Problems with the INM: Part 1 – Lateral Attenuation

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ABSTRACT

Validation of INM predictions finds agreement when the monitoring position is close to or directly underneath the flight track. At locations to the side of the flight track where the angle from the receiver point to the aircraft is less than 20^o, INM underestimates the noise level. With the need for inclusion of helicopters operating at Australian Defence establishments in ANEF contours, investigations have revealed a major component of the aforementioned anomaly to be associated with an incorrect application of lateral attenuation. Correcting the NPD data curves to exclude lateral attenuation found agreement between measurement and predicted results. Following communication with the FAA and presentation of research material to the US Standards committee for Aircraft Noise (SAE-21) an acknowledgement of lateral attenuation discrepancies has resulted in INM version 6.2 having the capability of turning lateral attenuation off. The lateral attenuation difficulties/effects and our procedure for correcting the INM database is discussed.

THE INM

The Integrated Noise Model ("INM") is used throughout the world for noise contour modelling of aerodromes where the predominant noise emission sources are those associated with fixed wing aircraft.

Australia utilises the ANEF system for aircraft noise modelling and relies upon the INM program for generating such noise contours. In Australia the ANEF contours are issued in the public domain and are used as land-use planning plots for the determination of residential developments. As such the accuracy of the INM output is very much dependent upon the source material used to derive such noise contours. Before an ANEF is endorsed as the official land use planning contour map a detailed review of the source data is undertaken by our aviation authority (AirServices Australia) but the review only looks at flight tracks, aircraft distribution and aircraft numbers.

In general, helicopter operations at airports are a minor issue in terms of the overall noise exposure, although they tend to generate a more specific type of noise complaint due to the nature of helicopter transit lanes and dedicated flight tracks at relatively low altitudes.

However, for military airports helicopter operations may be a significant contribution to the overall noise exposure. Five years ago our organisation was engaged by the Department of Defence to conduct measurements to include helicopter movements into ANEF contours. As a result of trying to verify field measurement results with that obtained from the INM (utilising the suggested helicopter noise curves with version 6) a number of interesting technical problems arose, of which for helicopter circuit operations the critical issue of lateral attenuation was presented to the March 2004 meeting of SAE-A21 Helicopter Noise Working Group (Cooper, 2004).

Initially there was difficulty in determining how one was to develop an NPD curve from actual measurements. The FAA provided advice which did not accord with SAE documentation or alternatively nominated the derivation of NPD curves based on different thrust settings from that used for a base NPD curve. However, theoretical NPD curves expressed in terms of engine power settings as used for fixed wing aircraft does not make sense for helicopter operations, i.e. change of pitch/collective rather than a direct change in engine throttle as experienced in fixed wing aircraft. SAE AIR1989 nominates generalised equations for helicopter SEL values but does not consider PNLTM or EPNL values, which are the essential curves for an ANEF.

In Australia, we utilise an ANEF System which is a modification of the NEF System using different weighting factors for day and night to reflect the Australian conditions. Using the INM program, the ANEF contours are normally produced by persons that could be best described as "software oriented people with extensive experience in aircraft operations" as the primary input to the INM is one of developing flight tracks, profiles, aircraft operating power settings etc. Rigorous testing and examination of the input data are carried out by people that understand the operation of airports, flight tracks, aircraft etc., but generally there is negligible verification of such input data or the INM outputs by persons trained in acoustics.

The different versions of INM have involved investigations into noise prediction of aircraft and extensive refinements in computer programming algorithms etc, such that we now have a more sophisticated aircraft noise model compared to that that was available when the INM was first issued.

The use of an ANEF/NEF for the production of noise contours based on a yearly average does not provide a simple means of verification, as one cannot simply measure the aircraft noise of the entire year to determine the ANEF/NEF levels. What has tended to occur in practice is that persons predict dB(A) noise levels which may then be checked by monitoring systems (both unattended and attended) to correlate between the actual and predicted levels.

