TRANSPORTATION RESEARCH
CIRCULAR

Number 473 May 1997

Aircraft Noise Modeling

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

TRANSPORTATION
RESEARCH
CIRCULAR

Number 473, May 1997
ISSN 0097-8515

AIRCRAFT NOISE MODELING

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PREFACE

Models of aircraft noise are important tools for planning, implementing, and evaluating measures for noise abatement and reducing the noise exposure of people living and working in the vicinity of airports. The Federal Aviation Administration (FAA) and the United States Air Force (USAF) have been leaders in the development and use of aircraft noise models.

At the request of FAA, the Transportation Research Board (TRB) organized and managed a two-day invitational workshop on aircraft noise modeling at the J. Erik Jonsson Center of the National Academy of Sciences in Woods Hole, Massachusetts, in May 1996. The invitees were drawn from Federal Government agencies, aircraft manufacturers and consulting firms.

The purposes of this workshop were to review the present state of noise modeling technology, with special emphasis on the FAA Integrated Noise Model (INM), and to obtain information and guidance on the future direction of noise modeling. The objectives of the workshop were to consider:

- The adequacy of current noise models and their supporting data bases;
- Harmonization of various models now available (here and abroad) as a way of achieving greater compatibility among noise models, reducing model development costs, and working toward standardized procedures for computing aircraft noise;
- Adaption of current noise models to new applications; and
- Identification of research needs and approaches for advancing the state of noise modeling technology and practice.

TRB wishes to thank all who took part in the workshop for the generous gift of their time and experience and for their many helpful insights. TRB is particularly indebted to Robert L. Miller of Harris, Miller, Miller & Hanson, Inc., who chaired the workshop and ably guided the discussion and to Thomas L. Connor and Jake A. Plante of FAA for their direction and support in planning the workshop.

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OVERVIEW

THE NEED FOR AIRCRAFT NOISE MODELING

With the introduction of jet aircraft in the late 1950s and their subsequent rapid growth in the civil aviation fleet during the late 1960s, the problem of aircraft noise at commercial airports became a sensitive public issue. Communities surrounding airport sites and those lying under approach and departure flight paths grew increasingly vocal about the disruptive effects of aircraft noise and demanded that it be reduced, restricted, shifted away from noise-sensitive areas, or (in extreme cases) banned altogether.

The Federal Aviation Administration (FAA), airport operators and planners, and the aircraft manufacturing industry undertook a wide variety of programs to lessen the noise exposure for residents and other noise-sensitive land uses in communities neighboring busy commercial airports. Several approaches were taken: reducing aircraft engine and aerodynamic noise, revising aircraft operating procedures, realigning approach and departure paths, restricting the hours of airport operation, providing sound insulation for buildings in noise-sensitive areas, buying up property and relocating residents, and adopting land-use policies that encouraged development more compatible with (or less sensitive to) airport activity. Many airport operators instituted strict noise criteria and developed extensive noise monitoring programs to ensure these criteria were met.

It quickly became apparent that new noise measurement techniques had to be developed, that reference data bases of aircraft noise and performance had to be assembled, and that better methods had to be devised for predicting noise exposure patterns and evaluating proposed mitigation actions. This called for a descriptive and predictive tool (a model) capable of depicting noise propagation and quantifying the impacts on surrounding communities. To be of greatest utility, the model would have to be capable of integrating airport geometry, noise levels, atmospheric conditions, and aircraft performance characteristics into a single, unified picture of noise exposure patterns in and around airports.

WHAT IS AN AIRCRAFT NOISE MODEL?

An aircraft noise model is essentially a group of equations that describes the relationship among various factors contributing to the intensity and distribution of aircraft noise. Typically, a model has three major components:

- The core equations—computational algorithms for calculating the sound level produced, on average, by a specific type of aircraft performing a specific operation and for calculating cumulative noise levels by all the types of aircraft using a given airport;
- An aircraft data base containing the noise and performance characteristics of each type of aircraft (jet or propeller-driven) operating at a given airport;
- Additional inputs for environmental factors affecting sound levels (typically airport elevation, temperature, atmospheric pressure, wind direction and speed, runway gradient, etc.) as well as operational information such as traffic mix, runway usage, and flight tracks.

The typical output of each model run is a set of noise contours of equal sound exposure level. The noise impact of a single aircraft is often referred to as a *noise footprint.* The cumulative impact of a series of individual aircraft operations over a specified time are generally referred to as *noise contours.*

Noise models are designed primarily to describe and quantify the predicted noise impacts of aircraft operations at specific sites, but they have other applications. They can also provide a benchmark for noise analysis and comparison of predicted and measured sound levels. They are a valuable tool for planning airports, airspace, and operating procedures. They can help evaluate the effectiveness of remedial measures to mitigate aircraft noise. They can support formulation of noise standards. They can be used as a research tool to gain better understanding of noise propagation and to point the way for development of better noise control techniques.

SYNOPSIS OF FAA AIRCRAFT NOISE MODELING

FAA became actively involved in research and development of aircraft noise models in the early 1970s. Several versions were developed by government agencies, (FAA, DOT, NASA, DOD) and by major aircraft and engine manufacturers. In fact, the first version of FAA's Integrated Noise Model (INM) dates back to 1978. These early models (including the first version of INM) relied on large main frame computers and batch processing. They were somewhat cumbersome to run and were hampered by incomplete, inadequate, or incompatible, data bases on aircraft noise and performance. Each model had a somewhat different set of equations and computing

algorithms. As a result, it was difficult to compare the outputs of one with another.

