SELECTION OF THE PARAMETERS THAT INFLUENCE THE NOISE PRODUCED BY AIRCRAFT ON CITIES WITHIN THE ONLINE MONITORING SYSTEMS

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Abstract. As almost a permanent issue around our lives, the noise pollution produced by aircraft in the surrounding airports areas is treated with major concern by airport management and local authorities. In the last years, through the deep penetrating of social networking and access to the information of a large-scale population, an important issue like airport related noise received a high interest. Noise monitoring modules integrated into airport monitoring systems, are used to measure sound level time history, identifying sound events and assigning the individual events to each particularly aircraft. A noise event is identified by threshold limits applied to the time history, as amplitude and duration. In order to create an automated monitoring system, the proper and optimal numbers of parameters which are stored, analysed, transmitted and displayed by smartphones, in order to create a large-scale information distribution of information to the population through smartphones and to contribute thereby to the general concept of smart city.

Key words: applied acoustics, noise monitoring systems NMS, airport noise, ADS-B/MLAT, intelligent city, smartphone applications.

1. INTRODUCTION

Noise pollution, besides the chemical, dust and other types of pollutants is in the focus of either the different industries, service providers, as of authorities and not the last of population, as the main affected society member. With the recent increase of air transportation volume, the noise related level became even a health threaten for population living or working around airports. Many rules were implemented and upgraded in time with the role of reducing it or at least to keep it under a certain accepted level and to be more and precisely informed about health threatening levels, different monitoring systems were implemented, mostly by airports administrations.

Noise monitoring modules integrated into airport monitoring systems, are used to measure sound level time history, identifying sound events and assigning

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the individual events to each particularly aircraft. A noise related event is identified by threshold limits applied to the time history, as amplitude and duration. While the classical noise maps are based on prediction models, made on the base of same constant input conditions, the real time model allows permanent updating of the noise levels in the interest zone and according with permanent changeable meteorological conditions.

ICAO (International Civil Aviation Organization) as a specialized agency of the United Nations was establish in 1944 for studying the regulations for safe and management of air transport around the world. Starting with the 16th session of ICAO which was held in Buenos Aires in 1968 it was proposed a study of environmental protection and in 1972 first results of the study were adopted by Annex 16, Chapter 2 – Aircraft Noise [1], for subsonic jet airplanes. With Chapter 4, in 2001, ICAO adopts the standard for subsonic jet and heavy propeller airplanes.

As a main legislative noise pollution initiative is Directive 2002/49/EC which proposed the general rules for the assessment and management of environmental noise [2]. In 2010 ICAO published the Report on Environmental Management System (EMS) Practices [3] in the Aviation Sector which summarized demands for environmental protection against aircraft noise among other factors and rules to limit or reduce the impact of aircraft noise. After many years when the noise produced by airplanes was a matter of aircraft validation addressed for specialists and producers, in the last years the noise around the airports became an important concern for local authorities and also for a large amount of people which are directly affected by this phenomenon. During the years, the simulated models and on-line real monitoring procedures were studied and adopted to give information about the aircraft noise levels in airports and surrounding areas and the parameters as aircraft speed, angle of descent or lift-off and aircraft weight were studied with the aim of reduction the aircraft jet noise [4]. According to Flightpath 2050 [5], until the year 2050 there should be a 65% reduction of perceived noise compared to the average of the year 2000.

In 2017, the European Commission has introduced a mandatory condition that all large aircraft should have ADS-B (Automatic Dependent Surveillance-Broadcast) transponders till 2020 [6]. Using ADS-B transponders for flight tracking, the collected data are presented on websites such as Flightradar24, Planefinder, Planeflighttracker or FlightAware, and are used to gather information for airports and local authorities and also for the public, with aircraft's position and flight data taken in real time.

