Psychological assessment of noise annoyance due to low sonic boom

Conference Paper · April 2020

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Psychological Assessment of Noise Annoyance due to Low Sonic Boom

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ABSTRACT

Legal bans prohibit over land supersonic flights for any commercial aircraft. Those restrictions, aimed at decreasing noise annoyance on residents living along the flight path, have made supersonic commercial air traffic unprofitable, which resulted in the abandonment of the last supersonic passenger aircrafts in 2003. In recent years however, aviation industry has started to redesign supersonic aircrafts aiming at producing considerable less adverse noise impacts than former supersonic flights. The new way of surpassing the Mach 1 border has since become known as "low sonic boom" or "sonic thump". For several years, simulation and laboratory studies have been carried out to estimate human responses to low sonic boom. In Galveston, Texas, NASA conducted a community response study to quiet supersonic boom produced by special supersonic F18 flight manoeuvres (diving) over sea. However, so far no field study exists that has tested the impact of low supersonic flights en route on the population underneath.

The EU Horizon 2020 project RUMBLE (RegUlation and norM for low sonic Boom LEvels) aims at producing scientific evidence to determine the acceptable level of overland sonic booms and the appropriate ways to comply with it. For this, as part of the RUMBLE project experimental indoor and outdoor studies on human responses to sonic boom are carried out. The results of these studies together with an extensive review of existing scientific evidence on methodologies of noise impact research and results on human responses to subsonic and supersonic aircraft noise are collected to derive recommendations for a field study on human responses to supersonic flights en route. In this contribution, first ideas for a design of such a field study with regard to the noise effect assessment are discussed.

1. INTRODUCTION

While the example of the Concorde being dismissed from service is already 17 years old, publicity sees another icon of aviation passing while this is being written. The recent years have brought up a number of new planes, each of them reaching for new superlatives making air travel either more efficient, comfortable or economical. In 2005 the Airbus A380 taking off for the first time turned heads globally, and was publicly perceived as a technical milestone, making its sheer size the new sensation in the aviation industry. However in recent years, order numbers have dropped and the sensation appears to fade out of public perception.

Due to another recent drop in order numbers Airbus has announced to quit production of their flagship aircraft in 2021. The gap is supposed to be filled by more efficient and flexible mid-sized planes, which offer more benefits in regards to fleet management and are perceived as more environmentally friendly.

As a result of the recent developments, innovations mainly target smaller planes which are not able to carry as many passengers, but can instead be designed to fly faster than the speed of sound [1]. Breaching the sound barrier though is associated with loud noises along the flight path, the sonic boom that propagates along the entire flight path while travelling at supersonic speeds. Due to the intense sound emissions and accompanying phenomena such as vibration and rattle noises in ground structures, supersonic air travel over land was quickly suspended, making the purpose build planes even more expensive to run, as they were particularly unefficient whilst travelling below the Mach 1 border. Since then legal regulations prohibiting commercial over land flight beyond such speeds, forcing aviation industry to make noise emissions of the new jets a main issue of considerations while paving the path for a return of supersonic civil flights [2].

2. HUMAN PERCEPTION AND RESPONSE TO SONIC BOOM

"A typical conventional (non-minimized) sonic boom time waveform measured at the ground looks roughly like the letter N" [3, p. 1], accordingly, the term "sonic boom" appears to be somewhat misleading. Audible sonic boom noise on the ground actually consists of two booms that follow each other immediately, which leads to the impression of only one boom. Many times these noises have been described as "explosion", "burst" or "detonation" [3, 4]. Additionally, like the afore mentioned noises, sonic booms emit (very) low frequencies [3, 5, 6]. Comprehensibly, noises like that are assumed to have a major impact on human perception and response and are estimated to be more annoying than overflights by a subsonic aircraft [2, p. 586, 7]. [4] summarized that humans describe three aspects of sonic booms as most disturbing:

1. Being startled
2. Noticeable vibration and rattle
3. Concern about the possibility of damage from the booms.

Despite one finding indicating that startle and rattle response are largely covered by standard annoyance items [8] different studies have further investigated the effects of startling [7, 9–11] vibration and rattle [7, 12–16] and concerns regarding damage possibly taken to own property [17, 18] all of them acknowledging them as drivers of annoyance in humans. These findings result in the necessity to minimize noise impact as far as possible.

Additionally, a penalty in dB has been proposed by researchers for rattle noises perceived inside a room by 3-9 dB and for vibration by 0-5 dB [16] for lower vibration and 4-8 dB for higher vibration [14, 19].

Driven by these implications, a growing body of interdisciplinary research has started to join efforts to shape aircrafts in order to decrease noise when travelling at supersonic speed, for an overview see [20, 21].

The majority of scientific findings however derive from simulator studies. That is, except for the NASA'S QSF 18 test flights, there is no actual data of a non-adapted population ever to be confronted with low sonic booms. While those test flights have been executed with an F 18 fighter jet, executing a “sonic dive manoeuvre” over residents of Galverston (Tx), no population to date has ever been exposed to a low sonic boom emitted by a low boom demonstrator.

