

The effects of aircraft take-off thrust reduction on noise exposure around the airport

NAKAZAWA, Toshiyasu¹, SHINOHARA, Naoaki
Aviation Environment Research Center, Organization of Airport Facilitation
5F, 1-3-1, Shiba-koen, Minato-ku, Tokyo, Japan, 1050011

HANAKA, Kazuyuki
Narita International Airport Promotion Foundation
Chiba, Japan

ABSTRACT

Currently, airline and pilots use some method of aircraft engine thrust reduction during take-off and climb operations, for reasons of environmental and economic profits. Because of these operation methods, the aircraft profile has changed to a tendency that aircraft climb gradient is clearly lower and the engine thrust is reduced, as compared with the previous one.

In order to understand how these trends affect noise exposure, the results of measurement of aircraft noise and flight profiles at the airport in Japan were analysed. However, parameters for confirming the reduced thrust amount can only be obtained from Flight Data Recorder or Quick Access Recorder on the aircraft. Instead of that, the measured noise and flight profile were analysed and the condition of the aircraft engine thrust was inferred.

Then altitude change and thrust change due to thrust reduction were inferred by analysing these results in relation to aircraft type, take-off weight and ambient temperature. Finally, it was examined how much thrust reduction affect noise exposure around the airport.

Keywords: Aircraft Noise, Engine thrust reduction

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1. INTRODUCTION

Recent aircraft operating for passenger transport does not operate with the engine thrust close to the maximum but can operate as necessary with minimal engine thrust as required. For this reason, many aircraft are currently take-off and climb operation with reduced thrust for environmental and economic merits.

It was reported in INTER-NOISE 2018^[1] that the aircraft profile is clearly to decrease due to the thrust reduction. And, compared to the altitude profile in 2008,

¹ t-nakazawa@aeif.or.jp

the altitude profile in 2017 clearly decreased in climb gradient, and the noise level measured on the ground did not increase correspondingly. From these results, it can be estimated that there is some change in engine thrust.

While flying from the airport to the airport, the aircraft selectively uses thrust according to the flight phase. When departing from the airport, the aircraft first uses take-off thrust in the take-off section and then flies using climb thrust in the climbing section. The take-off thrust is the thrust which starts from the take-off roll and is used from altitude 0 ft to roughly 800-1,500 ft, and it is the strongest thrust in flight. The climb thrust is the thrust that is used at the altitude of 10,000 ft or more after the end of the take-off thrust and is the second strongest thrust after the take-off thrust during flight. In most current passenger aircraft, these two thrusts can be reduced. Especially, since the take-off thrust has a large energy, the merit obtained by reducing the thrust is also great.

In the steepest climb procedure usually used in Japan as a noise abatement departure procedure, a take-off section and a climb section are defined. The take-off section starts with take-off thrust at an altitude of 0 ft, ends by switching to climb thrust at an altitude of 1500 ft or more, and thereafter becomes the climb section. In the noise abatement departure procedure NADP1 and NADP2 defined by ICAO, the take-off section ends at an altitude of 800 ft or more, and thereafter becomes the climb section.

Since higher flight performance is required for take-off and climb section, Rated-thrust is defined as the default thrust, which is close to the maximum thrust. Additionally, in the aviation regulation ^[2], two methods of the thrust reduction are allowed. One is Derated-thrust which reduces at a certain rate such as 5%, 10%. Another is Reduced-thrust which continuously sets the reduction amount according to the temperature and so on. In case of take-off it is possible to greatly reduce the engine thrust by combining these two methods.

Considering how thrust reduction affects noise, it is inferred that two contradictory changes occur simply. One is the possibility that the noise decreases by the reduced thrust. The other is the possibility that altitude decreases due to thrust reduction and the noise on the ground increases. Because of these trade-offs, it is hard to see how thrust reduction affects the noise impact around the airport.