According to ECAC Doc.29, contour maps should be created as a legislated imposed rule to be used as indication about the aircraft noise impact around airports [7]. The aircraft noise prediction model calculates the noise levels and make the contour maps around airports produced by aircraft departures and arrivals on a time period. The model calculates the noise levels as $L_{Aeq,day}, L_{Aeq,night}, L_{DEN}$ and $L_{max,avg}$, and will allocate these levels to individual source of noise produced by aircraft. Single-event sound levels *SEL* and L_{Amax} are calculated using a number of receivers placed in fixed points around the runway and around the airport and adjacent residential area.

There were introduced algorithms for updating the aircraft fleets information and corresponding flight events to be applied till 2025. Such algorithms were applied to historical flight movement data at three European airports, and the resulting flight events were used to predict the future airport noise contours by Preto M. et. al. in 2020 for Heathrow, Frankfurt and Schwechat airports [8]. Besides noise thresholds, other methods were used to identified aircraft noise related events, like pattern recognition based on neural networks or hidden Markov models [9], with reduced success due to aleatory noisy background. Same approach was done by C. Asensio et. al. [10] for cases where no radar data were available and in a good signal-to-noise ratio condition. Feed-forward Neural Networks combined with a weighted addition where noise signal features were obtained from the auto-regressive model and the 1/12 octave analysis, were applied by Fernández et al. [11]. Optimization of flight path near the airports was researched by Khardy S. to find the optimal trajectory for noise and fuel consumption reduction [12].

Zdhanko et al studied the adverse factors to people of airport noise and emphasize the environmental, hygienic, and social impact relative to physical factor of noise produced by aircraft and also by different other noise sources related to airport activities [13]. An extensive study was done by Wright et. Al. in 2018 around the residential zones exposed to aircraft noise which is a main reason for associated increased risk of hypertension, cardiovascular disease and myocardial infarction, stroke and cardiovascular related mortality. By contrast, they highlighted that that the noise profile around airports with lower air traffic volumes and no night flights has relatively little influence on health [14].

Not all the aircraft have ADS-B transponders to transmit the longitude and latitude, so multilateration transponders signal (MLAT) is used to determine the location by calculation the difference of the time of arrival taken from different receiving stations, as in Fig. 2. Besides aircraft noise related classification, the airport authorities are using ADS-B/MLAT data for airspace organization, runway operations, capacity optimization, traffic synchronization, service and delivery management.

Usually, the airports have own NMS with event detection and aircraft classification using data collected from airport radars. Giladi made a comparison of collected data taken from classic airport monitoring system and those from ADS-B and made the conclusion that both has the same accuracy and could be implemented with good and reliable precision [15].

ISO 20906 standard settle the demands for identifying and assignment the aircraft type of sound events from continuous measurements [16]. Event classification has the aim to differentiate the aircraft events from non-aircraft ones and between them. Such classification is done according with the relation between maximum sound pressure level and the sound exposure level, and spectral information. Such acoustically data are corelated with non-acoustical data, like flight paths, aircraft identification and position information and the entire procedure could be done automatically. The monitoring system is gathering the aircraft related information like A-weighted sound exposure level taken on a defined time, maximum sound pressure level, and the environmental information as wind speed and the presence of precipitation, all of them in a time stamp. According with ISO 20906, the time window of interest of measured signal is approximative 12 seconds. As time dimension, t_{10} is the time period of recoding data taken with 10 dB less than maximum sound pressure level, as in Fig. 1.

