ABSTRACT
The European project Silence is dedicated to the reduction of railway and roadway noise in urban areas. Within the frame of the subproject E, a global and comprehensive noise reduction process was undertaken both for passengers and freight trains where railway manufacturers are in charge of the reduction of the main noise sources of trains: the Diesel powerpack, its cooling system, the wheel-rail contact, the traction engine, the HVAC. In the same time, the subproject G deals with the noise radiated by the track. Solutions are also proposed. The final goal of the project is to run optimised trains on optimised tracks to assess the noise reduction in operating conditions. To this end, states of the art of the noise radiated by a train (electrical multiple unit, Diesel multiple unit, freight wagons), a tram and a metro are presented. The acoustic characteristics of the main sources and the potential of noise reduction of each one is also depicted. The global noise reduction that can be reached by combining the solutions is assessed by simulation (developed in subproject B of the Silence project) and discussed.

INTRODUCTION
The 6th Framework Programme EU supported SILENCE Integrated Project, aims at developing an integrated system of methods and technologies for an efficient control of urban noise [1]. “Integrated system” means the combined consideration of city authorities, individual traffic (on road) and mass transport (on rail and road) with a holistic treatment of all traffic noise facets: urban noise scenarios identification, individual noise sources (vehicles on infrastructures) reduction, traffic management, noise perception and annoyance. It gathers 43 partners including cities authorities, car and railway industry manufacturers, public transport operators, road technology laboratories and universities. It started on February 1rst 2005 for a duration of three years. The general approach chosen was the following:
- Assessment of urban noise situations from noise maps,
- Definition of typical urban noise scenarios for road and rail, called “validation platform”, which form the reference working basis for the project,
- Identification, for each noise scenario of the noise abatement priorities and noise reduction potentials.

The rail situations considered in the project include trams, metros in open air and trains. The application of the general approach to rail scenarios is described in [2] with an emphasis on the acoustical testing methods used or developed to identify precisely and rank acoustical sources on rail vehicles. In the next paragraphs, the state of the art of the noise radiated by a train (electrical multiple unit, Diesel multiple unit, freight wagons), a tram and a metro are presented.

The acoustic characteristics of the main sources and the potential of noise reduction of each one are given. The global noise reduction that can be reached by combining the solutions is assessed by simulation and discussed in the last paragraph.

NOISE SOURCES OF HEAVY AND LIGHT RAIL ROLLING STOCKS
In the following paragraphs, the acoustic characterisation of a bimode, electrical and Diesel, multiple unit train, freight wagons, trams and metros are presented.

Acoustic characterisation of an Electrical / Diesel multiple unit train
A bi-mode multiple unit train (BMU) called Autorail Grande Capacité (AGC) from Bombardier Transportation, used in France for regional service, has been characterised according to ISO3095:2005 standard. An array of microphones was used to quantify the contribution of the
main sources to the pass-by noise in normal operating conditions. The measurement campaign was performed in Maison-Alfort near Paris, French “validation platform” of the Silence project, and in Pierrelatte (south of France) in a quiet area. The results of the first step of the measurement campaign confirm that the AGC train is one of the less noisy multiple unit train. The source ranking was performed using an array of 62 microphones arranged according to Underbrink geometry [3] and located 6m from the track. A beamforming algorithm used after a dedopplerisation technique gives the noise maps. Then, each area where a noise source appears was selected to extract the position, the level and the spectrum of the source. Characteristics of the main sources are then used to build a simple model of the train and compute the contribution of each source to the pass-by noise measured at 7.5m from the track. An example of such a result is presented figure 1. In this case, a reduction of the pass-by noise can be reached only by acting on several sources simultaneously. The power pack (Diesel engine and cooling of its compartment), its exhaust, its inlet, the cooling system must be optimised to obtain a significant noise reduction.

Figure 1.-Contribution of the main noise sources of the AGC train to the pass-by noise in Diesel mode at 30kph

In Diesel and electric modes at 30 kph or 80 kph, the rolling noise contribution is always one of the most important. In Diesel mode, the power pack and its cooling system are the main contributors in the low frequency bands. In electric mode, the contributions of the HVAC and the electric converter (and its cooling system) cannot be neglected below 500 Hz and above 3KHz.

