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Comparison of Cabin Noise of Airport Express Rail Systems

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Abstract: In this paper, the cabin noise of four airport express rail systems, namely the Taiwan Taoyuan International Airport MRT, the Hong Kong Airport Express, RER B service from Paris Gare du Nord to Paris Charles de Gaulle Airport, and the Shanghai Maglev, have been measured. These four airport express rail systems have different specifications and maximum speeds, ranging from 100 to 300 km/h. The results show a significant low-frequency noise content below 100 Hz, which would not be captured if the measurements were conducted in dB(A). The difference between L_{eq} in terms of dB(C) and dB(A) ranges from 11.3 to 17.0 dB. The maximum speed of the Taoyuan Airport MRT was found to be the lowest at 100 km/h and with the lowest L_{eq} in terms of 66.4 dB(A) and 81.4 dB(C). The Shanghai Maglev has a maximum speed of 300 km/h but a relatively low L_{eq} of 69.7 dB(A), although its top speed is almost three times the maximum of the other airport rail systems. It also has the lowest L_{max} of 73.1 dB(A) among the four rail systems. Moreover, the Paris RER B railway system, with its top speed of 120 km/h, was measured to have the highest L_{eq} and L_{max} values of 72.8 dB(A) and 83.8 dB(A), respectively.

Keywords: airport express; rapid transit; cabin noise; low-frequency noise; maglev

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1. Introduction

The overall success of air transport and airport-based economies typically depends on several factors, such as airport facilities, ease of movement within the airport, and connectivity between cities and airports. Unreliable or unpredictable connecting transport services between cities and the airport may cause travelers to miss a flight or miss a meeting. For example, Taxi passengers can be caught in a traffic jam during peak time or occasional traffic accidents, resulting in an unavoidable delay. Major airports usually contribute significantly to traffic on the roads around them. Therefore, planning for airports is generally accompanied by investments in highways and mass transit systems if impacts on road congestion and related air pollution need to be maintained within acceptable bounds. Over the past few decades, rapid transit systems or dedicated subways have provided a potential alternative solution for transferring people from the central city to the airport and vice versa. These services can quickly transport the bulk of passengers from one place to another among all types of road transports without potential traffic disruptions during peak hours. The high-speed express trains provide hassle-free, reliable, and comfortable transportation with ideally no time delay. In addition, the high-speed express train systems have often been associated with a reduced environmental footprint of the aviation industry, eventually helping towards attaining a sustainable urban environment [1]. The high-speed airport express rail systems have been successfully used in many countries to provide fast passenger rail transport from an airport to a nearby city by mainline or commuter trains, rapid transit, or light rail. Airport express rail systems have been popular solutions in European and Asian countries, such as Germany, France, Japan, China, Taiwan, and Singapore. The airport train service is among the first impressions of the city on the visitors. Any discomfort on commuters after a long flight might not be conducive to a good travel experience. Hence, supervision of the airport express rail system's key aspects, including cabin temperature, seating arrangements, luggage racks, interior designs, train windows, route location map, and upcoming station announcements, are mandated. Along with these factors, the cabin noise assessment of these rail systems is vital for ensuring cabin comfort.

In this regard, several research works have reported the cabin noise performance of the high-speed rail systems. Xie et al. [2] characterized the cabin noise of light rail systems in Taiwan and Singapore. Jeon et al. [3] measured background noise levels regarding speech privacy and annoyance in a train cabin. The average interior noise level inside a high-speed train cabin was found to be between 59 and 63 dB(A), taking normal speech levels into account. Zhang et al. [4] investigated the exterior and interior sound source distribution of a high-speed train. Their findings revealed that the significant external noise source was located in the bogie and pantograph regions. Moreover, the maximum noise levels inside the cabin were measured near the sidewalls and the roof of the high-speed train coach. Garg et al. [5] recorded and analyzed the carriage noise for different high-speed rail systems: Shanghai–Nanjing intercity railway, Taiwan high-speed rail, and Sanyo Shinkansen, Japan. Their results revealed that average noise exposure to passengers for both high-speed and express trains was under 85 dB. Furthermore, the average noise levels in express trains were usually lower than in high-speed trains. Hong et al. [6] investigated the noise in the passenger cars of high-speed trains operating at 100 and 300 km/h. Budge-Reid [7], in an article describing the planning and design of the Hong Kong airport railway, mentioned that the interior noise level was set at a much quieter level than on existing trains during that time. Their main objective was to improve the intelligibility of train announcements and project the image of business class travel. The external noise generation was also reduced to meet the increasing pressure from the environmental lobby and increased public sensitivity to noise. Although the general design requirement for most of the airport express is to offer a better comfort level for the cabin emulating air travel, there are relatively limited reports or studies on the cabin noise of these airport express services.

Furthermore, most reported studies related to airport express have been associated with their environmental impact on soundscapes. Chen et al. [8] reported a case study on the high-speed Maglev train noise and its impacts on residents staying nearby the track. Lee et al. [9] assessed the perception of high-speed train noise in rural soundscapes. He et al. [10] investigated the public perceptions of the environmental impacts of high-speed trains in China. Lee et al. [11] performed the noise assessment of the elevated rapid transit railway lines in Singapore and Taiwan. Li et al. [12] measured the pass-by noise for a high-speed moving train in China. These works have mainly focused on the effect of high-speed railway systems on the nearby environment. Li et al. [13] investigated the interior noise of the high-speed train using the operational transfer path analysis (OTPA) method. Most recently, Noh [14] investigated the low-frequency rail interior noise reduction performance of silicon rubber-based multilayer panels. However, little progress has been made towards cabin noise characterization of high-speed trains despite its significance.

This study aims to investigate the cabin noise of four airport express rail systems: the Taiwan Taoyuan International Airport MRT, Hong Kong Airport Express, RER B train service (Paris), and Shanghai Maglev. The Taoyuan International Airport MRT connects Taipei, New Taipei, and Taoyuan with Taoyuan International Airport. The Hong Kong Airport Express connects the Hong Kong International Airport with the Asia World-Expo exhibition and convention center. The RER B line runs between Paris Gare du Nord to Paris Charles de Gaulle Airport and the Shanghai Maglev, which carries passengers between Pudong airport and Longyang Road station. The four airport express rail systems have different designs with maximum speeds ranging from 60 to 300 km/h.

