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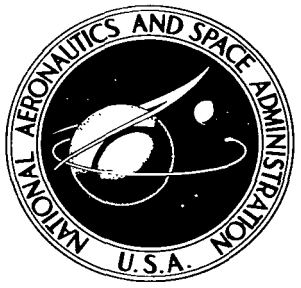

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Aerospace Medical Research Laboratories
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Harvey H. Hubbard

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SUMMARY

Data are presented from a series of community-reaction flight experiments in which the population of a large city was repeatedly exposed to sonic booms in the range of overpressures up to about 3.1 lb/sq ft. Results were obtained from direct interviews, analyses of complaint files, and engineering evaluations of alleged damage and are correlated with information on aircraft operations and sonic-boom pressure measurements.

Personal-interview studies indicated that about 90 percent of those contacted experienced some interferences as a result of sonic booms, about 35 percent were annoyed by them, less than 10 percent had contemplated complaint action, and less than 1 percent had actually filed a formal complaint. The total number of complaints and subsequent claims were approximately proportional to the number of flights. Building responses are a significant factor in community response. Alleged building damage was superficial in nature and consisted mostly of cracks in brittle surfaces. Contributing factors other than sonic booms were noted in most of the damage cases. There were no reports of direct adverse physiological effects.

INTRODUCTION

Aircraft in supersonic flight generate pressure waves that are perceived along the ground as sonic booms. These sonic booms may interfere in some way with the activities of people who are exposed. As a result of this interference, people may become annoyed, and in the extreme cases this annoyance could lead to unfavorable reaction. Such reaction is usually evident from registered complaints of annoyance or claimed damage to personal property.

The subject of community reaction to sonic booms is important because it may influence the manner in which military training operations are carried out and, in addition, may have a marked effect on the configuration and operating

conditions of proposed supersonic commercial transports and on their route structures, particularly for overland operations.

Because well-documented community-response-to-sonic-boom information is not available, the field experiments reported herein were accomplished. For the purposes of evaluation, the opportunity was taken to investigate reaction to sonic booms in a large community already familiar with them. These evaluations included extensive interview studies in the community and on-the-spot analyses of complaints and alleged damage reports. Information resulting from these studies was correlated with the sonic-boom-exposure information associated with supersonic flights for which altitude, Mach number, time of day, and flight corridor were under close control. Some preliminary conclusions from the interview phase of this study are presented in reference 1.

Preparation of the present paper was motivated by the need for making available in one document the main findings of the study. Studies relating to the community-response phase of the program were made by the National Opinion Research Center, University of Chicago, 55 Fifth Avenue, New York, New York. Those studies relating to architectural and engineering evaluations were made by Clark, Buhr, and Nexsen, Norfolk, Virginia. Both were under contract to the NASA Langley Research Center. The present paper contains a brief summary of the information included in the above studies. Included herein are descriptions of the site used and the data-gathering procedures as well as the research findings. Particular attention is given to the results of interview studies involving residents of the community and to architectural and engineering evaluations of claimed damage incidents.

GENERAL CONSIDERATIONS

Program Site

Advantage was taken of the fact that the metropolitan area of St. Louis, Missouri (see fig. 1), with a population of about 2,600,000 (about 550,000 families), had many desirable features for a study of community reactions to sonic booms. For instance, this area has commercial jet and propeller-aircraft operations, a history of previous sonic-boom experience, no sharp or irregular topographic features, structures and buildings of various types of construction and ages, and was accessible to the required aircraft staging points.

All supersonic flights relating directly to the study in this area were assigned the code name "Bongo" and were flown over a predetermined supersonic corridor which traversed the selected area. The approximate ground track of the Bongo flights is shown by the solid line in figure 1. It can be seen that this ground track passes along the edge of the main urban area of greater St. Louis. The dashed lines parallel to the ground track line are placed at 4-mile intervals to indicate the lateral extent of the area. Data were obtained out to a lateral distance of about 16 miles from the ground track. All urban areas in the flight corridor are indicated in the figure by the hatched areas. Areas not hatched are of relatively low population density.

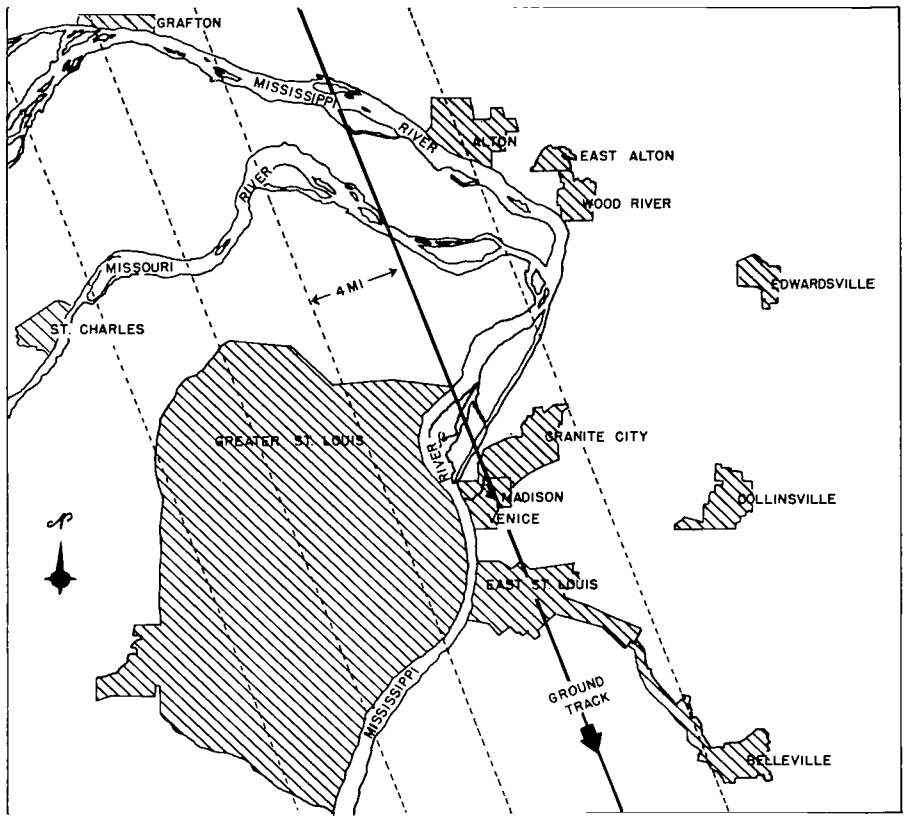

Figure 1.- Map of Greater St. Louis area with ground track of Bongo aircraft superposed. Shading denotes urban areas.

Sonic-Boom-Exposure History of the Area

There were some carefully monitored special flights during the period when information was collected as well as several unmonitored flights previous to the study period. The complete log of known supersonic flights for which sonic booms occurred in the St. Louis area both prior to and during this period is given in table I. It can be noted that the first flight was made in July 1961 and that up to the time of the community-response study, at least 34 flights were known to have been made. Most of these flights were over or near the ground track of figure 1, but there is a possibility that some of these flights were made over a different ground track than the one shown. Thirteen special flights were made in this same corridor at various times of day and night during a 6-day period beginning November 6. No other supersonic activity occurred in the vicinity during this time except for one afternoon flight of undetermined origin. Subsequent to these special flights, 29 others were known to have been made. Four of these, which occurred on January 3, 1962 and January 6, 1962, were also special flights at a relatively lower altitude and with higher associated sonic-boom pressures. A total of 76 supersonic flights was thus known to have been made in the test area during a 7-month period.

By way of review, the sonic-boom time-history traces are included in figure 2. These traces were measured during the experiments and serve to illustrate the types of sonic-boom signatures to which the residents in the community were exposed. The top trace is representative of an exposure outdoors in an open area. The bottom trace is an example of the pressure signature experienced inside a one-story frame building. It should be noted here that a different inside exposure might exist, depending on the geometry and location of the room, the size of the building, and its construction. It is significant to note, however, that the inside exposures are of lower intensity, exist for a longer period of time, and are generally more complex in nature than the outside exposures. As a matter of further information, an indication of the ranges of outside sonic-boom peak overpressures (Δp_o in fig. 2) to which the community was exposed is given by the data of figures 3 and 4 and table II.

