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SONIC BOOM ACCEPTABILITY STUDIES

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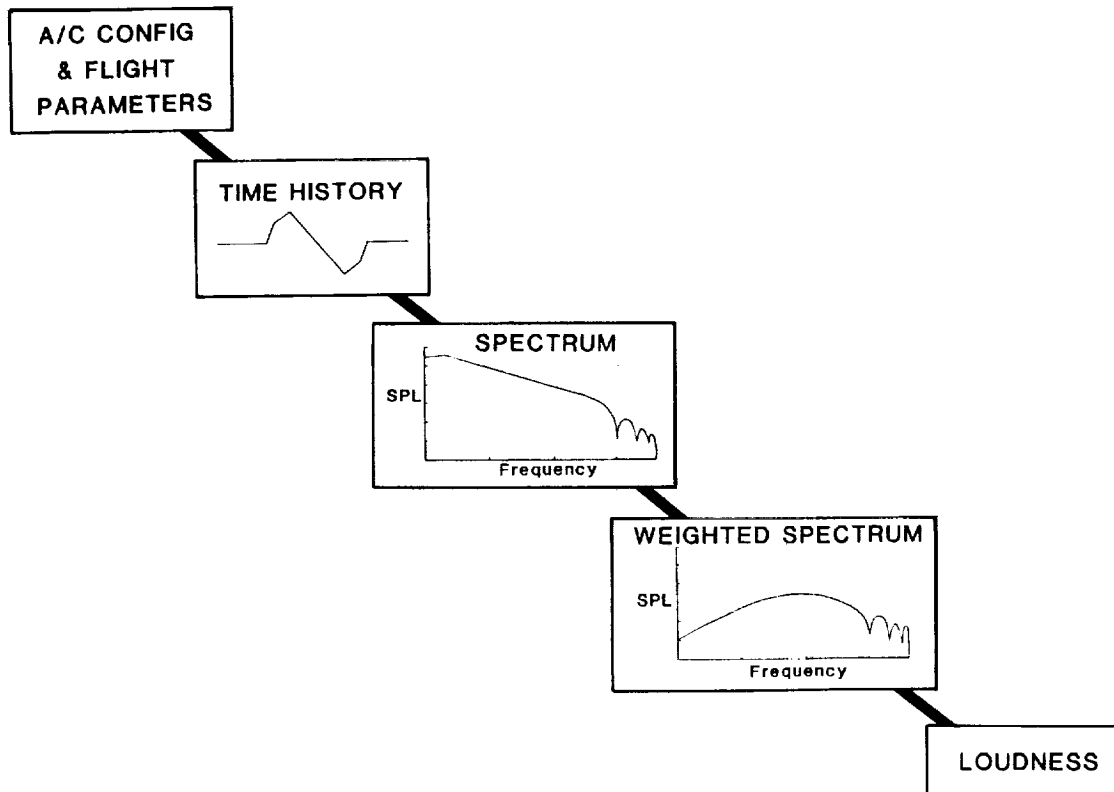
- Loudness model
 - predicted benefits through shaping
- Sonic boom simulator
 - description and results summary
- In-home simulation system
 - description and purpose
- Community response survey
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SONIC BOOM LOUDNESS PREDICTION MODEL

The determination of the magnitude of sonic boom exposure which would be acceptable to the general population requires, as a starting point, a method to assess and compare individual sonic booms. There is no consensus within the scientific and regulatory communities regarding an appropriate sonic boom assessment metric. Loudness, being a fundamental and well-understood attribute of human hearing was chosen as a means of comparing sonic booms of differing shapes and amplitudes.

The figure illustrates the basic steps which yield a calculated value of loudness. Based upon the aircraft configuration and its operating conditions, the sonic boom pressure signature which reaches the ground is calculated. This pressure-time history is transformed to the frequency domain and converted into a one-third octave band spectrum. The procedure is based largely on an approach described by Johnson and Robinson (ref. 1), and utilizes Stevens' Mark VII loudness method (ref. 2). The essence of the loudness method is to account for the frequency response and integration characteristics of the auditory system. The result of the calculation procedure is a numerical description (perceived level, dB) which represents the loudness of the sonic boom waveform.

