Project 005 (A, B) Noise Emission and Propagation Modeling

The Pennsylvania State University, Purdue University

Project Lead Investigator

Victor W. Sparrow
Director and Professor of Acoustics
Graduate Program in Acoustics
Penn State
201 Applied Science Bldg.
University Park, PA 16802
+1 (814) 865-6364
vws1@psu.edu

University Participants

The Pennsylvania State University

- P.I.: Victor W. Sparrow, Professor of Acoustics
- FAA Award Number: 13-C-AJFE-PSU, amendments 005.
- Period of Performance: August 18, 2014 to December 31, 2015
- Task(s):
    1. Improve modeling of atmospheric absorption of noise at en-route altitudes
    2. Assess applicability of meteorological reanalysis models for possible use in FAA noise tools

Purdue University

- P.I.(s): Kai Ming Li, Professor of Mechanical Engineering
- FAA Award Number: 09-C-NE-PU-016
- Period of Performance: June 1, 2014 to September 1, 2015
    3. Investigate the convective amplification effects of fast moving sources

Project Funding Level

FAA funding to Penn State in 2014-2015 was $132,000. FAA funding to Purdue in 2014-2015 was $80,000. Matching funding not yet received, but funds from both years 1 and 2 will be matched in year 2.

Investigation Team

For 2014-2015 the investigation team included:

Penn State

Victor W. Sparrow (PI)
Graduate Research Assistant Erik Petersen (atmospheric absorption investigation)
Graduate Research Assistant Rachel Romond (meteorological reanalysis data investigation)

Purdue

Kai Ming Li (PI)
Graduate Research Assistant Bao Tong (en-route cruise aircraft investigation)
Graduate Research Assistant Yiming Wang (en-route cruise aircraft investigation)

Project Overview

The FAA has been funding research efforts in developing enhanced noise emission and propagation capabilities to better support environmental impact studies at both local and national levels. The main focus in the near and mid-term is to increase the Research Readiness Level (RRL) of the capabilities so that they can be further matured for implementation into the FAA tools. Validation of the modeling capabilities will be the central focus in 2014 and beyond. Via recent US-EU research collaboration, the field measurement database (BANOERAC) is becoming available for model validation. This database contains acoustic time history of flight events from various types of commercial aircraft during cruise, climb and descent phases of the flight. In addition the DISCOVER/AQ and Vancouver Airport Authority databases are similarly coming on line for use in the project. These datasets make model validation possible. In addition the work will make existing models ready for simulating real weather conditions via proper treatment of the meteorological input parameters and to establish a common basis for comparing US and EU models.

Task 1 "Improve the modeling of the atmospheric absorption of noise at en-route altitudes" (Joint with ASCENT Project 7)

The Pennsylvania State University

Objective(s)

As field measurement databases of aircraft noise recordings were not available this year, the objective of the task became to assess the updated Sutherland and Bass atmospheric absorption model in comparison with the existing ANSI/ASA S1.26 standard for atmospheric absorption.

Research Approach

The research team produced predictions of absorption and dispersion in the atmosphere of en-route aircraft noise by using the ANSI S1.26 algorithm and an updated algorithm of Sutherland and Bass. Disagreement between predicted absorption coefficients are attributed to differences between the two models and reference atmospheric profiles. The differences in profiles were found to be larger than differences in the models. In particular, it was found that the molar concentration of H20 was found to be a significant factor for absorption predictions in the atmosphere.

Using the Sutherland and Bass algorithm, the relative contribution of separate physical absorption mechanisms such as classical thermoviscous effects, rotational relaxation, and vibrational relaxation losses, were compared as a function of frequency and altitude. It was found that vibrational relaxation is the dominant absorption mechanism over the range of 125 to 1000 Hz and from 0 to 10 km. It turns out that the vibrational relaxation could be broken down into the O2, N2, CO2 and O3 components. Figure 5.1 shows the sum of the vibrational effects combined, where the absorption coefficient is plotted as a function of frequency and altitude. Figure 5.2 then shows the individual contributions from each of the constituent gasses. For example, one can clearly see that the major absorption contributions at about 5 or 6 km altitude comes from the O2 contribution, and that the CO2 contribution is only for higher altitudes and frequencies.

Although vibrational relaxation gives way to classical losses above 10 km, it was shown that carbon dioxide-induced vibrational relaxation contributes up to 14% of the total loss at 15 km altitude. Cumulative absorption over a vertical propagation path can be calculated by numerical integration, but the discretization step sizes should be no greater than 1 km to avoid under sampling the absorption curves to 0 to 18 km altitude. Finally, dispersion was analyzed by calculating the phase speed increment due to O2, N2, C02, and O3 as a function of altitude. Dispersion due to O2 accounts for approximately 85% of the phase speed increment from 0 to 18 km. At 0 km, the phase speed increment due to N2 accounts for the majority of the remaining 15%, but decreases with increasing altitude. The percent contribution of CO2 is small at 0 km and increases to 14% at 18 km. The CO2-induced dispersion may affect sonic boom shock structure of supersonic aircraft at cruise altitudes.

