Noise Pollution
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CHAPTER 13

Aircraft Noise Generation and Control: Noise Around Airports

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13.1 INTRODUCTION

13.1.1 Early Recognition of the Aircraft Noise Problem

In the early days of the development of the air transportation system, the sound of the aircraft was considered a sound of progress and was recognized as an indication of affluence by the nation favoured with an air transportation system. This view was shared by the individuals who were fortunate enough to fly on the nation's airlines. As time progressed, and particularly with the introduction of the turbojet aircraft in the late 1950's, the noise generated by aircraft was no longer viewed with pleasure. The early turbojet aircraft, which received its propulsive force from the momentum exchange resulting from the high-velocity jet exhaust, became more efficient as the jet velocity increased. The noise generated by the aircraft also increased, approximately proportional to the eighth power of the jet velocity, and public complaints about aircraft noise increased accordingly.

As the problem of aircraft noise increased, it became apparent to a large number of international officials and aircraft manufacturers who held a conference on the subject in London, (UK International Noise Conf., 1966) that the aircraft noise problem should be addressed and that means of control were necessary to prevent the noise issue from becoming a major deterrent in the orderly development of the air transportation system. The seriousness of this potential constraint to the air transportation system was manifest in the attitude of airport neighbours, many of whom lived and worked in noise impact situations considered by most psychoacousticians to be environmentally unacceptable. In fact, the airport neighbours had in some cases been led to believe that aircraft noise could increase mortality rates among impacted people, as well as induce birth defects in unborn children, and also to cause excessive mental stress. The fact that these views have not been established as credible and the fact that physical demonstrations against airports have tended to diminish in recent years is attributed to the efforts of the early investigators, who at the time of the London Conference and afterwards recognized the seriousness of the aircraft noise problem and instituted programmes to ameliorate the impact of aircraft noise.

13.1.2 Elements of the Problem

Control of Aircraft Noise at the Source, Operationally, and at the Receiver

In some countries, virtually no new airports are being opened for operation and many improvements in airports are being inhibited largely because of environmental impacts, mostly attributable to public concern about aircraft noise. Faced with this constraint, it is apparent that aircraft noise is an environmental cost which should be an internalized cost recognized as part of the total operating costs of the air transportation system. Realizing this fact, there have been voluntary, as well as regulatory, attempts to control aircraft noise. Addressing this issue as an international problem, the International Civil Aviation Organization held a 'Special Meeting on Aircraft Noise in the Vicinity of Aerodromes' in 1969, which was the first attempt by an international body to develop standards for the control of aircraft noise. Initially, these standards addressed the conventional fleet of turbojet aircraft, which were beginning to dominate national airport noise exposure. Since the 1969 special meeting, the ICAO's Committee on Aircraft Noise has traditionally led in the development of standards for light and heavy propeller-driven aircraft, for supersonic transport aircraft, for helicopters, for STOL aircraft, and for auxiliary power units. All of these standards tend to seek a solution to the aircraft noise problem at source. Over the past 12 years, these source noise control measures have been extremely effective. It is estimated that the noise levels of aircraft entering the fleet could be from 15 to 20 decibels higher than those currently entering the fleet had not specific noise standards been established.

A second important element of the aircraft noise control problem is related simply to the manner in which the aircraft are operated. Operations of aircraft at airports should be controlled to reflect the proximity of the airport neighbours to the airport runways. In some cases, a rapid initial climb will provide better noise control than can be obtained by a low altitude thrust reduction with the accompanying lower noise levels.

Noise control operational procedures, in general, are a compromise with respect to the distribution of aircraft noise. In all cases, however, it is of primary importance to ensure that operational procedures are clearly demonstrated to have no advance impact on aircraft safety.

A third element of the aircraft noise problem can be controlled largely through the airport design and through land-use planning. It is this element of noise alleviation around airports which is usually the direct responsibility, though not necessarily completely under the control of the airport proprietor.

