DOI: 10.61782/fa.2023.1184

forum acusticum 2023

# DESIGN OF AN ON-BOARD NOISE MITIGATION SYSTEM FOR A TRAM VEHICLE

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## ABSTRACT

This paper presents the results of the design of noise reduction measures for the Florence "Sirio" Tram. This activity was performed in the framework of the Life "SNEAK" project ("Optimized surfaces against noise and vibrations produced by tramway track and road traffic"), LIFE20 ENV/IT/000181. Specifically, bogie skirts - i.e. noise barriers positioned on board of the vehicle, directly connected with the tram bogie – were designed and optimized to mitigate noise emissions from the wheel area.
A test campaign was carried out to acquire sound profiles describing the emissions of interest of the Sirio tram. Repeated measurements were performed to measure: i) rolling noise emitted by the bogie while the tram is moving along a straight line at maximum cruising speed (50 km/h); ii) braking noise in a full stop; iii) squeal noise, which happens when the tram passes through a tight curve in absence of lubricant.
A customized solution, which implements a sound-insulating and sound-absorbing panel placed in front of the wheel, was designed to replace the existing set of wheel covering panels. Such a device includes an extended barrier towards the ground to limit the noise emission area to a minimum.
The preliminary results obtained with the proposed solution, which was tested in a simplified scenario, are discussed in the paper.

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**Keywords:** *squeal noise, noise mitigation, tram*

## 1. INTRODUCTION

The impact of tram noise on everyday life quality in urban areas is widely discussed in literature [1–6]; Figure 1 depicts the breakdown of the tram noise in its components [7].

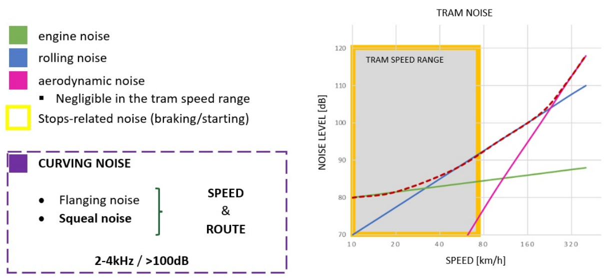


**Figure 1.** Tram noise contributions.

Several different approaches aiming at tram noise pollution reduction are described in literature: from boogie skirts, to damping elastomers, to wheel/rail friction control or contact optimization [8–14].
In the framework of the SNEAK Project different solutions to reduce the squeal and rolling noise of the Florence tram lines were developed [15]. In particular, combinations of sound-insulating and sound-absorbing panels, to be added to the current bogie with non-invasive and cheap changes to the bogie design, were investigated.

To assess the effectiveness of the designed solutions, an experimental test was designed. The test, described in the following paragraphs, relies on the reproduction of a simplified – yet representative – synthetic noise emission on a stationary tram in a controlled environment.

## 2. MATERIALS AND METHODS

The most suitable area for introducing noise reduction devices on the tram was individuated in the wheel cover panel of the driving bogies. The rationale behind this choice is: significant room for intervention, ease of access for mounting and maintenance, adjacency to the main sources of squeal and rolling noise (wheel/rail contact point) and engine noise (located directly behind the panel).

### 2.1 Panel Design Configuration

Three different noise reduction solutions were developed: i) SHIELD MK1, created by adding an adjustable miniskirt to the baseline panel and applying sound-absorbing material blocks on the interior surface; ii) SHIELD MK2, which, adds to MK1 an additional block of sound-absorbing material on the miniskirt inner surface; iii) SHIELD MK3, which adds to MK1 a polyester foam on the miniskirt inner surface. The sound-absorbing blocks used were mainly tuned for peak absorption at 2500 Hz, corresponding to the squeal noise frequency, but also for a broadband absorption in the frequency range of 500-1500 Hz linked to rolling, engine and braking noise.