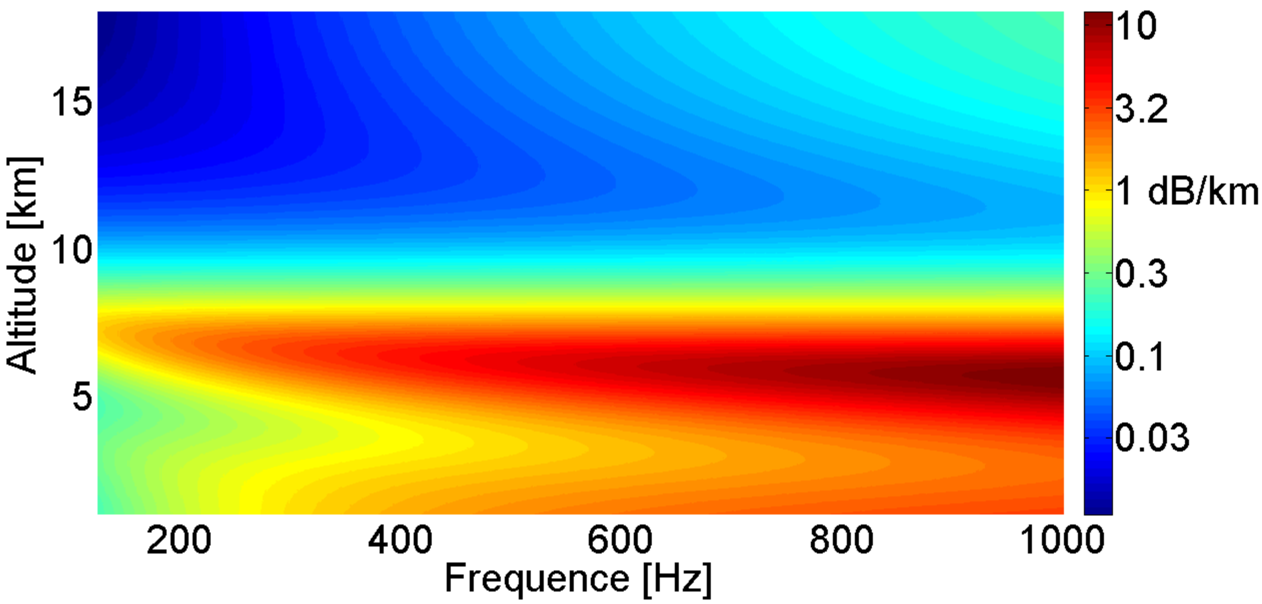

Fig. 5.1. Total absorption coefficient due to vibrational relaxation losses, as a function of frequency and altitude.

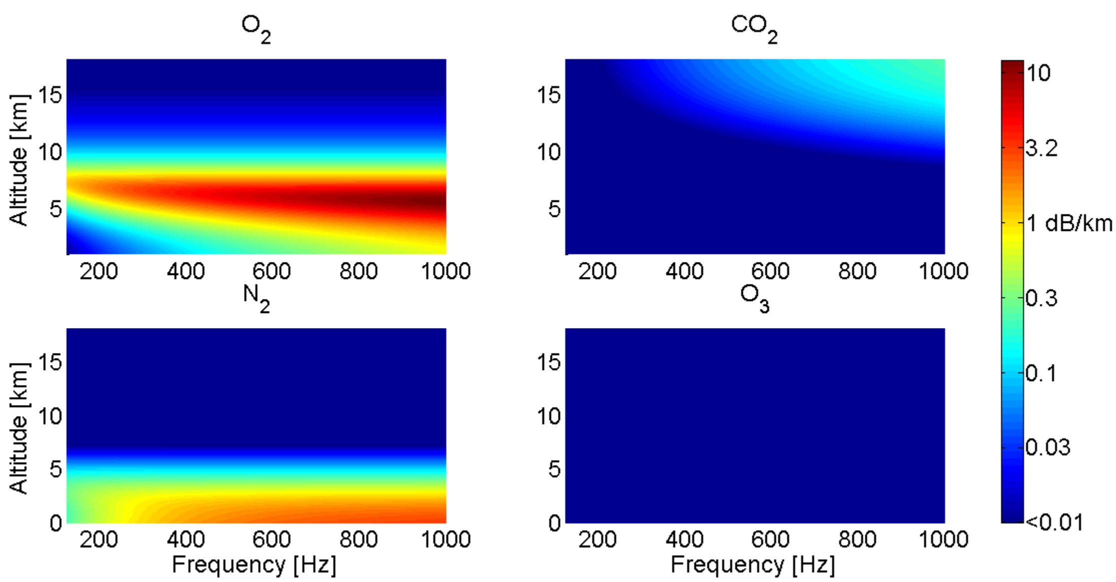

Fig. 5.2. Contributions to vibrational relaxation loss due to different constituent gasses. O2 losses are dominant and peak at about 6 km altitude, N2 losses extend to low frequency but are restricted to lower altitudes, CO2 has the largest effect at high altitudes and frequencies, and O3 does not contribute substantially.

Milestone(s)
N/A

Major Accomplishments
An understanding of the Sutherland and Bass updated atmospheric absorption algorithm has been achieved.

Publications
Peer reviewed journal publications:

N/A

Published conference proceedings:

- E. Petersen and V. Sparrow, "Effects of carbon dioxide on atmospheric absorption for en-route aircraft and supersonic aircraft," Internoise 2015; San Francisco, August 10-12, 2015.

Abstract and conference presentation:

- E. Petersen and V. Sparrow, "Differences in atmospheric absorption coefficients between ANSI/ASA S1.26-2014 and an updated model," 169th meeting, Acoustical Society of America, Pittsburgh, PA, May 2015 [J. Acoust. Soc. Am. **137** (4, Pt. 2) 2198 (2015)].

Outreach Efforts
Penn State has been in contact with NASA Langley Research Center regarding the potential consequences of CO2-induced dispersion for the prediction of sonic boom signatures.

Awards
None.

Student Involvement
Graduate Research Assistant Erik Petersen was the primary person working on this task. He will graduate with an M.S. in Acoustics in December 2015, and at the time of this writing he is currently looking for employment.

Plans for Next Period
None, task completed.

References

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- L. C. Sutherland and H. E. Bass, "Atmospheric absorption in the atmosphere up to 160 km," J. Acoust. Soc. Am. **115**(3) 1012-1032 (2004).
- L. C. Sutherland and H. E. Bass, "Erratum to J. Acoust. Soc. Am.," J. Acoust. Soc. Am. **120**(5) 2985 (2006).

Task 2 "Assess applicability of meteorological reanalysis models for possible use in FAA noise tools"
The Pennsylvania State University

Objective(s)
Determine if meteorological reanalysis datasets and corresponding input parameters are useful for aircraft noise propagation prediction and whether the same can be integrated into the AEDT noise analysis framework.

Research Approach

Introduction

AEDT's acoustic propagation algorithms currently assume a homogeneous and still propagation medium. This omits variable acoustic absorption and refraction (bending) of sound as the sound travels from the source to a receiver. Future versions of AEDT may be able to include refraction in sound propagation calculations by including the inhomogeneity of the medium. This would allow prediction of ranges of received sound level that would occur due to atmospheric effects. Currently available surface-based atmospheric models [Wilson, 2004] are not appropriate for analysis of flight operations because they rely on the theory of the atmospheric surface layer. The thickness of the surface layer changes throughout the day, but generally makes up the lowest ~300 m of the atmosphere. This constitutes less than 5% of the propagation path of sound emitted from a typical en-route aircraft and received on the ground.

