Influence of Chair Vibrations on Indoor Sonic Boom Annoyance

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Abstract. One goal of NASA's Commercial Supersonic Technology Project is to identify candidate noise metrics suitable for regulating quiet sonic boom aircraft. A suitable metric must consider the short duration and pronounced low frequency content of sonic booms. For indoor listeners, rattle and creaking sounds and floor and chair vibrations may also be important. The current study examined the effect of such vibrations on the annoyance of test subjects seated indoors. The study involved two chairs exposed to nearly identical acoustic levels: one placed directly on the floor, and the other isolated from floor vibrations by pneumatic elastomeric mounts. All subjects experienced both chairs, sitting in one chair for the first half of the experiment and the other chair for the remaining half. Each half of the experiment consisted of 80 impulsive noises played at the exterior of the sonic boom simulator. When all annoyance ratings were analyzed together there appeared to be no difference in mean annoyance with isolation condition. When the apparent effect of transfer bias was removed, a subtle but measurable effect of vibration on annoyance was identified.

INTRODUCTION

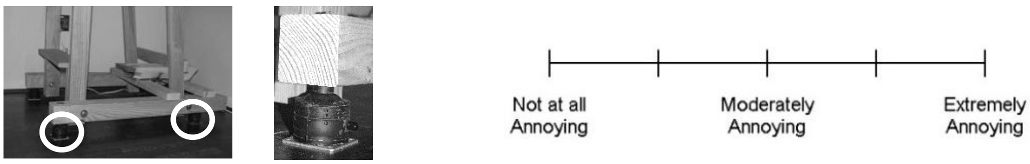
One goal of NASA's Commercial Supersonic Technology Project is to identify candidate noise metrics suitable for regulating quiet sonic boom aircraft. Choosing a noise metric that corresponds to annoyance is complicated by several factors including the impulsive nature and pronounced low frequency content of sonic booms. For indoor listeners in particular there is uncertainty about whether direct bodily contact with vibrating objects or surfaces causes more annoyance than the sound alone. This question is particularly pertinent for quiet sonic booms, which have comparatively less energy at high frequencies and are less audible than conventional sonic booms. The answers to this question will inform noise metric selection.

The literature contains conflicting conclusions about the influence of direct bodily contact with vibrating objects and surfaces on indoor sonic boom annoyance. Results from a seminal field study by Kryter [1] suggest that direct contact with a vibrating object or surface does not affect annoyance, so annoyance is completely determined by the sound of the boom. By contrast, multiple laboratory studies conducted at NASA Langley Research Center in an indoor sonic boom simulator indicate a strong relationship between floor vibrations and annoyance [2,3]. It is not clear whether the relationship between vibrations and annoyance is causal.

The current study tested the hypothesis that vibration experienced through direct bodily contact with vibrating objects and surfaces increases annoyance caused by sonic booms. Two identical chairs were used in the investigation. One chair was "isolated" from floor vibrations by placing it on four pneumatic elastomeric mounts. The other chair was "nonisolated" and placed directly on the floor. A suite of 80 impulsive noises were played at the exterior of the sonic boom simulator, and transmitted through the structure to the interior, where test subjects record their annoyance ratings. The noises consisted of sonic booms, blasts, car door slams, and gunfire. The acoustic levels at both chair locations were comparable, and the noises ranged in Perceived Level [4] from 47-87 dB. Differences in annoyance ratings between the two chairs were analyzed for evidence of increased annoyance in the nonisolated chair.

FACILITY AND TEST METHOD

The test was conducted in a single room test chamber built using residential construction materials and methods typical in the United States [5]. Exterior to two of the facility walls are loudspeaker arrays that produce an exterior stimulus that transmits indoors and causes both audible noise and structural vibration in the test chamber. This arrangement mimics the excitation that would occur to a corner room of a residential home. Two rigid wooden chairs were used in this test. Compliant seating surfaces were not used because of the person-to-person variation in whole body vibration that can result from compressible cushions.

