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Time-of-Day Corrections to Aircraft Noise Metrics

Proceedings of a Workshop held at
NASA Langley Research Center
Hampton, Virginia
March 11-12, 1980

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Time-of-Day Corrections to Aircraft Noise Metrics

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Proceedings of a Workshop sponsored
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PREFACE

The Workshop on Time-of-Day Corrections to Aircraft Noise Metrics, sponsored jointly by the Federal Aviation Administration and the NASA Langley Research Center, was held at the NASA Langley Research Center March 11-12, 1980. The Workshop was funded by the Office of Environment and Energy of the FAA and the Acoustics and Noise Reduction Division (ANRD) of the NASA Langley Research Center. Financial support was also indirectly obtained from the many organizations who provided the time and supported the expenses of their staff members who were in attendance.

The objective of the Workshop was to develop information on noise metrics needed to guide government policy and rulemaking decisions. Time-of-day corrections to cumulative metrics were the primary concern. The participants were asked to focus on two areas: background/applications and research.

The position (perspective) papers given by William J. Galloway and James M. Fields set the tone for the Workshop discussions. Transcripts of the position papers and the individual statements of roundtable participants are included in this report as well as summaries of the discussions held in the workshop sessions. The style of each workshop session varied; thus, the "Closing Remarks" are dissimilar in format.

The efforts of Ann Suit, Office of External Affairs, and Barbara Fryer, ANRD, in logistics and in tape transcription which helped to make for a well-organized conference and greatly assisted in the publication of this report are gratefully acknowledged. The assistance of the Scientific and Technical Information Programs Division of the NASA Langley Research Center in publishing these proceedings is also gratefully acknowledged.

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March 12, 1980

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WORKSHOP PARTICIPANTS

Mr. Louis Achitoff	Federal Aviation Administration - Eastern Region
Mr. Jay W. Bauer	National Bureau of Standards
Mr. Paul Borsky	Columbia University
Mr. J. D. Collier	Air Transport Association
Mr. Bill Connors	Airport Operators Council International
Mr. Thomas L. Connor	Federal Aviation Administration Headquarters
Mr. Jimmy Cawthorn	NASA Langley Research Center
Mr. Sherman Clevenson	NASA Langley Research Center
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Dr. Thomas K. Dempsey	NASA Langley Research Center
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Dr. F. John Langdon	Building Research Establishment - England
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Mr. David A. McCurdy	NASA Langley Research Center
Mr. Mickey McPike	McDonnell Douglas Corporation
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Mr. John B. Ollerhead	Loughborough University - England
Mr. John C. Parnell	R. Dixon Speas Associates
Mr. William Piper	Flying Tigers Airlines
Mr. Richard Popper	Columbia University
Dr. Clemans A. Powell	NASA Langley Research Center
Dr. John Powers	Federal Aviation Administration Headquarters
Mr. John W. Reynolds	Federal Aviation Administration Headquarters
Mr. Christopher G. Rice	University of Southampton - England
Dr. William T. Shepherd	Federal Aviation Administration Headquarters
Dr. Kevin Shepherd	Bionetics, Inc.
Mr. David G. Stephens	NASA Langley Research Center
Mr. Louis Sutherland	Wyle Laboratories
Mr. Richard M. Tedrick	Federal Aviation Administration Headquarters
Dr. G. J. van Os	TNO - Netherlands
Dr. Francis Ventre	National Bureau of Standards
Dr. W. Dixon Ward	University of Minnesota
Mr. John E. Wesler	Federal Aviation Administration Headquarters

INTRODUCTION

Aircraft noise description has been a subject of interest for more than 25 years. A great variety of attempts have been made to devise units which reliably relate the physical aircraft flyover events to some form of human response. Two broad metric types have evolved over the years, single event and cumulative. Despite the diversity in approach among the various cumulative metrics, one unifying thread exists, the application of penalties for noise occurring at night or in the evening. The rationale for these penalties has been somewhat obscure and there has not been widespread agreement on their ability to predict night aircraft noise annoyance. Nevertheless, the penalties are in widespread use, and this fact is one of the primary reasons for reluctance to change to other possibly more valid means of describing noise, assuming such metrics exist. Various government agencies have used two different cumulative metrics for describing aircraft noise - day-night average sound level, L_{dn}, and noise exposure forecast, NEF. The night penalties in these two metrics differ slightly, but both purport to describe the added community annoyance attributable to night aircraft operations. This dichotomy in metric usage was largely eliminated recently when the FAA decided to adopt L_{dn} as its preferred cumulative metric for assessing aircraft noise impact. With virtually all Federal agencies now in agreement on the metric to be used, it is important for the FAA, as a noise regulator, to determine the gaps that may exist in the community modeling implied by L_{dn} and, particularly, the research needs to remedy these deficiencies. Since the FAA will be using L_{dn} in support of its rulemaking and policy development actions, it is imperative that any real or potential limitations in this metric be accounted for.

The objective of the Workshop was to develop information on noise metrics needed to guide government policy and rulemaking decisions. Time-of-day corrections to cumulative metrics were the primary concern. The participants were asked to focus on two areas: background/applications and research. In the first area, discussion topics included the technical bases for time-of-day corrections, needs and criteria, current practice and experience, government policy and regulation, and economic, social, and other impacts of using corrections. Research discussions dealt with past research, statements of current problems, needed research areas, and specific research approaches.

The NASA Langley noise research team has established a leading role in the study of community impact of aircraft noise. They are clearly well qualified to propose needed research and interpret the efficacy of the research proposals of others. They were asked to join the FAA in the sponsorship of this Workshop with the special tasks of devising proposed research programs and moderating the research discussions of others.

The meeting was organized in a roundtable-workshop format as shown on the agenda. The roundtable sessions consisted of invited statements by organizational representatives with specific interest in time-of-day corrections. These statements provided the background for the discussions in the workshop sessions. The statements of each of the participants at the roundtable were recorded and are reported here as they were presented at the meeting. The Background/Applications workshop session was divided into several discussion groups. Summary statements of each group's discussions are presented in this report as well as a number of individual views. The Future Research workshop session dealt with a number of topics which are summarized in the summary statements from the session.

WELCOME

Donald P. Hearth, Director, NASA Langley Research Center: Let me welcome you to the Langley Research Center. We're happy to cohost this Workshop with the FAA. We at Langley have been in the noise research business since World War II, and most of the effort from those early years was how to quiet the source of the noise; starting in the late 1960's, about 10 or 12 years ago, we began doing work on human response to aircraft noise. We have, we think, an excellent set of facilities here at Langley and I think a really very good staff and some very good research programs; speaking as a resident of Newport News, located fairly close to Patrick Henry Airport, I think time-of-day effects on human response to noise are important. We are looking forward to this Workshop as perhaps being a way of helping us tune up our research program, and I know the FAA is looking forward to its providing them some input and helping them meet their regulatory responsibilities. It is a good relationship we have with the FAA, and I think this Workshop is another example of that. I also understand that Congress has asked the FAA to standardize the units for measuring the noise, and as a nonacoustician I have trouble with dB, dB(A), PNDB, EPNDB, NEF, etc. So please be successful. It would really help me in dealing with Homer; I have trouble with his language. I really do welcome you to this Workshop and it certainly is a very timely subject and we look forward to the results of this meeting and I think for the FAA the same thing applies. May I introduce John Wesler, Director of Environment and Energy at FAA. This Workshop was initiated from his office and we're most happy to welcome him here.

John E. Wesler, Director of Environment and Energy, Federal Aviation Administration: I would like to thank you all for coming, add my welcome to that of Dr. Hearth, and thank Langley for having us. We are happy to be here largely because they do such a nice job of putting on conferences such as this. We appreciate it - Langley does all the hard work and we take part of the credit. In keeping with what we hope to be a rather informal, but productive workshop, I would like to start by asking each of you to introduce yourselves, to make sure that everyone is aware of who is here and which organizations are represented. [See "Workshop Participants."]

Thank you for coming this morning. I know with all the conferences that are going on around the country it's always a chore to attend another one and we do sincerely appreciate your coming here; we feel that we have an important subject, although it is a narrow subject to cover for the next day and a half. It is particularly pertinent right now because 3 weeks ago yesterday [on February 18] President Carter signed into law what is euphemistically called the Aviation Safety and Noise Abatement Act of 1979. Among other things that this law does, some of which are good and some of which are bad, it requires the DOT (FAA) to take some actions. If I may read very briefly what some of these actions are - we essentially are required by regulation within 12 months to do three things:

(1) Establish a single system of measuring noise, for which there is a highly reliable relationship between projected noise exposure and surveyed reactions to people to noise, to be uniformly applied in measuring the noise at airports and the areas surrounding such airports

(2) Establish a single system of determining the exposure of individuals to noise which results from the operations of an airport and which includes but is not limited to noise intensity, duration, frequency, and time of occurrence

(3) Identify land uses which are normally compatible with various exposures of individuals to noise

Note that in establishing the first requirement, the single system of measuring noise, we are to find one which is highly reliable compared with peoples' reaction. In establishing the second one, the single system for determining the exposure of individuals, there is no such requirement for high reliability. Perhaps it was not intended that way, but that is the way it came out. To put this into a little more perspective, I would like to quote from Senator Cannon who was chief sponsor of this act, as I am sure you probably know. I would like to quote from him speaking from the floor during the debate in the Senate - prior to passage of this particular bill. Senator Cannon said "I wish to place particular emphasis on the requirement included by the conferees that the single noise exposure measurement system to be adopted by the FAA is to have a highly reliable relationship between the system's projected noise exposure and the surveyed reactions of the people living in the noise exposure area. This language directs the FAA not to adopt an existing system until it has been modified and proved reliable."

We are faced with adopting these things within the next 12 months. If we had to reach a decision today, I expect that we would adopt the following things: for the single system of measuring the aircraft noise, we would adopt the A-weighted sound level, slow response; for the single system of measuring noise exposure for individuals, we would probably adopt the average day-night sound level. In fact, the FAA has adopted L_{dn} or average day-night sound level as the preferred means for evaluating noise exposures around airports. Insofar as identifying the land uses that are compatible with noise exposures, I expect we would probably follow the lead that Bill Galloway has set for us in developing an American national standard on this subject. These are the three actions we would probably take today in response to this new requirement; but we don't have to make these decisions today, we have a year in which to make them. Therefore, some of the discussions for today and tomorrow and perhaps some of the research which you all will recommend may have a bearing on the final adoption, selection, and establishment of these two single systems as we are required to do by Congress.

In adopting the average day-night sound level last December as the preferred FAA system, we weren't entirely comfortable and that is the reason for this conference today and tomorrow. Our feeling of discomfort had to do primarily with the nighttime weighting. The time-of-day weighting has given the name to the conference we are holding today. We are somewhat uncomfortable with this weighting for basically two reasons: the idea that it is applied as a step function, that is, promptly at 10:00 at night and promptly removed at

7:00 in the morning, and that of the 10 dB value. Although intuitively it seems quite proper to have a nighttime penalty, the basis for 10 dB and the basis for a step function for 10:00 to 7:00 seems somewhat soft to us. Therefore, we have asked your advice in helping to determine if in fact it is soft or if there is a good basis for selecting this weighting. There are other considerations of course in selecting some sort of a nighttime penalty or weighting that would be given to noise exposure metrics. One of course is simplicity of use. This I think is particularly important for airport users, because we are dealing generally 5, 10, or 15 years into the future to predict the effects of a new runway, a new airport, changed procedures, or whatever the effect that is being evaluated for noise exposure purposes. Trying to predict 5 to 15 years ahead of time, particularly to any great detail - if, for example, we had to predict any operations by hour of day - becomes an extremely difficult procedure. Therefore, a simple step function such as the 10 dB nighttime penalty in the average day-night noise level has a lot of advantages to it for that reason. From an airport point of view, we feel that nighttime weightings are extremely important because one of the usual noise abatement methods brought up at almost any airport is that of a nighttime curfew. The heavier the weightings on the nighttime operations, the more attractive the nighttime curfew would appear to be. I think this factor is probably more important to us in aviation than it is to other types of noise exposure, whether they be railroad, automotive, or industrial. Certainly, an unfair penalty weighting which makes curfews appear more attractive than they are, can cause a lot of harm to our national air transportation system. We are interested in this subject and in what you have to tell us later today. We are asking you therefore to assess two things: what is the scientific or research basis for the nighttime penalty, and if it is appropriate, what research we might (NASA, FAA, and EPA) undertake to pin this down to provide a more factual basis for a nighttime penalty.

With that beginning I would like to introduce, in order to give us some perspective of historic development of noise exposure metrics and particularly the nighttime penalty, Dr. Bill Galloway. At the conclusion of Bill's talk, Dr. James Fields will give us a research perspective on time-of-day effects on noise annoyance. Jim is an NRC-NASA Senior Resident Research Associate at the Langley Research Center. Bill doesn't really need an introduction - he is the principal consultant for Bolt Beranek and Newman from the West Coast, and we are happy to have him on the East Coast.

HISTORICAL DEVELOPMENT OF NOISE EXPOSURE METRICS

William J. Galloway
Bolt Beranek and Newman Inc

As I mentioned to several of you this morning, the way the chips fell as to who was selected to do what in the introductory part of this workshop, all I have to do is tell you what happened; I don't have to tell you why. That is left to Jim Fields.

What I thought I would do is essentially trace briefly some of the historical events that led to the introduction of night penalties, then go briefly into their effects on two things. First, what happens with different kinds of day/night operations when different night penalties are employed. I will consider these effects in terms of the difference between a nighttime-weighted cumulative measure of noise exposure versus simply not using any night weighting at all, in decibels. Then to put the effects on operations into perspective, some simplified equations will be used to allow you to play games with operations to see what effect night weighting has as compared to no weighting. Finally, since new methods seem to be proposed about every 5 years in this business, and it's been 7 years since anybody came up with a new scheme, I'm going to give you another proposal at the end of my talk.

I'm going to focus basically on the events and steps that took place leading to actions in this country. I'll mention briefly a few methods that have been proposed in Europe - other approaches that were used to adjust levels for night corrections. However, I'm going to key this talk mainly to those events which affect fundamentally the planning operations and documents which have come out in our country.

Probably the starting point is around 1951 when Ken Stevens, Walter Rosenblith and Dick Bolt were working on their preliminary studies which led to the original composite noise rating scheme, or CNR. This was a method for attempting to relate the physical noise and other attributes in the community to some method to estimate the community response that would be expected.

There were no social surveys available; the input data in terms of community response were basically assessments of case histories. Among the cases were airports, one was a wind tunnel - in essence, different kinds of community noise situations where there was some degree of community response.

In the process of evolving the procedures in the original CNR, in their opinion two things entered into their saying that there should be some additional consideration given to events that occur at night. During the evolution of this first CNR, not only a nighttime adjustment was proposed, but also the background sound levels at night were brought into the picture. Basically what this amounted to was that operations were separated into night and daytime;

the time period at night was not defined. Noises that happened at night were penalized 5 decibels. Moreover, since background noises seem to decrease at night, an additional 5 decibels were applied in the background level adjustment which was in another section of the CNR procedure. But that effectively resulted in a 10 decibel adjustment for night operations - ten decibels on exposure, the integral of sound level over time. The difference between exposure and level is what causes some of the confusion over the differences in night penalties between CNR, NEF, and L_{dn}.

In the original CNR development there were about 11 case histories used. In a later publication, I think in about 1955, the authors added something like the order of a dozen more case histories. They made some modifications in the expected response scale but basically the system remained the same. This original work was done as part of a program for the Air Force in its earlier look at community noise problems.

Again for the Air Force, in 1957, the first specific procedure for airport noise and land use planning was introduced. This was Technical Note 57-10, which was produced by Ken Stevens and Adone Pietrasanta. Basically it was simply an implementation of material that had been gathered for a number of years. There were no magic new response data that were brought into its development. It was basically a first step as to how one can take sound level measurements from airplanes in flight and tie them together into a system that will allow you to predict noise contours.

It is worth pointing out that they used a cumulative noise measure in this 1957 document, an equivalent level, that is, an energy average level, if you will, over a 24-hour period. At that time, for reasons that are still obscure, three time periods were introduced. From 6:00 a.m. to 6:00 p.m. essentially took no penalty; from 6:00 to 11:00 p.m., they introduced a 5 decibel penalty; from 11:00 p.m. to 6:00 a.m., a 10 decibel penalty. There still could be some additional adjustments for background sound levels, but this adjustment was rarely used. The 10 decibel night penalty has now showed up twice.

The next phase of development was a modified CNR specific to airport land use planning. We looked at, in this case, specifically airport case histories - a number of air base situations, run-up problems, flyover problems, that sort of thing, and tried to see how they applied to Air Force operations. There were about 30 case histories involved and the system came out not too different in the end from the original CNR approach. The most significant difference was that perceived noise level had come into being and at that time the Air Force and FAA wanted a planning guide that was based on perceived noise level. The FAA wanted to incorporate commercial aircraft in the procedure to do similar analyses so that it would be used for military/commercial operations. The airport CNR is based on a report that was first prepared in 1961, revised in 1962, and eventually made it to publication in 1964. This was a very simple guideline. The name of the game was to provide a planning tool, and as I remember the instructions it was such that it could be used by a brand new lieutenant in the Air Force who had never seen any of these problems in his life. Since this was the lowliest job to which he could probably get assigned, he was to make the noise analyses. The procedure had to be something where one could sit down without a calculator and use a very simplified procedure (the simplification would later cause problems) to do a noise analysis of operations at an Air Force base.

