Measuring short-term noise annoyance to determine the impact of low sonic boom noise

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ABSTRACT

Supersonic flights allow a significant reduction of travel time on long journeys. However, the strong impact of supersonic booms on community responses to noise is well known. A new generation of supersonic planes is designed to distinctively lower the acoustical impact of sonic booms on the ground. It is unknown how people living underneath a flight route react to this new low supersonic boom. The Horizon 2020 project RUMBLE gathers ideas and approaches to set up regulations for new supersonic planes. Within the next years, it is attempted to conduct test flights with new supersonic plane demonstrators. Further on, it is intended to use these test flights to conduct a field study on the impact of the new low sonic boom on residents living underneath the flight route. Within the RUMBLE project, we have developed a concept for the assessment of en-route short-term annoyance of the exposed population by means of the experience sampling method. The concept will be presented and discussed with regard to similarities and differences between short-term and long-term annoyance assessments and their potential contributors.

INTRODUCTION

Although since the mid-1940s, technology was ready to push airplanes beyond the Mach 1 border, the civil aviation industry never really caught up with the not-so-recent technological benefits and chances of said technology. The Tupolew T144 and the Concorde became legends but have both come to fame with rather tragic histories accompanied by horrible crashes, unreliability, extraordinary maintenance costs, and uneconomical fuel consumption. While many people nonetheless enjoyed watching these planes and felt the possibility of significantly less time spent travelling for the benefit of longer gross times for recovery or business purposes, the fascination for people living in proximity to the flight paths was only short-lived: The N-Waves, publicly commonly called "sonic boom" caused major noise annoyance [1] and even struck some people with the fear of structural damage to their properties and startled them. Rightfully the last supersonic passenger jet was dismissed from duty in 2003. Since then, many new planes have been introduced, many of which rather unspectacular, but also literal giants like the Airbus A380.

For a couple of years now, research has increasingly focussed on bringing back high-speed air travels, promising to half the time spent on a plane, which seems particularly daunting for frequent flyers and those who fly long distances. These new planes are supposed to reach their supersonic travel speed, which is currently estimated at Mach 1.2- 1.4 overland, thanks to a radical reconstruction of the plane's shape [2], enabling an omission, or at least a big decrease regarding noise emissions.

The strictly regulated certification and authorisation of such new planes need research to gain insight into the impact of low-sonic boom emissions on human perception and responses to make authorities decide on the possibility of lifting the ban on supersonic flight over land. For the next years, NASA has planned test flights with the currently developed LSB flight demonstrator X59 [3], and in a couple of years, a community response survey on the impact of the sonic boom of the X59 is intended to be carried out in the U.S.

Similar planning exists for a community response study in Europe. The European Horizon 2020 funded research project RUMBLE (RegUlation and norM for low sonic Boom LEvels; 2017 – 2020) "is dedicated to the production of the scientific evidence requested by national, European, and international regulatory authorities to determine the acceptable level of overland sonic booms and the appropriate ways to comply with it." (https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/aviation/rumble).

Within the framework of RUMBLE, the authors of this contribution have developed concepts and recommendations for a socio-acoustic survey on community responses to LSB to be carried out once an LSB demonstrator is flying in Europe. In this paper, we discuss current considerations to assess the effects of LSB on annoyance using a short-term noise response assessment and to exercise the experience-sampling method by means of a cell-phone implemented survey. While in another proceeding, we have already discussed a preliminary version of our approach towards the overall survey design [4], here we want to describe the proposed survey methods in more detail and discuss the differences of noise annoyance as reported in short- and long-term assessments and transfer findings from existing literature on the topic of low sonic boom.