SONIC BOOM LOUDNESS PREDICTION MODEL

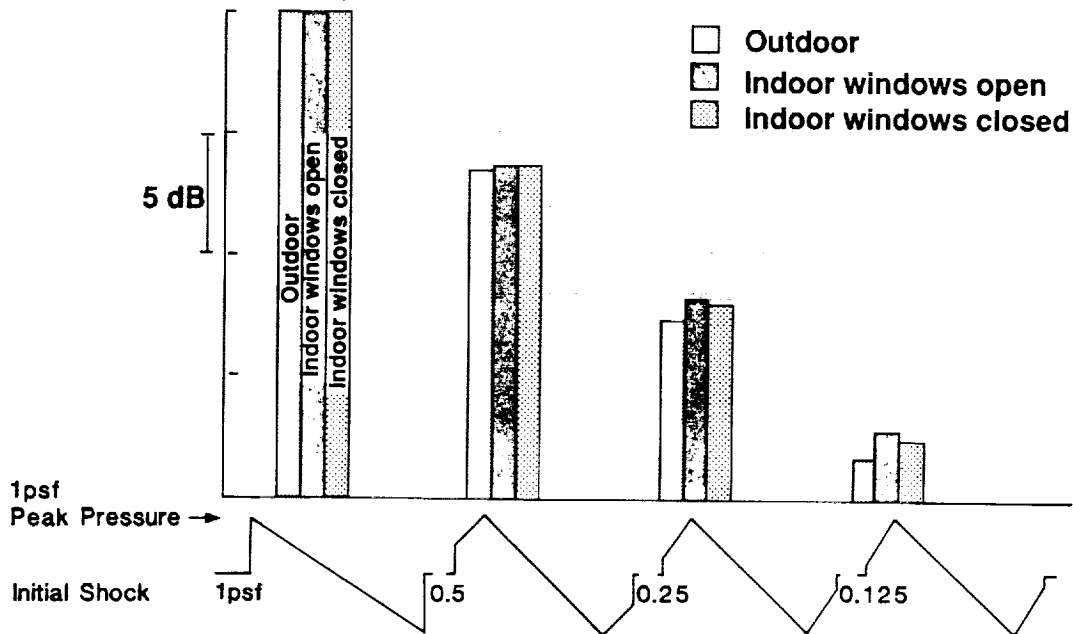


LOUDNESS OF SHAPED SONIC BOOMS

The loudness calculation procedure was applied to a range of shapes of sonic boom signatures. The shapes are illustrated at the bottom of the figure and include the classical N-wave and a range of other symmetrical shapes. All have the same peak overpressure and initial rise time; the amplitude of the initial shock is varied over a range from 1 psf to 0.125 psf. Calculated loudness is seen to systematically decrease with decreasing values of the initial shock amplitude. Although the acoustic energy contained in each boom shape is approximately the same, the high frequency content is reduced when the initial shock amplitude is reduced. The observed decrease of loudness is a reflection of the greater sensitivity of the auditory system to high frequencies rather than low ones.

Measured noise reduction provided by typical residential structures was used to calculate indoor loudness levels for the same range of sonic booms. The results presented in the figure are normalized to the N-wave sonic boom loudness level, for conditions of windows open and closed. The same trends are observed for both indoor and outdoor listening conditions. This assessment of indoor levels obviously makes no attempt to include effects of building vibration or secondary acoustic radiation due to rattling objects.

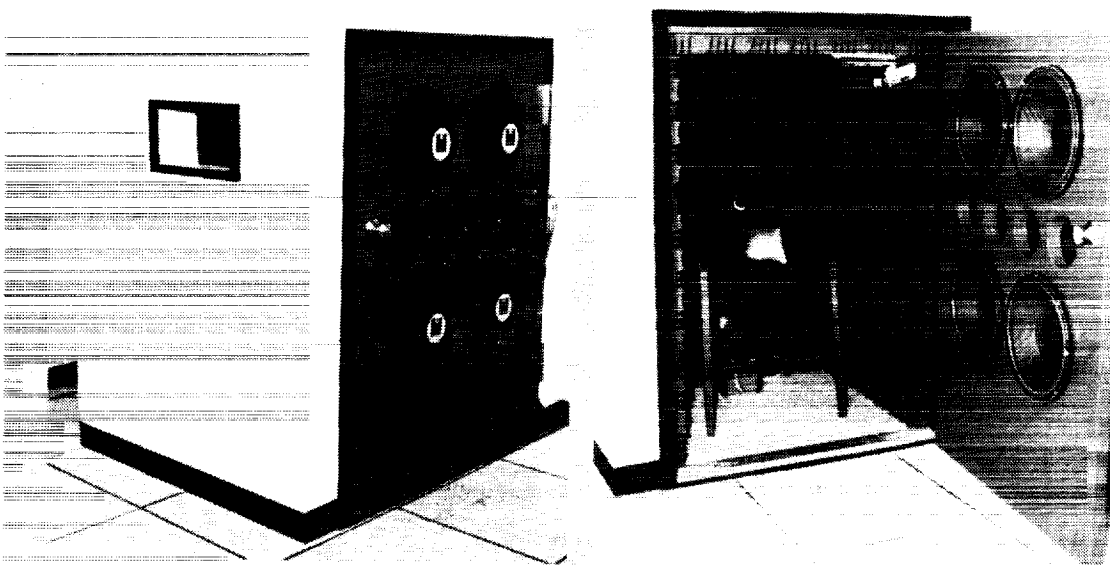
OUTDOOR/INDOOR LOUDNESS OF SHAPED BOOMS



SONIC BOOM SIMULATOR

A sonic boom simulator (ref. 3) has been constructed at the NASA Langley Research Center to enable loudness measurements to be made with test subjects using sonic booms of the types described above. The simulator is patterned on one previously used at the University of Toronto (ref. 4). The acoustic signals are computer-generated to enable compensation for inadequacies present in the sound reproduction system and distortion produced by the acoustical characteristics of the enclosure. The rigid, airtight, concrete enclosure is driven by eight loudspeakers. The system is capable of generating approximately 140 dB sound pressure level (4 psf) and has a low frequency limit of approximately 0.4 Hz.