3. CONDUCTION OF A FIELD STUDY

To lift legal bans and enable new technology to enter the market, it is hence necessary to conduct a field study to assess human perception and response to low sonic boom. Here, we give our recommendations regarding the design for the conduction of a field study on community responses to low sonic boom coming from demonstrator test flights. Our recommendations refer to the assessment of the responses to sonic boom, only. Recommendations referring to the exposure assessment are not included. In the following we will discuss our recommendations in more detail.

Selection of Study Areas and Participants

Study areas should be selected due to their topographic characteristics. We propose to sample answers from rural as well as urban areas, to gain insight into the differences between crowded places with a high level of infrastructure and more quite sites, where we assume people have higher expectations towards their environment regarding quietness and relaxation [22, 23]. This can also take into account differences in atmospheric spreading of the low boom shock waves and the propagation throughout the different areas [24] and possibly different atmospheric distortions [5].

Since there is currently no population to ever hear en-route low sonic boom noises as emitted by a flight demonstrator, this serves also as an opportunity to test the role of information on perceived annoyance, as this appears to be one of the most important factors in non-acoustical noise annoyance mitigation to date [25–27].

Therefore we recommend splitting the total sample into two more subsamples, one of which will receive written information about the procedure and purpose of the study, while said information will remain undisclosed from the other subsample for the time of the field study. Furthermore, it is likely that people living underneath a flightpath far away from an airport without experiencing landings and take-offs (LTO flight procedures) differ from those living in an airport region and experiencing visually landing and starting air planes and the noise produced by LTO flights. Therefore, in addition, study areas in airport regions (e.g. defined by average sound level contours) and outside those regions are proposed. Finally this would result in a 2 x 2 x 2 study design Table 1.

Region	Area type	Information	
		yes	no
En route	urban		
	rural		
Airport region (LTO)	urban/rural		

Table 1: Proposed study design for area selection for a community survey on low supersonic boom

Recruitment

Decreasing response rates in all disciplines of empirical research demand an effective recruitment strategy to raise interest for the study at hand. To ensure proper response to the call for participants, we recommend paying incentives and using multiple recruitment strategies.

Invitations will be sent into the different selected regions via mail, additionally, calls for participants will be spread out via mail. Multiplicators can be used to gather further interested participants among the pre-selected initial sample and inform them about the study.

Once the flight path has been defined, the next step is to browse the areas underneath it and to sort them into the different categories as shown in Table 1.

Surveys

Regarding the surveys we propose a threefold approach to gather data of perceived annoyance by low sonic boom overflights among the population. This approach is related to the NASA Quite Sonic Flights [QSF 18] field study [16] in Galveston, Texas as well as the “Waveforms and Sonic Boom Perception and Response” [WSPR] study, conducted at the Edwards Air Force Base in 2011 [28]. This approach will facilitate the comparison of findings from the NASA studies with the results from the European test program.

The following surveys are included in the suggested study program:

1. A background survey,
2. a single event survey,
3. a general assessment survey.

The purposes and contents of these three surveys will be discussed in the following paragraphs.

Background Survey

The Background survey will be used as an overall screening tool, to gather participants and to raise awareness for the actual single event study. Recruiting will be accomplished by multi-methodal announcement measures to motivate as many people as possible from the randomly selected address pool to participate in the study [29, 30]: Leaflets, advertisements in newspapers, emails, social media, personal invitation letters, and, if necessary to achieve an adequate sample size, the use of existing survey panels of commercial social research institutions.

To increase reach and comfort as far as possible participants can choose between different survey modes (mixed-mode approach). That is, they can choose either to fill in an online questionnaire or use a paper-pencil questionnaire that will supplement the personal invitation letters [31].

The background survey will assess basic socio-economic matters which are common in empirical studies to describe samples, such as age, sex and education. It will further feature some standardized, retrospective noise responses such as the annoyance assessment according to ISO/TS 15666 [32] for prevailing sources of environmental noise and reported noise-related sleep disturbance. It is further suggested to include crucial items concerning relevant non-acoustic factors such as participants' noise sensitivity and their attitudes towards new technology and aviation in general, as those are to be seen as co-determinants for any source of noise annoyance [33].

Single Event Survey

The single event study will be the main tool for assessing sonic boom noise annoyance. It will be conducted as an experience sampling study [34], nowadays mostly operated on participants' mobile devices. However, there will be some supplemental paper-pencil issues, to compensate in case of technological issues throughout the study. A paper-based survey appears in light of most recent community low boom studies as most promising in regards to a high response rate [35]. However intuitively it is to be assumed that once participants do not reside at home, it is a lot more practical to not carry pen and paper survey forms, but rather have a smartphone implementation of the surveys. This also allows for a timeliness control of the returned surveys [35].