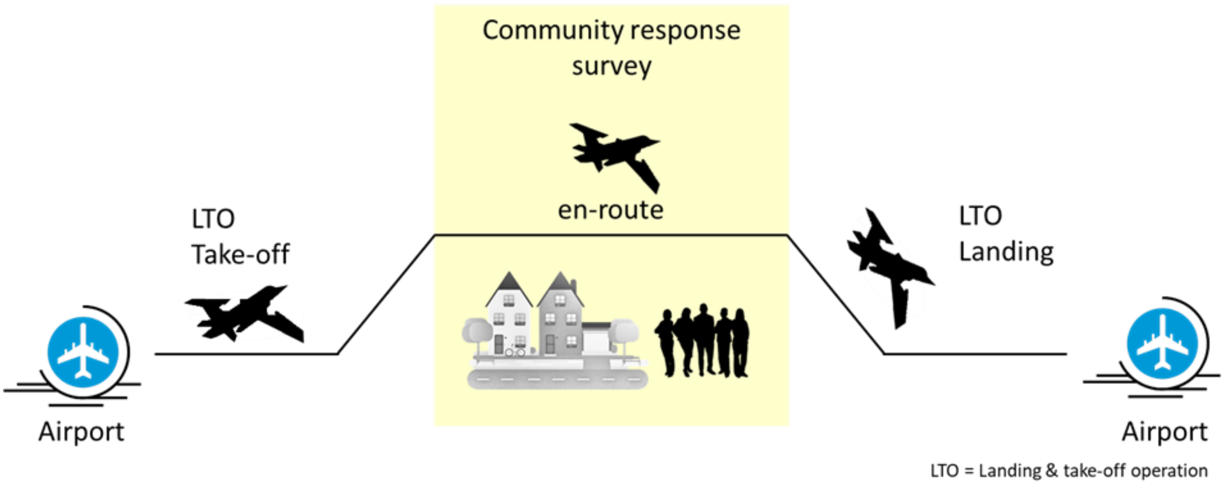

Figure 1: Low-boom demonstrator flight including the phases take-off, supersonic flight en-route (with low sonic boom), and landing operation

One of the main differences between 'conventional' socio-acoustic surveys on community responses to subsonic aircraft noise and the intended survey on the impact of low sonic boom is that it is the noise impact of aircraft flights en-route that is of interest in this study (Figure 1) whereas studies on the effects of conventional aircraft noise usually take place in airport regions and, thus, focus more on landing and take-off operations (LTO).

SHORT- AND LONG-TERM NOISE ANNOYANCE

Exposition-response curves for environmental noise sources are usually compiled using regressions and long-term, cross-sectional studies, gathering retrospective noise annoyance judgments. Among others, these efforts have led to standardised procedures such as the assessment of long-term noise annoyance (last 12 months or so), following recommendations of the ICBEN Team #6 [5]. For the survey on the effects of low sonic booms (LSB), it is not optional to do so, as no population has ever been exposed to LSB noise or experienced the en-route flight characteristics of the new type of jet.

There have been some advances in research and technology itself, enabling data collection and evaluation that is, on the one hand, closer to the event as compared to retrospective surveys on long-term noise responses and, on the other hand, closer to real-life than experimental setups under controlled conditions.

Further, of course, modern problems require modern solutions, and as with technological advancements in the aviation industry, almost everybody meanwhile owns a smartphone, which makes experience sampling setups less demanding, as there is no need to care about a substitute pocket P.C. anymore or to carry loads of printed paper to fill in a survey form whenever it is desired to do so. Additionally, first approaches to field studies led by NASA [6][7] have also been conducted as a short-term noise annoyance assessment, which offers the benefit of better comparability of the studies to one another. Although NASA has made some considerable progress and was the first institution ever to assess in-field low sonic boom human perception, both their studies are not really comparable with what is being planned here, but rather as a methodological test for later actual field studies. Both studies had an F-18 jet execute sonic dive manoeuvres [8][9] to produce low-sonic booms over the research areas, which is to be regarded as a step forward compared to the simulator studies but don't actually test en-route aircraft noise.

Having established that for our purposes, a short-term noise assessment is a way to go – and frankly, due to the lack of any long-term data the only way to go in the field - the question remains in how far the to be collected short-term annoyance data may relate to data retrieved from the long-term retrospective equivalent. The determination of the long-term effects is crucial as in future these planes may go to be run on schedule and, with decreasing costs, may likely find their way into more and more fleets. To shed some light on the differences between short- and long-term noise annoyance responses, we took a look at existing short-term aircraft noise response assessments, as this is as close as it gets to our initial question.

According to the ICBEN recommendations [5], long-term noise annoyance is measured by means of using two scales: A verbal 5-point scale and an 11-point scale from 0 to 10 with verbal endpoints. Respondents are asked to think about a longer period of time ("the last 12 months or so") when entering their estimation of noise annoyance. Several language adaptions exist meanwhile, making noise annoyance ratings for different sources comparable almost worldwide. Asking the question like that requires a minimum exposition to a noise source for at least weeks or months depending on the past period of time to be included in the annoyance judgment. That is not applicable in this study, as we are talking about LSB demonstrator test flights, which have never been done before. Thus, there has not been any exposition to the noise source at all. The situational noise assessments accordingly are conducted about a much shorter time frame, so the question and possible outcome expectations have to be adjusted to fit the context.