SONIC BOOM SIMULATOR

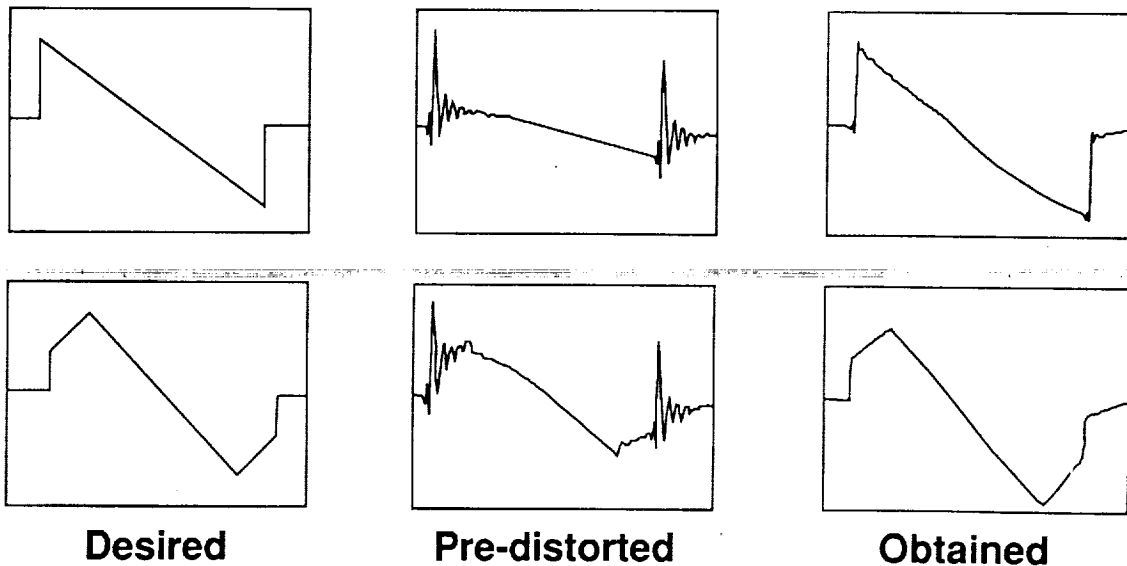


EQUALIZATION BY PRE-DISTORTION

The sonic boom simulator has an inherently poor frequency response. At low frequencies, the loudspeakers drive the enclosed volume of air very efficiently. At higher frequencies, efficiency is reduced and phase distortion is introduced by the loudspeaker crossover electronics and by acoustic resonances within the enclosure. To obtain an undistorted sonic boom in the simulator requires a broadband equalization filter with good frequency resolution and good low frequency response. To accomplish this a time domain method was used to design a broadband equalization filter. The time domain method used was the Widrow-Hoff least mean-square adaptive algorithm. Further details are given in reference 5.

The figure illustrates the results of the equalization process. On the left are shown the waveforms which are required. On the right are the waveforms as measured by a microphone in the simulator. The signals which were generated by the computer to achieve these waveforms are shown in the center.

EQUALIZATION BY PRE-DISTORTION



SUMMARY OF SIMULATOR EXPERIMENTS

A summary of the tests conducted in the sonic boom simulator are described in the figure. The pilot study was aimed at examining testing procedures and to confirm that the simulator was fully operational and reliable. The test sounds consisted of mostly N-waves with a range of overpressures and rise times. Two shaped booms were also included. The psychometric method employed was the constant stimulus difference method (paired comparisons). The results in terms of the effects of rise time on judged loudness were in accord with earlier studies, and were predictable by the loudness calculation procedure. The second study concentrated on a large range of N-waves and a smaller number of shaped booms. All the characteristics of a N-wave were systematically varied. The method of category scaling was employed using both loudness and annoyance descriptors. The results confirmed the loudness model predictions and no differences were found between loudness and annoyance judgements. The most recent study examined a wide range of shaped booms. In contrast with the earlier studies a few non-symmetrical booms were also included. The loudness judgements for the symmetrical booms were in good agreement with the predictions of the loudness model.