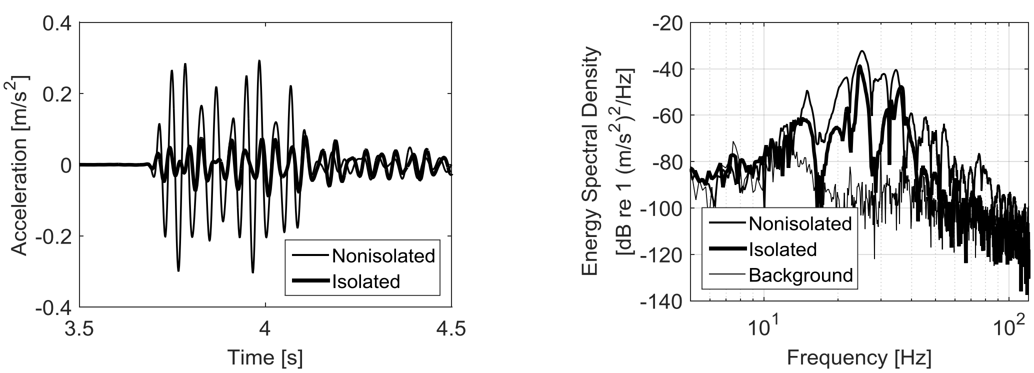


(a) (b) (c)

FIGURE 1. (a) Two of the four isolators circled in white (b) close-up of isolator mounted to 4x4 wood (c) category scale graphic

Pneumatic elastomeric vibration isolators were mounted to the legs of one test chair (Figs. 1a and 1b) to decouple the chair motion from the facility floor. The second chair was placed directly on the floor without isolators. The relative effectiveness of isolators was assessed by comparing the acceleration of both chairs, while occupied, in response to several sonic boom waveforms. Chair acceleration was measured at five locations on the underside of the chair seats and averaged. The effectiveness of the vibration isolation is shown in Fig. 2. A relative reduction in peak w_k-weighted acceleration on the order of 10 dB was observed between the chairs. For the stimuli studied in this test, this reduction in level typically, though not always, results in peak acceleration values below the w_k-weighted whole-body vibration perception threshold of 0.015 m/s^2 [6], while levels in the nonisolated seat were typically above this threshold.

The acoustic field at the two listener locations was measured using a microphone placed at ear height in the unoccupied chairs. Ideally, the acoustic levels would have been the same at the two listener locations for all of the test sounds. However, small differences were observed due to room modes. The mean and standard deviation of difference in Perceived Level between seat locations for the suite of test sounds was 0.5 ± 1.3 dB. Subjects rated annoyance along a continuous category scale, shown in Fig. 1c, using a dial input device connected to a notebook computer. The location of the rating on the scale was converted to a numeric score between 0 and 4 and averaged across all subjects. All subjects experienced both seats, sitting in one seat for the first half of the experiment, and the other seat for the remaining half.

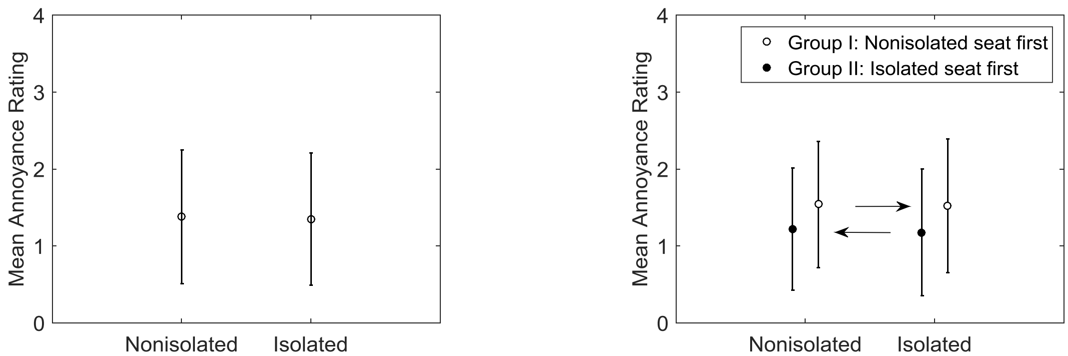


(a) (b)

FIGURE 2. Sample acceleration response in the nonisolated and isolated chairs, (a) time domain and (b) frequency domain. Signals in both time and frequency domains are shown after w_k weighting for human sensitivity to full-body vibration [6].

RESULTS: EFFECT OF ISOLATION CONDITION

The research hypothesis was that test subjects would rate signals as more annoying in the nonisolated seat than in the isolated seat, due to increased vibration. The hypothesis was tested using a two-sample *t*-test comparing mean annoyance rating across 80 signals between the nonisolated and isolated seats. The result is not statistically significant, as illustrated in Fig. 3a. Either vibration did not measurably affect annoyance, or there was a flaw in the experimental method.