For the moment, literature is relatively scarce in regards to short-term noise response assessments compared to retrospective surveys on long-term noise responses. The situation is somewhat different with regard to soundscape research. Here, several tools are established reaching from the assessment of soundscape as experienced in situ, among them the application of the experience-sampling method [10] via simulated or reproduced to the recalled soundscape in memory [11], and a standard for soundscape assessment methods including in-situ assessments is developed [12].

However, some papers on the assessment of short-term noise responses outside the laboratory in the field have been identified, and the number of such studies is expected to increase. With regard to short-term aircraft noise annoyance as assessed by use of the experience-sampling method (ESM), Schreckenberg and Schümer [13] reported "that besides the hourly sound level, the number of flyovers, operational factors (take-offs/landings) and attitudinal factors such as expectations concerning future after airport expansion, aircraft-related fears and confidence in authorities have an impact on the hourly annoyance." Additionally, they found a direct and consistent relationship between their short-term noise annoyance ("hourly") and long-term annoyance ratings, indicating that a "noise annoyance in combination with activities" [activities performed while exposed to noise] is to be seen as a valid indicator for long-term aircraft noise annoyance," which is a crucial finding, as data from short-term studies may be used to make first estimations about possible effects of long-term exposition. However, short-term annoyance ratings were lower than long-term annoyance in absolute rating values, and the correlation between short-term- and long-term annoyance was consistent but moderate (around r ~ .40 to .55). This is in line with Bartels [14], who also reported lower rating values of short-term (hourly) aircraft noise annoyance compared to long-term annoyance and a moderate correlation between these judgments.

These results partly relate to Steffens et al. [15], who showed a tendency of situational and personal factors to be represented in the momentary assessments. The findings were then related to retrospective soundscape measurements, executed at the end of the experience sampling study, and also showed a similar trend. The relation of Steffens et al.'s study is limited, as the retrospective evaluations only targeted the whole day, respectively the past week, so there is a different definition of "long-term" underlying the hypothesis in their study as compared to the time period for the estimations underlying the ISO/TS 15666.

In another ESM study that was conducted in the U.K., using data of the Mappiness dataset [16] Fujiwara, Lawton, and MacKerron [17] also found negative interactions between social wellbeing[1] and aircraft noise exposure, which turned out significant at the 66 dB aircraft noise contour and affected mainly happiness and relaxation. As a result, the researchers discuss the finding that although people experience stress while being in or around an airport, they also tend to report higher measures of happiness than would be expected at a given level of perceived stress. Having discussed their results, the authors stated that it might be a policy-relevant finding that "[…] those present in noise contours and not benefiting from the

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[1] In this example, the subjective wellbeing scale also features a measure of noise annoyance

economic or leisure benefits airports provide are likely to suffer negative effects on their SWB due to noise" (p. 49).

Another ESM approach led by Bartels et al. [14] took a closer look at the relation of daily activities and aircraft noise annoyance around the Cologne/ Bonn Airport in Germany. Most importantly, it was found that acoustical parameters only accounted for 13% of perceived annoyance in the hourly surveys that were passed to participants between 7:00 and 23:00 o'clock. The explained variance more than doubled (27%) once the study also took account for personal and situational variables. Annoyance ratings were significantly larger in the morning; although this effect was not large, it is argued to be consistent with existing literature. Also, the effects of some activities performed were significant, showing –intuitively- participants being more annoyed when listening to the T.V./ radio as compared to when being physically active. According to the researchers, results indicate that hourly short-term annoyance is best reflected by models that contain not only noise levels but also situational and personal variables. Comparing the role of non-acoustic contributors to short-term and long-term annoyance, the authors found situational factors to be more important for explaining short-term annoyance, whereas personal and social factors showed higher effects on long-term annoyance. This is also in line with the results of the impact of non-acoustic factors on short-term and long-term annoyance reported by [13].