In order to confirm this, it is necessary to obtain the information of the noise on the engine side. However, since it was not possible to obtain onboard data such as the Flight Data Recorder or Quick Access Recorder, in which measurable indicators such as N1% and EPR of aircraft engines were recorded. Therefore, it is necessary to estimate engine thrust status from another method. As a method of confirming engine thrust from outside of aircraft, we examined and tried a method using the noise level itself. Then the impact of the thrust reduction on the noise around the airport was considered.

2. ESTIMATION OF NOISE LEVEL AS SUBSTITUTE FOR ENGINE THRUST

2.1 Method

In order to confirm the reduced thrust, it is necessary to look for alternatives to values such as N1% and EPR. Then using the noise level which can be measured outside the aircraft are examined.

NPD data used in segment models are based on the idea that noise levels and engine thrust correspond to each other. This means that when the noise level is processed to NPD data that value may be associated with the engine thrust. However, there is no detailed description of how to produce NPD data in the currently published ICAO Doc. 9911 2nd edition^[3] and ECAC Doc. 29 4th edition^[4]. Therefore, retroactive to ECAC Doc.29 2nd edition^[5], ICAO Circular 205^[6], the noise levels at aircraft side are estimated with reference to the method of producing NPD data from the noise measurement results.

In this method, 1/3 octave band levels are measured on the ground when the maximum noise level of the flyover aircraft. Each band levels at the side of the aircraft are estimated taking into consideration geometric attenuation and air absorption attenuation according to the weather conditions and the distance from the aircraft measured. In this report, these distances are normalised to point of 1 meter from the aircraft. Finally, the noise level at the aircraft side is estimated by summing up these band levels. It is to be noted that estimated engine noise levels contain the airframe noise or the noise directivity of aircraft engine.

In order to measure the noise of the take-off section where the thrust reduced, noise measuring point was set just below the flight path where the aircraft altitude is 1650ft or less (Japanese steepest procedure altitude 1500ft plus runway elevation 150ft). Aircraft noise was measured for seven days from October 26th to November 3rd, 2017 at 4.5km on the extension of runway-A (4000m) at Narita Airport in Japan. In order to obtain the altitude, ADS-B was recorded, which is a broadcast including the three-dimensional aircraft position measured by GPS on the aircraft. During the measurement, the weather was fine with an average temperature of 15.2C and a wind of 6 kt or less.

These data were classified by flight movement and categorized by aircraft type and flight operation type. The aircraft type that can obtain the sufficient number of operating flights with the take-off was extracted. The altitude obtained by ADS-B was corrected to the true altitude with air temperature and pressure, and the slant distance between the aircraft and the measurement point was calculated. Finally, geometric attenuation and air absorption were applied in consideration of air temperature, humidity, and slant distance, and an estimated noise level at a side point of the aircraft was calculated.

2.2 Frequency distribution of estimated noise level as substitute for engine thrust

The results are compared with B767-300, B787 (B787-8 and -9) for which a sufficient number could be measured, and aircraft size are similar. Generally, there is a proportional relationship between take-off weight and engine thrust. However, since take-off weight is unknown, it is assumed that take-off weight is proportional to the fuel amount linked to the distance to the destination airport, and the distance to the destination airport is used for analysis. The great-circle distance of each aircraft is calculated from the latitude and longitude between the airports, and results are classified into three categories such as long-haul, medium-haul, and short-haul aircraft. Figure-1 shows the frequency distribution of the estimated noise level at the aircraft side as substitute for the engine thrust.