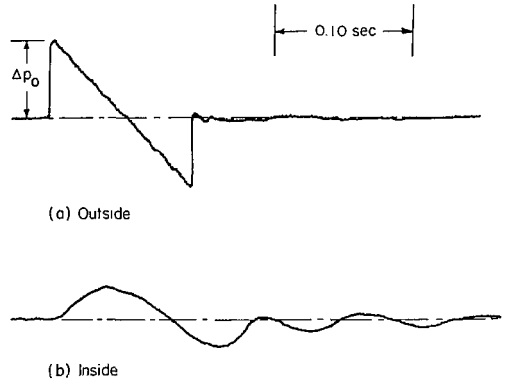

Figure 2.- Tracings of F-106 sonic-boom pressure signature recorded both outside and inside a building in the area.

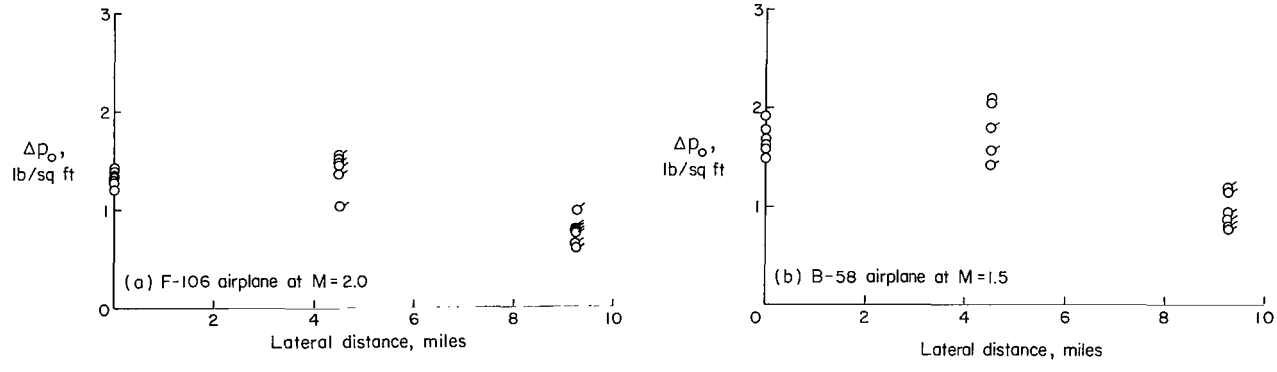

Figure 3.- Measured ground overpressures as a function of lateral distance for flight of F-106 and B-58 aircraft at an altitude of 41,000 feet in St. Louis area. Ticked symbols indicate estimated ground pressures based on free-air measurements and were adjusted by multiplying free-air values by a factor of 1.8.

The data of figure 3 apply directly to the flights of the F-106 and B-58 aircraft utilized in the special flights and for the flight corridor of figure 1. These data are only for measurements made at a flight altitude of

41,000 feet. Estimates of the pressure exposures, based on theory and experiments, as a function of distance are presented in table II for the F-106 airplane at 41,000 feet and for the B-58 airplane at several altitudes. It can be seen that a variation of peak overpressures was evident in the measurements of figure 3; this variation seemed to be about ±0.3 lb/sq ft (smaller than in ref. 2) from the mean value at each station. It can also be seen that the measured values at the first lateral station are sometimes higher than those obtained on the track. This latter result would not normally be predicted (table II) but could be accounted for by the presence of a localized warm air region in the atmosphere above the city.

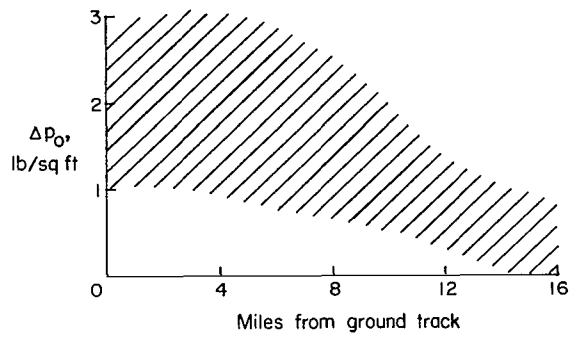

Figure 4.- The estimated ranges of sonic-boom overpresssure as a function of distance from ground track for Bongo flights.

The data of figure 3 and table II have been used as a basis for the estimated ranges of overpressures of figure 4. The crosshatched region includes specifically the overpressures of the Bongo flights but also would include those of the other flights of table I. The peak overpressures are seen to vary from about 0.8 to 3.1 lb/sq ft near the track and from 0 to about 0.8 lb/sq ft at the most distant locations.

Weather Conditions

For the series of flights during the week of November 6 to November 12, the weather ranged from clear to overcast; temperatures ranged from below freezing to almost 75° F; the surface winds varied from 0 to 15 miles per hour; and the four flights on November 12 encountered slight precipitation.

Although formal weather measurements and observations were not made during flights subsequent to the week of November 6 to November 12, a wide range of weather conditions was experienced. During the flights on January 3, overcast skies and heavy precipitation were experienced, whereas on January 6 the flights were accomplished during a heavy snowfall with a ground cover of approximately 8 inches of snow.

Data-Gathering Procedures

Community acceptance of sonic booms of varying intensities generated along the flight corridor was evaluated by a statistical survey of personal reactions using interview methods within the exposure area. Subcommunities interviewed were selected to represent a variety of acoustic environments relative to the area along the ground track. Some sampled areas were located directly under the ground track, others were off to the side of the ground track but experienced similar exposures, and others were located at varying distances from the ground track and were free from direct overflights.

Immediately following the initial series of flights (starred in table I), approximately 100 households were interviewed in each of 10 sampled areas. The initial respondent contact consisted of a detailed intensive interview 1 to $1\frac{1}{2}$ hours long. The interview did not reveal the purpose of the study but was described to the respondent as a broad community survey of how people felt about the communities in which they live. The background and personal characteristics of the respondents were recorded, as well as complaint potential, attitudes and experiences toward the community, toward commercial and military aviation, and other related basic variables. Respondents were told that the survey would continue for several weeks and that the interviewer might call back to obtain additional information.

Approximately 2 weeks following completion of the initial interviews, a second series of supersonic flights was made over the same ground track. These four flights were scheduled to provide fewer but more intense booms than were experienced during the first exposure. Call-back and control interviews were begun within 2 days.

These call-back interviews were conducted primarily by telephone and were concerned with those respondents for whom initial interviews had been successfully completed. Control interviews involved an independent population sample that was queried at the same time as the re-interviews in order that their responses could be compared with those of the call-back interviews. The control group was necessary to measure a "panel effect," which is the effect of a first interview upon a respondent's reactions in a re-interview situation. Completion of the control and call-back interviews was delayed somewhat because of unfavorable weather conditions; however, all field work was completed and coding and data processing were begun in early February. A total of 1,043 respondents completed both the interview and re-interview and 298 control interviews were also completed.

Architectural and engineering personnel were made available for field investigations of all reports of alleged damages to property claimed to have resulted from the special flights. These immediate inspections were accomplished with the cooperation and support of experienced U.S. Air Force investigation teams. Visits were documented with photographs, engineering reports, and reports of the general state of repair of the basic structure.

Participating Organizations

In addition to the cooperative job of overall planning, which was participated in jointly by the U.S. Air Force (USAF), National Aeronautics and Space Administration (NASA), and Federal Aviation Agency (FAA), there were some specific responsibilities assigned to each.

The USAF furnished the technical monitor for the community-response interview studies and provided aircraft support, public information, and legal

services. NASA accomplished the physical sonic-boom measurements and provided the technical monitoring of the contract work related to evaluation of alleged sonic-boom-induced damage. The FAA Headquarters coordinated the flight scheduling and air traffic control operations, and the local FAA office in the area provided radar tracking and guidance of aircraft. The U.S. Weather Bureau accumulated pertinent weather information and provided subsequent analyses. The community interview studies were accomplished under contract by the National Opinion Research Center of the University of Chicago, and the engineering survey studies of alleged damage were accomplished under contract by Clark, Buhr, and Nexsen of Norfolk, Virginia.