2. Methods

2.1. Airport Railway Lines

The noise assessment was performed for four different airport railways in Taiwan, Hong Kong, Paris, and Shanghai.

2.1.1. Taoyuan International Airport MRT, Taiwan

The Taiwan Taoyuan International Airport MRT (Mass Rapid Transit), commonly known as the Airport MRT, is a rapid transit line of Taoyuan Metro that connects different municipalities of Taipei, New Taipei, and Taoyuan with Taoyuan International Airport, as shown in Figure 1. The service has been in operation since 2017. The express service takes about 35 min from Taoyuan Airport Terminal 1 to Taipei Main Station and 38 min from Terminal 2 to Taipei Main Station at an operating speed of about 95 km per hour and a maximum speed of 100 km/h. For the present study, the measurement was carried out on an express train service stopping at two stations between Taipei Main Station and the airport.

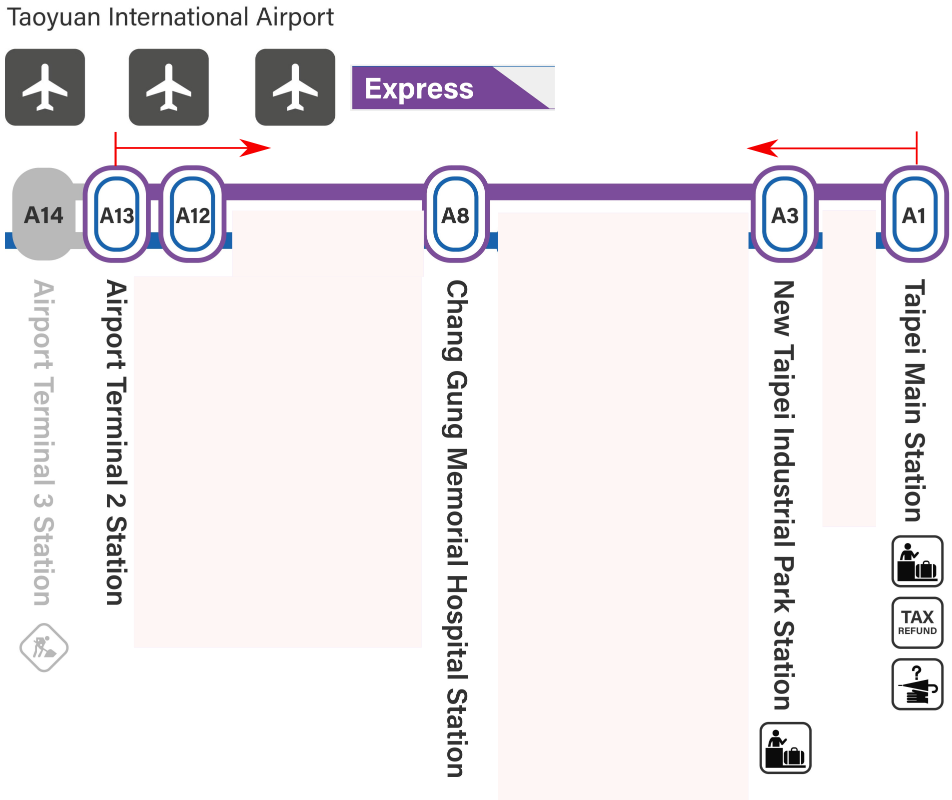

Figure 1. Taoyuan Airport MRT route map (Business Department, 2020). The cabin noise was recorded for the in-bound journey between Airport Terminal 2 Station (A13) and Taipei Main Station (A1) via the express route.

2.1.2. Hong Kong MTR Airport Express

The Airport Express of Hong Kong is one of the fastest Hong Kong MTR system lines and has been in operation since 1998. It connects the vibrant downtown areas with the Hong Kong International Airport and the Asia World-Expo exhibition and convention center. Figure 2 shows the route map for Hong Kong MTR Airport Express line. For the present study, the measurement was carried out from the Hong Kong station to the airport, which takes about 24 min with an average speed of 135 km/h.

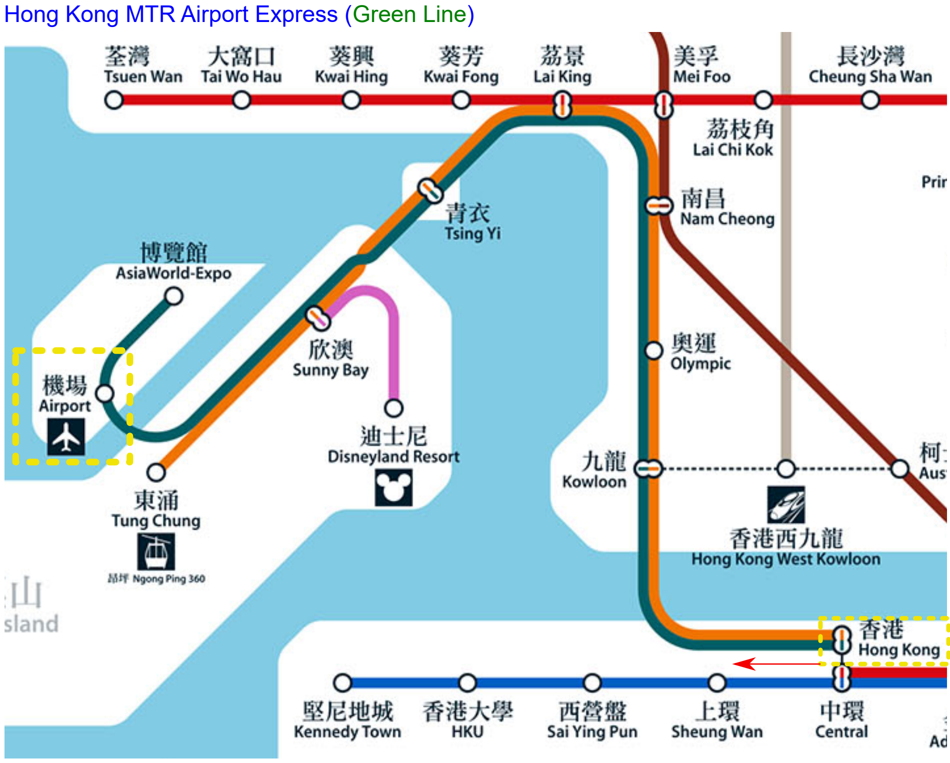

Figure 2. Hong Kong MTR Airport Express route map.

