# Consideration of meteorological effects on noise propagation by using the aircraft noise prediction model in JAXA's DREAMS project

Hirokazu ISHII[1]; Takatoshi YOKOTA[2]; Koichi MAKINO[3]; Toshio MATSUMOTO[4];
Naoaki SHINOHARA[5]; Msayuki SUGAWARA[6]

[1] Japan Aerospace Exploration Agency, Japan

[2-4] Kobayasi Institute of Physical Research, Japan

[5] Narita International Airport Promotion Foundation, Japan

[6] Aviation Environment Research Center, Airport Environment Improvement Foundation, Japan

## ABSTRACT

Japan Aerospace Exploration Agency has conducted a research project called DRAEMS. Its main aim was to develop technologies for future air traffic management systems which will enhance safety, efficiency, user convenience, and environmental compatibility of flight operations. One of the research topics examined by the project is noise abatement technology. Its key element is an aircraft noise prediction model which can take into account the effect of meteorological conditions on noise propagation. This paper investigates the ground effect on aircraft noise propagation, focusing on the variation of lateral attenuation due to the meteorological conditions. It is shown that the variations become significantly large under upwind propagation conditions.

Keywords: Aircraft Noise, Prediction, Propagation, Meteorological effects
I-INCE Classification of Subjects Numbers: 13.1.1, 24.6, 76.1.3

## 1. INTRODUCTION

With the growing demand for world air transportation, the volume of air traffic is already approaching and will soon exceed the capacity limit posed by current air traffic control. Consequently, there is a need for a new air traffic management (ATM) system capable of enhancing the safety, and improving the efficiency and environmental compatibility of air transportation.

Air traffic in Japan is also forecast to grow by 50 percent over the period 2005-2027, and Japan Civil Aviation Bureau developed a long-term plan called CARATS (Collaborative Actions for Renovation of Air Traffic Systems) (1), and initiated collaborative work among industry, academia and government to reform Japan's ATM system.

The Japan Aerospace Exploration Agency (JAXA) has been supporting the research and development under the CARATS framework and has conducted a research project called DREAMS (Distributed and Revolutionarily Efficient Air-traffic Management System) (2). One of the research topics examined by DREAMS was noise abatement flight technology. Its aim was to maintain community noise exposure at current levels even in the presence of up to a 50 percent increase in air traffic volume. In order to achieve this goal, JAXA has developed a system that optimizes approach paths considering the meteorological effects on noise propagation. It should be noted that the approach paths were optimized not to minimize the area exposed to excessive noise, but to minimize the area which would need additional countermeasures such as construction of a new buffer zone in the airport vicinity. A key element of the system was the development of an accurate aircraft nose prediction

[1] ishii.hirokazu@jaxa.jp
[2] t-yokota@kobayasi-riken.or.jp
[3] makino@kobayasi-riken.or.jp
[4] matsumoto@kobayasi-riken.or.jp
[5] shino@napf.or.jp
[6] m-sugawara@center.aeif.or.jp

model, which is able to predict a time series of instantaneous noise levels at arbitrary observer positions by considering the effect of meteorological conditions on noise propagation (3).

There are numerous methods to examine noise contours around airports, with ECAC Doc.29 (4) and ICAO Doc 9911 (5) being among the most popular and well-established ones. These methods used SAE AIR 5662 (6) to predict lateral attenuation, namely, excess attenuation of sound propagating from an airplane to observers on the ground and along flight path. Although the lateral attenuation prediction in SAE AIR 5662 considers engine-installation effects, long-range air-to-ground attenuation, and over-ground attenuation, it does not take into account the effects of meteorological conditions on noise propagation.

This paper first gives an overview of the noise prediction model developed in JAXA's DREAMS project. Then it shows the results of case studies to examine differences of lateral attenuation predicted by the DREAMS' model under various meteorological conditions. These results are compared with predictions based on ECAC Doc 29 to discuss the applicability of the model.

