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ACOUSTICAL COMPARISON OF CONVENTIONAL TAXIING AND DISPATCH TOWING – TAXIBOT´S CONTRIBUTION TO GROUND NOISE ABATEMENT

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Abstract

Beside noise of airborne aircraft as a primary noise source at airports, ground operations, such as taxiing, have contributing and non-negligible impacts on airport noise levels. To address this issue amid growing environmental awareness, the deployment of electromobility at airports is planned to be extended. One such electrical mobility device is a dispatch towing vehicle called TaxiBot, which was first tested at Frankfurt International Airport in 2014. This paper aims to quantify noise reductions of dispatch-towed aircraft in comparison with conventional taxiing operations. It derives a new measurement method from existing and comparable standards, describes the measurement procedure, and presents the results. Finally, a conclusion and outlook is given.

1 Introduction

Aircraft taxiing is a highly inefficient process, because engines are not optimized for an operating point at idle thrust setting. This in turn leads to relatively high fuel consumption and noise and pollutant emissions. One approach that addresses this issue are dispatch towing operations, which means that an aircraft is towed by a vehicle from an initial parking position to a de-coupling position close to the head of a runway. Merely the towing vehicle accomplishes the ground propulsion of the aircraft, therefore reducing engine runtime to a warm-up phase. During the dispatch towing process, the Auxiliary Power Unit (APU) is operating and provides electrical and pneumatic energy. An example for a dispatch towing vehicle is the newly developed TaxiBot (see Fig. 1). It is a towbarless, semi-robotic tractor for aircraft, which is powered by two diesel-electric hybrid engines. The TaxiBot enables similar velocities compared to conventional taxiing procedures and the pilot is able to control the combination of aircraft and TaxiBot by using the tiller and brakes in the cockpit. The TaxiBot holds currently a certification for aircraft of type Boeing 737-500 and is deployed in daily operation at Frankfurt International Airport. [9]

Fig. 1. TaxiBot towing a B737-500. [Source: Lufthansa LEOS]

The objective of this paper is to present an evaluation of the TaxiBot's potential to reduce noise emitted during aircraft taxiing. For this purpose, acoustic measurements were conducted applying precedingly developed methods and the recorded data was analyzed.

2 Relevant Standards for Acoustic Measurements

At present, no standards exist for the acoustical comparison of conventional taxiing and dispatch towing operations. To address this issue, applicable standards, e.g. for overflight and road traffic pass-by noise measurements, were identified and relevant measurement requirements were compiled in a previously published work [7]. The determined standards

[2] – [6] specify requirements with regard to measurement instruments and equipment, test environment, meteorological conditions, background noise level, as well as test method. Table 1 summarizes the most important requirements and their corresponding standards, which have to be complied with in order to perform comparative acoustic measurements. A more detailed explanation is given in [7].

3 Measurement Methods

Two measurement methods yield results for the acoustic evaluation of dispatch towing operations using the TaxiBot. One method allows a comparison of an aircraft (for instance type B737-500) taxiing under own engine power with the same aircraft towed by the TaxiBot (TaxiBotting). The other method enables a comparison of the TaxiBot with a conventional towing tractor (Goldhofer AST-2 [13]) while standing with engines idling. The subsequent sections give a brief overview of the measurement conditions and methods (for further explanations see [7]).

3.1 Measurement Conditions at Frankfurt Airport

Due to prevailing frame conditions and safety requirements at Frankfurt Airport, specifications made in the standards are partially modified. Furthermore, it has to be ensured that airport operations are taken into account and are not disturbed.

The measurement environment is located at the southern end of runway 18 (see Fig. 2). The end of the runway is three to four kilometers apart from the airport's terminals and hangars and is thereby far enough away from all relevant reflective surfaces. The measurement environment can be considered as an open area with essentially free field conditions above an acoustically hard and reflective surface, which consists of concrete.

The measurements were conducted on May 15, 2014 during Frankfurt Airport's night flight ban in order to keep the background noise level as low as possible and to preclude noise from departing and arriving aircraft. This ensured a sufficient difference of measured signals and

Table 1. Requirements specified in standards for acoustic measurements.