No new response data had been gathered in this country, yet in the development of the aircraft CNR one question considered was whether or not to incorporate a nighttime adjustment based upon the case history information. The case history data were not too firm, but one other thing was available. Results of the first London Heathrow social survey were becoming accessible at the time, however tentative they might be. The data came in pieces; the correctness of the analyses we will let Jim Fields discuss and I won't go into it. At that time the interpretation, presented in the British noise and number index (NNI) system (which we took at face value), was that about a 17 unit in NNI difference was required to obtain comparable responses in the nighttime versus daytime. That is, the noise exposure had to be 17 units lower at night if one were to balance the responses. Correctly or incorrectly, that was the statement. We translated the NNI back into the equivalent CNR terms and said about 17 units of NNI to us was worth about 11 units of CNR, which wasn't too different from the 10 used previously, so 10 decibels was kept as the offset in CNR. Now because CNR worked in 5 decibel increments, things were always done in steps; a continuous scale was not used. It was simply that using 5 decibel steps, two steps (or 10 decibels) was the nighttime adjustment. Again with the exception of the data from Heathrow, no other new response input was used.

By 1967 - every 5 years seems to have generated a change - the perceived noise level PNL had evolved into effective perceived noise level EPNL, not quite in the form that was eventually used in FAR 36, but very similar. The PNL weighting for frequency response at that time was not quite the same as it is today, but for all practical planning purposes it can be considered to be the same. Although EPNL has been refined substantially as to how one calculates and measures it, the essence of EPNL was pretty much evolved at that time. In order to transfer the CNR kind of analysis into a procedure in which noise levels of individual aircraft were related to EPNL, two studies were undertaken: one by BBN and one by an SAE research group. Basically the two studies came out essentially the same, saying we should convert CNR by taking the PNL and replacing it with EPNL but not do much else with anything in terms of the other adjustments. In other words, simply adopt what we had in CNR with just a change to EPNL and an arbitrary constant. The result was NEF. Here is the first place where the exposure versus level adjustment starts getting into the act and starts affecting operations more strongly. The assumption that was made from the previous work was that nighttime exposure would be offset from daytime exposure by a 10 decibel adjustment for nighttime. The night by definition at that time was 10:00 p.m. to 7:00 a.m., a nine hour period. Daytime was obviously 15 hours, so balancing the exposure at night versus the exposure in the daytime required greater adjustment on level at night than it would if some other time period was involved. In essence it came out to be about a 12 decibel adjustment on level, with the effect on operations being a factor of 16.7 operations at night equated with one in the daytime. I'll show you some simplified equations to let you play operational games with later, but in essence that's basically what happened.

I should point out that other developments of cumulative noise measures with night adjustments were taking place about this time. The European countries were very much involved. International Standards Organization (ISO) was considering various measures for land-use planning purposes, International Civil Aviation Organization (ICAO) was beginning to get going in some of its activities, the state of California was evolving its airport noise standards, so a number of different approaches were being considered. California adopted community noise equivalent level (CNEL) which uses the same nighttime adjustment as one of the proposals within ICAO for a three-period day. That is, a daytime period running to 7:00 p.m., an evening period in which some penalty was attached (this was from 7:00 p.m. to 10:00 p.m.), and then basically the 10:00 p.m. to 7:00 a.m. night period. Typical proposals were that the evening periods be penalized the equivalent of 5 decibels, while additional nighttime adjustments or penalties would also be used. The California method applied the 10 decibel night penalty against level, not exposure, so instead of a 16.7 type multiplier on operations to come out equivalent to daytime, a 10-times multiplier applies.

You will see later that these wrigglings around may have an important impact on numbers of airplane operations, but they really don't make much difference in terms of their eventual effect on the sound levels. I'll give you some examples here in a minute.

Other methods to weight nighttime operations have been used in Europe. I'll only mention two of them. In talking with Mr. Van Os this morning, we recalled the Dutch proposals of the mid-60's. They didn't like the step function at 10:00 p.m., so they have a sliding scale which starts at 6:00 p.m. with a 2 decibel penalty, then in the next hour 3 decibels, and so on through the transitional period of full nighttime. This proposal was discussed, as a matter of fact, in the ISO circles. For reasons John Wesler referred to earlier, that is, it's hard to predict which numbers of operations and which kinds of airplanes are going to exist hour by hour when planning 10 to 15 years in advance, the proposal was not adopted by ISO. People who do this kind of projection have enough trouble figuring out what can be expected in 24 hours, let alone breaking the figures down into these other hours. With this and similar proposals, the interesting thing is that basically these adjustments were judgmental decisions made without a tremendous amount of background to justify the choices. Case histories, people's complaints, intuition, the whole bit were reflected in these judgments. Much of the justification for night penalties depends on the change of background levels - pretty much a concession that, yes indeed, the other sound levels in the community do go down somewhat at night compared to daytime operations. All thru this history the choice of nighttime penalties is basically a judgment made by a group of people or by a group of committees, not decisions made from a lot of hard social data.

In the early 70's, in the Title 4 report of the Clean Air Act for EPA, Ken Eldred took another look at a number of case histories. His point was that with better physical measurements available, he could explain some of the case histories that were available to him. He had about 50 case histories to look at for which he tried to make correlations of community response with and without making nighttime adjustments. Without applying any nighttime penalties, he got something like a 4 decibel standard error in his predictions of response versus sound level measurements. When he applied the nighttime adjustment, the standard error was reduced to something on the order of 3 decibels. Now that doesn't sound like a big difference, but at least it was in the direction that it was better to have a nighttime adjustment than not.

There is one example I want to show you later. It is a French nighttime adjustment which absolutely baffles most of the people that I know. It amuses me because it is so complicated - there isn't much basis for it - but if you think our methods are bad, wait and see how much worse they could be.

In 1973, EPA in its report to Congress as part of the Noise Control Act had to adopt a measure for cumulative noise for use around airports, and this is of course where day/night average sound level was brought into the picture. I wouldn't say that it was a unanimous agreement, by any means, but certainly agreement was reached that, at least for community measures, A-weighted sound level was the preferred measure. With all of its other problems, the fact that it had been used for a number of different sound sources and that it was relatively easily measurable were to its credit. The fact is that it doesn't do that bad a job, subjectively, compared with any other measure when one takes weighted sound levels and compares them with judgments of noise events. It was pretty well agreed that, for a cumulative noise measure, an integral of A-weighted sound level over time should be used. There was a lot of discussion about what one does about day versus night, a lot of discussion but not a lot of new input. What was available were a number of measurements of average sound level over daytime versus nighttime periods, plus the previous history.

There was speculation as to whether to use 8 decibels, 10 decibels, 12 decibels, or some other value for a nighttime penalty. It turned out that for most situations there was little numerical difference which one you used. In essence, a 10 decibel penalty on level was selected as being a sort of compromise position. Again, no extensive social response data existed; only the information that had historically been available was used in this decision.

So where are we? We have 20 years between about 1953 to 1973 in which several different community noise measures have been used. Everyone of them incorporates a nighttime adjustment, largely on the basis of intuition and case history input, and this is about it. Now what does this imply, in terms of both operations and levels? Let me show you a few figures. I told Jim Fields I would give him most of the time, so it will take about 5 minutes to run thru these figures.

Just to give you an idea of what can happen between the day and night sound levels at an airport (just to enliven things a little bit), let me show you a graph of the hourly average sound levels, with and without operations at night, measured at a point on the order of 2 miles from the approach to runway 25 at Los Angeles airport. The top line in figure 1 was taken before the switch in operations at the airport; the bottom line shows the change in levels, obvious when we knock out 50 to 60 flights at night. Now you notice that there is a pretty high hourly average level varying from 75 to 80 decibels most of the time. At nighttime if the operations are removed, you drop from

75 or so down below 50 - about 25 to 30 decibels knocked out of the night operations. Clearly here is a case where removal of nighttime levels really makes a difference.

The next figure (figure 2) is a collection of a variety of situations. The ordinate is the difference in the daytime average sound level and the nighttime equivalent sound level using the 10:00 p.m. to 7:00 a.m. nighttime period, while the abscissa is day-night average sound level with the 10 decibel nighttime penalty. There obviously is a great deal of scatter. Basically the trend seems to be that if you have fairly low levels to begin with, the nighttime levels are much lower than the daytime levels. At the higher levels, the difference between day and night doesn't change too much. There is a tendency at all times, however, for the average sound levels at night to be lower than they are during the daytime, which is not too surprising.

I mentioned previously that there was a question about the difference in weighting level versus exposure. L_{dn} and CNEL weight level at night by 10 decibels. NEF weights nighttime by 10 decibels for exposure and effectively 16.7 times operations, or 12 decibels, for level. What these differences mean can be seen in figure 3. I want to introduce and get you thinking in terms of fractions of nighttime operations, which makes things easier to manipulate. This figure shows the nighttime penalty introduced as the increment that the night adjustment provides over an unweighted 24-hour average sound level if one applies the night penalty on level or exposure as a function of the fraction of nighttime operations. The typical airport is not the major transoceanic type with lots of nighttime operations. A typical middle-sized airport has probably something in the neighborhood of more than 80 percent of operations during daytime. For such operations NEF, which weights exposure, has on the order of 2½ decibels of night penalty more than a measure like day-night average sound level, which weights night sound levels.

To put things in a simplified form so that you can compare some of the metrics, refer to figure 4. Whatever kind of measure - L_{dn}, NEF, CNR, or anything that accumulates levels on a basis of a mean square or energy level - can be expressed as L_α as shown in the figure by using the appropriate individual event measure L_β. All the measures can then simply be written as the sum of three terms: the energy average of the levels of individual events, an effective number of operations, plus a constant. For example, the constant is 49.4 for L_{dn}, which is 10 times the number of seconds in 24 hours, while an arbitrary constant of 88 is used in NEF. The key is to make the assumption that day operations and night operations in terms of the aircraft mix are homogeneous. If not, you have to wriggle them around, but let's make that assumption for the moment. Then you can express the differences in nighttime penalties in terms of the formulas for the effective number of operations, effective number meaning how you apply a weighting function to night operations. For example, as shown in figure 4, for NEF the effective number of operations is simply the total in 24 hours times a multiplier for operations that occur during the night. NEF basically has a multiplier that is one plus 15.7 times the fraction of operations that occur at night. L_{dn}, or any other weighted level measure with a 10 decibel night penalty, uses a multiplier of one plus 9 times the fraction of operations during nighttime. If you put in an evening adjustment of 5 decibels with a 10 decibel night adjustment, you have the multiplier shown for CNEL in the figure.

My favorite example is the French isopsophic index, Λ, which has two characteristics. One is that it is complicated. In comparison with the other measures in which there are simply multipliers which affect total operations, Λ has a series of extra multipliers. The second characteristic is that the multiplier also varies with the number of operations. That is, the more operations you get, the bigger the nighttime adjustment becomes. If you're not sure how well you understand L_{dn}, NEF, or CNEL, I sure don't know how you're going to understand this one.

The effect of the different nighttime adjustments is shown in figure 5 for two-example mixes of operations. The values listed are the increments in decibels that the night penalties produce compared with a 24-hour average level without penalties. One example assures a constant number of events per hour. It's not the worst case, but it's as bad as I can think of. To put you more in the perspective of a more realistic airport, the second example has an operational mix of 75 percent daytime, 17 percent evening, and 8 percent night. This is very representative of a fair number of airports. You will notice that the increments over a 24-hour average sound level come down to something that is not nearly so strong. The Λ index, by the way, was calculated for 240 operations per day.

Suppose, since we haven't had any new night penalty proposals for 5 years, we try something else. One of the primary objections to the current methods is that irrespective of whether it is 10 or any other decibel value, there is a very valid argument against the proposition that no penalty exists at 9:59 p.m. while at 10:01 p.m. it does. We know this is silly. It's useful in terms of planning purposes to make such a break simply because it's functional in the computations. As alternative approaches, consider the following. Suppose we were to say that we will assume that the time weighted integral of level, such as L_{dn}, is held constant, but we want to allow some kind of transition period so that the abrupt change at 10:00 p.m. doesn't take place. We still may have some step functions at either end of the various time periods, but maybe we can ease into it less abruptly than we now do. We can consider this as one alternative here. As another, suppose we said that we would allow a transition period between 9:00 p.m. and 11:00 p.m. instead of the abrupt 10:00 p.m. change, if we were willing to accept some moderate additional penalty in order to be able to move the time period limits around but still keep the 10-decibel level penalty during the remaining part of the night. Or as another alternative, what happens if we move the 10:00 p.m. limit to 11:00 p.m.? If you look at airline schedules, you find often that a lot happens right after 10:00 p.m. but beyond 11:00 p.m. things die off at many airports. Would this help on the operations side if one were willing to take a slightly larger night penalty on the fewer operations that occur late? These alternatives are summarized in figure 6.

Consider some numerical examples shown in figure 7. If you take my previous 75/17/8 mix and assume that operations in the evening hours are more or less uniformly distributed, you can show for the first proposal that to maintain the same effective L_{dn} would require a multiplier of 4 on operations during this transition period. So changing to a two hour transition with a one hour later start of night operations could be accomplished in its integral effect by an operations multiplier of 4, which is a 6-decibel level correction.

The second proposal, changing the nighttime limits from 10:00 p.m. to 7:00 a.m. to an hour later (11:00 p.m. to 7:00 a.m.), would require an operations multiplier during nighttime of about 15, which is not quite 12 decibels on level.

Although these possibilities are not meant as firm proposals, they do show a way in which one could ameliorate the operational problems to some degree yet still retain a weighted sound exposure equal to the current L_{dn} method. I'll throw them out to you for your consideration.

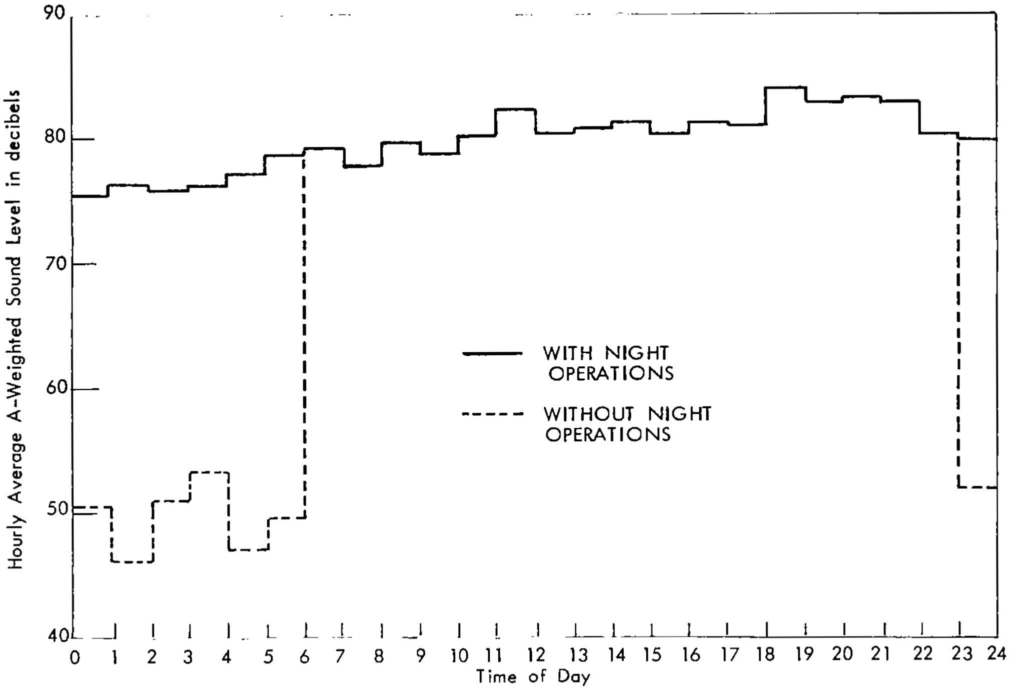

Figure 1.- Hourly noise levels for a 24-hour period in the high noise exposure area.

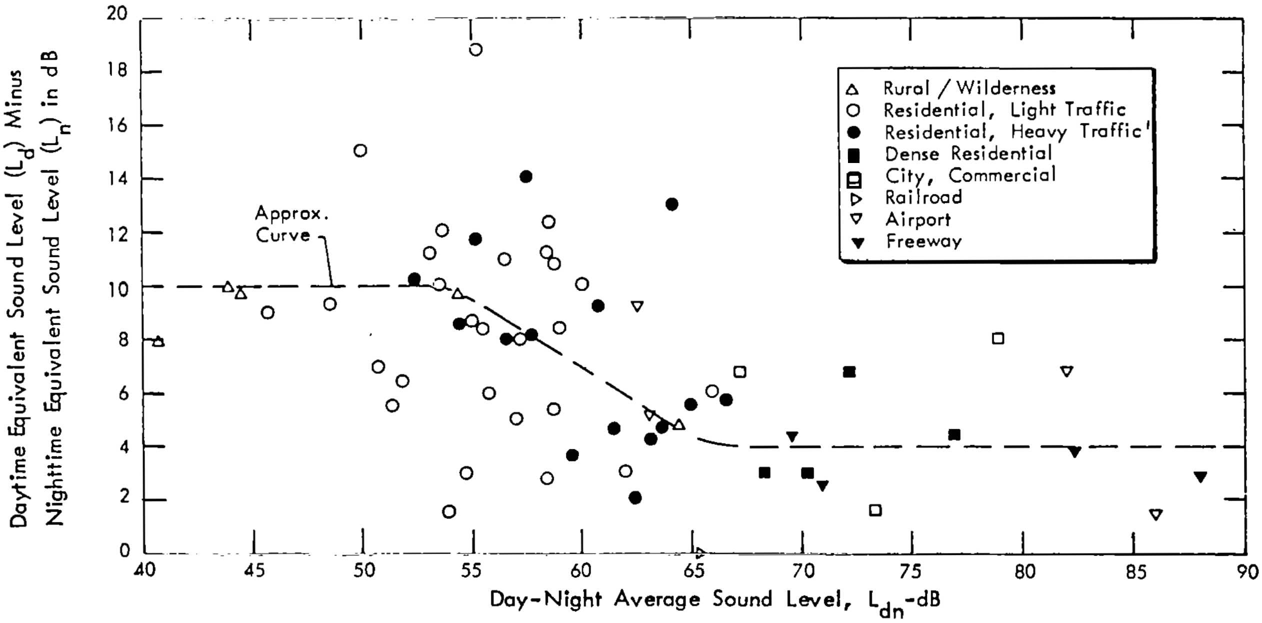

Figure 2.- Comparison of the difference between day and night values of the equivalent sound level with the day-night average sound level L_{dn}.