## 2. NOISE PREDICTION MODEL IN DREAMS

In DREAMS' noise prediction model, instantaneous octave band sound pressure level in arbitrary observer position was formulated as follows:

$$L_p^f(r) = L_w^f + \Delta L_{\mathrm{dir}}^f - 11 - 20\log_{10}(r) + \Delta L_{\mathrm{grnd\&met}}^f + \Delta L_{\mathrm{atm}}^f \quad (1)$$

where

| | |
|---|---|
| $f$ | : octave band center frequency [Hz] |
| $r$ | : distance between the source and observer [m] |
| $L_p^f(r)$ | : sound pressure level at the observer [dB] |
| $L_w^f$ | : sound power level of the source [dB] |
| $\Delta L_{\mathrm{dir}}^f$ | : adjustment for three-dimensional directivity of the source [dB] |
| $\Delta L_{\mathrm{grnd\&met}}^f$ | : adjustment for the effects of ground and meteorological conditions [dB] |
| $\Delta L_{\mathrm{atm}}^f$ | : adjustment for atmospheric attenuation [dB](7) |

In Eq. (1), the source model was defined as octave band sound power level, $L_{\mathrm{w}}^f$, with adjustment of the three-dimensional directivity of the source, $\Delta L_{\mathrm{dir}}^f$, at given engine power setting. Sound power level and adjustment for longitudinal directivity were developed from measured noise data (8). Adjustment for lateral directivity was added according SAE AIR 5662 to obtain the three-dimensional directivity.

The propagation model included spherical attenuation, atmospheric absorption, and adjustment for the effect of ground and meteorological conditions as shown in Eq. (1). This model used two methods to obtain the meteorological effects on propagation, namely a numerical computation using Green's Function Parabolic Equation (GF-PE) method for precise prediction and a table lookup among the GF-PE computation results for faster calculation.

Meteorological condition were considered in the view of wind and stability, and typical speed of sound profiles were defined for all combination of the wind and the stability classes as proposed by IMAGINE project (9). The GF-PE computations were then conducted with typical speed of sound profiles. The effects of atmospheric turbulence were also considered in the GF-PE computation by using von Kármán distribution (10). Since the noise prediction model was newly-developed, field experiments were conducted to verify its prediction accuracy (11,12)

## 3. LATERAL ATTENUATION PREDICTION

### 3.1 Prediction Conditions

Figure 1 shows the definitions of geometric parameters. The prediction parameters, respect are shown in Table 1. It is assumed that an aircraft is flown straight and level at a constant speed of 80.2 m/s over a flat terrain with acoustically soft surface with the effective flow resistivity of 300 kPa s/m$^2$. The sound source was assumed to be an aircraft of type B777-300 B767-300, or B787-800. The variation of lateral attenuation was examined with the slant distance, $L$, and the elevation angle, β. Therefore, the observer point and aircraft height were varied according to the combination of the slant distance and the elevation angle. Lateral attenuations shown later in this paper were estimated from predicted $L_{AE}$ at respective observer points by normalized by the $L_{AE}$ at the observer point at the same slant distance and an elevation angle of 90 degrees.

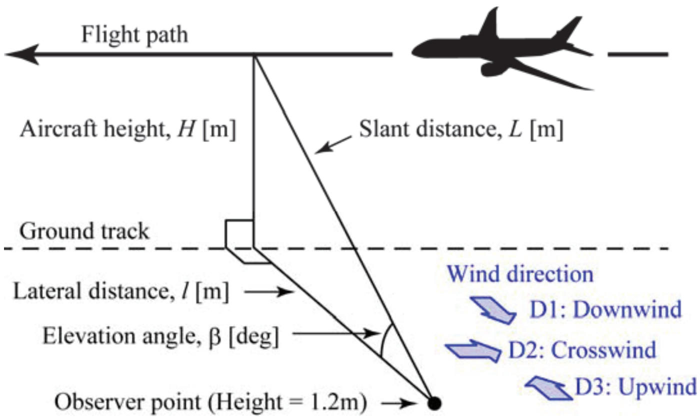


Figure 1 – Definitions of geometric parameters

Table 1 – Prediction parameters

| Parameter | Values |
|---|---|
| Aircraft speed [m/s] | 80.2 |
| Effective flow resistivity [kPa s/m$^2$] | 300 |
| Slant distance, $L$ [m] | 30.5 – 914.3 (30.5-meter interval) |
| Elevation angle, β [deg] | 1, 2, 5, 10, 20, 40, 90 |
| Aircraft type | B777-300, B767-300, B787-800 |