In some situations, EPNL is measured and compared with the computer predictions but such measurements are time consuming, involve specialised instrumentation and require persons that understand what is being recorded and assessed. Therefore the cheap option is normally to use a dB(A) measurement. In many instances persons conducting the measurements are not privy to the operation of the INM program and just simply provide a set of results for comparison by others who operate the program.

It is necessary to provide details as to how some verification methods are used because there have been claims over a number of years that the model is inaccurate for positions to the side of the flight path but reasonably accurate under the centre flight path. In 1996 a study was conducted in Sydney (AirServices Australia 1997) that verified this to be the case and identified that for locations to the side of the flight track there could be errors of up to 7 dB(A). The study identified the INM predictions underestimated the noise levels from aircraft operations when compared to actual measurements.

The concept of noise contours to the side of the flight track being out by 7 dB(A) is somewhat of significance in terms of planning policies and similarly such an underestimate would be significant when the ANEF/NEF contours are used to ascertain aircraft noise affecting residential areas. This underestimation of the predicted noise levels to the side flight path has not been discussed in the public domain and is a matter that the bureaucracy appears to have ignored. No investigation was undertaken in the AirServices Australia Sydney study to explain the basis of the underestimation of aircraft noise.

Submissions by Challis, Cooper, Bray with respect to a Senate Inquiry into the Precision Radar Operations for Sydney Airport (McMichael 2000) raised the issue of errors in the INM with reference to the under prediction of maximum noise levels for the residential area of Pymble. Responses provided by authorities indicated the “side line” discrepancy was a matter for international investigation.

Because Australia utilises the ANEF System (a modified version of NEF) for describing noise around an airport, when the Department of Defence was required to review the ANEF contours for aerodromes where the predominant use of helicopters occurs, it was necessary to utilise the INM to produce the ANEF contours. An attachment to Version 6.1 of the INM provided a helicopter database in terms of dB(A) SEL for a number of helicopter types, but did not include any EPNL data that could be used for the purpose of developing the ANEF contours.

As EPNL data was required for such helicopters in the form of NPD curves it was necessary for a measurement program to be undertaken. During the course of deriving NPD curves for seven helicopters used by the military in Australia a number of acoustic issues were identified, as discussed in these series of papers.

One of the issues that were investigated is related to the noise levels determined by the program for locations to the side of the flight path.

NPD TESTING

The Acoustic Group was requested by the Department of Defence to conduct measurements of helicopter operations and derive the base curves required for INM in terms of EPNL, PNLTM, dB(A) Max and SEL.

Examination of the aircraft assessment section of ICAO Annex 16 (ICAO Annex 16 - Amendment 7 2001) and in turn the INM Handbook (FAA 1999) referred to a number of SAE documents setting out procedures for estimating noise levels from both fixed wing aircraft and helicopters (SAE 1845, 1989 and 1751).

The requirement for developing a Noise Power Distance (NPD) curve involves noise measurements of the aircraft at locations directly under the flight path where the operating parameters of the aircraft are understood. The acoustic data is recorded and normalised for temperature, humidity and location of the aircraft to the nominal flight path in accordance with ICAO and SAE procedures from which regression analyses can be developed for such operating procedures. The rates of decay of noise over distance can be determined and then extrapolated to include the standard NPD distances that are used in INM (that in effect go out to 25,000 ft). Obviously there is a problem of conducting a measurement for a helicopter 25,000 ft above the microphone. Practical constraints of helicopter operations and the available area of the test sites supplied for our measurements found (in terms of normal helicopter operations of take off and landing) a limitation of 3500 ft AGL, and 2,000 ft AGL at one test site.

Typical helicopter operations are different to acoustic certification procedures as one does not normally find helicopters in the commercial world (or even the military world) that operate at all up maximum weight and at the maximum speed limits, which are the basis of certification testing. The testing program included certification procedures versus normal operations where the certification type testing revealed noticeably higher noise levels.

