International Journal of Aviation Science and Technology

Research Article

A Comprehensive Study On The Effects Of Noise Abatement Departure Procedures On Noise Contours Around Tan Son Nhat International Airport

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Abstract

In recent years, accompanied by economic growth, air transportation in Vietnam has rapidly risen with the introduction of many new airlines. This situation has led to an increase in aircraft movement frequency flying in and out of the airports and raised concerns about the effects of increased noise exposure levels on public health and the natural environment in the vicinity of the airports. Vietnam authority has also issued several documents to regulate the establishment of the noise contour maps to evaluate the current noise exposure levels around airports in Vietnam and recognized the noise problem in aviation as a significant issue. One of four measures to reduce the noise around airports introduced in the Balanced Approach to Noise Management of the International Civil Aviation Organization is noise abatement operational procedures. This research is one of the first attempts to provide a comprehensive study on predicting the noise levels and establishing noise contour maps around Tan Son Nhat International airport with the assumption that aircraft take-off following the noise abatement departure procedures 1 and 2 using MATLAB software. The computed noise contours for both procedures show that the day-evening-night equivalent noise levels range from 45 dB(A) to 60 dB(A) around the airport, with the difference in noise levels between the two procedures primarily occurring at the end of the runway due to the difference in stepped departures. These results provide a reference for the authorities to study further in applying suitable noise reduction plans in the vicinity of airports.

Keywords

Airport noise contours,
Noise abatement departure procedures,
Noise contours,
Noise contours map,
Noise map

Time Scale of Article

Received 5 May 2022
Revised until 25 May 2022
Accepted 4 November 2022
Online date 29 December 2022

1. Introduction

Noise exposure levels generated by aircraft movements around airports are recognized as a critical issue that has far-reaching effects on the health of those living near airports. Many developed countries have established noise contour maps combined with noise monitoring systems in the vicinity of the airports as an effective way to assess the noise exposure levels generated by flight operations. However, in the rest of the world, especially in many developing countries, evaluating the effects of noise and proposing measures to reduce the area affected by high noise exposure levels is still challenging due to restricted data assessed and technical limitations. Various international studies related to noise issues around airports have been conducted in recent years, such as: (Paulo, 2012) provide a method to compute the noise level and plot

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DOI: 10.23890/IJAST.vm03is02.0203

the noise contours around airports using measured data conducted in the street instead of using specific software. With this method, the noise levels generated by aircraft operations can be computed, and the noise contours can be plotted without the need to measure 24 hours in each noise calculation point. (Pertiwe et al., 2018) developed the noise mapping for the case study Adi Soemarmo airport in Boyolali, Indonesia --the second largest airport in Central Java Province, Indonesia-- using MATLAB software. The results showed that the Weighted Equivalent Continuous Perceived Noise Levels (WECPNL) were in the range of 65 dB(A) to 87 dB(A) based on the data during the busiest schedule in September 2016, with 22 departures and 22 approaches. (Halil et al., 2020) assessed the aircraft noise emission around the International Eskisehir Hasan Polatkan airport using multiple techniques with two main stages. In the first stage of their study, the day-evening-night noise levels were simulated using IMMI software. The result showed that the noise level around the airport did not exceed the maximum allowable limit based on local law. The noise field measurement was conducted during the second stage to assess the noise level generated by the most operated aircraft Cessna 172-S in the concerned airport using TESTO 812 type-2 sound level meter. The result showed that the noise level created by this type of aircraft exceeded the lowest exposure limit, and then some measures aimed to prevent the noise level were examined. Numerous domestic and foreign researchers have conducted various studies on assessing noise problems around some major airports in Vietnam in both analytical and experimental methods. Some of these studies can be listed as following: (Ha et al., 2010) joined the project investigating and evaluating air and noise pollution, thereby establishing a noise map around Tan Son Nhat International airport and supposing solutions to reduce the effects. (Lan et al., 2019) conducted much research related to the effects of aircraft noise on the health of the community living around Noi Bai International airport. (Loc et al., 2019) compared the noise contours calculated using noise-power-distance data provided by EUROCONTROL and the measurement-based noise-power-distance data for Noi Bai and Da Nang International airports. (Lien et al., 2019) presented the response of the community living around the Tan Son Nhat airport to aircraft noise changes by comparing two surveys conducted 11 years apart in Ho Chi Minh city. (Tuan et al., 2021) described comprehensively the structure of the noise monitoring and control system expected to be deployed in the Tan Son Nhat International airport. Most of these research has shown that the aircraft noise has considerably affected the quality of living for the communities living around these airports. The previous research conducted in 2020 showed that the day continuous equivalent noise levels created by aircraft taking off from Tan Son Nhat International airport during the day-time from 0700 to 1900 range from 60 to 70 dB(A) within the departure zone area. The noise levels at some noise-sensitive points, such as at the university, hospital, workplace, and so forth, were obtained using an analytical method and verified through some noise field measurements using the Larson Davis noise measurement device. The method to determine noise levels used in this research is an inheritance and development from the previous research and will be described in section 2. The computed noise results at some noise-sensitive areas in the departure zone of the airport demonstrated exceeding the permissible noise levels given by Vietnamese Law (Kiet, 2019). To prevent the effects of aircraft noise and narrow the affected area of communities living in the vicinity of the airport, this is necessary to consider studying to apply some measures recommended by ICAO and stated in the Balanced Approach to Noise Management. Four measures to reduce the noise introduced by ICAO include: Reduction of noise at source, Noise abatement operational procedures, Operating restrictions, and Land-use planning and management. Based on the current situation at the Tan Son Nhat International airport, the airport is located inside a high-density of population, and the noise exposure levels generated by flight operations were demonstrated that exceed noise limits. This paper chose the noise abatement departure procedure to study as a part of an intensive effort to reduce the noise exposure levels generated by aircraft operations to the sensitive population living around the airport. It can be seen as the next step in predicting and evaluating noise levels created by flight operations with the assumption that aircraft fly out of the airport applying the noise abatement departure procedures – one of the recommended measures to reduce the noise problem in the vicinity of airports- on the noise contour maps around Tan Son Nhat International airport. In this study, the noise abatement departure procedures are assumed to be applied; therefore, it can be seen as a future scenario. Flightpath analysis must be conducted to obtain the noise levels generated by the specific NADP 1 and NADP 2 flight paths.

2. Method

The level and extent of noise levels created by aircraft movements following NADP 1 and NADP 2 are computed in terms of noise contours. It is done by collecting the data of the target airport, statistically analyzing the number of movements, the type of aircraft operating at the airport, and representative flight path analysis for each aircraft type with specific flight procedures. In this research, ICAO's flight path segmentation modeling mentioned in Document 9911

(ICAO, 2009) is used to compute the noise levels around Tan Son Nhat International airport. After that, the flight mechanics equations from SAE-AIR-1845 are used to determine the flight profile when the aircraft departs assumed following NADP 1 and NADP 2. Finally, the Noise Power Distance table from EUROCONTROL is used to interpolate or extrapolate the noise levels propagated from the aircraft to the ground. The process of establishing the noise contour maps for two different flight paths using noise abatement procedures is described in the following figure.

