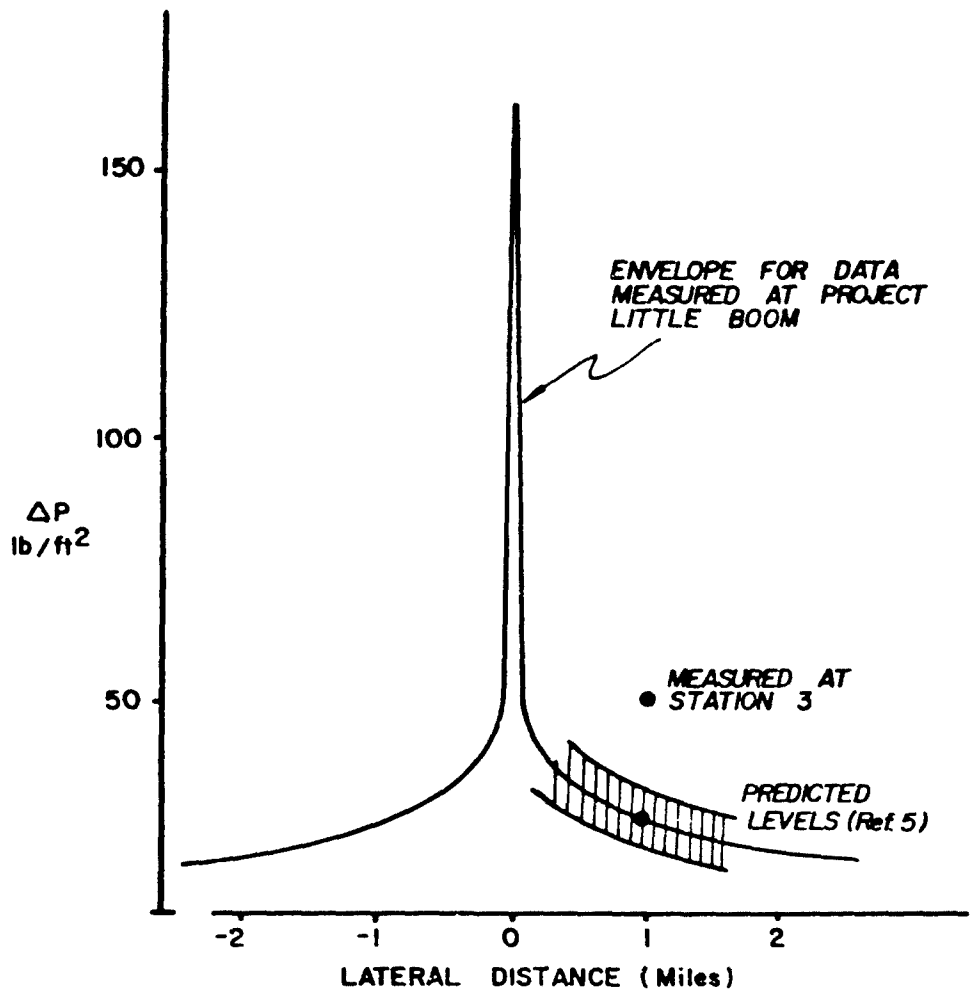

Fig. 11. Measurement at Station 3 of Single Sonic Boom Which Far Exceeds Predicted Levels Based on Measurements Obtained at Project Little Boom (Ref. 5)

Topography at Belmont and Stone Cabin Ranch are such that overpressures must be assumed to have varied widely over small distances. There is no way to determine the exact position of the aircraft with respect to the recording microphone for the data obtained at these two occupied locations.

A summary of the signature durations (Δt) of the measured overpressure is also contained in table II. Durations (Δt) were typical of those to be expected from this fighter aircraft at these minimum altitudes. Calculated durations defined by the expression $t = \frac{\ell}{v}$ where ℓ = the length of the aircraft, and v = the velocity in ft/sec were approximately 10 to 15 milliseconds less than the actual measured durations. This is in good agreement with another low altitude study in which calculated periods were consistently lower than measured values.

