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DETERMINING ACCEPTABLE LIMITS FOR AVIATION NOISE

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1. INTRODUCTION

This paper reports on parts of an extensive review of the use of the Noise Exposure Forecast (NEF) measure to manage aviation noise in Canada[1,2,3]. The work included evaluations of: noise contour prediction procedures, the components of the NEF measure, and the effects of aviation noise on people.

A review of the historical development of the NEF measure showed that it evolved from the earlier Composite Noise Rating (CNR) procedure and that it gradually changed from a general measure of environmental noise to a measure of aviation noise[4]. Changes were based on intuition and the results of practical consulting case studies of various types of noises. At no time were the developments of the measure or the related expected community response, the result of extensive systematic studies. With the development of equal noisiness contours and the Perceived Noise Level rating[5], the CNR was transformed into the NEF. It was adopted by Canada shortly before it was replaced by the day-night sound level (L_{dn}) in the United States.

Similarly, recommended land use planning limits in Canada could not be traced to any systematic study of peoples' responses to aviation noise. The lack of systematic studies supporting the use of the NEF measure, and recommended Canadian land use planning limits, as well as the changing conditions at Canadian airports, and an international trend for adopting A-weighted aviation noise measures, were seen to be significant reasons for re-evaluating the use of the NEF measure and the associated land use planning limits. This paper describes the key steps in arriving at new estimates of acceptable residential land use planning limits for aviation noise.

The Noise Exposure Forecast values produced by Transport Canada's NEF_1.7 prediction program are referred to as NEF_{CAN} values. They are estimated to be 4 points greater than true measured NEF values. NEF values are estimated to be 35 points less than associated L_{dn} values, or L_{dn} values are 31 points higher than NEF_{CAN} values.

2. HEARING IMPAIRMENT AND OTHER MEDICAL EFFECTS

As a result of many industrial studies, noise induced permanent threshold shifts (NIPTS) are one of the better understood effects of high levels of noise on humans. The U.S. EPA concluded[6], that below an exposure of a 24 hour L_{eq} of 70 dBA, significant NIPTS are not likely to occur. This is approximately equal to an L_{dn} of 72 or an NEF_{CAN} of 41. It is very unlikely for residents near airports to be exposed to such high levels 24 hours per day. A number of studies have confirmed this by finding no relation between aircraft noise levels and measures of residents' hearing(e.g.[7]).

Various studies have tried to relate admissions to mental hospitals to aviation noise levels, but have failed to produce conclusive results[8]. A number of studies have tried to relate aviation noise levels to factors related to the growth and reproduction of subjects living near large airports. These studies have often been found to use methodologically flawed or unreliable procedures.

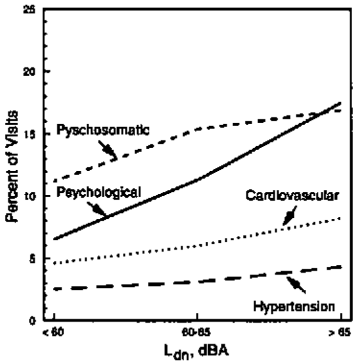

Fig. 1. Knipschild's general practice survey results[9].

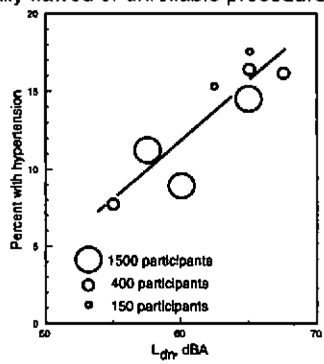

Fig. 2. Prevalence of hypertension versus noise level[10].