13.1.3 Control Measures Available to Airport Proprietors

Airport Community Planning Programme

In some countries the airport proprietor is the party solely legally responsible for the impact of aircraft noise. This reasoning is often based on the fact that the location of the airport, the type of operations, the geometric layout, and the size of the airport are all design decisions made by the airport proprietor. With this responsibility, the airport proprietor should have a reasonable number of prerogatives at his disposal for the control of aircraft noise. The airport developer should be involved in the community's long-range land use planning programme and should have the benefit of zoning restrictions to prevent the encroachment of airport communities on the airport after it has been built. The airport proprietor should also be in a position to acquire adequate land for noise impact control and should have available noise impact estimation procedures to assist in the appropriate layout and design of the airport. In this context, it is particularly desirable that the airport designers utilize all natural barriers, such as rivers, busy highways, or commercial areas as points of noise concentration, thus reducing the need for distribution of the noise to residential neighbourhoods.

13.2 AIRCRAFT NOISE GENERATION

To understand the problem of airport noise control, it is useful to have an understanding of aircraft noise generation. Different types of aircraft have noise sources which are uniquely characteristic of the type of propulsion system used by the aircraft. Many of the sources are common to all of the aircraft types, but contribute in different magnitude.

Extensive research and development efforts have been undertaken to understand the noise mechanisms and in some areas the control devices are fairly well advanced. In other areas, the mechanisms are not understood and the control process has just been initiated.

13.2.1 Jet Noise Source

The early turbojet aircraft produced a single-exhaust stream of hot gases, which provided thrust in proportion to the jet velocity and the mass flow of gas in the single-jet exhaust stream. The jet-exhaust noise sources result from the mixing of the hot-core exhaust stream with the surrounding environment, from

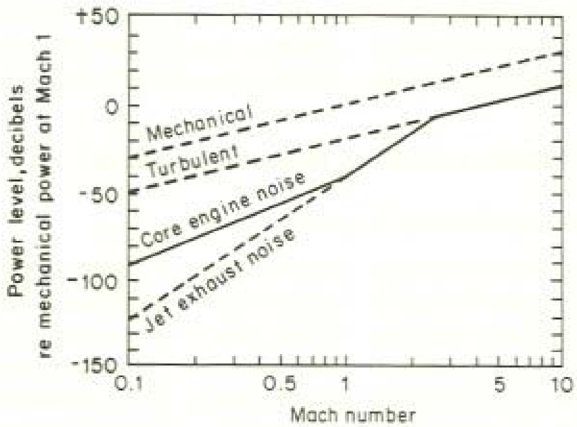

Figure 13.1 Variation of turbojet engine noise with jet Mach number

the shock associated noise when the flow is supersonic, from the core-engine noise, including combustion noise, and from aerodynamic noise resulting from the compressor or turbine systems. In Figure 13.1 (Powers, 1971), the relative engine noise source power levels are presented in decibels referenced to a turbojet's mechanical power at a Mach number of 1.0. It is noted that the mechanical energy varies with the third power of the jet Mach number and, hence, increases by 30 decibels for each order of magnitude increase in jet Mach number. The turbulent energy of the jet is approximately one percent of the mechanical energy and is shown at a 20 decibel reduced power level. Jet-exhaust noise theory predicts that the acoustical power varies with the eighth power of the jet velocity, which is equivalent to an 80 decibels change for each order of magnitude in Mach number. This power-law relationship has been substantiated by a large collection of experimental data; however, it is noted that core-engine noise tends to dominate in the lower jet velocity regions. Unfortunately, the core-engine noise source is difficult to control.

Since the predominant frequency in the jet is inversely proportional to the jet diameter, the larger diameter jets tend to produce a low-frequency dominated noise. With this fact in mind, early researchers attempted to shift the dominant frequencies of the jet spectra to higher values which were more rapidly attenuated by propagation through the atmosphere. This was accomplished by constructing exhaust nozzles, which were subdivided into many smaller individual nozzles or which had various forms of shutes and flutes designed to improve mixing of the exhaust flow with the external atmosphere. Several examples of jet-mixing suppressor designs are shown in Figure 13.2. In view of the complexity of the jet-suppressor designs shown in the figure, a design guide (Report No. FAA-RD-76-79, 1979) has been developed to identify the

Figure 13.2 Examples of full-scale jet noise suppressor tests on JT8D engine (Courtesy of Boeing Airplane Company from Document D6–40613-K, April 1980)

acoustic suppression phenomena involved and the impact of the suppressors on the thrust performance for different configurations. The design guide can be used to assess the relative effectiveness of different suppressor configurations, and is applicable for most of the concepts, (e.g., multiple-nozzle suppressors, shutes, etc.) when operated in either single- or dual-flow installations. These devices, in general, provide a moderate reduction of jet noise, but were constrained by the fact that the jet thrust was reduced correspondingly. In some cases, the loss of performance experienced by aircraft tended to offset the noise reduction provided by the exhaust nozzle configuration.