Measurement instruments and equipment	Class 1	e.g. DIN EN 61672-1 [6]
	Time weighting F Frequency weighting A	DIN ISO 362-1 [5]
Measurement environment	Hard, flat surface	e.g. DIN ISO 362-1 [5]
	Dry surface	DIN ISO 362-1 [5]
	No sound reflecting objects near by	DIN EN ISO 3744 [2]
	No person between microphone and acoustic source	DIN ISO 362-1 [5]
Meteorological conditions	Ambient temperature between 5 °C and 25 °C	DIN ISO 362-1 (5 °C) [5] DIN 45643 (25 °C) [4]
	Relative humidity between 30 % and 80 %	DIN 45643 [4]
	No wind speeds higher than 5 m/s	e.g. DIN 45643 [4]
	No precipitation	e.g. DIN 45643 [4]
Background noise	Measurement before and after each test series for 10 s	DIN ISO 362-1 [5]
	At least 10 dB, preferably 15 dB lower than source	e.g. DIN EN ISO 3744 [2]
Test method	Reproducible and representative conditions	DIN EN ISO 3744 [2]
	Microphone position: horizontal distance to test track 7.5 m, height 1.2 m	e.g. DIN 45642 [3]
	Microphone reference axis horizontal and perpendicular to test track	e.g. DIN 45642 [3]
	Measurement duration at least as long as the sound pressure level undercuts L_{max} less than 10 dB (5 dB)	DIN 45642 [3]

background noise level of at least 15 dB(A) during all measurements.

A weather tracker monitored the meteorological conditions during the measurements. All weather parameter met the limitations according to DIN 45643 [4] and DIN ISO 362-1 [5]. Measured wind speeds were in the range of 2 m/s to 5 m/s. The ambient temperature amounted to 10 °C to 11.5 °C and the relative humidity to 73 % to 80 %.

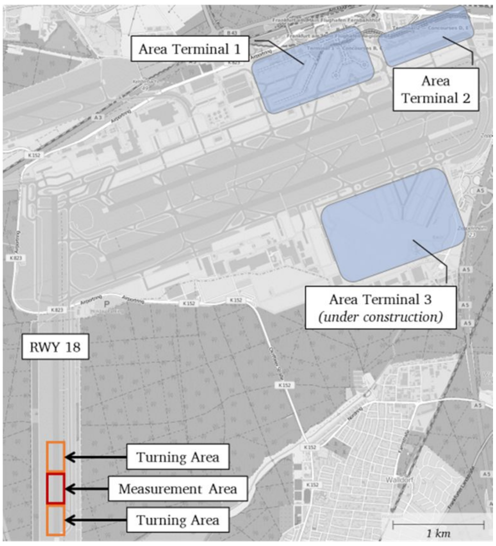

Fig. 2. Layout of Frankfurt International Airport and location of the measurement environment. [Map source: www.openstreetmap.org]

3.2 Measurement Method for Pass-By Configurations

Fig. 3 depicts the setup for comparative pass-by noise measurements. The measurement area has a length of 100 m, which corresponds with three times the length of a TaxiBotted B737-500. The width of the measurement area is 45 m. This results from safety requirements for the microphone position. The maximum lateral distance of 7.5 m between the microphone position and the test track of the sound source, which is demanded by the standards DIN 45642 [3] and DIN ISO 362-1 [5], was not realized due to safety regulations at airports. The compulsory lateral safety margin between the aircraft and any foreign object or person is specified by aircraft and engine manufacturers [1]. This is considered by positioning the microphone 7.5 m away from the aircraft's wingtip instead of the test track center line.

A cuboid reference boundary surrounds the entire moving sound source. It creates an enveloping surface with the dimensions of the aircraft or the combination of aircraft and tractor (TaxiBot), respectively. The microphone is centered lengthwise in the measurement area and its reference axis is oriented perpendicular to the runway center line. It is mounted at a height of 1.2 m above the ground. The data acquisition system records automatically by using triggers (infrared light gates) located at the beginning and the end of the measurement area. Adequate maneuvering space is available in front of and after the measurement area to turn the aircraft or aircraft tractor combination around and to provide enough space for acceleration and deceleration. Therefore, it is possible to measure pass-by noise from different directions (left to right and vice versa).

The taxiing pilot was briefed to maintain a constant speed and to pass through the measurement area straight on the runway center line. The pass-by speeds represent typical speeds for taxiing aircraft at Frankfurt Airport, which are in the range of 17 kts to 22 kts [10].

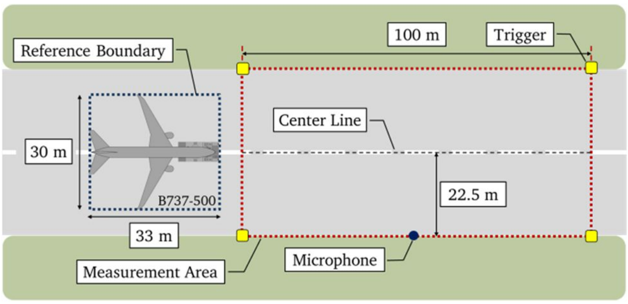

Fig. 3. Setup for pass-by sound pressure level measurements.