Two recorded sonic booms were analyzed by Fourier methods (ref 7) utilizing an electronic computer and are shown in fig 12. The graph presents the energy density as a function of frequency. The energy density spectrum E for the signal is

$$E = 10 \log_{10} 2\pi \mid S(\omega) \mid^2$$

with

$$S(\omega) = \int_0^T p(t)\, e^{-j\omega t} dt$$

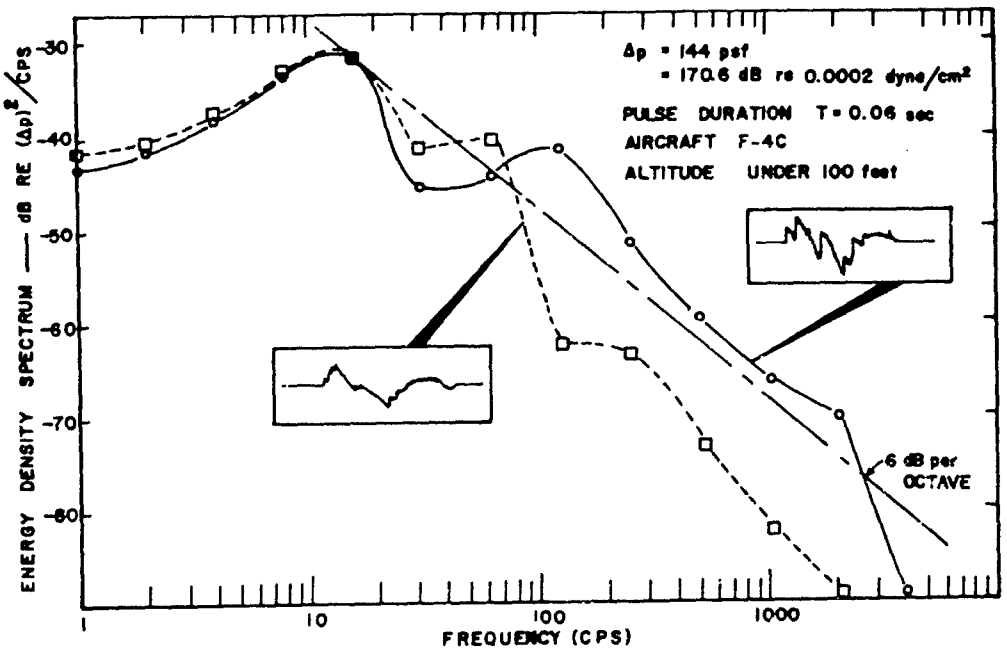

Fig. 12. Energy Density Spectrum of Two Measured Sonic Booms

Where T = duration of the boom pressure pulse, p(t) = pressure time function and $\omega = 2\pi f$, where f = frequency. Both signatures were generated by the same type aircraft, at about the same altitude and have the same peak overpressure of about 144 psf. One was recorded by the reference Photocon system and does not appear in the summary table.

The energy density spectrum of the signature with larger numbers of individual components contained more energy in the high frequency bands (solid lines) even though the fundamental frequencies were identical. Sonic booms with multi-saw tooth components and faster rise time, e.g., more energy in the high frequency bands, are judged to be louder than those without these components but of the same peak overpressure (ref 8).

Energy density spectrum analyses of various idealized sonic booms (ΔT = 0.04, 0.40, and 4.00 seconds) were calculated and are shown in figure 13. A sonic boom with a duration of ΔT = 0.04 seconds is typical of a fighter aircraft at low altitude and ΔT = 4.0 sec is representative of an SST size aircraft. For ΔT = 0.04 seconds, the fundamental frequency peaks at 17 cps, for ΔT = 0.4 it is 1.7 cps and is 10 dB lower in magnitude than the longer boom.