**HSR SONIC BOOM
ACCEPTABILITY**

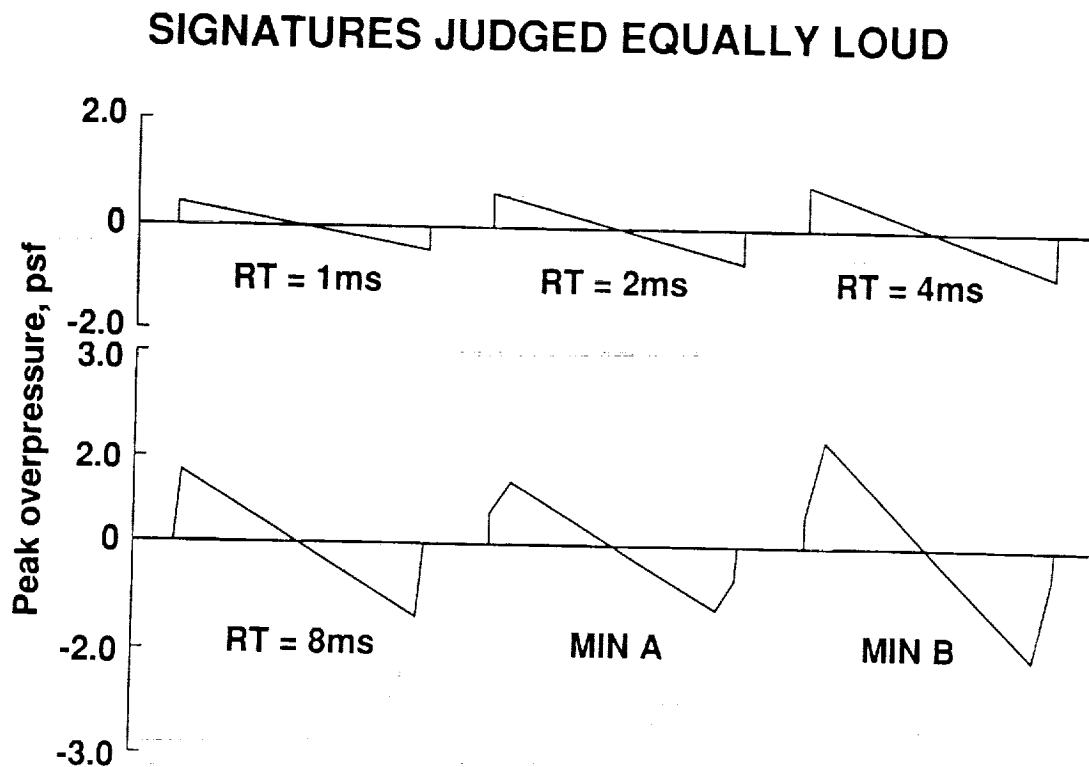
SONIC BOOM SIMULATOR

SUMMARY OF EXPERIMENTS

	# subjects/ # booms	Test Sounds	Major findings
Pilot Study	32 / 72	Symmetric N-waves Rise time, pressure.	Effects of rise time & pressure predicted by loudness model.
Exploratory study of boom shaping	72 / 150	Symmetric N-waves & shaped booms. Duration, initial rise time and peak pressure.	Validated loudness model. Loudness = annoyance. Duration unimportant.
Quantification of boom shaping	60 / 248	Symmetric and asymmetric shaped booms. Initial and secondary rise times. Initial/peak pressure.	Validated loudness model. Secondary rise time unimportant.

SONIC BOOM SIGNATURES OF EQUAL LOUDNESS

The figure illustrates a range of sonic boom signatures which were judged to be equally loud by a group of 32 test subjects. For the N-waves it is evident that the rise time (RT) is related to loudness such that, for equal overpressure, the shorter the rise time the greater is the loudness. The shaped booms (MINA and MINB) have an initial rise time of two milliseconds and a relatively slow rise to the peak pressure. It is clear that the loudness of the shaped booms is dominated by the initial, sharp pressure rise.

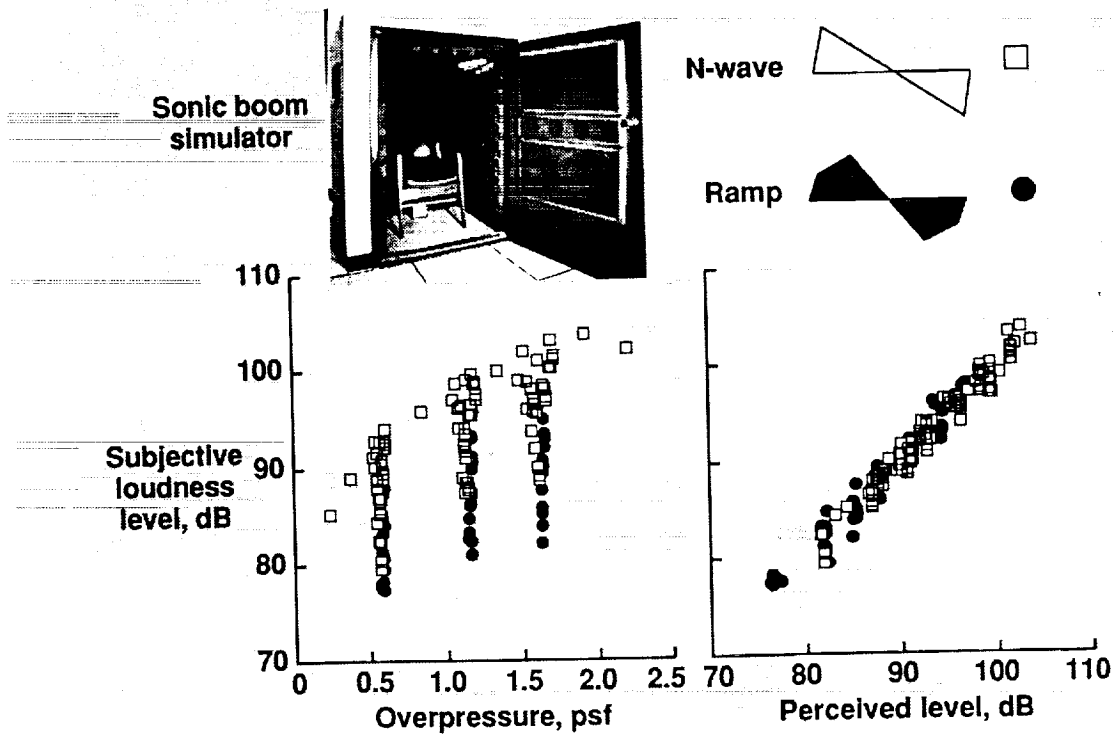


SUBJECTIVE RESPONSE TO N-WAVES AND SHAPED BOOMS

Loudness category scale judgements were obtained for a wide range of N-waves and a limited range of shaped booms. The loudness judgements were converted to a scale having decibel-like properties and, in the left figure, are plotted against the peak overpressure of the signatures. The range of subjective loudness, for a particular peak overpressure, is vast. In the case of the N-waves this variation is largely attributable to the rise time of the signatures. For the shaped (ramp) signatures the peak overpressure of the signature is a poor predictor of the loudness since the loudness is largely governed by the strength of the initial shock.