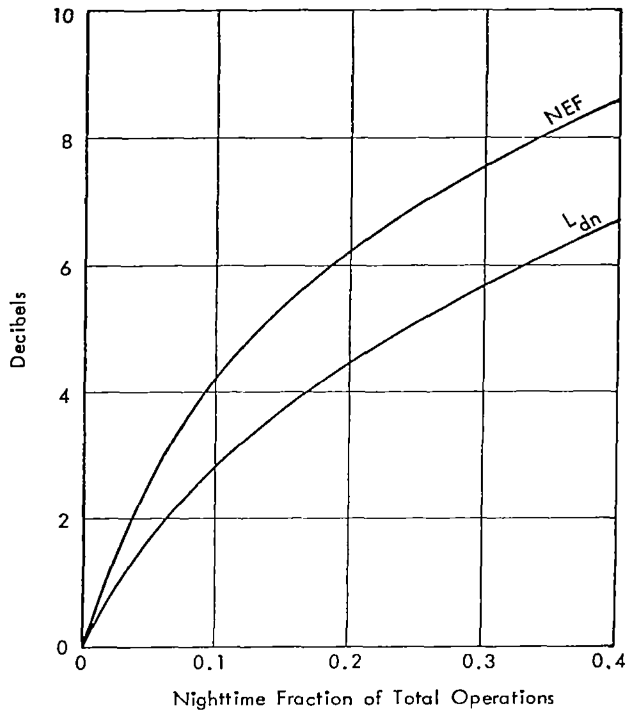

Figure 3.- Increase in level due to application of a nighttime weight in decibels for day-night average sound level and noise exposure forecast.

$$L_\alpha = 10 \log_{10} \left(\frac{1}{N} \sum_{i=1}^{N} 10^{0.1 L_\beta} \right) + 10 \log_{10} N_{eff} - C$$

Measure	N_{eff}
NEF	$N(1+15.7\ f_n)$
DNL	$N(1+9\ f_n)$
CNEL	$N(1+2\ f_e+9\ f_n)$
Λ	$N^{1.6}(1-f_1-f_2)\ (3f_1+f_2)^{0.6}$

f_n is fraction between 2200-0700

f_e is fraction between 1900-2200

f_1 is fraction between 2000-0200

f_2 is fraction between 0200-0600

Figure 4.- Cumulative noise measures.

	Constant N per hour	75/17/8
NEF	8.4	3.4
DNL	6.4	2.2
CNEL	6.7	2.6
Λ^a	11.7	11.6

[a]N = 240

Figure 5.- Increment in decibles between night penalties and 24-hour average sound level.

1) a. Use 2100-2300 as transition time.

   b. Have moderate transition time penalty.

   c. Use 10 decibel penalty from 2300-0700.

2) a. Use 2300-0700 as night period.

   b. Have larger night penalty.

Figure 6.- Alternate night-penalty proposals.

Proposal	Percent flights at time periods –
1	86.3% 0700-2100 8.7% 2100-2300 5.0% 2300-0700 Operations multiplier during transition: 4.1 (6.1 dB)
2	95% 0700-2300 5% 2300-0700 Operations multiplier for night: 15.4 (11.9 dB)

Figure 7.- Examples from alternate night-penalty proposals.

RESEARCH PERSPECTIVE:

TIME-OF-DAY EFFECTS ON NOISE ANNOYANCE

James M. Fields*
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As you may have noticed, the whole conference is divided between research and applications. The first obvious indication of this comes from comparing my presentation with Bill Galloway's. I have been asked to give a research perspective.

By way of introduction I should say that over the past year at NASA I've been looking at existing surveys of people's response to environmental noise. I've identified about 150 of these social surveys. About half of these concern aircraft. I will be drawing in one way or another on about 20 of these surveys in what I say. I should make it clear that I will not be providing a summary of these surveys' findings, but rather I will try to provide a perspective of the overall research approach to time-of-day studies.

Here is an overview of what I am going to say. (See fig. 1.) First, we want to take a look at the existing time-of-day research effort. Then we will examine some of the complications that these research findings have raised for the research approaches that have been used. Next, I will offer a conceptual framework for further time-of-day research. Finally, I will suggest some of the implications for the research methods that should be used.

When I looked at the time-of-day research that had been done, it seemed to divide into two general areas. (See fig. 2.) There is, of course, the time-of-day weighting issue, which Bill Galloway talked about. In the other area, which we might call the nighttime response model issue, a large amount of research is concerned with how people respond at night and how sleep disturbance and overall annoyance at night are related to noise level. A large number of issues could be brought up here, but let's just take the simple graphic one in this figure (fig. 2). We might think that during the daytime there is a roughly linear increase in annoyance with increasing noise level. At night though, the graph suggests that there might be a different type of response model with some kind of threshold phenomena.

In the area of research that has to do with the time-of-day weighting, one simple weighting model is presented in figure 2 where the overall response is a function of the level during the day and the level during the night. We aren't making any assumption about whether it's decibels or energy which is being added. The critical point here is that the whole focus of the research

*NRC-NASA Senior Resident Research Associate is to find the value of the weight which determines the relative effects of daytime and nighttime noise levels.

There has been a large amount of useful time-of-day research. I don't have time to go through it here, but I would like to take one piece of research that brings some particular issues into sharp focus. (See fig. 3.) This study was carried out at Los Angeles International Airport by Fidell and Jones. It's good that Sandy Fidell is here. He can keep me honest in case I bring up anything that is incorrect. Up to April 29, 1973, there had been about 50 flights a night over this area. From April 18 to 28 there were 328 interviews carried out. About 20 percent of the people interviewed in the high-noise-level area reported some sort of sleep interference in the past week. From April 29 on there was an almost complete elimination of flights from 2300 to 0600. A month later, an additional 228 interviews were conducted. In the same area sleep interference was now reported by about 22 percent. The change in sleep interference is insignificant. The most important finding is that in spite of a definite reduction in number of flights there was no change in annoyance. This finding raises four questions. (See fig. 3.)

The first question is whether people are insensitive to any change in operations. Fortunately there has been a recent study around the Burbank airport where a change in operations for several months meant a change in noise levels for many people. Interviews before and after the change show that people do report less annoyance after the reduction in noise level. The answer here then is "No". People are sensitive to some changes, at least when there are changes in daytime noise levels.

The second question is whether nighttime reactions are integrated over very long periods. In this study only about a month had elapsed since the change. People may still have been reacting to something that happened last summer when they were kept awake for one night. I think that a long period of integration is a possibility. We will come back to the problem later but I should say that since the particular question at LAX was about sleep disturbance in the past week, the period of integration can probably not explain this finding.

The third question is whether, even after the change, people were exposed to aircraft noise during a proportion of the hours when they were trying to sleep. There is a change here during a very substantial period of 7 hours. However, most people sleep 8 hours instead of 7. Some don't even try to sleep until after 2300. Others may be up before 0600. As a result, most people are exposed to some aircraft noise during the time they try to sleep. I examined this 2300 to 0600 period in the second Heathrow survey and found that 96 percent of the population would still have some flights going over during their sleep period. This may partly explain the continued sleep disturbance at LAX. Whatever the explanation, the central finding is that after an important reduction in the number of flights, there was no decrease in nighttime annoyance. This raises the fourth question, Does the number of flights have only a small effect at night? (See fig. 4.)

There is some evidence which suggests that the number effect and other components of the response model should be different for the day and night. I would like to just mention a few findings. Several studies in addition to the LAX study suggest that the number effect is weaker at night than during the day. In the second Heathrow survey the noise and number trading factor was weaker at night. The railway survey which I conducted in Great Britain showed that though the peak noise levels at night had an effect, the number of events at night had virtually no effect on annoyance. Some of the work John Ollerhead has done suggests that the number effect may be weaker at night. On the other hand, I will have to say that the evidence is not completely clear. One piece of Paul Schomer's work suggests that there may be a fairly strong number effect at night.

Day and night response models can also differ with respect to certain mediating variables; that is, there is some evidence that people's responses are affected by different variables at night more than during the day. Dr. Langdon in England and Aubrey in France found that older people and women are more likely to be disturbed by noise at night than are younger people or men. In general, we find that age and sex do not affect daytime annoyance.

The second general finding from the studies is that the simple time-of-day weighting model which we examined earlier (fig. 2) is inadequate. One reason for this conclusion is that there is not a consistent finding on the weights. Although generally nighttime noise is more annoying, different studies have provided different estimates for the value of the nighttime weighting factor. Depending on the study, you can find support for from a 0 to 17 dB weighting. The first Heathrow study suggested that 17 NNI (noise and number index) was a reasonable first adjustment. That has been transformed by other researchers into other energy measures with different assumptions to show there should be either an 11 or a 14 dB weighting. The railway study I conducted indicated no effect for numbers of nighttime events. Borsky suggests that his data support a 3 dB weighting. Schomer suggested something like 7 to 10 dB. The most striking feature of the reports presenting these findings is the tentativeness, even for researchers, with which they state their findings. I would like to quote from the much heralded first Heathrow study. "We must emphasize however, that this particular conclusion concerning critical nighttime exposure levels must be regarded as only a very tentative estimate, in view of the scanty evidence on which it is based." I think that if we took the time to go over the evidence we would find that, if anything, the statement overestimates the quality of the evidence.

The second point I would like to bring up is that the simple time-of-day weighting model is inconsistent with the research evidence. This should be leaping out at you by now. Half of the time-of-day research assumes that you can use the same metric for day and night (only the weight differs), while the other half shows that you cannot use the same metric for day and night. The simple time-of-day weighting model is inconsistent with the research findings. What do we conclude then? (See fig. 5.)

There are two conclusions. First, we need a more realistic conceptual framework to take into account the differences in the response models for the night and the day. Second, we need some new types of study approaches. Ollerhead, the authors of the TRACOR surveys, and a number of other researchers have all pointed out that one of the major reasons we don't have definitive findings from existing studies is that the daytime and nighttime noise levels are too highly correlated in the samples. In fact, we should not be too surprised at the lack of progress when we realize there has never been a study which has been specifically designed to obtain good estimates of the nighttime weighting. All the findings come from studies which were designed for other purposes.

The two conclusions in figure 5 can be seen as the outline for the research part of this workshop. I want to try to cover the conceptual framework in this paper. The study approaches will be the subject of one of the remaining roundtables and workshops.

I have my own time-of-day response model (fig. 6). It has been labeled "tentative" to encourage discussion. The overall response to noise is some function of what happens during some number of different periods. What is important about each period is, first, the noise. The purposely vague term "noise" is used here because I'm not sure what sort of metric or description we ought to have. What's happening in the period has to do with the noise as well as any mediating variables. Beyond that there are the questions as to how the characteristics of these different periods are being combined. Is it energy addition or is it some sort of independent effects addition? Last is the question of weighting. How much weight should be given to the noise environment in each period?

This model suggests a research program where it is necessary to define the number of time periods, the dose response model for each time period, the mediating variable models, a model for combining all the period effects, and the weights for combining the periods. In the remaining time, I would like to just briefly go through each of these components to put forward what I think the major issues are.

The first problem is the definition of time periods. There is obviously a day/evening/night possibility. Perhaps there should be more periods. It may be that weekends are different. Galanter in some of his work has even suggested that there may be some sort of an interaction, that on the weekend there might need to be a different division of the periods. I have, however, looked at the TRACOR data. They suggest that the same time periods apply for the weekend as during the week, even though there might be a heightened reaction on the weekends.

Now, consider the second point, the dose response model for each period. (See fig. 7.) I see three research areas here. The first is the noise metric. We've said there is some evidence that the number of events has less effect at night than during the day. Perhaps the energy model doesn't represent all periods. A second issue is the shape of the dose response relationship. As I mentioned before, there may be some sort of threshold effect here. I don't know of any good survey research evidence on this issue. It may seem fairly obvious that if we want to look at the response at night, we have to look at that response against the nighttime noise level. All the published results that I've seen, which compare daytime and nighttime activity interference by noise level, graph them both against the same 24-hour noise level. The only analysis which provides some evidence on thresholds is some work in Switzerland where the noise is represented by L_{eq} for each period. In that particular case, there is no evidence that the shapes are any different for different times of day. The third dose response issue is the more usual one. The question is simply whether the degree of response is different at different times of day even though the response model is otherwise the same during the different periods.

The third set of research issues for the time-of-day response model concerns the mediating variables (fig. 8). There are a number of issues we could talk about here which are outlined in figures 9 and 10. I'm just going to focus on the second issue in figure 8: the effect of the value of the mediating variable during the time period. In this case, there is the same relationship of mediating variable to response in the two time periods. For example, where there is a low ambient noise level, people are more annoyed than where there is a high ambient noise level. During the daytime, though, most people (90% in fig. 8) are in high-ambient-noise-level conditions; thus, the total response should be something like the dashed line in time period 1. At night most people (90% in fig. 8) are in the low-ambient-noise condition; thus, there may be a heightened overall response such as the dashed line in period 2. There are a number of mediating variables listed in the research. Those I have seen are listed in figure 9: the time a person spends at home, the room in the house that a person sleeps in (Is it in the back?), and ambient noise level. It has been suggested that age and sex have a different effect on daytime and nighttime annoyance.

Now let's consider the last time-of-day research issue: the model for combining periods (fig. 11). I suggest two alternative models here. One is the energy summation model such as L_{dn}. This can be compared to the independent effects model. In the independent effects model, the effect of any one time period is independent of the noise level in the other period. No matter what the noise level is during the day, if you reduce the nighttime level by a certain amount there will always be the same annoyance reduction. That is quite a different model from the energy summation model. Just take as an example, a 70 dB L_{eq} during the day and 50 dB L_{eq} during the night. We could ask whether there is any value in further reducing the noise level at night. Well, with the independent effects model there is; by further reducing nighttime noise, there can be a further substantial reduction in annoyance. According to the energy summation model, on the other hand, because the effect of the antilog of the nighttime level would be completely lost in the antilog of the daytime level, there would be no benefit at all in reducing the noise level further at night. I have discussed only two models but have left open the discussion of other possibilities with the "Others????" category. A model which might fit here would be one which would allow for time-of-day weights to vary with the amount of time people are at home. This is just one of a variety of other approaches which might be suggested.

Let's note one condition which is needed for a critical test to choose between the models. The requirement is that a study be designed where the day and night noise levels are not too highly correlated.

The last research issue is the traditional one of choosing weights for combining noise periods. This is essentially one of solving an equation for values of the weights. Of course, you have to decide which of the alternative models will be considered. I don't know of many attempts to choose between those two models. In fact, because day and night levels are so highly correlated, there aren't good data sets to help choose between the models. In general, the weak effects of nighttime levels on overall annoyance in the LAX study and second Heathrow study suggest that perhaps the energy summation model makes somewhat more sense. On the other hand, where the two models were examined in Bradley's work on traffic noise in Canada, a slightly higher correlation was found for the independent effects model. I think the intercorrelations are so strong that there isn't a lot to be drawn from these results.

I have suggested a time-of-day response model. I think this research approach contains two suggestions for study design discussions in the workshop and roundtable. (See fig. 12.) First, a wide range of time-of-day environments is needed for studies. Secondly, I would suggest that this large time-of-day model will have to be developed sequentially. The complexities and number of unknowns with respect to basic questions about the shape of the relationship and the noise metric are so great that it seems to be unlikely that we are going to specify the model in a single research project. Most likely we will have to develop any model sequentially.

OVERVIEW OF PAPER

REVIEW TIME-OF-DAY RESEARCH EFFORT

EXAMINE COMPLICATIONS RAISED BY RESEARCH FINDINGS

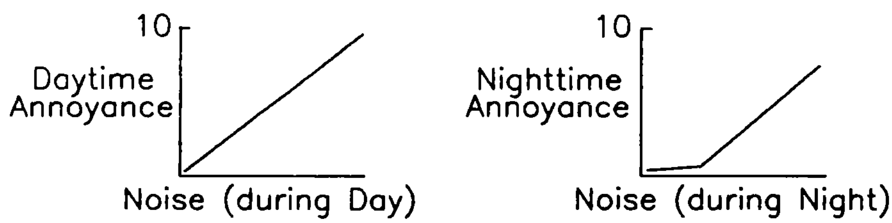
OFFER CONCEPTUAL FRAMEWORK FOR TIME-OF-DAY RESEARCH

SUGGEST IMPLICATIONS FOR RESEARCH METHODS

Figure 1

PREVIOUS TIME-OF-DAY RESEARCH ISSUES

- NIGHTTIME RESPONSE MODEL



- **TIME-OF-DAY WEIGHTING MODEL**

Simple Model

$$\text{OVERALL RESPONSE} \propto L_{DAY} + W \cdot L_{NIGHT} + C$$

Figure 2

LAX NIGHT FLIGHT REDUCTION STUDY

APRIL 18–28, (328 INTERVIEWS)

–20% REPORT SLEEP INTERFERENCE (50 FLIGHTS A NIGHT)

APRIL 29, ALMOST COMPLETE ELIMINATION OF FLIGHTS FROM 2300–0600

MAY 29–JUNE 11, (228 INTERVIEWS)

–22% REPORT SLEEP INTERFERENCE

QUESTIONS RAISED BY LAX STUDY

ARE PEOPLE INSENSITIVE TO ANY CHANGE?