13.2.2 Turbofan Engines

Turbofan engine noise is generated by a combination of mechanisms. The number of fan and compressor blades combined with their rotational speeds generates the primary fundamental harmonics discrete-tones. The vortex flow around and shed by the blades produces the broadband noise over a large frequency range. An additional source of fan and compressor noise is generated by the interaction of the wakes from the rotor and stator vanes, which are in series. When the fan or compressor blades operate at supersonic tip speed, another noise source called 'combination-tone noise' is generated. The fundamental advantage of turbofan engines from the noise standpoint results from a two-stream mixing process, which takes place when the high-velocity core is mixed with a lower-velocity fan-flow and then the combined stream is mixed with the external flow. The net result is equivalent to a lower noise level than would be generated by the single-stream flow.

The turbofan engine has also advanced the development of sound absorbing material to reduce the tonal characteristics of engines. The sound-absorbing material has been shown to be very effective, but its design is directed towards a single frequency and is not effective over the entire frequency range of the turbofan engine. Techniques recently have been developed to increase the effective frequency range of sound absorbing materials.

A recent innovation in the control of noise from turbofan engines has been the introduction of internal mixers. The internal mixer functions by combining the fan-flow and the core-flow inside of the engine and produces a lower mean velocity and a control velocity profile, which can be optimized for noise control.

13.2.3 Supersonic Transport and Rotor Noise

The introduction of the supersonic transport has resulted in an additional problem for the airport proprietor. The thrust necessary for flight at supersonic speeds is most efficiently generated by pure jet engines and is considerably higher than the thrust needed for subsonic cruise aircraft. As a result, the take-off noise levels of supersonic transport aircraft tend to be very large. A related problem, which does not result in an airport noise impact, is the problem of SST's sonic boom. The sonic boom problem has been found to be controllable only through the use of operational restrictions on SST overflights.

Another dominant aircraft noise generating mechanism is the rotor noise of propeller-driven aircraft and helicopters. In this case, the general mechanism for the propeller-driven aircraft and helicopters is essentially similar, however, there are practical differences resulting from configurational design. Both noise sources are composed of the rotational component, which occurs at the fundamental blade-passing frequency and its harmonics. Additionally, the vortex noise and thickness noise provide the elements of a broadband structure which add to the total noise spectra. The helicopters have an additional noise source resulting from the interaction between blade-wakes and the advancing blade (Figure 13.3), (Foster, 1978). This interaction can occur between the forward and aft blades of a tandem rotor aircraft or between the main and tail rotors of a single main rotor helicopter. The control of rotor noise has not reached advanced technological stages as yet and most noise control emphasis is directed at the reduction of blade-tip Mach number. This means of achieving noise control unfortunately results in a performance loss and must be compensated for by increasing the blade solidity or changes in other design parameters.

13.2.4 Source Noise Control by Regulation

The Evolution of International Noise Standards

Following the 1966 London Conference, considerable effort was directed towards the development of international aircraft noise-control standards. While it is recognized that the noise-control standards themselves do not result in a reduction in noise generation, it is apparent that the aircraft designer must include control of noise as an important design parameter in the aircraft design. The standards developed in the 1969 time frame were generated under the guidelines that regulation should provide relief and protection to the public from unnecessary aircraft noise and that regulation should be consistent with safety, economically reasonable, and technically practicable. The initial standards were designed for subsonic turbojet aircraft. Consideration of the noise levels of existing aircraft, the fact that a new generation of high bypass-ratio turbofan engines was being developed, and that technical improvements in nacelle design could be achieved through the use of sound-absorbing materials resulted in the conclusion that appreciable reduction in existing noise levels could be accomplished. The standards were also designed to be compatible with airworthiness requirements and operational