2.1.3. RER B Line Paris

The RER B line in Paris is a direct rail link between Paris (Denfert-Rochereau, Saint-Michel-Notre-Dame, Châtelet-Les-Halles, Gare du Nord) and Paris-Charles de Gaulle Airport. Figure 3 shows the route map for RER B line Paris. The measurement was carried out on an RER B regular service from Gare Du Nord to Paris-Charles de Gaulle Airport for the present study. The train has a maximum speed of 120 km/h.

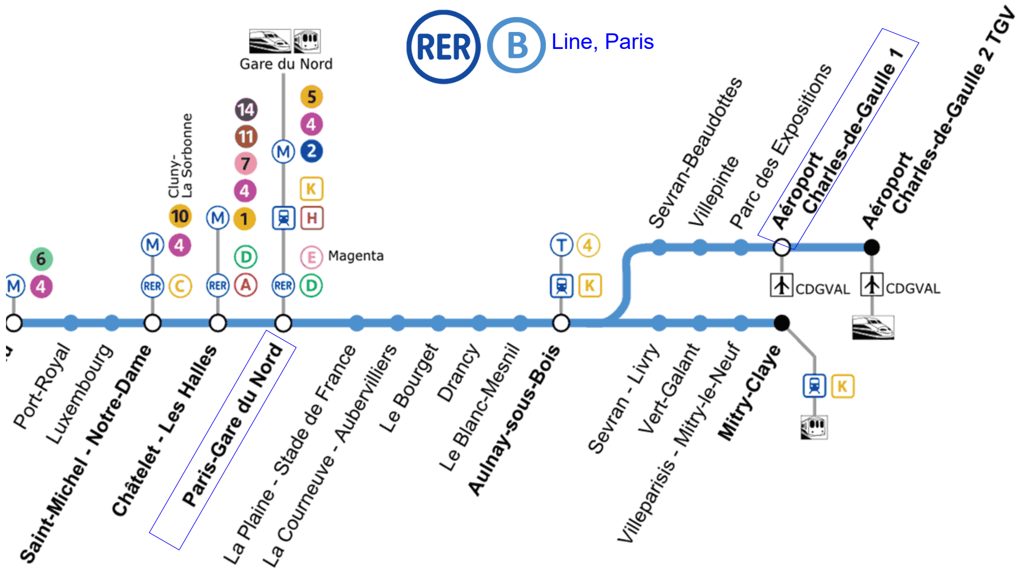

Figure 3. The Paris RER B line route map.

2.1.4. The Shanghai Pudong Airport (PVG) Maglev Trains, China

The Shanghai magnetic levitation railway (Maglev) carries passengers between Shanghai Pudong International Airport and Longyang Road Metro Station on the outskirts of central Pudong, a 30 km stretch with a traveling time between 7 min 20 s and 8 min 10 s. Figure 4 shows the route map for the Shanghai Pudong Airport (PVG) Maglev train. Depending on the time of the service, the top speed is either 431 or 300 km/h with an average speed of 249.5 and 224 km/h, respectively. The line is the third commercially operated maglev line in history after the British Birmingham Maglev and the German M-Bahn, and also the oldest commercial Maglev still in operation. It is the first commercial high-speed Maglev with a cruising speed of 431 km/h and the fastest commercial electric train globally. It has been in operation since 2002. For the present study, the measurement was carried out on a train with a maximum speed of 300 km/h.