An integration over the whole time-level block represent the exposure level of an event *Le* and is considered as if all the sound energy is compressed in a period of time, and is expressed by the following equation:

$$L_E = 10 \log\left(\frac{1}{t_0}\int_{t_1}^{t_0} 10^{L(t)/10}\mathrm{d}t\right). \qquad (1)$$

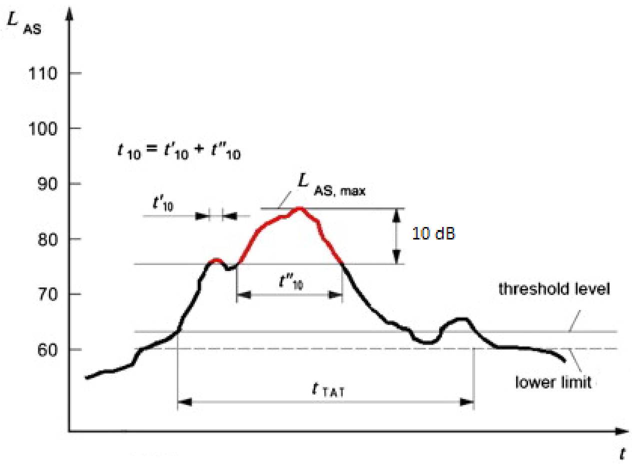


Fig.1 – Noise pattern according with ISO 20906.

Sound Exposure Level SEL is an A-weighted *Le* with a duration of 1 second, as stipulated by the standard ISO 1996 as L_{AE} and is calculated with the formula:

$$L_{AE} = 10 \log\left(\frac{1}{t_0}\int_{t_1}^{t_0} 10^{L_A(t)/10}\mathrm{d}t\right), \qquad (2)$$

where $t_0 = 1$ sec.

For easier representation, with such sound exposer level could be modelled contour areas maps around the airports that are not always verry accurate, being only simulations. With further processing, such maps could be updated with data taken from on-line monitoring systems. For example, ECAC models simulates SEL generated by aircraft on the ground and around the flight trajectories [17–19]. This exposure level is an important indicator for residential areas, where should not be above the threshold of 30 dBA inside dwelling, according with regulations. Also, near the airport's runway high level of sound exposure of workers could lead to hearing loss in time.

Time-weighted equivalent sound levels are taken into account the most important sound energy received from the aircraft and is expressed by the following formula which takes into consideration *N* noise events which takes place over a T_0 duration (defined usually different from country to country over the day, evening or night):

$$L_{eq,W} = 10\log\left(\frac{t_0}{T_0}\sum_{i=1}^{N} g_i 10^{L_{E,i}/10}\right), \tag{3}$$

where g_i is a time-of-day dependent weighting factor (applied for day, evening and night) and represents in fact a multiplier for the number of flights passing over the considered periods and expressed by

$$g_i = 10^{\Delta_i/10},$$

Δ_i is the decibel weighting for the i-th period,

Time-of-day equivalent sound levels weighting is represented through the formula:

$$L_{\max} = 10\log\left(\frac{1}{N}\sum_{i=1}^{N} 10^{L_{\max,i}/10}\right). \tag{4}$$

Average maximum sound level

$$L_{eq,W} = 10\log\left(\frac{t_0}{T_0}\sum_{i=1}^{N} 10^{\left(L_{E,i}+\Delta_i\right)/10}\right). \tag{5}$$

Day-evening-night level L_{den}, represent a similar with L_{eq} noise level index, adopted by the European Commission which weights evening noise by 5dB and night-time noise by 10dB, taken into account a variation of community noise sensitivity across the 24-hour day, when noise is less tolerable during the evening and the night than during the day.

$$L_{den} = 10\log\frac{1}{24}\left[12 10^{\frac{L_{day}}{10}} + 4 10^{\frac{L_{evening}+5}{10}} + 8 10^{\frac{L_{night}+10}{10}}\right]. \quad (6)$$

In Romania, the day-time is 07:00-18:00, the evening-time is 18:00-23:00 and the night-time is 23:00-07:00. The L_{den} and L_{night} indices are calculated based on L_{Amax}. The *SEL*-value of a noise event is calculated by integration of the discrete noise contributions of the aircraft along the flight path and the integration steps are between 2 and 10 seconds.