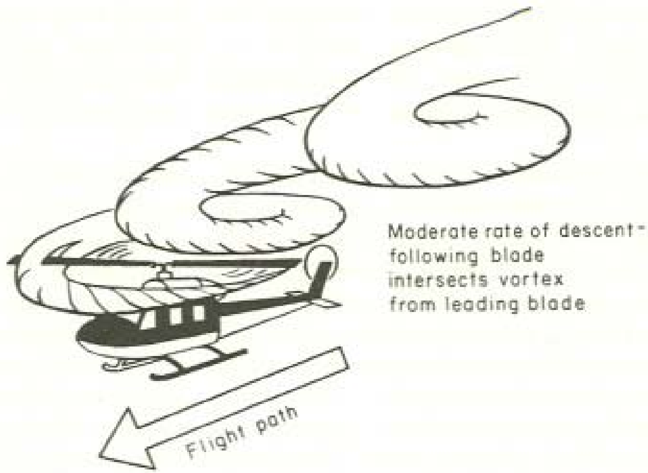

Figure 13.3 Tip vortex interaction

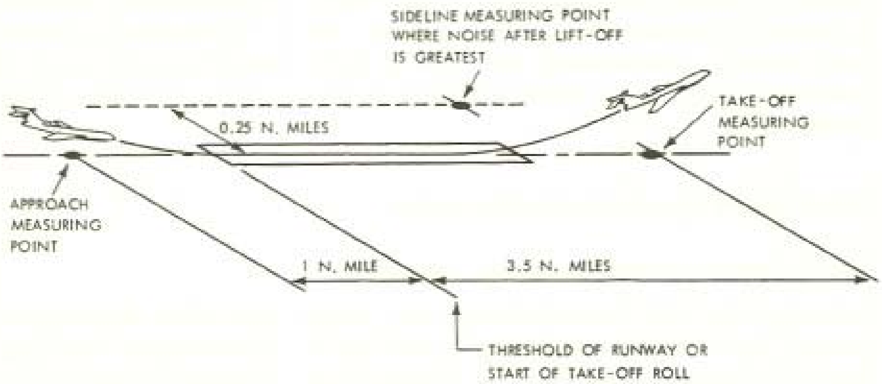

Figure 13.4 Noise measuring points for airplane type certification

practice, which lead to the stipulation of noise-level criteria achievable during normal airport flight operating conditions. The noise-level criteria were expressed in a newly developed unit called the Effective Perceived Noise Level (EPNL), which was designed to reflect public reaction to the noise of turbojet aircraft and to provide a regulatory incentive to aircraft designers to control the objectionable characteristics of aircraft noise. The noise levels were measured by a microphone array utilizing the three-point concept shown in Figure 13.4, which specified measurement point locations at specific distances for assessment of take-off, sideline and approach noise. These measurement point locations were considered to be representative of the airport-community interface and were intended to provide airport proprietors with useful guidance

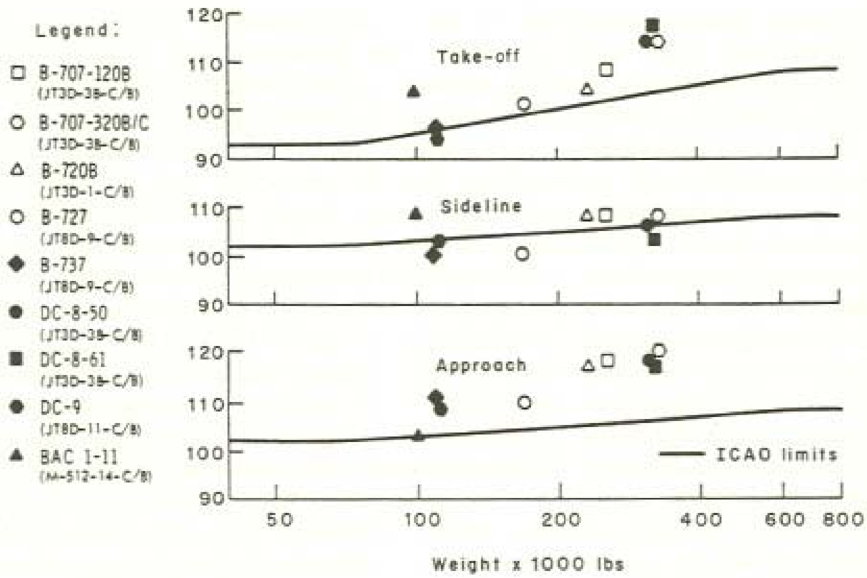

Figure 13.5 Uncertificated noise levels (EPNdB) (estimated)