In sum, long-term annoyance is moderately related to short-term annoyance. Both are moderately affected by sound levels. Non-acoustic factors contribute both to short-term as well as long-term annoyance, with situational *in situ* factors being more important for short-term annoyance and personal and social factors for long-term annoyance. Long-term annoyance assessment in terms of asking respondents to think of past several (e.g. 12) months is not possible for a community response survey during LSB demonstrator test flights. Generalisable results can be obtained by assessing short-term annoyance repeatedly over a period of several days with several assessments per day within an ESM approach. In addition, assessing the overall annoyance due to LSB after several days and/or at the end of the ESM survey allows estimating a summarising 'medium-term annoyance', which may be a link between short-term (or event-related) annoyance and long-term annoyance over a period of several weeks or months. Therefore, for studying community response to LSB, a mixed approach combining different event-related as well as retrospective summarising sub-surveys are proposed. Such a mix of surveys was also applied by NASA in the QSF18 study conducted at the coast of Galveston, Texas, where military F-18 jets performed low boom dive manoeuvres over the ocean to project low-boom shockwaves ("carpet boom") onto the population that had been instructed to evaluate the effects of the booms in single-event and daily summary surveys preceded by a background survey [7].

PROPOSED STUDY DESIGN

The proposed community response survey to LSB, further called CRLSB study (study on community responses to low sonic boom), aims at studying the impact of LSB test flights en-route on the annoyance of people living underneath the flight routes of the LSB demonstrator. Such a field study conducted in Europe has to account for at least four points:

1. An aircraft naturally has to reach its destined speed of at least Mach 1 to elicit low sonic booms and therefore is immensely fast. An area overflown at those speeds accordingly has to be very large, probably several of hundreds of kilometres.
2. People in Europe and all around the world live in mixed environments. There are rural communities surrounded by nature with very few additional background noise sources, but

there are also urban areas, which are heavily crowded and include many different noise sources present at once.

3. As LSB planes are likely going to be mostly used on long-distance flights, different climate zones and atmospheres should be taken into account, in particular as these factors (climate, atmosphere, meteorological conditions) have an impact on the transmission of LSB to the ground [3]. In addition, different seasons should be considered in order to account for different meteorological conditions.
4. Effects of information have been suspected to moderate noise annoyance [19]. As a result of the huge communication effort made in the QSF18 study, Page et al. [7] recommend carefully consider communication aspects and recommend strategies for the engagement with communities for the community response survey carried out within the Low-Boom-Flight demonstration (LBFD) as planned for the X59 study. For the European CRLSB study, it is suggested to systematically study the impact of variations in the degree of communication in order to be able to quantify the effects of the LSB separately from the effects of the communication on the community responses.

Considering these points in a CRLSB study leads us to the proposal of the study design with two separated sites per cell as depicted in Table 1. In addition, in order to address different seasons, the study is proposed to be carried out in two different seasons, i.e. a participant takes part in two different seasonal measurement waves. In sum, we propose a 4 (climate zones) * 2 (site types) * 2 (information degree) with altogether 16 different conditions of examination taking place in a warmer and a colder season.

Table 1: Proposed study design for a CRLSB study in Europe

Number of sites	**Type of site**				**∑ sites**
	Urban, en-route		**Rural, en-route**		
	Degree of information / communication				
Climate region	**low**	**high**	**low**	**high**	
Scandinavia	2	2	2	2	8
West Europe (France, UK)	2	2	2	2	8
Central/East Europe	2	2	2	2	8
Southern Europe	2	2	2	2	8
∑ sites	8	8	8	8	32

EXPOSURE ASSESSMENT

In the study area types, a sufficiently large number of people should be living to achieve a minimum required sample size, takng into account expected response rates.

Two models are proposed with which the number of people exposed to LSB can be estimated for a given en-route segment: A low fidelity model, which estimates the number of people in rural and urban areas within the LSB carpet and is used in the first exploratory phase to select potential flight routes. The second model is a more detailed method, providing information that is useful to finetune the pre-selected routes and prepare the surveys.

With the low fidelity model, the theoretical width of the sonic boom carpet for an en-route flight segment at given Mach and altitude, under standard atmospheric conditions, is estimated following the approach of Liebhardt [20]. The information on the sonic boom carpet can be merged with data from background noise and population databases, enabling to identify rural and urban areas and obtaining an estimation of the exposed number of people living under the sonic boom carpet.

To get more detailed information on the LSB exposure and to prepare the corresponding survey, the NENA model, developed by ANOTEC in the NINHA project to establish the impact of en-route noise of open-rotor aircraft can be taken and adopted to sonic boom exposure estimation [23][24]. In a first step, the near-field noise signature has to be determined by any available sonic boom prediction model, based on the aircraft configuration and operating conditions for the considered en-route segment (Mach number and flight altitude). The resulting signature is then propagated to the ground by a third-party propagation model, taking into account the appropriate atmospheric conditions. For the given en-route segment, NENA generates an elevation map for the potentially affected area. This map can be used by the propagation module. Then, a contour map can be determined for the sonic boom noise metrics of interest (see example in Figure 2).