The European Civil Aviation has introduced an index named *Number Above Threshold* (NAT) as the number of noise events with maximum sound levels reaching or exceeding a certain threshold value, in our case night 70(dB), for every defined as critical over a period of day. Such levels are different from country to country and are an important indicator from the perspective of psychoacoustic reaction of people, as for example, indicate the level when they are disturbed and wakeup from the sleep.

2. MEASUREMENT PROCEDURE

In order to realize the identification and classification of aircraft sound events, ADS-B/MLAT signals transmitted directly by all the airplanes included in a specific area should be collected. Such signal contains information about airplane identification data, GPS location, altitude, speed, direction of flight, etc. ADS-B/MLAT received signal is synchronized with sound measured data with the aim of precisely attributing the sound event to specific airplane. The data messages transmitted by the airplane are done at incremental intervals of 0.5 or 1 second at 1090 MHz frequency. ADS-B/MLAT system generate and transmit an interrogation message at a frequency of 1030 MHz with register requests and through the receiving antenna array receives the transmissions from the target airplane and the timestamps from each antenna. ADS-B transmits DF17/18 download formats (the content of data-field is 17/18 decimal, coded as Pulse Position Modulation) without radar interrogation. The received information contain data about aircraft identification, altitude, encoded latitude and longitude and velocity. For aircraft without transponders, multilateration MLAT version is used, as in Fig. 2.

Although our main concern was to obtain a cheaper solution than wide classical used ones, we have chosen only reliable hardware components, capable to resist in any real environment conditions and to be implemented even by small airports or by local unspecialized authorities. Service and maintenance in time being an important concern, we have allocated high speed data transmission solution which allowed us the remote configuration control. We considered that 4G transmission offers us a good data transmission speed for the present configuration, but upgrading to 5G could offer in the future better integration possibilities over IoT with airport or communities management systems.

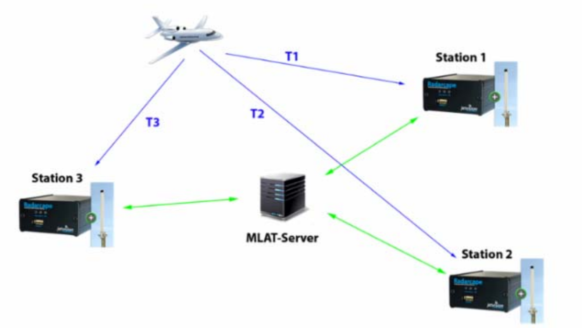


Fig. 2 – MLAT system using difference of signal arrival time for aircraft localization.

For data acquisition MONODAQ-E-ACC – IEPE acceleration sensor amplifier was used, with the following characteristics: IEPE and voltage input, input ranges: 10 V, 5 V, 1 V, 200 mV, high-pass filter 1 Hz, 4 mA, TEDS over IEPE, 24 bits, up to 50 kSamples/s., with DEWEsoft X3 software support. A software sequencer was used to make the acquisition and triggering process automated.

The ultrasonic weather station has the following specifications: 0–60 m/s range, ±2% @12 m/s accuracy, 0.01 m/s resolution, 0.25 seconds response time and 0.01 m/s threshold time, 0 – 360° direction range. The station transmits the data at a frequency of 1 Hz. A pre-polarised G.R.A.S. 40AE microphone with 3.15 – 20 kHz range, 15 dB(A) to 148 dB dynamic range was used, with preamplifier and weather and bird protection. In Fig. 3 is presented the noise monitoring architecture with sketched flow of data.