Program Responsibility Assignments

This section describes the responsibility assignments of the various organizations involved in the joint USAF-NASA-FAA sonic-boom flight program. Selection of the site, determination of the overall scope of the program, and the procedures involved were accomplished jointly by the personnel of these agencies. Specific responsibilities in the specialty areas described below were assigned to the appropriate organization, as indicated.

Aircraft operations.- A B-58 bomber bailed to Aeronautical Systems Division (ASD), for use at Edwards Air Force Base, and operational F-106 fighter aircraft from Air Defense Command (ADC), Bunker Hill Air Force Base, Indiana, participated as flight-test aircraft. Refueling was accomplished for the B-58 with an ASD, Wright-Patterson Air Force Base KC-135 tanker in the area of Cave-in, Missouri. The F-106 made a single pass over the target area and then returned to base without refueling. All Bongo flights were accomplished over the same predetermined supersonic corridor on a heading of 160° magnetic. A schedule of the supersonic flights over St. Louis, Missouri during the period from July 1, 1961 to January 31, 1962 is contained in table I. The Bongo flights for which detailed data were collected are indicated by asterisks.

On two occasions during the interviewing phases of the program, it became necessary to request additional supersonic activity that was not included in the original flight schedule. In one instance, approximately 2 weeks following the initial series of flights, the sonic-boom activity in the area had decreased to such an extent that interviewers were not obtaining spontaneous responses about the sonic boom. Since the design of the interview was based upon the spontaneous response, additional acoustic exposures were necessary for the continued success of the interviews.

A similar situation occurred in early January when the Strategic Air Command (SAC) Radar Bomb Score (RBS) training program was temporarily interrupted on the same date as the last Bongo flight. Re-interviews were begun after the last Bongo flight. Since the SAC-generated sonic booms had been providing a necessary background exposure for the community-reaction program, it appeared that a sudden absence of sonic-boom activity might introduce a bias into the call-back interviews. Therefore, additional flights were again accomplished.

Tracking and air traffic control.- Air traffic control and the Bongo flights of November 6 to November 12, 1961, were coordinated by personnel from FAA Headquarters, Washington, D.C. Local FAA personnel coordinated all flights subsequent to the first series except for special flights accomplished after January 6, 1962. Bongo aircraft were assigned a higher priority than all except special military traffic during the scheduled flight times. Conflict with other air traffic was minimized because of the high altitudes at which most Bongo flights were accomplished.

Local FAA personnel formulated a radar control procedure whereby Bongo aircraft were guided along the flight corridor and a permanent record was made of the plan position and ground speed of the aircraft. The aircraft were directed from an area north of the city in such a manner that steady level supersonic flight was accomplished in a southerly direction across the target area. The F-106 aircraft made one supersonic pass over the target area and then returned to base at Bunker Hill. Where two passes are indicated in quick succession, two different aircraft were utilized. B-58 aircraft returned to north of the city following the first supersonic run and then made a second pass over the target area. Subsequent to the supersonic runs during November 6 to November 12, 1961, refueling was accomplished and the B-58 aircraft returned to Edwards Air Force Base. The B-58 flights of January 3 to January 6, 1962, were accomplished without refueling.

Overlays of all Bongo flights were prepared from information on the FAA surveillance radar plan-position-indicator (PPI) scope. No maneuvers or quick deviations from the flight path were observed during the supersonic runs. Maximum lateral deviation of the Bongo aircraft from the ground track was only $1\frac{1}{4}$ miles. This deviation was negligible for the purposes of the community-reaction program.

Public information.- In late July 1961 the Strategic Air Command began using the St. Louis area as a B-58 Radar Bomb Scoring target city. Prior to the first RBS Mission, the SAC-Convair sonic-boom orientation team initiated a public information program that was climaxed with a dinner presentation to civic leaders, local fire and law enforcement officers, members of the news media, civil defense personnel, and the like, of populated areas to be affected by the RBS missions. This presentation provided information concerning SAC, the B-58, details of the RBS training activities, and the sonic boom. USAF officers from the Public Information Office (PIO) of Scott Air Force Base maintained this sonic-boom public information program during the entire RBS training period by providing periodic news releases, films, and frequent lectures to community organizations.

The policy of public information agreed upon by all agencies participating in the community-reaction sonic-boom program was that Bongo flights would be treated as regular RBS training missions. This policy was coordinated with SAC Headquarters by USAF PIO, as recommended by the community-reaction program. Information requests originating from the press, television news personnel, and the like, were received by the PIO.

Processing of complaints and claims.- At the time that St. Louis was selected as the area for the Bongo flights, the Public Information Office and the Judge Advocate General Office (JAG) at Scott Air Force Base had already implemented a carefully organized program to process complaints and claims of damage to property due to sonic booms. All responses, whether complaint or claim, were received by the JAG office and a permanent record was made of the details of the response and of action taken by the Air Force.

During the Bongo program, responses received by the PIO and JAG offices were monitored by personnel of the sonic-boom program in order that any unusual reaction could be detected and appropriate action initiated to modify the overflights as might be required. No unexpected reactions were observed, however, and the flight schedules were accomplished as planned.

Public response - interview study.- The personal interview studies in the community were conducted under NASA contract by the National Opinion Research Center (NORC) of the University of Chicago. Technical direction and monitoring of this contract was accomplished by the Bio-Acoustics Branch, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. In October 1961, NORC assigned a local field supervisor to direct the personal-interview community-reaction-to-sonic-boom program in the area. The basic purpose of the project was not disclosed to the supervisor since this knowledge would have no beneficial influence upon the performance of the interviewing task. Approximately 50 interviewers were hired and subjected to an intensive training program. Interviewers and respondents were told only that the University of Chicago was doing a study about how people felt about living in different places. Concurrent with the hiring and training of interviewers, subcommunity sample regions were selected within the area. Selection of a subcommunity was based upon such criteria as a mild or intense exposure area as determined by distance from the ground track; high, middle, or low socioeconomic level; a minimum of 200 homes to permit a random selection of households; and the like.

Subsequent to formal training, practice interviews were conducted. The practice interviews were accomplished during the same time period as the initial series of Bongo flights. Some of these interviews were successful enough to be included in the regular interview sample.

The intensive interviews were begun on November 13, 1961. Each of the initial interviews required from 60 to 90 minutes for completion. A total of 1,145 initial interviews were concluded about December 15, 1961. A total of 1,011 of the 1,145 respondents were re-interviewed between January 8, 1962, and January 28, 1962.

Physical measurements of sonic-boom pressures.- Sonic-boom pressure measurements were made by NASA Langley Research Center personnel for the Bongo flights accomplished from November 6 to November 12, 1961. Recording stations were located on the ground track and at distances of about 4.5 and 9 miles laterally from it. Each station was connected by telephone to the main control station located at the FAA facility. Free-air and ground pressures were measured in addition to measurements taken inside three different buildings. The outputs of commercially available microphone systems modified in frequency

response were recorded on recording oscillographs. The frequency range of the overall system was 0.02 to 5,000 cycles per second. Usable data were obtained for all November flights in the series with one exception, wherein a recording station became inoperative because of electrical difficulties.

Engineering evaluation of damage reports.- The evaluation of alleged damage reports was accomplished under contract to NASA Langley. Representatives were present in the area for the series of flights made during November 6 to November 12, 1961 and during January 3 to January 6, 1962. In cooperation with the JAG and PIO offices at Scott Air Force Base, cases involving claims of damages to property attributable to past sonic booms were reviewed. Photographs and engineering reports were obtained for claims that had been investigated by the USAF.

In the company of USAF inspection teams, which consisted of an engineer, a legal officer, and a photographer, contractor personnel inspected damages reported to have been caused by the Bongo flights. When possible, entire building structures were carefully inspected to determine the general state of repair and to establish whether there were other probable causes of the damage that were unrelated to the sonic boom.

Informal inspections were made of structures in areas in which the community reaction interviewing was conducted in order to categorize the structures by type, age, and general condition. During the flight tests, engineers inspected approximately 165 reports of damage attributed to sonic booms.