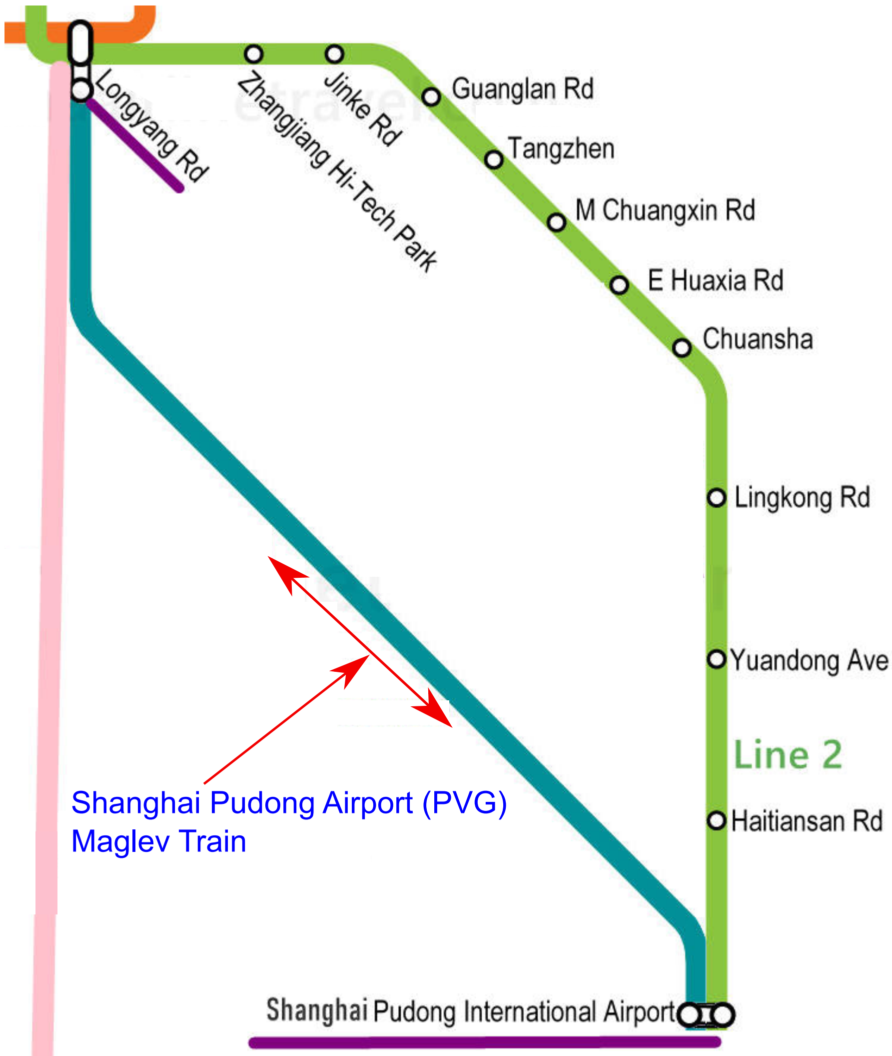

Figure 4. The Shanghai Pudong Airport (PVG) Maglev train route map.

2.2. Measurement Equipment and Techniques

The noise measurement was performed using an in-house developed app known as Noise-explorer with the smartphone's microphones calibrated against a typical type 1 sound level meter. Details of the calibration process can be found in recently reported work by Garg et al. [15] and Lee et al. [16]. The software application recorded the cabin sound in the waveform audio file format (WAV) and the average, maximum, and minimum sound levels. Recording for each segment started with the closing of the door and ended before the door's opening. The noise during the opening and closing of doors was not recorded in the soundtrack. Moreover, the noise was measured along the centerline of the coach. The obtained results have been presented in the Equivalent Continuous Sound Pressure Level L_{eq} for the whole duration. The software also captured the L_{eq} value in the text file every five seconds. The maximum value of L_{eq} for every five seconds, namely the L_{max} , was also reported. For all express rail systems, the user performed the noise recording while sitting on a chair situated near the cabin windows.

3. Results and Discussion

3.1. Taoyuan Airport MRT

The cabin noise measurements were performed for Taoyuan Airport MRT for in-bound journeys. The first trip was from Taoyuan Airport Terminal 2 to Taipei railway station and the second trip was from Taipei station back to the airport Terminal 2. The cabin noise for the in-bound trips was recorded in five segments, designated as segments 1 to 5. Measurements were avoided while the train stopped at the two intermediate stations. The measurement results for these two trips are presented in Table 1 for the journey from Airport Terminal two to Taipei station and from Taipei station back to Airport Terminal 2. For the trip from Taoyuan Airport Terminal two to Taipei station, the total measurement duration was 35 min and 47 s with a L_{eq} of 66.6 dB(A) or 81.8 dB(C), a difference of 15.2 dB. For the trip from Taipei station to Taoyuan Airport Terminal 2, the total duration of the measurement was 35 min 27 s, almost the same periods for the first trip, with a L_{eq} of 69.5 dB(A) or 81.3 dB(C) and a difference of 11.8 dB. As shown in Table 1, for the in-bound trips from Taoyuan Airport Terminal 2 to Taipei station, the measurement time for segment 2 was the highest. The measured sound pressure level spectra for both trips are presented in Figure 5. Both A-weighted and C-weighted scales have been plotted from the measured sound levels. As shown, the low-frequency contents of the measured sounds can be visualized in C-weighted scale plots, which the A-weighted scale could not capture. Furthermore, the spectra were slightly different for both trips. The spectrograms for the five segments in terms of dB(A) and dB(C) for the inbound trip from Airport Terminal 2 to Taipei station are presented in Figure 6. As expected, the spectrogram showed a significant low-frequency noise below 100 Hz for all three segments. There was underlying low-frequency noise below 100 Hz for the trips compared to intermittently higher frequency noise.

Table 1. Measured overall equivalent (eq) and maximum (max) cabin noise levels for the Taoyuan Airport MRT line.

Taoyuan Airport MRT	Segment	Duration (s)	L_{eq} (dB(A))	L_{max} (dB(A))	L_{eq} (dB(C))	L_{max} (dB(C))
Airport Terminal 2 to Taipei Station	1	105.5	68.7	75.9	80.7	84.1
	2	780.0	67.1	85.4	81.8	90.6
	3	346.3	65.1	74.6	83.4	97.6
	4	467.7	63.0	71.6	80.3	87.9
	5	447.5	68.2	78.3	81.7	89.0
Taipei Station to Airport Terminal 2	1	468.9	70.4	84.3	80.9	89.0
	2	665.0	69.4	80.1	82.0	91.5
	3	300.2	64.4	75.4	78.0	85.2
	4	591.6	69.0	80.3	81.0	88.7
	5	97.0	74.2	81.5	85.3	88.5