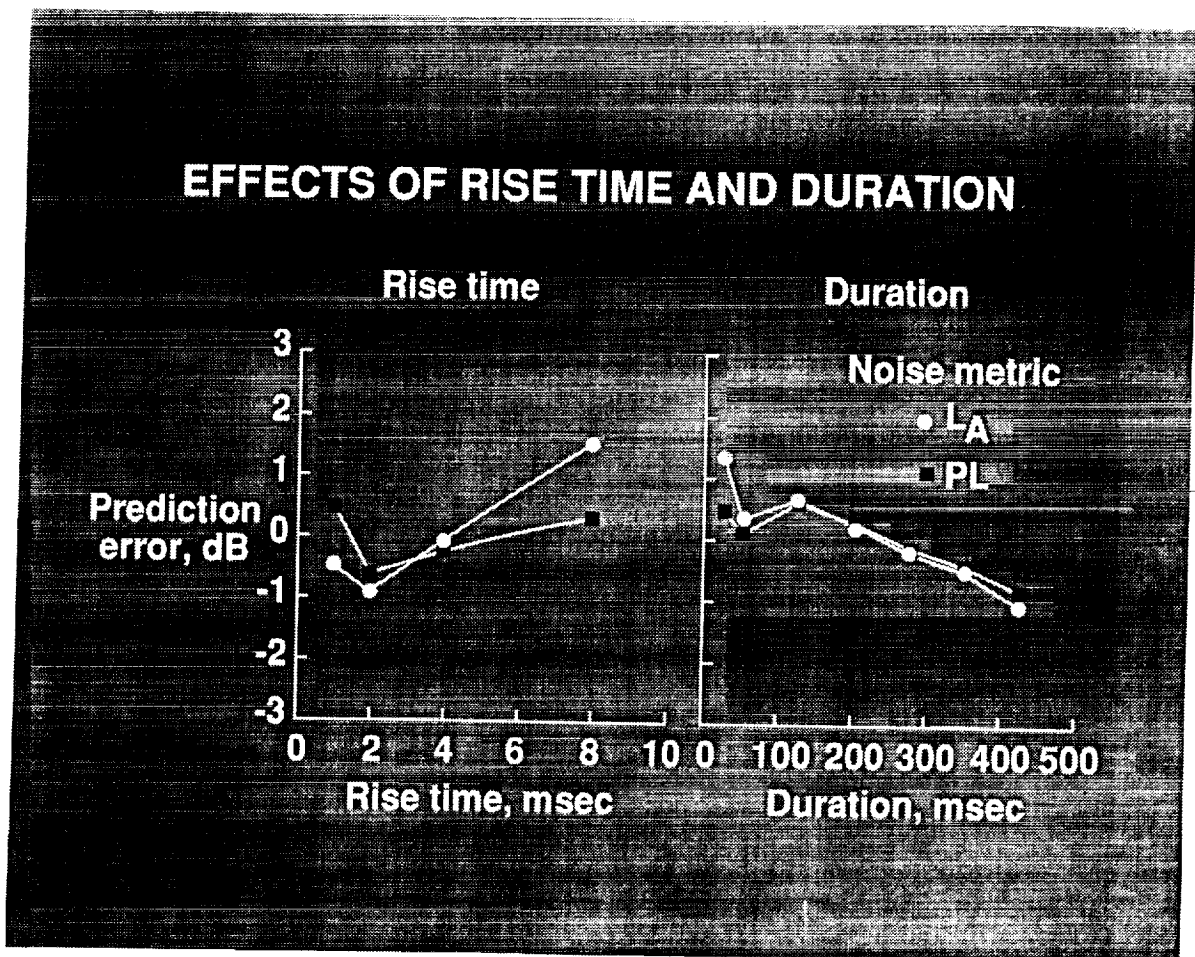
The right hand figure shows the same subjective judgements plotted against predicted loudness based on the loudness model (perceived level). It is clear that the measured and predicted loudness values are in good agreement. The loudness model is able to largely account for the effects of rise time and the differences in boom shapes.