Various every day events including exposure to noise can trigger responses from our cardiovascular system. It has often been suggested that prolonged exposure to noise could act as a stressor and lead to hypertension or other more serious effects to our cardiovascular system. Investigations to look for such effects in industrial situations have produced conflicting results. A series of studies near Amsterdam's Schipol airport have shown a consistent pattern of effects. The results from a general practice survey[9] in Fig. 1 show several types of medical complaints to increase with aviation noise level. Results from another study by the same research team[10] showed a number of cardiovascular problems to occur more often with higher levels of aviation noise. Fig. 2 shows the relationship between the prevalence of hypertension and aviation noise levels. While these results are from one research team at one airport, they do seem to present a consistent pattern of medical effects starting between L_{dn} 55 and 62 dBA.

3. SLEEP INTERFERENCE

There have been many studies of the effects of noise on sleep. Although laboratory studies can be well controlled experiments, they create an artificial setting and Thiessen's results[11] showed subjects' awakening responses may take as long as 24 days to habituate. Field studies may have more realistic settings but it is very difficult to manipulate noise levels without subjects being aware of the experimental procedure.

Griefahn[12] reviewed a large number of surveys and produced the graph shown in Fig. 3 to summarise the overall trends. It represents the responses of the most sensitive portion of the population (older subjects) and indicates that there would be very few awakenings below maximum indoor noise levels of 54 dBA.

A recent example of one of the better field studies[13] measured sleep disturbance in peoples' (mostly well insulated) homes near British airports. Results from this study shown in Fig. 4 indicate, that above an L_{max} of about 75 to 80 dBA, arousals increase with increasing noise levels. For well insulated homes this would correspond to indoor noise levels similar to Griefahn's threshold of arousals.

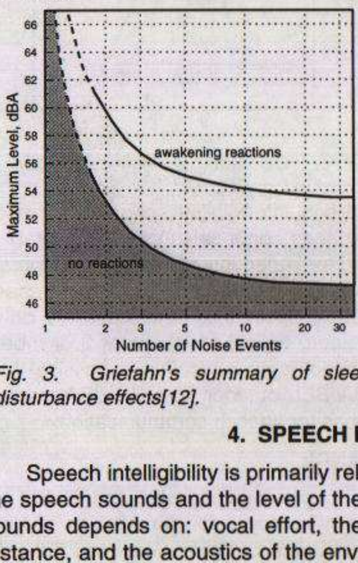

Fig. 3. Griefahn's summary of sleep disturbance effects[12].

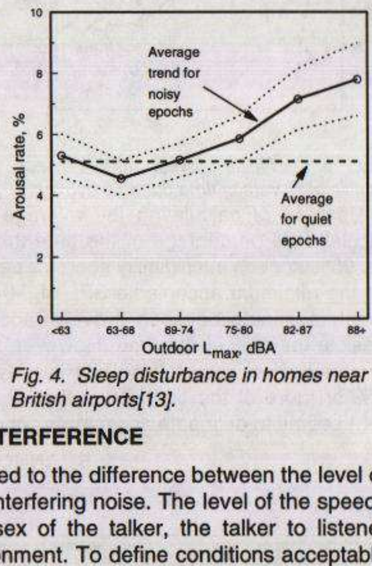

Fig. 4. Sleep disturbance in homes near British airports[13].

4. SPEECH INTERFERENCE

Speech intelligibility is primarily related to the difference between the level of the speech sounds and the level of the interfering noise. The level of the speech sounds depends on: vocal effort, the sex of the talker, the talker to listener distance, and the acoustics of the environment. To define conditions acceptable for almost all talkers, Pearson's[14] speech source level data for females using 'normal' vocal effort were used. To include almost all talkers, a speech source level of 51 dBA, which is 1 standard deviation below the mean for this case, was used. In the past, speech interference has been assessed in terms of integrated measures such as L_{eq} and the time variation of the aircraft noise has been ignored. Fig. 5 illustrates the variation of the noise level during an aircraft flyover. The corresponding L_{eq} is 62.2 dBA. A speech source level of 51 dBA would suggest that speech communication with a 'normal' voice level would be impossible for many talkers. This plot also shows speech intelligibility scores calculated on a point by point basis during the flyover. The speech intelligibility scores are unacceptably low for only about half of the 1 minute shown on this plot. Thus estimating speech interference from L_{eq} values over-estimates the negative effects.