ARE NIGHTTIME REACTIONS INTEGRATED OVER VERY LONG PERIODS?

WERE PEOPLE EXPOSED TO AIRCRAFT NOISE DURING SOME SLEEP HOURS?

DOES THE NUMBER OF EVENTS HAVE ONLY A SMALL EFFECT AT NIGHT?

Figure 3

FINDINGS FROM TIME–OF–DAY RESEARCH

- RESPONSE MODELS DIFFERENT FOR DAY AND NIGHT
  - WEAK NUMBER EFFECT AT NIGHT
  - MEDIATING VARIABLES
- SIMPLE TIME–OF–DAY WEIGHTING INADEQUATE
  - NO CONSENSUS ON WEIGHTS
  - INCONSISTENT

Figure 4

CONCLUSIONS ABOUT TIME-OF-DAY RESEARCH STRATEGY

- MORE REALISTIC CONCEPTUAL FRAMEWORK NEEDED
- NEW TYPES OF STUDY APPROACHES NEEDED

Figure 5

TENTATIVE TIME-OF-DAY RESPONSE MODEL

- MODEL

$$\text{OVERALL RESPONSE} = f\,[\underbrace{W_1(\text{NOISE}_1, M_1)}_{\text{Period 1}}, \underbrace{W_2(\text{NOISE}_2, M_2)}_{\text{Period 2}}, \ldots \underbrace{W_t(\text{NOISE}_t, M_t)}_{\text{Period } t}]$$

- **RESEARCH PROGRAM TO DEFINE COMPONENTS IN MODEL**

  Definition of Time Periods

  Dose Response Model for Each Time Period

  Mediating Variable Model for Each Time Period

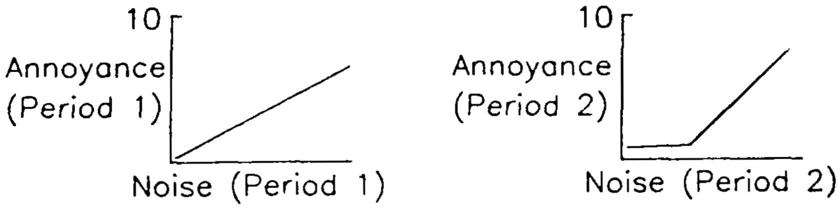
  Model for Combining Period Effects

  Weights for Combining Periods

Figure 6

DOSE RESPONSE MODEL FOR EACH PERIOD
RESEARCH ISSUES

- NOISE METRIC
- SHAPE OF CURVE



- DEGREE OF RESPONSE

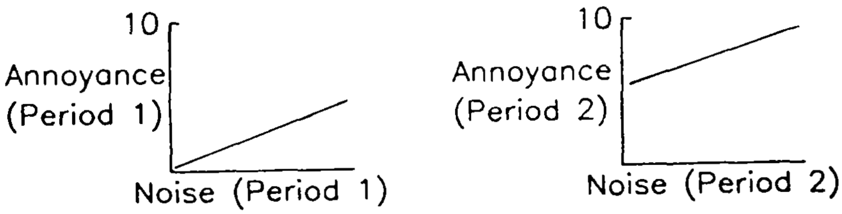
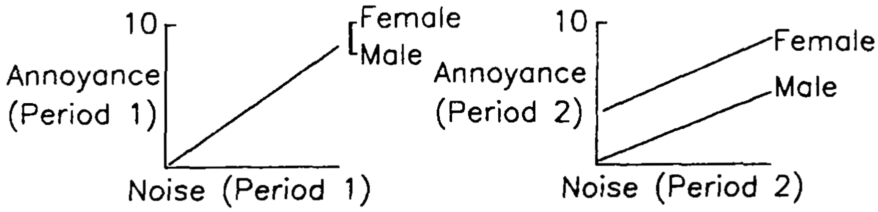


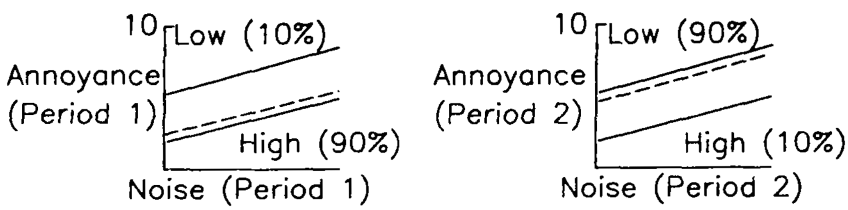
Figure 7

MEDIATING VARIABLE MODEL FOR EACH TIME PERIOD
RESEARCH ISSUES

- EFFECT OF MEDIATING VARIABLE



- VALUE OF MEDIATING VARIABLE DURING TIME PERIOD



(Ambient Noise Levels)

Figure 8

MEDIATING VARIABLES

CONTRASTING EFFECT VARIABLES

- **Sex**
- **Age**

DIFFERENT VALUES FOR MEDIATING VARIABLE DURING TIME PERIOD

- **Ambient Noise Level**
- **Exposure Position at Home**
- **Time at Home**

Figure 9

DEFINITION OF TIME PERIODS

SEPARATE TIME PERIODS NEEDED WHEN:

- Different Noise Metric
- Different Dose Response Relationship
- Different Mediating Variable Effect
- Different Mediating Variable Values

Figure 10

MODEL FOR COMBINING PERIODS

ALTERNATIVE MODELS

- INDEPENDENT EFFECTS

  OVERALL IMPACT = $\beta_1(\text{NOISE}_1) + \beta_2(\text{NOISE}_2)$

- ENERGY SUMMATION

  OVERALL IMPACT = $10 \log_{10}[\beta_1(\textit{antilog}\frac{L_1}{10}) + \beta_2(\textit{antilog}\frac{L_2}{10})]$

- OTHERS????

CRITICAL TEST

- ANNOYANCE FOR DIFFERENT PROPORTIONS OF DAY AND NIGHT NOISE

Figure 11

IMPLICATION OF RESEARCH APPROACH FOR STUDY DESIGN

- WIDE RANGE OF TIME-OF-DAY ENVIRONMENTS NEEDED
- MODEL MUST BE DEVELOPED SEQUENTIALLY

Figure 12

ROUNDTABLE I - POLICY/IMPACTS

Chairman: J. E. Densmore
Federal Aviation Administration

J. E. Densmore, Federal Aviation Administration: The planning of this workshop began early last fall. When Congress heard about it, it was just enough incentive to resolve several years of debate on noise legislation. They realized that they better hurry up and tell the FAA what to do. And as John Wesler has already mentioned to you they came out with the Aviation Safety and Noise Abatement Act of 1979. Now I don't know how they date things in Congress. That act was voted on in 1980 and signed into law in 1980 but it is the act of 1979. As John Wesler mentioned they put in Title I, which requires the FAA to establish by regulation a system for measuring noise, a system for evaluating noise, and to identify normally compatible land uses. As we said the initial reaction is, well, aren't these metrics dBA and L_{dn}? We've had a number of discussions already this morning of some of our concerns about this. We believe that the basis for L_{dn} should be examined, both the amplitude and the time base for it. It is not our intent here to criticize any of the research that has gone on; rather, we wanted to assemble a group of experts, a group of professionals both in and out of the government, to review the situation. We would hope that this workshop identifies areas of future research, which would provide profitable answers to the Nation's needs. You have already noted that it is very unlikely that future research will be planned, funded, and implemented in time to evolve sufficient information that would influence rule making action within 12 months. But certainly the discussions here concerning past research and ongoing research will influence it, and certainly this is an open question in the sense that any regulation, in light of new information, can be amended in the future. I think we are all motivated to maximize the acceptability of aviation in the communities which aviation serves. Therefore, we feel it is important that noise exposures be depicted reliably. If airports, for example, are considering implementing restrictions at airports, the environmental benefits of these restrictions need to be properly evaluated and assessed in order that reasonable conclusions have a chance of being made.

The purpose of this roundtable is to set the stage for the other workshop discussions. We have invited panel members here who represent organizations which have been vitally affected by noise impacts and the means of representing these impacts. We thought it was important, then, for each of them to make a statement as to what they consider important and what they want on your minds as we continue in these workshop discussions. As mentioned earlier, we are planning on issuing a proceedings on this workshop, and if any of you have prepared statements, we would appreciate copies of them.

At this time I would like each of the panel members to make a brief statement as to what they feel is important in considerations of time-of-day assessments and then we would like to open the panel to discussion from the audience. However, we don't want to get into technical detail at this point; I think the technical details are much more important in the workshops. We would like to restrict the discussions to areas of clarification, or possibly other views. First, I would like to introduce Rudy Marrazzo from the Environmental Protection Agency.

Rudolph M. Marrazzo, Environmental Protection Agency: I am very pleased to be here today to share in the work and discussions of this workshop. With such an experienced group bringing their collective knowledge to bear on the topic of time-of-day corrections for noise descriptors, I am sure that the results of this workshop will be quite productive. As part of my contribution, I would like to take a few minutes to review EPA's original selection of the day-night average sound level, with its inherent 10 dB weighting incorporated for night-time noise, and to discuss some considerations that EPA feels are important for improving time-of-day penalties.

At the outset, let me summarize EPA's point of view on the use of sound descriptors for assessing environmental noise. As you know, EPA relies heavily on the L_{dn}, with its 10 dB nighttime weighting. We have, in fact, actively encouraged its use by all federal agencies concerned with noise control, as well as by states and municipalities for use in their noise assessment and control activities. We realize that future research may indicate a weighting value either greater or smaller than the 10 dB may be appropriate and the best predictor of human response. We are aware of the criticisms of the 10 dB night-time weighting, and we fully support collective efforts like this workshop which we hope will lead to the research or study that is necessary to determine the appropriateness of various time-of-day weightings.

In regard to time-of-day penalties, it seems that this workshop will concentrate on various technical aspects such as the direction of appropriate research, the interpretation of resulting data, and the use of research results to weigh the merits of different systems of time-of-day weightings. Nevertheless, at the same time, we should not ignore some of the other less technical, but important, factors that must govern the selection and adoption of descriptors or noise metrics to be used for noise assessment purposes. These factors include various scientific, technological, economic, and social-policy considerations inherent in the choice of a particular metric of time-of-day weighting.

It would first be helpful to review how and why EPA selected the L_{dn}, or the day-night average sound level, for use as a single, universal noise descriptor. The specific reasons for this selection were detailed in the EPA levels document published in 1974. Briefly, L_{dn} is an A-weighted equivalent sound level with an added penalty or weighting for nighttime exposure. A-weighting was chosen as the frequency weighting for measuring sound levels because it is convenient to use, it accurately corresponds to human subjective response, and it is already in use extensively throughout the world. For sounds which vary in level over time, the A-weighted equivalent sound level L_{eq} was chosen to provide a single-value characterization of environmental noise. It was also selected because it correlates reasonably well with the many effects of noise on people, even for wide variations in environmental noise levels and time patterns, provided that it was not an effect where the time of occurrence - daytime versus nighttime - was relevant. For the latter case, the L_{dn} was selected as a descriptor for time-varying noise for a 24-hour period, differing from the L_{eq} in the 10 dB weighting imposed for the nighttime hours of 10:00 p.m. to 7:00 a.m. Available information showed that this scheme correlates with human response to noise as well as more complicated metrics or rating schemes, such as those that may have different corrections applied to daytime, evening, and nighttime periods. Furthermore, L_{dn} has the virtue of simplicity. The L_{dn} descriptor is now typically used to characterize the outdoor noise environment in urban areas. It has the advantage of being convenient to use, and it is applicable to all major sources of noise, such as traffic noise, aircraft noise, construction noise, and so forth. Thus, in this sense, L_{dn} may be termed a universal descriptor.

This brief review brings us to the present, and to the focus of this workshop. The question which we wish to bring to bear is what other factors should this workshop keep in mind as it considers research steps for the development of a more scientifically ideal time-of-day weighting penalty system. In this regard, I hope to leave you with one thought: The considerations that need to be made at this workshop are much more complex than simply initiating and conducting laboratory, field, or community studies of human subjective response to noise as influenced by time-of-day factors, and attempting to directly apply the results of such investigations to the derivation of some "ideal" descriptor or weighting penalty.

First, we must keep in mind some additional scientific considerations. In considering alternative weighting systems, what will their impact be on our ability to account for all of the relevant effects of noise on people - not only annoyance, but, for example, the disturbing effects of noise on the sleep process? We believe it is necessary to protect against more than just annoyance. Our concern is protecting human health. Further, how will changing methodologies of scientific studies influence the selection of appropriate weighting factors? The descriptors or weightings that must ultimately be applied to projections of the effects of noise on people must be representative of those effects, not simply reflections or subtleties of the particular study methods used. Finally, how long will it take to develop suitable alternatives and obtain anticipated research results? We believe that to protect human health it is necessary to use and actively apply those current, accepted procedures that are now available and in use, rather than abandoning those techniques and waiting for a better system.

Next, we should keep in mind the impact of the selection of a particular time-of-day weighting system on the implementation of practical, everyday noise control measures as being applied throughout the United States. Specific noise control choices are being made on the basis of costs versus anticipated benefits of noise control. Of course, the estimates of benefits of noise control depend, in part, on the nature of the noise descriptors being employed. A change in the time weighting in a metric may well lead, right or wrong, to a change in the rank order of preferred noise control options. For example, it may help change the decision for a community between controlling noise from a truck route that is active during certain hours at night to dealing with noise from daytime construction activity.

Also, there are some cost considerations that are associated with the selection of different time-of-day weightings. These range from the cost of making baseline and assessment noise measurements, to the cost of overestimating or underestimating the amount of noise reduction that may be required in a specific situation to achieve a certain level of benefit.

Finally, there are certain social implications inherent in the final selection and use of a time-of-day weighting factor. The environmental decisions we make have associated with them certain social implications; our assessment methods influence our decisions, and underlying assessment of course is the particular metric or time-of-day weighting used. In selecting appropriate time-of-day weightings, we must keep an eye on the possible implications or influence of that selection. For example, any time-of-day weighting that may be selected for use with regard to aircraft noise will undoubtedly transfer for use into community noise programs. Bioacoustic research pertaining to aircraft noise has led the way to our understanding of the effects of noise on people. Any time-of-day weighting that is selected appropriate to aircraft noise must be suitable as well for application to other nonaircraft noise sources. Further, we must consider the implications of alternative time-of-day weighting systems on the ability of local communities to maintain effective noise control programs at a reasonable cost. Moreover, we must consider how alternative methods will affect communities' desires to have the flexibility to find the right noise control solution to fit specific local conditions. We must also recognize the implications of selected alternatives upon the outcome of local planning decisions.

In summary, there are a number of considerations to weigh in the selection of an appropriate time-of-day weighting. A number of these were accounted for in EPA's original selection of L_{dn} with its 10 dB weighting for nighttime noise exposure. Although L_{dn} has performed well, EPA is aware of its weaknesses. We support the investigation of more suitable descriptors. But such descriptors must not only be more suitable from a scientific standpoint, they must also reflect, at least in a broad sense, each of the considerations that went into the original selection of L_{dn}, as well as the additional scientific, technological, economic and social considerations that I have mentioned.

James F. Miller, Department of Housing and Urban Development: I am pleased to participate in this workshop and to provide a brief overview of my comments and concerns with noise metrics and time-of-day corrections.

The major programs of the Department of Housing and Urban Development are to provide assistance to people and communities for housing and development activities. We are concerned that housing and other activities are located in a suitable living environment. Environmental noise is an important site factor in determining the suitability of a site for housing or other noise sensitive activities. We consider that the activities assisted by the Department are not noise producers but noise receivers. Thus, a determination must be made by HUD staff that noise from external sources at a proposed site is acceptable for residential activities. We are also an agency which does not produce noise data but usually has to rely on noise data prepared by others. We are not noise experts and therefore are subject to the actions and agreements of agencies having the background and experience in developing noise metrics and assessing the effects of noise on people. To operate in an efficient and consistent manner, we desire that a common noise metric be adopted for use by both noise producers and noise receivers and by both developers and users of noise data.

The Department has a history of dealing with environmental noise and noise metrics dating back almost two decades. In the early 1960's we supported the actions of the military and the FAA when they developed the guidelines on the use of composite noise rating CNR as the appropriate aircraft noise metric. This was day/night weighted, and it was the state of the art at that time and it seemed logical and supportable, so we used that particular system. In 1971 when the Department issued a formal noise policy, it dealt not only with aircraft noise, but with other kinds of noise - railroads, highways, and industrial. Again, we supported what the noise data producers and the scientific community judged to be the right kind of metric for aircraft noise and accepted the noise exposure forecast NEF system, which was also day/night weighted. We used a different system for assessing highway noise and a different system for assessing railroad noise; however, these were not day/night weighted for our site evaluation. These differences presented a problem. We did, however, have a day/night weighting implied in these nonaircraft noise systems since we had an interior nighttime standard that covered the hours from 11:00 p.m. to 7:00 a.m. Thus, in terms of the internal environment - the interior environment of the house - we did have a weighting system even though it was not present in our exterior standards for nonaircraft noise. Subsequently, we reevaluated our noise policy and issued a comprehensive revision on July 12, 1979.