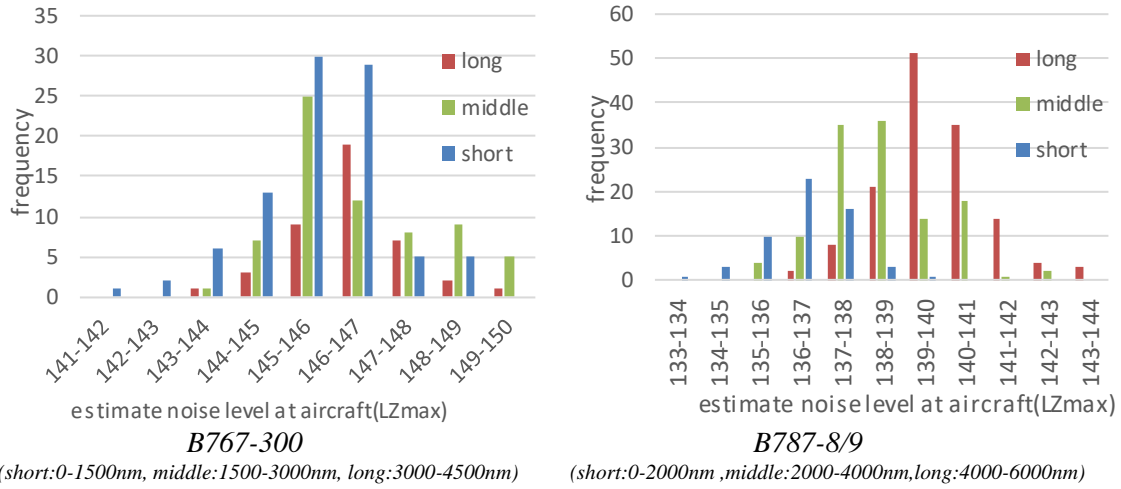


Figure 1. frequency distribution of estimated noise level as substitute for engine thrust

Both aircraft type distributions are about 10 dB wide. Usually, a long-haul aircraft has heavy take-off weight and high thrust, and conversely, a short-haul aircraft has light take-off weight and low thrust. The frequency distribution of the estimated noise level is as well. From these results, it is considered that the estimated noise level represents the state of engine thrust.

From the distribution state, there is difference that the distribution of the B787 's estimated noise level is clearly separated depending on the trip-distance category, and B767 is not. The distribution of B787 is that the noise level is high for long-haul aircraft and low for short-haul aircraft, while B767 has the same distribution of noise level regardless of trip distance. According to the reported result of INTER-NOISE2018^[1], the comparison of the altitude profile of ANP database with the altitude profile of take-off weight measured at Narita Airport showed that engine thrust of measured B767 is not reduced much because their difference in the climb gradient is small, that of B787 is reduced because the climb gradient of measured B787 is low.

If this is also the case, in the frequency distribution of estimated noise level, engine thrust of B787 indicated by the estimated noise level is supposed to reduce at middle-haul and short-haul. On the other hand, the engine thrust of B767 indicated by estimated noise level is not supposed to reduce, and the distributions overlap even with aircrafts of different trip-length. From this difference, it is supposed that when the thrust is reduced, the peaks of the middle-haul and short-haul estimated noise level distribution move to the lower side.

2.3 Relationship between aircraft altitude and estimated noise level as substitute for engine thrust

Next, Figure 2 shows the correspondence between the altitude and the estimated noise level. The vertical axis of the figure is the estimated noise level ($L_{Z,Smax}$) as substitute for engine thrust, and the horizontal axis is true altitude (ft) of aircraft. Since

the distribution of altitude and estimated noise levels is wide and quantitative analysis is difficult, so this result is considered qualitatively.