(a) Ratings by seat (30 subjects per data point) (b) Ratings by seat order (15 subjects per data point)

FIGURE 3. A comparison of mean annoyance ratings. Error bars indicate one standard deviation.

RESULTS: EFFECT OF SEAT ORDER AND TRANSFER BIAS

According to the test design, subjects were randomly assigned to Group I or Group II. Subjects in Group I sat in the nonisolated seat first, and subjects in Group II sat in the isolated seat first. The implicit assumption was that subjects would make annoyance ratings in each seat independent of their experience in the prior seat. To test this assumption, the ratings were compared within each group. Contrary to expectation, there appears to be a relationship between group number and mean annoyance rating. As shown in Fig. 3b, there is no statistical difference in mean annoyance rating between isolation conditions within each subject group. Apparently mean subjective annoyance ratings depend heavily on ratings made in the previous seat. The authors turned to the literature for an explanation of this dependence.

According to the literature, results from a subjective experiment comparing two conditions may exhibit the effects of transfer bias, in which a subject's past observations influence future observations [7]. Transfer bias obscures the true effect of the conditions. Poulton studied the effects of transfer bias, offered theoretical explanations, and described some alternate designs and methods of analysis [7,8]. In a simple experimental design, the same subjects are used to compare two conditions. Group I experiences condition A followed by B, and Group II experiences condition B followed by A. It is usually assumed that a symmetrical transfer effect exists, in which subjects learn how to respond with practice throughout the test, and fatigue affects results in the latter portion of the test. These types of symmetrical transfer would affect both subject groups equally, and the transfer would not affect the difference in response of the two groups or the difference in response of the two conditions.

However, transfer bias can also be asymmetrical [8]. A test subject may learn a strategy for making judgments in the first condition and then use the same strategy in the second condition, where it is no longer appropriate. This learning from the first condition that is carried over to the second condition results in an interaction between conditions and order. The measured difference between the two conditions is then reduced. The usual statistical model that assumes additive condition and order effects is therefore violated. Conventional methods of analyzing results of balanced designs give as much weight to conditions experienced second as to conditions experienced first. If asymmetrical transfer is present, these methods may be unsatisfactory.

An alternate method for analysis consists of comparing only the results from the first session for each group while discarding results for the second condition for both groups. It can be said that this effectively substitutes transfer from a condition in the lab test to previous experiences outside the lab. Poulton argues that the previous experiences from outside the lab should be comparable for most subjects, so that the effect is neutral [8].

The current study design and results match the transfer bias examples that Poulton describes. Subjects were randomly assigned to one of two groups, and both groups experienced the sonic booms under both conditions, in an isolated seat and in a nonisolated seat, but in opposite orders. For Group I, annoyance did not change appreciably with isolation condition. For Group II, annoyance did not change appreciably with condition, and annoyance levels were lower than Group I for both conditions. This seems to indicate a two-way asymmetrical transfer bias, in which the groups learned a strategy for rating annoyance in the first condition and then carried over their strategy to the second condition. There is no reason to suspect a difference in the two groups, as the subjects were assigned randomly to each group. The transfer bias effectively reduces the observed difference in annoyance between the two isolation conditions when the full dataset is analyzed.

Following Poulton's guidance, the data was reanalyzed comparing mean annoyance ratings only for the first isolation condition with 15 subjects per seat. The resulting mean difference in annoyance ratings between seats was 0.33 ($t(159) = 19.369$, $p < 0.001$), which was approximately 7% of the scale. This result suggested a subtle but measurable effect of seat vibration on annoyance to sonic booms.

CONCLUSIONS AND FURTHER WORK

The switching of seats midway through the test likely obscured the main effect of vibration isolation on annoyance. When results were reanalyzed using only the first seat condition for each group, a subtle but measurable effect of seat vibration on sonic boom annoyance was detected. Test subjects switched chairs in Kryter's field test, which suggests that those results might also be subject to transfer bias. However, the transfer bias is difficult to assess because the report cited does not indicate the order in which subjects experienced different seat conditions. It is recommended that future testing in the laboratory and field be designed to minimize or control for transfer bias between test conditions. A new study is being planned in which vibrations will be generated at realistic levels using an inertial shaker mounted directly to each seat. Results from this study should not be subject to transfer bias from switching chairs.

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