There are different types of normal operating conditions that occur for helicopter operations. The author has conducted measurements and assessments of over 60 different helipads in Australia, where there was both a maximum level (fast response) and a L_{eq} noise target at residential premises. As a result of such testing the author is aware of different fly - eighbourly techniques and the consequence of different loadings of the helicopter or restrictions that may occur with respect certain flight techniques/profiles. However, for normal commercial operations there are typical profiles and speeds that provide a consistent range of noise emission levels for medium weight helicopter operations when operated on designated flight profiles.

NPD curves for 7 military helicopters were developed in terms of takeoffs, landings and over-flights by taking the results of monitoring at positions under the flight track from approximately 250 metres from the termination point (helipad) out to position of approximately 2,000 metres from the termination point. In some instances, due to the test site the full 2000 metre distance was available, but for one site there was an outer limit of approximately 800 metres from the termination point. From the maximum level results regression lines were developed. The field measurements results revealed that the maximum level and time duration parameters had a different rate of decay.

Circuit Height and Expanding Contours

The NPD curves were derived from the field measurements recorded under the flight track and agreed with the measurement results. Figure 1 shows the NPD curve for helicopter type F (military troop carrying helicopter) that incorporates the distance and atmospheric attenuation to reference NPD locations. However, when the same NPD curves were applied to locations not under the flight path the model under-predicted the measured noise levels by up to 12 dB(A).

When helicopter operations involving circuits data was placed into an INM operating model the results did not agree with the field measurements. On increasing the circuit height the INM output generated higher noise levels for locations 1000 – 200 metres to the side of the flight track.

Normally in terms of airport operations there is a fixed circuit height for an aerodrome that (other than for a general aviation airport) does not provide a significant contribution to the noise contours.

However, for military aerodromes there can be a significant component of the total movements involving circuit work. For an aerodrome which is predominately for helicopter training, circuit operations comprise a high proportion of the total operations and there can be different circuit heights depending upon the type of training activities and day or night profiles. For some training exercises there can be small circuits wholly contained inside the aerodrome boundary.

The initial IMN runs for helicopter circuit/training operations confined to inside the aerodrome boundary experienced an increase in the area of the noise contours when the height of the helicopter was increase. In an acoustical sense this output defies logic in that one expects the equal noise contours to contract if the aircraft height is increased.

The concept of increasing an aircraft height above an aerodrome and finding the contours expanding is counter intuitive to what INM operators would expect for such operations. In the first instance queries were raised concerning the accuracy of the measurement data and the derived NPD curves, not an issue with INM. As the NPD curves had been based on measurements under the flight path but INM provided significantly lower noise levels to the side it was necessary to find out what INM was doing.

What became apparent is that it is rare in Australia for aerodromes to be checked for acoustic compliance or validation of individual flight profiles set out in the noise model. Flight path monitoring is used to indicate noise events that may be attributed to aircraft and determine overall levels. In these cases the overall noise is a mixture of aircraft and the existing ambient – not aircraft noise contributions.

Neither AirServices Australia (Kenna) or the FAA could give an answer to this issue of expanding contours or the underestimation of the noise to the side of the flight path.

Only in very specific studies, where the intent is to ascertain an aircraft noise contribution, attended measurements have been undertaken (AirServices Australia Study, Jandakot airport and Moorabbin airport) and directly compared with INM predicted levels.

There is now a trend for environmental authorities to request dB(A) levels for modelling in both maximum and SEL contours. The Department of Transport and Regional Services propose the use of an N70 concept by producing a 70 dB(A) contour associated with an aircraft operation. The N70 concept is proposed as an alternative to the ANEF, but the N70 is not endorsed in Australian Standard AS2021.

A very significant consequence of producing an N70 or a dB(A) maximum level contour is that this permits the community to take measurements and determine whether the aircraft noise agrees with the contours or not. Therefore the anomaly of errors in the INM associated with small circuits or increasing the circuit height had to be resolved.

Whilst this issue been raised in the past, but not resolved, a number of trial runs with the INM were able to determine that when the assessment location was directly under a centre line the increase in the height did not cause an increase in the contour area but actually caused a decrease, as expected by the NPD curve. Therefore the issue was what was INM doing for predictions to the side of a flight track?