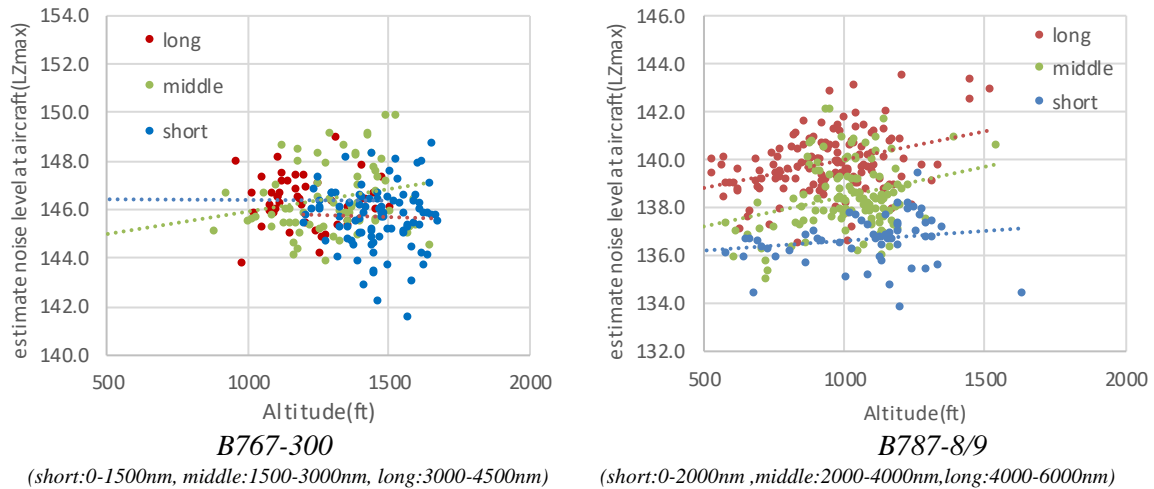


Figure 2. relationship of aircraft altitude and estimated noise level as substitute for engine thrust

Usually the altitude is high for high thrust and low for low thrust. Looking at the B787 by trip-distance, the rise in estimated noise level is slightly proportional to the rise in altitude, but the B767 is not. And B787 flies around similar altitudes regardless of the estimated noise level, but B767 shows the relationship that the long-haul aircraft flies low altitude, the middle-haul aircraft flies medium altitude, and the short-range aircraft flies high altitude.

From these results it is supposed that the aircraft that does not use reduced thrust like the B767 has a relationship between take-off weight and altitude, although there is no relationship between take-off weight and thrust. Furthermore, it is supposed that the aircraft using reduced thrust like B787 has a relationship between take-off weight and thrust, though there is no relationship between take-off weight and altitude.

Finally, it was experimentally estimated how much the noise value would be reduced when the thrust was reduced. The regression coefficient was 400 to 500 as a result of regression analysis of the altitude and estimated noise level according to the trip-distance as shown in Figure-2. That means, when the estimated noise level as substitute for engine thrust is reduced by 1 dB, the altitude decreases by 400 to 500 ft at this measurement point. Assuming that the aircraft passing an altitude of 1200 ft reduces the thrust by an estimated noise level of 1 dB, the altitude drops to 800 ft, resulting in a noise increase of 1.76 dB in slant distance decrease, and a total noise increase of 0.76 dB at the measurement point. Note, however, that the coefficient of determination r^2 is about 0.1 and it has less validity. It is necessary to consider other measurements and many factors for valid estimation.

3. DISCUSSION

Currently, many aircrafts operate with engine thrust reduction during take-off and climb operations, for reasons of environmental and economic profits. In order to

understand how these trends affect noise exposure, the results of measurement of aircraft noise and flight profiles at Narita airport in Japan were analysed. However, parameters for confirming the reduced thrust amount can only be obtained from Flight Data Recorder or Quick Access Recorder on the aircraft. Instead of that, the measured noise and flight profile were analysed, and the condition of the aircraft engine thrust was inferred.

The estimated noise level at the side of the two types of aircraft B767 and B787 was calculated as substitute for engine thrust, and from the distribution tendency it was found that the estimated noise level is represented engine thrust. In addition, it was found that engine thrust of short-haul and medium-haul aircraft decreased from engine thrust of long-haul aircraft, and it was supposed because a result of the thrust reduction.

From relationship between estimated noise level as substitute for engine thrust and aircraft altitude, it is supposed that the aircraft that does not use reduced thrust like the B767 has a relationship between take-off weight and altitude, although there is no relationship between take-off weight and thrust. Furthermore, it is supposed that the aircraft using reduced thrust like B787 has a relationship between take-off weight and thrust, though there is no relationship between take-off weight and altitude.

However, for accurate noise influence analysis, it is necessary to examine the quantitative correspondence between the estimated noise level and the engine thrust parameters. Furthermore, in order to use for the noise calculation around the airport, it is necessary to measure and study in a wide area around airport. These are future work.

4. REFERENCES

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