**Figure 2.** MK2 SHIELD prototypes.

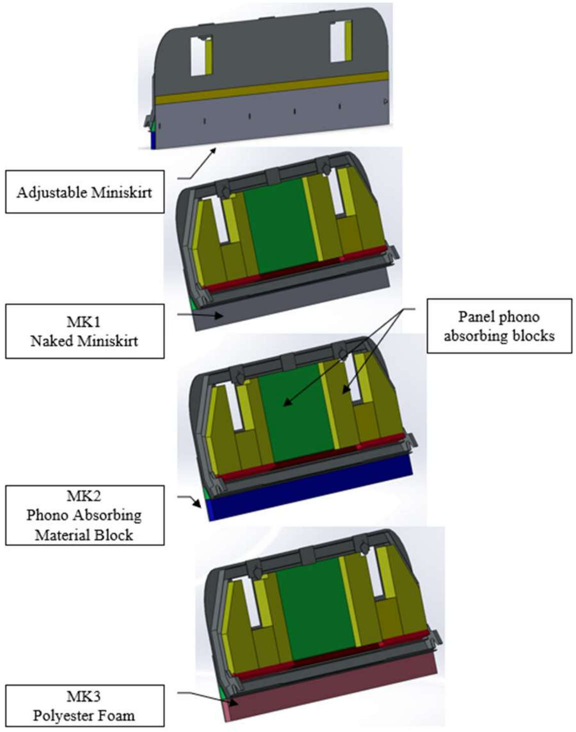


**Figure 3.** SHIELD CAD.

## 3. EXPERIMENTAL TEST SET UP

The evaluation of the different proposed solutions was performed as follows. First of all, the tram noise spectra for the marching and squeal conditions were acquired in controlled conditions. In the second phase, the acquired signals were reproduced with an electroacoustic source placed under a stationary tram into the deposit. Correspondence between reproduced and acquired signals at the microphone was assessed as a sanity check.
The different panel prototypes were hence mounted on the tram and the response at the microphone was collected and compared to evaluate the effectiveness of different proposed solutions. This setup was adopted for the following reasons: i) ease of mounting for the different panels; ii) no need to require any safety authorization for mounting the prototypal panels on an in-line marching tram; iii) controlled conditions for future comparative evaluations.

### 3.1 Tram Noise Spectrum Acquisition

Experimental measurement of the Sirio tram noise was divided into two different phases.

Initially, the marching tram noise spectrum was acquired on a rectilinear path. Tram speed was monitored to assure that a constant speed of approximately 50 km/h was maintained during the passage in front of the measuring station.
Then, the squeal noise spectrum was acquired inside the deposit area on a curvilinear path; tram speed was monitored during the passages in front of the microphones.
Both the marching and the squeal noises were collected in two different tram configurations: with and without the baseline wheel cover panel mounted on the bogie.

### 3.2 Test Scenarios Description

The simplified test scenario depicted in Figure 4 was used for the different prototypes performance assessment. In particular, the acoustic source was placed next to the tram wheel, with the tram in stationary conditions, and the speaker reproduced the noise signals acquired in the first measuring session without the baseline wheel cover panel.

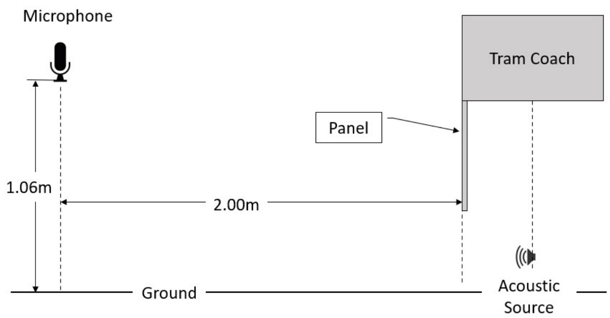


**Figure 4.** Experimental setup scheme.

## 4. RESULTS

### 4.1 Spectra Acquisition Results and Assessment of the Proposed Solutions

The comparison of spectra collected in the second measuring session in different panel configurations (No panel / Baseline panel / Shield MK1 / Shield MK2 / Shield MK3) gave the possibility to evaluate the effectiveness of different proposed solutions. E.g., in Figure 5, spectra obtained using the squeal noise signal, with the main peak at 2500 Hz, are shown for "No panel" and "Baseline panel" configurations.
Results are reported in terms of Leq evaluated referring to an average time of 28s.

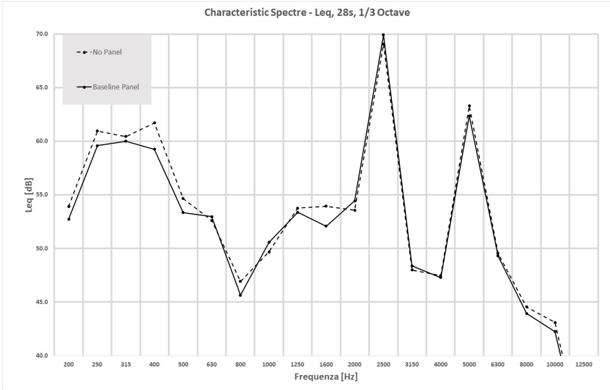


**Figure 5.** Squeal Noise Characteristic Spectrum in "No panel" and "Baseline" configuration.

Finally, spectra obtained by using the squeal noise signal and all panel configurations are presented in Figure 6 and summarized in Table 1.