### 3.2 Meteorological Conditions

The effective sound speed profiles proposed in the reference model of IMAGINE project (9) were used to describe various meteorological conditions such as vertical profiles of wind speed, atmospheric temperature, and stability. Tables 2 and 3 show the wind speed and stability categories. The meteorological classification contains the combination of 5 wind speed categories and 5 stability categories. In addition, 3 wind directions shown in Figure 1 and Table 4 were assumed in this study. Therefore, 75 meteorological conditions were examined.

## 4. RESULTS AND DISCUSSION

### 4.1 Comparison with ECAC Doc.29

Figure 2 shows lateral attenuation obtained for observer points at elevation angles of 1, 2, 5, 10, 20, and 40 degrees. Lateral attenuation was predicted using the DREAMS' model for all combination of the aircraft types and the meteorological conditions, and the blue lines in Figure 2 show the arithmetic averages and the standard deviations of the prediction, and the red lines shows the ECAC Doc. 29 model. Note the vertical axes of these figures have respective ranges for better legibility.

At the elevation angles of 1 and 2 degrees, the averages of the lateral attenuation by the DREAMS' model show good agreement with ECAC Doc. 29 model at lateral distances over 600 meters. On the other hand, the averages of the DREAMS's prediction for lateral distances shorter than 600 meters are larger than ECAC Doc. 29 model.

At the elevation angles of 5 and 10 degrees, the average lateral attenuation is smaller than ECAC Doc 29 model at long lateral distance, but it becomes larger at shorter lateral distance.

At the elevation angles of 20 and 40 degrees, the DREAMS' model shows good agreement with ECAC Doc. 29 model. Since the standard deviation is less than 0.62 dB, it can be considered meteorological conditions hardly affect lateral attenuation at a higher elevation angle.

Table 2 – Wind speed categories in IMAGINE

| Wind speed category | Mean wind speed at height of 10m |
|---|---|
| W1 | 0 to 1 m/s |
| W2 | 1 to 3 m/s |
| W3 | 3 to 6 m/s |
| W4 | 6 to 10 m/s |
| W5 | > 10 m/s |

Table 3 – Stability categories in IMAGINE

| Stability category | Time of day | Cloud cover |
|---|---|---|
| S1 | Day | 0/8 to 2/8 |
| S2 | Day | 3/8 to 5/8 |
| S3 | Day | 6/8 to 8/8 |
| S4 | Night | 5/8 to 8/8 |
| S5 | Night | 0/8 to 4/8 |

Table 4 – Wind direction categories in this study

| Wind direction category | Direction |
|---|---|
| D1 | Downwind (blown from the ground track toward the observer) |
| D2 | Crosswind (blown parallel to the ground track) |
| D3 | Upwind (blown from the observer to the ground track) |