We were pleased with the EPA initiatives in promoting the day-night average sound level L_{dn} as a uniform metric since we wanted to develop a single standard for all types of noise. So we adopted L_{dn} as being the best metric for us in applying our noise policy to HUD-assisted programs. We like this particular system and we feel that it accommodates total exposure regardless of the noise source. This is important since we have many more sites exposed to highway noise in urban areas than we do from aircraft noise. We believe that this particular metric correlates well with the known effects of noise on people, it seems to be simple and understandable, and it considers the effects of noise on normal residential activities. In these activities we must be concerned with sleep, communication and other usual living activities. The L_{dn} metric relates to annoyance and complaints according to the information that we have. Since we were dealing with people and where they live, the nighttime weighting is important because nighttime ambient noise levels are lower. The normal activities are at a slower pace, the children have gone to bed (therefore, not making a lot of noise), and in all, external nighttime noise is more intrusive.

We have watched the growth of noise metrics beginning with CNR which under current policy we no longer use; under current policy for aircraft noise, we accept only L_{dn}, NEF, or community noise equivalent level (CNEL). Over the period of years that we have been involved with noise, the transition from CNR to NEF seemed to be a step in the right direction and we supported that move. We have not supported moves to describe environmental noise in terms of "footprints" or single event noise.

We want to get on with our business, the business of providing services to people - mortgage insurance or assistance for housing, assistance to community development and other activities. We can control the kinds of assistance we provide these cities, developers, or individuals, based on certain environmental factors which we judge important, including environmental noise. We want to settle on a metric that we think, after all these years, is workable. We believe that whatever metric we have for aircraft noise, this metric must also correlate with whatever other kinds of noise we are concerned with in urban areas - noise from highways, industry, railroads, etc. We do believe that a nighttime weighting is important. If we are looking at refinements to the state of the art, whether it's three time periods, two periods, or 15 periods, or any combination, I think it is important to ask ourselves what these refinements do for us in the long term. I think that in the minds of the general public and urban communities it will create more confusion in this business than there already is. I believe that this is an important consideration as we are beginning to learn of communities becoming interested in local noise regulations. Another question I would pose is whether the changes are going to be significant in real on-the-ground situations?

We need to proceed with our business. I would summarize that our position is that the day-night weighted average sound level L_{dn} now in use by many agencies is the metric recommended by HUD for defining noise exposure. While not perfect, it evolved from a large body of experience. We in HUD believe that this metric also meets most user requirements. While additional health and nuisance effects research may, over time, provide some refinements to the day-night weighting factor, the use of L_{dn} should not be delayed until this further research is complete.

<u>J. Donald Collier, Air Transport Association of America</u>: As most of you know, I'm sure, the Air Transport Association represents most of the major airlines of the United States and, as associate members, airlines of Canada as well. We appreciate the opportunity to contribute to this forum as much as we can. We are not scientifically oriented; we don't have a research base to draw from; but we do appreciate the opportunity of letting you know how we think the subject matter impacts our business.

I'm just speaking from a rough outline today, as we were expecting an informal, untaped workshop, but I hope I can give you a couple of ideas which can be meaningful. There are basically two ideas.

One idea is <u>curfew</u>. The L_{dn} descriptor strikes us as being a form of curfew because it encourages us to operate at times other than during the weighted nighttime. This gives the airlines problems in that it deprives the public of a needed service during the curfew hours. The airlines respond to a public need during the nighttime hours by conducting heavy mail and cargo operations;

and even though passenger operations are not generally all that active at nighttime, a number of very important passenger markets are served at night. It discourages an efficient utilization of our equipment, and further, when you try to compress all of your operations into a daytime schedule, it creates more congestion during those hours. I think that most of you are aware of the problems we have with congestion these days already.

The second problem we have is litigation. Foremost in our minds now is a recent Superior Court of California decision in a Burbank-Glendale-Pasadena versus Hughes Airwest litigation. This is a situation where FAA, in granting money for the airport, included requirements in their contract for the airport operator to keep the cumulative noise at a given level. The airport passed its requirement on to the users of the airport in the form of a requirement that any increased operations had to be justified in advance by analysis proving that the increased operations would not cause the cumulative noise level to go above the prohibited value. The defenses of Hughes Airwest, who were sued by the airport when they increased operations without providing said analysis, based on preemption and burden on interstate commerce, were defeated. If this type of requirement placed by the airports on the operators prevails and spreads across the country as these things have a tendency to do, if successful, a dire result would occur.

We see this as a great problem, and when you are playing with cumulative noise levels as with the L_{dn} descriptor, you will have a carrier playing paper games with the calculations and really defeating the intent of the regulations, i.e., protecting the community. These paper games can be really quite dramatic when you are using an energy summation descriptor as a basis for your limit, where 10 operations at 9:59 p.m. are equivalent to one operation of the same airplane at 10:01 p.m. and where 10 operations of an airplane at 90 dB are equivalent to 100 operations at 80 dB. I think those types of paper games really defy logic, and so we are deceiving ourselves and we're deceiving the public, which is very problematical to us.

A number of things have been said for the simplicity of the L_{dn} descriptor, and I think the airlines or a number of us have in the past been very much in tune with that idea. But when you consider the potential for litigation that is arising at our airports, the concept of simplicity in a noise descriptor is just way out - we should shift the focus to accuracy.

Moving toward a conclusion, I would like to go back to the introductory remarks about the congressional mandate for a new noise descriptor. I would say that the mandate does not include a requirement to standardize with the other government agency operations and the other metrics even though there is no doubt that it is desirable to have uniformity across the country. It seems to say that we have got to have a new metric and we can't stick with what we have - what we have is too simple. Further, I would think that what's happening with the L_{dn} metric when you have a nighttime weighting factor, or even with the other metrics where you have an evening weighting factor built into the format, is that when the final number comes out of your computer, you lose sight of what your value judgment is in terms of how bad nighttime flight is as opposed to daytime flight. Its value is predetermined so that the person who is using it at the airport really sort of loses sight of it. I would think that one possibility would be a factor which segregates out of the number the consideration of your nighttime weighting factor. Some communities may like to have a lot of cargo activity at night, or want to cater to reduced fares for their citizens which would be possible at night because the airline can operate cheaper. I would think that would be a valid consideration, to have a descriptor which leaves in a clear presentation the separate elements so that you do not make their value judgments for them.

I would finally like to see something done about the anomaly that is created by the energy summation method. I must apologize to Jim because in private conversation with him it was said that the energy summation was not going to be part of the discussion. But the more you get at the problem of the L_{dn} weighting, the more you have to recognize the basic fallacy with the energy summation method. Therefore, the airlines reiterate their objection to L_{dn} on this basis.

Bill Connors, Airport Operators Council International: Most of you may know that the AOCI represents airports in the world emplaning more than 90 percent of the passengers that fly. I am the chairman of the environmental committee and as such would like to speak to you today on behalf of the airport operators. Being an airport operator has its advantages. I talked to Jim Densmore about this time last week and we discussed how we were getting here. He said he was going to fly and I said I was going to drive. I didn't realize how much good fortune I had until after lunch, when I was out on the field, turned on the radio, and got the tower frequency. Some pilot didn't identify himself; he said, "What time is it?" The controller, quick on his feet, said "Well, if you're TWA it's 15:12:21:Z and if you're American it's 1:12 p.m. EST, and if you're Delta it's oneish, and if you're NAN-3 (FAA aircraft), its Tuesday, March 4, 1980."

There are other advantages to being an airport operator. I'm a user; I'm addicted. I'm following on to the things that Mr. Marrazzo and Mr. Miller and Mr. Collier said - someone has to use this metric. Someone has to field the questions of the public, and whether the federal government preempts the operator in some areas or not (we'll leave that to some lawyers to debate), the fact is that airports are operated by town folk who you can get a hold of. When it's noisy at night or at a public meeting describing a new runway or a runway extension, or building a new cargo complex, or whatever the proposition might be, you have to explain the impact of noise to somebody. Community development and forecasting are what this metric will be used for. It will describe something, some impact that has to be followed on with determination of what is compatible and what's in the mandate to the FAA. It occurs to me that there will be a relevant range of values, for whatever metric used, which will be used to implement these community planning and land use compatible decisions. It's likely you won't say that at 65 L_{dn}, if that is what is selected, you should no longer have residential uses, and at 67 L_{dn} you shouldn't have hotels and motels, and so on. It won't be that precise; it will be a range. Consequently, any determination of what the nighttime weighting is and its influence on the determination of the cumulative measure, or with whatever measure we end up, has to be viewed from the user's part of this whole business of measuring the impact of aircraft operations or noise impact by any mode of transportation. I must agree with one of the assessments that there is probably a threshold at night that is encountered in determining annoyance. I have a very good friend in San Diego that espouses to the first barking dog theory. He doesn't want to get all the dogs that bark at night, just the first one that wakes him up. Maybe we should have a curfew from 9:00 p.m. to 11:30 p.m. and let everybody go to sleep and then they won't be disturbed in light sleep. Some of these ideas ought to be kicked around, but always you have to remember that somebody who doesn't have the educational/scientific background/basis for making the decisions, or understands the nuances of the metric, as you gentlemen might, has to explain it to the community. Whether it is a consultant or a member of some agency staff, the whole point of this is to keep it simple; you can't afford to overlook that. The person that calls on a noise hot line at some airport at 3:00 a.m. because an airplane flew out and disturbed the individual really won't appreciate the scientific sensitivity of some French formulation of noise measurement that exponentially increases with each occurrence, because they were awakened at 3:00 a.m. The user, as Mr. Galloway pointed out, is most likely going to be the equivalent of the first lieutenant assigned to the base as it was in 1950 to work out a compatibility plan around the airport with another local agency.

I would like to point out one last thing on behalf of the operators. The fact of keeping it simple goes hand in hand with what has gone on in the past. We, for the first time, are enjoying the relative tranquility that EPA, FAA, and HUD are all saying it's not too bad if you measure noise impact in L_{dn}. First, that is a first, that the consistency among agencies be maintained. While I think it's fine that everyone is here working on this nighttime weighting factor at Langley, you have to keep it simple, and you have to reflect on the fact that over 20 years the 10 dB addition, by convention, if you will, has been acceptable. People understand it, might not agree with it, but if it is hard to prove, it's hard to refute. With that note I think we should get on to looking at how the noise metric could be refined for the purposes that it will serve, but also keeping in mind the purposes it will be used for by others.

ROUNDTABLE II - RESEARCH METHODS

Cochairmen: H. G. Morgan and D. G. Stephens
NASA Langley Research Center

Homer G. Morgan, NASA Langley Research Center: This will be the second roundtable - we plan to run for about 1-1/2 hours, after which we will break for coffee and reconfigure the rooms for the workshop sessions. At break time we will distribute a list of attendees and workshop assignments. The panel members of the second roundtable are: David Stephens, NASA Langley Research Center (Cochairman); Gene Galanter, Columbia University; C. Stanley Harris, Air Force Aeromedical Research Laboratory; Raelyn Jannsen, Environmental Protection Agency; Karl Kryter, Stanford Research Institute; and John Langdon, Building Research Establishment (England). The plan for the workshop is to allow each panelist to make a statement or remarks about the direction of research, research needs, and methods on the topic of day/night weighting. I suggest that questions and comments be restricted to points of clarification during the statements. Afterwards, we will open the floor for discussion so that anyone who wants air time can have it. We will try to limit debate at this point. We are looking for different perspectives and trying to identify the issues. We will get to the details in the workshop session.

At the risk of overstructuring, David Stephens and I are going to introduce a structure to keep the workshop on schedule. We are going to show you an agenda that we will try to follow. It is also an outline of the report that we hope to make to the group as a whole tomorrow morning. We will be showing it again and talking about it as we go on through the day. Wi will have a straw man that follows this outline. At the risk of appearing to sell a particular approach, which is not our intent, we are putting up the straw man to focus your attention on the topics (see fig. 1).

FUTURE RESEARCH WORKSHOP
TOPICS OF DISCUSSION

(AGENDA)

1. RESEARCH OBJECTIVES
2. RESEARCH APPROACH
3. TIME OF DAY RESPONSE MODELS
4. METHODS OF RESEARCH
5. CRITERIA

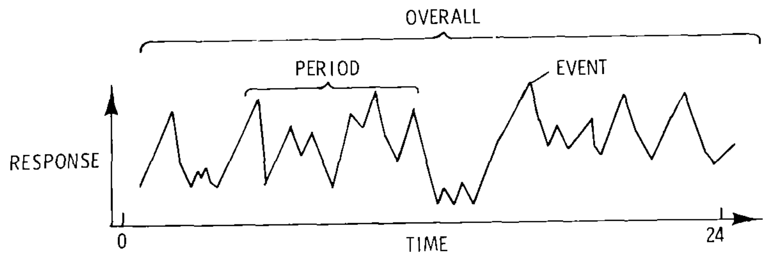
Figure 1

We want to smoke out the ideas and to get the inputs that are really going to impact and improve the research program. The objective is to surface the issues. In order to get us started, I am going to ask Dave Stephens to be the first panel member to take the floor. He will use this opportunity to present the straw man. We will then go down the panel and give each one a chance to speak. Dave, will you lead off?

David G. Stephens, NASA Langley Research Center: Referring back to figure 1, Jim Fields and I will take the first pass thru the first four items to stimulate discussion. We certainly don't feel that we have the answers to these questions, but we have some ideas to explore with you. First, if we are going to talk about future research or the direction of future research, we need a definition of the research objectives, item one on the list. I suspect that if we went around the room and took a poll on the objective of future research, we would get many different answers. For example, discussion this morning centered around the selection of a proper metric. I think the problem from the research point is much deeper than the selection of a metric. From our point of view, the objective (as shown in fig. 2) is to quantify human response to aircraft noise as a function of time of day or at different times of day.

RESEARCH OBJECTIVES

- QUANTIFY HUMAN RESPONSE TO AIRCRAFT NOISE AS A FUNCTION OF TIME OF DAY
  - EVENT RESPONSE
  - PERIOD RESPONSE
  - OVERALL RESPONSE



- DETERMINE RELATIVE IMPORTANCE (WEIGHTS) OF NOISE EXPOSURE IN EACH TIME PERIOD TO OVERALL RESPONSE

Figure 2

The responses that we think are important are responses to single events (or individual aircraft overflights), responses to periods of noise (or groups of overflights), as well as the response to the 24 hr exposure. As shown in figure 2, we would like to go from the physical noise exposure as a function of time to the response to these events at different periods of time. If you agree that the objective of the research is to provide the ability to go from a physical description of the noise to a response as a function of time, we must have a dose response relationship for the different time periods of interest. Figure 3 illustrates this point.

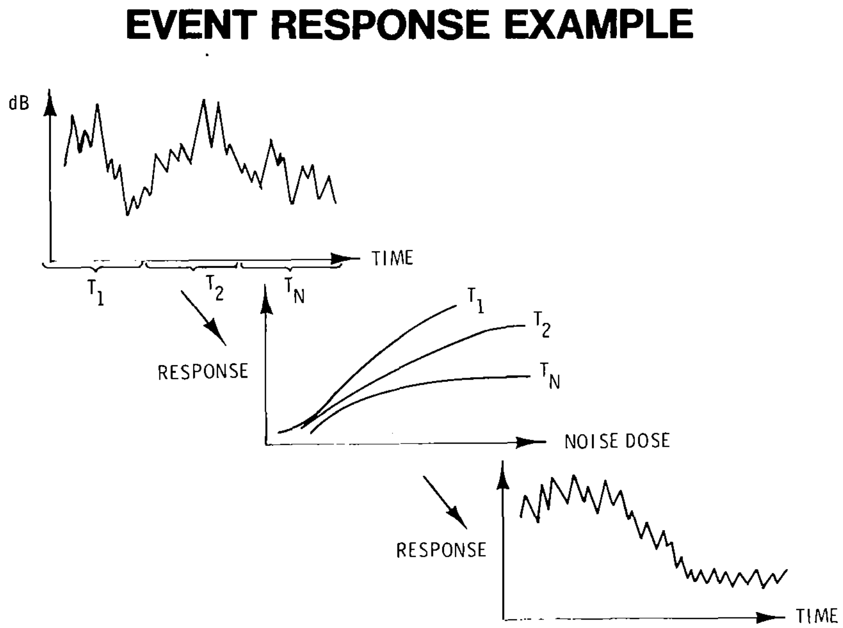


Figure 3

If one has a recording of the physical noise environment, and if dose response relationships for particular time periods of interest are available, the physical environment can be transformed into a subjective environment. Obviously the research has to be directed toward determining the dose response relationship which in turn requires a good metric for describing the noise dose. Day-night penalties or time penalties between periods are represented by the differences in the dose response curves across time periods. Similarly, if period responses are of interest, that is, if we have noise distributions at different time periods (see fig. 4), and would like to go from the physical description to some subjective response as a function of time, a multiple event dose response relationship for each of the time periods will be required. Thus, if the objective is to go from the physical description to the subjective description then the Research Approach (fig. 5) must be directed toward obtaining the necessary dose response relationships as a function of time. In addition to knowing how people respond to periods of noise at different times of day, it would be desirable to know the relative importance of the periods, or how the periods "add up", as discussed by Jim Fields.