PREDICTION OF SUBJECTIVE RESPONSE TO SONIC BOOMS



EFFECTS OF RISE TIME AND DURATION

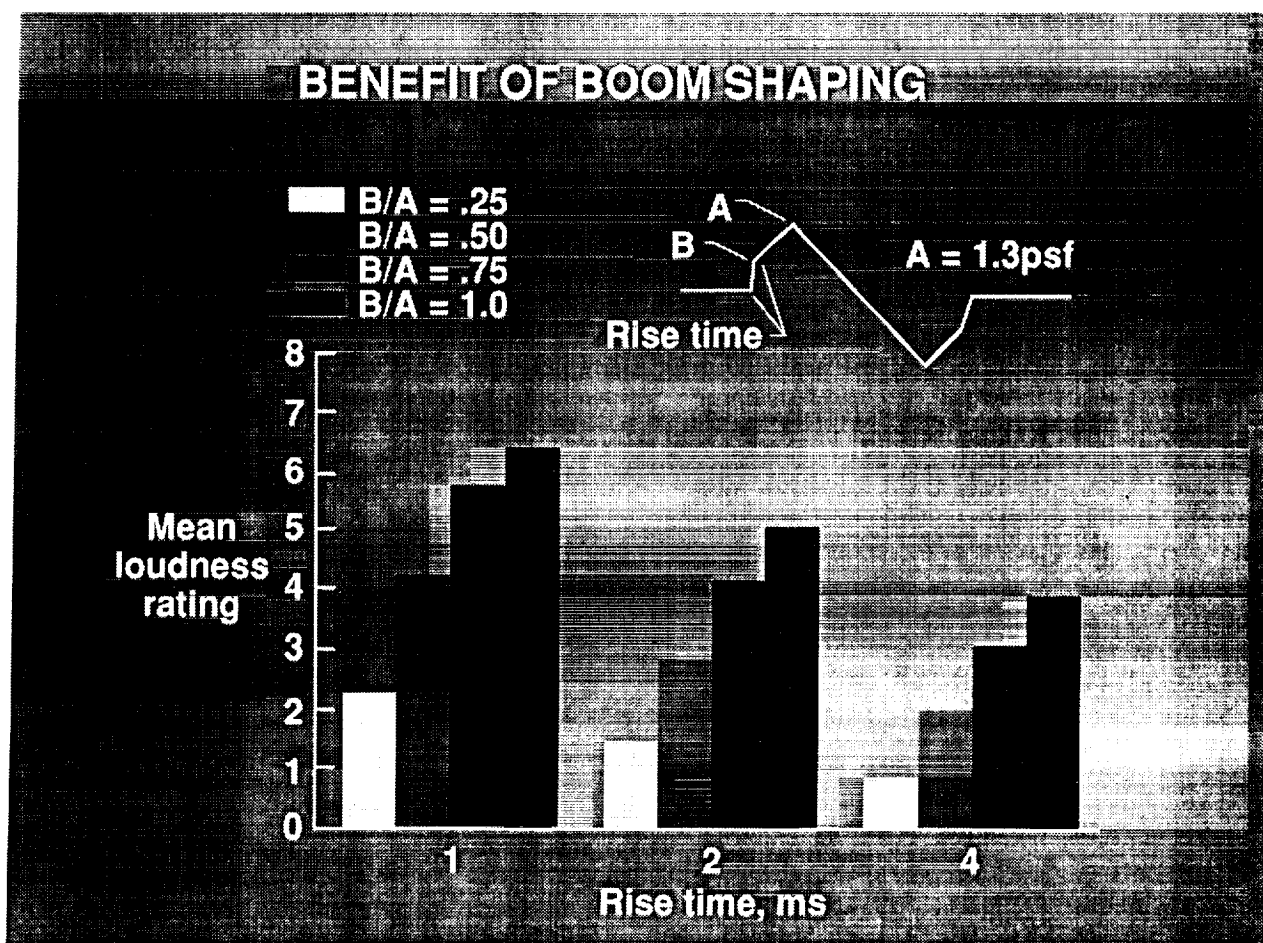
The data from the previous figure were examined to determine if the loudness prediction method was able to fully explain the effects of rise time and the duration of the signatures. The figures illustrate prediction error as a function of rise time and duration. The prediction error is a measure of residual variation which the loudness metric is unable to explain. The results for two metrics are shown; perceived level (PL) and A-weighted sound pressure level. A positive prediction error can be interpreted as meaning that the sound was judged to be louder than the calculated metric would indicate. For the case of rise time the residual effect not explained by PL is very small (± 0.5 dB). For A-weighted sound pressure level (L_A) the residual variation is significantly greater. The residual effect of duration is small for both metrics, particularly when one considers that the range of practical interest for a supersonic transport is from 200-400 msec.



BENEFIT OF BOOM SHAPING

The most recent simulator test was aimed at investigating the loudness of a large range of shaped booms. The signature in the figure is representative of the test stimuli. With the exception of the total length (duration) of the signature, all parameters were systematically varied. For a given peak overpressure, the loudness was highly dependent on the amplitude and the rise time of the front (and rear) shock. The loudness was found to be independent of the secondary rise time (between points B and A) which ranged from 20-50 msec. The total duration of the booms was held constant at 300 msec.