To include the medium inhomogeneity at all altitudes relevant to en-route flight noise, accurate upper-air atmospheric data are required. The data source needs to have relatively high resolution, and needs to include all the atmospheric variables required to calculate an acoustic field. A perfectly realistic representation of the medium is not feasible in terms of both data availability and computational efficiency. It is necessary to find a compromise between a homogenous-atmosphere assumption and a perfect recreation of the atmosphere in all dimensions of time and space. The atmospheric data also need to be consistently collected and quality-controlled, represent an adequate spatial sampling of the propagation field, and be openly accessible. One type of data product that satisfies these criteria is meteorological reanalysis.

Reanalysis

Meteorological reanalysis is a process that incorporates measurements of the atmosphere into a long-term model of the earth's geologic-oceanic-atmospheric system to produce a 4-D representation of the atmosphere in space (latitude, longitude, and altitude) and time. In a global reanalysis, observations of the oceans and atmosphere are collected from around the world over an extended time span. These observations are fed into a physics-based model of the atmosphere in a detailed data assimilation process. Reanalysis incorporates many historical observations over an extended time period (years to decades) using a consistent oceanic-atmospheric model and data assimilation scheme. The model is run forward in time, and the calibration and settings/sensitivities of the model are periodically checked against the collected observations. The model is used to predict analysis states, which are best estimates of the state of the total atmosphere for a number of points in time over a distribution of spatial locations.

Currently, about a dozen state-of-the-art reanalysis products exist. They are conducted and maintained by different entities, and each use slightly different atmospheric models, data assimilation methods, analysis time spans, and spatial coverage and resolution. The appropriate choice of reanalysis product depends greatly on the intended use. We have investigated two of these current reanalysis products for possible use in representing the atmosphere in an aviation noise model. The two products are the NCDC/UCAR's Climate Forecast System Reanalysis (CFSR) [Saha, et al., 2010] and NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA) [NASA, 2012].

Both CFSR and MERRA provide analysis points every 6 hours from 1979 to the present, providing excellent temporal coverage and resolution. Both CFSR and MERRA provide global coverage at a geographic resolution better than 1 degree latitude by 1 degree longitude. Figure 5.3 shows the geographic coverage and resolution for CFSR over the continental United States. Both CFSR and MERRA have vertical coverage from the ground to well past the altitude required for analysis of en-route operations (up to approximately 48 km for CFSR and 65 km for MERRA). The vertical resolutions vary with altitude, but both products are similar, ranging from approximately 100 m (near the ground) to approximately 2 km (at an altitude of 20 km). In addition, both CFSR and MERRA contain the necessary data fields (ambient pressure, temperature, humidity, wind speed and wind direction) for calculation of the sound speed and acoustic absorption coefficient at altitude. CFSR contains additional data fields for temperature at the ground, humidity at 2 m, and wind speed at 10 m. CFSR was ultimately chosen for this proof-of-concept project because of these additional data fields and because of the accessibility of the data.

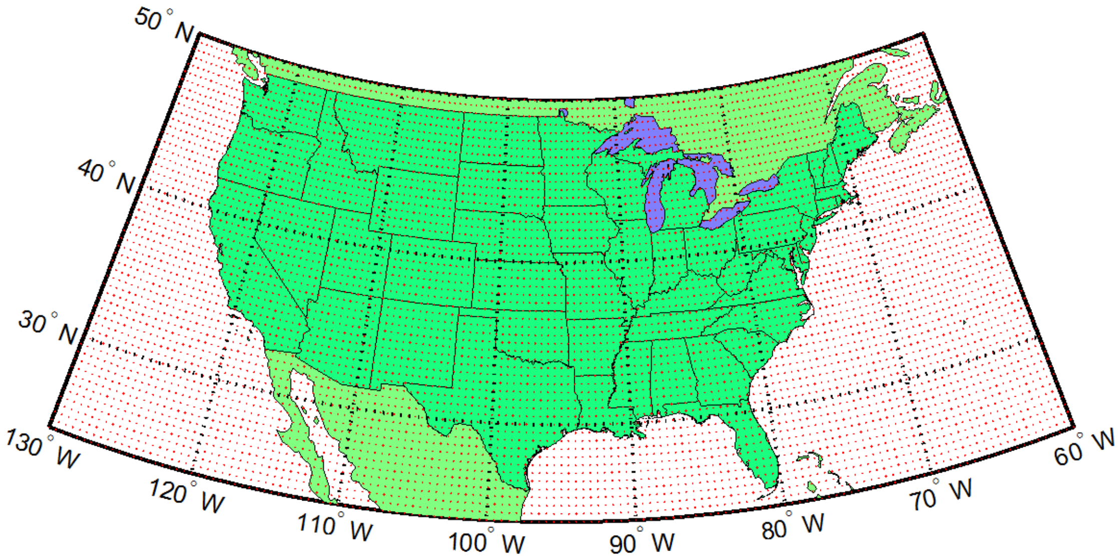

Fig. 5.3: Geographic distribution and resolution of CFSR analysis points (in red) over the continental United States. Figure by R. Romond.

Long-Term Metrics

Historical atmospheric data could be used to improve the prediction of long-term average noise metrics by including the effects of meteorological conditions on acoustical propagation. Based on methods by previous researchers [Salomons, van den Berg & Brackenhoff, 1994; Heimann & Salomons, 2004], the statistics of occurrence of meteorological conditions can be used to weight the sound level predictions for certain propagation conditions before they are averaged to find long-term average sound level predictions. To do this, long-term periodic meteorological measurements can be grouped into a number of classes, while the average meteorological conditions of each class *k* is used to calculate the received sound levels L_k that would occur under each condition. If each class *k* happens w_k% of the time, the long-term average level L_{eq} is the weighted average of each class level L_k, or

$$L_{eq} = 10\log_{10}\sum_{k=1}^{N} w_k 10^{L_k/10}$$

Upper Atmosphere

As previously mentioned, methods exist to include measured atmospheric data in acoustic propagation calculations. However, the methods are based on measurements made at or near the ground, and they rely on Monin-Obukhov similarity theory of the atmospheric boundary layer theory to extrapolate the values higher into the atmosphere. These methods have been validated for ground-to-ground sound propagation, but Monin-Obukhov similarity theory is only valid for the lowest ~300 m of the atmosphere [Wyngaard, 2010]. The existing methods would only be appropriate for aircraft ground operations such as taxiing and run-ups. They would not be appropriate for analysis of air-to-ground propagation where an aircraft is at altitude.