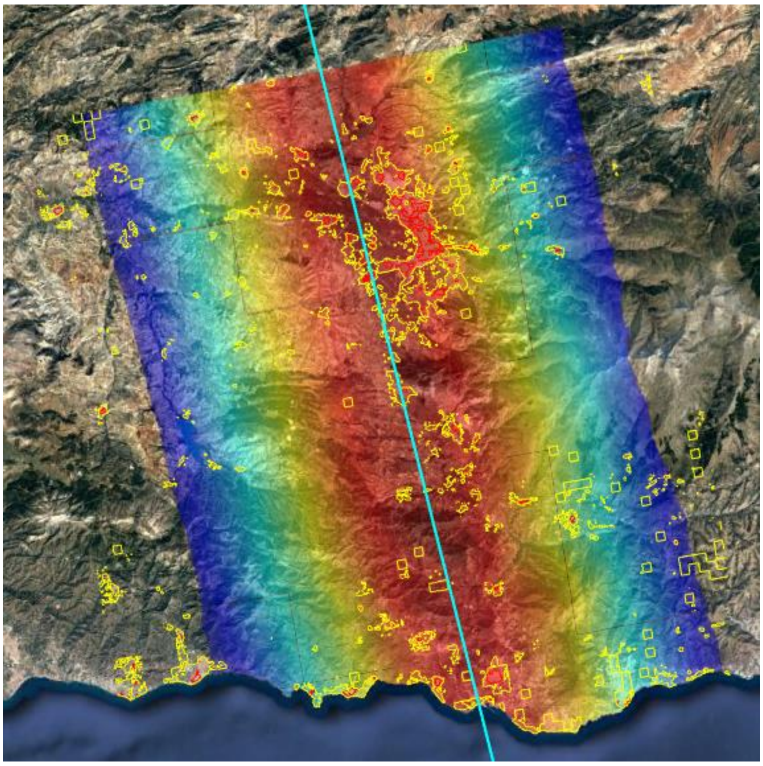

Figure 2: LSB level (P.L.) and population map for an en-route flight segment over the South of Spain

For this, the sonic boom noise metrics module developed in RUMBLE WP3 can be used [25]. Usually the population data is provided as population density for each cell (in this case [45] with a cell size of 100x100m). Depending on the objective of the survey, a certain threshold may be set for the density, above which the area is considered urban, whereas for lower densities, the area will be deemed rural. Once this threshold has been set, the number of people in rural and urban areas can thus be determined. Rural and urban population locations are provided through a kml file for use in Google Earth. Together with the sample size and estimated noise impact level, this facilitates the selection of the most interesting locations for recruitment. The NENA model also allows assessing the exposure of study participants to LSB during the study with a cell size of 100x100m.

SURVEYS

We propose using three surveys during the in-field study:

- A baseline survey/screening,
- an ESM survey (single LSB-event-related survey)
- End-of-week and End-of-study-period summary survey

A threefold approach would be equivalent to NASA's WSPR and QSF18 studies [6][7] which has been proven successful and would further make our efforts more comparable to the NASA studies. The baseline survey would assess basic constructs, such as living conditions, basic socio-demographic variables and other constructs, regularly asked for, noise sensitivity and a roundup of other noise sources, which participants find to be most common in their current environments. The information gathered in the baseline survey would later be used to describe the sample and estimate the quality of the collected data, and to allow for sub-group analysis (e.g. with regard to noise sensitivity). We recommend following a mixed-mode approach, i.e. to hand out a paper/ pencil version and simultaneously use an online form as the preferred modes of administration vary throughout the demographic [26].

The ESM survey, i.e. the short-term LSB-event-related survey, would be used to measure noise annoyance by low sonic boom overflights during the test flight phase together with the assessment of vibration annoyance, startle responses, loudness/noticeability, as well as participants current activity and location. Participants would be instructed to fill it in multiple times throughout a day. At this point, it remains undecided which software is to use. In any case, we aim for an app-based survey, which either is to be locally installed on the device or implemented as a web app on the mobile device, i.e. can be administered from the web browser of all mobile devices.