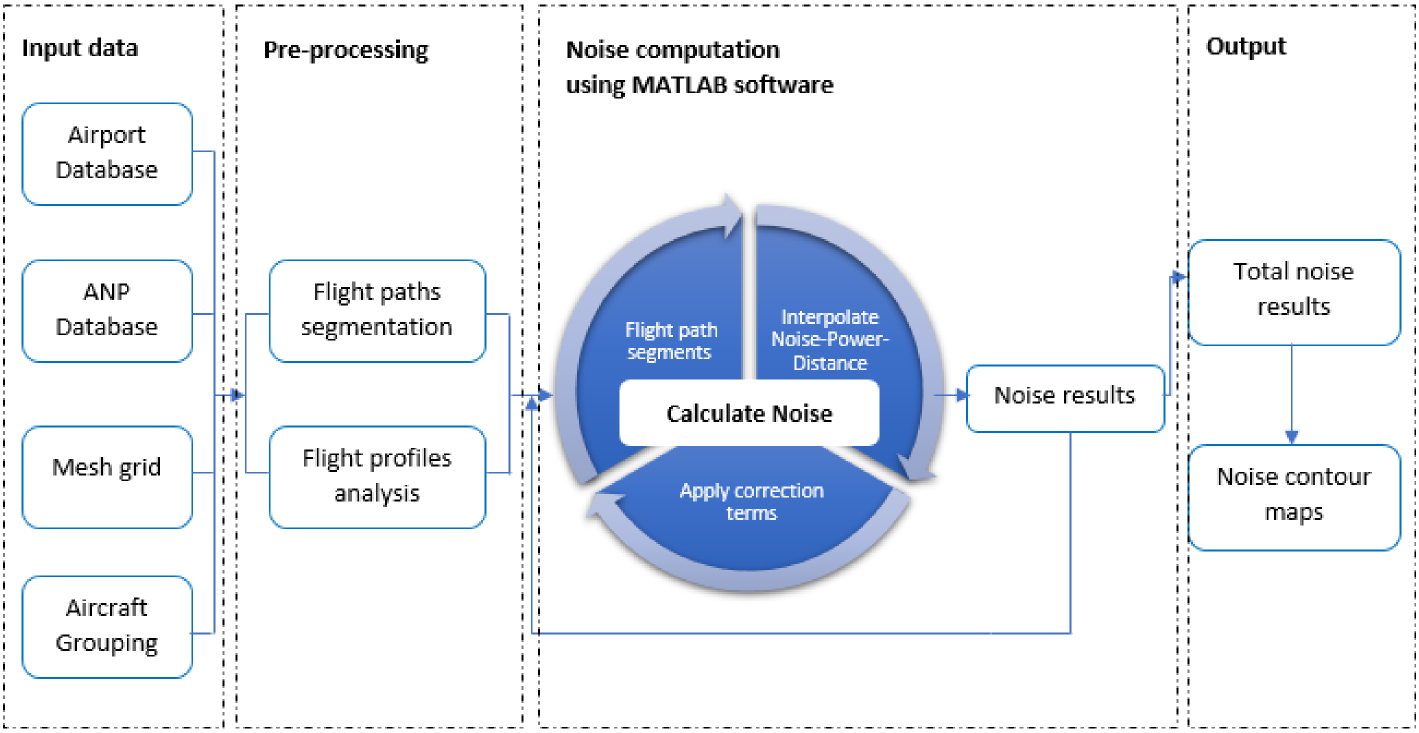

Fig. 1. The general process to compute the noise contours around Tan Son Nhat International airport

As shown in Figure 1, the general process to obtain the noise contours generated by aircraft movements following NADP 1 and NADP 2 is divided into four main steps: Input data, Pre-processing, Noise computation, and Output. To complete the first step, this is necessary to collect information about the Tan Son Nhat International airport. This step was done by gathering the airport data by assessing the Aeronautical Information Publication (AIP) issued by the Civil Aviation Authority of Vietnam (CAAV) at the time of research. The Aircraft Noise Performance database is one of the essential data needed to compute the noise contours. This database is controlled by EUROCONTROL and can be freely accessed through the website. The database contains the noise levels related to the slant distance between the noise source and the noise receiver point and the aircraft's engine thrust in different metrics widely applied to evaluate the effects of aircraft noise levels in most countries globally. It also provides information about the performance of many aircraft operating at most busy airports recently. The noise computation domain surrounding the Tan Son Nhat International airport is limited with the assumption that the aircraft do not change its heading to the start of roll stage within the entire computation domain. The process of generating the mesh grid to cover the computation domain is described in section 2.3. In the pre-processing step, the flight path segmentation modeling described in Document 29 of the ECAC is used to analyze the flight path of each representative aircraft when they are assumed to depart following the NADP 1 and NADP 2. These specific noise abatements take-off procedures are guided in Document 8168 of ICAO, pointing out a sequence of procedural steps that the aircraft must follow to satisfy the noise reduction purpose in the departure zone of the airport. These mentioned steps are done by computing some critical parameters such as rate of climb, altitude, and calibrated airspeed using flight mechanics equations found in the Aerospace Information Report 1845 published by the Society of Automobile Engineers (SAE). After obtaining the flight paths and flight profiles for the specific noise abatement departure procedure, the flight path of each representative aircraft is segmented into small segments, such as the velocity of two adjacent segments not being more significant than 10.3 m/s (20 kt). Due to the aircraft is assumed not to change its heading in the whole computation domain, the aircraft bank angle would be zero. Only three main parameters, including the aircraft's velocity, engine thrust, and height at each sub-segments start-point and end-point, are determined. The unique parameters representing the whole segment will be found based on the geometry relationship between the flight path segment and the noise grid. A code was designed using MATLAB software to compute the noise exposure levels created by each segment of each representative aircraft to the noise grid and then compute for a single flight path. This procedure is repeated to obtain the noise exposure levels generated by the rest of the flight paths of the representative aircraft. Finally, the noise contours will be obtained using the natural neighbor's interpolation technique described in section 2.3. The day continuous noise level (L_{day}) and the day-evening-night continuous noise level (L_{den}) is computed by adding the contribution of all aircraft operating during the time of research which is weighted to account for the difference in the background noise during the day, evening and night time.

2.1 Airport data collecting

Located inside the high density of the noise-sensitive area with a distance of only 6.5 km North West from Ho Chi Minh City center, Tan Son Nhat International Airport - the case study of this research, is one of the largest and busiest airports in Southern Vietnam, serving more than millions of passengers annually in normal operating conditions. The airport uses two parallel runways, including RWY 25L/07R and RWY 25R/07L. The dimensions of these runways are 3828 m x 45 m and 3050 m x 45 m, respectively (AIP Vietnam, 2021). In the scope of this research, all flight operations collected in March 2020 took place in the runways 25R and 25L, with RWY 25L primarily used for take-offs and RWY 25R primarily used for landings. Theoretically, the noise levels computation can be separated into two runways. However, due to the two runways used at Tan Son Nhat International airport being close to each other (365 m), it is assumed that both take-off and landing operations of aircraft taking place on the single runway 25L (CAAV, 2019), then all noise computations are conducted using the dimension and direction of the RWY 25L

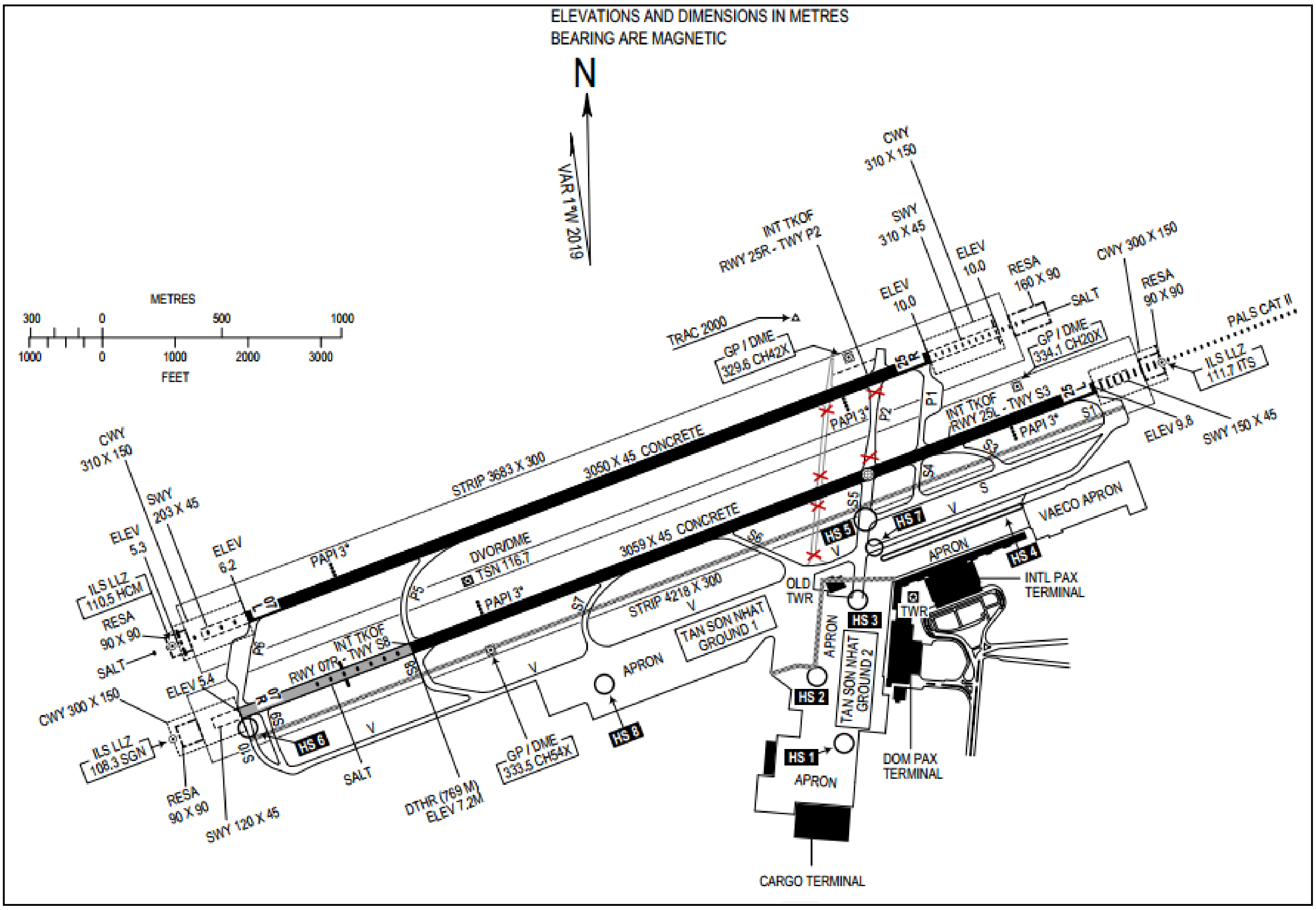

Fig. 2. ICAO Aerodrome Chart of Tan Son Nhat International Airport (AIP Vietnam)

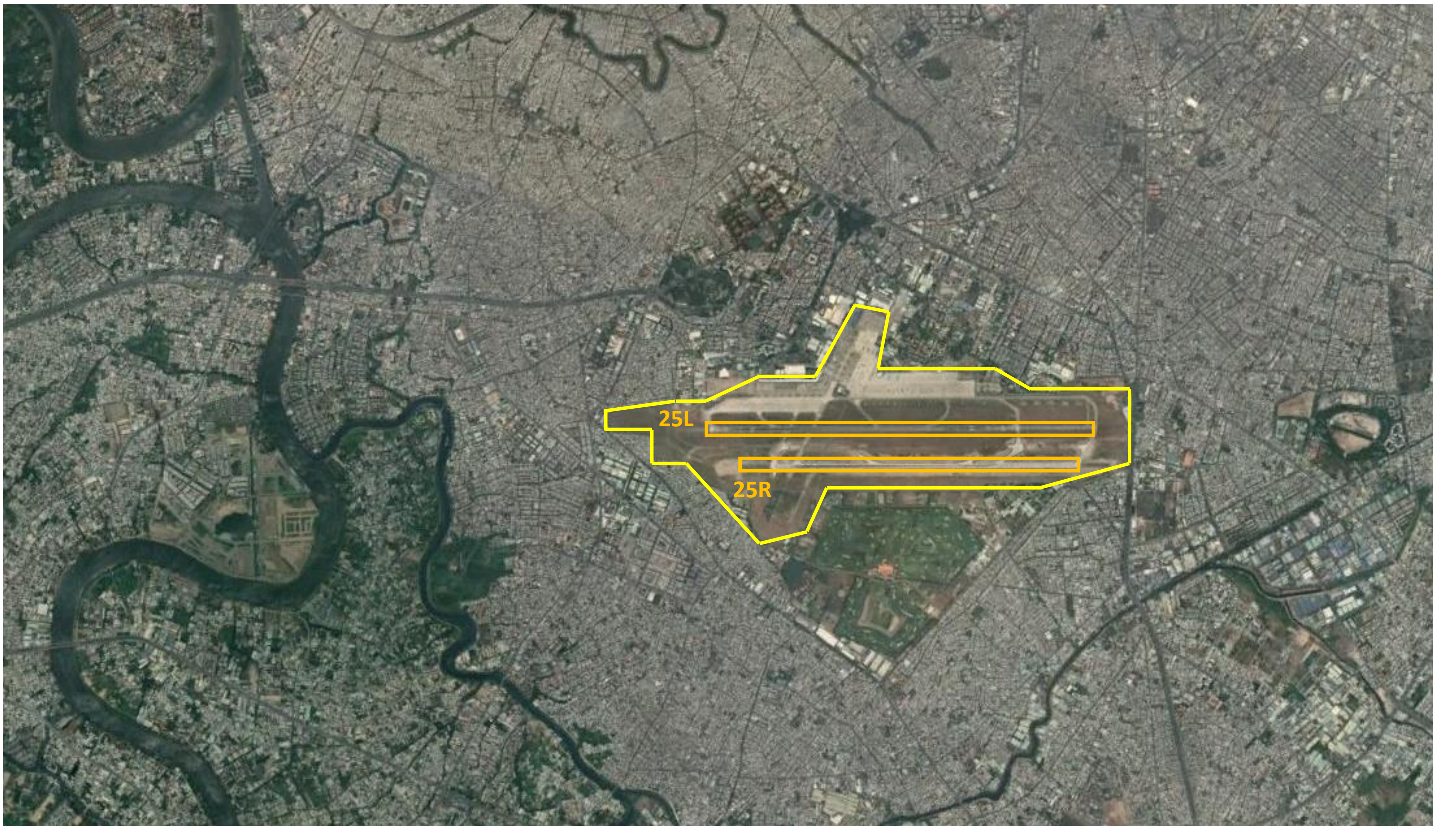

Fig. 3. Tan Son Nhat International Airport

2.2 Aircraft Noise Performance Database

The Aircraft Noise Performance (ANP) database is an essential and necessary database for calculating aircraft noise contours. The ANP database is maintained and managed by the United State Department of Transport, EUROCONTROL, and the European Aviation Safety Agency (EASA). This database provides aircraft performance and noise characteristics for more than 150 civil aircaft types as the airframe/engine combinations, used to determine the maximum and exposure-based noise metrics. This database is consistent with the noise contours calculation methodology described in the Aerospace Information Report (AIR) 1845 of the Society of Automobile Engineers (SAE), Document 9911 of the ICAO, and Document 29 of the ECAC. The details about this ANP database can be found in Appendix G, Volume 2, Document 29 of the ECAC. The Noise-Power-Distance (NPD) table is a part of the Aircraft Noise Performance database. The table provides the noise levels in different metrics as a function of the slant distance from the noise source to the ground and the engine thrust. These values were collected based on field noise measurements conducted some days in the United States. The noise exposure levels generated by each sub-segment of the single flight path can be obtained by interpolating or extrapolating this table with the engine thrust and slant distance computed using the flight mechanics equation and geometry relationship.

2.3 Noise mesh grid generation

The range of the noise computation domain is limited to ± 7260 m (25000 ft) on the horizontal axis and ± 3658 m (12000 ft) on the vertical axis, with the origin (0,0) located at the start-of-roll point on runway 25L. The unstructured grid using Delaunay triangulation covers the computation domain generated using GMSH software. The principle of using the unstructured grid is to divide the continuous noise computation domain into discrete points where each point is the intersection of the Delaunay triangulation's edges.

The noise exposure levels generated by aircraft movement will be computed at each discrete point. There are 1678 nodes in total, each node equivalent to each noise receiver point. An interpolation technique is used to interpolate the noise levels for the entire computation domain. Numerous research has been conducted in the field of interpolation techniques (Yen et al., 2020; Tan et al., 2014; Hugo et al., 2009). In the scope of this research, these techniques are not described in detail. The natural neighbor interpolation technique was chosen to interpolate the noise levels when some research proved that this technique has certain advantages and gives better results than most other interpolation techniques for surface modeling (Yen et al., 2020).

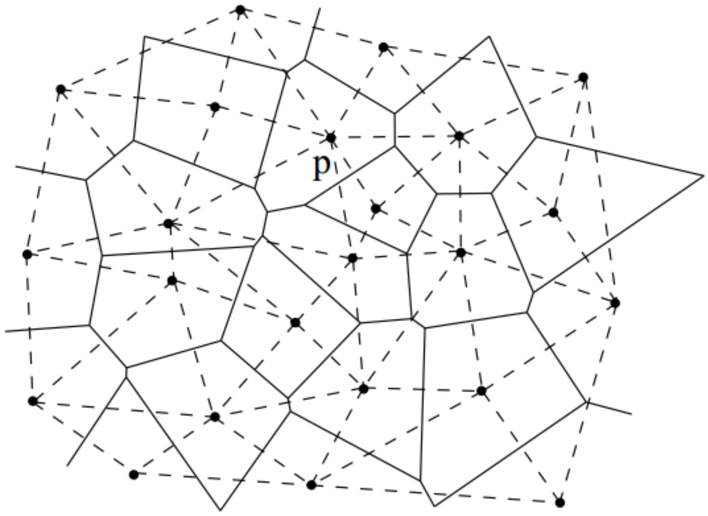

Fig. 4. Voronoi diagram and Delaunay triangular (Hugo Ledoux & Christopher Gold, 2005)

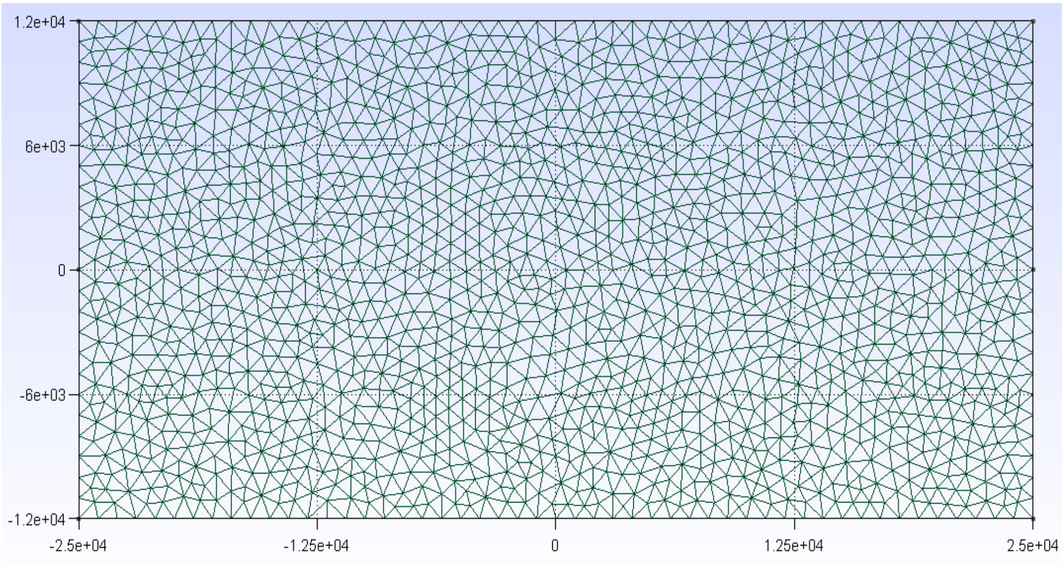

Fig. 5. The mesh grid of noise computing domain

2.4 Aircraft grouping

In March 2020, aircraft data operating at Tan Son Nhat International Airport consisting of aircraft type and operating frequency were collected and statistically analyzed using Flightradar24 web-based application. There have been 5063 flight operations for take-off and landing pairs of 15 aircraft types with 84 specific engine-airframe combinations. Theoretically, noise levels could be calculated for specific aircraft types with engine-airframe combinations. Nevertheless, this approach will take a significant amount of time and resources. An alternate method is to group individual aircraft types having similar noise and performance characteristics so that a single aircraft category can represent them (ECAC, 2016). The aircraft types operating at Tan Son Nhat International Airport were grouped based on the criteria recommended in Document 29 of the ECAC:

Table 1. Parameters for aircraft grouping

Criteria	Description
Maximum take-off mass	light, medium, heavy aircraft
Type of engine	turbojet, turbofan, and turboprop
Number of engines	two, three, or four engines
By-pass ratio	low, medium, high
Installation of the engines	rear-fuselage-mounted engines and wing-mounted engines
Type of operation	departures and arrivals
ICAO noise certificate	based on noise certification according to ICAO Annex 16, Volume 1

Table 2. Aircraft groups and aircraft representatives.

Aircraft Type	Group Name	Aircraft Representative
Airbus A319/320/321, Boeing 737/757	C	Airbus A321-232
Airbus A320/A321 Neo/Neo X*	C*	Airbus A321-232
Boeing 787, Airbus A350, Airbus A330	D	Airbus A350-941
Airbus A340, Boeing 747, Boeing 777	E	Boeing 747-400

Table 3. Aircraft representative and its default weights.

Aircraft Type	Representative Aircraft	Default Weights (kg)
Airbus A320 Family, Boeing 737/757	Airbus A321-232	77000
Boeing 787, Airbus A350, Airbus A330	Airbus A350-941	234000
Airbus A340, Boeing 747, Boeing 777	Boeing 747-400	304000

Table 4. The number of aircraft movements for take off-landing in March 2020.

Group	Day (0700-1900)	Evening (1900-2200)	Night (2200-0700)
Airbus A321-232	2813	564	470
Airbus A350-941	438	202	281
Boeing 747-400	160	52	83
Total	3411	818	834

Table 5. Standard Noise Abatement Departure Procedures

ICAO A or NADP 1	ICAO B or NADP 2
Take off Max TO Power	Take off at Max TO Power
Climb at constant speed to 457.2 m (1500 ft) AFE	Climb to 304.8 m (1000 ft) AFE and pitch-over to accelerate at full power to clean configuration
Reduce thrust to Climb Power	At clean configuration, cutback to climb power
Climb at constant speed to 914.4 m (3000 ft)	Climb at constant speed to 914.4 m (3000 ft)

Based on the above criteria, the aircraft operated at Tan Son Nhat International airport in March 2020 are classified. After grouping the whole aircraft with similar noise characteristics into groups, an aircraft representative with the highest movement frequency during the research time will be selected to represent.

The aircraft group C* has a relatively similar geometry characteristic to the aircraft group C. However, these aircraft were separated into a new group to account for the difference between the new generation engine NEO/NEO X and the old one CEO of Airbus A320 Family aircraft. These types of engines, NEO and NEO X, are significantly improved and reduced in noise compared to conventional engines CEO used on Airbus A320 family aircraft. Moreover, the ANP database does not provide specific noise and performance information for Airbus A320 family aircraft using NEO and NEO X engines. An alternative way is to use the information of Airbus A321-232 aircraft using CFM engines for those using NEO and NEO X engines and add the following amount of take-off adjustment as described below:

$$N_{dep\_C} = 0.43 \cdot N_{dep\_C*} \quad (1)$$

Where N_{dep_C} and $N_{dep\_C^*}$ is the number of aircraft group C and C* movements, respectively. The aircraft groups are reduced to three groups. The nominal weights of each representative aircraft used for flight profile computing are selected based on the Aircraft Noise Performance database in Table 3.

Table 4 above shows the number of take-off movements for each aircraft group per aircraft representative operating at Tan Son Nhat International airport during the time of a day:

2.5 Flight path analysis and flight profile calculation

The International Civil Aviation Organization has assisted in developing and standardizing the low noise operational procedures for both take-off and landing in terms of the stepped departure and stepped approach procedures to achieve the noise reduction purpose in the vicinity of the airports. In the scope of this research, the noise abatement departure procedures are mainly focused on analyzing to compute the noise levels. The flight path of each representative aircraft was analyzed and calculated with the assumption that aircraft take-off following the NADP 1 and NADP 2. The detailed noise abatement departure procedural steps are described in Table 5, including some target points that the aircraft must be respected to reduce the noise levels in the vicinity of the airport.

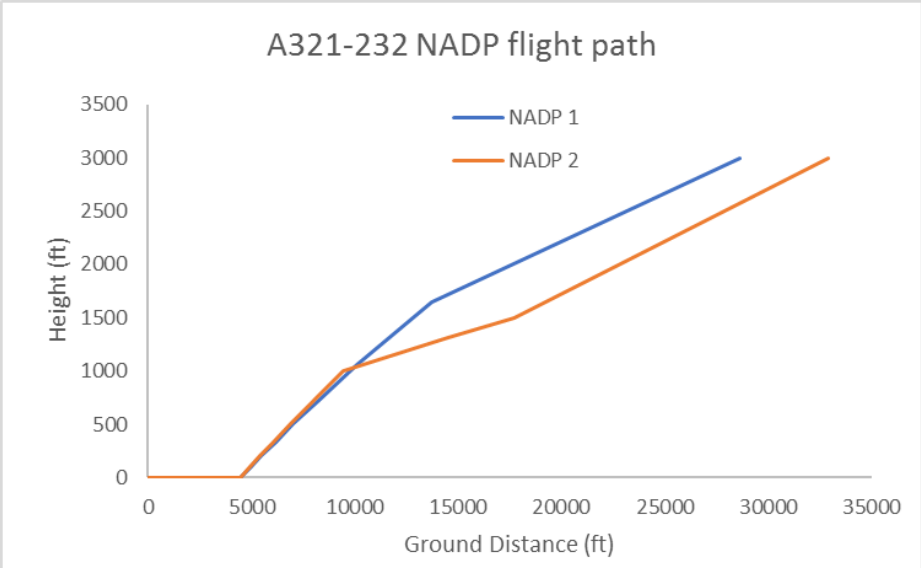

Fig. 6. The computed NADP 1 and NADP 2 flight path of Airbus 321-232

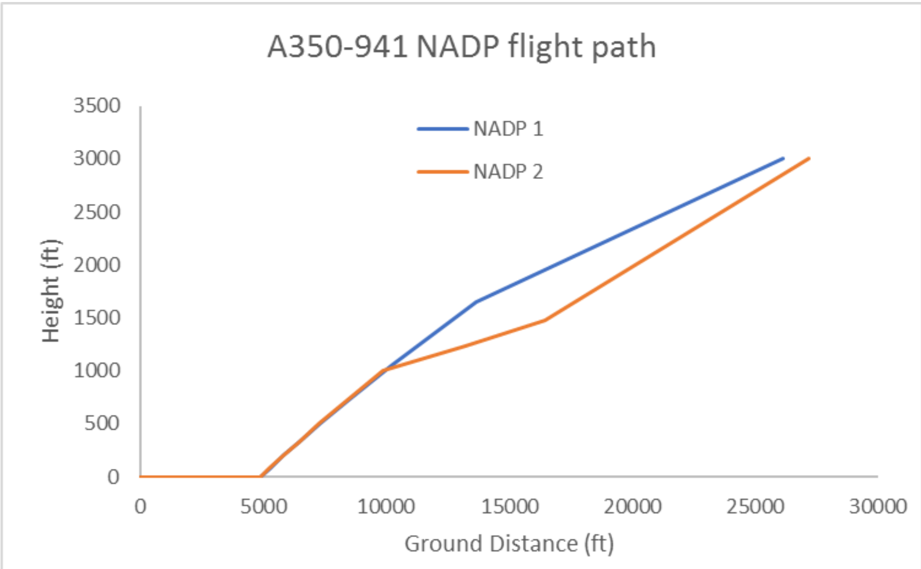

Fig. 7. The computed NADP 1 and NADP 2 flight path of Airbus 350-941

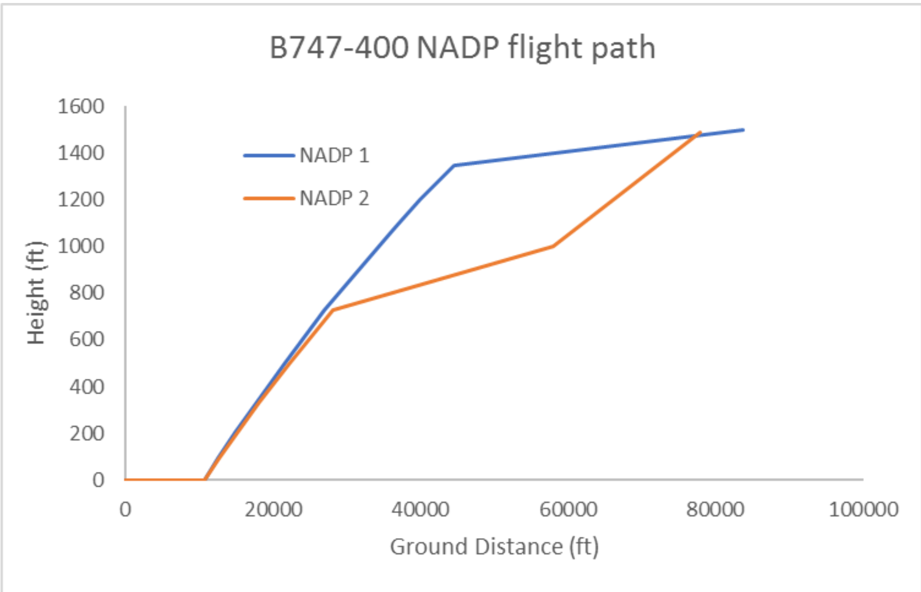

Fig. 8. The computed NADP 1 and NADP 2 flight path of Boeing 747-400

The flight mechanics equations were used to compute the performance of the representative aircraft operating at Tan Son Nhat International airport during the time of research to achieve the flight paths of aircraft flying with noise reduction procedures or so-called NADP 1 and NADP 2 flight paths. These steps were done using the flight mechanics equations for noise computation purposes supposed in the SAE-AIR-1845. These equations are used for computing the engine thrust, take-off ground roll, landing ground roll, speeds, and height of each stage of the flight path. It contains some constants coefficients that can be collected from the ANP database.

The following figures show the computed NADP 1 and NADP 2 flight paths for each representative aircraft, including Airbus A321-232, Airbus A350-941, and Boeing 747-400

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After obtaining the flight path and flight profile at each target point in the noise abatement procedural step, the flight path of each representative aircraft is divided into sub-segments, such as the velocity at two adjacent segments not exceeding 10.3 m/s (20 kt). Then the flight profile will be recalculated for the start and the end of each sub-segment. The essential parameters consist of engine thrust, aircraft's velocity, height of each sub-segment, and the nearest distance, so-called the slant distance- the nearest distance between the sub-segment and the noise receiver point or the noise grid was also calculated through the geometry relationship. Depending upon the location of the noise grid and the sub-segment, these mentioned parameters are precisely determined with the method described in Document 9911 given by ICAO. Figure 9 below presents the geometry relationship between the sub-segment and the noise grid in terms of some parameters. In the departure stage, there are two separate steps that the aircraft must follow, including the take-off ground roll stage, where aircraft accelerate from the start of roll point in the RWY 25L to the take-off velocity, and the airborne stage begins at the time the aircraft lifting off. Considering a sub-segment, this can be three different possible locations of the noise grid related to the sub-segment, including behind, alongside, and ahead.

Figure 9 shows an example of the relationship between a sub-segment defined from start-point 1 to end-point 2 and a noise receiver point or noise grid. In this case, the noise grid is alongside the sub-segment, then some

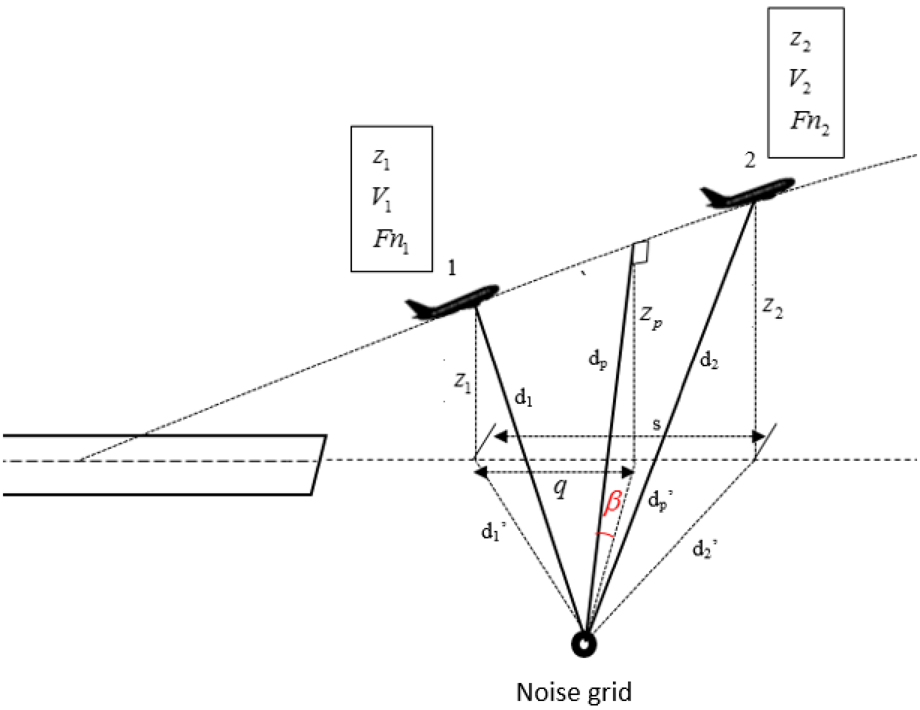

Fig. 9. The geometry relationship between sub-segment and noise grid

parameters must be determined to compute the noise exposure level received at the noise grid. These parameters include the slant distance d_P (which is laid on the sub-segment when the noise grid is alongside the segment or laid on the extended line of the segment when the noise grid is ahead or behind the segment), the height at the intersection between the slant distance and the segment z_P, the length of the segment in the ground track s, the length q from the start-point 1 and the nearest distance from the noise grid to the ground track $d_P{}'$ and the angle β between the slant distance d_P and $d_P{}'$.

2.6 Noise calculation

For evaluating aircraft noise levels around the airports, two metrics are used in this research complied with the guidance of the Civil Aviation Authority of Vietnam, including A-weighted single sound exposure level (SEL or L_E) and A-weighted equivalent continuous day-evening-night sound level (L_{den}). The NPD table is used the slant distance and the engine thrust obtained as described in the section 2.2 to extract the noise exposure level generated by each sub-segment to the ground. Due to the NPD table providing the noise levels for a particular combination of slant distance and engine thrust, the computed values are rarely available in the NPD table. Therefore, the interpolation or extrapolation formula must be used to obtain the noise exposure level for the computed values. These steps are done through the following formula:

The noise level at engine power P1 and distance d is given by

$$L_{P1,d} = L_{P1,d1} + \frac{(L_{P1,d2} - L_{P1,d1}) \cdot [log_{10}(d) - log_{10}(d_1)]}{[log_{10}(d_2) - log_{10}(d_1)]} \quad (2)$$

The noise level at engine power P2 and distance d is given by

$$L_{P2,d} = L_{P2,d1} + \frac{(L_{P2,d2} - L_{P2,d1}) \cdot [log_{10}(d) - log_{10}(d_1)]}{[log_{10}(d_2) - log_{10}(d_1)]} \quad (3)$$

And finally, the interpolated or extrapolated noise level at engine power P and distance d is given by

$$L_{P,d} = L_{P1,d} + \frac{(L_{P2,d} - L_{P1,d}) \cdot [log_{10}(d) - log_{10}(d_1)]}{(P_2 - P_1)} \quad (4)$$

Where the $P1, P2$ are the engine thrusts which its noise data included in the NPD table, $d1, d2$ are the slant distances which its noise data included in the NPD table. As mentioned in section 2.2, the NPD table is established by noise field measurement with strict conditions. These reference conditions can be found in Document 9911 of the ICAO, and the flight path the aircraft must be followed to conduct noise measurement on the ground is called the NPD flight path. The principle of noise calculation in this Section considers each sub-segment part of an NPD flight path, then uses the NPD table with two input values consisting of slant distance and engine thrust to obtain the NPD noise exposure level. The noise level contributed by each sub-segment to each noise receiver point after being interpolated or extrapolated from the NPD table will be adjusted to account for the difference between the actual flight path and the NPD flight path. The contribution from one flight path segment to noise exposure level can be expressed as:

$$L_{E,seg} = L_{E,NPD}(P,d) + \Delta_V + \Delta_I(\phi) - \Lambda(\beta,l) + \Delta_F \quad (5)$$

where $L_{E,NPD}(P,d)$ is the noise exposure level at engine thrust P and slant distance d obtained in the NPD table; $\Delta_V, \Delta_I(\phi), \Lambda(\beta,l), \Delta_F$ are called "correction terms" to account for the effect of duration, installation, lateral attenuation, and segment correction, respectively. The formulas to compute these correction terms can be found in Document 9911 published by ICAO.

Calculation of single event noise exposure level LE or SEL

The $L_{E,seg}$ computed in the previous section is the noise exposure level created by a single sub-segment to the noise grid. The single event noise exposure levels generated by a representative aircraft flying in a specific flight path or a particular set of continuous sub-segments were calculated by summing all the noise exposure levels of each sub-segment using the following formula:

$$L_E = 10 \cdot log\left(\sum_i^j 10^{\frac{L_{E,i}}{10}}\right) \quad (6)$$

where $L_{E,i}$ is the noise exposure level caused by sub-segment i^{th}

Calculation of day-evening-night cummulative noise level L_{den}

It is necessary to account for all aircraft movements during the day, evening, and night intervals to evaluate comprehensively the noise level generated by aircraft operating, as listed in Table 4. The cumulative noise levels or the equivalent continuous noise levels for the day, evening, and night intervals describes the cumulative noise exposure from all events over 24 hours a day and are calculated as follows:

$$L_{eq} = 10 \cdot log\left[\frac{1}{T}\left(n_C \cdot 10^{\frac{L_{AE,C}}{10}} + n_D \cdot 10^{\frac{L_{AE,D}}{10}} + n_E \cdot 10^{\frac{L_{AE,E}}{10}}\right)\right] \quad (7)$$

Where n_C, n_D, n_E are the number of aircraft movements of each group respectively; L_{eq} will become L_{day}, $L_{evening}$, and L_{night} with T being the time interval such as day-time (12 hrs), evening-time (3 hrs), and night-time (9 hrs), respectively. The day-evening-night equivalent noise level L_{den} is then calculated based on L_{day}, $L_{evening}$, and L_{night} by the following equation:

$$L_{den} = 10 \cdot log\left[\frac{1}{24}\left(12 \cdot 10^{\frac{L_{day}}{10}} + 3 \cdot 10^{\frac{(L_{evening}+5)}{10}} + 9 \cdot 10^{\frac{(L_{night}+10)}{10}}\right)\right] \quad (8)$$

The evening and night time are weighted 5 dB and 10 dB respectively to account for background noise reduction during these periods. Therefore the noise levels created by aircraft movement will be felt more apparent than during the day-time when the background noise is relatively higher. Finally, the noise contour maps for day-evening-night equivalent continuous noise levels were established by interpolating the value of all noise receiver points inside the computing domain around Tan Son Nhat International airport.

3. Results and Discussion

Figures 10 to 12 below show the noise contours for single event noise exposure levels generated by each representative aircraft Airbus 321-232, Airbus 350-941, and Boeing 747-400 flying out of the Tan Son Nhat International airport following the noise abatement departure procedures NADP 1 and NADP 2, respectively.

The computed noise contours using (Eq 5) and (Eq 6) described in the previous section result in noise exposure levels ranging from 85 dB(A) to 65 dB(A) around the Tan Son Nhat International airport for NADP 1 and NADP 2. The difference between the noise contours shape of representative aircraft is due to the difference in the performance of each aircraft in the specific phase of departure, such as take-off ground roll and initial climb. With the variation in the number of movements during the day-time, evening-time, and night-time, the cumulative noise continuous level must be computed to comprehensively evaluate the extent and effect of noise generated by aircraft movements to the ground. This cumulative noise is computed in terms of day-evening-night noise exposure levels using (Eq 7) and (Eq 8), as shown in the figures below

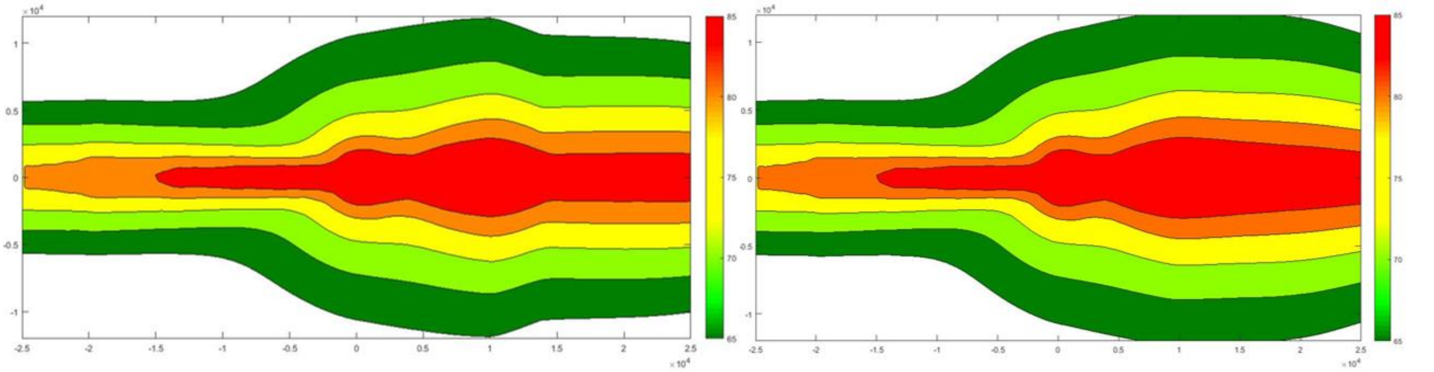

Fig. 10. Noise contours for Airbus 321-232 movements following NADP 1 (left) and NADP 2 (right)

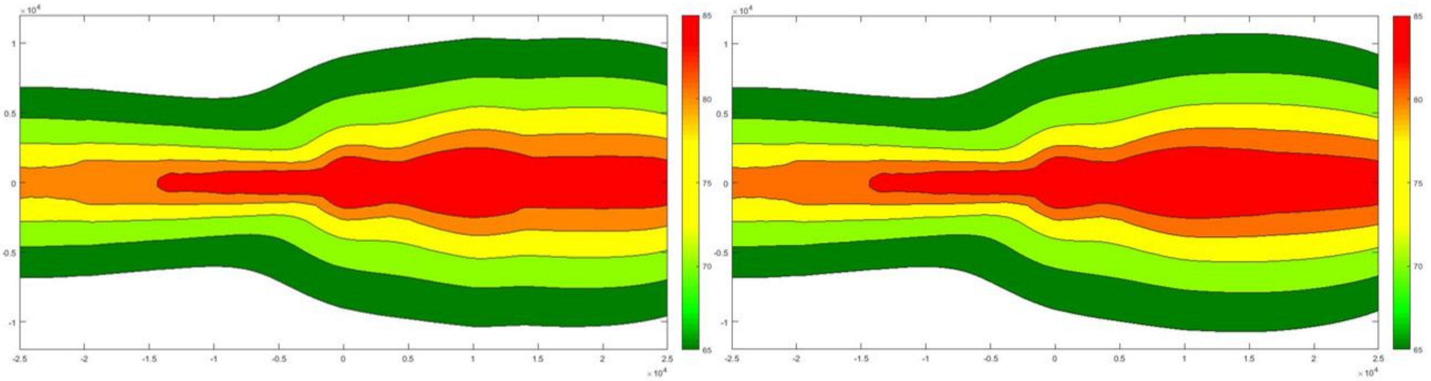

Fig. 11. Noise contours for Airbus 350-941 movements following NADP 1 (left) and NADP 2 (right)

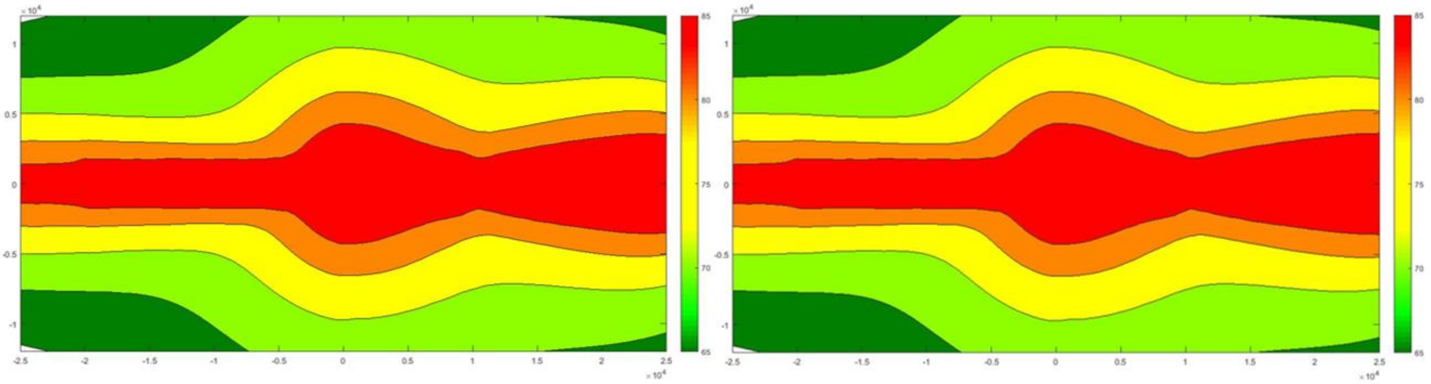

Fig. 12. Noise contours for Boeing 747-400 movements following NADP 1 (left) and NADP 2 (right)

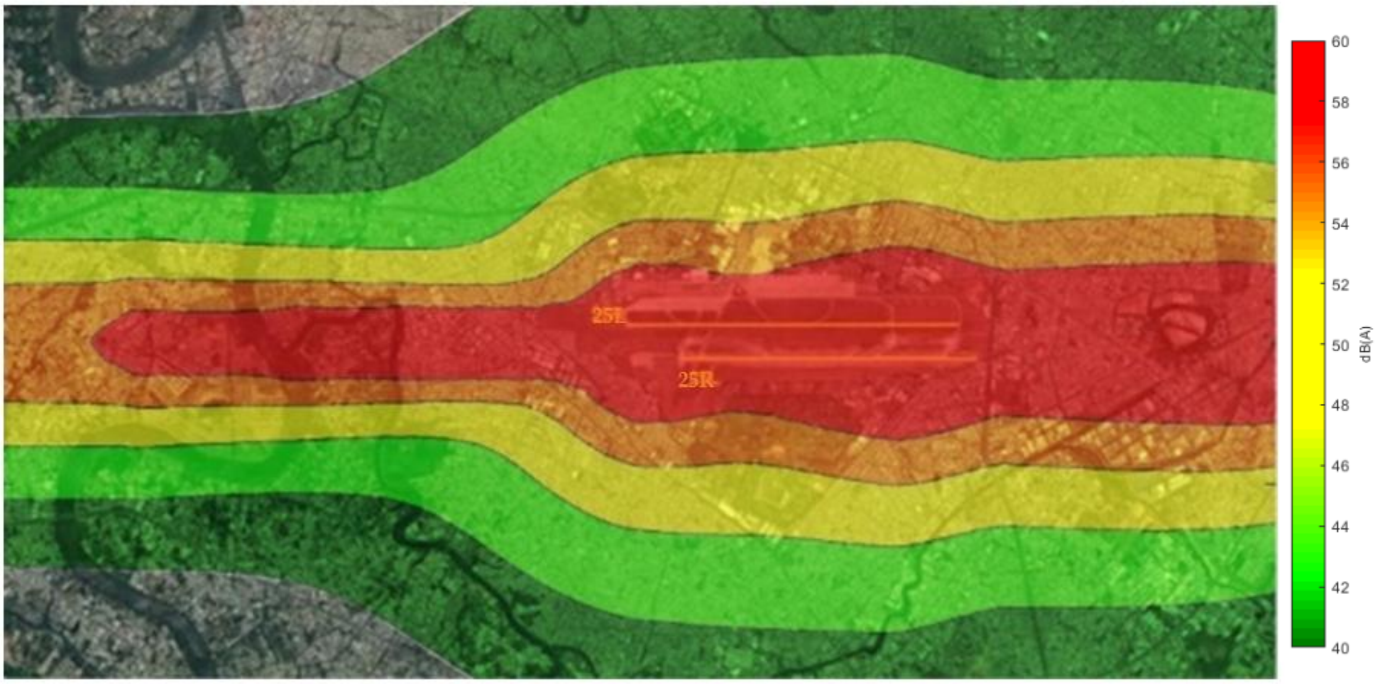

Fig. 13. The L_{den} noise contours map for aircraft movements following NADP 1 (cumulative noise exposure from all events over 24 hours).

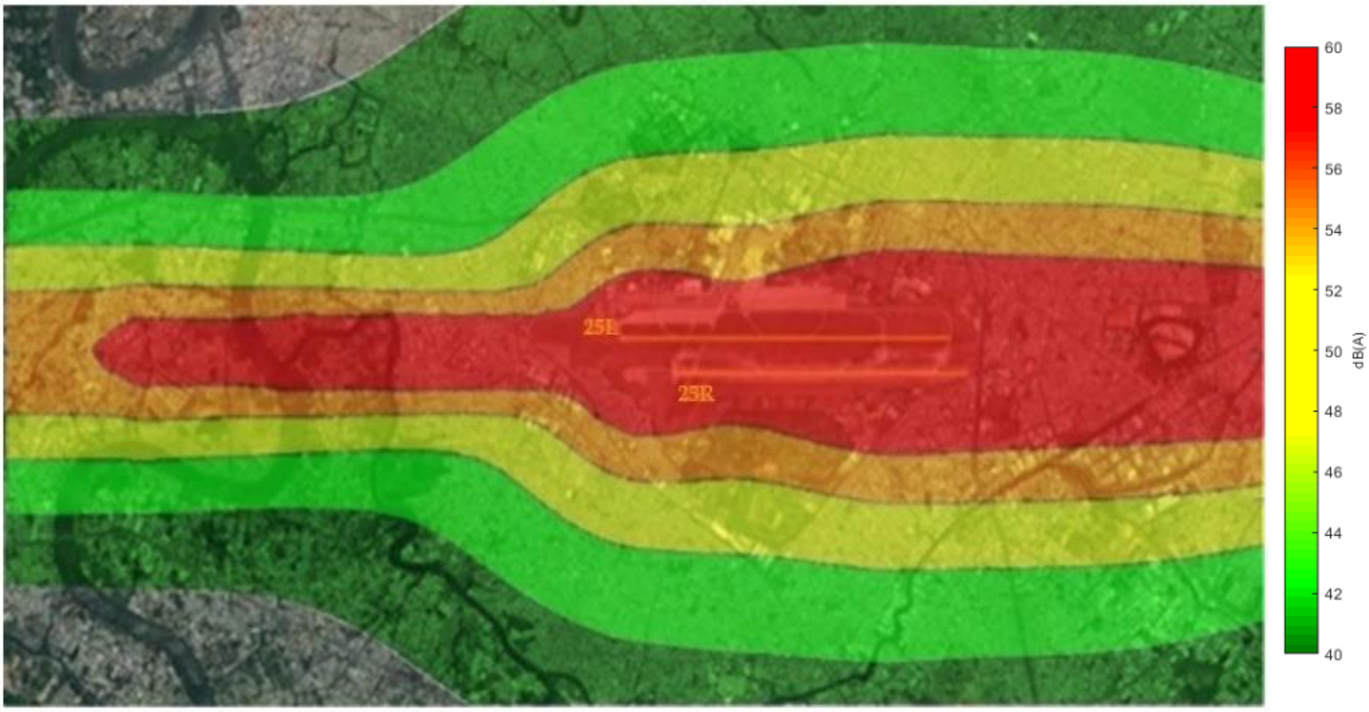

Fig. 14. The L_{den} noise contours map for aircraft movements following NADP 2 (cumulative noise exposure from all events over 24 hours).

The highest simulated day-evening-night equivalent noise levels in the noise contours for both procedures are 60 dB(A) which occurs in the region nearest the ground track – parallel to the runway and directly beneath the flight path – and gradually decreases in the area far from the airport. These results are consistent with the natural characteristics of noise generated by aircraft movements when the noise levels are related to the slant distance between noise sources and noise receivers and aircraft engine thrust. The following figure expresses noise contour lines for aircraft movements following flight procedures NADP 1 and NADP 2 around Tan Son Nhat International airport in the exact figure.

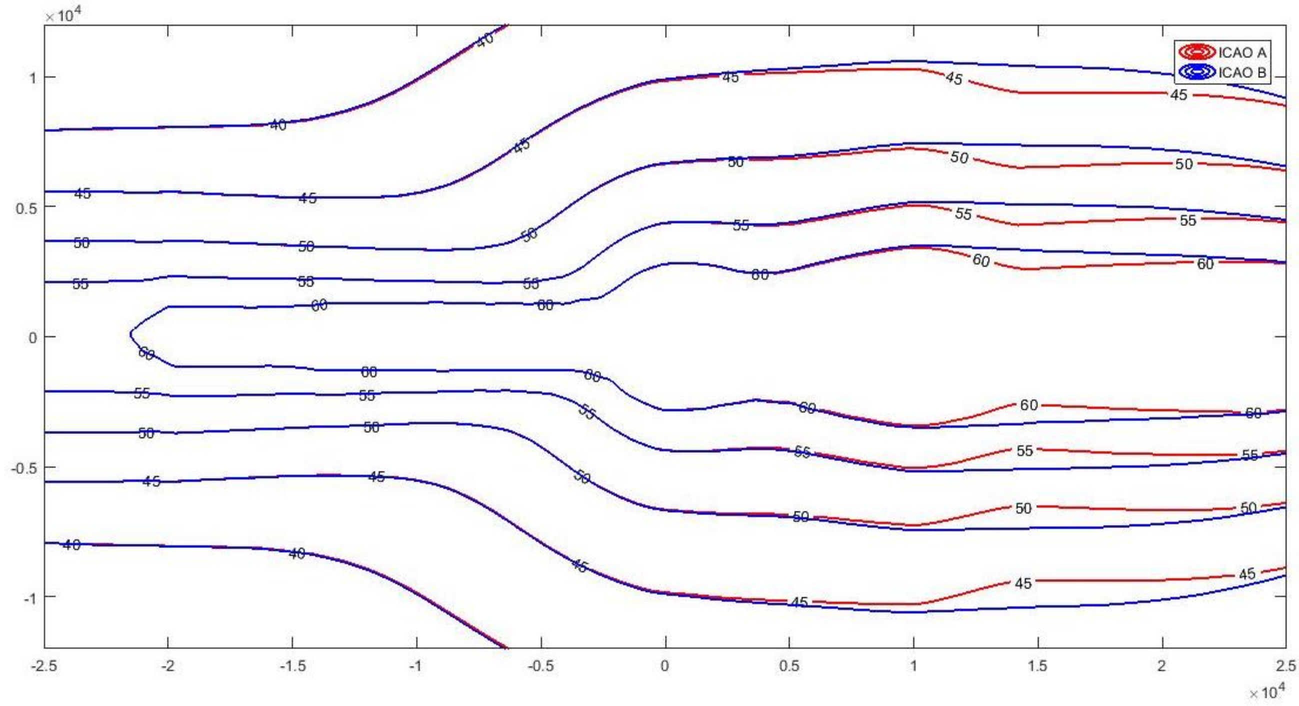

Fig. 15. The L_{den} noise contours line for aircraft movement following NADP 1 and NADP 2 (or ICAO A and ICAO B).

4. Conclusions

This research has successfully simulated the noise contour maps assuming that aircraft depart from the Tan Son Nhat International airport following the noise abatement departure procedure 1 and 2. The results show that noise levels range from 40 dB(A) to 60 dB(A), with the significant difference between the two procedures occurring at the end of the runway when the aircraft begins to lift off and conduct the initial climb phase. That is because those aircraft following the NADP 1 must climb as fast as possible to 914.4 m (3000 ft), and thus, the contour lines of the departure area will be slightly narrower than the NADP 2 when the aircraft fly far away from the runway. The results have presented that if the noise abatement departure procedures are applied in daily aircraft operation, the day-evening-night exposure levels around the airport generated by aircraft taking off around the Tan Son Nhat International will range from 40 dB(A) to 60 dB(A), which is an acceptable level that does not risk harming human health demonstrated by numerous research studies. The established noise maps are the basis for effectively assessing the noise levels at Tan Son Nhat International airport for the authority, thereby providing solutions for rational land use planning in the affected area by high noise levels. Moreover, it also aids the authorities in issuing regulations on noise level limits and aiming to develop noise contour maps for all major airports in Vietnam. As a matter of fact, adopting noise-reduced take-off procedures is a small part of the effort to prevent noise pollution around airports, and it also requires meticulous study to ensure that safety is prioritized. Each noise reduction procedure has its advantages and disadvantages; therefore, to select the appropriate noise abatement procedure to apply for the specific airport, it is necessary to thoroughly consider the situation and the extent of the noise-sensitive area around the airport. These steps can only be completed in partnership between researchers, aviation authorities, and airlines. In further studies, it is necessary to study the combination of different noise reduction measures that suit the actual conditions at the airport as suggested by ICAO in order to get better noise reduction effects. The results of this study can also be integrated into the geographic information system (GIS) to assess the number of affected populations in the high noise levels areas at the departure zone of the Tan Son Nhat airport.

Nomenclature

ADS-B : Automatic Dependent Surveillance-Broadcast
AIP : Aeronautical Information Publication
AIR : Aerospace Information Report
ANP : Aircraft Noise Performance
ECAC : European Civil Aviation Conference
GIS : Geographic Information System
ICAO : International Civil Aviation Organization
NADP : Noise Abatement Departure Procedure
NDP : Noise-Power-Distance
RWY : Runway
SAE : Society of Automobile Engineers

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