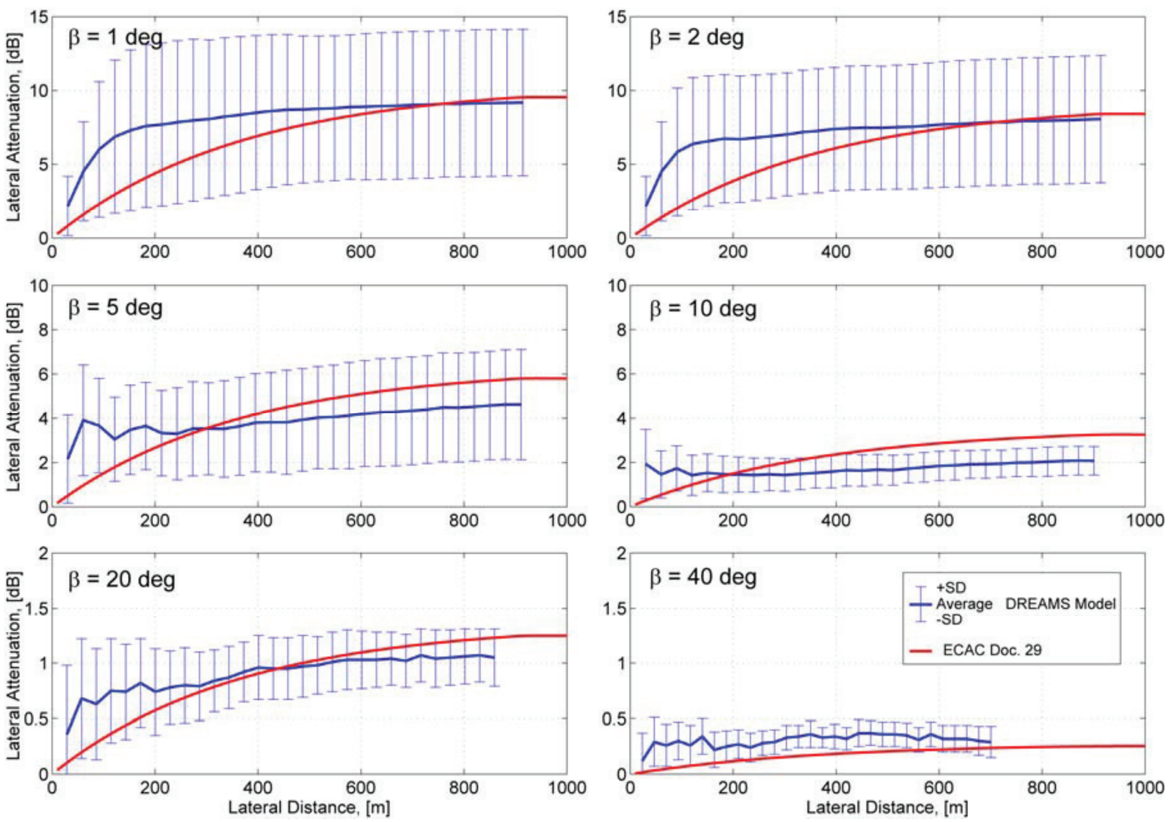


Figure 2 – Comparison of lateral attenuation predicted by DREAMS' model and ECAC Doc.29

### 4.2 Effects of Meteorological Conditions

Figure 3 shows the difference of lateral attenuation due to meteorological conditions at an elevation angle of 2 degrees. It is shown that the lateral attenuation predicted by the DREAMS' model is smaller than ECAC Doc. 29 model in downwind conditions, and it becomes larger in upwind conditions (D3). Under downwind conditions, it is shown that the wind speed and the stability cause small variation, and the lateral attenuation is smaller than that in the ECAC Doc. 29 model. On the contrary, under upwind conditions, the lateral attenuation shows notable variation depending on the wind speed and stability conditions. Moreover, the lateral attenuation increases rapidly as the lateral distance increases, and it reaches almost constant values at lateral distances over 200 m.

Figure 4 shows similar plots at an elevation angle of 5 degrees. The lateral attenuation under downwind and crosswind condition does not vary according to the stability. As for the upwind conditions, the change in lateral distance cause little variation of lateral attenuation.

## 5. Concluding Remarks

This paper presents an investigation into the ground effect on aircraft noise propagation, focusing on the variation of lateral attenuation due to the meteorological conditions. Lateral attenuation of noise from aircraft flying a straight level flight profile was predicted using DREAMS' noise prediction model which can consider the effects of meteorological conditions on noise propagation. The prediction results were compared with the model described in ECAC Doc. 29. It is shown that:

- Lateral attenuation varies significantly at low elevation angle,
- Lateral attenuation by ECAC Doc. 29 is within the variation range of the lateral attenuation predicted by DREAMS' model considering the effects of meteorological conditions,
- Wind speed and stability cause little variation of lateral attenuation in downwind propagation conditions, and
- The variation of lateral attenuation due to meteorological conditions is significantly large in upwind propagation conditions.