By the mid-1980s noise modeling technology was considerably more advanced due to the rapid development of PC-DOS microcomputers that had several times the capacity and speed of the old main frames, at a fraction of the cost, and were small enough to sit on a desk top. The intervening years also brought improvements to the data bases and computational methodology for better compatibility.

Aircraft noise modeling had reached a point where it was possible to contemplate developing a standard set of equations for calculation of noise contours that could be used by all of U.S. civil aviation.

Under the aegis of the Society of Automotive Engineers (SAE), FAA and other Federal Government agencies joined with aircraft manufacturers, airlines, airport authorities, and noise modeling experts to develop a common method for calculating aircraft noise. This standard, *Procedures for the Calculation of Airplane Noise in the Vicinity of Airports* was issued in 1986 as SAE Aerospace Information Report (AIR) 1845.

Working through the International Civil Aviation Organization (ICAO) and in consultation with European aviation agencies and industry representatives, FAA next set about obtaining international consensus on the use of AIR 1845. Agreement was reached in 1988 with the publication of ICAO Report 208, *Recommended Method for Computing Noise Contours Around Airports*, which, in effect, acknowledged AIR 1845 as an internationally applicable standard.

By these two steps, FAA laid the groundwork for incorporating improved standards into its noise assessment methodology, principally the Integrated Noise Model (INM). The adoption of AIR 1845 and ICAO Report 208 provided FAA the confidence that a set of equations and associated data bases could be put together and used, in effect, as a national standard. This was accomplished in INM version 3.9, released in 1987.

The development and application of INM solidified FAA's position as a world leader in aviation noise modeling and as a technical arbiter on aircraft noise analysis. INM is used commonly in the United States for FAR Part 150 noise compatibility planning and FAA Order 1050 environmental assessments and environmental impact statements. It is widely used here and abroad for a variety of noise modeling tasks and noise impact analyses.

OTHER NOISE MODELS AND DATA BASES

INM is but one of several aircraft noise models that have been developed and used by government agencies and private firms over the past 20 years. Most are based on the AIR 1845 standard, but with variations and additions to serve different purposes or applications.

One of the earliest models (which predates INM) is the NOISEMAP model developed by the U.S. Air Force (USAF) to analyze noise impacts of military operations at USAF bases. A derivative model, ROUTEMAP, was created by USAF to study low-level routes used for training flights, military exercises, and air defense activities. Another derivative, MR_NMAP, is used for military operational areas and ranges. This family of models uses a design similar to INM in some respects but different in several ways, mostly dictated by military considerations (INM 5.1 now has a military aircraft data base drawn from NOISEMAP for studies of military-civil joint-use airports). The distinction between NOISEMAP and INM sometimes prevents direct comparison of model outputs.

Harmonization of INM and NOISEMAP is widely recognized as desirable, but it has not yet been accomplished. Use of NOISEMAP's NMPLOT countouring program in INM Versions 5.0 and 5.1 has made it possible to compare/combine INM, NOISEMAP, and the Federal Highway Administration Traffic Noise Model (FHWA TNM) output.

Another example is the development of the Helicopter Noise Model (HNM) that uses a special helicopter performance data base and calculation routines adapted to civil helicopter operations. FAA plans to integrate this model with INM in the near future.

Major U.S. aircraft manufacturers (notably Boeing and McDonnell Douglas) each have models developed for their own purposes. They are largely compatible with INM in terms of basic methodology, but they contain many special-purpose additions and aircraft performance parameters that are not contained in INM.

Derivative versions of INM capable of wide-area noise analysis have been developed by the FAA for agency study.

For example, to study noise in the airspace over the State of New Jersey, FAA and the Volpe National Transportation Systems Center (VNTSC) developed an INM derivative called the Expanded Integrated Noise Model (EINM). A similar and more recent effort is the Chicago Metropolitan Airspace Analysis Planning Project study (CMAAP) that quantifies the noise impact of aviation activity over a 21,600 square mile area in southern Wisconsin, northern Illinois, and northwestern Indiana—a region that includes the O'Hare, Midway, and Milwaukee airports, as well as several smaller commercial-service and general aviation airports in the three-state area. An improved derivative of INM, the Noise Impact Routing System (NIRS), is being used for this analysis.

Many airports are supplementing their modeling capabilities today with noise monitoring systems that compute noise exposure directly, based on measurement of sound levels at several sites on and around the airport. ARTS radar track data, complaint reports, and other environmental and operational data are combined for enforcement and planning purposes

Several foreign countries have developed their own noise models. A recent example is the Norwegian Topography Integrated Noise Model (NORTIM). Based on INM, NORTIM is intended to predict the effects of terrain (e.g., mountainous features) and acoustically hard surfaces (such as water, concrete, or asphalt) on noise propagation. The model is capable of examining the interactions of four factors: slant range, varying terrain slopes, natural acoustically hard surfaces and man-made noise barriers.