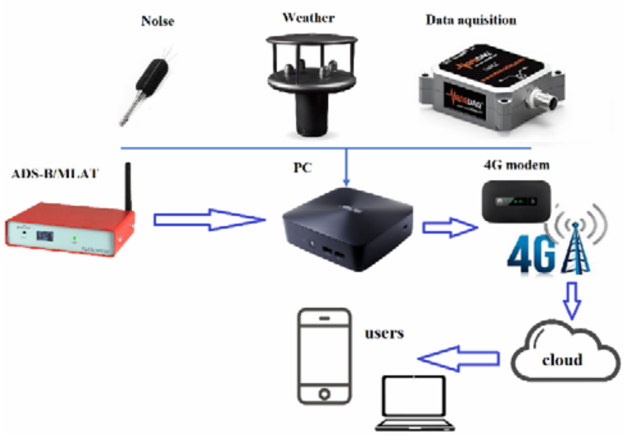
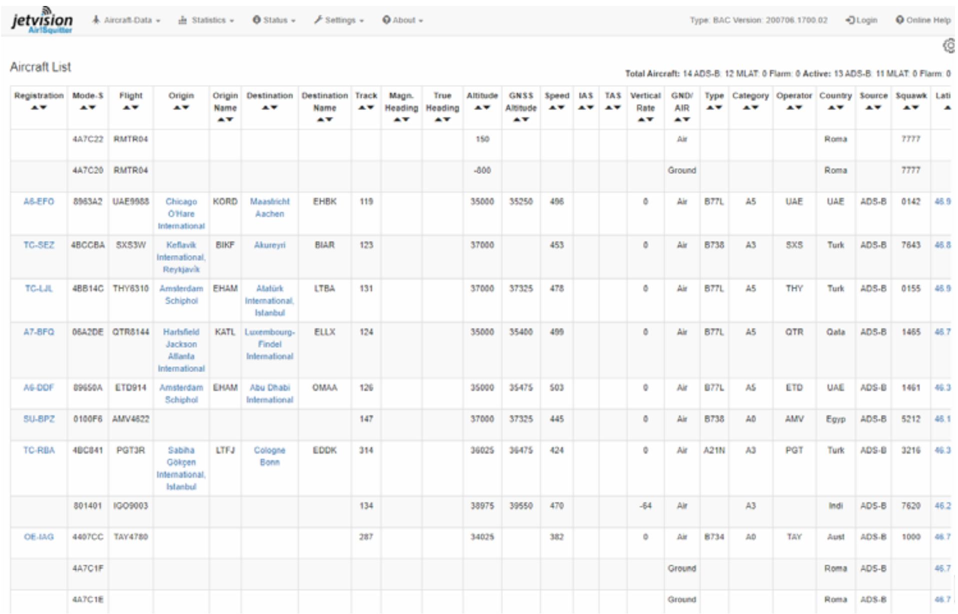


Fig. 3 – NMS architecture.

The general airport data which defined are: airport coordinates (longitude: 26.0844123, latitude: 44.5707306, elevation: 95m), average air temperature (20°C), average relative temperature (20%), average wind speed (3.5 m/s).

Synchronized signal obtained from ADS-B/MLAT (as in Fig. 4.) and sound monitoring system, locally processed and transmitted over 4G modem to a database server.