Weather information.- Weather information was accumulated to assist in estimating possible influences of various atmospheric conditions on the direction and intensities of the sonic-boom pressure waves. A meteorologist from the U.S. Weather Bureau, Washington, D.C., provided weather information to the program coordinator during the first series of overflights in the area. Weather measurements were made as close as possible to the times of the Bongo flights with a portable rawinsonde station located about 20 miles south of the center of the area in the vicinity of Scott Air Force Base. Additional rawinsonde soundings were requested from Weather Bureau facilities at Columbia, Missouri, which is about 100 miles northeast of the area. Surface observations were obtained at Lambert Field, Missouri, which is within the area, and at Scott Air Force Base, Missouri. Ambient temperature readings for altitudes of 1,000, 1,500, and 2,000 feet were requested from all commercial aircraft taking off from Lambert Field.

RESULTS AND DISCUSSION

Results of direct interviews with people in the community and the engineering evaluations of reports of alleged damage are correlated with other data which describe the test conditions. The nature of the sonic-boom problem and the associated responses to sonic-boom exposures are discussed in terms of the nature of reaction and specifically of the complaints and claims. The results are stated briefly and are illustrated graphically where practical. A discussion of the factors believed to be important is also included.

Nature of Reaction

Much knowledge has been accumulated by population-sampling studies regarding the manner in which communities ordinarily react to various situations which affect their personal and community activities. However, such information is not sufficient to permit an accurate prediction or estimate of the reaction of a specific population to a particular stimulus such as the sonic boom. It is necessary, in this instance, to acquire information about the community under consideration and the characteristics of the stimuli to which it will be exposed in relation to the nature of reaction.

General community reactions.- When a community is periodically exposed to sonic booms, the overall reaction pattern is judged to be as indicated schematically in figure 5. Initial reaction is high due to a number of factors, some of which are associated with the novelty during the "learning" phase of the situation. After the initial exposures, the population accommodates to the stimulus and reaction decreases as the community becomes more experienced and informed about the operation. Once accommodation is achieved, the reaction may remain at a low level for an indefinite period of time. Accommodation for a particular community is dependent upon a set of circumstances such as frequency of occurrence of booms, intensity level, time of day, knowledge of the cause of the booms, and reasons for their necessity, and so forth. As long as the reaction resulting from the stimulus variables remains well below the tolerance limit, accommodation continues and the reaction levels may remain relatively unchanged. An increase in any one or several of these stimulus variables may very well drive the reaction curve upward toward a tolerance limit - this limit is dependent on many factors.

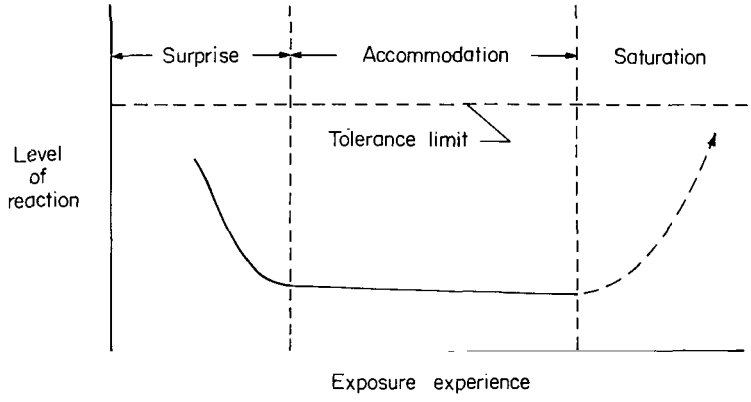

Figure 5.- Schematic illustration of level of community reaction in an area of continued exposure to sonic booms.

Two things should be noted with regard to the curve of figure 5. The abscissa for this curve has not been completely defined but it may involve several physical factors such as frequency of exposure, total number, and intensity. Its designation on the figure as some discrete value is thus an oversimplification. Similarly, there are many factors (some of which are subjective in nature) contributing to reaction, which also are not defined. Population centers which have participated as target cities for military training operations

have generally passed from the "surprise" region indicated on the curve to the "accommodation" region where they remained during the entire training program; that is, sonic-boom exposure continued for about 6 to 12 months without serious incident and was then terminated. In view of community reaction, the successful execution of these training programs demonstrates that the sonic boom has been tolerated or accommodated to in several specific situations.

During the execution of the interview study, which concluded after 66 flights, the general reaction of the population remained at the accommodation level. A widespread familiarity and knowledge about the causes of sonic booms and the necessity of having them existed with this population. It should be noted that 74 additional supersonic flights occurred during the 3 months following completion of the activities of the research program. At the end of this latter flight activity, which is not included in the log of table I, the overall reaction to the sonic-boom exposures apparently approached a tolerance limit for that community and the number of complaints increased markedly. Although this increased complaint response was generally associated with one or two supersonic flights, it was the opinion of some of the local Air Force officials that the community may have been exposed too often or to excessive overpressures, or both. The outburst of complaints was judged by these officials to grow out of annoyances that had been accumulating for several weeks and was not due solely to the one or two specific flights mentioned.

Individual reactions.- The nature of the reaction problem from an individual viewpoint as treated in this study is illustrated schematically in figure 6. In the instance of a formal complaint or claim of damage to property, the outlined sequence of events preceding that response has probably occurred. All reactions do not, however, run the entire course and culminate in a formal complaint or claim, for at any point after the sonic-boom stimulus, this pattern may terminate for various reasons.

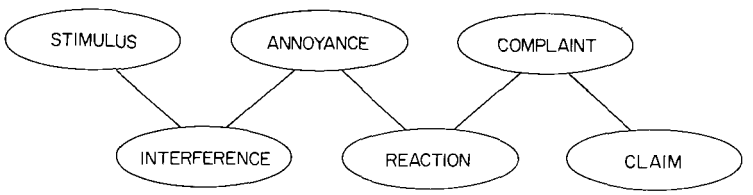

Figure 6.- Nature of reaction problem of individuals exposed to a sonic-boom stimulus.

The term interference is defined as disturbance of or interference with normal residential living activities. A sonic boom may be perceived, however, without causing any interference. All people who report interference are not necessarily annoyed. Whether interference creates an annoyance is dependent upon a number of attitudinal variables to be discussed later, some of which are not even related to the boom. The net result of annoyance might be the registering of a complaint. A complaint may involve a report of assumed damage to property but does not represent action for reimbursement. A claim, on the other hand, involves the submission of executed forms to the government and a request for payment for assumed damages.

Tables III to V illustrate the type of results obtained from the personal interviews. Table III gives a list of frequently reported interferences, and for various distances from the ground track of figure 1, the percentages of the number interviewed at each distance who reported each type of interference are given.

The most frequently reported interferences, shaking of the house and being startled, are shown to be about equally prevalent among the various distance groups. The closest residents at 0 to 4 miles report the other four interferences as occurring more often than do those residents at 12 to 16 miles. It was expected that the closest residents would show a significantly greater response than the distant ones, simply on the basis of the higher overpressures near the ground track. (See fig. 3.) However, distance from the ground track was not a sensitive discriminator of interferences for the conditions of this experiment.

The data of table III were noted to fit the requirements of a Guttman Scale of intensity of interference. A person reporting the least frequently mentioned types of interference would be judged most intensely affected because he would report the other interferences also. On the other hand, a person mentioning house shaking may or may not also mention the other interferences.

Information relating to reported annoyances as a function of distance are presented in a similar manner in table IV. Distance is seen not to be a sensitive discriminator of annoyance either. When the data of tables III and IV are compared, however, it can be seen that all respondents who reported interference were not annoyed. This result is illustrated more directly by the data of table V, which summarize the results of all interviews. The percentages reporting annoyance are markedly lower than those reporting interference. It is significant to note that there is direct relationship between the factors of annoyance and interference, and the same rank order exists in both cases.