It would be preferable to include the full atmospheric profiles extracted from the reanalysis data. This ensures that the entire propagation space is represented, and that few assumptions are made about the state of the atmosphere. If necessary, the extracted profiles can be simplified and/or parameterized. This might increase processing efficiency because only the parameterization coefficients would be carried through the calculation (rather than the full profiles). Two possible methods are curve-fitting and layering.

In curve-fitting, a vertical profile is represented by a mathematical function where altitude z is the independent variable and the temperature, wind speed/direction, humidity, or ambient pressure is the dependent profile. Functions currently being considered are linear, logarithmic, log-linear, and polynomial. In layering the atmospheric profiles are split up into layers. Each layer can be homogeneous, or linear/logarithmic/log-linear. A spline fit would combine curve-fitting and layering, but care must be taken to ensure that the function isn't over-determined and includes spatial variations ("wiggles") that don't exist in the raw data. In either case, it is important to accurately represent the value at the ground, the gradient, and both the location and value of any inflection points.

Proposed Approach for Year 2

Figure 5.4 shows the currently proposed method, developed over the last year, for using CFSR atmospheric reanalysis data in an acoustic propagation model. The raw data is downloaded from UCAR and pre-processed to select relevant data fields for the geographic area under consideration. The raw data .grb files contain one year of 6-hourly global data per file. The pre-processing routine selects the analysis location (out of the available locations shown in Figure 5.3) closest to the airfield. Then, vertical profiles of temperature (T), wind speed and direction (u), humidity (h), and ambient pressure (P) are extracted. Either single-time profiles are chosen, or the profiles are averaged over the applicable time period. The resulting atmospheric profiles are then converted to profiles of acoustic variables. Temperature and wind speed/direction profiles are converted to a sound speed profile c(z). Temperature, humidity, and ambient pressure profiles are converted to an acoustic absorption coefficient profile $\alpha(z)$. Finally, the calculated sound speed and absorption profiles are entered into an acoustic ray tracing program, along with source parameters and receiver grid information. The ray tracing program then calculates the received noise contour at the ground, taking into account the atmospheric conditions originally extracted from the CFSR data set.

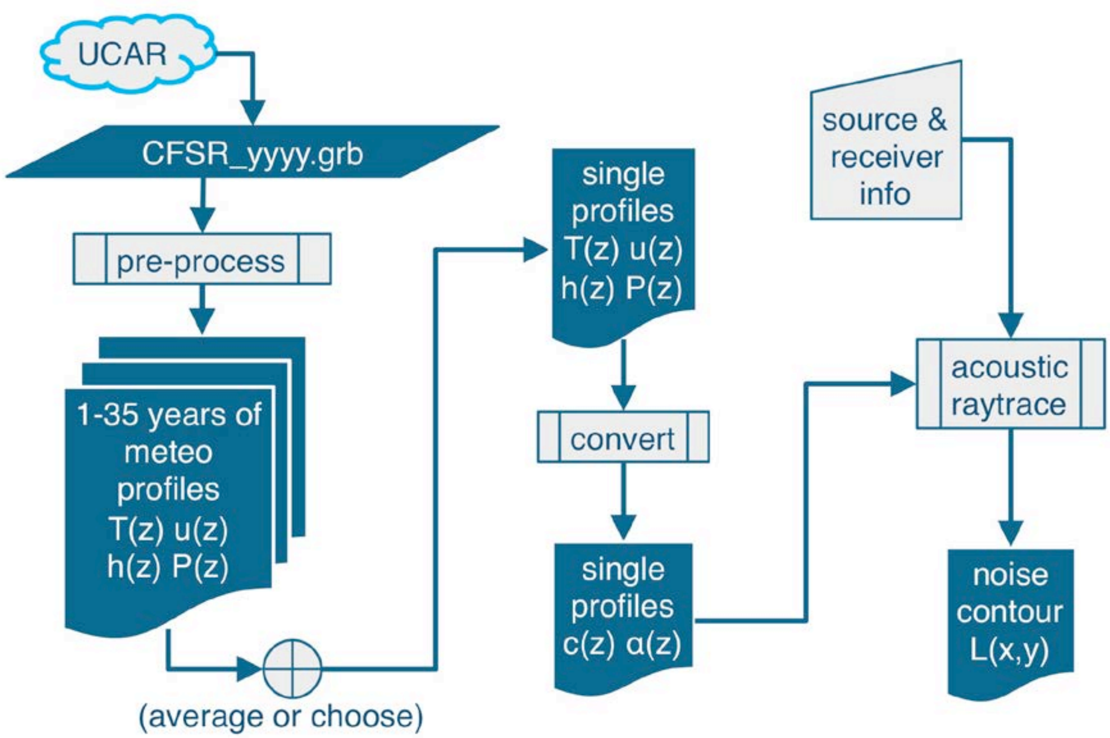

Fig. 5.4: Proposed method for integrating CFSR atmospheric data into a noise model. The meteorological profile parameters are temperature (T), wind speed and direction (u), humidity (h), ambient pressure (P). The profiles required by the acoustic ray tracing program are sound speed (c) and acoustic absorption coefficient (α). The independent variable for each profile is altitude (z).

Milestone(s)
N/A

Major Accomplishments
It has been determined that meteorological reanalysis may provide an avenue for the integration of noise and emissions meteorological information in FAA tools such as AEDT.

Publications
None.

Outreach Efforts
Presentation by Graduate Research Assistant Rachel Romond at 25 August 2015 FAA External Tools teleconference.

Awards
None.