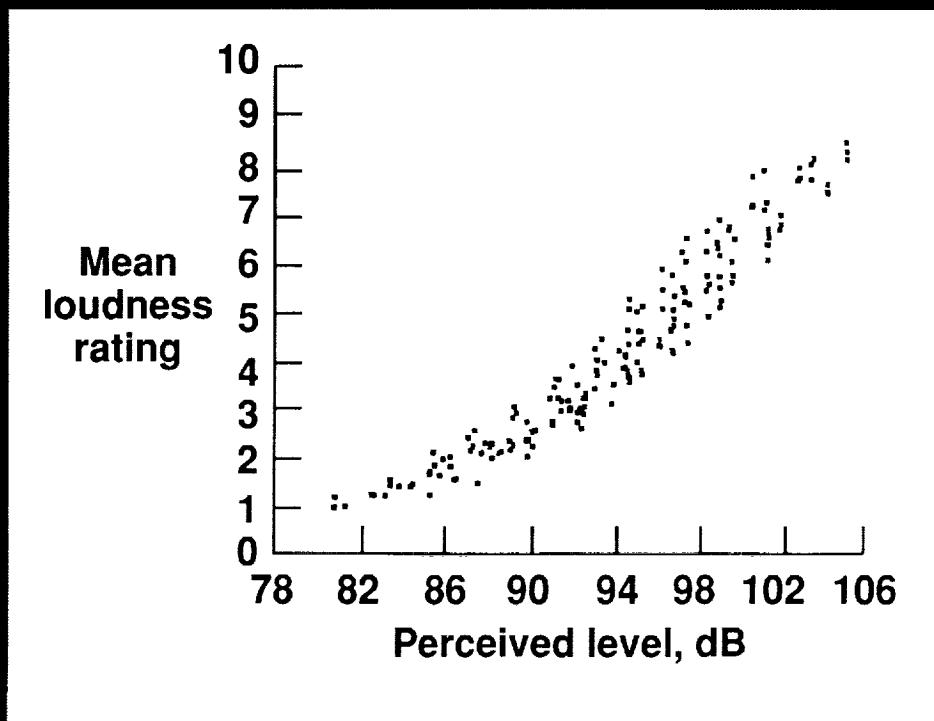
The figure presents the mean loudness ratings for a subset of the test stimuli. The effects of rise time and initial shock amplitude are evident.



PREDICTION OF SUBJECTIVE RESPONSE TO SHAPED BOOMS

The ability of the loudness model to predict the subjective response to a large range of shaped booms is illustrated in the figure. The mean loudness ratings are shown as a function of the predicted values expressed in units of perceived level, dB. It is evident that the variance of the mean ratings which is not predicted by the metric calculation procedure is approximately ± 2 dB. Ongoing analyses are addressing the source of this residual variation.

PREDICTION OF SUBJECTIVE RESPONSE TO SHAPED SONIC BOOMS

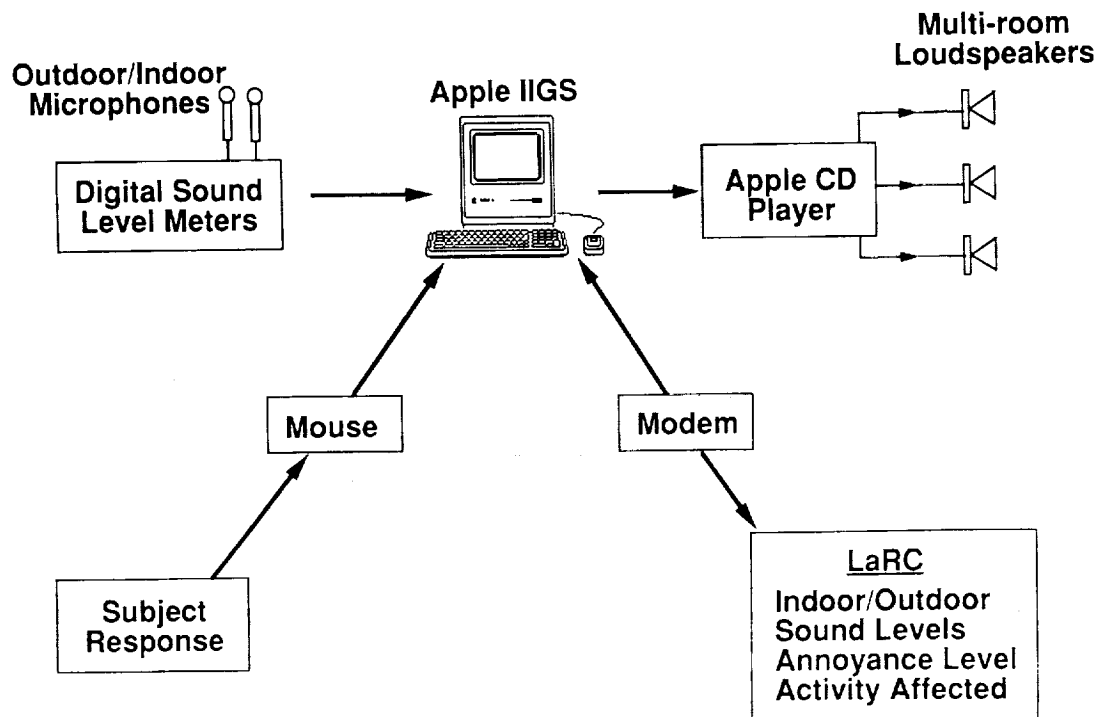


IN-HOME NOISE MONITOR-CONTROL-RESPONSE SYSTEM

The preceding laboratory studies were aimed at investigating the characteristics of sonic booms which affect their perceived loudness. Such studies are not suitable for determining a sonic boom exposure that might be acceptable to the general population. To establish a relationship between acceptability and exposure requires that people be exposed to sonic booms on a regular basis as part of their everyday lives.