Registration	Mode-S	Flight	Origin	Origin Name	Destination	Destination Name	Track	Magn. Heading	True Heading	Altitude	GNSS Altitude	Speed	IAS	TAS	Vertical Rate	GND/AIR	Type	Category	Operator	Country	Source	Squawk	Lati
	4A7C22	RMTR04								150						Air				Roma		7777	
	4A7C20	RMTR04								-800						Ground				Roma		7777	
A6-EFO	8963A2	UAE9988	Chicago O'Hare International	KORD	Maastricht Aachen	EHBK	119			35000	35250	496			0	Air	B77L	A5	UAE	UAE	ADS-B	0142	46.9
TC-SEZ	4BCCBA	SXS3W	Keflavik International, Reykjavik	BIKF	Akureyri	BIAR	123			37000		453			0	Air	B738	A3	SXS	Turk	ADS-B	7643	46.8
TC-LJL	4BB14C	THY6310	Amsterdam Schiphol	EHAM	Atatürk International, Istanbul	LTBA	131			37000	37325	478			0	Air	B77L	A5	THY	Turk	ADS-B	0155	46.9
A7-BFQ	06A2DE	QTR8144	Hartsfield Jackson Atlanta International	KATL	Luxembourg-Findel International	ELLX	124			35000	35400	499			0	Air	B77L	A5	QTR	Qata	ADS-B	1465	46.7
A6-DDF	89650A	ETD914	Amsterdam Schiphol	EHAM	Abu Dhabi International	OMAA	126			35000	35475	503			0	Air	B77L	A5	ETD	UAE	ADS-B	1461	46.3
SU-BPZ	0100F6	AMV4622					147			37000	37325	445			0	Air	B738	A0	AMV	Egyp	ADS-B	5212	46.1
TC-RBA	4BC841	PGT3R	Sabiha Gökçen International, Istanbul	LTFJ	Cologne Bonn	EDDK	314			36025	36475	424			0	Air	A21N	A3	PGT	Turk	ADS-B	3216	46.3
	801401	IGO9003					134			38975	39550	470			-64	Air		A3		Indi	ADS-B	7620	46.2
OE-IAG	4407CC	TAY4780					287			34025		382			0	Air	B734	A0	TAY	Aust	ADS-B	1000	46.7
	4A7C1F															Ground				Roma	ADS-B		46.7
	4A7C1E															Ground				Roma	ADS-B		46.7

Fig. 4 – Row of ADS-B/MLAT data.

A zone of monitoring should be defined, in this case a square of 30x30 km, which should cover the airport zone and adjacent residential areas. Sound exposure level is obtained by integration of sound pressure level over the area of 10 dBA lower than slow A-weighted sound pressure level *LASmax*, also named by ICAO, "10dBA down time". For a reliable event identification, ISO 20906 standard imposed a 15 dBA difference between *LASmax* and the background level. Within the monitoring zone, all the aircraft located at an altitude lower than 1700 m are considered as noise harmful source and should be taken in consideration as trigger for starting the data acquisition.

3. RESULTS

The monitoring station was placed near the International Airport Henri Coandă Bucharest, like in the Fig. 5 with monitoring station location. The system was installed for a period of 3 days for complete data acquisition, during the days and nights.

Fig. 5 – Airport Henri Coandă map with monitoring station location.

The processing of noise signals consisted of the few steps, followed with exporting data in .txt format and the running of sets of Python scripts. In order to identify the events produced strictly by aircraft without the residual noise, the following functions have been defined: the entire data set was divided into 10 800 second sessions, statistical indices *L10* and *L90* were calculated, *L90* being used as background noise level.

A set of triggers and thresholds were defined in a function called peaks_finder in order to identify the aircraft passes. Thus, a first conditioning was for the noise level of the events to exceed L10, to have a maximum duration of 15 seconds and the distance between two consecutive events to be of minimum 30 seconds. According with ISO20900 standard, the duration of each event t_{10} is the time period of recoding data taken with 10 dB less than maximum sound pressure level, as in Fig. 1. Thus, for each previously identified event, the peak value was recorded and the time of the event was identified by decreasing 10dB in both parts of the noise curve relative to the maximum peak of the event.

The final filtering of events consists in including a conditioning phase who imposed the rule that the maximum peak amplitude to be greater than 65dB and the duration of the event to be no less than 5 s and greater than 15 s. All events that meet these conditions are considered valid and the remaining events are considered invalid as shown in Fig. 6.

After sorting all the events it follows the calculation of the acoustic parameters of each event, Leq and SEL, the duration in seconds of the event, the period of the day (day, evening, night) in which the event was produced, and all these identified values are correlated with the air traffic data. The last step in data processing is calculation of the day-evening-night levels according to equation (6).

Figure 6 shows a data session of 10.800 seconds that includes the measurement of noise during the night (before 7:00) up to 6000 seconds after which the L_{Aeq} curve present an increase of the level produced by the activity of the city.