Student Involvement
Graduate Research Assistant Rachel Romond is the primary person working on this task. She is working toward a Spring 2016 or Summer 2016 graduation with her Ph.D. in Acoustics.

Plans for Next Period
In the next year R. Romond will simulate aircraft noise propagation through the atmospheric data provided by meteorological reanalysis, assessing the advantages and deficiencies of this combination.

References

- Wilson, D.K., Ostashev, V.E. and Mungiole, M. (2004). “Categorization schemes for near-ground sound propagation,” in *Proceedings of the International Congress on Acoustics*, Kyoto, Japan, pp. 361-364.
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- Heimann, D. and Salomons, E.M. (2004). “Testing meteorological classifications for the prediction of long-term average sound levels,” in Applied Acoustics **65**(10), pp. 925-950.
- Wyngaard, J.C. (2010). *Turbulence in the Atmosphere* (Cambridge University Press). ISBN 978-0-512-88769-4.

Task 3 "Investigate the convective amplification effects of fast moving sources"
Purdue University

Objective(s)

The purpose of this work is to improve aircraft noise propagation prediction by including the realistic effects of fast moving aircraft at en-route altitudes, particularly the convective amplification effects, currently not included in current FAA noise tools.

Research Approach

Executive Summary

A simplified ray model has been developed to compute the pressure time history for a moving aircraft under cruise conditions. An incoherent sum is applied to the direct and reflected wave terms which allow the sound field to be decomposed into individual contributions due to: source convection, spherical divergence, ground effect, source directivity, and atmospheric absorption. An accurate and efficient method for computing the Doppler factor using existing ray parameters has been identified. A semi-analytical approach for approximating the sound field for a two-layered LSSP using a polynomial representation is developed. The aim is to apply these techniques to estimate the noise propagation environment from experimental data and to extend the predictions to non-measurement locations.

Several factors have been identified which have a strong impact on the resulting sound field. For example, source directivity appears to be sensitive to small gradients in the directivity pattern especially for the aircraft on approach. Additional data should be collected within this range to accurately model the sound field before it propagates to the ground. Dopplerization of the frequency along each propagation path leads to a time-dependent atmospheric absorption profile for the continuously moving source. This effect may become important when a broadband noise signal is considered since low-frequency components would become more prominent after the Dopplerization. Consequently, the pure tone analysis performed may not be applicable to realistic aircrafts noise sources that also contain broadband noise characteristics. The superposition principle can be applied to further the investigation.

Sound field predictions of en-route aircraft

Experimental sound field time histories for the Profan Test Assessment (PTA) aircraft under cruise condition was obtained from a NASA technical paper [1]. The data represents an ensemble average from an 8-microphone array positioned directly below the flight path (along the direction of motion). For flight series 100, the aircraft was located at an elevation of 9,357 m with a nominal source Mach number of 0.706. For flight series 200, the aircraft was located at an elevation of 4,755 m with a nominal source Mach number of 0.7. The source spectrum contains a strong tonal component at around 230 Hz, which was applied in the subsequent analysis. A one-parameter ground model with an effective flow resisivity of 515,000 MKS Rayls is used to model a hard-packed dirt road in our study.

The ANSI/ASA S1.26-1995 standard [see description under ASCENT 5 task 1] is used in the computation of atmospheric absorption coefficients. The atmosphere behaves as a low pass filter that is sensitive to changes in the temperature, humidity, and pressure. These three parameters vary with elevation according to the horizontally stratified atmosphere approximation. An atmospheric absorption profile is obtained by specifying a temperature, humidity, and pressure profile. Although experimentally obtained meteorological data was used in the NASA ray model, atmospheric conditions were not explicitly provided within the report. A linear sound speed profile (LSSP) using the 1976 U.S. Standard Atmosphere profile is implemented and the relative humidity is adjusted to obtain good agreement with a subset of the NASA data. For the initial 11 km, the sound speed gradient is given by $\Delta c = -0.004\ s^{-1}$, which represents an upward refracting atmosphere typically observed during the day.

The atmosphere is decomposed into horizontal layers of thickness < 30 m and the absorption coefficient is computed for each layer following the guidelines of the international standards for prediction of aircraft noise [2]. Using a polar coordinate system centered at the center of curvature for each ray path, the total atmospheric absorption along the ray path can be computed efficiently. En-route measurements were made using a chase plane to obtain the source directivity pattern for the PTA aircraft as shown in Fig. 1a. An Advanced Subsonic and Supersonic Propeller Induced Noise (ASSPIN) program was used by NASA to interpolate the source directivity pattern. A smooth source directivity pattern is obtained by approximating the source directivity predictions provided in Ref. [1] as shown in Fig. 5.5b. The source directivity level correction is computed using the emission time ray launch angle along with a cubic spline interpolation for the required angular evaluation.

Figure 5.6a shows the variation in the ray launch angle with time for several different sound speed gradients. The source speed is fixed at $U = 0.706\ c_0$ in the comparisons across the various sound speed profiles. Rays launched at the distance of closest approach (i.e., 90°) travel along a straight line trajectory. The reception times which intersects the 90° line correspond to the shortest time delay, $T_{d,min}(t_e)$, for the wavefront to be experienced at the receiver. In the situation of an LSSP, the average speed of sound at the mid-point between the source and the receiver elevation can be used to determine $T_{d,min}(t_e)$. Note that predictions before t = -38 s are not shown in the upward refraction case (Δc = -0.004 s^{-1}) due to the shadow zone effect. As expected, the wavefronts arrive sooner for the faster average speed of sound medium (downward refracting) than the upward refracting case.

The source directivity appears to be sensitive to small deviations in the directivity pattern (Fig. 5.5b) especially in the region between the elevation angles of 30° to 60° for the approaching source. This is related to the rapidly increasing ray launch angle during approach. Hence, additional source directivity data should be taken within this range to accurately model the sound field before it propagates to the ground. The phenomena is suppressed in the numerical simulations by applying the smooth source directivity pattern from Fig. 1 to the predictions in Fig. 5.6b.