CURRENT STATUS

INM UPGRADES

INM has been enhanced and upgraded several times over the past 10 years. A major release, INM 5.0, issued in August 1995 included nearly all features of earlier versions and several important new enhancements (In January 1997, INM Version 5.1 was released. The primary enhancements provided were the addition of the NOISEMAP military aircraft noise data base and the ability to run INM as a true 32-bit application under Windows 95). Among these improvements were new computer codes and computation algorithms that provide faster run times and more accurate noise predictions. Also included were new features that permit entry of a wider variety of input conditions and model outputs. The net result was a model that is easier to use, more flexible in its applications, and capable of displaying outputs in a greatly expanded number of ways. Among these were:

- Simplified entry of aircraft track data,
- User-defined noise metrics,
- Calculation of noise exposure at specific population points or special on-airport or off-site locations,
- Expansion of geographical data files for hundreds of U.S. airports and runways, and
- Quick conversion of INM output graphics to CAD drawings.

PLANS FOR THE FUTURE

Several near-term enhancements of INM are contemplated or in progress. Chief among them is integration of the Helicopter Noise Model (HNM) into INM. Performance data on more commuter and general aviation aircraft will be incorporated in the INM data base. New algorithms for estimating takeoff speed profiles and calculating takeoff noise will be added. The capability to specify the airline and the aircraft type for each operation in the OAG file will be added.

PROBLEMS AND ISSUES

Over the past decade computer-based aircraft noise models have proved to be indispensable tools for prediction of noise exposure, quantification of noise impacts, evaluation of remedial measures, and design (or redesign) of airports and airspace. These models and their associated data bases have become progressively more powerful, sophisticated, complex, flexible, and user-friendly—to the extent that they constitute the basis for virtually all kinds of aircraft noise analysis and simulation.

Despite the remarkable advances in model technology and noise analysis, aircraft noise modelers still face a number of problems and issues. Three areas are of primary concern:

- The adequacy of present noise modeling technology with respect to accuracy, validity, and flexibility.
- The application of existing noise models to types of assessments that are of much greater scope, serve different purposes, or call for new, unfamiliar, and perhaps more sophisticated or complex forms of analysis; and
- Organizational and institutional questions concerning standardization or harmonization of noise models, data base access and use, and formulation of revised rules and procedures for aircraft operation.

MODELING TECHNOLOGY

The AIR 1845 standard is now over 10 years old. The equations and calculating procedures that form the core of INM are based on the modeling technology and the knowledge of noise effects that existed in 1986. Much has changed over the intervening years. Desk-top PCs and networks have replaced mainframes and time sharing. Operating systems have become faster, more powerful, and more versatile and at the same time more user-friendly. Data bases have been greatly expanded and contain more detailed and precise information on aircraft performance. More environmental variables have been incorporated.

Much of FAA's attention since the introduction of INM has been directed toward refining details, defending the accuracy and validity of data bases and noise predictions, adding enhancements that permit a wider and more flexible range of analyses, and speeding up or facilitating computational routines.

Many in FAA and in the aviation community at large believe that it is time for a comprehensive reexamination of the fundamental equations contained in AIR 1845 and AIR 1751 (*Predictive Method for Lateral Attentuation of Airplane Noise During Takeoff and Landing.*)

Reexamination of INM

In revisiting the core equations it will be important not to lose sight of the manifold successes of INM. It is also important to bear in mind that INM was designed as a standard tool for predicting noise exposure and for airport and airspace planning—a purpose that INM, on the whole, has fulfilled very well. No one suggests a complete revamping of INM, just a careful examination of what needs to be done to strengthen the basic framework of equations, to add features that will improve the accuracy and consistency of predictions, and to establish (or reconfirm) the validity of model results. Among the components that need attention are those that involve aircraft weight, thrust settings, approach and departure profiles, and lateral attenuation.

In the course of this effort, a second objective should be assessment of whether the present model structure can be adapted to new applications, such as prediction of wide-area noise exposure, effects produced by overflight of national parks and wilderness areas, noise effects on populations residing under en route air corridors, and levels of noise exposure produced by surface transportation activity and other nonaviation noise sources in the vicinity of airports.

Desirable New Features

INM is by no means a complete simulation of exposure to aircraft noise. The state of noise modeling and other practical considerations at the time INM was developed dictated many simplifying assumptions and sacrifices of detail. Experience with the model over the past decade strongly suggests several new features that could improve predictive accuracy or provide greater insight into noise propagation phenomena. The interest in these enhancements is not just to add "realism" but to improve understanding of what various aircraft performance and situational variables contribute to overall noise exposure.

Terrain Effects

A substantial number of airports have approach and departure flight paths over water. Others have surrounding ridges, peaks, or irregular topography, that

affect noise propagation. Addition of a model component to capture the effects of sound propagating over water or the effects of intervening terrain between aircraft and receivers would be of considerable value.

Atmospheric Effects

INM contains only a limited number of atmospheric variables—barometric pressure, temperature, and runway headwind. Most calculations assume standard-day atmospherics with very little range of adjustment. Atmospheric conditions such as humidity, wind direction and velocity aloft, and turbulence are not modeled, even though they are known to affect sound propagation. Inclusion of these variables in INM could help reduce the disparity between measured sound levels and model-predicted values.

One-third-Octave-Band Data

INM noise computations have traditionally been based on overall A-weighted sound levels, without regard to the frequency content of aircraft noise. However, the effects of propagation components such as atmospheric absorption and ground reflection are frequency-dependent. It is expected that the inclusion of a one-third-octave-band data base and associated propagation equations would improve model accuracy, especially for applications including variable or mountainous terrain.

Directivity

INM uses a simplified directivity pattern. The noise footprint generated is two-dimensional and does not vary with altitude. Inasmuch as lateral attenuation varies as a function of altitude, the addition of a vertical (Z) axis would afford a way to describe the true shape of the noise envelope of an aircraft in flight. Three-dimensional directivity would not only add realism; it would also provide a more accurate picture of sound exposure along the flight path.