3.3 Measurement Method for Tractors Standing with Engines Idling

The other measurement method enables a direct comparison of the TaxiBot, on the one hand, and a Goldhofer AST-2, on the other hand.

The Goldhofer AST-2 tractor is a tractor for narrow-body aircraft, which is able to perform pushbacks, repositioning procedures, and maintenance tows for B737-500 aircraft [14]. Although it is not designed and certified for dispatch towing operations, it has an equivalent performance spectrum and similar dimensions compared to the TaxiBot.

Measurement methods for the determination of sound power levels (according to DIN ISO 3744 [2]), which require an enveloping surface around the sound source could not be realized at the airport. To quantify sound pressure levels in the near field of the tractors, the measurement method was simplified with lateral measurement points. Fig. 4 shows the measurement setup. In accordance to the pass-by setup, a reference boundary is specified around the tractor. Furthermore, two measurement planes, which are parallel to the reference boundary of the tractor, are spanned in distances of 1 m and 4 m. The second measurement plane is chosen to characterize a decay of the sound pressure level in the immediate vicinity of the tractor. Overall 58 microphone positions are located on the measurement planes and symmetrically distributed with reference to the tractor's lengthwise axis. Furthermore, Fig. 4 depicts the relative distances between the microphone positions. A higher resolution of the measurement grid is implemented in the region of the engines. In accordance with the pass-by setup, microphones are situated at a height of 1.2 m. Data acquisition time is set to a duration of 10 seconds for each measurement position.

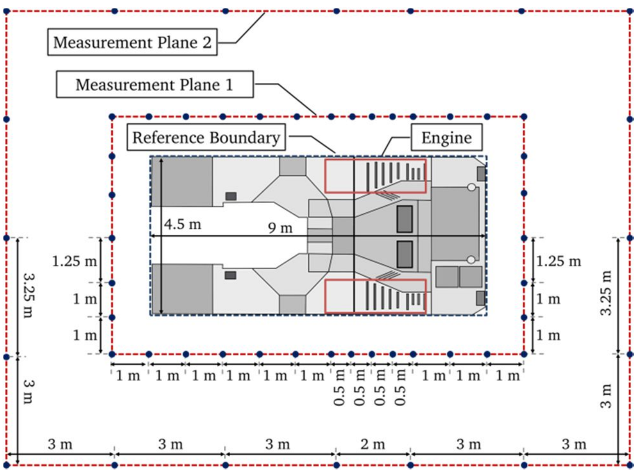

Fig. 4. Setup for sound pressure level measurements of standing tractors with engines idling.

4 Measurement Results

This section presents the measurement results obtained by means of both introduced methods.

4.1 Pass-By Measurement Results

Two different configurations (solo aircraft and combination of aircraft and TaxiBot), with four runs for each case, were measured within the test period. During the pass-by of a solo B737-500, the aircraft's main engines were running and the APU was switched off to reproduce a conventional taxiing process. On the contrary, during TaxiBotting the aircraft's main engines were switched off and the APU was running. The determined quantities were the A- and F-weighted maximum sound pressure level, $L_{AF,max}$, the A-weighted energy-equivalent continuous sound pressure level, $L_{A,eq}$, and the sound exposure level, L_{AE}. L_{AE} has a reference duration of 1 s and was recorded to account for slight variations in pass-by speeds and to eliminate the influence of the measurement duration.

Fig. 5 depicts the measurement results for both configurations. The top end of each bar in the chart indicates the calculated average sound pressure level for all vehicle pass-bys and the error bars represent a 90 % confidence interval (according to VDI 3723 [15]). A comparison of both configurations, i. e. "Taxiing aircraft" and "TaxiBotted aircraft", shows that a TaxiBotted B737-500 with switched off main engines yields sound pressure level reductions of ΔL_{AE}=12.7 dB(A), $\Delta L_{AF,max}$=16.6 dB(A), and $\Delta L_{A,eq}$=13.2 dB(A), even though the APU is running. These decreases are subjectively perceived as a significant reduction of loudness [12].

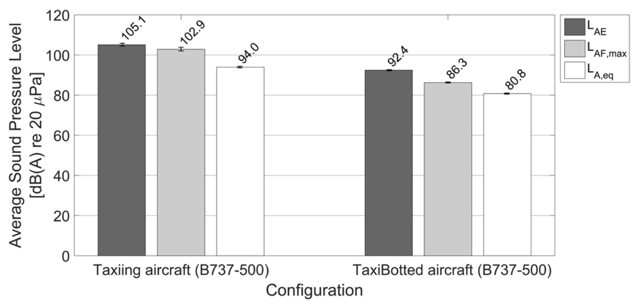

Fig. 5. Pass-by measurement results for a conventionally taxiing B737-500 and a TaxiBotted B737-500.