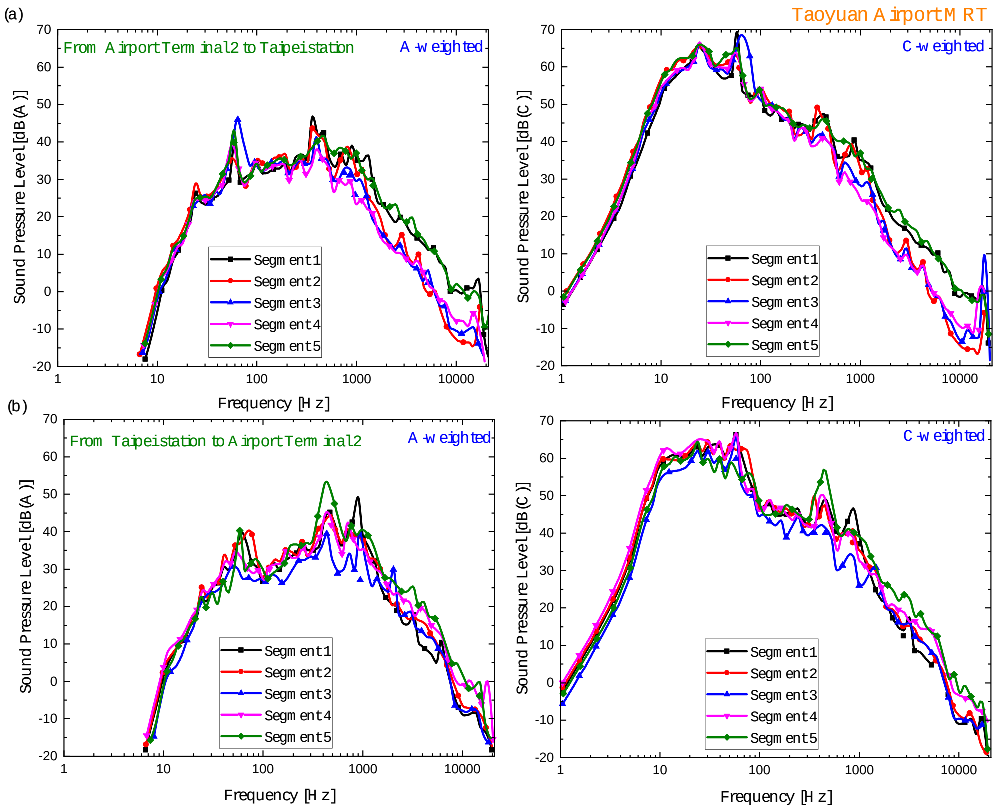

Figure 5. Sound pressure level spectrum of the five segments measured for Taoyuan Airport MRT while (**a**) Travelling from Airport Terminal 2 to Taipei station, and (**b**) Travelling from Taipei station to Airport Terminal 2.

3.2. Hong Kong MTR Airport Express

The cabin noise measurements were carried out from the Hong Kong station to the airport. The measurements were conducted in seven segments with a total duration of 18 min and 31 s, slightly shorter than the reported duration of 24 min. The measures were suspended when the train made the intermediate stops at Kowloon and Tsing Yi stations. The results are presented in Table 2. The overall L_{eq} was 71.3 dB(A) or 86.6 dB(C), with a difference of 15.3 dB between the A-weighted and C-weighted measurements, indicating a significant presence of low-frequency content. The spectrum in terms of dB(A) and dB(C) for segment 5 shows the most prolonged measurements in Figure 7. In terms of dB(A), the most significant frequency is about 700 Hz, and all the lower frequencies below 100 Hz are scaled down significantly. However, for noise presented in dB(C), the dominating frequencies are below 100 Hz. The spectrograms for segments 1–6 in terms of dB(A) and dB(C) are presented in Figure 8. The spectrogram showed the significant presence of low-frequency noise below 100 Hz for all three segments. Once again, there is a dominating low-frequency noise below 100 Hz throughout the journey, and the higher frequency noise only occurs intermittently.

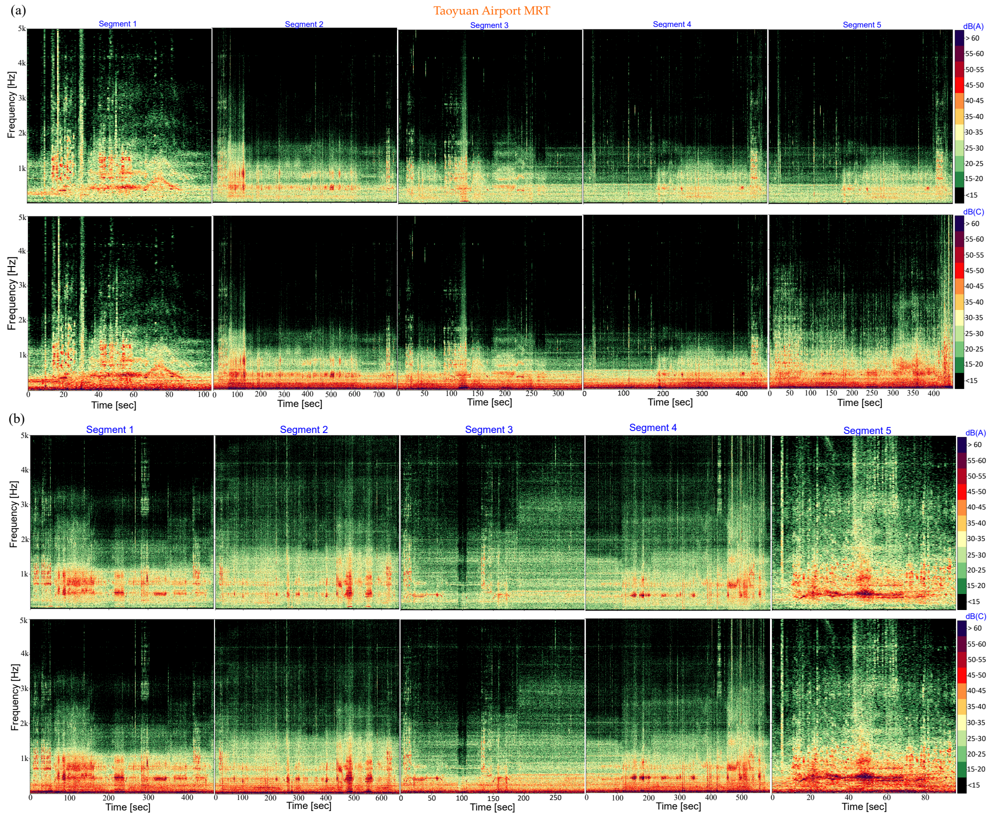

Figure 6. The spectrograms for all five segments for Taoyuan International Airport MRT while traveling from (**a**) Airport Terminal II to Taipei station and (**b**) Taipei station to Airport Terminal II. The spectrograms are presented in dB(A) and dB(C) scales.

Table 2. Measured overall equivalent (eq) and overall maximum (max) cabin noise levels for the Hong Kong MTR airport express.