Future work includes further investigation on the meteorological effects on aircraft noise propagation and improved methods for computing the noise contour around airports.

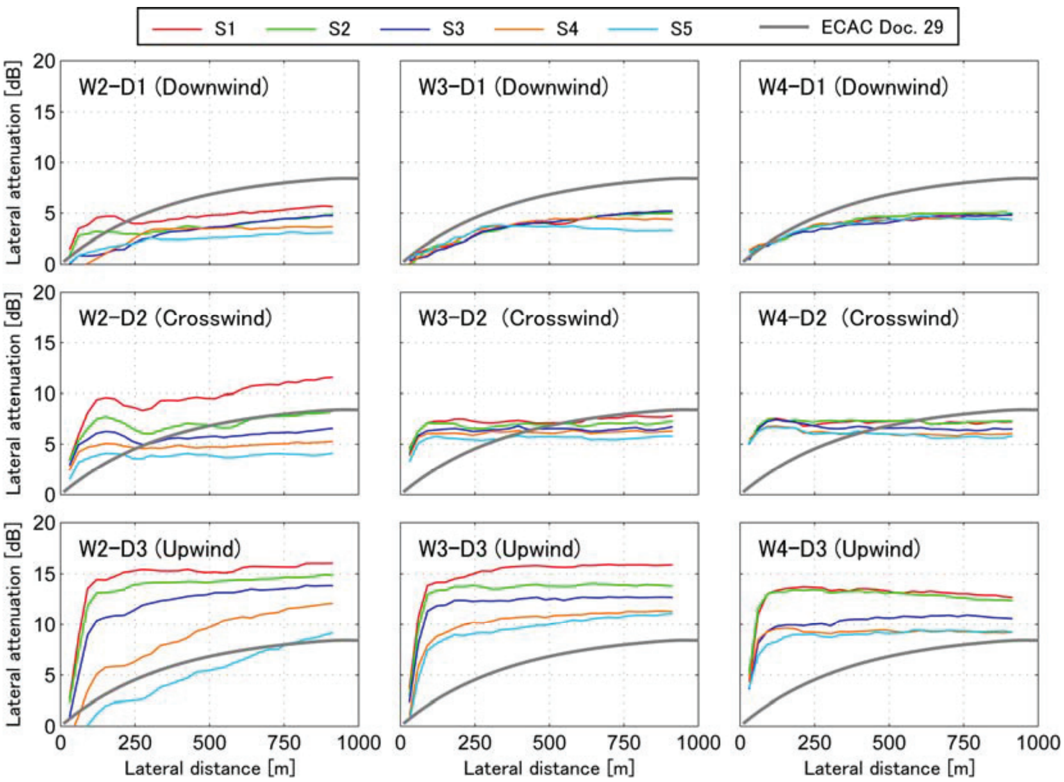


Figure 3 – Difference of lateral attenuation due to meteorological conditions (β=2 deg)