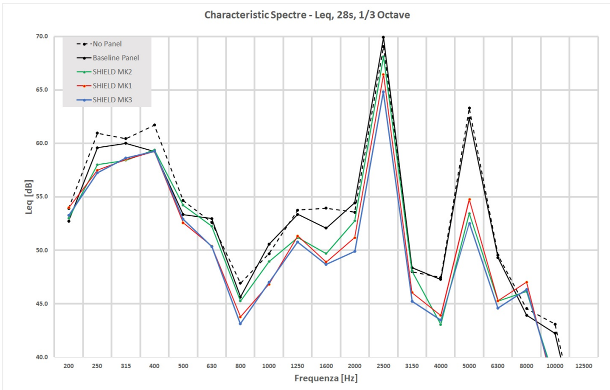


**Figure 6.** Spectra results for the different panel configurations.

**Table 1.** Sound pressure level at mic (Figure 3).

| *Panel Configuration* | *Leq(A) [dB]* |
|---|---|
| No Panel | 71.9 |
| Baseline Panel | 72.2 |
| SHIELD MK1 | 68.7 |
| SHIELD MK2 | 70.1 |
| SHIELD MK3 | 67.3 |

## 5. DISCUSSION

All the tested configurations provide a reduction in the measured noise levels in all the significant frequency bands. A significant impact appears on the squeal noise frequency, with a maximum reduction of approximately 5 dB for the SHIELD MK3 with respect to the baseline configuration at 2500 Hz. MK1 overperforms MK2 despite the addition of sound-absorbing blocks to the miniskirt in the second prototype. A first hypothesis on this phenomenon lends towards the presence of more poorly oriented reflecting surfaces, specifically the side faces of the blocks, which might affect the overall performance of the device. This aspect will be explored in the future steps of work, which further include the optimization of the MK2 and MK3 configurations and the assessment of the noise reduction of the tram in operative conditions, along with the industrialization process of the solution.

## 6. ACKNOWLEDGMENTS

The authors would like to thank all who sustained them with this research, especially the European Commission for its financial contribution to the Project into the LIFE+2020 Program.
Moreover, the authors would like to thank Hitachi Rail, Pantecnica s.p.a and Phononic Vibes s.r.l. for the support in the design and realization of the prototypes and Gest s.p.a and Hitachi Rail for the support during the experimental tests.

## 7. REFERENCES

1. Cik M, Lienhart M, Lercher P. Analysis of psychoacoustic and vibration-related parameters to track the reasons for health complaints after the introduction of new tramways. Applied Sciences (Switzerland). 2016;6.
2. Khelf M, Boukebbab S. The effect of noise on the comfort of passengers inside the tramway and its impact on traffic congestion in the urban area. Journal of Vibroengineering. 2018;20.
3. Panulinova E, Harabinova S. NOISE ANNOYANCE FROM TRAM TRAFFIC IN THE URBAN ENVIRONMENT. Civil and Environmental Engineering. 2022;18.
4. Panulinova E, Harabinová S, Argalášová L. Tram squealing noise and its impact on human health. Noise Health. 2016;18.
5. Rylander R. Physiological aspects of noise-induced stress and annoyance. J Sound Vib. 2004.
6. Klein A, Marquis-Favre C, Champelovier P. Assessment of annoyance due to urban road traffic noise combined with tramway noise. J Acoust Soc Am. 2017;141.
7. Governi L, Carfagni M, Borchi F, Puggelli L, Buonamici F. State of the art about solutions for tram noise reduction in the framework of the Life SNEAK project. Internoise 2022 - 51st International Congress and Exposition on Noise Control Engineering. 2022.
8. Nowakowski T, Firlik B, Staśkiewicz T. Developing assumptions for the tram noise attenuation passive system using the Noise Maps analysis method. Archives of Acoustics. 2019;44.
9. Louen C, Wehrens A, Vallée D. Analysis of the Effectiveness of Different Noise Reducing Measures Based on Individual Perception in Germany. Transportation Research Procedia. 2014.
10. Dumitriu M, Cruceanu IC. On the rolling noise reduction by using the rail damper. Journal of Engineering Science and Technology Review. 2017;10.
11. Ma Z, Wang A, Gao X, Gu X, Ju L, Wang Z. Rail Vibration and Rolling Noise Reduction Using Tuned Rail Damper for Vulcanized Bonded Baseplate. Notes on Numerical Fluid Mechanics and Multidisciplinary Design. 2021.
12. Frid A. Skirts and barriers for reduction of wayside noise from railway vehicles - An experimental investigation with application to the BR185 locomotive. J Sound Vib. 2003.
13. Vogiatzis K, Argyropoulos J, Veletsos P. Squealing noise abatement techniques in athens tram network. 17th International Congress on Sound and Vibration 2010, ICSV 2010. 2010.
14. Ahn S, Nam C, Choi S, An D, Kim I, Seo K, et al. A study on squeal noise reduction considering the pad shape of the disc brake system for urban railway vehicles. Journal of Mechanical Science and Technology. 2021;35.
15. Bracciali A, Megna G, Bernardini M, Governi L, Bartalucci C, Colucci G, et al. A new procedure to carry out noise and vibration measurements oriented to support an annoyance evaluation in the framework of the Life SNEAK project. Internoise 2022 - 51st International Congress and Exposition on Noise Control Engineering. 2022.