Interferences are observed objective experiences that people report as interruptions to living activities. Annoyances, on the other hand, are subjective in nature and are thus also dependent upon a wide range of attitudinal variables. Some of the variables considered to be significant in this study are familiarity and understanding of stimulus phenomenon, necessity and importance of the associated mission, considerateness and attitude of the aircraft operator, intensity of disturbance and the possibility of reducing it, attitude toward neighborhood, general readiness to complain, and damage believed to have occurred to property. Each of these factors may have a positive or a negative influence upon the attitude of the respondent. For example, factors such as lack of understanding of the sonic boom, disliking the neighborhood, or reported damage to property may contribute to a feeling of annoyance. The opposite attitude regarding each of these items would contribute to a feeling of acceptance or accommodation. The manner in which a community is predisposed regarding these factors may largely influence the amount of annoyance with the boom that is reported.

The complaint potential of a community is believed to be a function of the following factors: the frequency of exposure, the amount of annoyance, the

damage believed to have occurred, the necessity and importance of the operation, the possibility of reducing the exposure level, and the extent to which the community is organized for collective action.

Another factor which seemed to be significant was exposure to commercial jet noise. A portion of the population interviewed during the study was geographically located near the commercial airport and was periodically exposed to jet aircraft noise. It was found that respondents who reported that their activities were greatly disturbed by civil jet aircraft noise in practically all cases reported relatively greater interference and annoyance with sonic booms. Likewise, those who were not disturbed by jet noise were also not disturbed by sonic booms.

Those interviewed in the St. Louis area expressed positive feelings toward almost all attitudinal variables discussed and subsequently expressed a very low annoyance reaction. A different combination of attitudes or reactions to these factors could result in a much higher level of annoyance with sonic booms. Consequently, knowledge of the attitudinal characteristics of the people in a community is a necessary prerequisite to consideration of the nature of their reaction to a stimulus such as the sonic boom.

Complaints

A rather complete file on complaints received over a 10-month period was maintained in the Judge Advocate General's Office at Scott Air Force Base. Individual cards containing brief but pertinent information relative to each complaint had been prepared and were used for some overall statistical analyses. In addition, an attempt was made to document in detail the particular circumstances relating to complaints originating as a result of the Bongo flights.

Overall correlation with flight activity.- The data of figure 7 are included to illustrate the relationship between the number of complaints registered and the number of supersonic flights performed over the area. Cumulative totals of complaints and number of flights are plotted as a function of elapsed time in months, beginning in July. It can be seen that roughly 5,000 complaints were received over a time period of about a year as a result of approximately 150 supersonic flights (74 of these occurred after the termination of the research study). The number of complaints is noted to be roughly proportional to the number of flights. At about the 9-months point, the number of complaints increased sharply until the flights were terminated in the tenth month.

A number of factors apparently contributed to this increased response. A heavy concentration of booms occurred just prior to this period, and it is suspected that the intensity of some of them was greater than had been previously experienced. A local newspaper presented a series of articles on the booms and demanded discontinuance of the supersonic flights. The nature of these articles made it socially acceptable to complain and to register claims. The reader is reminded that this increase in the level of reaction was entirely

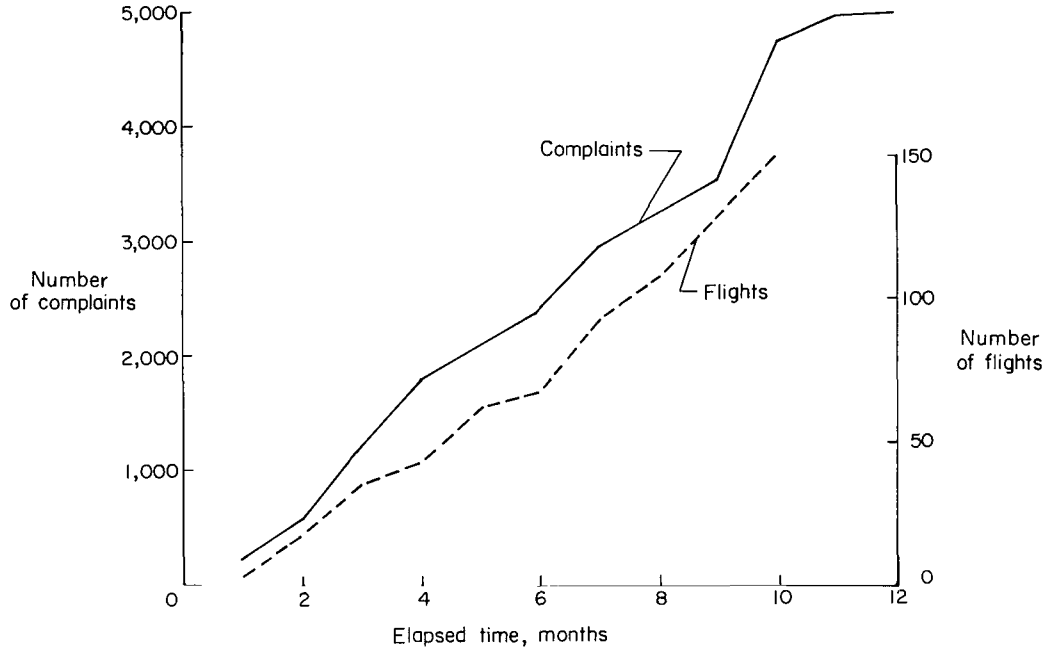

Figure 7.- Accumulative totals of supersonic flights and associated complaints as a function of elapsed time. Data are included for a 12-month period in the Greater St. Louis area.

unrelated to the Bongo program, which had been completed approximately 3 months prior to this occurrence.

Methods of registering complaints.- About two-thirds of the complaints were made by telephone and approximately one-third by letter. In a few instances personal visits were made to the complaint center. It is possible that the number of telephone complaints was limited by factors peculiar to that particular area. For instance, a long distance call was required from the area to the Scott Air Force Base complaint center, and it was frequently difficult to complete a call promptly because of the large volume of telephone traffic. Some information which illustrates the time lag between the actual exposure and the registering of a complaint is included in figure 8. Data are shown only for those cases (1,762 in number) for which the complaints could be correlated with particular flight operations. Forty percent of the total complaints were registered during the first day after these operations, approximately 60 percent had been registered by the second day, and approximately 90 percent had been registered within 2 weeks.

Types of complaints.- A statistical study was made of 3,114 complaint report records to tabulate the types of incidents reported and their frequency. These results are summarized in the bar graph of figure 9. This graph presents various types of alleged damage mentioned in the complaints and indicates the percentage of the total complaint reports that made reference to each of these categories. Most complaints involve the mention of plaster and window damage; other occurrences such as cracked walls, broken mirrors, bric-a-brac, and so forth, are mentioned less frequently. It is probably significant that only

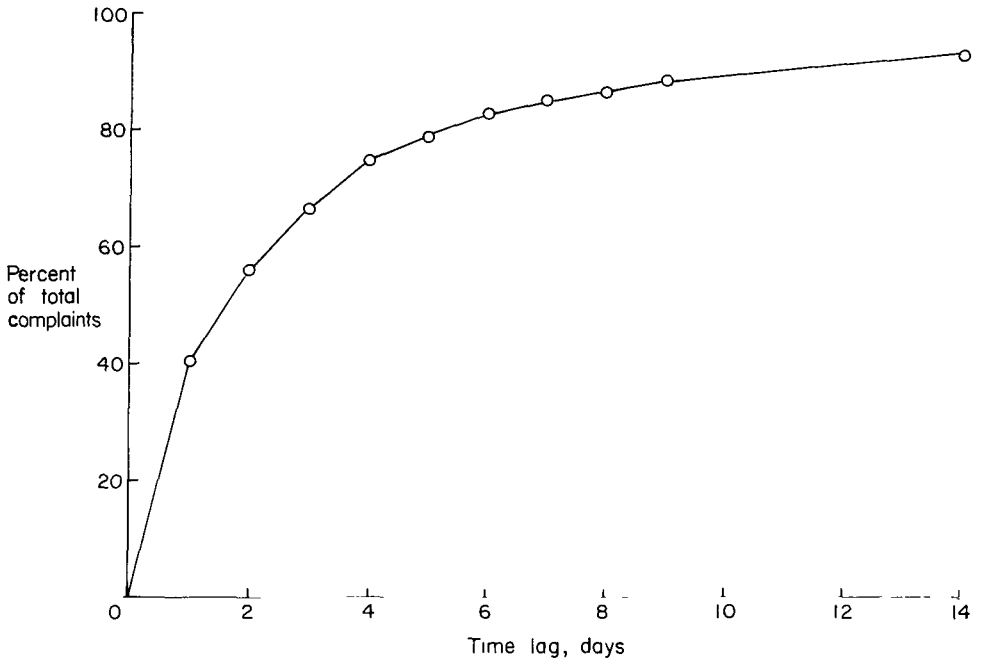

Figure 8.- Percent of total complaints received due to supersonic flights as a function of time lag in days between the flight time and the time of recording of complaint. Data are based on 1,762 cases in the Greater St. Louis area.