Acoustic characterisation of freight wagons
A measurement campaign was carried out by DB to characterise the main noise sources of “state of the art” freight wagons. The four-axle grain silo car Tagnos 898 equipped with composite break shoes has been chosen. A spiral microphone array with a diameter of 4m consisting of 90 microphones was used to characterise the noise sources. The noise maps of the test freight train at 80 kph and 40 kph show that the only sound source identified at pass by is the rolling noise. It must be however kept in mind that brake rigging noise being non stationary and not a point source is not necessarily “seen” by the antenna. Figure 2, the averaged one-third octave spectra of the equivalent sound pressure level of the train pass bys are presented together with the spectra of the area of the bogies estimated with the antenna. Absolute values can not be compared because the antenna estimation is computed at 1m and pass-by measurement performed at 7.5m. The comparison of the shapes of the curves shows that the local maxima at 1 kHz (noise radiated by the track), 2 kHz and 3,15 kHz (wheel noise) emerge in the spectra of the pass-by signal and in the characterisation of the rolling noise source with the antenna.
This measurement campaign reveals that, even if reduced by up to 10 dB thanks to the wheel treads composite brake blocks, the rolling noise is the main source of freight wagons.

**Acoustic characterisation of trams**

For light rail, three trams have been characterised: the T3000 Flexity Outlook Tram from Bombardier Transportation in Brussels, French Standard Tram and Citadis 302 from Alstom in Paris.

T3000 is a modern low floor design and well representative for the state-of-the art in terms of noise performance of trams today. It is equipped with resilient wheels to reduce noise and ground-borne vibrations. The wheels are prepared with fixing holes on the rim to allow additional noise absorbers. Bogie sides are completely covered with skirts for aesthetics and noise reasons. Converters, HVAC systems, converters for traction motors and auxiliary equipment are positioned on the roof. It was found from the stationary tests that the roof-mounted sources were insignificant compared to the sources in the bogie region. Therefore, it was not considered meaningful to carry out acoustic tests with an antenna of microphones which is not able to separate sources as close to each other as the wheel-rail and traction motors in the bogie area. The source identification was instead performed by a step-by-step procedure consisting of:

- stationary tests to quantify sources possible to operate at standstill,
- running tests to quantify contribution from the rolling noise assuming that the contribution from other sources were known.

The result is presented in figure 3.
The traction motor noise and the rolling noise were found to be the two most prominent sources during the running tests, with an overweight for the rolling noise. The contribution of the roof-mounted equipment such as converters and HVAC units was of secondary importance (around 15 dB below the rolling noise).

For the French Standard Tram, the source ranking was performed by RATP using a cross-shaped antenna of 23 microphones and the same signal processing methods than for the characterisation of the noise sources of the AGC train. The rolling noise was found to be the one most prominent source during the pass-bys. This source dominates by some 5 to 8 dB(A) over the other noise sources. This could in part be explained by the very high roughness on rails. The contributions of the traction motor and the roof mounted equipments such as converters, were of secondary importance. Results are confirmed for the Citadis 302 tram also characterised by RATP.

**Acoustic characterisation of metros**

Two rubber-tyres metros (MP73 and MP89) and two light rail metros (MF67 and MF77) have been also characterised by RATP. The traction noise (motor + gear box) and the rubber-tyres noise were found to be the two most prominent sources during the pass-bys at 70kph whereas the rolling noise is the only one important source at 40kph. The auxiliaries were secondary importance. As for the trams, the rolling noise of the light rail metros is the most prominent source. It dominates by some 3 to 4 dB(A) over the other noise sources.

**POTENTIAL OF REDUCTION OF THE MAIN NOISE SOURCES**

According to the results of the acoustic characterisation of the multiple unit train, freight wagons, trams and metros, the noise sources that contribute the most to the pass-by noise must be reduced. Studies are in progress in the Silence subproject E and presented in the following paragraphs. For each source, an estimation of the noise reduction that can be achieved is proposed.

**Powerpack and exhaust**

The powerpack is one of the main source of the multiple unit train in Diesel mode running at low speed. In order to reduce its contribution, a work is in progress involving Alstom and Iveco to reduce the noise of the Diesel engine itself, for example, by optimising the pre-injection on the common rail of the Diesel engine. To reduce the transfer path, some methodologies are being developed to optimise the quantity and the location of the damping materials very close to the engine (see figure 4). Twists and turns are also a solution to enclose the power pack and preserve the air flow of the cooling (see figure 4).

The noise reduction of the exhaust must also take into account the integration of the particles filter which implies to remove one expansion chamber and find other solutions like the Helmoltz resonator to reduce the noise. The potential of noise reduction of the powerpack is around 3 dB(A) on the Diesel engine, 3 dB(A) on the transfer paths and 3 dB(A) on the exhaust.