Segment	Duration (s)	L_{eq} (dB(A))	L_{max} (dB(A))	L_{eq} (dB(C))	L_{max} (dB(C))
1	111.6	73.8	81.4	88.3	100.3
2	103.8	72.6	76.4	85.0	90.7
3	221.2	67.8	75.4	86.2	93.6
4	270.5	73.5	88.8	88.1	95.7
5	300.2	67.9	77.6	85.6	92.8
6	73.0	68.1	75.4	84.5	87.5
7	31.0	74.5	81.8	81.6	86.1

3.3. RER B Line: From Gare du Nord to CDG Airport

The sound pressure levels were measured in four segments for the RER B line while traveling from Gare du Nord to CDG airport. The total journey time for the trip was about 33 min 26 s. The measured data for these four segments are presented in Table 3. The overall sound pressure levels for the RERB line were measured to be 74.3 dB(A) or 85.6 dB(C). An 11.3 dB difference varied between A-weighted and C-weighted scales, indicating a significant presence of low-frequency content. The sound level spectrum in terms of dB(A) and dB(C) for all four segments is shown in Figure 9a. In terms of dB(A), most of the lower frequencies below 100 Hz are scaled-down significantly except for the peak close to 100 Hz. In terms of dB(C), there are a few more dominating frequencies near 200 and 300 Hz. The significant presence of the low-frequency content of the rail noise can also be predicted by the corresponding spectrograms (Figure 9b).

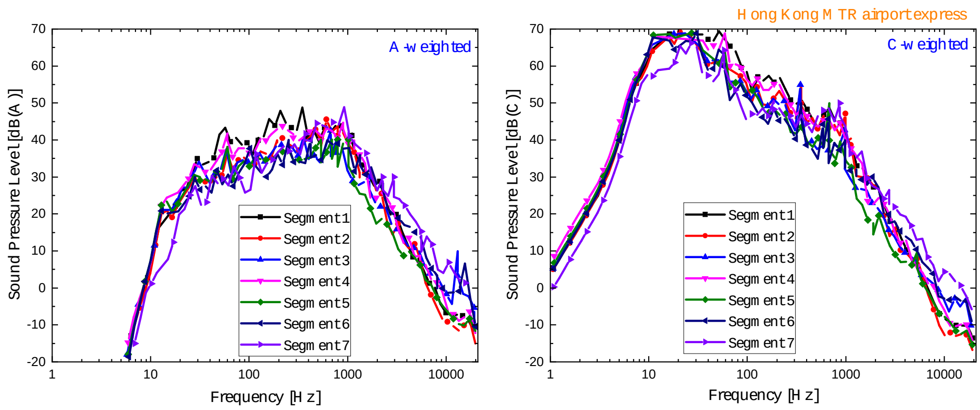

Figure 7. Sound pressure level spectrum of seven segments measured for Hong Kong MTR Airport Express while traveling from Hong Kong to the airport.

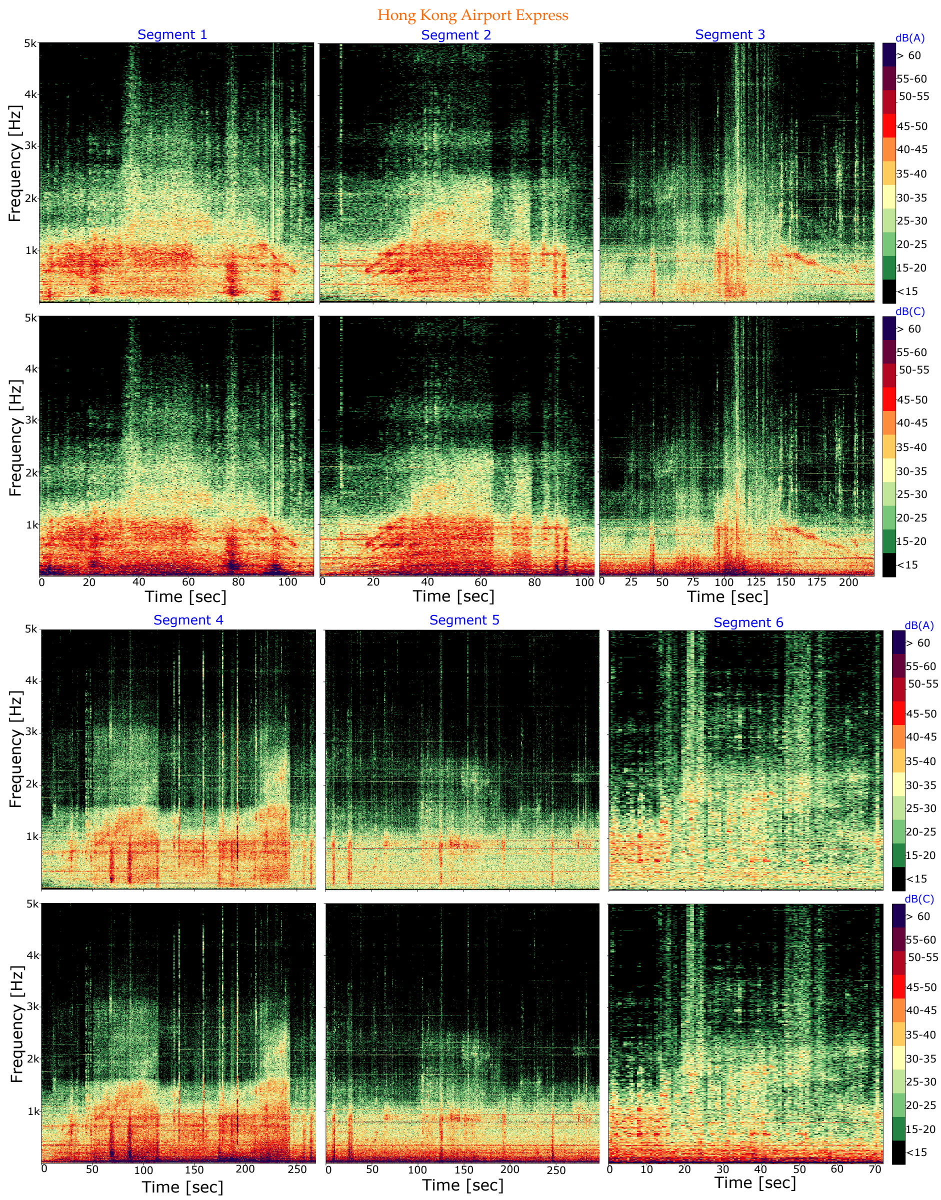

Figure 8. The spectrogram for six Hong Kong Airport Express segments in dB(A) and dB(C) scales.