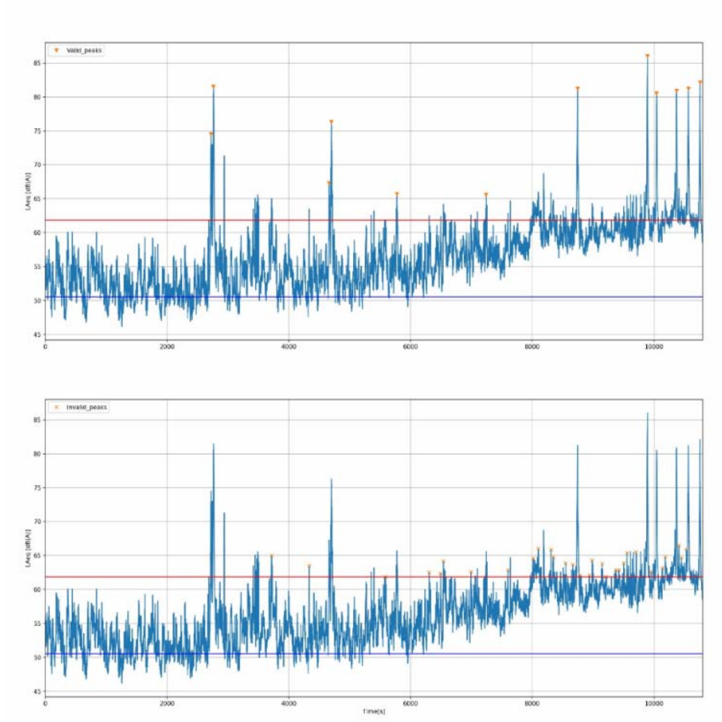


Fig. 6 – Time history background environmental and aircraft noise data *LAeq* [dB].

In the case of real time and long-term monitoring systems, an important issue is the memory allocation. In the high rates of data acquisition procedures, which is a specific action in the field of NMS, large amounts of data should be processed, even not all of them contains important information. By including in the acquisition architecture of a series of triggers the memory occupancy are reduced even from the beginning. Even so, from the communication and data transmission expectations, not the data which contain information should be transmitted, but only the results of calculation.

From the point of view of software resources and memory optimization, all the calculations are done locally, at a computer which is part of the monitoring station and only the results are sent through 4G modem or over the Ethernet connection to a data-base server (or application server). Such remote connectivity to the field monitoring station offers to the service and maintenance personal an easy possibility for instant parameter and configuration changes.

Environmental parameters, like meteorological data, are stored on the monitoring system and transmitted at the same logging increment as acoustic data (over 4G modem, Ethernet). Through the same remote interface, the service personal can have access to the speed and direction of the wind, humidity, air temperature and rain occurrence, in real time. Such parameters, even they are not an important information for the large public users, are still an important factor to be introduced as correction in acoustical calculations or to be used as triggers for starting-stopping the noise recording (like is the case for rain occurrence).

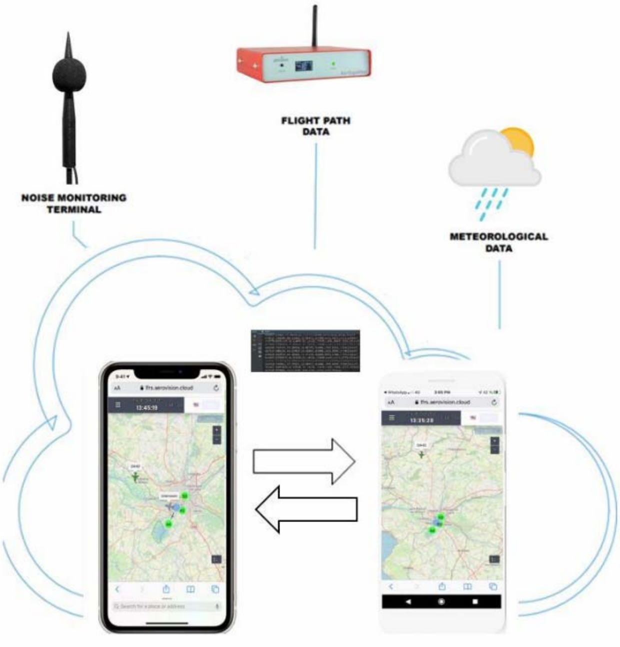


Fig. 7 – NMS data flow.