Fig. 6 shows time histories of the short-term $L_{A,eq,\Delta t=5ms}$ (averaging time period of five milliseconds) for two exemplary pass-by measurements. These are characteristic for a taxiing B737-500, on the one hand, and a TaxiBotted B737-500, on the other hand. For the interpretation of the results it needs to be considered that both measurements have different durations (14.09 s for Taxiing, 14.64 s for TaxiBotting). Hence, the pass-by speed of the taxiing aircraft is slightly higher than the speed of the TaxiBotted aircraft, which means that their positions are not equal at a certain point in time.

For a comprehensible illustration of the measurement results, both progressions are smoothened and the appropriate 0.90 quantiles ($Q_{0.9}$) are plotted above and below the splines, thereby enveloping them. The maximum value of $L_{A,eq,\Delta t=5ms}$ amounts to 106.6 dB(A) for Taxiing and 89.3 dB(A) for TaxiBotting.

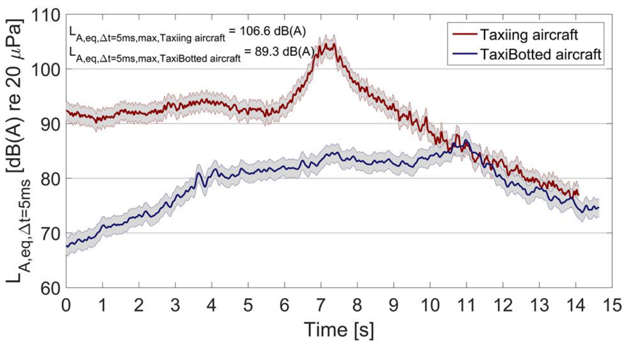

Fig. 6. $L_{A,eq,\Delta t=5ms}$ time histories of two exemplary pass-by measurements (conventionally taxiing B737-500 and a TaxiBotted B737-500).

The peaks of both time histories are shifted against each other. The $L_{A,eq,\Delta t=5ms}$ of the taxiing aircraft shows its maximum value in the middle of the measurement time frame, whereas the maximum $L_{A,eq,\Delta t=5ms}$ of the TaxiBotted aircraft occurs at about 2/3 of the time frame. Since the microphone is positioned halfway along the test track, the predominant sound sources of the approaching aircraft are the engines' fan and compressor, which are emitting sound towards the front. In the beginning, the sound pressure level stays almost at a constant level until a measurement time of t = 5.5 s. Then, it increases rapidly until its maximum is reached right after the engine nacelles pass the microphone, where the jet, turbine, and combustor sounds are prevalent. Afterwards, the level decreases constantly until the aircraft leaves the measurement area and the data recording is automatically stopped.

However, a comparison of the TaxiBotting procedure, shows that the sound pressure level firstly increases gradually until t = 4 s. Then, the slope of the graph becomes smaller as the TaxiBot-aircraft combination passes the microphone and the graph reaches its maximum at t = 11 s, when the APU exhaust outlet moved approximately 20 m past the microphone position. Additional measurements, which are not presented in this paper, show that the APU is the prevailing sound source and that the TaxiBot has a minor contribution to the total sound pressure level [8].

In addition to the time histories, Fig. 7 illustrates the one-third octave band spectrum of both pass-by measurements. The $L_{A,eq}$ is plotted against frequency bands. For these selected cases, the overall $L_{A,eq}$ amounts to 94.8 dB(A) for Taxiing and 81.3 dB(A) for TaxiBotting. The TaxiBot procedure induces a $L_{A,eq}$ reduction in a frequency range from 70 Hz to 11 kHz. The spectrum of the taxiing aircraft exhibits a superposition of broadband jet noise, fan, and turbine noise, which contains tonal and broadband components. The most prominent peak is at 10 kHz where an $L_{A,eq}$ of 87.8 dB is reached. The spectrum of the TaxiBotted aircraft is also composed of broadband and tonal noise. Yet the tonal component is here more distinct than in the spectrum of the taxiing aircraft. The APU of the measured B737-500 (type Sundstrand APS2000) has a rotary frequency of 754 Hz [11], which, however, is filtered out due to A-weighting of the signal and therefore cannot be detected in the one-third octave band spectrum anymore. Still, peaks can be identified at one-third octave midband frequencies of 1 kHz, 2 kHz, 4 kHz and 8 kHz.