PERIOD RESPONSE EXAMPLE

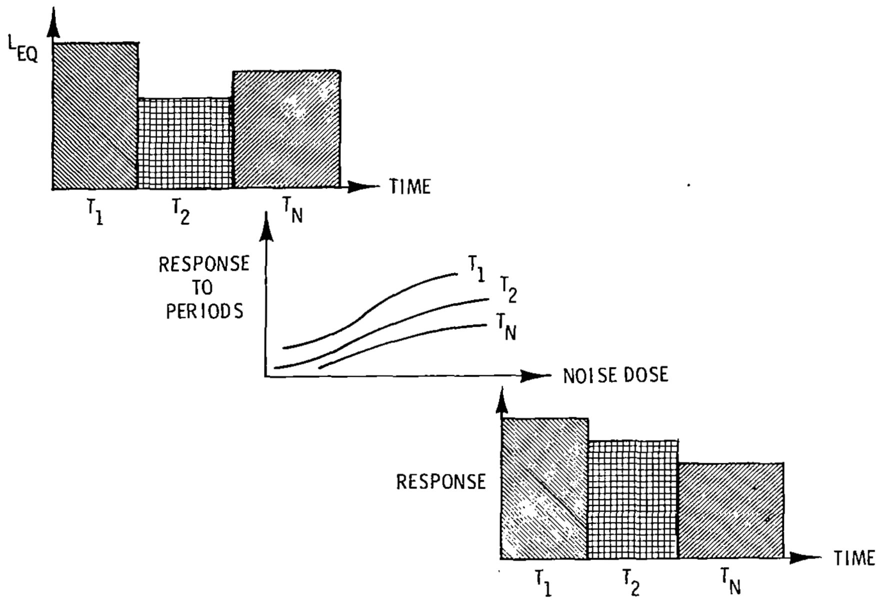


Figure 4

RESEARCH APPROACH

- DETERMINE DOSE-RESPONSE RELATIONSHIP FOR SEVERAL TIME PERIODS
    - EVENT RESPONSE
    - PERIOD RESPONSE
    - OVERALL RESPONSE

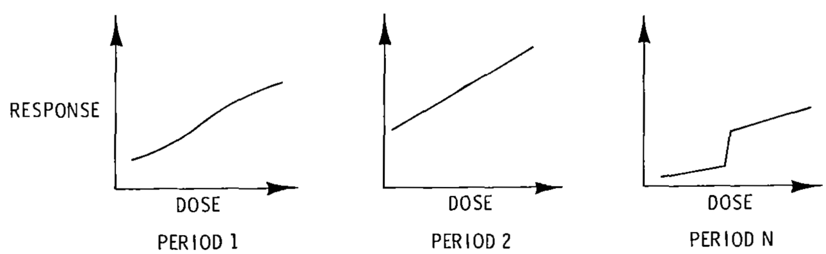


Figure 5

In summary, I think from the standpoint of research objectives we should focus on noise dose-response relationships not only for 24 hour time periods, but also for single events, at different time periods, as well as response to periods of noise. Hopefully, we can determine the relationship between the period response and the overall response. Jim Fields will next discuss research models and methods to achieve the research objectives that I have discussed.

James M. Fields, NASA Langley Research Center: We saw this morning that one of the biggest problems faced in assessing time-of-day effects is in designing survey samples so that the nighttime and daytime noise levels are not too highly correlated. In an attempt to encourage discussion on this problem I suggest six alternative research approaches:

1. Laboratory study projection to other times of day
2. Jury ratings at home
3. Regular reporting (Button Pushing)
4. Immediate recall (Telephone Follow-up)
5. Unique Operating Change Survey
6. Conventional Multi-environment Survey

The laboratory approach is limited to exposing subjects to noise at one time of day and then asking subjects to try to project how they would feel at another time of day. People can be easily exposed to a large number of different noise level environments with this method.

The second approach is labeled "jury rating at home". Tom Dempsey of NASA Langley plans a study of this type in airport communities in the future. In this case subjects are in their homes with the experimenter. As aircraft go over, the subject is asked to rate the aircraft. This can be done during the day and the evening, although it does not seem to be very reasonable for the night. Both the laboratory projection and jury rating methods produce information which is of questionable usefulness for estimating time-of-day effects under real situations when people are likely to be concentrating on other activities.

Several regular reporting or "button pushing" studies have been carried out by BBN. In these studies an experimenter is not present but the person has some way of recording reactions to flights which are noticed at home. The potential of this approach has not been fully explored. Ideally, a person would have a highly portable device with an electronic annoyance scale on it so that when an annoying aircraft was noticed, the subject could immediately push a button to indicate the degree of annoyance. This would be automatically associated with a time signal so that later the human response could be linked up with the actual noise exposure from the aircraft. An important characteristic of the approach is that the person knows beforehand that he is to report how he feels about the aircraft that go over. Any one individual could participate for several weeks and thus rate many aircraft. The unique aspect is that the ratings could be linked up with each flight through the button pushing device. Of course, summary period ratings for days or parts of days could also be obtained and linked to the survey noise levels for those periods.

The fourth method, the immediate recall, telephone follow up method has not been used before even though it draws on researchers' experiences with a number of telephone follow-up surveys. People are again asked about the immediately preceeding noise environment. In this case though they do not know beforehand that they will be asked to evaluate flights. They are telephoned after the researcher knows just what the noise environment has been. People are asked about the last hour, the previous evening, last night, or any other period of interest. With this design, variation in the noise exposure is built in by taking advantage of natural variations in noise levels over short time periods. The person is not alerted about the time when the rating will occur. Since it is a longitudinal survey, the respondent would have been telephoned several times at widely spaced intervals.

The LAX night-time operation change study is an example of the unique operation change survey method. Here there is a change in the noise environment at one time of day, but not at other times. The obvious attraction of this technique is that it is directly related to noise policy. There is a change in the noise environment combined with a measurement of human reactions to that change. The difficulty is in the limited number of study opportunities of this type.

The conventional multi-environment survey attempts to include a range of different time-of-day noise environments by including many different locations. This can be done by including several airports or sometimes several locations under different flight paths. It has been difficult in the past, however, to get enough variation in day-night noise environments with only a few airports.

In this presentation, I have suggested only six research approaches. I hope there will be others which we will discuss and evaluate in the workshop session.

Raelyn Jannsen, Environmental Protection Agency: I would like to start by reiterating something Mr. Marrazzo said this morning about EPA's role. EPA's noise program operates under legislation that states a Congressional goal of protecting the public health and welfare from noise impact. In following this mission, we consider research not only in the sphere of subjective response to noise, which is very important, but also research on physiological, biochemical and other aspects of the response to noise. We do use subjective response data in a concrete way in analyzing and quantifying benefits of our regulations, and we also employ other dose-response relationships to quantify these benefits.

I have been asked to speak specifically about sleep research this afternoon. In the sleep disturbance area, we use a couple of dose-response criteria which are based on objective measures of sleep disturbance. The first figure shows the probability of a noise induced shift in sleep state - in other words from a deeper to a lighter stage - for a single event exposure of a given level. The second criterion is the probability of awakening at a given noise exposure level shown in the second figure.

PROBABILITY OF A NOISE INDUCED SLEEP STAGE CHANGE

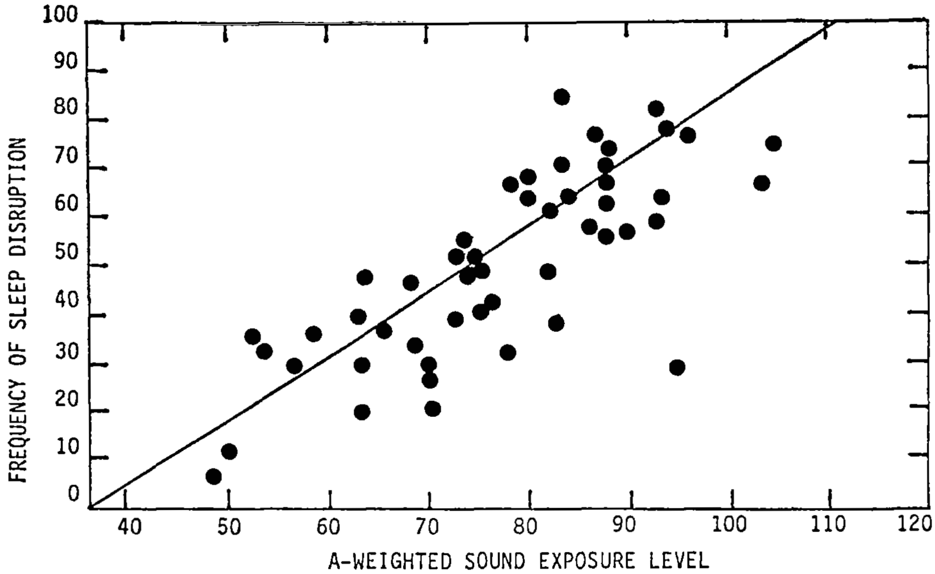


Figure 1

PROBABILITY OF A NOISE INDUCED AWAKENING

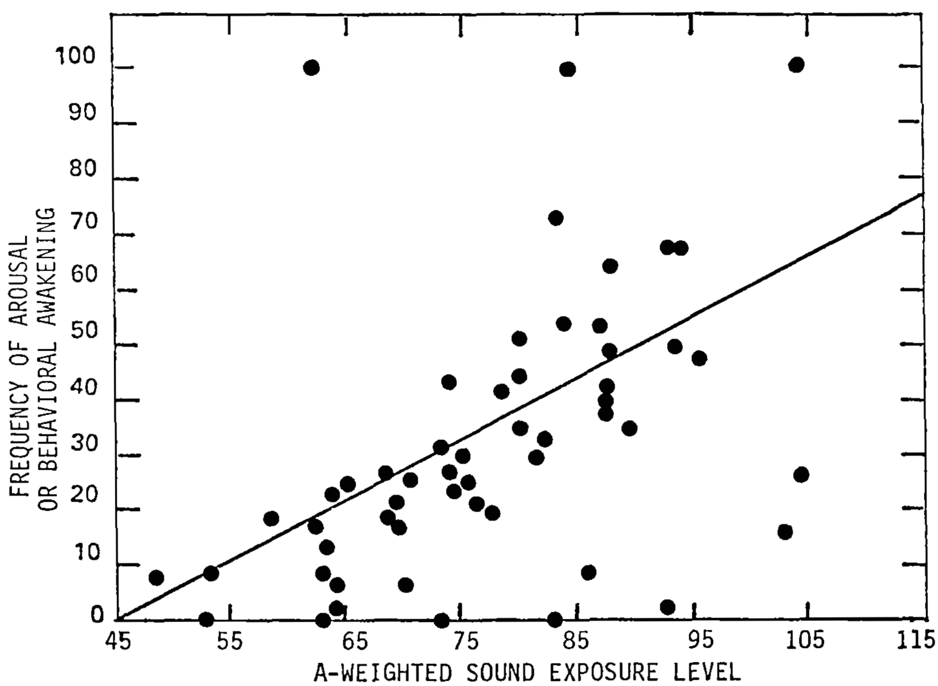


Figure 2

Both of these have been developed for us by Jerry Lukas[1], based on a fairly broad range of studies - all of those that were in the literature that can be directly compared to each other (using the same method of scoring sleep and so forth). Presently, we would like to see some more progress on sleep disturbance in a couple of different directions. One is that we would like to see some refinement of these criteria for what we consider special populations. These criteria are largely based on studies of young adults, although not exclusively, and it is well known that the elderly are more susceptible to sleep disruption. We also would like to broaden the applicability of the criteria to groups such as the ill, shift workers and other potentially sensitive groups. Secondly, we have another concern with quantifying what we call the health consequences of sleep disturbance. Of course we are concerned mainly about chronic sleep disturbance by noise and what the effects may be beyond the short term measures of awakening or shifting sleep stage. How does chronic sleep disturbance affect health parameters like resistance to disease, for example? How does chronic sleep disturbance affect performance - on the job and otherwise, driving in traffic, etc? These are the research questions of most concern to EPA. Because I am the only one speaking specifically about sleep research at this meeting, I would like to summarize the status of sleep research in the Federal government, generally, which I think can be characterized overall as being decentralized and without a unitary focus. There is no single agency in the Federal government which has responsibility for sleep research, research on sleep disturbance, or research on the meaning of sleep disruption. At the National Institutes of Health there is no specific institute that sleep researchers can approach with a proposal and be sure that there will be some funding in the sleep area. The same is true at the National Institute of Mental Health, and this is a problem that is being discussed right now within the Department of Health, Education and Welfare. There is a new program with HEW that is not a research program, at least not at the outset, which is called Project SLEEP. The impetus for this project was a study by the Institute of Medicine (of the NAS-NRC) on sleeping pill use and abuse in the United States. As you may imagine, there are several areas of mutual concern between the EPA and HEW on sleeping pill use. For example, a study conducted in the Netherlands[2] indicates that an airport community showed greater drug consumption in both the sedatives and hypnotics categories than a matched non-airport community; so there are areas of mutual concern and we are coordinating with HEW on Project SLEEP. NIOSH, also in HEW, is doing a little bit of sleep research work on shift workers and this is also aimed at more or less the meaning of the disturbance of sleep on a chronic basis. There, to my knowledge, they have been using exclusively subjective measures. At Walter Reed, the Army is doing some research in the sleep area, particularly with regard to performance, and they are using a wrist actigraph which records bodily movement, a fairly good measure of sleep disturbance. The Navy sponsors a fair-sized out-

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[1]Lukas, J. S.: Measures of Noise Level: Their Relative Accuracy in Predicting Objective and Subjective Responses to Noise During Sleep. EPA-600/1-77-010, 1977.

[2]Knipschild, P.; and Oudshoorn, N.: Medical Effects of Aircraft Noise: Drug Survey. Int. Arch. Occup. & Environ. Health, vol. 40, 1977, pp. 197-200.

of-house research program on sleep and related biochemical and other factors. That's more or less the status of the Federal government sleep research at this point. I would also like to add one other point - we are looking forward to final results of a series of studies that are being sponsored by the Commission of European Communities. They are sponsoring four teams of sleep researchers in 4 countries: the Netherlands, Germany, France, and the UK. We're hoping that their final results will give us a good boost so that we can build on the foundation they have laid.

C. Stanley Harris, Air Force Aeromedical Research Laboratory: I would like to briefly describe a study we have planned to investigate the nighttime penalty for noise. The basic idea of our proposed survey is simple. We would like to conduct a survey at two fairly noisy Air Force (AF) bases; one with few nighttime operations and the other with a large number of nighttime operations. There should be sufficient population densities surrounding these bases so we can get an adequate sample size, and of course, the populations should be similar in socioeconomic characteristics. After analyzing the survey results we would like to be able to say whether there should be a nighttime penalty for noise and if so, what size the penalty should be. This sounds simple enough; however, it is not so simple. In fact, it may be that we cannot find AF bases that will give the nighttime penalty a very severe test. We might be able to determine that a penalty is needed, but not be able to determine exactly what size the penalty should be. The problem is not that AF bases are not loud enough, the AF has plenty of noisy bases. The problem is that there are not that many AF bases that have a high percentage of nighttime operations, and the percentage of nighttime operations determine the size of the actual penalty. For purposes of our survey we would like to find an AF base that has approximately 50 percent nighttime operations. This is probably not possible. A few bases reach 20 to 25 percent nighttime operations, but AF wide, the average percentage of nighttime flights is probably about 10 percent. The average is also 10 percent for Strategic Air Command (SAC) bases, which generally are our noisiest bases. This relatively low average came about because many prohibitions have been issued against nighttime flying by local AF bases and by AF Command levels. In many instances, these prohibitions were meant to reduce the nighttime noise levels. As one example, McClellan AF Base, since 1967, has tried to keep nighttime flying at less than 5 percent because of community noise problems. Many AF personnel believe that the low percentage of nighttime flights has been one of the major reasons that the AF has not had more noise complaints from communities surrounding AF bases. Therefore, they are strongly opposed to eliminating or lowering the nighttime penalty for noise without strong evidence that this will not bring about increased complaints from the community.

Let's examine what would happen if we reduced or eliminated the present 10 dB penalty for nighttime exposure to noise. For example, let's look at one of the worst cases. If 20 percent of the flights are at night, we find an actual penalty of 4.47 for an imposed penalty of 10 dB, 3.62 for an imposed penalty of 7.5 dB, and 2.55 for 5 dB. The difference in actual penalties for imposed penalties of 10 and 5 dB is only 1.9 dB. This difference does not seem large, and one may wonder if the size of the imposed penalty is important for existing conditions. One way of addressing this question is to calculate L_{dn} levels for the three different imposed penalties based on 24 hour L_{eq} levels from 51 to 81, and then use Schultz's curve for relating L_{dn} to the percent highly annoyed (percent HA) and then compare the difference in percent HA at each level. The greatest difference occurs at the highest 24 hour L_{eq} level that we choose. The difference in percent HA for the 10 dB penalty and the 7.5 dB penalty is only 3.94 percent. The difference between 10 and 5 is only 8.12 percent. These differences are not impressive and are just about within the standard error of measurement.

Now let's examine what happens to the size of an area that an AF base must consider as impacted by noise when the size of the nighttime penalty is reduced. The finding is: small changes in the size of the penalty result in large changes in the size of the impacted area. Specifically, consider 10 percent nighttime flights, since this is the average percentage of AF nighttime operations, and calculate the reduction in the size of the L_{dn}>65 dB contour area. With 10 percent nighttime flights, the actual penalties and differences between actual penalties are as follows:

Imposed Penalty	Actual Penalty	Difference
10 dB	2.79 dB	
7.5 dB	2.17 dB	.62 dB
5 dB	1.46 dB	1.33 dB

These differences wouldn't matter much in terms of differences in predicted percent HA values; however, they are very important for deriving contour sizes. Now let's consider the changes in L_{dn}>65 dB contour areas as a function of the differences in the size of the actual penalty. For SAC bases, since these are the loudest, the percent changes in contour area as a function of actual penalty differences are as follows:

Actual Penalty Difference	L_{dn}>65 dB
.62 dB (between 10 & 7.5)	Reduction of 9.4 percent
1.33 dB (between 10 & 5)	Reduction of 19.11 percent
2.79 dB (10 and No Penalty)	Reduction of 35.91 percent

We have not taken the next step and obtained population densities and calculated the decrease in the number of people who would be considered impacted by noise, but in some cases the reductions would be tremendous. One might think that these large reductions in contour areas would make the AF happy. This is not true for two primary reasons.