An effective LSSP prediction is given in Fig. 5.7 for flights 112 and 215 to estimate the shape of the NASA ray model using a pure tone at f_0 = 230 Hz, corresponding to the fundamental blade passage frequency. An OASPL correction factor of 150 dB is added to both flight predictions to approximate the source spectrum as a pure tone instead of a broadband signal. The 1976 U.S. standard atmosphere profile with a 70% relative humidity is applied in both simulations for the atmospheric absorption calculations. However, the actual atmospheric conditions may be different. The red prediction curves are time shifted to visually match the NASA PTA data.

Atmospheric absorption is applied along the physical ray path. The Dopplerized frequency is constant along each ray path according to our path integral analysis and Snell's law. Hence, the Dopplerized frequency represents a physical phenomena which should be considered in computing the atmospheric absorption losses for a high speed moving source as done in Fig. 5.7.

Figure 5.8 highlights the effect of atmospheric absorption on shaping the leading edge of the waveform (i.e., aircraft on approach) due to the large propagation distances involved. Source directivity shapes the trailing edge of the measured signals due to the strong roll-off rate behind the propfan engine. A comparison of the atmospheric absorption model with and without Dopplerization of the source emission frequency is shown. Agreement between the two predictions occur only at the distance of closest approach (i.e., t = 29 s) where the Doppler factor is unity. Because atmospheric absorption is a strong function of frequency, there is a significant difference between the two predictions for a high speed aircraft.

The sound field for a monopole source in the absence of atmospheric absorption and source directivity effects is illustrated in Fig. 5.9a. The white regions correspond to the shadow zone. Figure 10b illustrates the full effects of atmospheric absorption and source directivity on the predicted sound field extended to various sideline distances. The overhead flight source directivity pattern is extended into three-dimensions by revolution about the horizontal axis. Apart from a constant time delay due to synchronization with the experimental data, the results at y_r = 0 correspond to the Flight 112 predictions shown in Fig. 5.7a. The predicted sound field time-history can be used to estimate the amount of time the noise is audible (i.e., the event duration). As to be expected, the event duration decreases with increasing sideline distances. Furthermore, the same trends observed in the NASA PTA overhead flight data are present in the extended plane predictions.

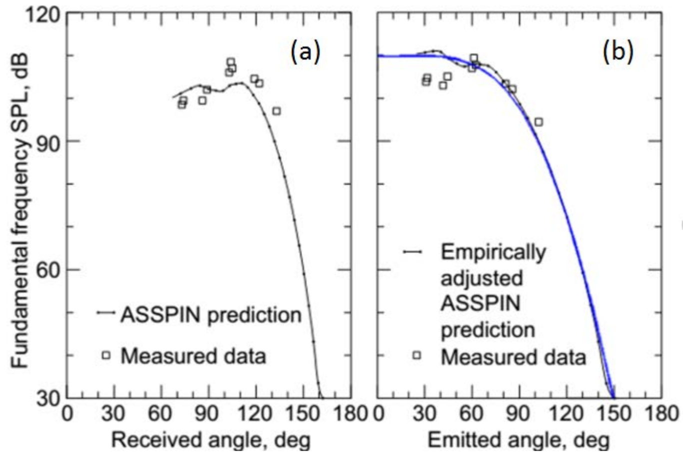

Fig. 5.5: NASA PTA aircraft source directivity pattern for flight series 100. The received angle is transformed into the emitted angle for usage in the emission time coordinate ray model. The blue curve is the approximated directivity pattern used in our analysis.

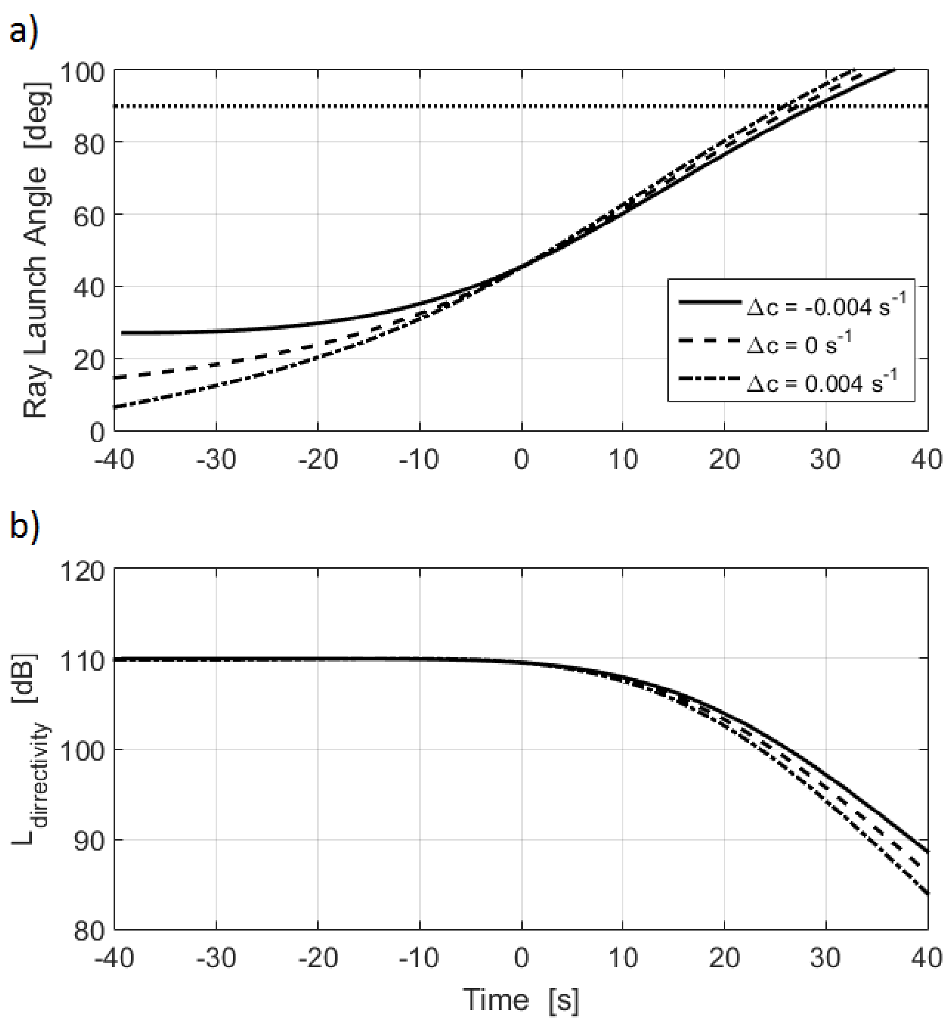

Fig. 5.6: Flight series 100 ray model predictions under various LSSP's. a) Ray launch angles. b) Source directivity correction factor. The source speed is fixed at $U = 0.706\, c_0$