Track Dispersion

The capability to use radar-derived data from ARTS to create dispersed flight tracks is a new feature added in INM 5.0. At present, track representations in the INM model are two-dimensional. Because ARTS data also include altitude information from aircraft equipped with altitude-encoding transponders, this opens up the possibility of generating more precise three-dimensional flight profiles that take into account the effect of altitude.

Modeling Air Traffic Procedures

The availability of ARTS radar data provides on opportunity to model air traffic procedures more precisely. This would be useful not only for airport noise studies, but also for purposes of wide-scale noise mapping and assessments of aircraft activities in national parks, wilderness, and recreational areas.

DATA BASES

INM and other noise models are supported by a number of data bases. They include reference noise data, files on aircraft performance, environmental and geographic variables, and various other general or specific factors pertinent to calculating noise exposure. The procedures used to develop and maintain these data bases also need to be reassessed.

Review of Existing Data Bases

As part of the overall examination of noise modeling, existing data bases should be scrutinized and standardized wherever possible. They should be assessed with regard to content, accuracy, reliability, level of detail, and technical features such as format, file structure, units of measure, and suitability for user applications.

This is not an ancillary matter. The most common complaint of data base users is the limited amount of data presently available. Users believe that many current problems stem not from the models themselves but from the lack of noise and performance data for a variety of aircraft.

New Data Bases

In several cases, the data needed for improvements in noise modeling do not exist or have not been compiled in usable form. The following areas of investigation have been identified:

- Noise emanation from the rear of aircraft during engine run-up, takeoff and initial climb in departures and during thrust reversal in landing;

- Expansion of data on aircraft performance, especially for turboprop aircraft used by regional and commuter carriers and general aviation;
- More detailed records of noise variation by hour, day, season, and annual total operations;
- Extension of the noise data base to include long-distance propagation of sound generated by en route traffic in high-altitude flight corridors;
- Data on power schedules and engine thrust parameters;
- Spectral and directional data to account for air absorption, directivity, and ground effects; and
- Data from newer sources such as ARTS radar and geographic information systems.

APPLICATIONS AND PRACTICE

The utility of noise models and their suitability in certain applications has sometimes been criticized. Although most users have found close correlation between INM-predictions and field-measured data, some have expressed dissatisfaction with noise model results for certain types of analysis, particularly those for which INM was not originally intended. Many feel that new, improved, noise assessment techniques and interpretive methods could be developed to replace or supplement those now in common use.

Correlation of Calculated and Measured Noise Levels

A common observation of model users is the discrepancy between model results and the noise actually measured at noise monitoring sites. Studies conducted at airports and data collected by aircraft manufacturers have sometimes shown large variations between model predictions and actual field-measured values. In general, models usually provide suitable agreement with average noise levels, but in a number of instances they have been found to consistently understate average noise levels in comparison with on-site measurements. These inconsistencies are most likely due to variables not included in the model equations (e.g., wind, turbulence, or types of ground surface). But there are other possible explanations. It may be that measured noise is higher than calculated values because of how aircraft are actually operated. It could also be that background noise from surface transportation (automobile traffic at and around airports, aircraft ground handling and service equipment, and perhaps other mobile or stationary non-aviation sources) introduce errors into measured sound levels. FAA has endeavored in recent years to use study data from field measurement programs to improve modeling accuracy.

Understanding Model Limitations

A widespread feeling in the aviation community is that the average annual modeling procedures now in use do not always provide adequately consistent predictions. Airlines, in particular, voice the opinion that noise abatement regulations and the attendant operating procedures they must follow create conditions that affect them adversely.

To some degree the problem lies not in noise models, but how they are used. In some cases models are incorrectly applied or used for purposes not intended in the model design. Inappropriate corrections may be introduced in misguided efforts to get "more accurate" results or to resolve certain anomalies. Users may have unreasonable expectations of what models can do and how closely they must agree with measured data.

What is needed is revision and expansion of existing user manuals to provide nationally uniform guidelines, clarification of what models can and cannot do, and instruction on how to conduct noise analyses studies and interpret the results. Several universities and private firms offer courses and training programs on noise modeling. They are useful and provide valuable instruction, but they are not a completely satisfactory solution. On the other hand, there is valid complaint that existing models are limited in their ability to handle local applications. Some means should be provided (and ground rules should be established) for adapting models to account for special conditions and procedures.

Airline Problems

Airlines want to avoid operating under the multiplicity of local noise restrictions and abatement procedures. They argue that aircraft operating rules for noise control purposes should be standardized nationwide, with few or no local exceptions. This would both simplify pilots' tasks and enhance compliance with noise standards. To this end, airlines would welcome a thorough review of approach and departure procedures to reduce the variation from airport to airport and to bring manufacturers' manuals, airline operating rules, and FAA standard procedures closer to uniformity. This would provide two significant benefits: greater operating efficiency for air carriers and more consistency in how noise abatement procedures are carried out.

The following are specific questions that airlines would like to see examined.

Takeoff Thrust Settings

Expert opinion varies on what should be the appropriate thrust setting for modeling takeoff and climb performance and on which jet engine parameter is the best measure of the thrust actually delivered in flight. The difference of opinion also extends to whether takeoff weight or stage length is the better determinant of thrust settings. The problem is technical, but there are important implications for the sound levels generated during takeoff and climb.