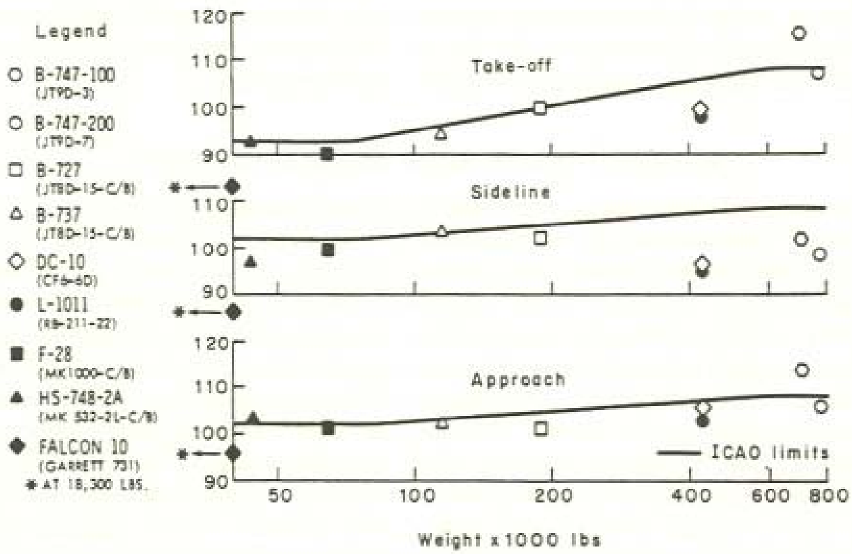

Figure 13.6 Certificated noise levels (EPNdB)

in the determination of acceptable aircraft for operation at their airports. Figures 13.5 and 13.6 show representative noise levels for aircraft designed prior to the establishment of the initial ICAO noise limits and the noise levels of some aircraft certificated to the ICAO standards (Convention on International Civil Aviation, 1978). The implementation of the initial international noise standards has resulted in aircraft which are approximately 10 to 15 decibels quieter than those designed without noise-level constraints.

Since the initial standards were promulgated, additional standards have been enacted which progressively broaden the scope and increase the stringency of the noise level requirements. In the mid-1970's, all newly produced aircraft were required to meet the initial noise standards. Internationally, many nations are in the process of requiring that all aircraft meet the initial ICAO standards by a specific date during the time period 1985–1990 as a condition for operation at their airports. Also in the late 1970's, a more stringent set of noise-level limits were promulgated which will require further reductions in allowable noise levels by 5 to 9 decibels for second generation aircraft designs. Additionally, international standards have been developed for the new design and new production of small and large propeller-driven aircraft, for civil supersonic aircraft, and are in the process of being finalized for civil helicopters. In many respects, aircraft complying with the international standards will be required to achieve the ultimate in source noise control available through the application of advanced acoustic technology. This is not to be construed as implying that all of these actions will in any way eliminate aircraft noise. Even when the optimum noise control technology is applied to aircraft designs, the remaining noise resulting from moving-off a substantial mass from the ground and into the air will create a residual noise-control problem which must be addressed by the airport proprietor.

13.3 CONTROL OF NOISE AROUND AIRPORTS

For many years, the basic concept that aircraft noise abatement is and must be a shared responsibility of all elements of the aviation industry has been articulated. In the United States, for example, that concept is the basis for the United States' Aviation Noise Abatement Policy (Dept. of Transportation, 1976), which has formally been in effect for approximately five years and has been in effect informally since the seriousness of the aircraft noise problem was initially realized. The contribution of the aircraft engine and airframe manufacturers to the control of noise has been reviewed in the previous section. The air-carrier segment of the aviation industry has also made substantial investments in the control of aircraft noise through the replacement of older, noisier aircraft with new quieter aircraft. These replacement programmes, because of the extreme financial burden involved, are necessarily long-term actions and, hence, the benefits come in small increments which are difficult for airport neighbours to fully appreciate. The airport proprietor, who is responsible for the noise impact, is not independently responsible for implementing the remaining measures for noise control. In many cases, implementation of the necessary noise control measures can only be accomplished in cooperation with the aircraft operators and the Federal authorities.