The energy density spectra of the measured sonic booms agree closely with those of the idealized booms. The measured sonic booms have a ΔT = 0.06 seconds, which corresponds to a fundamental of 17 cps and are 22 dB below ΔP. In general, a roll-off of 6 dB per octave from the fundamental is the same for both the measured and the idealized sonic booms.

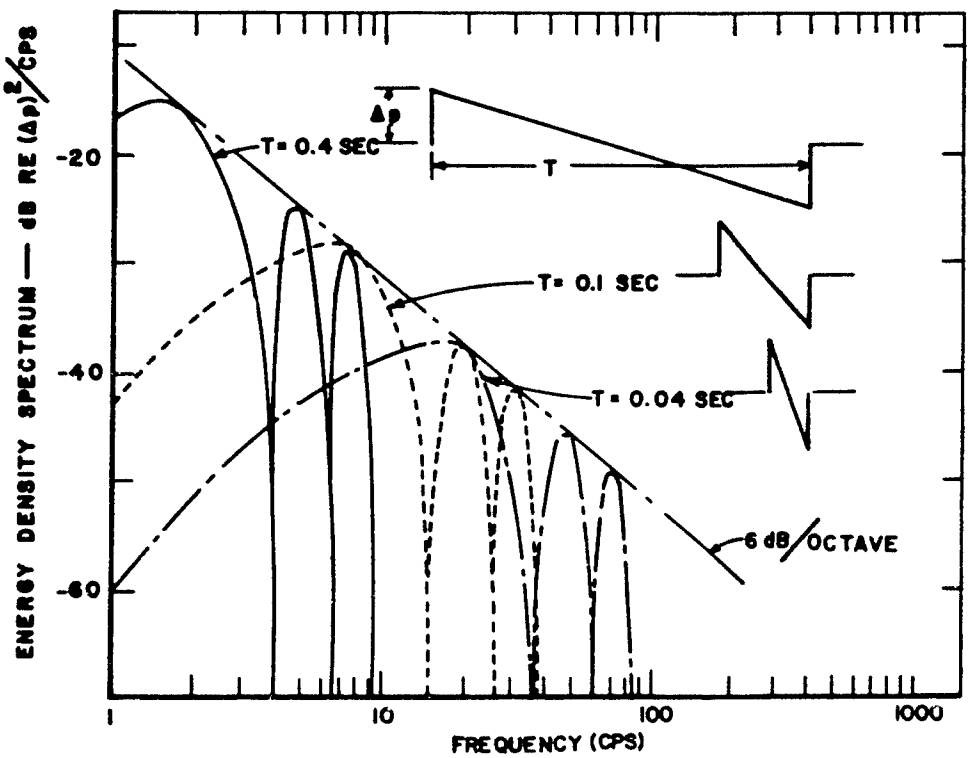

Fig. 13. Calculated Energy Density Spectrum of Idealized Sonic Booms of Different Duration

Section III.

OBSERVATIONS AND SUBJECTIVE EVALUATIONS

Prior to initiation of the series of supersonic test flights Air Force personnel visited occupied areas near the flight corridors to carefully observe structures and to inform residents of the nature of the study and of what might be expected to occur in their respective localities. Some of the same personnel who participated in the pretest visitations were present at the various occupied sites during most of the sonic boom exposures that occurred. In addition, an Air Force veterinarian surveyed and observed livestock in the area in a similar manner to obtain baseline preexposure data for later comparisons with responses of exposed animals. Consequently, competent observers obtained information on structures, people, and livestock prior to the exposures, during the exposures, and after the exposures.

STRUCTURES

Observed structures in the exposed residential areas consisted of very old frame and brick buildings in poor states-of-repair and both old and new campers and trailers. The poor conditions of the structures prior to test, the small number of them as well as the lack of overpressure data at the sites of the structures precludes relating overpressures to responses of specific types of construction. However, the buildings and their states-of-repair probably are representative of the kinds of structures that may be expected in other remote areas selected as sites for future low-level supersonic flight programs.