Each event-related measurement would start with a notification indicating to fill in the questionnaire. It is intended to send this notification up to 30 minutes *after* the LSB overfly over the study site and not before as it was done in the QSF18 study [7], because we would suggest avoiding attentive listeners as, in our opinion, this threatens the ecological validity of the assessment. In addition, in order to minimise socially desirable responding (a tendency of respondents to answer in a manner regarded as desired by others and acquiescence response bias (tendency to agree with statements independent from the content), we suggest notifications are sent out, and the measurement takes place when no supersonic overflight occurs. These notifications in 'no boom' conditions would be distributed randomly across the study periods. The first question, then, would be whether the participant has recently (within the last 30 minutes) heard a sonic boom/unexpected sound. If yes, the LSB-related questions would follow; otherwise, the participants would just be asked for their recent (main) activity and location within the last 30 minutes.

The number of overflights over a study site and, thus, the number of measurements per day and participants to a large extent is dictated by the flight schedule to be developed when the demonstrator is available for test flights over European soil and by operational restrictions depending among others on meteorological and atmospherical conditions. However, it is expected that, on average, a participant would have not more than four LSB overflights per day.

The participants would do their assessments for 14 days within a 1-month period, both in the warmer and colder season.

The third kind of survey is proposed at the end of each ESM assessment week. This survey would aim at ascertaining the LSB annoyance and disturbances of activities within in the past week, plus some more global items referring to residential satisfaction, health-related quality of life and wellbeing within the past week, the perception of the communication strategies that have been applied before and during the ESM study as well as the acceptance of technology, based on the information given to participants. Additionally, it is proposed to assess the elements of annoyance (disturbances, emotional responses, perceived capacity to cope with noise) by means of the Multiple-Item-Annoyance Scale [MIAS] [27]. MIAS would facilitate the comparison of short- and long-term LSB annoyance, as it would assess the noise perceived over a longer time period and promotes understanding of activities mostly disturbed by LSB throughout the study period as well as the understanding to what extent LSB affects the perceived control.

Furthermore, the assessment of non-acoustic factors is suggested at the end-of-week-questionnaire at the end of the season period of the CRLSB study. In particular, those factors are regarded as important that are known to be correlated with annoyance to a higher degree and are modifiable. Sanchez et al. [99] categorised non-acoustical factors accordingly and identified attitudes towards the source, perceived fairness of procedures (regarding decision making, e.g. on aircraft noise-related issues, flight paths, operations, or the implementation of new aviation technology), trust/misfeasance in authorities, perceived control and the capacity to cope with noise, satisfaction with sound insulation and temporal factors to be modifiable to a high degree and of high importance for annoyance. As the survey is on community responses to noise within the context of the potential future implementation of new technology (low sonic boom aircraft), the attitudinal factors related to the source and relevant authorities are regarded to be of high interest for the CRLSB study. Also, towards the end of a season period of the CRLSB study, the end-of-week survey can be slightly modified to additionally assess ratings of the pleasantness of the ESM survey overall. This can help to avoid further compliance issues and determine if there is additional annoyance perceived by participants due to the recurring sampling intervals throughout the study duration.

While the QSF18 study summarised findings at the end of each day, we tend to propose to avoid this, as a daily summary would likely bear only a few more insights as compared to the ESM survey, plus it results in an additional survey interval, participants will have to complete per day, which can lead to further corruption of compliance.

Exercising a three-staged design, we hope that this would allow collecting as much relevant data as possible while putting the least strain on participants. Following up with an experience sampling study can be demanding towards participants, especially to those who usually do not tend to surveil their smartphones steadily throughout the day. Overstraining participants accordingly would likely result in enhanced drop-out rates [29][30]. To keep compliance as high as possible, we also emphasise the recommendation to pay a small amount of gradual incentives, as this could offer a benefit to participants when being compliant with the procedure [29][31].

CONCLUSION

In this contribution, we worked out proposals for a community response study to be executed once an LSB demonstrator arrives in Europe, enabling us to collect real-time annoyance data from local residents living along the flight paths. We argued using the experience sampling method is not only advised but also offers benefits that cannot be found in a cross-sectional study. To emphasise this, we discussed findings of literature taking the ESM approach to the assessment of noise responses, and in particular aircraft noise annoyance, and displayed a variety of results and interpretation of the data that has largely profited from in-situ measurements.

For the proposed CRLSB study, we suggest considering, besides annoyance responses, people's activities and locations as well as their personal dispositions and attitudes and beliefs related to LSB and to the implementation of such new technology in general. For this, we have proposed a three-stage study design including a baseline survey, an event-related ESM study and summarising assessments at the end of a study week and study period (per season).