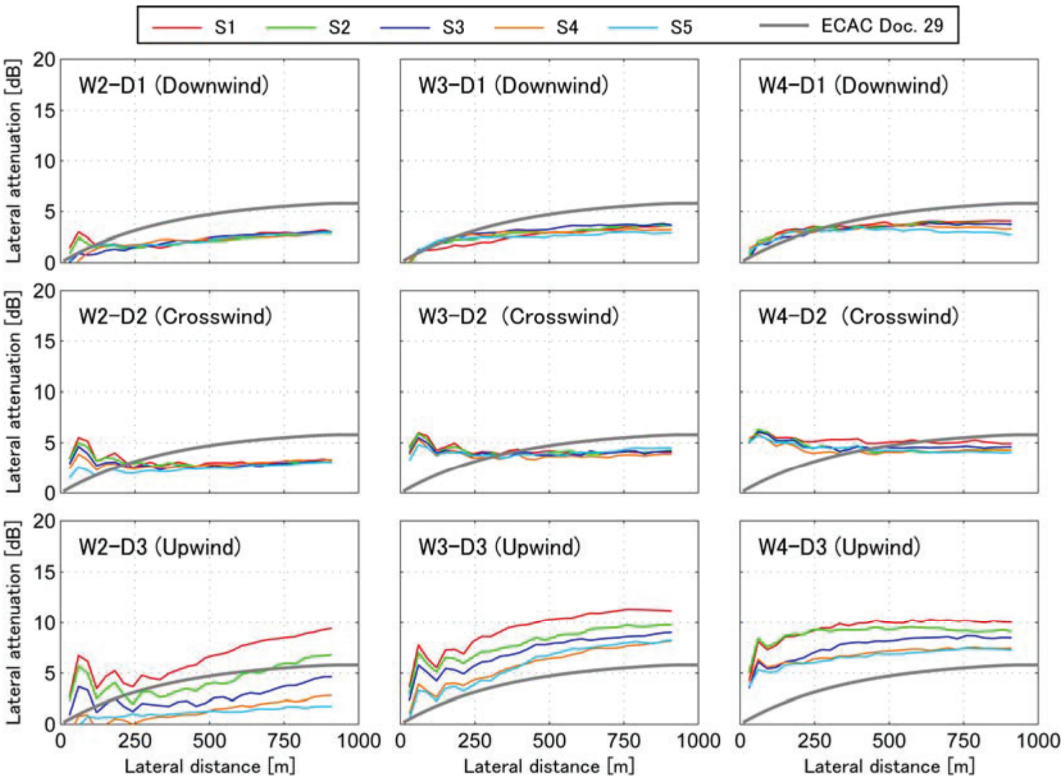


Figure 4 - Difference of lateral attenuation due to meteorological conditions (β=5 deg)

## REFERENCES


1. Long-term vision for the future air traffic systems: Changes to intelligent air traffic systems [Internet]. 2010. Available from: http://www.mlit.go.jp/common/000128185.pdf
2. Ishii H, Okada S, Yokota T, Sugawara M. JAXA's research plan for next generation air traffic management system (DREAMS) and noise abatement flight technologies. In: Proc Inter-Noise 2012. New York City, NY, USA; 2012.
3. Ishii H, Harada K, Makino K, Yokota T, Shinohara N, Sugawara M. Development of an aircraft noise prediction model considering the effect of meteorological conditions in JAXA's DREAMS project. In: Proc Inter-Noise 2013. Innsbruck, Austria; 2013.
4. Report on standard method of computing noise contours around civil airports. 3rd ed. European Civil Aviation Conference; 2005. (ECAC Doc. 29; vol. 2, Technical Guide).
5. Recommended method for computing noise contours around airports. International Civil Aviation Organization; 2008. (Doc 9911).
6. Method for Predicting Lateral Attenuation of Airplane Noise. SAE International; 2012. (SAE AIR 5662).
7. Acoustics -- Attenuation of sound during propagation outdoors -- Part 1: Calculation of the absorption of sound by the atmosphere. 1993.
8. Makino K, Yokota T, Okubo T, Matsumoto T, Yamamoto K, Kawase Y, et al. Development of the precise aircraft sound source model based on direction-of-arrival estimation using cross-correlation technique. In: Proc Inter-Noise 2013. Innsbruck, Austria; 2013.
9. IMAGINE - Reference and engineering models for aircraft noise sources. 2006. (Deliverable 9 of the IMAGINE project; vol. 1).
10. Yokota T, Makino K, Matsumoto T, Yamamoto K, Ishii H. Database of correction for meteorological and ground effects developed for the aircraft noise prediction model in JAXA's DREAMS project. In: Proc Inter-Noise 2015. San Francisco, CA, USA; 2015.
11. Yokota T, Okubo T, Makino K, Matsumoto T, Yamamoto K, Ishii H, et al. Experimental study of meteorological effects on sound propagation from an elevated source. In: Proc Inter-Noise 2013. Innsbruck, Austria; 2013.
12. Ishii H, Yokota T, Makino K, Shinohara N, Sugawara M. Verification of an aircraft noise prediction model developed for JAXA's DREAMS project. In: Proc Inter-Noise 2015. San Francisco, CA, USA; 2015.