Departure Profiles

FAA Advisory Circular 91-53A defines two noise abatement departure procedures (NADP): 1) a close-in NADP intended to provide noise reduction for noise-sensitive areas near the departure end of a runway and 2) a distant NADP intended to provide noise reduction for all other noise-sensitive areas on the departure path. Studies have shown that use of NADP can produce significant noise reductions in the population exposed to DNL greater than 65 dBA.

Adoption of NADPs by airlines has been slow in coming, and each airline has a different interpretation of AC 91-53A. The departure profiles published in aircraft manuals represent what most airlines would consider an extreme power cutback scenario—not a nominal procedure. The result is that INM tends to predict greater noise reduction for the published NADP than airlines ordinarily achieve in their typical departure routines.

It would be helpful if FAA were to develop guidelines for airport operators to use in evaluating NADPs. In cooperation with airlines and aircraft manufacturers, FAA should seek agreement on the practicality and safety of the flight procedures required for noise abatement.

Interpretation of Rules and Procedures

The controversy over NADPs is but one facet of the more general problem arising from the disparities among FAA flight regulations, manufacturers' manuals, airline operating rules, and local noise restrictions. An additional complication is the difference between the rules (whatever they may be) and the actual approach and departure profiles flown by aircrews. There are scant data on "real-world" pilot performance, but it is reasonable to assume that there is enough variance in flying technique, specific circumstances, and other operational considerations to affect sound levels by as much as 5 and perhaps 10 dBA one way or the other. This deviation from nominal performance is enough to distort any estimate of model accuracy. This matter has never been studied closely, and it deserves attention.

ORGANIZATIONAL AND INSTITUTIONAL ISSUES

Noise modeling has become an indispensable tool for evaluation of aircraft noise impacts, noise compatibility planning, and other forms of noise assessment. INM, based on AIR 1845 and developed by FAA, has been widely distributed in the civil aviation community. While other models are also available, INM is by far the most commonly used. With the most recent enhancements and additions, it has become the virtual standard model in the United States. Over 2,500 copies of INM are now in use in this country and abroad.

Harmonization

The state of noise modeling technology has reached a point where many in the civil aviation community now believe that INM and the various other models used for noise evaluation and prediction should be made mutually compatible. Such compatability does not necessarily imply establishing a single, universally used, model. Different versions and derivatives could coexist and be used for special purposes or as supplements. The only requirements are that they use standard inputs and produce comparable results. To the extent practicable, they should embody similar (if not identical) basic equations and computation paradigms, common aircraft performance and environmental parameters, and uniform (or at least readily convertible) units of measure and forms of output. In the end there should be a family of analytic and predictive tools that yield comparable outputs and mutually consistent noise predictions.

Compatability is both a technical issue and a matter of organizational and institutional relationships. What role(s) should government agencies, industry associations, and private concerns play in the process? How can the interests of the various stakeholders be best served and protected? What organizational arrangements should be employed to carry out the integration effort? What mechanisms should be put in place to manage and oversee a newly developed family of models?

The issue of compatability must be addressed at two levels, domestically and internationally.

In the United States, responsibility for noise modeling has been divided. FAA has taken the lead role for civil aviation through the INM program, and DOD has been responsible for NOISEMAP and related models for military aviation. Should this separation be continued, or should the two programs be unified? Merger of the civil and military programs in some form of joint sponsorship (perhaps with NASA participation as well) could result in substantial cost savings and provide for better management and coordination of future noise model development.

As difficult as noise modeling at the national level may prove to be, the issue of forging international harmonization is far more complex. Individual countries in Europe, Asia, and Latin America have different noise modeling methods—some based on INM, others developed on their own. Custom, specific needs, local conditions, and concerns about national autonomy may prove to be major obstacles. In Europe the issue is further complicated by the question of whether aircraft noise standards will be set by individual countries or by the European Civil Aviation Conference (ECAC) for its members as a whole.

The goal of harmonization as seen by many parts of the aviation community is to obtain the widest possible consensus on noise modeling procedures and the highest quality data bases. Computer programs and the associated data should be available to anyone worldwide. Ideally, everyone should be able to use the same computation methods with common data to obtain the same calculated noise contours.

Data Bases

Harmonization is not confined to modeling technology. It also extends to the data bases that support model applications. Questions about the quality and reliability of existing data bases were mentioned earlier.

A matter of equal concern to model users is access to data and procedures for information sharing. Some data sources may not be open to all users due to proprietary interest or desire on the part of data base owners or custodians to preserve competitive advantage. The cost of obtaining access to privately owned data bases may be prohibitive, and securing access may be cumbersome and time-consuming. A companion concern is the availability of, and ease of access to, technical information provided to model users by the custodians of noise models and data bases.

Procedures for Setting Standards

As technical solutions to modeling problems are being devised, it will also be necessary to work out the procedures and agreements for gaining acceptance within the aviation community and assuring that technical solutions are put into practice. The approach most likely to gain user participation and approval is a broad outreach to the aviation community at large to canvass their views on the most important problems and how to resolve them. Participants in the FAA/TRB workshop identified several organizations and user associations that should be involved. A list of these groups is provided in Appendix D.

SUMMARY OF ACTION ITEMS AND PRIORITIES

At the conclusion of the workshop the participants identified action items for FAA to consider, grouped by suggested priority (high, medium, low). These were not offered to FAA as firm recommendations, but as a general sense of the participants' views on important problems and issues pertaining to the current state and future needs of noise modeling technology and applications.