Following the proposed approach would, however, include the limitation of in-situ LSB annoyance and medium-term annoyance (weekly) assessment and would not allow for insights to a long-term low sonic boom exposition over a period of months. However, in-situ data can give some hints about possible long-term effects and possibly pave the path to find indicators that give a better insight into long-term noise annoyance.

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.

REFERENCES

[1] Coulouvrat, F. (2009). The Challenges of Defining an Acceptable Sonic Boom Overland. In *15th AIAA/CEAS Aeroacoustics Conference (30th AIAA Aeroacoustics Conference)* (pp. 1–12). [Reston, VA]: [American Institute of Aeronautics and Astronautics]. https://doi.org/10.2514/6.2009-3384

[2] Graham, D., Dahlin, J., Meredith, K., & Vadnais, J. (2005). Aerodynamic Design of Shaped Sonic Boom Demonstration Aircraft. In *Aerospace Sciences Meetings: 43rd AIAA Aerospace Sciences Meeting and Exhibit*. [Place of publication not identified]: [publisher not identified]. https://doi.org/10.2514/6.2005-8

[3] Doebler, W. J., Wilson, S., Lobeau, A., & Sparrow, V. W. (2020). Five-year simulation study of NASA's low-boom carpets across the contiguous United States of America. *Proceedings of Forum Acusticum 2020*. Lyon, France.

[4] Grossarth, S., Schreckenberg, D., Van Oosten, N., & Meliveo Luis. Psychological Assessment of Noise Annoyance due to Low Sonic Boom. *Proceedings of Forum Acusticum 2020*. Lyon, France.

[5] Fields, J. M., Jong, R. G. de, Gjestland, T., Flindell, I. H., Job, R.F.S., Kurra, S., . . . Schuemer, R. (2001). Standardised General-Purpose Noise Reaction Questions For Community Noise Surveys: Research and a Reccomendation. Journal of Sound and Vibration, 242(4), 641–679. https://doi.org/10.1006/jsvi.2000.3384

[6] Page, J., Hogdon, K., Krecker, P., Cowart, R., Hobbs, C. M., Wilmer, C., . . . Phillips, D. (2014). *Waveforms and Sonic Boom Perception and Response (WSPR): Low-Boom Community Response Program Pilot Test Design, Execution, and Analysis.*

[7] Page, J., Hogdon, K. K., Hunte, R. P., Davis, D. E., Gaugler, T. A., Downs, R., . . . Cutler, C. (2020). *Quiet Supersonic Flights 2018 (QSF18) Test: Galveston, Texas Risk Reduction for Future. Community Testing with a Low-Boom Flight Demonstration Vehicle: Volume II: Appendices* (No. NASA/CR–2020-220589). Hapton, VA.

[8] Haering, E. A. (2005, July). Flight Demonstration Of Low Overpressure N-Wave Sonic Booms And Evanescent Waves. In *AIP Conference Proceedings* (pp. 647–650). AIP. https://doi.org/10.1063/1.2210436

[9] Page, J. (2017). Sonic boom weather analysis of the F-18 low boom dive maneuver. *The Journal of the Acoustical Society of America*, *141*(5), 3626. https://doi.org/10.1121/1.4987791

[10] Craig, A., Moore, D. & Knox, D. (2017). Experience sampling: Assessing urban soundscapes using in-situ participatory methods. *Applied Acoustics, 117*, 227-235.

[11] Aletta, F., Kang, J., & Axelsson, Ö. (2016). Soundscape descriptors and a conceptual framework for developing predictive soundscape models. Landscape and Urban Planning, 149, 65–74. https://doi.org/10.1016/j.landurbplan.2016.02.001

[12] International Organization for Standardization (2018). Acoustics – Soundscape – Part 2: Data collection and reporting requirements (ISO/TS 12913-2:2018).

[13] Schreckenberg, D., & Schuemer, R. (2010). The impact of acoustical, operational and non-auditory factors on short-term annoyance due to aircraft noise. In *Proceedings of Internoise 2010* (pp. 1–10).

[14] Bartels, S. (2014). Aircraft noise-induced annoyance in the vicinity of Cologne/Bonn Airport. The examination of short-term and long-term annoyance as well as their major determinants. Technische Universität Darmstadt (Dissertation).