13.3.1 Operating Measures

Typical of such cooperative measures are the implementation of aircraft operational noise-control procedures in the airport vicinity, which require the co-operation of the air traffic and airspace managers, the operating airline, as well as the airport proprietor. The following are representative noise control operating measures.

A. Noise Preferential Runways

The noise preferential runway use system utilizes the runways which can take advantage of natural terrain around the airport, such as requiring approaches over rivers or industrialized areas to avoid the noise impact on residential communities. In cases where this is not possible because the airport is completely surrounded by residential communities, the possibility of distributing the noise burden through a rotating preferential runway use system may be explored. The preferential runway use system must be flexible to accommodate expected but varied meteorological conditions and in all cases must be implemented in a manner ensuring maximum safety.

B. Displaced Thresholds

In certain situations, if the runways are of sufficient length, the approach threshold can be displaced to require the aircraft to touch down at greater distances from the start of the runway and hence at a further distance from the airport boundary. This may require movement of ILS landing aids but can provide noise relief by maintaining a greater displacement between the aircraft and the airport residential neighbourhood.

C. Take-off Noise Abatement Procedures

The control of aircraft take-off noise can be accomplished by requiring thrust reduction relatively near to the ground at airports where the residential neighbourhoods are fairly close to the take-off ends of runways (Figure 13.7). The aircraft in this case would climb over the residential area at reduced power which would minimize the noise in the residential community being overflown. When the aircraft has passed the residential area, normal climb power can be re-applied until cruise altitude is reached. If the residential community is further displaced from the airport boundary, it is generally desirable to climb as

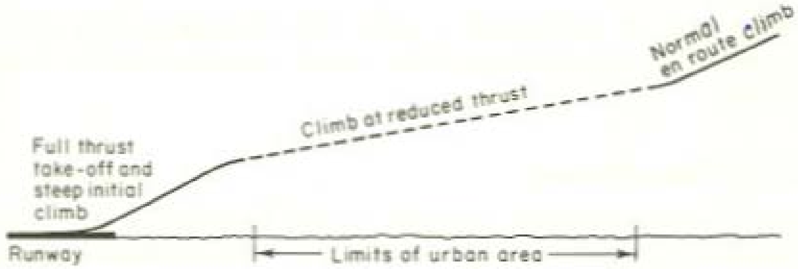

Figure 13.7 Noise abatement takeoff procedure

rapidly as possible to obtain the maximum altitude over the residential areas before reducing power. The steep-climb procedure is not effective if the residential neighbourhoods are close to the sidelines of the airport runway. In this case, it is desirable to reduce thrust soon after the aircraft comes out of the extra lateral attenuation phase, which is associated with the propagation of noise when the aircraft is near the ground. Standardization of noise abatement operational take-off climb procedures is considered highly important for effectivity, especially from a safety standpoint. Currently, the Operational Panel of the ICAO Airworthiness Committee is in the process of recommending standardized noise abatement departure procedures which take into account fuel conservation, as well as neighbourhood noise impact.

D. Approach Procedures

In the last ten years, probably more has been done to control approach noise than noise during other operational modes. The approach procedure some years ago consisted of an extended flight at approximately 1500-ft altitudes with the aircraft in the maximum approach flap configuration and, hence, maximum noise condition until it intercepted the normal 3 degree glide-slope and proceeded to touchdown. The 1500-ft approach is being replaced in the United States by a local-flow traffic management programme, which reduces the flying time at altitudes below 10,000 ft, eliminates holding, and provides the shortest practical route for the aircraft to take all the way to touchdown. The use of the minimum certificated approach flaps has also standardized approach procedures, which assist in reducing the noise. Other techniques used to control approach noise are identified as the decelerating approach and the flap-management approach. Both of these procedures control the noise on the ground by reducing the engine thrust levels during approach.