During the measurement campaign, air traffic data were taken using two ADSB receivers AirSquitter from Jetvision, which is an integrated device with all features for problem-free ADS-B and MLAT reception and the data flow is summary sketched in Fig. 7. Feeders are also available for FlightRadar24, FlightAware, Opensky Network, Planeplotter and ADSB Exchange.

Connection is done over Wi-Fi or LAN, and supports simultaneously multiple users via desktop, tablet or smartphone. Extensive map display on the web browser, filter options, status, range and performance diagrams. For non-ADS-B aircraft identification, it was used multilateration MLAT method provided by Jetvision. The AirSquitter is continuously connected to the internet and the radar data is transmitter to the *mlat.jetvision.de:10011* server which provides back the location of the non-ADS-B aircraft.

The software for aircraft monitoring uses programming languages such as C# (C-sharp) and C++. Messages are queried and processed from their monitoring status in a specific HTTP web-request format as in Fig. 8. These decoded messages correspond to data structures, specific to each type of aircraft, generated by the receiver device, are displayed in a list, to be analysed later.

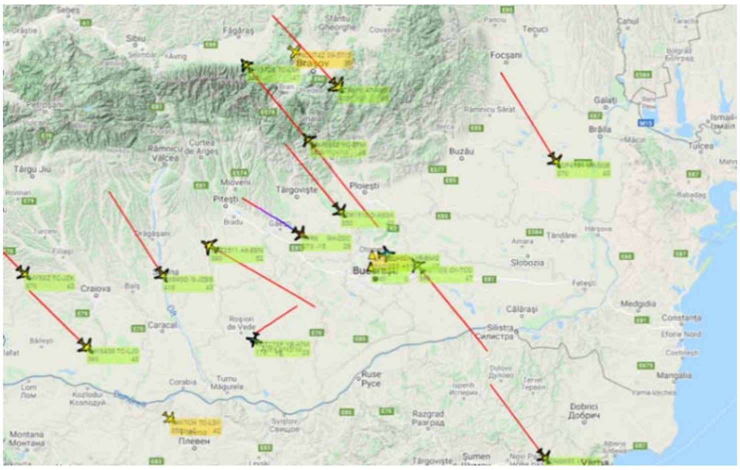


Fig. 8 – On-line visualization of airport traffic and noise related events.

4. CONCLUSION

A noise monitoring system which use ADS-B/MLAT traffic information is considered as an easy to be implemented and not expensive solution, compared with sophisticated radar based classical systems and because of this, could be applied to all the airports, even if they are small, noise being a general issue which affect population at large–scale. Remote maintenance and configuration could save a lot of effort from the experts in keeping the system working, knowing that it is installed for a long period of time and with not an easy access. Also, such systems are easy to be accessed by local authorities to keep tracking of noise airport noise related events and thus to be able to propose more precise and reliable rules to prevent exceeded noise levels which came from adjacent airports. The networking of information is also a way to keep the local authorities in direct connection with population, especially if this system is interfaced with other monitoring structures, like pollution. Regular people could also easy check such noisy events and forward related complains to local authorities using a simple smartphone access, or could use such problematic information to make themselves aware of local real environment when decide to move in a certain zone, by checking the time history noise events.

We appreciate that the proposed solution was a cheaper one, made without any important quality rabat and using only reliable hardware components, capable to resist in any real environment conditions and easy to be implemented even by small airports or by local unspecialized authorities.

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