[15] Steffens, J., Steele, D., & Guastavino, C. (2017). Situational and person-related factors influencing momentary and retrospective soundscape evaluations in day-to-day life. *The Journal of the Acoustical Society of America*, *141*(3), 1414. https://doi.org/10.1121/1.4976627

[16] MacKerron, G., & Mourato, S. (2018). Mappiness 2.0 [iPhone App]. London, UK.

[17] Fujiwara, D., Lawton, R. N., & MacKerron, G. (2017). Experience sampling in and around airports. Momentary subjective wellbeing, airports, and aviation noise in England. *Transportation Research Part D: Transport and Environment*, *56*, 43–54. https://doi.org/10.1016/j.trd.2017.07.015

[18] Bartels, S., Márki, F., & Müller, U. (2015). The influence of acoustical and non-acoustical factors on short-term annoyance due to aircraft noise in the field - The COSMA study. The Science of the Total Environment, 538, 834–843. https://doi.org/10.1016/j.scitotenv.2015.08.064

[19] Schreckenberg, D., Moehler, U., Liepert, M. & Schuemer, R. (2013). The impact of railway grinding on noise levels and residents' noise responses – Part II: The role of information. *Proceedings of INTER-NOISE 2013. Paper No. 250*, Innsbruck/Austria.

[20] Liebhardt, B. (2019). Sonic Boom Carpet Computation as a Basis for Supersonic Flight Routing. In *AIAA Aviation 2019 Forum*. Reston, Virginia: American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2019-3387

[21] Aspuru, I., & Van Oosten, N. (2009). *BANOERAC Final Report*. Motril, Spain: ANOTEC Engineering, 2009.

[22] European Union (2016). *GHS population grid, derived from EUROSTAT census data (2011) and ESM R2016*. Retrieved from https://data.europa.eu/euodp/es/data/dataset/jrc-ghsl-ghs_pop_eurostat_europe_r2016a

[23] Van Oosten, N. (2013). *Noise Impact of aircraft with Novel engine configurations in mid- to High Altitude operations NINHA: D.4.6 Publishable project results*. Retrieved from https://cordis.europa.eu/project/id/266046/reporting

[24] Van Oosten, N., & Collin, D. (2014). NINHA: Noise Impact of aircraft with Novel engine configurations in mid- to High Altitude operations. *Proceedings of Internoise 2014*, 1–10.

[25] LeGriffon, I. (2020). *RUMBLE deliverable D3.1 – Benchmark Test Case Results On Implemented Sonic Boom Noise Metrics*.

[26] Glass, D. C., Kelsall, H. L., Slegers, C., Forbes, A. B., Loff, B., Zion, D., & Fritschi, L. (2015). A telephone survey of factors affecting willingness to participate in health research surveys. *BMC Public Health*, *15*, 1017. https://doi.org/10.1186/s12889-015-2350-9

[27] Schreckenberg, D., Belke, C., & Spilski, J. (2018). The Development of a Multiple-Item Annoyance Scale (MIAS) for Transportation Noise Annoyance. *International Journal of Environmental Research and Public Health, 15*(5). https://doi.org/10.3390/ijerph15050971

[28] Sanchez, D., Naumann, J., Porter, N., & Knowles, A. Current issues in aviation noise management: A non-acoustic factors perspective. *Proceedings of the 22nd International Congress on Sound and Vibration, 22.* Retrieved from http://iiav.org/archives_icsv_last/2015_icsv22/content/papers/papers/full_paper_523_20150409162310359.pdf

[29] Wen, C. K. F., Schneider, S., Stone, A. A., & Spruijt-Metz, D. (2017). Compliance With Mobile Ecological Momentary Assessment Protocols in Children and Adolescents: A Systematic Review and Meta-Analysis. *Journal of Medical Internet Research*, *19*(4), e132. https://doi.org/10.2196/jmir.6641

[30] Van Berkel, N., Ferreira, D., & Kostakos, V. (2017). The Experience Sampling Method on Mobile Devices. *ACM Computing Surveys*, *50*(6), 1–40. https://doi.org/10.1145/3123988

[31] Yu, S., Alper, H. E., Nguyen, A.-M., Brackbill, R. M., Turner, L., Walker, D. J., . . . Zweig, K. C. (2017). The effectiveness of a monetary incentive offer on survey response rates and response completeness in a longitudinal study. *BMC Medical Research Methodology*, *17*(1), 77. https://doi.org/10.1186/s12874-017-0353-1