**Cooling unit of the Diesel engine**

The cooling of the Diesel engine is located on the roof of the train. A work is carried out, involving Bombardier Transportation and KTH, to reduce its contribution which is important at low running speed. The cooling is composed of 2 heat exchangers and 2 axial fans. New concepts presented figure 5 are proposed and assessed.
The reduction potential of noise of the cooling unit is around 5 dB(A). Damping materials like microporous panels and optimised heat exchangers can be used to reduce the broad band noise. Pure tones generated by the axial fans can be suppressed by optimising the blades or using radial fans.

Rolling noise
Rolling noise remains the main noise source for light and heavy rail. For freight wagons, composite break block is the first solution to preserve the wheel roughness and thus reduce the noise of 10 dB(A) compared to cast iron break block.
Damping of the rail and the wheel are also solutions that can be used. Rail dampers (see figure 6) are now homologated in France and optimised in the Silence SP-G subproject by Corus and DB. A noise reduction of 3 dB(A) is validated, 4 dB(A) is expected by optimising the clip of the damper and the shape of the masses.

Due to the high temperature of freight wheels during the braking phase, the use of damping materials is not suitable. Then, Lucchini is developing in subproject E a new concept of wheel dampers. The damping is provided by the friction between two plates, one fastened to the wheel and one fastened to the rim (see figure 6). Breaking test on a DB freight wheel are in progress on the Trenitalia test bench. Modal analysis and TWINS simulations will be able to estimate the noise reduction that will be validated in normal operating conditions on DB freight wagons equipped with prototypes. A noise reduction of 3 to 4 dB(A) is expected, that can be combined with the noise reduction provided by the rail dampers. For trams, resilient wheels mainly dedicated to reduce ground vibration can be completed with wheel dampers. Like for heavy rail, rail dampers can also be added on the infrastructure.

ASSESSMENT OF THE GLOBAL NOISE REDUCTION
In the frame of the Silence project, most of the noise reduction solutions developed in subproject E will be tested on the “validation platforms” with solutions developed in subproject G for the infrastructure. Nevertheless, all the solutions can not be put together on a single prototype of rolling stock. Then, the global modelling tool developed in subproject B is used to assess the impact of the combination of noise reduction solutions.
The characteristics of the main noise sources presented in the first paragraph are used to define source models (position, level, spectrum) [4]. These models are used as input of a sound synthesis software that simulates the train pass-by [5]. Then, a parametric study using existing noise sources and optimised ones can be conducted to estimate the noise reduction achieved by combining the solutions. Such a study has been carried out for the AGC train. Using the characteristics of the sources measured with the array of microphones and the potential of reduction of each source, several combinations of optimised sources have been simulated.
Figure 7, a comparison is presented between the simulated signature and the measured one that was used to validate the definition of the AGC train in the global modelling software. The results of the parametric study are summarised in table 1. As the AGC train (“standard case”) is one of the quieter train, a “noisy case” has been considered. It is representative of a common Diesel multiple unit train in service since 10 years without encapsulation of the Diesel engine and optimised skirts.

![Figure 7](image)

Figure 8.-Measured and simulated signatures and spectrum of the AGC train pass-by

Table 1.- results of the parametric study for the pass-by noise reduction of the AGC train at 80 kph in Diesel mode

<table>
<thead>
<tr>
<th>Configuration</th>
<th>L\text{A}_{\text{eq,}t\text{p}} \text{(dB(A))}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard case</td>
<td>76.2</td>
</tr>
<tr>
<td>Noisy case</td>
<td>77.1</td>
</tr>
<tr>
<td>Exhaust optimisation</td>
<td>76.4</td>
</tr>
<tr>
<td>Cooling optimisation</td>
<td>74.9</td>
</tr>
<tr>
<td>Rail dampers</td>
<td>75.2</td>
</tr>
<tr>
<td>Rail and wheel dampers</td>
<td>74.7</td>
</tr>
<tr>
<td>All the solutions</td>
<td>72.9</td>
</tr>
</tbody>
</table>

The results show the difficulty to optimise a quiet train like the AGC. A reduction of 4.2 dB(A) can be reached by combining all the solutions.

**ACKNOWLEDGMENT**
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**CONCLUSION**
The European project Silence is dedicated to the reduction of railway and roadway noise in urban areas. Within the frame of the subproject E, work is in progress to reduce the noise of the Diesel powerpack, its cooling system, the wheel-rail contact, and the traction engine. Track contribution is also studied in subproject G. The next step concerns the “validation platforms”: as the state of the art trains, wagons, trams and metros have been characterised in normal operating conditions, optimised rolling stocks will run on optimised tracks to assess the noise reduction in operating conditions of some solutions. In addition, the global modelling software developed to simulate the train pass-by in the time domain will be extended to study car noise. Parametric studies on the combination of optimised sources to reduce the pass-by noise of train and car is carried on.

**References**: