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NOISE CONTROL FOR A BETTER ENVIRONMENT

Considering the influence of the sound source noticeability on aircraft noise annoyance

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ABSTRACT

This paper considers a possibility to mitigate noise annoyance due to low-level but highly frequent flyover noise exposure from a viewpoint of reduction of the noticeability of the sound source. Despite the remarkable sound reduction at the source, there are still a lot of complaints about aircraft noise. People living near the flight path, even if far from the airport, also make complaints about aircraft flying just overhead. In Tokyo metropolitan city, airport capacity expansion by introducing new flying routes over the city area is planned to prepare for the Olympics being held in 2020. Thus, it is urgent to resolve such complaints and to prevent outbreak of serious noise disputes beforehand. This paper looks back on such issues of complaints happened in Japan and discusses a possibility to mitigate noise annoyance by reducing the frequency people may feel aircraft flying overhead through flight route controlling.

Keywords: Aircraft Noise, Annoyance, Noticeability
I-INCE Classification of Subject Number: 66

1. INTRODUCTION

In Japan, despite a remarkable progress in the introduction of low noise aircraft, noise complaints are continually brought to airport authorities. With the adoption of area navigation, aircraft fly along the flight path as if trains run on the rail, which causes noise complaints against incessant noise events from aircraft flying overhead from people living underneath the path. While under the progress in the planning to expand air traffic capacity in the Tokyo metropolitan area aiming to prepare for the Olympics, this paper discusses a possibility to lessen such noise complaints by reducing the noticeability of the sound source through adjustment of flight paths by taking into consideration human sense concerning the detection of sound arrival direction. Controlling of flight paths for the decrease of noise impact may have not been considered from a psycho-acoustical viewpoint because of the speciality of flight control management. This paper also discusses time difference to recognize a sound source between visual and aural senses. Noise annoyance is a general psychological feeling of life disturbance accumulated by long-term repetitive exposure to aircraft noise, which may not link straight to the 'qualia' being conscious of a sound source, but the possibility of the outbreak of noise complaints may be lessened through the reduction of the noticeability of flying aircraft.

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2. REVIEW OF NOISE ABATEMENT BY OPERATIONAL PROCEDURES

2.1 Framework of Noise Measures and Noise Abatement Flight Procedures in Japan

Aircraft noise measures around civil airports in Japan have been performed under the framework of noise measures consisting of emission control (noise certification and controlling operational procedures, etc.) at the source side, transmission control (reforming airport structures, airport removal, etc.) and immission control (home removal, soundproofing of houses, etc.) at the receiver side [1] . As operational measures, noise abatement flight procedures, preferential use of specific runways and flight paths were implemented appropriately according to the situation of individual airports, but in recent years the introduction of the latest noise abatement flight procedures such as area navigation (r-NAV) and continuous descent approach are also in progress gradually. Restrictions of flight operations at night have been also implemented as emission control means at many airports.

Internationally, ICAO recommends Balanced Approach (BA) to aircraft noise management that noise measures should be performed based on combining appropriate combination of four basic elements (measures at the source, noise abatement flight procedures, land use planning and management and flight restrictions as the final means) according to airport characteristics [2] . Japan has implemented all but the land use planning among the four elements of the BA. Above all, the introduction of low-noise aircraft has greatly contributed to the improvement of acoustical environment around the airport [3] . As a result, aircraft noise is no longer considered as a critical environmental problem, and the national budget for environmental noise measures has been drastically reduced. Meanwhile, now in the Tokyo metropolitan area, expansion of air traffic capacity for international aviation is an important issue to prepare for the hosting of Tokyo Olympics, etc., and it is about to introduce flight routes to fly aircraft above densely populated city areas in the metropolitan area to realize the capacity expansion. It is, however, inevitable to manage new noise issues such as noise complaints about low level but highly frequent aircraft flyover sound caused by the operation of aircraft flying overhead relatively far from the airport as well as about noise annoyance issues due to seasonally or temporally biased exposure to aircraft noise.

When we consider the management of noise exposure in the vicinity of airports, particularly in areas underneath the flight path before landing or after take-off, rather distant from the runway, we remember that there are two basic ways of flight path control methods; dispersion and concentration. Taking the former policy means aiming at noise influence dispersed to realize noise sharing or fairer noise burden, whereas taking the latter means aiming at minimization of noise impact area by confining noise exposure within a narrow area underneath the path. The former is found in the airspace where the spacing is adjusted by the radar vector before the final approach, while the latter corresponds to the situation underneath the flight path where aircraft approaching using the area navigation. The latter is causing new noise complaints far from the airport.

2.2 Issues of Low-Level but Highly Frequent Flyover Noise Exposure

At Haneda International Airport, high noise region became confined on the sea surface owing to the airport removal to offshore, introduction of LDA approach, flight route control, etc. However, with the expansion of traffic capacity, the fourth runway D was constructed and was put into service in 2010. After the start of using D-runway, as is shown in the right figure of Figure 1, flight routes for south wind were totally changed [4] . Fixed flight routes over the densely populated Chiba City were set up for south wind situation and aircraft came to precisely fly along specified flight routes, using area navigation, at a short interval as if trains run on the rail. Air traffic concentration happened to occur above the densely populated Chiba City, 20 km or farther distant from the airport, resulting in severe noise complaints in case of south wind configulation of flight routes against the low level but incessant flyover noise exposure with a maximum noise level of at most 70 dB and one flight event per a few minutes. It was unbearable for people living underneath the flight path, although confining flight routes in a narrow corridor was determined after discussion between local authorities and the national government.

This might be a result of sensitization in psychology, i.e, progressive amplification of the negative reaction to the stimulus of repeated exposure to low-level flyover noise. Aircraft flying along a fixed route became a topic of concern. Repeated similar experiences forced people be aware of aircraft flying as ‘Aircraft fly again and again!’ People became active in listening to aircraft flyover, clearly hear it, hear loud sound and it changed to ‘worried about the sound.’ Aircraft flying both from the north and from the south intersect each other directly above a fixed point, which made a fuss due to an illusion of aircraft collision and led to a spurred sensitization. Furthermore, the head of the local government said as ‘unbearable.’ If, conversely, people's consciousness was made not to go toward the flying aircraft, habituation might have worked and aircraft sound might have been gradually less of concern. In fact, in the past, aircraft did not always fly overhead because flight path was scattered, and aircraft noise was not a major problem.

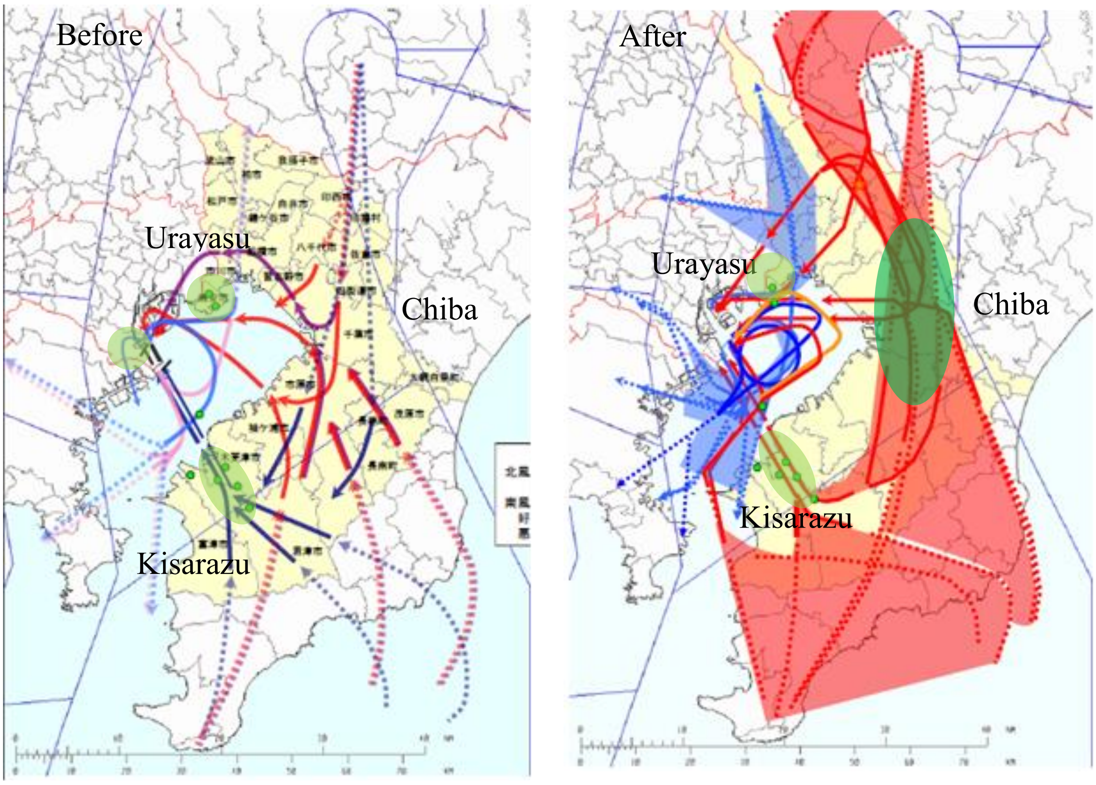

Figure 1. Comparison of flight routes and areas of noise complaints (green coloured circle) between before and after the start of using D runway at Haneda [2] .

Similar problems of low level and frequent aircraft flyover noise are there in countries other than Japan. In UK, at Gatwick and Heathrow, runway construction and rerouting was considered as options for expanding the airspace in the metropolitan area and a pilot operation was conducted at Gatwick in 2014 and residents under the route in areas far from the airport and politicians objected to the low level but frequent noise exposure as ‘absolutely intolerable’. To cope with it, the Ministry of Transport decided to set up multiple routes and use those alternately to provide a respite period [5,6,7].

Next, in USA, when San Francisco International Airport changed flight routes from the south with the introduction of NextGen at the end of 2015, resulting in severe noise complaints in areas far from the airport. Residents under the route in an area 30 km distant from the airport complained as aircraft were frequently flying low overhead and noise was loud. The FAA agreed to review the rerouted flights [8].

Finally, at Washington National Airport, flight route was changed to fly aircraft along the Potomac River as part of airspace review with the introduction of NextGen [9]. This change reduced the variation in the route, delay, fuel consumption and noise in remote areas, while noise and complaints increased in the area directly below the route. Therefore, the airport authority provided residents with a tool for checking the route and altitude online. It also conducted a trial to use three routes offset from the rNAV route that flies along the Potomac River for one month in 2015 .

As a result of checking the offset on the WebTrack, which opens actual situations of airport operation and noise to the public, the path width was concentrated within ± 500 ft on the right bank of Francis Scott Key Bridge at a distance of 7 km from T/O roll and 5 km to touch down. Flight altitude was 2,000 - 3,000 ft for takeoff and 1,000 ft for landing. Although using these routes offset does bring no significant change in noise level, airport officials seem to think that it is important to let aircraft do not always fly over the resident.

3. POSSIBILITY TO LESSEN NOISE ANNOYANCE THROUGH FLIGHT PATH SCATTER CONSIDERING HUMAN SENSE ON SOUND DIRECTION

In summary of the issue of low-level but highly-frequent flyover noise exposure described in the previous section, when aircraft fly overhead, people easily notice it and come to listen to the sound consciously. If it is repeated frequently, the sound comes unbearable and to be perceived as serious noise. Reference 10 suggests that clues we identify the sound arrival direction are as follows; in case of azimuth angle, we use a clue of differences in time and sound pressure of sound arrival between left and right ears in the frequency band of 1.5 kHz or less, whereas in case of elevation angle (front vs. rear and up vs. down) we use a spectral cue (spectral characteristics) in the frequency band of 5-10 kHz. It is said that, in particular, a frequency component of around 7 kHz is said to contribute to the discrimination of sound from directly above. However, since the target aircraft fly as high as 4000 ft, the main frequency components of the sound observed on the ground are rather low, i.e., roughly 125 Hz to 2 kHz as illustrated in Figure 2. So, as can be seen from Figure 3, the sound arrival direction in the horizontal plane (i.e., left or right and the front or back) is perceptible, while no clues are there to identify the sound arrival direction in the vertical plane, i.e., up or down [11] .

On the other hand, the interaural difference in perceptibility of sound intensity dependent on azimuth angle θ in Figure 4 can be considered also applicable to all sounds coming from any axisymmetric direction with respect to the straight line passing through the left and right ears. Thus, if the sound arrival direction is expressed using the elevation angle, which is equal to $\alpha = 90°-\theta$, and when spectral components of the source sound lie in the frequency region of 2 kHz or less, the interaural level difference becomes 1~2 dB if $\alpha = 80°$ (i.e., $\theta = 10°$) and 2~3 dB if $\alpha = \theta = 45°$. In other words, if α stays 80° or higher, the level difference remains to be only 1~2 dB, which is the lower bound we can identify the difference of sound arrival direction different from the sound coming down from directly above. In case of α ~45°, the level difference becomes to 2~3 dB and we can clearly identify that the sound comes from a different direction from directly above. In conclusion, it can be said that the limit of being able to clearly perceive the difference whether elevation angle of 45° is the border line whether the incident sound comes from directly above or not. If we apply this to the situation where aircraft fly at an altitude of 4000 ft above Chiba and assuming that flight path is deflected 4000 ft laterally of the observer, elevation angle becomes 45° and slant distance becomes √2 times the flying altitude. As a result level attenuation of the observed sound due to spherical spreading becomes 3 dB greater, which makes the observer feel to hear the sound arriving from a direction different from overhead.

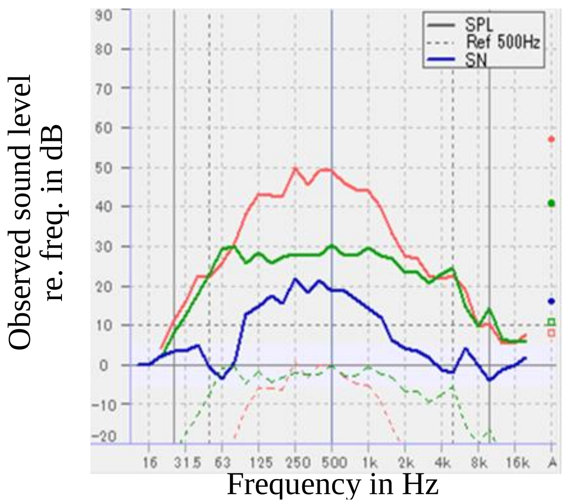

Figure 2. Illustrated noise spectrum of aircraft flying over Chiba City: Red:aircraft noise, green: background noise and Blue: S/N ratio. The dotted graphs show their levels relative to 500Hz [10] .

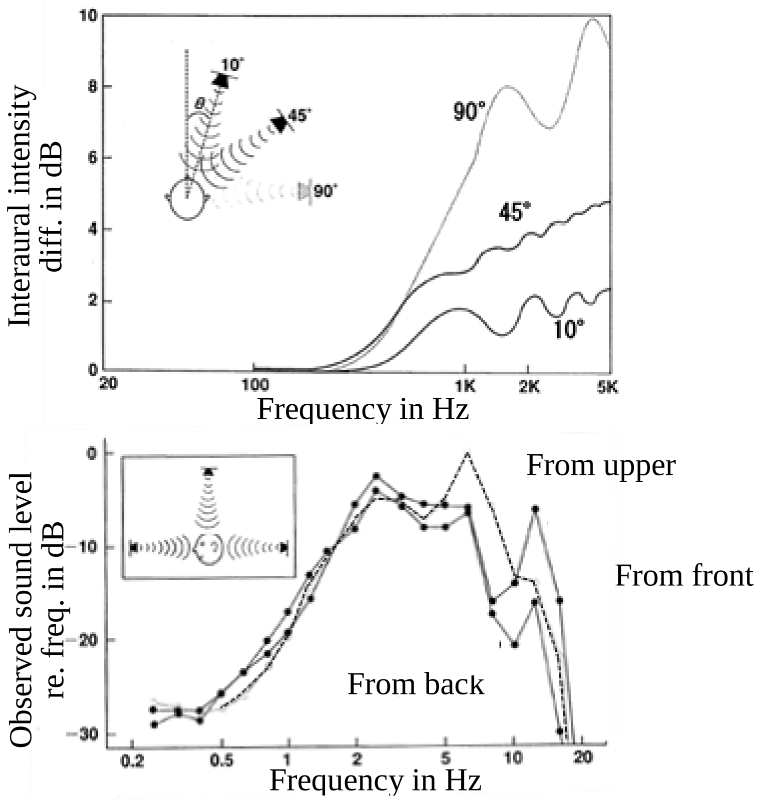

Figure 3. (Upper) Lateral difference in perceptibility of sound intensity. (Lower) Comparison of intensity spectra among sounds arriving from overhead, front and back [10] .

Thus, as the resolution in the auditory sense on sound arrival direction in the vertical section is poor, our feeling as if the sound of aircraft flying above comes down from overhead does not disappear so long as elevation angle dose not become to 45° or lower. It was not possible to investigate at what elevation angle we visually feel that an object exists above, but it was guessed to be relatively low elevation angle, similar to auditory sense, because we imagine that natural enemy to human was not in the sky but near the ground and it was not necessary to be sensitive to the difference in vertical direction. In other words, as far as elevation angle is about 45 ° or higher, we may always feel that aircraft fly overhead.

As mentioned in 2.2, before the start of using D runway at Haneda, aircraft flying above Chiba City flew at a lower altitude, but flight routes greatly scattered and not so many noise complaints were brought. On the other, after the start of service of D runway, area navigation (rNAV) was introduced in the midst of everyone's attention. As a result, although aircraft were controled to fly higher than before, residents living under the flight path came to be exposed to low-level but highly frequent aircraft noise. All residents were aware of that change from the beginning, listened to the aircraft sound always as coming down from overhead and as louder and more annoying. If possible to change the rNAV route timely and to reduce the frequency to feel as if aircraft fly overhead, it may enable to break some conditions under which the mechanism of the noise issue (low-level but highly frequent aircraft noise) holds and to reduce the degree of serious annoyance.

Finally, consider the influence of repetition of flyover sounds on noise annoyance. At which frequency of flyover events do we come to feel as aircraft fly overhead frequently? We may not feel as aircraft fly frequently when aircraft fly overhead once every hour, but in case of once every two minutes, we will definitely feel it is highly frequent repetition. The feeling changes dependent on time interval and the total of flyover events.

When aircraft fly above Chiba for approaching to Haneda in case of sounth wind, the maximum number of landing per hour is about 40. Half of those come from the north and the other half comes from the south just before the final approach. Thus, about 20 aircraft per hour fly overhead before the final, which means that one aircraft fly overhead every three minutes. If it is possible to provide two optional parallel flight routes on both sides of the specific original route and to use the three routes in turn at certain time intervals, which will be determined from the viewpoint of safety in air traffic control, people under the three routes will have a noisier time slot of 30 minute long with 10 aircraft flying overhead every three minutes and afterward will have a quieter hour as respite without being annoyed through noticing aircraft flying overhead. Twenty flights per hour is the upper limit. Actual situation is expected as a bit more sparse; e.g., if we suppose 6 flights per 30 minutes, aircraft only fly at 5 minute intervals, which may reduce the probability people notice aircraft flying, and their feeling of annoyance due to ‘aircraft flying their overhead frequently’ may be also lowered considerably.

We are sensitive to a change in our surrounding, but when the change is not dangerous to our lives, we will be gradually habituated and accept it as a part of our usual life situation. So, if possible to increase the number of aircraft flying step by step toward the target state over a long period of six months to a year, we expect that the feeling of annoyance due to low-level but highly frequent overhead aircraft flying will be reduced.

4. RELATIONSHIP BETWEEN VISIBLE AND AUDIBLE

It is said that when receiving an audio-visual stimulus from the outside and recognizing it, nerve activity of the cerebrum has to last at least 0.5 s till the awareness of it, but the time of awareness goes back to the moment of stimulation [11-15] . It is also said that our brain reproduces the process of 'stimulation - response' in the brain itself, feedbacks it negatively to the primary sensory cortex (auditory/visual), takes the difference from the actual input stimulus, and recognizes a change in the stimulus, which leads to the consciousness that it is visible and/or audible: In case of the visual nerve system, input information from the retina travels to the occipital visual cortex through the lateral geniculate nucleus of the thalamus, and then to the rear parietal lobe for the spatial and motor recognition and to the inferior temporal for the shape and colour recognition through the process of information abstraction, but there are nerve paths to return information to the primary visual cortex. In case of the auditory system, input information from the inner ear travels to the primary auditory cortex through the medial geniculate nucleus of the thalamus, and then to the auditory speech area through lateral cortex for language recognition and to the amygdala through the prefrontal cortex for the emotional response. There are also nerve paths to return to the primary auditory cortex. In short, when looking at an airplane flying while scattering roars, we construct an audio-visual movie picture in our brain, calculate the difference from the actual input, rewind it to the moment of the input, and recognize and become aware of an aircraft flying in real time.

When we imagine a scene that an acquaintance speaks in our brain, the voice we hear is felt really like that person. Similarly, when we recall a scene that an aircraft flies, we can hear the sound reproduced in the brain really like that aircraft. Contrary to it, if we can weaken the binding of visual and aural perceptions, may we disturb the integration of the two senses in the brain information processing stage and as a result weaken the awareness of the sound source?

5. INFLUENCE OF TIME DIFFERENCE IN THE PERCEPTION OF FLYOVER NOISE BETWEEN AURAL AND VISUAL SENSES ON NOISE ANNOYANCE

There may have been no study analysing the relationship of the way of controlling flight operations with noise annoyance reduction from a neuropsychological view point. Though it might not necessarily be realistic, the author tries to discuss if the time difference between visual and aural recognitions when an aircraft passes overhead may affect the outbreak of noise disturbance [16] .

In the late 1990's, after the opening of Kansai International Airport constructed on an artificial island in Osaka Bay, flying over land after the take-off became a major social problem in terms of noise impact. After a severe controversy among stakeholders, the minimum altitude at which aircraft fly over land was set up to 8000 ft, resulting in the settlement of the issue and no concern about noise afterwards. Next, a similar controversy was raised at Chubu International Airport, and the minimum height of flying over land was limited to 6000 ft, resulting in very few voices to complain about noise afterwards. On the other hand, about 10 years ago just after the start of the fourth runway D, the flying altitude heading for Haneda Airport over Chiba City was raised up to 4000 ft, but there was an outbreak of serious noise complaints against the low-level but highly frequent flyover noise from people living underneath the flight path and the issue continues.

At Haneda, it is planned to introduce flight routes passing over the Tokyo city area early next year, in which aircraft approaching under south wind and good weather conditions are scheduled so that aircraft enter the air space over the central Tokyo at an altitude of 6,000 ft, then descend to 4,000ft and fly heading for final approach directly above the central downtown, and thus an outbreak of noise issues is concerned.

In Clause 3, the author discussed a possibility to solve the issue of noise impact of low-level but highly frequent aircraft sound events, of which the maximum AS sound pressure level is 65~70 dB at most, by dispersing the flight path in space (left/right) and time and by lowering the possibility of sound source recognition. Here, the author examines the relationship of the outbreak of noise complaints with the flight altitude from the viewpoint of time difference in the sound source recognition between visual and aural means.

A lot of aircraft fly around above the metropolitan area, but in case of aircraft cruising at a high altitude of 30,000ft, the AS-weighted sound pressure level becomes less than 50 dB, and it is less likely to notice. If looking up at the sky, finding a contrail and noticing that an aircraft flies, it seems as if it moves without sound like a silent movie.

On the other hand, in case of aircraft taking off or landing at Haneda, the aircraft altitude during the flight over down town is about 10,000 ~ 4,000 ft, at which the AS level observed is roughly speaking 50~70 dB. As the aircraft descends, its figure becomes visible and the sound can be heard, but those areas are located far from the noise zones specified for noise impact mitigation measures around the airport.

Now, Figure 4 shows a result of calculation concerning the relationship of flight positions and times of the sound source observation when an aircraft flies horizontally at heights of 4,000 ~ 10,000 ft over the observer. Flight positions were related with times of sound radiation or observation within the '10dB-down' duration, which is almost equal to a range of angle of view (~ ±70°). In the figure, times of various AS levels observed were related to flight positions when those levels occurred, as illustrated for the case of level flight at the altitude of 8,000 ft: the time when the aircraft arrived at a position emitting the sound of 10dB-down level ($L_{\mathrm{AS,10dB\text{-}down}}$), the time when that level was observed, the time when the aircraft came directly above the observer, the time of L_{ASmax} observation, the time when the aircraft emitting the sound of $L_{\mathrm{A,10dB\text{-}down}}$ again and the time when that level was observed. From this illustration, we can see that the time of L_{ASmax} observation is delayed by 7 s behind the time of aircraft passing directly above the observer, the aircraft moves 971 m ahead from just above and the change in angle of view is 22 °. Similarly, the time delay and moving distance are 3.5 s and 485 m in case of altitude 4,000 ft, 5.2 s and 727 m in case of altitude 6,000 ft, and 8.7 s and 1,212 m in case of altitude 10,000 ft. These results suggest that when listening to a sound of a plane flying overhead at high altitudes and searching the figure in the sky soon, it is often difficult to find it. The plane will go away while doing it. Note that calculation of the times was carried out without considering factors affecting sound propagation such as the sound source directivity and air absorption. If those are taken into consideration, aircraft positions may be a bit different.

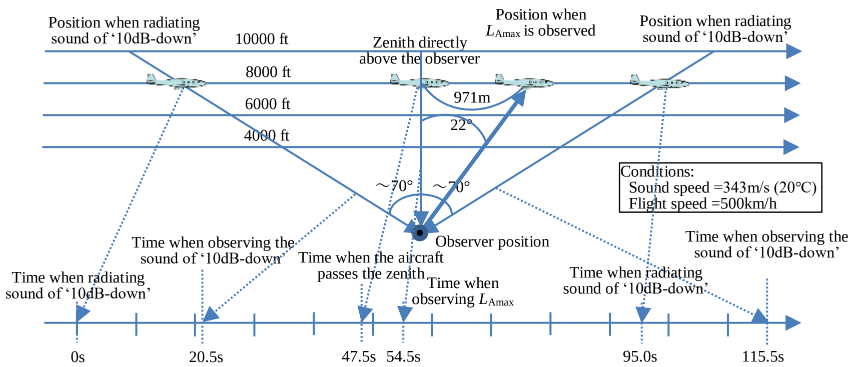

Figure 4. Relationship of aircraft positions and observation times durng level flight [16] .

Apparent size of aircraft was compared between aircraft flying below 4,000ft and above 6,000ft as a factor affecting the perception of aircraft flying. In case of B737-800 (body length 40 m), angular size is 1.9 ° at a distance of 4,000 ft, whereas it becomes 1.3 ° at 6,000 ft and 0.95 ° at 8,000 ft, which means that angular size remains less than 2 ° at 4,000 ft or longer. In case of large aircraft such as B787 and B767, angular size is over 2 ° at 4,000 ft, but below 2 ° at 6,000 ft or higher. Note that angular diameter of a Japanese ten-yen coin (23.5mm) is 2.2 ° when looking at the tip of an extended hand holding a coin. Besides, as the ventral side of aircraft body is no paint usually, it becomes less noticeable from the blue sky as the altitude is higher. As a result of these reasons, it is barely possible to recognize aircraft flying at 4,000 ft or lower, but it becomes difficult to do it at altitudes higher than 4,000 ft.

When an aircraft flies overhead at an altitude of 4,000 ft or less, it is easy to recognize the aircraft visually as well as aurally. The time difference between visual and aural recognition times is also small. As a result, visual and aural images of the aircraft are easily integrated each other. On the other hand, when the aircraft flies at 6,000ft or higher, sound level decreases, visual size becomes smaller and the gap in the sound source recognition times between visual and aural means becomes larger. As a result, it becomes difficult to associate the visual image with the aural one.