Further point by point calculations of speech intelligibility scores were made and the resulting average speech intelligibility scores were related to indoor SEL values of aircraft flyovers in Fig. 6. These results suggest, that with 'normal' vocal effort (51 dBA), acceptable speech intelligibility (95%) is achieved for indoor SEL values of 64 dBA or less. For a well insulated Canadian home this was estimated to correspond to an outdoor SEL of approximately 90 dBA.

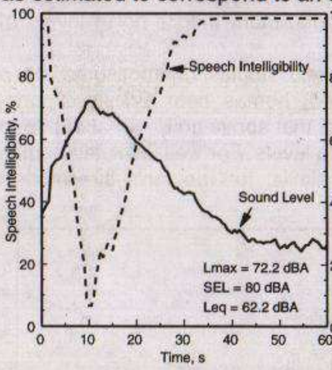

Fig. 5. Noise levels and speech intelligibility versus time during a flyover.

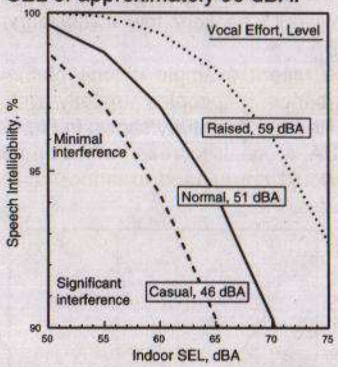

Fig. 6. Calculated speech intelligibility versus indoor SEL.

Instead of calculating the average speech intelligibility score, one could calculate the percentage of the time that speech communication is acceptable (i.e. 95% speech intelligibility score or better) for varied intervals between flights. For the minimum acceptable SEL of 64 dBA from Fig. 6, and the extreme case of only 1 minute between flyovers, acceptable speech communication is only possible for 71% of the time. However, for more typical situations of 3 or more minutes between operations high quality speech communication is possible for 90% or more of the time. Thus the 90 dBA SEL outdoor limit (64 dBA indoor SEL) seems to delineate acceptable conditions for speech communication.

5. ANNOYANCE

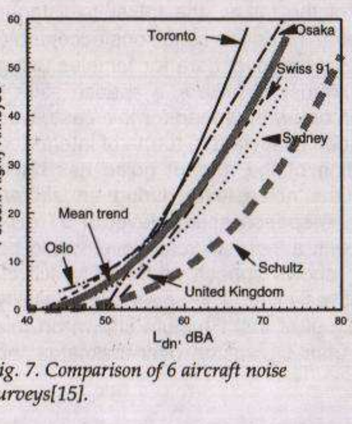

Fig. 7. Comparison of 6 aircraft noise surveys[15].

In a previous paper[15] the results of modern annoyance surveys at major airports were compared with the Schultz mean dose response curve. The comparisons shown here as Fig. 7 indicated that residents near major airports were considerably more annoyed by airport noise than suggested by the Schultz curve. Whereas the Schultz curve suggests that about 15% are highly annoyed at L_{dn} 65, the Mean response curve of the major airport studies suggests that 15% highly annoyed occurs at about an L_{dn} of 56 dBA.

Although this new result seems more appropriate for major airports, there are many other unresolved issues. There is some evidence that general aviation noise is more disturbing than commercial traffic and that residents near smaller airports are less disturbed than those near larger airports. Unfortunately, in many studies the effects of variations in the type of operations and airport size are not separately identified. Other types of environmental noises tend to be less annoying at the same noise levels. However, the responses of subjects exposed to combinations of types of sources can produce quite complex interactions.

No evidence was found that subjects' responses to a given level of aircraft noise are changing over time. Studies at Heathrow[16] and in Switzerland[17] both suggest that dose response curves of annoyance to aviation noise are quite stable over periods of up to 20 years.