The summary, presented in outline form below, itemizes areas and specific topics that many at the workshop believed to deserve attention. Cross-references to the discussion of these topics in the body of the report are provided.

HIGH PRIORITY

1. Document INM model characteristics (pp. 7-10)
   - Limits
   - Error bounds
   - Sensitivities
   - Data sources
   - Suitability for current and prospective applications
2. Reexamine the AIR 1845 standard (p. 8)
   - Validation of basic equations
   - Definition of new flight profiles and procedures
3. Review procedures for determining lateral attenuation (p. 12)
   - Validation of AIR 1751 equations
   - Adjustment of coefficients as needed to correspond with field measurements
4. Standardize and improve model input data bases (pp. 12, 13)
   - Sources
   - Data formats
   - Operator inputs
   - Radar track data
   - Aircraft performance characteristics
5. Analyze and validate the effects of variable thrust approaches on aircraft noise (p. 13)
6. Investigate the usability of ARTS radar track data (pp. 12, 13)
   - Accuracy
   - Procedure for data smoothing
   - Agreement between FAA and airport operators on use of radar data
7. Integrate INM and NOISEMAP (pp. 8, 14, 15)
   - Harmonization of model operation and outputs
   - Setting policy on use and preferred applications
8. Include and Expand use of one-third octave band data (p. 12)
   - Accuracy
   - Methods of integration and summation
   - Effect on model run time

MEDIUM PRIORITY

9. Reexamine sound levels produced by use of reverse thrust in landing (pp. 12, 13)
   - Reduction of noise spikes
   - Timing and duration of thrust reverse application
   - Confirmation of measured sound levels
   - Method for modeling thrust reverse
10. Explore use of additional atmospheric variables as model inputs (p. 12)
    - Humidity
    - Wind direction and velocity aloft
    - Turbulence

LOW PRIORITY

11. Study the effectiveness of Noise Abatement Departure Profiles (p. 14)
    - Noise reduction
    - Population exposure
    - Effects of new AC 91-53A procedures
    - Process for negotiation and adoption of NADPs
    - Safety implications
12. Incorporate terrain effects in INM (pp. 11, 12)
    - Overwater operations
    - Impedance effects of rugged topography, soft ground, wooded terrain, etc.
13. Review parameters for determining takeoff weight (p. 14)
    - Actual takeoff weight
    - Manufacturer-specified maximum takeoff weight
    - Stage length

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APPENDIX B AGENDA

AIRCRAFT NOISE MODELING WORKSHOP
National Research Council/Transportation Research Board
J. Eric Jonsson Center
Woods Hole, Massachusetts

May 23-24, 1996
Room 208

FINAL AGENDA

Thursday, May 23

7:30-8:30 Breakfast (Center Dining Room)

8:30 Welcome, Introduction — Bob Miller, Chair
Keynote Address — Tom Conner, FAA

9:00 ***Current Noise Modeling Issues Facing the Aviation Community***
Bob Miller, HMMH, Moderator
Propagation and Thrust Issues at Logan: Ken Eldred, KME Engineering
The UK Perspective: John Ollerhead, CAA
Current Military Issues: Ken Plotkin, Wyle Labs
International Airport issues: Oris Dunham, ACI

10:30 Break

10:30 **Panel Discussion** – ***How Does Industry Perceive Modeling Issues***?
Bob Miller, HMMH, Moderator
Metrics: Jim Brooks, Delta Airlines
Comments: Richard Coykendall, United Airlines
Problems in Norway: Kare Liasjo, SINSTEF DELAB
Aircraft Performance: Terry Thompson, METRON
A Manufacturer's Outlook: Daryl May, Douglas Aircraft
The Boeing Position: Michael Martinez, Boeing Commercial Airplane Group
ARTSMAP: Bob Miller, Harris, Miller, Miller & Hanson, Inc.

12:00 Lunch

1:00 **Identify Unaddressed Modeling Issues (Plenary)**
- Validation of Noise and Performance Data Bases?
- Use of Radar Data in Noise Modeling?
- INM versus NOISEMAP – the Standardization of Noise Models?
- Propagation – Terrain Effects, Long Distances, Barrier Performance?
- Overflight of Parks?
- En Route Noise?
- Other?

1:30	**Breakout Groups – As Assigned**
2:30	Break
2:45	Given the Variety of Modeling Issues, are there Cross Culture Solutions? i.e., "Harmonization" – Where is the research most needed and are there common Interests?
4:15	Reconvene Plenary to Summarize Group Discussions
5:00	Adjourn
6:00	Social
6:30	Dinner – New England Clambake

Friday, May 24

7:30-8:30	Breakfast (Center Dining Room)
8:30	Review of Group Discussions
9:00	Priority Ranking of Technical Issues in Airport Noise Modeling
10:15	Break
10:30	Federal and International Reactions – Where Do We Go from Here?
12:00	Adjourn

APPENDIX C OPENING REMARKS

Thomas L. Conner
Federal Aviation Administration

I also want to welcome you to the Airport Noise Modeling Workshop and I want to thank TRB for arranging and hosting this session. Airport noise modeling has been near and dear to me for many years. I hope that we can use this workshop to revitalize research activities in this area.