Lateral Attenuation

INM obtains an allowance for attenuation due to distance and atmospheric conditions from the NPD curves and a further attenuation identified as lateral attenuation.

Lateral attenuation is identified to be additional attenuation due to ground effects, scattering effects and possible directional characteristics of aircraft. The equations provided in the INM Handbook refer back to an SAE document (AIR 1751) and indicate that if the aircraft, in relation to an observer, is at an angle greater than 60 degrees then lateral attenuation does not apply, but for angles below 60º lateral attenuation does apply.

From Section 8.3.2 of the INM 6.0 Users Guide the lateral attenuation is identified as:

> When the airplane is on the ground:
> $G = 15.09(1 - \exp(-0.00274\, D))$ $\quad 0 <= D <= 914$ m
> $G = 13.86$ $\quad D > 914$ m
> Where G is ground-to-ground attenuation (dB), and D is the horizontal lateral distance to the airplane (meters).
>
> When the airplane is airborne:
> $L = (G/13.86)\,(3.96 - 0.066\,\beta + 9.9\,\exp(-0.13\,\beta)$ $\quad 0 <= \beta <= 60$
> $L = 0.0$ $\quad 60 < \beta <= 90$
> Where L is the total lateral attenuation (dB), and β is the elevation angle to the airplane (degrees).

Figure 2 shows the relative angles (β) for a slant distance of 10000ft for different circuit height, which from the above equations identifies allocated attenuations for each NPD location shown in Table 1.

Table 1. Lateral attenuation (dB) for 10000ft Slant Distance Calculated from the airborne equation

Relative Angle (degrees)	2.3	4.6	6.9
Lateral Attenuation (dB)	11.1	9.1	7.5

From an acoustic perspective it is somewhat difficult to accept that if one is 400 metres out to the side of an aircraft flight path and the aircraft is only a few hundred feet above the ground, that one could expect an additional attenuation in the order of say 10 dB(A) would result from ground absorption. It is somewhat even more difficult to accept that, if one considers the same horizontal position but now increase the aircraft to 600 metres AGL that there would be excess attenuation across the ground in the order of 7 dB.

As the aircraft is nowhere near the ground one could only have absorption around the ground receiving point (depending upon the type of ground surface). If one is utilising NPD measurements from the aircraft directly above the measurement position, any reflection from the ground surface would have already been incorporated in the results. This is where the concept of looking at the problem from an acoustically trained viewpoint is clearly superior to that of computer software operators, or flight operation people, who accept without question that INM is accurate.

On looking at the reference source data for the lateral attenuation equations (AIR 1751) one finds that the data was obtained before 1980. Reference to lateral attenuation relied on testing by Parkin & Scholes (1965) that determined ground loss attenuation by use of testing engines located relatively close to the ground and aircraft that have engines mounted in the body of the aircraft (Figure 3). Furthermore, the lateral attenuation graph (Figure 4) that comes from AIR 1751 it can be seen that theoretically the curves have a plus or minus factor.

As lateral attenuation could not be turned off in INM the lateral attenuation was determined for a series of positions and different heights of aircraft. These attenuations were added to the NPD curves (i.e. increased the database curves) and by nominating the adjusted NPD curves for circuit work there was agreement with our measurement results.

Clarification was sought from the authors of the INP Handbook (ATAC and Volpe Engineering) in relation to the lateral attenuation issues in the INM that were referred to the FAA with no success.

Table 2 sets out the adjustments to the NPD database to account for low level circuit training for a troop carrying helicopter. Figure 5 compares the original NPD curve with the adjusted curve to make INM 6-1 work for low level circuits.

CONCLUSION

Comparison of field measurements with INM predicted levels for low altitude operations found that the predicted levels were significantly less than the field measurements. Problems with the application of lateral attenuation in the INM for such situation would appear in a layman's sense to be a doubling of the attenuation components.

With the provision of the curves that have been determined, and if one reduces the lateral attenuation component (by adding the lateral attenuation figures to the NPD curves) so as to overcome the excess lateral attenuation for circuit work, agreement with the measurement results can be obtained.