Damage to structures was principally confined to glass breakage, plaster cracking and furnishings falling from shelves. In almost all cases glass breakage occurred at the side of the building facing the approaching aircraft. The extent and nature of the damage was not unexpected for the magnitude of the sonic boom exposures experienced. There was no damage in the trailers.

The most important knowledge gained from this experience was that window glass fragments were propelled in some instances for distances of appr. 12 feet by the booms generated by the F-4C. This is quite important in view of all previous experiences and studies that demonstrated that glass breakage due to booms of similar magnitude from (different) other aircraft simply fell to either side of the frame (ref 9, 10, 11). There is no technical explanation offered at this time as to why in this instance glass fragments were observed to be propelled upon breaking due to sonic boom. Now that this phenomenon has been observed in a test situation, it is very important to determine the probability that it might reoccur in other situations.

Sandia optical tracking station No. 13 on the flat track was selected as the bioacoustic observation site since it assured minimum aircraft ground clearances and maximum sonic boom overpressures. Most aircraft were less than 100 feet above the ground at this point on the course and peak positive pressures ranged from about 108 psf to 144 psf. A relatively new station wagon located 50 feet from the track incurred no breakage throughout the tests, although covers for the dome light and spare tire compartment popped out during sonic boom exposures. An already cracked safety glass window (side rear) of an older Sandia station wagon was shattered* by the first sonic boom to which it was exposed. The small side window of a camper (parked about 100 ft from the track) broke and glass flew out as far as 12 feet in the direction from which

*Glass did not fall; shattered pieces adhered to the flexible layer of safety material of the window.

the aircraft approached. (Campers located at the starting gates of the three tracks similarly experienced repeated window breakage. It is likely that super booms were experienced at these locations since aircraft were maneuvering to enter the gate and begin the pass). In a small building about 200 yards from the track the receiver of a wall telephone was repeatedly shaken off its cradle by the booms and some light bulbs inside the optical tracking station were broken. Clouds of dust rising in the air were observed to follow the sonic boom as it moved along the flight track, except for occasions when the ground was wet.

HUMAN RESPONSES

Bioacoustics personnel operating the main recording station were exposed to sonic booms ranging in peak positive pressure from 50 psf to 144 psf. Ear protection was worn by some individuals only during the first few runs while others did not use ear protection at any time. The pressure wave was felt by the entire head and body during boom exposures as a jarring sensation. Rather strong tactile and kinesthetic stimulation were experienced as well. Some momentary discomfort, fullness, and ringing of the ears were experienced with the more intense booms and these persisted from periods of a few seconds to as many as 60 to 120 seconds. For the most intense booms the symptoms of fullness, ringing, etc., were significantly greater in the ear facing the approaching aircraft than in the contralateral ear. Symptoms were essentially the same for both ears for the lesser intense booms.

No distinct auditory pain was reported although some booms were described as very sharp. Personnel further commented that the most intense booms would have been judged to be painful had they been any greater in magnitude. From this the threshold of pain for these individuals and kinds of exposures was perhaps close to but still greater than 144 psf. Although hearing acuity was not physically measured, subjects reported no indication of any observable symptoms of temporary hearing loss or other ear involvement.

Individuals performing routine tasks of photography and operation of the electronic equipment were required to visually follow the aircraft during its supersonic pass. Although task performance was not interrupted or bothered all personnel expressed avoidance behavior consisting of involuntary ducking and flinching in response to the boom experience. This behavior occurred for individuals with as well as without ear protection. Startle responses to the actual pressure wave also occurred. This behavior did not habituate during the three-day flight program. In fact, involuntary tensing or muscle set of the body in anticipation of booms appeared to be stronger for the later exposures than during the initial boom experiences.