Table 3. Measured overall equivalent (eq) and overall maximum (max) cabin noise levels for RER B from Gare du Nord to CDG airport.

Segment	Duration (s)	L_{eq} (dB(A))	L_{max} (dB(A))	L_{eq} (dB(C))	L_{max} (dB(C))
1	5.9	69.9	71.1	83.9	85.3
2	1010.7	71.0	84.7	84.5	93.8
3	728.0	76.9	91.3	87.5	96.4
4	261.4	73.3	88.2	81.0	89.1

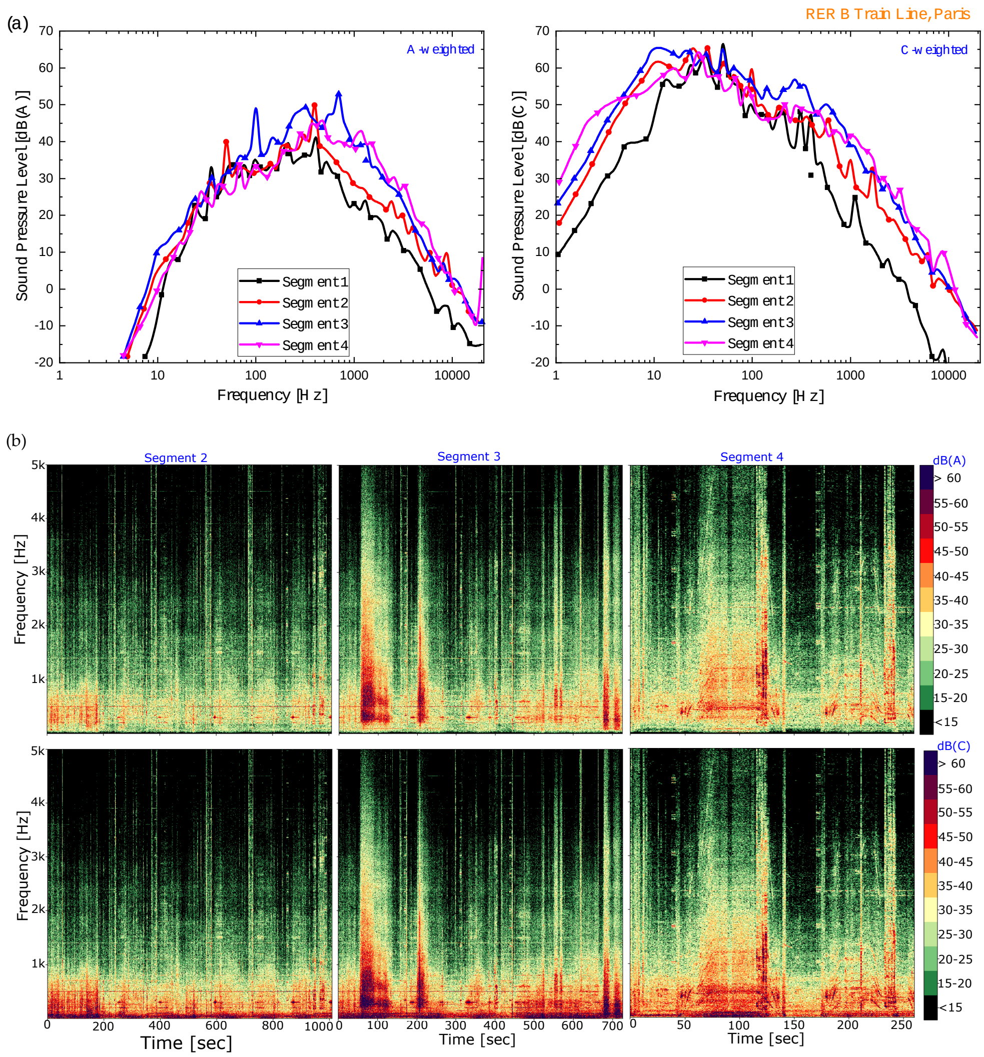

Figure 9. (**a**) Sound pressure level spectrum of four segments measured for RER B Paris while traveling from Gare du Nord to CDG airport. (**b**) The corresponding spectrograms for segment 2 (left), 3 (middle), and 4 (right) for RER B train line Paris in dB(A) and dB(C) scales.

3.4. Shanghai Pudong Airport (PVG) Maglev Train

The measurements for the trip were carried out in three segments with a total duration of 7 min 59 s, slightly shorter than the official stated 8 min 10 s with the slower running speed of 300 km/h. The results are presented in Table 4. The overall L_{eq} was 70.0 dB(A) or 87.0 dB(C), with a difference of 17 dB between the A-weighted and C-weighted measurements, indicating a significant presence of low-frequency content. Due to the different technology and higher running speed, Maglev had the highest Leq in terms of dB(C) among the five rail systems. The aerodynamic noise would typically increase with increased speed. The speed of Maglev at 300 km/h is much higher than the running speed of the other rail systems, but the cabin noise is only slightly higher than the other rail systems. The spectrum in terms of dB(A) and dB(C) for all three segments is presented in Figure 10a. In terms of dB(A), the most significant frequency is about 200 Hz, and all the lower frequencies below 100 Hz are scaled down significantly. However, for noise presented in dB(C), the dominating frequencies are below 100 Hz. The spectrogram for all three segments, including the acceleration phase, segment 2, and segment 3, including the deceleration phase, are shown in Figure 10b for dB(A) and dB(C), respectively. Comparing these two scales, one can note the significant presence of low-frequency content in the noise profile.

Table 4. Measured overall equivalent (eq) and overall maximum (max) cabin noise levels for Shanghai Pudong Airport (PVG) Maglev Train.