(1) The very great probability that a reduction in the size of the nighttime penalty for noise would result in a larger percentage of AF nighttime operations, and that this increase in percentage of nighttime operations would produce more complaints from the community. The AF would like very convincing

evidence that this is not so, because we have noise problems at many AF bases now.

(2) A reduction of the nighttime penalty for noise would reduce the size of the L_{dn}>65 dB contour area and could eliminate "buffer areas" surrounding many AF bases by encouraging development and increased encroachment.

Eugene Galanter, Columbia University: We are currently engaged in data collection in communities in the New York metropolitan area. Our primary goal is twofold - one is to converge a variety of psychological methods on the response concept of annoyance; our second goal is to see whether these various methods show time-of-day effects. We are doing this by selecting communities that permit a comparison between relatively high nighttime operations and other communities where there are relatively minimal nighttime operations, but where the overall noise loads in both communities index equivalently.

The first fact that emerges from our work is that the physical characterization of the acoustic events is very soft. I do not see any immediate relief from that problem at the theoretical or practical level. It is extremely difficult to characterize the noise load that the community bears, especially if one wants to include interior noise in people's homes, structural differences in multi-family construction, and differences at various times of in-home locations of the people themselves. One is forced into a statistical representation of community noise load. But the statistics are not stationary, either because of operational changes to shift specific community burdens, or seasonal changes associated with structure variations. The result is that acoustic statistical stationarity does not exist. Consequently, we are working with a dynamic system, even though we attempt to characterize that system as having well defined, temporally invariant, physical parameters. These remarks are offered to argue for a representation of aircraft flyover noise that is indexed to the acoustics of a single flyover event. From such a measure for single events we may then develop a model that combines these measures into an index that validly represents (in the sense of predicting individual annoyance) any arbitrary mix of overflights.

We often assume that the human response measure of annoyance is clearly defined and that our real problem is to find a representation of the acoustic parameters that will predict this "annoyance response." But the second fact is that this well known annoyance response is not only softer than the acoustic parameters, it is not even well enough formulated to let us select a set of models to estimate intrinsic human annoyance reactions. The consequence is that we have to estimate various acoustic parameters on one side, and various response parameters on the other, with no coherent model of either, or of the transfer function. We are trying to formulate a transfer function for which both scales, the ordinate and the abscissa, are not fully characterized.

I wanted to get these critical remarks on the record in order to assure you that we recognize fully the limitations of our own data, but are willing to present them as a pathmark for extending our understanding. So the last fact is that after one has made all the concessions to the inadequacy of the techniques, our recent results suggest that nighttime hours annoy people more with respect to aircraft in communities in which there are day and night overflights. In communities in which there are few night flights, the level of annoyance during night hours may be disproportionately less, but the annoyance of daytime overflights is about the same. Furthermore, it appears clear in the data that evening (i.e., "prime time") annoyance (8:00 PM to 11:00 PM) is greater per operation than late night or morning activities. These results lead to an urgent need for an appropriate annoyance response model.

I would like now to propose that in terms of simple equity a comprehensive community annoyance model cannot merely accept a summation of individual response annoyance based on replies to a questionnarie, no matter how subtle, complicated, or advanced. That is to say, the interpretation of the annoyance response data will depend on how the model is formulated to partition the individual annoyance magnitude of the reported judgments into its appropriate components. The first such component of total annoyance must be the acoustic impact of the overflights. The remaining annoyance may then be attributed to "background annoyance." We all recognize that when people report their annoyance they are simultaneously advancing at least two interests: the inquirer's interest in learning something about the noise the people experience, and their own personal interests in expressing comments they hope will result in an improvement of their position. This perfectly reasonable degree of self-interest which adds in some way to the total annoyance, cannot be predicted from an analysis of the acoustic events. Consequently, it is important that we find ways to characterize the human annoyance response data so they can be partitioned into the component that truly represents the acoustic impact, as well as those components that are attributable to the variety of other personal factors that may include the local real estate taxes, whether the respondent slept well the night before they answered the question, and so forth.

We do not have any guaranteed method for eliciting the response data that we can use to make this analysis, so the method of convergence of multiple responses seems a good and reasonable procedure to begin with. This position accepts the notion that categorical judgments are valid, that relative frequency judgments are valid, that complaint data are valid, but that all of these validities are only partial. Their convergences based on some plausible model will lead us to believe that we have estimators of aircraft overflight annoyance induced by acoustic impact, time of day, and other similar variables. Their remainders may give us insight into background annoyance effects.

Karl Kryter, Stanford Research Institute: In the context of this workshop I find myself of two minds. I can take the position that there should be no further research on the subject - that we have all that is needed. At the same time I can argue that there obviously needs to be a great deal more research. I would like to mention a few things on each side of these two positions. A lot of the research could be done not to prove or discover anything new, but to make more convincing what is already known. It is clear however, that such additional research is obviously going to cost a lot of money and take a lot of years. We are always going to be faced with the knowledge that we now have, so one should not expect any grand revelations that will turn the world around and show that much of the previous research findings were wrong.

Another consideration is (Galanter made this point very clearly) that we will likely have the same amount of variability in the findings tomorrow that we had yesterday and today. For one thing, we really do not describe the noise variable in terms of what people are hearing in real life. I would wager that much of the variability in attitude survey data is due to the lack of knowledge of what people are hearing in their ears, as it is to their personality, or whether they have a particular bias or not.

I would also like to point out that some of the individual variability formed in attitude surveys is attributable to a temporal factor. The problem is that the noise primarily bothers people only when they are talking or sleeping. Since different people have different life styles and do things at somewhat different times, it will be difficult to prove, I think, with greater accuracy than is now the case, what the nighttime penalty should be. At the same time, I would be remiss if I didn't indicate we needed more research. There are, of course, two areas of research that must be looked at. One is real life - the attitude survey, or the field research of what people do when exposed to noise in real life. The second, of course, is the laboratory approach, and I think neither one can answer the questions at hand without the other. Where you have seemingly inexplicable variability in the "real life" data, it is appropriate to look at laboratory findings in an attempt to find a reasonable basis for extrapolating functional relations among the "real life" variables as well as an explanation for variability in those data.

In that regard, I would like to point out that an extrapolation of the sleep data indicates that somewhere between 35 to 45 dB is at the threshold of noise arousal from sleep. However, the threshold level for noise interference with conversational speech in the quiet of the home is around 45 to 55 dBA. The signal to noise ratio would be about 0 dB. There is a 10 dB or so difference between these two thresholds that would substantiate the present 10 dB nighttime penalty.

It is perhaps also interesting to note that laboratory research on sleep shows that one is most sensitive to noise when going to sleep and when about to wake up. It is true that during the nighttime there will be cycles of relative sensitivity to sleep arousal, but the major problem with noise is when one is going to sleep. These laboratory data are perhaps relevant to data collected by BBN around New York in 1958 or so, where the FAA, I believe, operated a complaint center with well advertised telephone numbers. It was determined therefrom that on a level-basis-per-overflight, you needed about a 10 dB less level in the hours of about 10:00 PM to 2:00 AM to get the same amount of complaints per overflight that you get during the day. From 2:00 to 5:00 AM it was the other way - the noise could be higher in level than during the day and get about the same number of complaints. This jibes with the lab experiments that show you're more sensitive when you're going to sleep than when you are asleep. Except for the fact that people do not all go to sleep by 1:00 AM or so, a case could be made from both - some laboratory and real life date - that no penalty, or a negative penalty, would be appropriate for 2:00 to 5:00 AM or so. All in all, however, the single uniform penalty of 10 dB from 10:00 PM to 7:00 AM is probably about as complex a noise assessment procedure as would be practically workable.

F. John Langdon, Building Research Establishment (England): I would like to start by saying that the question we have to discuss in this workshop is not a mainstream issue in our research in the United Kingdom (UK) because we don't have quite the same problems of day/night distributions in aircraft operation as you have. So far as I can discover, at the present time we are mainly concerned with some sort of canonisation ceremony for the NNI, if that can be arranged.

At Building Research Station (BRS), we looked at L_{dn} from a slightly different standpoint, because it was brought forward as some kind of panacea for all our troubles. It was hoped, when put forward, that L_{dn} would apply not only to aircraft operation, but to transportation and community noise generally. Hence we wanted to test it against other parameters, in the area of traffic noise - our most widespread problem. This we have done, though without very much benefit, I must say. Because we found that what L_{dn} tended to do, with noise other than from aircraft, was merely to shift the intercept for the nuisance term in the noise/nuisance relationship. If the patterns of noise occurrences in say, traffic noise, are highly intercorrelated, so that taking the relationship of traffic flows for 50 or 60 sites within a city between 11:00 AM and 3:00 PM, for example, they would correlate with one another; and the same co-variant relationship would be preserved for the same sites between 9:00 PM and midnight. In such a case, it doesn't matter whether you add a nighttime weighting or not, for all this will do is shift the intercept. This is not in itself a criticism since you may in fact wish to shift the intercept. But it also means, and this is a criticism, that you will not obtain any increase in the explained variance, and this is basically, one hopes, what you are looking for in the results. Without this, the magnitude of the night weighting cannot be determined and is purely arbitrary.

I would like to point out that there must be, at the moment, about 9 or 10 different aircraft noise nuisance indices in use in different parts of the globe. I do not mean merely bright ideas in researchers heads, I mean actually under governmental operation. These indices break down into about three main types, involving a measure of the energy, the number of flights, and various combinations and treatments of these. Now the interesting thing to observe, watching from the sidelines (since I am not myself now concerned in aircraft noise research), is that all these measures are strongly entrenched in each of the countries that operate them. Although they operate on different principles, it seems that each is perfectly rational and quite satisfactory. In each case, the local scientific establishment supports them, and this encourages administrators to depend on them. Although they are different, the noise indices are not necessarily mutually exclusive - they don't disqualify each other - but they are different, yet nonetheless very strongly entrenched and strongly supported.

Now this means, I think, that in this area, the researcher, especially if he is engaged in social research, is inevitably put in the position of saying that although we must do further research, we know what the subject is going to be already. Dave Stephens was quite right in his presentations on the overhead projector. He showed a variety of response measures, together with the specified objective - and this was the noise dose in dB. There is your objective - already laid down. In such a case, any scientific quest for the basis of the physical correlate to the behavioural response is ruled out. What you are going to do is look for the best way of relating that response to an already determined noise measure - whether equal energy, or cumulative statistical, it is in the end, non-informational, merely some transform of sound pressure level over time. In this situation, it is impossible not to feel like the man who shows a map to another person and asks for directions, only to be told, "Well, if it was me, I wouldn't start from here." For this is where we find ourselves, as scientists. We didn't want to be standing just here, but this is where we are, so we have to do something; let's call it research.

Now I would like to step back a little and draw from my own, and my BRS colleagues, research experience a few points, as they have occurred to us in the UK, and which may be helpful here. First, when we speak, perhaps very generally, of an integrated human response over the whole period of the day - 24 hours - what exactly are we talking about? Well, the general adverse response or adverse reaction has been suggested. This is a nice phrase, a pleasant flow of words. But what does it mean in terms of hard scientific cash? If we examine all the conscious responses - annoyance, dissatisfaction, unacceptability - and the daytime activities - ability to read, to listen to music, various kinds of disturbance to these different activities - we find again and again that these are all highly intercorrelated with respect to noise. They always are. This means perforce, that to add one or another of them into a measure of general adverse response is going to add nothing. No gain in explained variance will ever be obtained by creating multiple correlations from items which are already highly intercorrelated. Items must be independent, or quasi-independent if they are to add to a descriptor.

So far we are considering only the conscious response during daytime. We can divide this into two daytime periods; the working day when people generally are absent from home (though some women and old people are at home), and the evening when the majority of the population are at home, at one time or another. This is the period of relaxation and leisure. There is of course, a further period shading into "night", and this varies from place to place but can be said generally to be between 10:00 PM and midnight when people are going to bed and trying to get to sleep. Curiously enough, Aubree produced such going-to-bed profiles for the Parisian population in 1971 and I produced similar data for London in 1972, and we found that in both cities people go to bed about the same time. "Gay Paree" is, it seems, pure illusion. However, to return to the main track, after midnight we have the sleep period when it seems it doesn't matter much what happens, unless a bomb drops. We can therefore divide up the day into periods with different sorts of activities. But we would be forced to admit that the measures most appropriate to each do not form a very happy family. For example, how does one join on and combine with daytime annoyance the results of field studies or experiments on people sleeping between midnight and 6:00 AM?

But leaving aside for the moment the problem of joining it all up, there is the problem of sleep quality itself. This is a problem which the European Economic Community (EEC) is tackling, a study for which UK has assumed part of the responsibility. For sleep alone, one way to deal with the problem of measurement is to develop a combined measure. This is a measure of sleep phase shift derived from EEG, related to measured noise - actual, not simulated laboratory noise, with people sleeping in their own homes - combined with a measure derived from a portable performance test on an apparatus subjects can wear and carry with them to perform a serial choice reaction time task to assess the effect of the noise exposure during the night on performance the following day. With such a combined measure we may obtain some insights into the relation of noise to sleep. The weakness of most sleep research at present is that while it reveals noise related phase shifts in EEG, it gives little indication of what they mean in deprivation or lowering of sleep quality. No doubt such changes are linked with changes in sleep quality, but we need to know precisely what they are and what they are worth.

However, let us assume that we have now been able to do this. We are now left with the problem of joining this measure, whatever it is, to the data of conscious response. The kind of measure we are likely to be looking for is therefore going to be something a little more complex than the sort of "general adverse reaction" that psycho-acousticians have had in mind so far.

This brings me to the next question: how are we to do the "joining up"? The conventional method for putting different things together in social surveys is not really very clever, whatever sophisticated names we like to call it by. It is not much more than throwing all the data into a computer with an optimising programme and seeing what comes out. This is called multiple correlation and regression analysis.

Of course, we can go on to do factor analyses by principal components to examine the general annoyance or disturbance score variance, looking for items which best account for that variance, purely in terms of the subjective response intercorrelations. We may then attempt to identify reported noise events and noise experiences which relate to these components and so explain the overall response to the noise. And if we are lucky, we can hope that our sleep measures will fit in with the daytime response data.

We can do all these things. But when we want to relate this data quantitatively to actual measured noise we are forced, willy-nilly, back to the regression model. This model has certain statistical requirements and we often know in advance that our data does not meet the axiomatic requirements of the model. It is a chastening experience to look through a few papers in the Journal of Applied Statistics and see how little the statistical procedures we are forced to use really admit of our operations, how little our data and the way it is distributed meet the theoretical requirements. We fall back on the old chestnut which says (as stated in a well-known textbook of Econometrics) - if you have a good (?) conceptual model, don't worry too much about this. In other words, you'll always get some kind of answer, forget about any statistical requirements.

In place of this, I and my colleagues have felt compelled to go back further and develop a more complex, more sensitive picture of the human being as a social being and his response as a social response. This means to go beyond the type of analysis I have just referred to, probably to non-parametric methods.

At the moment I am myself involved in a study of noise attenuation by the building, and a colleague is working on noise attenuation in retrofit (where a building is modified to reduce the impact of external noise). In both cases we are looking for results from MSA and Smallest Space Analysis, non-parametric techniques which do not aim merely to establish sets of numbers but to create a model of structural and organic relationships between the response data. Of course, to quantify the answers with respect to noise we shall probably have to return at some point to a parametric, regression type model. But we shall do so having established the values and the operational relationships between the terms. This is, I feel, the possible way forward, though I still feel that we are limited as regards the way we treat the acoustic data, which remains tied to a sound pressure model*.

A second aspect we are looking at very carefully is to try and characterize the periods of the day and night which are of varying importance to people subjected to noise, and to try and relate three things. First, the actual noise exposure for each period; second, the annoyance or disturbance felt in that period; and third, an independent sample which will give a picture of desire - when do people think quiet important. Finally, we want to see if we can bring the three together to give a profile, weighted over time.

I feel I have said enough, however inadequately, to give some idea of the way things are going with us. But for the moment, speaking quite personally, I'm not terribly optimistic. I do not mean to say we don't know anything. On the contrary, we know a lot. But against the sort of background I have tried to outline, I feel that given the laid down objectives, given the limited time and scope for research you now have at your disposal, you are just not going to make very much advance to the solution of these problems. So your, and probably our, administrators will most likely have to make do with the measures and procedures they have already.

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*I would have liked to have gone on to discuss the need for an information theory model to replace the crudity of measured sound pressure level, if the benefits of more sophisticated social research are to be reaped, but time was limited - like the scope for real new avenues in noise research in the NASA/FAA situation.

CLOSING REMARKS

John E. Wesler, Federal Aviation Administration: According to the schedule, this is the wind-up of our day and a half Workshop - we have been referring to it as a 2-day one but we are scheduled to close by noon and I think we will without any great difficulty. The next order of business is to hear from the two working groups that met yesterday afternoon and this morning. Workshop session I had to do with Impacts and Effects of Noise Metrics and was cochaired by Richard Tedrick and Bill Shepherd. Workshop session II had to do with Future Research and was cochaired by Homer Morgan and Dave Stephens.