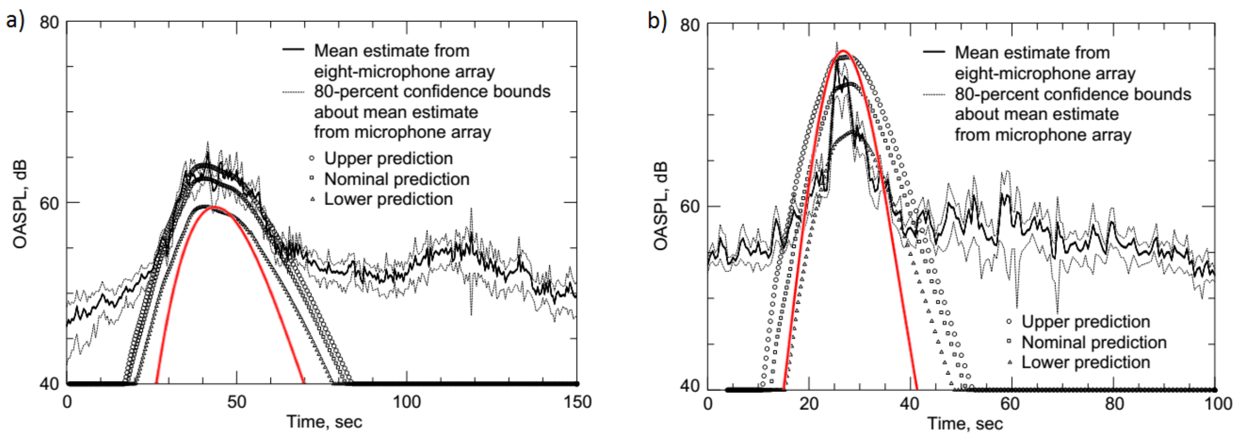

Fig. 5.7: Sound field time-history data from NASA PTA tests (shown in black). Red curves predicted using an effective LSSP for: a) Flight 112 with z_s = 9,357 m; b) Flight 215 with z_s = 4,755 m. The same atmospheric absorption profile and source directivity pattern are applied in both simulations.

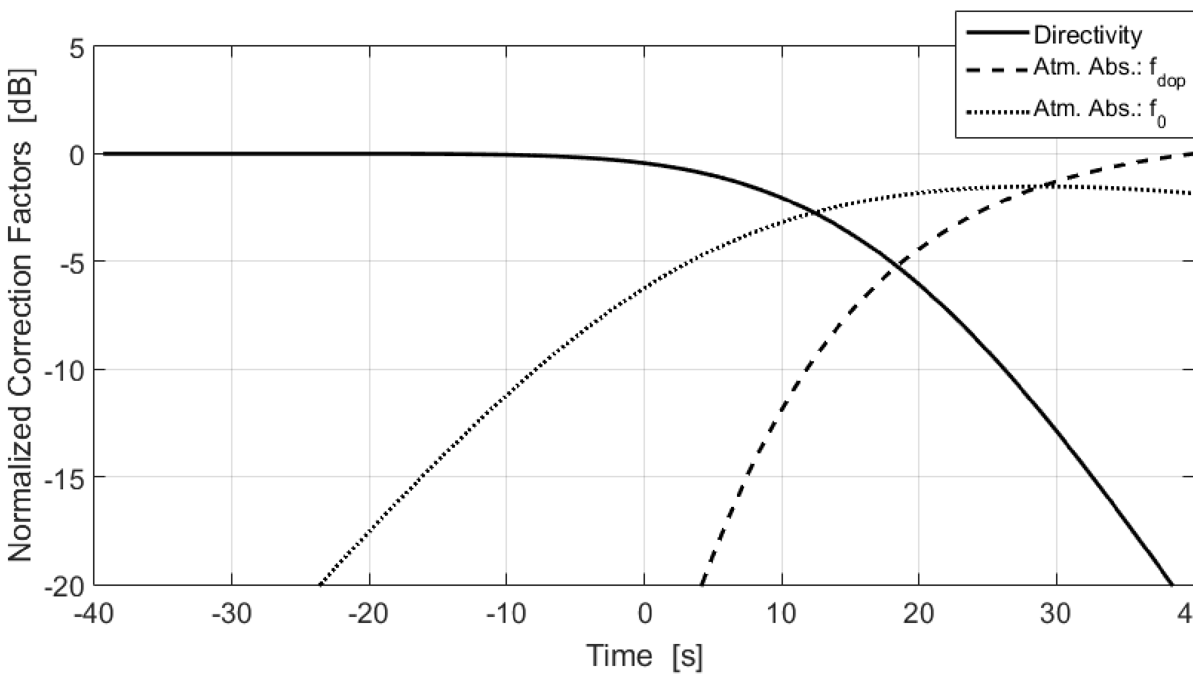

Fig. 5.8: Normalized level correction terms for source directivity and atmospheric absorption for Flight 112 in an effective LSSP of Δc = – 0.004 s^{-1}. The 1976 U.S. Standard Atmosphere profile with a uniform relative humidity of 70% is applied in the computation of the atmospheric absorption profile.