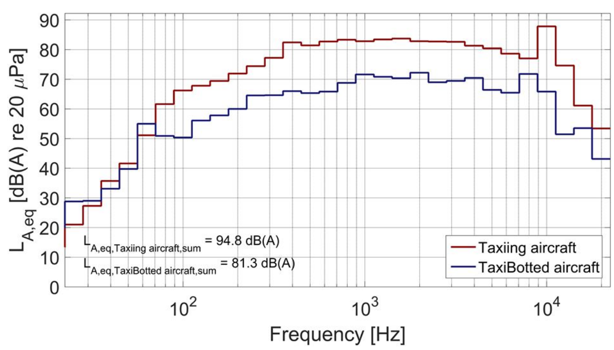

Fig. 7. 1/3-octave band spectrum of two exemplary pass-by measurements (conventionally taxiing B737-500 and a TaxiBotted B737-500).

4.2 Measurements Results of Tractors Standing with Engines Idling

This section compares the measurement results of a conventional Goldhofer towing tractor of type AST-2 to the TaxiBot. Both tractors were consecutively centered in the measurement grid according to previous explanations of the measurement method and data was obtained at the defined microphone positions. The values between the measurement positions are the result of a logarithmic interpolation.

Fig. 8 and Fig. 9 illustrate the energy-equivalent continuous sound pressure levels measured for 10 s, i. e. $L_{A,eq,10s}$, in contour plots. The AST-2 tractor reaches a maximum value of 79.4 dB(A) near the location of the main engine, which is arranged behind the driver's cab in the middle of the tractor. The contour plot is nevertheless not symmetrical to the longitudinal axis of the tractor, because the exhaust outlet is located in front of the rear tyre on the right side. By comparison, the contour plot of the TaxiBot is longitudinally symmetric due to its symmetrical design. Two diesel engines and exhaust outlets are each positioned on the right and left side of the tractor. The maximum sound pressure level of 83.5 dB(A) is recorded in this area. Additionally, two ventilation units are located at the rear of the vehicle and cause sound pressure levels of about 79 dB(A). The sound pressure levels measured around the TaxiBot are generally and moderately higher than of a Goldhofer AST-2 due to its higher engine power and the two diesel-electric hybrid engines on each side of the TaxiBot.

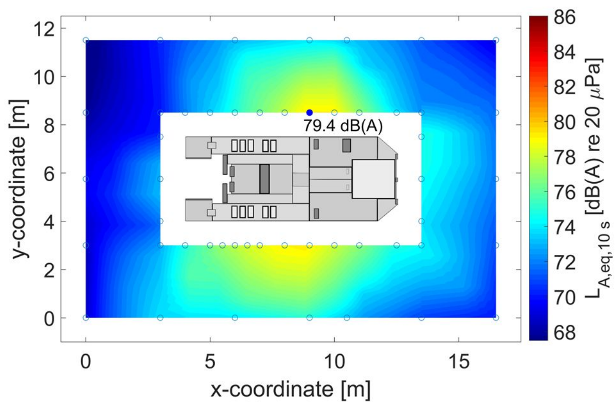

Fig. 8. Contour plot of a Goldhofer AST-2 tractor standing with engines idling.

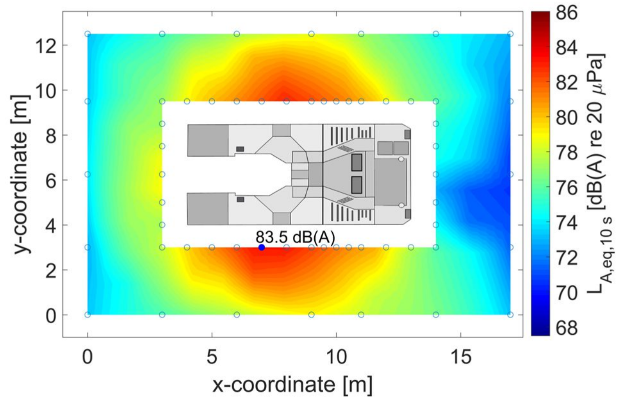

Fig. 9. Contour plot of a TaxiBot standing with engines idling.

5 Conclusion and Outlook

Based on the aforementioned results, the introduction of dispatch towing technologies such as the TaxiBot can achieve a significant reduction of ground noise at airports. This is shown for a one-to-one comparison and can be extrapolated to all taxiing movements on the apron and maneuvering area.

The measured values serve prospectively as input parameters for sound propagation calculations, hence facilitating analyses of future traffic mixes consisting of conventionally powered, electricly taxiing, as well as dispatch-towed aircraft.

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