I, like some of you here, have been associated with airport noise models for close to 25 years. Let me apologize beforehand for what may seem to be the "walk down memory lane" nature of my keynote to you. I have seen tremendous advances in computer technology from mainframes and timesharing to personal computers and networks. In recent years I have become more of a bystander as my work function has evolved in a different direction. I have observed the technological leap as we have transported our computer models to workstations and the most current operating systems. Our efforts have been a great boon to users as they can now more easily access devices and information systems to help them understand airport noise exposure and its effect.

Now is the time for the federal government to refocus and redirect our efforts to a more traditional role in this area. Let the marketplace develop the "bells and whistles" to help ease the application of these computer models and let the federal government devote its limited research resources in improving both the accuracy of the models' calculations and our scientific understanding of the impacts of aircraft noise exposure. It is also the duty of the federal government to promote the harmonization of airport noise analysis methodologies and the development of international standards governing these methodologies.

For me personally, the heyday of my work in airport noise modeling was during the late '70s and early '80s as a participant in the development of the Society of Automotive Engineers (SAE) Aerospace Information Report 1845, "Procedures for the Calculations of Airplane Noise in the Vicinity of Airports." Manufacturers, consultants, and government agencies worked together to produce the first set of standard equations for the calculation of aircraft noise and performance. Working with our European counterparts, these standards went international in 1988 with the publication of "Recommended Method for Computing Noise Contours Around Airports" by the International Civil Aviation Organization (ICAO).

With the establishment of these standards, we turned our attention elsewhere. At FAA, we focused on solidifying our position as the foremost leader in civil aviation noise modeling. We assumed the role of technical arbitrator on airport noise analysis. We committed research funding into making the tools "user friendly." We devoted further resources to fending off attacks on the accuracy of our models. This became a patchwork process of fixes to small components of the model without addressing the whole system. In the 10 years since the publication of AIR 1845, we never really turned our attention back to these standards. And in that time SAE Committee A-21 on Aircraft Noise has become a fairly lifeless forum that is dormant in this area.

AIR 1845 is becoming too old of a document to continue to use as a shield in defending our models. Recently a few of us in this room were involved in another one of those patchwork projects defending the accuracy of our model's aircraft noise data base. While the outcome showed that our methods do produce reasonable results, the findings did raise questions on whether some of our standards are outdated. We need to reexamine the core equations. We need to resolve any differences among the prominent airport noise models. We need to validate our systems. Finally, we need to revitalize an international forum to promote ongoing communication and coordination among the organizations engaged in airport noise modeling.

I want this workshop and you people to be the ignition key to get the bandwagon rolling. This process needs new blood and new ideas. With ever-shrinking federal research budgets, we require creative ways to address these issues. Thank you and let's get to work.

APPENDIX D AGENCIES, ORGANIZATIONS, AND USER GROUPS CONCERNED WITH AIRCRAFT NOISE MODELING

FEDERAL GOVERNMENT
- U.S. Department of Transportation (DOT)
  - Federal Aviation Administration (FAA)
  - Federal Highway Administration (FHWA)
  - Volpe National Transportation System Center (VNTSC)
- U.S. Department of Defense (DOD)
  - U.S. Air Force (USAF)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)

OTHER GOVERNMENT
- State, regional, and municipal governments and agencies
- Airport authorities

U.S. ORGANIZATIONS
- Airline Pilots Association (ALPA)
- Airports Council International (ACI)
- American Association of Airport Executives (AAAE)
- Air Transport Association (ATA)
- American Helicopter Society (AHS)
- Helicopter Association International (HAI)
- National Association of State Aviation Officials (NASAO)
- Regional Airline Association (RAA)
- Society of Automotive Engineers (SAE)

INTERNATIONAL ORGANIZATIONS
- European Civil Aviation Conference (ECAC)
- International Air Transport Association (IATA)
- International Organization for Standardization (ISO)
- North Atlantic Treaty Organization (NATO)

APPENDIX E GLOSSARY OF TERMS

A-Weighting. A weighting network used to account for changes in sensitivity as a function of frequency. The A-weighting network emphasizes the frequencies between 1 kHz and 6.3 kHz and deemphasizes frequencies outside this range in an effort to simulate the relative response of the human ear.

Acoustic Impedance. Acoustic impedance is defined as the product of the speed of sound in a medium and the density of the medium. For the purposes of noise modeling the medium is air. INM includes an acoustic impedance adjustment computed as a function of observer temperature, atmospheric pressure, and (indirectly) altitude that is applied to noise-power-distance data on a case-by-case basis.

Acoustically Hard Surface. Any highly reflective surface in which the phase of the incident sound is essentially preserved upon reflection. Examples of such surfaces are water, asphalt, and concrete.

Acoustically Soft Surface. Any highly absorptive surface in which the phase of sound energy is changed upon reflection. Examples include terrain covered with dense vegetation or freshly fallen snow.

Atmospheric Absorption. The change of acoustic energy into another form of energy (e.g., heat) when passing through the atmosphere. In INM, noise-power-distance (NPD) data are corrected for atmospheric absorption.