Summary Statements From Workshop Session I - Background/Applications

Richard Tedrick, Federal Aviation Administration: This workshop session was divided into four discussion groups. Discussion topics and summary statements for each of the groups are given. In addition, four individual recommendations are included.

Statement From Group I: Background of Present Corrections

The L_{dn} has evolved over a period of nearly 30 years. The two key concepts of equal energy and a 10 decibel penalty for nighttime operations were borrowed from earlier cumulative noise measures. Both were initially based on very limited data and on intuitive judgments of the developers. Some present studies tend to support these two concepts. However, other studies raise serious questions as to their validity. For example, some studies suggest that people are more sensitive to noise in the evening than late at night and even that there should be no nighttime penalty after people have gone to sleep. Other studies have suggested that the equal energy concept may not be applicable to annoyance.

Unfortunately, none of the studies to date have been of sufficient scope to verify the existing concepts or to offer solid alternatives. In the absence of alternatives, the demand for guidance material has led to the widespread use of L_{dn} especially in this country. It is not expected that current research programs will resolve these two key issues in the near future.

Statement From Group II: Uses of L_{dn}

Prediction/quantities of noise effects.- L_{dn} was developed over many years as a planning tool to relate physical measures of noise to measures of human response. These responses encompassed aggregate community response since at the time of development of related metrics, these were the only types of effects halfway quantified. More precise relationships were then applied, i.e., percent highly annoyed. However, because there are many health effects of noise that have not been precisely quantitied and because annoyance is felt by some to be an indicator of these other effects of noise, the dose-effect relationship for percent highly annoyed is being used by some as a surrogate for these other effects.

Applications.- L_{dn} is used as a planning tool to enable the planning of the airport system with respect to its relationship to the community. It is used for all noise sources at different governmental levels. With regard to aircraft noise, it can be used as an index for assessment and enforcement.

Merits.- The merits of L_{dn} are as follows:

Accepted by all levels of government

Accepted internationally

Used to assess all community noise sources

Relates to L_{eq} - generally accepted for hearing loss assessment

Relates to A-weighted level

Allows one to relate exposure to instantaneous rms level and single event level

Correlates well with human response

Nighttime penalty looks reasonable with regard to range of data

Ability to account for more than annoyance puts an adequate weight on other health effects

Quantifies dose as a single number

Deficiencies.- The deficiencies of L_{dn} are as follows:

Energy summation method dometimes yields bizarre results in nighttime weighting factor

Lacks uniform confidence in the scientific community

Hides some value judgments from the user

Ignores time of week and seasonal variations

Not known if the 10 dB penalty is truly representative of all effects

Not known if the time periods of application or the magnitude of the penalty are valid

Statement From Group III: Potential Impacts

Airport impacts.- The positive airport impacts are as follows:

Useful for evaluation of proposed changes to facilities and operations

Provides a basis for charges to users according to noise levels generated

Provides an aid for compatible land use planning

The negative airport impacts are as follows:

Legal ramifications

Potential for error in accurately describing the extent of impact for all parties

Operational restrictions may be imposed on airports on the basis of L_{dn}

Airline impacts.- The positive airline impact is as follows:

Protection of a facility required for continued service

The negative airline impacts are as follows:

Legal ramifications

Operational restrictions

- Curfew
- Runway use restrictions
- Aircraft type restrictions
- Reduction of service and revenues

Community impacts.- The positive community impacts are as follows:

Compatible land use planning

- Building codes
- Land use controls
- Remedial measures

Commonality of measurement of noise due to other sources for comprehensive analysis

The negative community impact is as follows:

Loss of service/revenues

Statement From Group IV: General

Any noise metric should relate in some fashion to human response. The response may be composed of a number of elements - annoyance, sleep interference, and others. The 10 dB correction in L_{dn} was predicated largely on the drop in background levels which typically occur inside and outside of homes during nighttime hours. This drop in level leads to greater intrusion of other noises. It seems intuitively reasonable that this would lead to greater annoyance. Some question concerns the selection of a 10 dB penalty based on the background level change in quiet areas rather than 5 dB from relatively noisy areas. It appears that a judgment was made to err on the conservative side. Other response data such as individual complaints, case studies and others are judged to lack the desired rigor to lead to the conclusion that may be implied by the fixed 10 dB step function penalty. Unanswered questions are, how much variability are users and impacted groups willing to accept in use of L_{dn} and its associated penalty? Also, is 10 dB a valid number clearly related to community response or is it merely an indicator that night noise is less acceptable than daytime noise? If it's merely an indicator, would some other number or means be more acceptable to a broader group of users?

Some concern was expressed regarding whether L_{dn} should be used as an implicit index of noise induced health effects. It was concluded that existing data do not support such an interpretation.

Changing lifestyles may be important in interpretations of noise measures. There are fewer people at home during the day and it is uncertain whether 10:00 p.m. to 7:00 a.m. represents the sensitive portion of the day. Recent data and interpretations suggest that evening hours may be more sensitive or that transition periods, such as the time people are going to sleep or when they are close to awakening to start their day, may be more sensitive than nighttime periods.

It was agreed that L_{dn} should be a rough screening device and that local decisions should not be based on assumed interpretations. An example of misapplication was cited wherein the penalty in L_{dn} overlooks critical daytime impacts such as school operations. If strict interpretation of L_{dn} implications were made, night operations might be shifted to the day, further exacerbating the school difficulties. It was suggested that it may be difficult to persuade the public of the need for local independent decisions since there is a tendency to imply validity in government statements or policies. An example cited was persistent misinterpretation of the EPA-Levels-Document data by various local groups or institutions.

Individual Recommendations

J. D. Collier, Air Transport Association:

(1) As a minimum, remove nighttime weighting and display day/night information and weekend/seasonal information separately.

(2) Seek some way to resolve the anomalies inherent in energy summation.

(3) Use L_{dn} only to describe annoyance, not health effects.

James Miller, Department of Housing and Urban Development: In order to proceed with the important business of attempting to achieve a greater measure of compatibility between airports and their neighbors, it is recommended that a single uniform noise descriptor be adopted for use by Federal agencies, airport and airline industries, and communities as a tool in decision making.

Recognizing the problem inherent in any descriptor which summarizes total noise, it appears that the day-night average sound level (L_{dn}) is useful for these purposes. In addition, it allows interested parties to combine levels from several sources to obtain total noise exposure. Over the years, citizens and communities have become confused with the seemingly endless parade of noise descriptors. This in turn may have thwarted positive programs to reduce noise exposure. While additional research may make minor changes in day-night weighting, this should not defer immediate use of L_{dn} as the preferred descriptor. Research on health effects should continue, but adoption of a uniform system should not be delayed pending these research results, given their uncertainties.

Rudolph M. Marrazzo, Environmental Protection Agency: The following recommendations are necessarily incomplete and are not to be construed as an official position:

(1) Any applied research into the derivation of a nighttime penalty other than 10 dB must be approached with the objective of improving our predictive abilities and planning capabilities, not just changing them. It should not lose sight of considerations of simplicity, uniform application and value to planning and enforcement, especially at local governmental levels.

(2) New nighttime weighting factors, if needed, should take into account other effects of noise, for example effects of noise on sleep and health effects. In other words, nighttime weighting penalties must account for more than just annoyance.

(3) New nighttime weighting factors, if needed, should be applicable to all sources of noise.

(4) New nighttime weighting factors, if needed, should be derived statistically, that is, account for those of the population who are more susceptible or sensitive to the effects of noise.

(5) It is recognized that there are some negative impacts upon the air traffic system associated with the use of L_{dn} in its present form. It is recommended that the FAA explore other methods to mitigate these problems without undermining a potentially useful assessment/planning tool.

Arnold G. Konheim, Civil Aeronautics Board: With respect to the near term, I recommend the continued use of L_{dn} as the metric for quantifying noise exposure. Based upon the merits and deficiencies of L_{dn}, which have been fully enumerated at this meeting, it appears that there is no single metric which could better serve for predicting human response to noise than L_{dn}. In addition to scientific arguments, L_{dn} is accepted nearly universally as the standard metric for assessing the effects of all sources of noise. In the absence of strong evidence to do otherwise it appears unwarranted and unwise at this time to replace L_{dn}.

Summary Statement From Workshop Session II - Future Research

Homer G. Morgan, NASA Langley Research Center: Dave Stephens and I will share this report. First, I will try to capture the essence of the workshop on research needs, and then Dave will add some details. Our attempt at structuring the discussion was only partially successful, but still provides the basis for Dave's report.

Our panel of research experts agree that time of day effects are real. This conclusion is based on intuition, experience, and even a little bit of hard data. They also agree that the problem is amenable to research. Several said, "Yes, I could design a study to get at the problem and answer the questions." However, it was apparent that each study would be different. They would have difficulty agreeing on the best approach, although alternate methods with promise do exist. Some ongoing research has potential for contributing to our understanding of the problem, but it came out loud and clear that we can't expect definitive answers from research in the one-year time frame specified by the legislative mandate. None of the researchers is ready to step up and say, "We can answer your question, John." On the other hand, we didn't hear strong evidence to say that L_{dn} was not appropriate or reasonable as the noise metric. Existing data and intuitition suggest noise has its biggest impact during the evening part of the day and that evening should be the focus of research on weighting. Dave Stephens will continue the report.

David G. Stephens, NASA Langley Research Center: Referring back to the agenda (fig. 1 of Roundtable II), we spent an hour discussing each of the topics; that is, the objectives of the research, some of the approaches of achieving the objectives, and finally some models and research methods. I took notes as we went thru the agenda, and I would like to discuss the highlights of our discussion with you as a form of workshop wrap up. First, we suggested an objective: "to quantify human response to aircraft noise as a function of time of day." Furthermore, we suggested getting response to single events and response to periods of noise as well as the overall response. There was fairly general agreement on objectives, but we did have a fairly lengthy discussion on the response measures of interest. There certainly wasn't a universal feeling that annoyance is either something you can define, or whether it is in fact an appropriate measure. Annoyance had the majority vote as a response measure, but sleep disturbance, for example, was suggested as being important at night. Unfortunately, if we want to trade off day and night effects, we must have consistent response measures between the periods - you can't easily trade the annoyance to daytime noise with sleep interference at night, for example. In summary, the one common measure to be applied across the time periods could be annoyance, and it should be examined for more than two time periods.

If one wants to go from the physical exposure to noise to the human response, the intervening step is the development of a dose-response relationship. Thus the approach to achieving the research objective is shown on the chart (fig. 3 of Roundtable II). One needs to know how people respond to noise at different time periods. The evening time period received a great deal of discussion as being of importance. Not only did people think that the evening period should be looked at for a dose response relationship, but Chris Rice suggested that we do our research in the evening since it is possibly the most representative time for conducting human response surveys. He questioned the logic of doing community surveys in the daytime when we are probably more interested in evening and nighttime response. There was also quite a bit of discussion about the differences between weekday response and weekend response. Gene Galanter had some data which show that people respond or project quite differently on weekends than they do during the week. From the standpoint of developing criteria, that idea should certainly be considered.

There was general agreement that we should go after responses in the different periods for two reasons: (1) that the level of response may change with time period; and, probably more importantly, (2) that the functional relationship may be quite different in different time periods.

Concerning the research model, Jim Fields talked about modelling in his opening paper (see fig. 1). He suggested that the response is the summation of some weighting factor, the noise, and the mediating factors in the different periods. To pursue this model of overall response, we have to decide upon the number of time periods we are going to look at, the dose-response level in each time period, the mediating variables, and how to combine time periods.

Probably the heart of our discussion involved the research methods. Again, to stimulate discussion, Jim Fields put up a chart indicating that there are six different methods, ranging from the laboratory to the community survey, and we looked at the pros and cons of the different methods (fig. 2). The important thing is that we do have some choices to make. It appears that there are a number of different methods to get at some of these problems.

TENTATIVE TIME-OF-DAY RESPONSE MODEL

- MODEL

$$\text{OVERALL RESPONSE} = f\,[\underbrace{W_1(\text{NOISE}_1,\ M_1)}_{\text{Period 1}},\ \underbrace{W_2(\text{NOISE}_2,\ M_2)}_{\text{Period 2}},\ \ldots\ \underbrace{W_t(\text{NOISE}_t,\ M_t)}_{\text{Period } t}]$$

- **RESEARCH PROGRAM TO DEFINE COMPONENTS IN MODEL**

  Definition of Time Periods

  Dose Response Model for Each Time Period

  Mediating Variable Model for Each Time Period

  Model for Combining Period Effects

  Weights for Combining Periods

Figure 1

TIME-OF-DAY RESEARCH METHODS

LABORATORY PROJECTION TO TIME OF DAY

JURY RATING AT HOME

REGULAR REPORTING (BUTTON PUSHING)

IMMEDIATE RECALL (TELEPHONE FOLLOW-UP)

UNIQUE OPERATION CHANGE SURVEY

CONVENTIONAL MULTI-ENVIRONMENT SURVEY

Figure 2

As part of our discussion in methods, Gene Galanter showed data that he has recently collected in the New York City area which show how people respond to noise as a function of time of day. He has broken the day up into 24 one-hour periods and shows a differential response for each hour of the day. That is, he has gone into people's homes and asked them to project their comfort and/or discomfort for each hour of the day and has found distinct trends with time. Again, these trends show that people do want more relief in the evening than in any other time period. The main point that Gene brought out, however, was the methodology. It appeared to be a good method and generally accepted. In summary, there are a number of different options from a research standpoint. Our first job as researchers is to select the most efficient, as well as effective, methods from these candidates and get started on some of these jobs.

Closing Statement

John E. Wesler, Federal Aviation Administration: I would like to close with a few profound words. We asked you here with the naive hope that we could concentrate on the time-of-day correction for any noise exposure metric. We wanted to emphasize that factor because of our uncertainty, but we basically intended that the meeting would review and catalog, if you will, our state of the knowledge on that subject. We also had hoped - and I think we achieved that purpose - that the meeting might provide some guidance and some direction for future research, with the thought that some future research would be necessary - and I think it is.

We couldn't keep away from the continuing saga of "can a single simple number called L_{dn} find happiness in today's complex world of aviation." This morning it is again very obvious that the problems of using any single system, such as the L_{dn}, certainly are not new - they haven't just arisen today. The state of the knowledge hasn't advanced very much recently, if at all, but the pressures for standardization have. They have increased recently to the point that Congress has taken action to require some standardization. Those reasons have all been mentioned yesterday and today. The airport operators need some tool to limit airport noise, because that limits their liability. The public has become more involved and demanded or required some single, simple system of measuring a very complex thing. The courts have become more involved - the Westchester case at LA being a good or bad example, according to which way you want to side. We're facing the question whether we want to, or whether we think we're ready, to or not. Idealistically, if we select a metric, it should be accurate, it should be simple to use, it should be understandable to non-sophisticated laymen - the public - and it should correlate pretty well to something we are trying to represent. I think that something we're trying to control and represent is compatible land use - land use compatible with noise exposure. I think the incumbent (L_{dn}) is relatively simple to use, and I think it is relatively easy to explain to the layman. The questions, of course, are whether it is compatible with its intended use and whether it is accurate. Those questions are at the heart of any decision of which metric to use and how to apply it, because the impacts on the National Air Transportation System can be severe. The air transportation industry is embattled enough at the present time, with rising fuel prices, with deregulation (good or bad), with requirements to meet noise limits already in place, and with further pressures, as Don mentioned, to even go beyond stage 2 to stage 3 and possibily further than that before too much longer. So, the potential impacts are severe; we can't forget those things.

But as an engineer and not a sociologist or psychologist, I doubt that there will ever be good accuracy in any metric that represents human response, with all its variables, to a changing thing such as noise - particularly from aircraft. We may never have an "accurate metric", but we have to do something - the world moves on. The best advice is always do right, but for God's sake do something - we're going to be in that position pretty soon. The world won't stop to wait for us to get an accurate position.

We had planned the workshop to review the day-night noise penalties. I think it was successful. I think the opportunity to get you all together in one place to understand each viewpoint better was useful. We don't have a consensus; nobody expected one. But, I do think we have a better understanding of where we are. If I may be rash enough to conclude in 20 words or less: we still have uncertainty; we're not going to have an answer very soon; and L_{dn} is the incumbent.

We will, within the next 6 weeks, provide you with printed proceedings of the day and a half, including the two papers given very well by Jim Fields and Bill Galloway yesterday morning, as well as summaries of the workshop discussions this morning. I would like, on behalf of the Federal Aviation Administration and the National Aeronautics and Space Administration, to thank you very much for coming. We appreciate it even though we don't always sound like it.

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15. Supplementary Notes

Sherman A. Clevenson: NASA Langley Research Center.
William T. Shepherd: Federal Aviation Administration.

16. Abstract

This report summarizes the proceedings of the Workshop on Time-of-Day Corrections to Aircraft Noise Metrics jointly sponsored by the Federal Aviation Administration and the NASA Langley Research Center. The workshop was held at the NASA Langley Research Center March 11-12, 1980. Two position (perspective) papers were given. The first dealt with historical and background aspects of corrections and the second reviewed research evidence supporting corrections and proposed research to further elucidate the validity of corrections. Two roundtable sessions and two workshop sessions completed the program. The first roundtable and workshop sessions dealt with impacts and applications of corrections, and the second roundtable and workshop sessions dealt with research aspects. Topics of discussion included health, welfare and economic impacts, needs and criteria, current practice and experience, government policy and regulation, previous research, research methodologies, and proposed research. Transcripts of the position papers and the individual statements of roundtable participants are included in this report as well as summaries of the discussions held in the workshop sessions.

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