Operational procedures have been considered for many years to be one of the most promising methods of controlling aircraft noise; however, their effectiveness is generally airport specific. The desire for uniformity in operations, which is considered by most pilots to be essential for the highest degree of safety, has resulted in only limited support for the use of operational noise-control procedures. Additionally, there is a tendency for the operational procedures to be aircraft specific as well as airport specific and, therefore, standardization of procedures across all aircraft types is difficult to realize.

13.3.2 Land-Use Control

Land-use control is synonymous with long-range airport/community planning to ensure that the airport will be able to provide the required service with reasonable prospects for minimizing noise impact, both in the present and in the future. The mechanism used for assessing the aircraft noise impact in the vicinity of an airport in the United States has been identified as the Integrated Noise Model (INM) (Dept. of Transportation, 1979). This noise planning model can be used to evaluate different techniques for reducing the noise impact or can identify how operations at the airport must be controlled to prevent excessive impact in specific airport neighbourhoods. The INM consists of summing the annual aircraft movements in the vicinity of the airport to represent an annual average daily noise impact contour as shown in Figure 13.8. The airport noise impact can be expressed in a number of noise metrics depending on the preference of the user. Currently, the noise metrics available from the model are 'cumulative metrics', such as Noise Exposure Forecast (NEF), Day-Night Average Sound Level (L_{dn}), Equivalent Sound Level (L_{eq}), and Community Equivalent Level (CNEL). Noise contours in these units can be computed and printed at selected map scales. Additionally, the model automatically provides numerical listings of the calculated noise values at all intersecting points on a grid which encompasses the airport and surrounding neighbourhoods. For the land-use planner or airport developer, the INM may be used to identify controls necessary to bring about noise compatibility. These controls may be identified by comparing the noise impact contours for different aircraft types, varied fleet-mixes, different aircraft operation procedures and flight tracks, as well as alternative airport-use restrictions.

13.3.3 Monitoring

Aircraft noise monitoring is useful primarily as a deterrent against individual operations, which make excessive noise. Monitoring is not recommended as a device for violating individual airline flights, but as a means of identifying airline-by-airline average compliance with airport plans. These uses are differentiated because the first can result in the 'beat the box' syndrome or generally unsafe operational practices; whereas the second use identifies airlines as good airport neighbours, which stimulates quieter operations for