Besides the survey response, by making use of the participants' smartphones, more technology is available for studying purposes, like for example location tracking or even a background noise recording. A list of categorized questions and response scales is given in Table 2.

We suggest to prompt for the surveys latest 15 minutes after the latest test flight to minimize retrospective bias and distortion as small as possible [36]. We also suggest to prompt for some false alarms to test participants overall attention and have a measure of plausibility.

Although there's also the possibility of letting participants report a boom by pressing a button [7] we prefer a remote prompt for a survey, as this appears to be more valid in terms of in-situ measurement and isn't as volatile towards false alarms. Furthermore, we suggest to assess responses to sonic booms by means of rating scales as this allows to gain more information about the intensity of the noise response.

The technological implementation of the survey should be achieved by an application, which should run at least on Android and iOS operated devices to make the study as accessible as possible. Alternatively, a web app could be used as this runs online independent from the mobile's operating system. However, the web app should allow for temporary offline data collection in case the mobile is not connected to the internet. The smartphone implementation has also been used in the WSPR and QSF studies.

Question	Scale
Was there an audible sonic boom in the last few minutes?	Yes/ no
Location: where and indoor/ outdoor	At home inside/ outside/ Not at home inside/ outside
Window position	Open/ ajar/ shut
Subjective loudness rating of the recent sonic boom	1. Very loud 2. loud 3. Rather loud than silent 4. Neither loud nor silent 5. Rather silent than loud 6. Silent 7. Very silent
Annoyance, startle, rattle, vibration	5 point verbal scale acc. to ISO/TS 15666
Activities performed while boom occurred	1. Talking, phoning inside the house 2. Listening to the radio, watching TV 3. Reading, thinking, focusing inside the house 4. Relaxing, knocking off at home 5. Having visitors, socializing inside the house 6. Residing, relaxing outside on own property 7. While having conversations outside on own property 8. While having conversations outside generally

Table 2: Survey and response scales for the single event survey

All items in the single event survey relate only to the current situation. This helps in keeping work through time as small as possible. We hope by doing so to grant for a higher compliance throughout the time of the study, which can be an issue in experience sampling studies [37]. We further will pay incentives for showing appreciation and to offer some kind of compensation to participants for their enduring compliance [38, 39]. Hence, a small amount of money will be paid to participants per submitted survey. In recent experience sampling studies, we usually paid 1€ per received assessment.

Three different implementations are available for the momentary surveys: a purpose build app, an experience sampling app as distributed by specialized companies or a web app, which doesn't need an app installation and is accessible from the internet browser of any mobile or stationary device with an internet connection.

Using data from the single event survey, we aim to assess in-situ exposure-response curves to predict annoyance from low sonic booms from thereon.

General Assessment Survey

The third survey will feature some general evaluation questions regarding the overall study time, which is supposed to give feedback to the researchers responsible for the study. It will also feature questions regarding the annoyance due to sonic booms throughout the duration of the test flights. Once again participants can choose if they want to do administer it online or as a conventional paper-pencil questionnaire.

Statistical analysis

The main statistical analysis will be the analysis of the exposure-response relationship for the assessed community responses to low sonic boom. For this, the address-related modelled acoustic metrics of the sonic booms will be merged with the data of the Single Event Study and the General Assessment Survey. The data of the Single Event Study are data from repeated measurements. Therefore, a hierarchical multi-level regression model for repeated measurements for the noise responses (e.g. annoyance) including the event-related noise metric, relevant non-acoustic factors and the study design factors 'information', 'area type', and 'region type' as predictors has to be applied. For the General Assessment Survey, in the exposure-response models the event-related noise metric has to be replaced by averaged, period-related noise metrics. Different models are proposed to be calculated stepwise in order to monitor the change in predicted variance of the response to the sonic boom. Prior to the exposure-response models the noise metric and potential non-acoustic contributors of the response to the boom can be identified in sensitivity analyses that best help to improve the prediction of the noise response.

4. CONCLUSION

Research in low sonic boom, or more adequately put "sonic thump" [16] is just at the beginning and setting up a study to investigate the short-term effects of shaped sonic boom noise on a population is a complex matter. Here, we proposed a preliminary study design to gather in-situ data from participants living among the flight path, once the first test flights are conducted in Europe. Consequences of a long-term exposition will not be offered by this study, but it can give a glimpse into the effects it has on participants' daily lives.

We proposed a study design that relies on state-of-the-art scientific approaches and modern technology to grant for a best as possible comparability with first NASA field studies using advanced statistical methods. First tests in the United States have shown that multilevel model approaches to low sonic boom annoyance indicate a better model fit, than the usual standard regression derived ones [40]. Since up to now, no field study has ever investigated effects of a low boom demonstrator in field, many things are left to be furtherly investigated.

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ACKNOWLEDGEMENTS

This study is part of the project RUMBLE (RegUlation and norM for low sonic Boom LEvels), which has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 769896.