6. ACCEPTABLE LIMITS

Acceptable land use planning limits for aviation noise were determined by first considering the noise levels at which various effects commenced. Fig. 8 compares the thresholds of the various negative effects of aviation noise. The first horizontal bar compares land use planning limits for new residential construction in 11 countries. These vary from a low of L_{dn} 54 dBA for Australia to a high of L_{dn} 69 dBA for Germany where these limits are part of a national law.

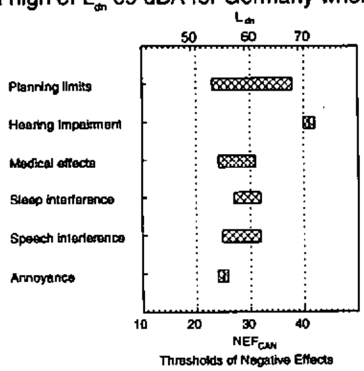

Fig. 8. Thresholds of the onset of various negative effects.

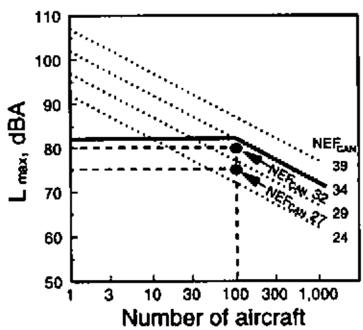

Fig. 9. Procedure for converting from L_{max} to NEF_{CAN} for a particular number of operations per day.

The threshold of possible NIPTS is shown to be NEF_{CAN} 41 (L_{dn} 72 dBA). The threshold of medical effects is based on the cardiovascular effects studies near Amsterdam which showed negative effects starting at an L_{dn} of 55 to 62 dBA. Field and laboratory studies of sleep interference suggest that sleep interference would increase above a threshold of an outdoor L_{max} of 75 to 80 dBA for well insulated Canadian homes (26 dBA noise reduction). Fig. 9 illustrates how these L_{max} values were converted to NEF_{CAN} values for a typical (worst case) condition of 100 operations/day. Aircraft noise levels above an indoor SEL of 64 dBA were shown to lead to speech interference for talkers using a 'normal' voice level. Using a procedure similar to that of Fig. 9, this was converted to an NEF_{CAN} value of 32 (L_{dn} 63 dBA). A 'casual' voice level would lead to a threshold for speech interference of NEF_{CAN} of 25 (L_{dn} 56 dBA). The threshold for the onset of significant annoyance to aviation noise was taken as the point of 15% highly annoyed from the new Mean response curve for major airports which is NEF_{CAN} 25 (L_{dn} 56 dBA).

Together these comparisons show that the threshold for negative effects to aviation noise is approximately NEF_{CAN} 25 (L_{dn} 56 dBA). Below this there is no substantial evidence of negative effects related to aviation noise levels. By NEF_{CAN} 30 (L_{dn} 61 dBA) all of the negative effects are established and are growing with increasing aviation noise levels. By NEF_{CAN} 35 (L_{dn} 66 dBA), the negative effects of the aviation noise are very significant.

These results suggest that noise levels greater than NEF_{CAN} 35 (L_{dn} 66 dBA) are not suitable for residential development and that above NEF_{CAN} 30 (L_{dn} 61 dBA) homes should have extra sound insulation.

7. CONCLUSIONS

The above land use planning recommendations were determined from the best available information when this work was completed over a year ago. It was also recommended that supplemental single event measures should also be considered. The discussions of speech and sleep disturbance above suggest initial estimates of recommended single event limits (SEL 90 dBA for minimal speech interference and L_{max} 80 dBA for minimal sleep disturbance). The single event limits should be applied at all sizes of airports, but would be most restrictive at smaller airports.

There are a number of areas much in need of further research. These would include studies to reconcile the differences between laboratory and field studies of sleep interference. It is also very desirable to separately determine the effects of airport size and aviation type on annoyance responses to aviation noise. Finally the question of adding extra sound insulation needs further study to determine if there are long term benefits in terms of peoples' responses to aviation noise.

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