Community Noise Exposure Level (CNEL). Denoted by the symbol L_{den}, CNEL is a 24-hour time-averaged sound exposure level adjusted for average-day sound source operations. In the case of aircraft noise, a single operation is equivalent to a single aircraft approach, departure, overflight, tour, or runup. The adjustment includes a 5-dB penalty for operations occurring between 1900 and 2200 hours (local time) and a 10-dB penalty for those occurring between 2200 and 0700 hours (local time). The L_{den} noise descriptor is used primarily in the State of California. L_{den} is computed as follows:

$$L_{den} = L_{AE} + 10*\log_{10}(N_{day} + 3*N_{eve} + 10*N_{night} - 49.4 \text{ dB}$$

where:

L_{AE} = Sound exposure level in dB;
N_{day} = Number of operations between 0700 and 1900 hours, local time;
N_{eve} = Number of operations between 1900 and 2200 hours, local time;
N_{night} = Number of operations between 2200 and 0700 hours, local time; and
49.4 = A normalization constant which spreads the acoustic energy associated with aircraft operations over a 24-hour period, i.e., $10*\log_{10}$(86,400 seconds per day) = 49.4 dB.

Contour Analysis. An analysis of an area encompassed by a graphical plot consisting of a smooth curve, statistically regressed through points of equal noise or time in the vicinity of an airport.

Day-Night Average Sound Level (DNL). Denoted by the symbol L_{dn}, DNL is a 24-hour time-averaged sound exposure level adjusted for average-day sound source operations. In the case of aircraft noise, a single operation is equivalent to a single aircraft approach, departure, overflight, tour, or runup. The adjustment includes a 10-dB penalty for operations occurring between 2200 and 0700 hours (local time). L_{dn} is computed as follows:

$$L_{dn} = L_{AE} + 10*\log_{10}(N_{day} + N_{eve} + 10*N_{night}) - 49.4\text{dB}$$

where:

L_{AE} = Sound exposure level in dB;
N_{day} = Number of operations between 0700 and 1900 hours, local time;
N_{eve} = Number of operations between 1900 and 2200 hours, local time;
N_{night} = Number of operations between 2200 and 0700 hours, local time; and
49.4 = A normalization constant which spreads the acoustic energy associated with aircraft operations over a 24-hour period, i.e., $10*\log_{10}$(86,400 seconds per day) = 49.4 dB.

Decibel. A unit of level which denotes the ratio between two quantities that are proportional to power. The number of decibels is 10 times the base-10 logarithm of this ratio. In INM the reference level is 20 μPa, the threshold of human hearing.

Directivity. The noise signature defined by a 360 degree area in the horizontal plane around a noise source. In INM measurement-based directivity is accounted for behind the start-of-takeoff ground roll, as well as for runup operations.

Divergence. The spreading of sound waves from a source in a free field environment. Two types of divergence are common, spherical and cylindrical. Spherical divergence is the transmission loss of mean-square sound pressure, which varies inversely with the square of the distance from a point source (e.g., a stationary aircraft). Cylindrical divergence is the transmission loss of mean-square sound pressure, which varies inversely with distance from a line source. Both spherical and cylindrical divergence are independent of frequency.

Equivalent Sound Level (TEQ). Denoted by the symbol L_{AeqT}, TEQ is ten times the base-10 logarithm of the ratio of the time-mean-squared instantaneous A-weighted sound pressure (during a stated time interval) to the square of the standard reference sound pressure. For the purpose of INM, the reference sound pressure is 20 μPa, the threshold of human hearing.

Ground Attenuation. The change in sound level, either positive of negative, due to intervening ground between the source and a receiver. Ground attenuation is a relatively complex acoustic phenomenon, which is a function of ground characteristics, source-to-receiver geometry, and the spectral characteristics of the source.

Ground Impedance. A complex function of frequency relating the sound transmission characteristics of a ground surface type. Measurements to determine ground impedance must be made in accordance with the ANSI Standard currently under development.

Lateral Attenuation. The attenuation of noise at receivers laterally displaced from the ground projection of an aircraft flight path. It is the sum of ground-to-ground attenuation and air-to-ground attenuation.

Maximum Sound Level (MXFA or MXSA). Denoted by the symbols L_{AFmx} and L_{ASmx}, respectively. Fast-scale response (L_{AFmx}) and slow-scale response (L_{ASmx}) effectively damp a signal as if it were to pass through a low-pass filter with a time constant of 125 and 1000 milliseconds, respectively.

Mean-Square Sound-Pressure Ratio. Commonly referred to as sound energy, acoustic energy, or just plain energy, the mean-square sound-pressure ratio is arithmetically equivalent to 10 Sound Level (SPL)/10, where the SPL is expressed in dB relative to the threshold of human hearing. (See SPL.)

Noise. Any unwanted sound.

Noise-Power-Distance (NPD) Data. A set of noise levels expressed as a function of 1) power (usually the corrected net thrust per engine) and 2) distance. The INM NPD data have been corrected for the effects of airspeed, atmospheric absorption, distance duration, and spherical divergence.

Observer. A receiver or grid point at which noise or time values are computed.

Sound Absorption Coefficient. The ratio of the sound energy, as a function of frequency, absorbed by a surface to the sound energy incident upon that surface.

Sound Exposure Level (SEL). Denoted by the symbol L_{AE}, SEL is ten times the logarithm to the base 10 of the ratio of a given time integral of squared instantaneous A-weighted sound pressure to the reference sound pressure of 20 μPa, the threshold of human hearing. The time integral must be long enough to include a majority of the acoustic energy of a sound source. As a minimum, this integral should encompass sound levels 10 dB down from the maximum sound pressure on either side.

Sound Pressure Level (SPL). Ten times the logarithm to the base 10 of the ratio of the time-mean-squared pressure of a sound, in a stated frequency band, to the square of the reference sound pressure of 20 μPa, the threshold of human hearing.

Spectrum. The resolution of a signal expressed in component frequencies, usually as fractional octave bands.