When aircraft fly overhead frequently, people easily come to notice it, watch those aircraft and listen to the sound, then be annoyed and finally come to feel the sound as intolerable. That is the mechanism of low-level but highly frequent aircraft noise issues. If possible to apply an appropriate offset, spatial or temporal, to the flight path, such feeling of disturbance can be reduced.

6. CONCLUSIONS

This paper considered a possibility to mitigate noise annoyance due to low-level but highly frequent flyover noise exposure from a viewpoint of reduction of the noticeability of the sound source. Despite the remarkable sound reduction at the source, there are still a lot of complaints about aircraft noise. People living near the flight path, even if far from the airport, also make complaints about aircraft flying just overhead. In Tokyo metropolitan city, airport capacity expansion by introducing new flying routes over the city area is planned to prepare for the Olympics being held in 2020. Thus, it is urgent to resolve such complaints and to prevent an outbreak of serious noise disputes beforehand. This paper looked back on such issues of complaints happened in Japan and discussed a possibility to mitigate noise annoyance by reducing the frequency people may feel aircraft flying overhead through flight route controlling. As a key to solve this issue, first, it was discussed to set up three adjacent route options based on the perceptibility of sound arrival direction, and to use those options in turn and provide quiet respite time to decrease noise annoyance. Next, as the basis for a new idea for reduction of noise annoyance, we examined the difference of perceptibility of flying aircraft between visual and aural senses and found that the time lag between aural and visual recognition of the sound source is large when aircraft fly at an altitude of 6,000 ft or higher and it is often not possible to identify aircraft sound even if it is visually captured. Such a large time lag between visual and aural source recognition may interfere with the sensory integration in the sound source discrimination in the brain information processing stage, thereby reducing the awareness of the sound source and the development of negative emotions such as discomfort and annoyance. In order to understand the intracerebral network activities from the visual and aural perception of a scene to the annoying emotion, our neuropsychological understanding must be spread to the basic intracerebral processing such as learning, long-term memory, declarative memory and emotional memory, etc.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. I. Yamada, “Continuing efforts and challenges to reduce the impact of airport noise in Japan.” Proceedings of INTER-NOISE 2012 (2012)
2. I. Yamada, “Considering noise policy for low-noise but frequent flyover events far from the airport,” ICBEN 2014 (2014)
3. I. Yamada et al., “Study on land use planning with improved noise compatibility around airfields.” INTER-NOISE 2012 (2012)
4. I. Yamada, “Possibility to realize noise impact mitigation taking account of human sensing of sound arrival direction for increasing airport capacity,” Proc., ASJ, SEP (2016)
5. http://www.bbc.com/news/uk-england-34805324
6. Gianluca Memoli, “Gatwick Airport Arrivals Review: Perception of Aircraft Height and Noise (Imm-15),” University of Sussex, 2018. ISBN: 978-0-9957862-3-3.
7. http://www.bbc.com/news/uk-england-30173769
8. http://www.sfgate.com/bayarea/article/Feds-to-review-flight-paths-as-Bay-Area-noise-6642238.php
9. http://www.flyreagan.com/dca/reagan-national-aircraft-noise-information
10. K. Iida et al., Spatial hearing, Corona Publishing (2010)
11. W. M. Hartmann, “How we localize Sound,” Physics Today Vol.52, No.11 (1999)
12. D. Kwon, Self-Taught Robots, SCIENTIFIC AMERICAN, MAR (2018)
13. M. Watanabe, Brain Consciousness Machine Consciousness - Neuroscience Science Challenge, Chuokoron-Shinsha, NOV (2017)
14. Brain science textbook Heart edition (Iwanami Junior Shinsho) Shinsho, JUN (2013)
15. Brain science textbook Nerve edition (Iwanami Junior Shinsho) Shinsho, APR (2011)
16. I. Yamada et al., “Influence of visual image of the sound source on noise annoyance of air and high-speed rail transport,” Proc., ASJ, SEP (2018)