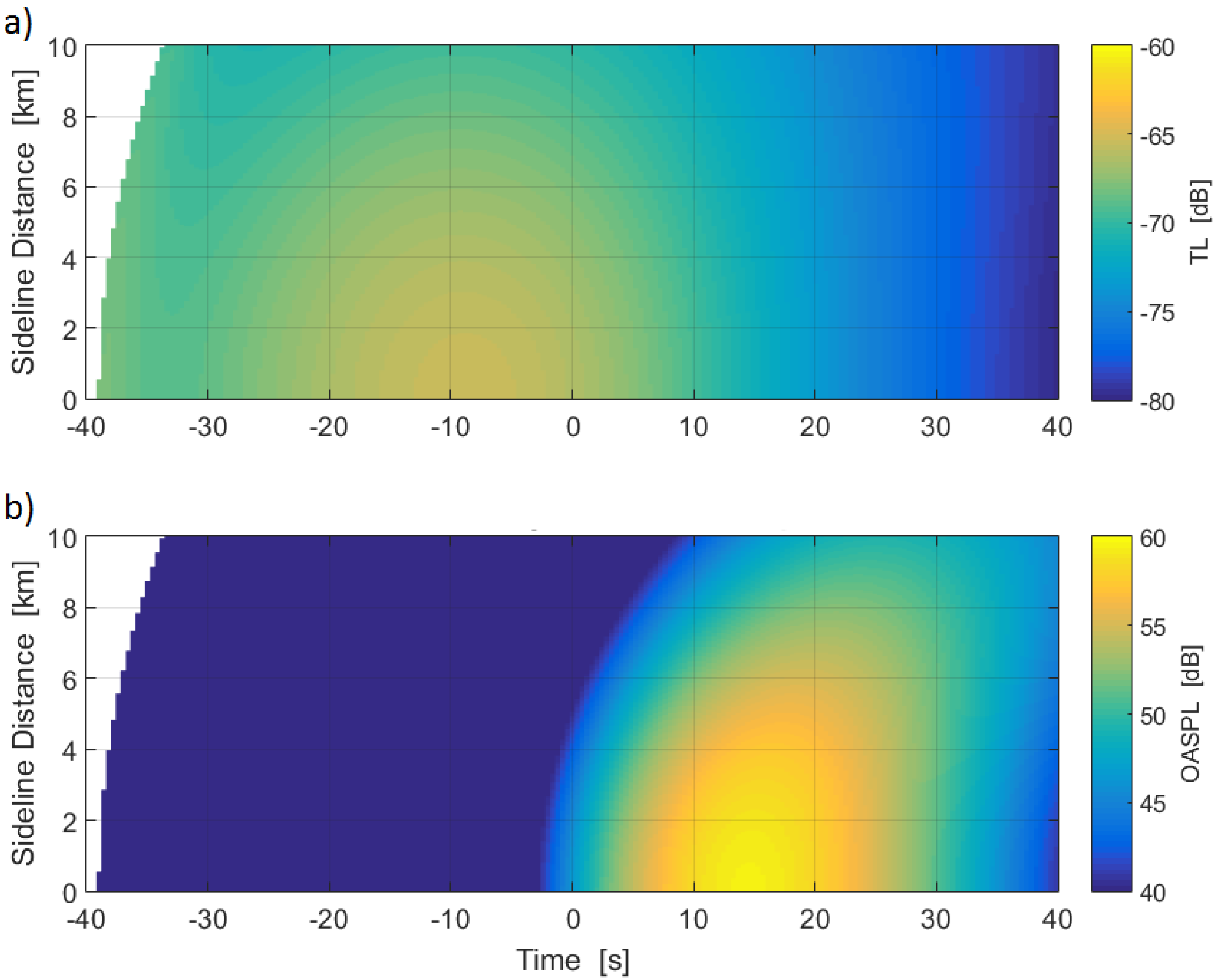

Fig. 5.9: Same propagation conditions as in Fig. 5.8. a) Monopole source; b) overhead flight data from Flight 112 is extended to various sideline distances via the proposed ray interpolation techniques. Atmospheric absorption and source directivity effects are included in Fig. 5.9b.

Milestone(s)

N/A.

Major Accomplishments

A simplified ray model has been developed to compute the sound field time history for a moving source under cruise condition. The Doppler factor in a refractive atmosphere is determined using two different ray paths separated by a small time interval. An incoherent sum is applied to the direct and reflected wave terms which allow the sound field to be decomposed into individual contribution from source convection, spherical divergence, ground effect, source directivity, atmospheric absorption, etc. It has been shown that our developed formula can be reduced to a comparable expression used in the Environmental Technical Manual for a monopole point source under cruise conditions. Several factors have been identified which have a strong impact on the resulting sound field. For example, source directivity was shown to be sensitive to small gradients in the directivity pattern especially in the region between 30° to 60°. This suggests that additional source directivity data should be taken in this range to accurately model the sound field before it propagates to the ground. It has also been shown that atmospheric absorption effects have a strong impact on the leading edge of the waveform. A simple formula for estimating the level correction term for an offset from the direct overhead flight path can be obtained given measurements along a nearby receiver location.

Publications

- B. N. Tong and K. M. Li, "Atmospheric effects on noise propagation from an en-route aircraft," Proc. Noise Con 2014, Fort Lauderdale, FL (Institute of Noise Control Engineering of the USA, Washington, D.C.)
- B. N. Tong and K. M. Li, "Sound field predictions of a monopole source moving uniformly in a stratified medium above an impedance plane," Internoise 2015; San Francisco, August 10-12, 2015.

Outreach Efforts

- A special session was organized for presenting the initial results in Internoise 2015, San Francisco, August 10-12, 2015.

Awards

- Bao Tong was awarded with the Best Student paper in Noise Con 2014 for his work on this project.

Student Involvement

Graduate Research Assistant Bao Tong was the primary person working on this task. He is now graduated with his Ph.D. in Mechanical Engineering, and he is employed by the FAA. A new PhD student, Yiming Wang, has been recruited to continue Bao's effort in the coming years. It is hoped to recruit an additional Research Assistant in the near future.

Plans for Next Period

The Purdue team will focus on (a) the review of past developments of en-route aircraft noise, (b) the examination and identification of remaining challenges, and (c) how the flight and noise data (obtained from Vancouver Airport Authority, Discovery A/Q and BANOERAC) can be used to validate the numerical model developed in the past years. In particular, we shall examine the combined effects of source directivity, high-speed motion and atmospheric absorption on the propagation of en-route aircraft noise. We also aim to review and analyze the available aircraft noise and flight trajectory database to determine if they can be used to investigate certain noise effects such as the effect of source motion and the effect of noise observed with different microphone placements.

References

[1] D.P. Garber and W.L. Willshire Jr. En route noise levels from propfan test assessment airplane. Technical Report 3451, NASA Technical Paper, 1994.

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