Segment	Duration (s)	L_{eq} (dB(A))	L_{max} (dB(A))	L_{eq} (dB(C))	L_{max} (dB(C))
1	205.5	69.8	74.2	86.7	98.3
2	134.5	71.7	72.7	88.9	90.1
3	138.9	67.5	72.3	84.4	90.1

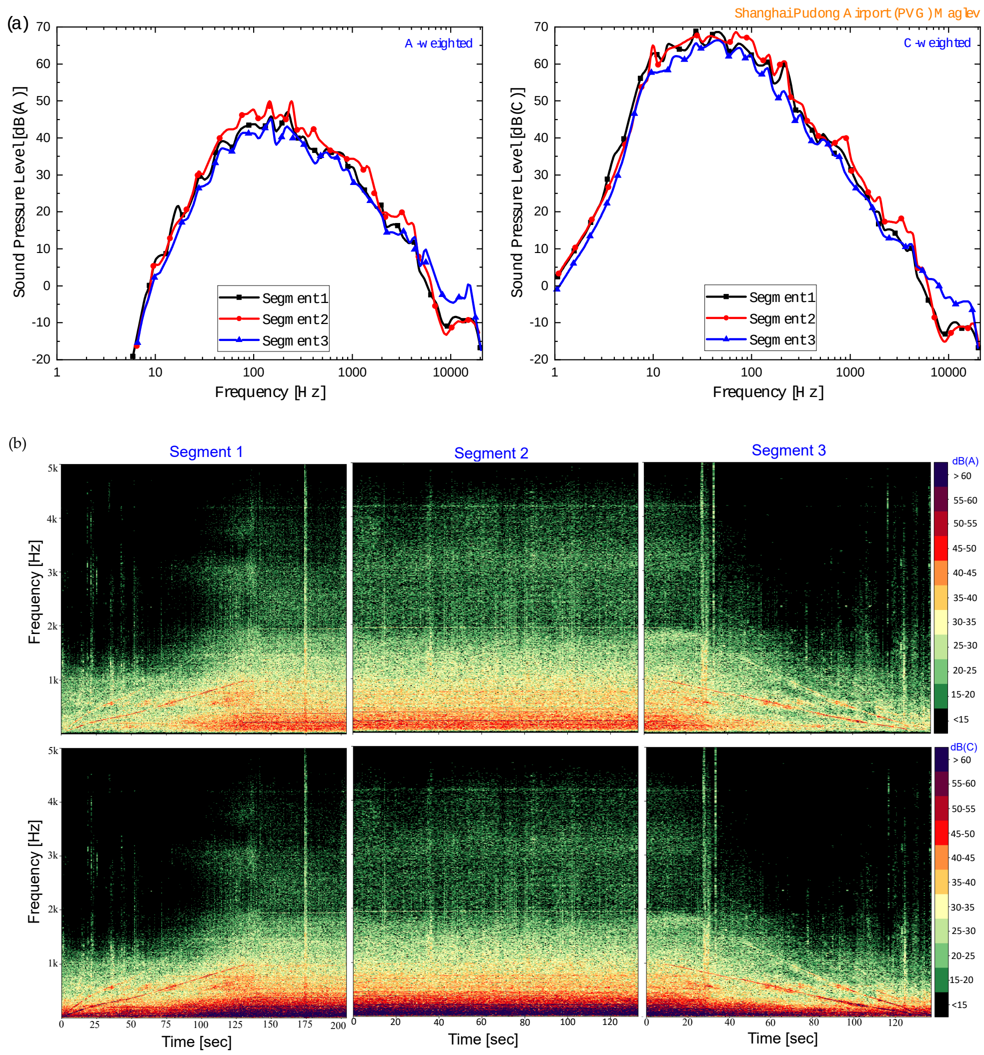

Figure 10. (**a**) Sound pressure level spectra for the three segments measured for Shanghai Pudong Airport (PVG) Maglev train while traveling from Shanghai Pudong International Airport to Longyang Road Metro Station. (**b**) The spectrograms for all three Shanghai Pudong Airport (PVG) Maglev segments. The spectrograms are presented in dB(A) and dB(C) scales.

4. Conclusions

In this paper, the cabin noise of four airport express rail systems, namely the Taiwan Taoyuan International Airport MRT, the Hong Kong Airport Express, the RER B train from Paris Gare du Nord to Paris Charles de Gaulle Airport, and the Shanghai Maglev, have been measured. The four airport express rail systems have different designs with maximum speeds ranging from 100 to 300 km/h. The findings are summarized in Table 5. The top speed of the Taoyuan airport MRT was the lowest among the four railway systems, i.e., 100 km/h, and had the lowest L_{eq} in terms of 66.4 dB(A) and 81.4 dB(C). The Shanghai Maglev has a maximum speed of 300 km/h but a relatively low L_{eq} of 69.7 dB(A), although its top speed is almost three times the maximum of the other airport rail systems. It also has the lowest L_{max} of 73.1 dB(A) among the four rail systems. Interestingly, the Paris RER B railway system, with its top speed of 120 km/h, was measured to have the highest L_{eq} and L_{max} values of 72.8 dB(A) and 83.8 dB(A), respectively. The outdoor condition of the RER B line might be an additional factor for such a high value of cabin noise.

Table 5. Summary of the average values of cabin noise for various airport express rail systems.

Segment	Max Speed (km/h)	L_{eq} (dB(A))	L_{max} (dB(A))	L_{eq} (dB(C))	L_{max} (dB(C))
Taoyuan Airport MRT	100	66.4	81.6	77.2	89.9
		69.5	81.4	80.3	88.6
Hong Kong Airport Express	135	71.2	85.6	79.5	92.4
Paris RER B	120	72.8	84.2	83.8	91.2
Shanghai Maglev	300	69.7	87.0	73.1	92.9

Furthermore, the results showed a significant low-frequency noise content below 100 Hz, which could not be captured if the measurements were presented only on the dB(A) scale. The difference between L_{eq} in terms of dB(C) and dB(A) ranged from 11.3 to 17.0 dB.

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