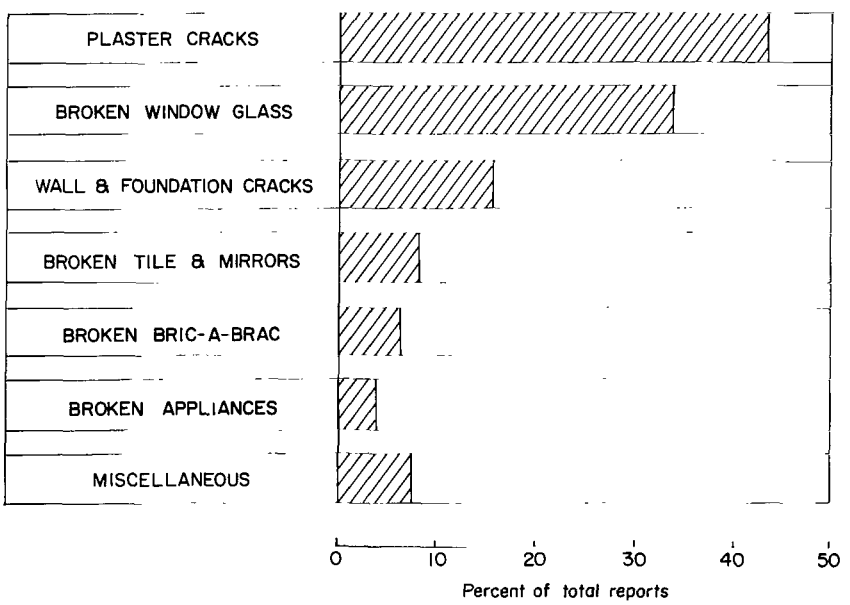

Figure 9.- Bar graph showing types of damage due to sonic booms reported in complaints (but not validated) in the Greater St. Louis area. Percentage values of abscissa are based on a total of 3,114 complaints for which data were available.

a few of those who registered complaints mentioned either personal injury or annoyance.

Engineering evaluations.- During the special series of 17 Bongo flights, a special effort was made to evaluate the damage reported in complaints related to these flights. The Scott Air Force Base office personnel who were on duty at appropriate times to receive telephone complaints worked closely with investigating teams made up of U.S. Air Force and the contractor's investigating personnel who, whenever possible, made prompt on-the-spot investigations at all sites from which complaints originated. In most cases these investigations were accomplished within a few hours of the time of the flight. The objectives of such prompt investigation were to evaluate the reported incident, to determine the nature of it, and to establish its validity.

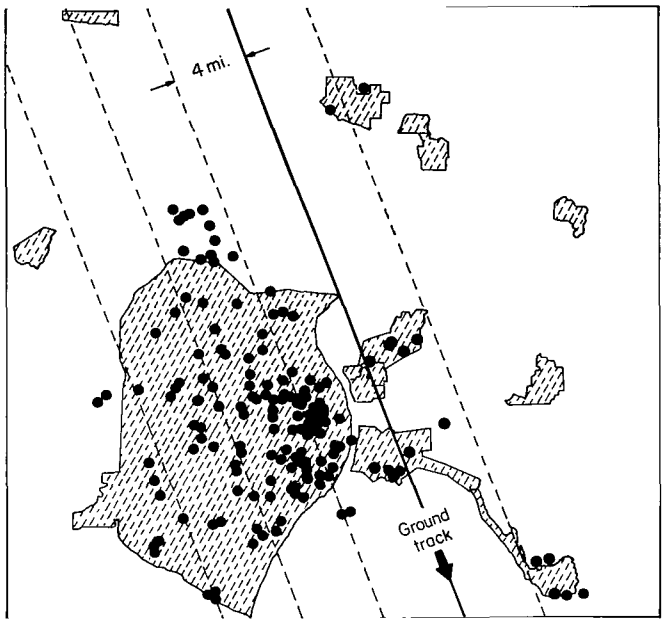

Figure 10.- Sketch of Greater St. Louis area showing aircraft ground track with locations of reported damage superposed. Data points apply to Bongo flights and indicate locations at which engineering evaluations of reported damage were performed.

As a result of the Bongo flights and associated field-investigating activity, approximately 165 on-site investigations were made at the locations shown in figure 10. As in figure 1, the ground track of the airplane, the dashed lines indicating lateral distance, and the urban areas are indicated. Nearly all the complaints were registered in or in close proximity to the urban areas.

One of the objectives of the investigating personnel was to make a survey of the damage existing at the site of the complaint. The bar graph of figure 11 has been prepared to summarize the findings of the investigators. It can be seen that plaster and window-glass incidents are most numerous in this graph also. Although the percentage breakdowns differ somewhat from those of figure 9, it was concluded that, in general, the existing condition was reported in a fairly accurate manner. It should be emphasized here, however, that this observed damage was not necessarily verified as having been caused by sonic booms.

As a result of the on-the-spot investigations by architectural and engineering personnel, some judgments were made regarding the validity of the claimed damage, that is, whether it was judged to be caused by sonic booms. In order to make such a judgment, it was, in many cases, necessary to make a rather detailed appraisal of the conditions of the building structure to note its age, state of repair, foundation settlement, and possible contributing

factors such as leaky pipes, leaky roofs, and so forth. As a result of these studies, it was concluded that about 35 percent of the alleged claimed damage incidents were obviously false; that is, they were of such a nature that the sonic boom would not have been the cause. Furthermore, about 45 percent were judged to be questionable because of the existence of other contributing factors such as aging of materials, settling of the building, poor workmanship, leaky pipes, and so forth. In only about 20 percent of the cases investigated was it judged that the reported damage could have been caused by sonic booms and that no visible contributing factors to the alleged damage existed. These latter cases were considered "possibly valid," although they were not observed to occur coincident with the sonic boom. Such a scheme of evaluation results in conservative estimates, that is, the complainant is strongly favored.

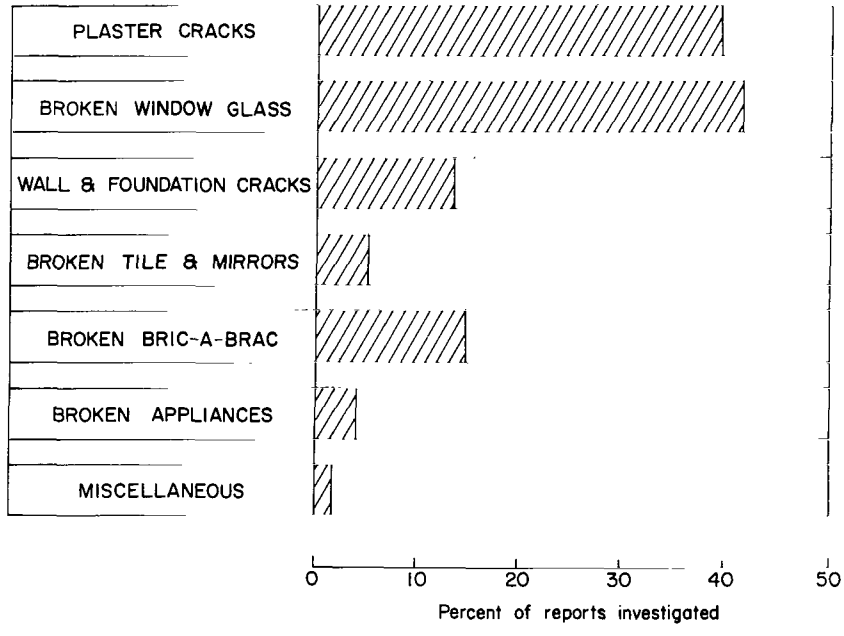

Figure 11.- Bar graph showing types of damage found but not validated during engineering studies of complaints due to sonic booms in the St. Louis area. Percentage values of the abscissa are based on a total of 165 complaints investigated as a result of the Bongo flights.

