HISTORICAL DEVELOPMENT OF NOISE EXPOSURE METRICS

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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.

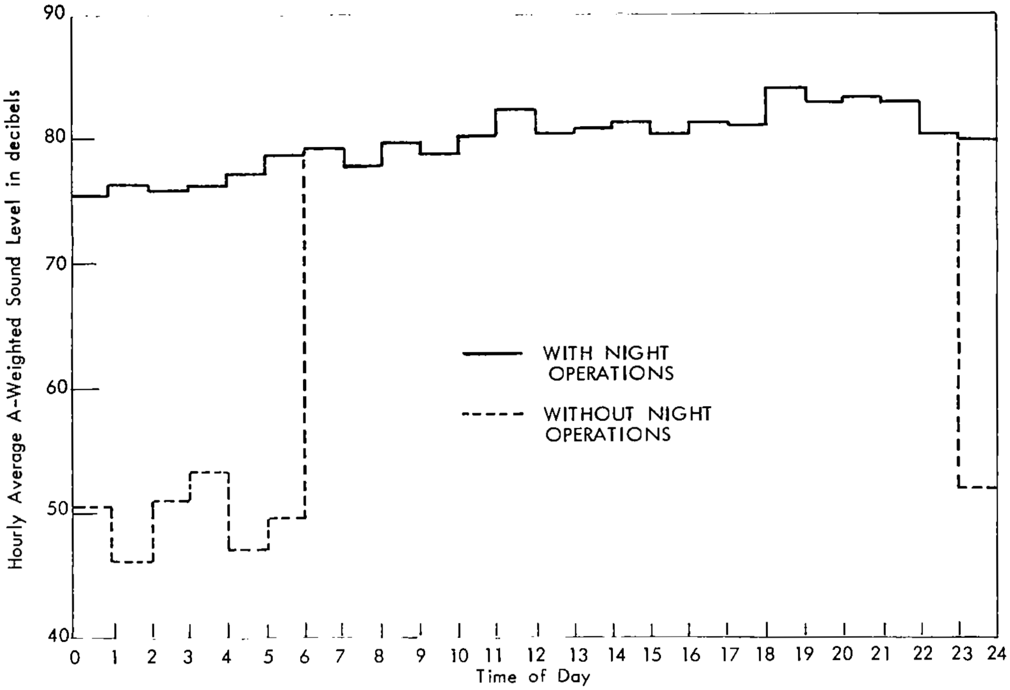

Figure 1.- Hourly noise levels for a 24-hour period in the high noise exposure area.

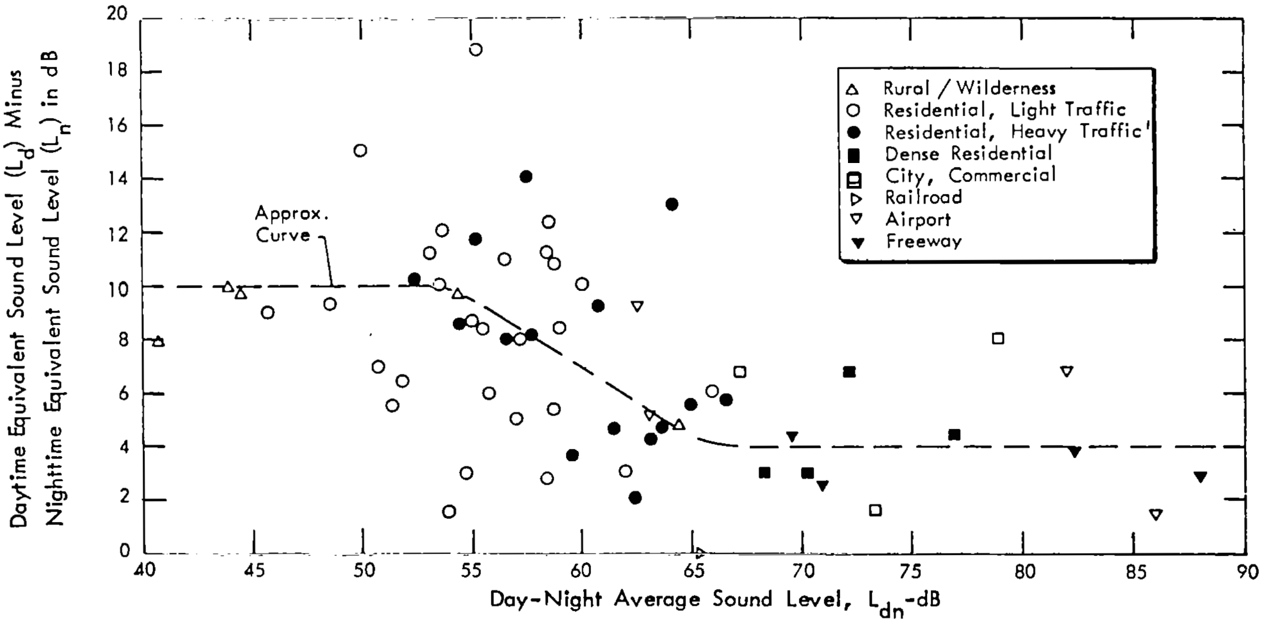

Figure 2.- Comparison of the difference between day and night values of the equivalent sound level with the day-night average sound level L_{dn}.

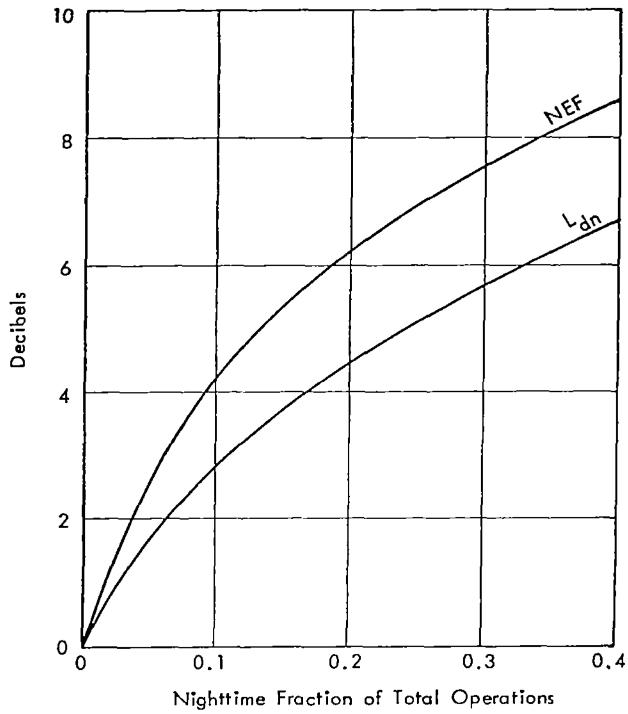

Figure 3.- Increase in level due to application of a nighttime weight in decibels for day-night average sound level and noise exposure forecast.

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

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.