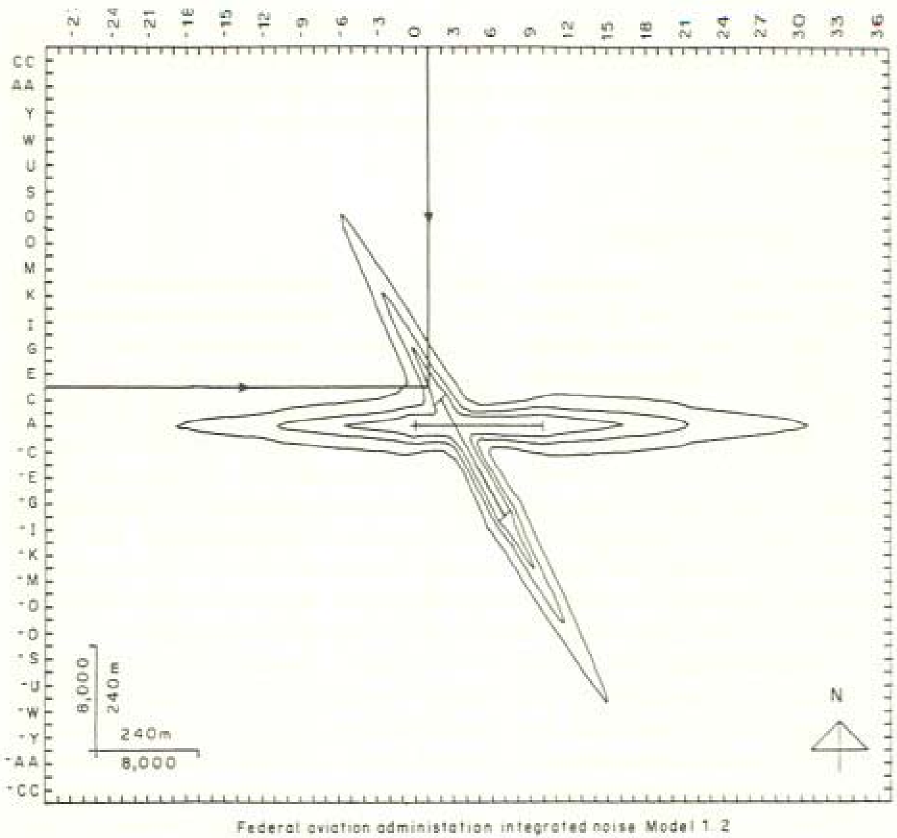

Figure 13.8 Example airport—NEF 30, 35 and 40

the public relation benefit available to the airline. The monitoring systems are also useful for checking the noise-exposure levels in any specific vicinity as a means of identifying problem areas which require special attention.

13.4 CONCLUDING REMARKS

It is clear that the burden of airport noise control will be the responsibility of the airport operators and proprietors for some time to come. The operator in his role as primary focal point for the control of airport noise may consider a large number of directly implementable options, many of which should be included in the initial airport development plan. (U.S. CFR 14, 1981, 1985). Further associated with the plan, if the airport proprietor has the authority, he can propose control of the use of land adjacent to the airport by zoning or other procedures. He can attempt to influence local building codes by advising that residential and public buildings in the vicinity of the airport be acoustically insulated and also be recommending a plan whereby future purchasers of real estate in the vicinity of the airport are made aware of the projected noise impact in areas of interest.

Working with other authorities and often with the support of financial institutions, the airport proprietor may seek to acquire land to ensure its future use for puposes compatible with the airport operations. If the land itself cannot be acquired, it may be possible to obtain air easement rights and to plan future runway developments in such a manner as to direct the noise to areas over which the proprietor has been able to acquire a degree of control. For site specific airports, some benefit may be gained by the construction of acoustic barriers or from the use of landscaping to modify the noise impact. These procedures often supply a minimum reduction of noise impact, but do provide an indication of concern by the airport proprietor for the welfare of the airport residents.

The operational procedures for noise-abatement control discussed above can be proposed by the airport proprietor as a means of noise control if it is endorsed by the national airworthiness authorities. Schemes consisting of use restrictions or noise-related landing fees may also be proposed if they are not in conflict with national prerogatives. Use restrictions could consist of limiting the number of operations per hour at different times during the day, of controlling the hours of operations, and of proposing specific evening and/or night-time curfews. Landing fees based on aircraft noise levels may prohibit operations of particular types or classes of noisy aircraft. While this set of options appears relatively straightforward, depending on the individual country's national regulations, the airport proprietor may find legal limitations to many of the use restrictions suggested. Guidelines on these limitations can only be general, but the limitations usually are legally acceptable if they are imposed equally and impartially and do not tend to discriminate against a particular class of aircraft operators. Care in application of use restrictions by the airport proprietor must be taken to ensure that the restrictions do not control the way aircraft are flown or do not constitute management of the navigable airspace. These functions are usually pre-empted by national governments. A final test of the viability of a use restriction is that it should not impose undue burden on interstate or foreign air commerce. Currently, the legal definition of undue burden has not been resolved and will undoubtedly be the subject of future legal decisions. In the meantime, as a general guideline the airport proprietor should keep in mind that use restrictions must be meaningful and non-arbitrary and that the noise control should be imposed equitably to all sources of noise in the vicinity of the airport.

In summary, while the burden of airport noise impact clearly falls on the airport proprietor, the means available to control that noise burden at any specific airport is limited by the airport's intended operational use. Obviously, it is considerably easier to control noise at new airports than to improve the noise situation at an existing airport, especially if that airport is operating at near capacity. The number of new airports which may be built, however, will be very much limited by public resistance unless the noise burden is reduced in magnitude and the cost of the burden generally internalized in the air transportation system. To accomplish this objective, all elements of the air transportation system must contribute to the control of airport noise to the maximum extent to ensure the orderly growth of one of the world's most important communicative resources.

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