The figure shows, schematically, the components of a computer-based system which will be used to examine peoples' responses to sonic booms in their homes. A prototype system is currently operational and is to be pilot tested in the near future. The system has three major functions. The first is the generation of simulated sonic booms. This is accomplished by means of a pre-recorded compact disk containing a range of sonic booms. The sonic booms are generated at programmed times and amplitudes by the computer-controlled CD player. The second function of the system is noise monitoring. This is to ensure that the sonic boom generation hardware is working properly, and also to measure the levels of sonic booms and ambient noise. The third function of the system is to record the residents' reactions to their noise environment. The resident will be prompted at periodic intervals to answer a battery of questions regarding their response to the sonic booms, activities affected, etc. The test conductor at the Langley Research Center is able to communicate with the computer in the home in order to transfer data, to ensure that the system is functioning correctly and, if necessary, to re-program elements of the study. This approach should enable response to be related to the amplitude and frequency of the sonic booms.

IN-HOME NOISE MONITOR-CONTROL-RESPONSE SYSTEM



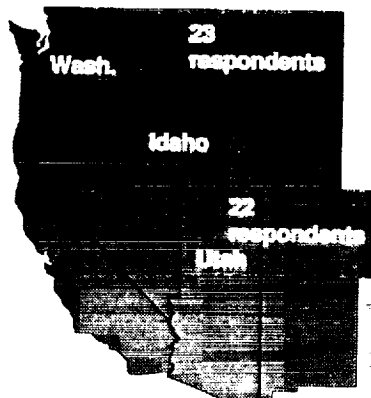
COMMUNITY RESPONSE TO SONIC BOOMS

The laboratory studies and the in-home system enable human response to sonic booms to be studied under relatively well-controlled conditions. However, they can be criticized on two grounds. The first is that the sonic boom simulation is less than perfect, and the second, more important criticism, is that the residents' response in an experiment may be different from that which occurs in an environment of long-term sonic boom exposure. To address these issues requires that a situation of long-term exposure be identified. An opportunity was provided by routine supersonic SR-71 training flights which have occurred in the western part of the United States for a number of years.

Unfortunately, during the planning phase of a community response survey the SR-71 fleet permanently ceased their training flights, so the proposed study was abandoned. In expectation of identifying alternate sites, a preliminary study was conducted with the major aim of developing a sonic boom response questionnaire. This study took place six months after the cessation of flights, but the delay was not considered to be a critical issue for questionnaire development. During the course of the study a small number of people were interviewed. The findings, although of only a qualitative nature, were found to be in general accord with earlier sonic boom response surveys.

PRELIMINARY SONIC BOOM SURVEY

Surveyed areas



- Objectives:
 - Develop sonic boom response questionnaire
 - Provide preliminary data on extent of sonic boom annoyance
- Sonic boom exposure:
 - Long term SR-71, 0.5 to 1.0 psf, ~ 1 per week
 - Exposure ceased 6 months prior to study
- Findings:
 - Little to moderate annoyance
 - Startle reaction frequently noted
 - Vibration frequently noted, some damage attributed to sonic booms

USAF/NASA SONIC BOOM STUDY

A joint study between the Air Force and NASA is being conducted in the Nellis Range in Nevada. The study has two major components. The first is the development and validation of a sonic boom exposure model which can predict the amplitudes and locations of sonic booms on the ground which result from a variety of supersonic operations. To support this objective, a large number of sonic boom measurements will be made over a six month period and will be related to aircraft operational information. The second component of this joint study is to conduct a community response survey of people exposed to these supersonic operations. The feasibility of performing such a survey is currently under investigation.

USAF/NASA SONIC BOOM STUDY

Nellis Range:

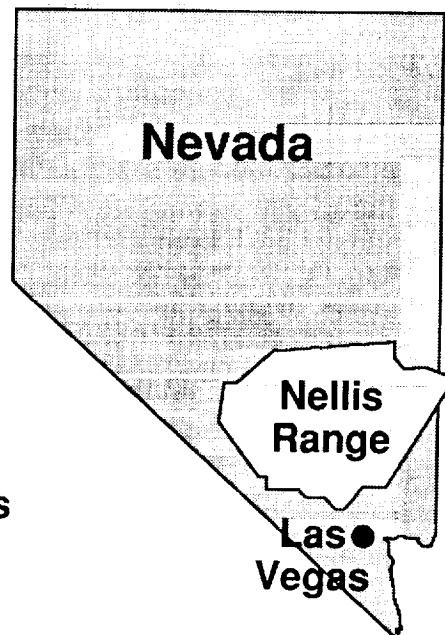
- Tactical Air Command supersonic operations
- >1000 sonic booms per year
- 0 - 3 p.s.f.
- Impacted population ~ 5000

USAF:

- Sonic boom exposure prediction model
- Model validation
 - Aircraft tracking
 - Sonic boom measurements (40 stations, 6 months)

NASA:

- Community response survey



- **Sonic Boom Simulator Operational**
 - high fidelity simulation
- **Loudness Model Validated**
 - large range of N-waves and shaped booms
- **Substantial Benefits Obtainable Through Shaping**
 - for "outdoor" listening conditions
- **In - home Simulation System Operational**
 - pilot tests imminent
- **Community Survey in Planning Stages**

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