Frequency of occurrence of alleged damage.- In an attempt to bring together the information presented in figures 1, 4, and 10, table VI has been prepared. An attempt is made in table VI to normalize the results already presented in terms of "valid" damage incidents per million population. Included are the ranges of Δp_o values associated with these data, the number of controlled flights which caused sonic-boom exposures in each of the segments of the community, the number of "valid" damage incidents estimated from the engineering studies, and the estimated population in each segment of the community based on 1960 Census Bureau publications for the area. It can be seen from these data that the largest number of incidents was found in the 0- to 8-mile segment,

and that none were reported beyond 16 miles. The greatest population concentration occurred in the 0- to 8-mile segment. In an attempt to account for the differences in the population densities, the number of valid incidents per flight per million people exposed has been computed. For the range of overpressures 0.4 to 2.3 lb/sq ft, a maximum of 0.83 damage incidents per flight per million population was tabulated. As shown in table VI, the largest number of incidents originated in the segment nearest the track, and there is a steady decrease in number of valid incidents as the distance from the track increases. A greater effect of distance is thus indicated in these latter data than was found in the interview data of tables III to V. One explanation is that the damage-incident data were related directly to the closely monitored Bongo flights whereas the interview data included integrated effects of previous flights as well. (See table I.)

Information from interviews.- A comparison was made between the complaints contemplated by those interviewed and the actual complaints that were recorded in the files. Only 9 percent contemplated telephoning, 7 percent felt like signing a petition, and 3 percent felt like visiting officials or setting up a committee. Only 7 of the 1,145 respondents interviewed, or about 0.6 percent, reported actually registering a complaint. Up to the time of the interviews, about 2,500 complaints had been recorded. This number of complaints agrees very well with estimates based on the results of the interviews, 550,000 families in the test area being assumed.

Claims

A record of claims, as well as complaints, was maintained at Scott Air Force Base for the entire period of the supersonic training missions in that area. A correlation of the cumulative complaints and the resulting claims is shown in figure 12. For the period indicated, only about 20 percent of the complaints registered resulted in formal claims for damage. Because of the required paper work involved, the filing of a claim usually followed the filing of a complaint by 1 or 2 months. It can be seen in the figure that after the complaint activity had essentially ceased (upper flat portion of curve), there was still considerable claims activity, and, in fact, the steepest part of the claims curve occurs about 2 months after the steepest part of the complaints curve and reflects the increased volume of claims resulting from the previously mentioned unusual flight activity during the tenth month.

The final total number of claims arising out of this time period of operations in the greater St. Louis area was determined from USAF files to be 1,624 as of January 1964. It can be seen that several hundred additional claims came in during the ensuing time period of about $1\frac{1}{2}$ years. The total value of all claims registered was $366,019.03. Of this number, 825 claims were approved for a total of $58,648.23 or an average of about $71 each.

Personal injury.- Concern has also been expressed about possible adverse effects of sonic booms on man. Two types of effects would be anticipated; those associated with direct impingement of the shock waves and those associated with falling objects.

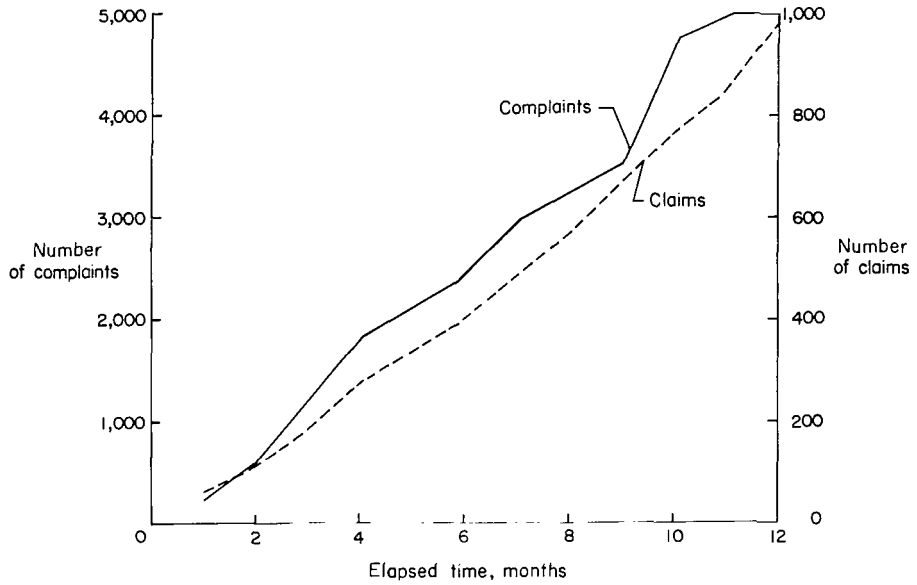

Figure 12.- Accumulative totals of complaints and associated claims due to sonic booms as a function of elapsed time. Data are included for a 12-month period in the Greater St. Louis area.

Although many millions of people have been exposed to date, no claims of direct injury resulting from sonic booms are known. As part of project "Little Boom," an experiment was carried out to determine what injuries, if any, would be inflicted on personnel due to intense sonic-boom exposure. (See ref. 3.) During this project, approximately 50 people of varying backgrounds were exposed to peak overpressures up to about 100 lb/sq ft. Such values are considered to be about 10 times as intense as any that would be generated in routine operations. No direct injury resulted from repeated intense exposure during these experiments.

Damage to structures and equipment.- On the basis of the field investigation and the complaint file analyses, it is judged that damage to structures can occur as a result of sonic-boom exposures and that such damage can be an important factor in community response. It can be seen that the type of damage most often reported related to secondary or decorative structural elements and consisted of cracks in brittle surface treatments such as plaster, tile, glass, masonry. Such damage is noted to be superficial in nature, is restricted to nonload-carrying members, and thus does not affect the strength of the primary structure. Furthermore, it is judged that the superficial damage usually reported is, in large measure, associated with stress concentrations in the structure. It is believed that these results would apply also for the range of overpressures expected during normal military and commercial operations.

Stress concentrations in buildings may be due to such factors as curing of green lumber, dehydration of cementitious materials, settling of foundations, poor workmanship, and so forth. Such factors exist in varying degrees in all structures and can contribute to failures when a triggering load is applied.

The overpressure of a sonic boom has this triggering action capability as do vehicle traffic, thunder and wind storms, heavy falling objects, and even many routine household operations. Well-constructed buildings in good repair would not be expected to experience serious damage. Superficial damage would not be expected either, except in situations where critical local stress concentrations existed. No reports of extensive damage to structures are known to have resulted from exposure to overpressures in the range illustrated in figure 4.

CONCLUSIONS

The following conclusions were drawn from a series of community-reaction flight experiments with F-106 and B-58 aircraft in which the population of a large city was repeatedly exposed to sonic booms during 1961 and 1962 in the range of overpressures up to about 3.1 lb/sq ft.

1. Personal interview studies indicated that after 66 supersonic flights, about 90 percent of those contacted experienced some interferences as a result of sonic booms, about 35 percent were annoyed by them, less than 10 percent had contemplated complaint action, and a fraction of 1 percent had actually filed a formal complaint.

2. The cumulative total of complaints recorded at any time during the program was approximately proportional to the number of supersonic missions. A large percentage of recorded complaints made some mention of alleged building damage. There were no direct adverse physiological effects.

3. Alleged building damage was superficial in nature, plaster and glass cracks being most numerous. Engineering evaluations showed that there were contributing factors other than sonic booms in many cases and that a large portion of reported damage incidents were probably not valid.

4. Approximately 20 percent of the recorded complaints ultimately resulted in formal claims for compensation. (Monetary value of those claims approved for payment by the U.S. Air Force averaged about $71 each.)