Exposures of 10 to 15 people at the main recording station confirm that no direct injury is incurred from exposures to exceedingly intense sonic booms by healthy young and middle aged persons. At other occupied locations, where ages of exposed individuals varied from 6 years to more than 70 years, no physiological symptoms or effects of the sonic booms were reported. No pain, fullness or ringing of the ears was observed. At these locations the magnitude of the overpressures were less than at the main recording station but significantly greater than any sonic booms experienced (average of 2.0 psf and less) or expected to occur in residential communities (ref 12, 13).

ANIMAL RESPONSES

Although the flight corridors were established over open range, no concentrations of cattle or horses were found directly under the tracks. Several small groups of cattle near the tracks and a horse in corral were observed and their responses prior to, during and following sonic boom exposures were cinematographically recorded. Responses were either unrecognizable or consisted

of an apparent alerting response accompanied by trotting off a short way. In addition, ranchers reported no observable response to the sonic booms of the livestock at various other locations on the range.

Several pilots reported having seen from the air cattle and horses run at the approach of the aircraft. In each case the livestock appeared to look toward the aircraft prior to the running activity. It is rather clear that the avoidance response was due to visual cues rather than the auditory stimuli. The basic auditory cues occur for low-level high-speed flight when the aircraft is overhead or has passed the observer, whereas the response in this situation occurred prior to the time the aircraft appeared overhead. Both cattle and horses run from circling helicopters that may be both seen and heard.

Some of the livestock and cattle observed during this program annually winter graze on the Sandia range and consequently were previously exposed to low-flying aircraft, sonic booms, and explosive blasts. Thus the lack of adverse response experience of this program cannot be generalized to other cattle and horses in other parts of the country. It is indicated, however, that for these preexposed animals some adaptation to the noise had occurred.*

*Personal Communication; Capt. Jack M. Heinemann, VC, Regional Environmental Health Laboratory, Kelly Air Force Base, Texas.

Section IV.

DISCUSSION AND RESULTS

Sonic booms generated by low-level supersonic flights of F-4C aircraft participating in Joint Task Force II operations near Tonopah, Nevada, were measured at three sites under and near the flight tracks and responses of structures, people, and animals were observed.

Findings include:

(1) Prior observations that very intense sonic booms do not harm or injure people directly were confirmed for elderly as well as young persons.

(2) Observations that fragments of window glass were propelled some distance indoors and outdoors by the F-4C booms, which is contrary to previous experiments that window glass broken by sonic booms is not propelled, but simply falls to the ground.

(3) Overpressures measured at distances of one mile or more from the flight track require further investigation. One measured pressure wave far exceeded in magnitude the levels previously measured at these distances and predicted by theory.

(4) Procedure and instrumentation used to record sonic booms appear valid.

(5) Acquisition of F-4C near-field ground overpressure recordings.

(6) Evidence that cattle and horses (with undetermined prior exposures to aircraft noise and sonic boom type sounds) do not necessarily respond adversely to low-flying subsonic and supersonic aircraft.

(7) Selection of courses for programs involving practice low-level supersonic flights that pass over or near structures or people will continue to pose a major problem. Intensive personal contacts and preprogram orientation with residents within distances of one mile lateral to the flight track are clearly indicated.

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13. ABSTRACT

Sonic booms generated by F-4C aircraft flying low-level terrain-following profiles during Joint Task Force II operations near Tonopah, Nevada, were recorded under and near the flight tracks, and responses of structures, animals, and people were observed. Recorded overpressures up to 144 psf were analyzed, correlated with available aircraft operations data, and compared with data from different aircraft flying similar profiles. Observations of structures, animals, and people were correlated with the measured overpressures. Results include acquisition of near-field recordings of overpressures generated by the F-4C, the finding that some window glass fragments were propelled a short distance rather than falling directly below the window, an instance in which the measured overpressure of a sonic boom 1 mile to the side of the track far exceeded the predicted value, the finding that livestock (undetermined prior exposure to acoustic stimuli in this situation) did not respond adversely to the sonic booms, confirmation that very intense sonic booms do not harm people directly and the reaffirmation that the selection of site locations for low-level supersonic training missions will continue to pose a problem.

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