5. For the range of overpressures 0.4 to 2.3 lb/sq ft, a maximum of 0.83 damage incidents per flight per million population was tabulated. (Damage referred to is superficial in nature, includes those claims only possibly "valid," and is of the type that might be triggered due to a small incremental load at a stress concentration.)

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., November 25, 1964.

REFERENCES

1. Power, J. K.; and Bates, George: Sonic Boom & Community Relations. [Preprint] 683B, Soc. Automotive Engrs., Apr. 1963.

2. Hilton, David A.; Huckel, Vera; Steiner, Roy; and Maglieri, Domenic J.: Sonic-Boom Exposures During FAA Community-Response Studies Over a 6-Month Period in the Oklahoma City Area. NASA TN D-2539, 1964.

3. Maglieri, Domenic J.; Huckel, Vera; and Parrott, Tony L.: Ground Measurements of Shock-Wave Pressure for Fighter Airplanes Flying at Very Low Altitudes and Comments on Associated Response Phenomena. NASA TM X-611, 1961.

TABLE I.- SCHEDULE OF KNOWN SUPERSONIC FLIGHTS OVER THE GREATER ST. LOUIS AREA

DURING THE PERIOD JULY 1, 1961, TO JANUARY 31, 1962

Date	Time, CST	Altitude, ft	Mach number	Type of airplane	Date	Time, CST	Altitude, ft	Mach number	Type of airplane
5 July	1142			B-58	9 November*	1258	41,000	2.0	F-106
9 August	1807			B-58	9 November*	1313	41,000	2.0	F-106
9 August	1815	46,000		B-58	10 November*	1759	41,000	2.0	F-106
10 August	1809	46,000		B-58	11 November*	0027	41,000	1.5	B-58
10 August	2223	46,000		B-58	11 November*	0050	41,000	1.5	B-58
10 August	2223	46,000		B-58	12 November*	0501	41,000	2.0	F-106
14 August	1437	50,000		B-58	12 November*	0518	41,000	2.0	F-106
15 August	1441	46,000		B-58	12 November*	1016	41,000	1.5	B-58
21 August	2136	48,000		B-58	12 November*	1041	41,000	1.5	B-58
21 August	2232	48,000		B-58	17 November	0055	46,000		B-58
22 August	2149	50,000		B-58	21 November	0615	46,000		B-58
23 August	2339	46,000		B-58	29 November	1230	41,000	2.0	F-106
29 August	2041	46,000		B-58	1 December	0930	41,000	2.0	F-106
31 August	1809	46,000		B-58	4 December	0930	41,000	2.0	F-106
31 August	2120	46,000		B-58	5 December	0805	46,000		B-58
5 September	2102	48,000		B-58	5 December	0930	41,000	2.0	F-106
5 September	2144	48,000		B-58	2 January	2118	46,000		B-58
7 September	2122	46,000		B-58	3 January*	2207	35,000	1.5	B-58
10 September	1804	46,000		B-58	3 January	2226	46,000		B-58
12 September	2133	50,000		B-58	3 January*	2231	35,000	1.5	B-58
13 September	2059	48,000		B-58	5 January	0016	46,000	2.0	B-58
13 September	2230	42,000		B-58	5 January	0032	46,000		B-58
14 September	0212	46,000		B-58	5 January	1612	44,000	2.0	B-58
17 September	2218	46,000		B-58	5 January	1626	44,000		B-58
20 September	2044	48,000		B-58	5 January	1642	41,000	2.0	B-58
27 September	2336	42,000		B-58	5 January	1657	41,000		B-58
3 October	0628	42,000		B-58	6 January*	2209	31,000	1.5	B-58
3 October	0227	42,000		B-58	6 January*	2228	31,000	1.5	B-58
3 October	2315	46,000		B-58	10 January	2100	46,000	2.0	B-58
5 October	0738	46,000		B-58	10 January	2115	46,000		B-58
10 October	1159	49,000		B-58	10 January	2202	46,000	2.0	B-58
24 October	0431	46,000		B-58	10 January	2220	40,000		B-58
24 October	0816	42,000		B-58	10 January	2246	42,000	1.5	B-58
30 October	0146	34,000		B-58	10 January	2906			B-58
6 November*	2304	41,000	2.0	F-106	14 January	2205	42,000		B-58
6 November*	2316	41,000	2.0	F-106	15 January	2131			B-58
8 November*	1105	41,000	1.5	B-58	23 January	2253	46,000		B-58
8 November*	1128	41,000	1.5	B-58	23 January	2303			B-58

*Denotes special "Bongo" flights.

TABLE II.- ESTIMATED SONIC-BOOM GROUND OVERPRESSURES AS A FUNCTION OF DISTANCE FROM THE GROUND TRACK FOR THE SPECIAL FLIGHTS OF TABLE I

Distance, miles	Δp_o, lb/sq ft, for -				
	B-58 at an altitude of -				F-106 at an altitude of -
	46,000 ft	41,000 ft	36,000 ft	31,000 ft	41,000 ft
0 to 2	1.6	1.8	2.3	2.7	1.3
2 to 4	1.5	1.7	2.1	2.4	1.2
4 to 6	1.3	1.6	1.8	2.1	1.1
6 to 8	1.2	1.4	1.5	1.6	1.0
8 to 10	1.1	1.2	1.2	1.2	.8
10 to 12	1.0	.9	.8	.8	.6
12 to 14	.9	.7	.6	.4	.4
14 to 16	.8	.6	.4	.2	.3

TABLE III.- PERCENT OF THOSE INTERVIEWED IN EACH DISTANCE SEGMENT OF THE ST. LOUIS AREA WHO REPORTED VARIOUS INTERFERENCES DUE TO SONIC BOOMS

Number interviewed	Distance segment, miles	Percentage of those interviewed who reported the following interferences:					
		House shaking	Startled	Sleep interrupted	Rest and relaxation interrupted	Conversation interrupted	Radio and television interrupted
192	0 to 4	89	72	52	28	26	18
360	4 to 8	92	76	39	26	27	18
168	8 to 12	94	74	43	26	22	11
425	12 to 16	94	74	42	20	17	11

TABLE IV.- PERCENT OF THOSE INTERVIEWED IN EACH DISTANCE SEGMENT OF THE ST. LOUIS AREA WHO REPORTED ANNOYANCE AS A RESULT OF INTERFERENCES DUE TO SONIC BOOMS

Number interviewed	Distance segment, miles	Percentage of those interviewed who reported annoyances due to the following interferences:					
		House shaking	Startled	Sleep interrupted	Rest and relaxation interrupted	Conversation interrupted	Radio and television interrupted
192	0 to 4	46	32	27	19	9	10
360	4 to 8	34	33	24	19	10	8
168	8 to 12	38	29	18	14	5	3
425	12 to 16	37	31	19	12	6	5

TABLE V.- PERCENTAGE OF 1145 INTERVIEWED IN THE ST. LOUIS AREA WHO REPORTED VARIOUS INTERFERENCES DUE TO SONIC BOOMS AND RESULTING ANNOYANCE

Nature of interferences reported	Percentage of total interviewed who	
	Reported interference	Reported annoyance
House shaking	93	38
Startled	74	31
Sleep interrupted	42	22
Rest and relaxation interrupted	24	16
Conversation interrupted	22	10
Radio and television interrupted	14	6

TABLE VI.- ESTIMATED FREQUENCY OF OCCURRENCE OF VALID DAMAGE INCIDENTS PER FLIGHT PER MILLION PEOPLE IN THE ST. LOUIS AREA FOR VARIOUS RANGES OF SONIC-BOOM OVERPRESSURES

Variables	Distance from flight track			
	0 to 8 miles	8 to 12 miles	12 to 16 miles	Over 16 miles
Δp_o, lb/sq ft	0.8 to 3.1	0.4 to 2.3	0 to 1.2	0 to 0.8
Number of flights	17	17	17	17
Number of "valid" incidents	35	10	3	0
Population*	1.54×10^6	0.72×10^6	0.32×10^6	--------
Valid incidents per flight per million people	1.34	0.83	0.55	0

*Based on 1960 census.

NASA-Langley, 1965 L-4234

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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