With the corrections identified the INM for helicopter circuit operations and standard NPD curves for normal take off and landing operations one can develop the required ANEF contours. Similarly by having different NPD curves for circuit work to normal landing and take off operations accurate dB(A) and N70 contours are obtained.

If contours using the INM (without the lateral attenuation adjustments in the NPD database) were prepared for low level circuit operations then the contours would appear to underestimate the noise by some 10 or 11 dB. The consequence of planning decisions arising from the introduction of a helicopter fleet to an airport based on the "normal INM" noise contours, and the consequences that may occur from a community educated in terms of their rights about noise exposure, leaves one in a very serious dilemma as to who would be held responsible for what appears to be a problem in the program.

As a result of the author highlighting to the SAE Committee (Cooper 2004) the lateral attenuation issues and the FAA acknowledging the problem, the latest version of INM (V6.2 issued in 2006) now allows the lateral attenuation to be turned off for helicopters and propeller aircraft.

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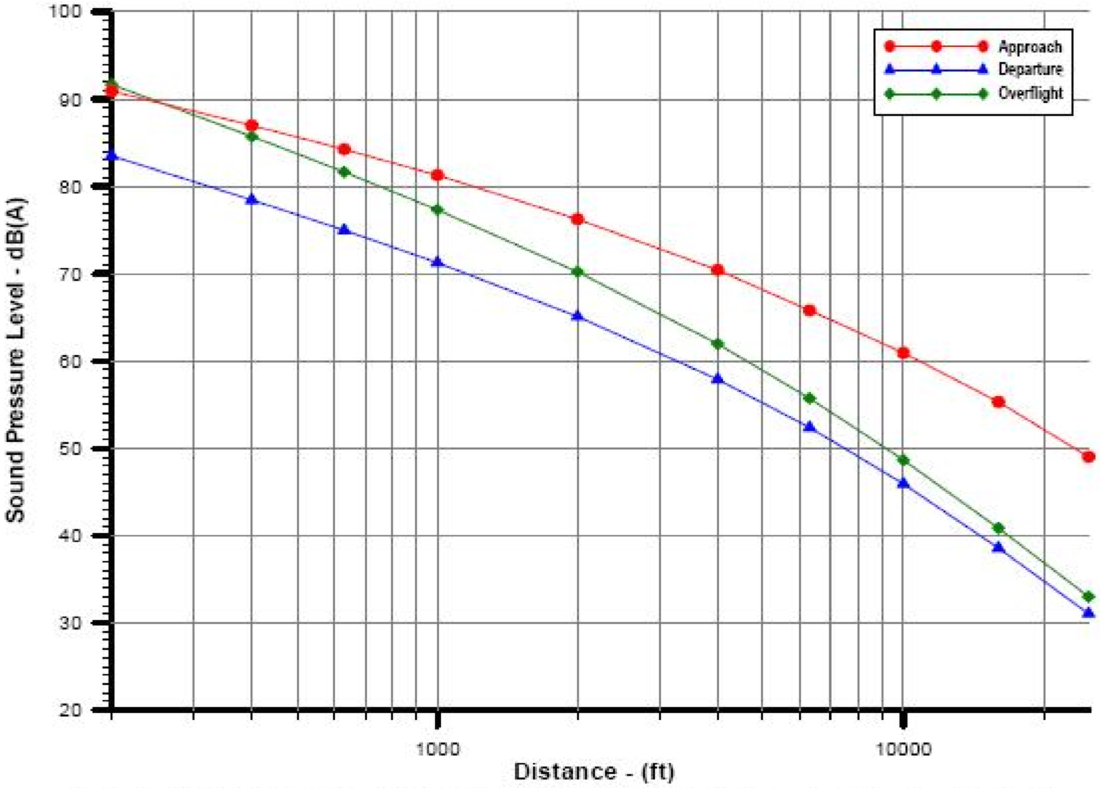

Figure 1. Helicopter Type F (Military Troop Carrying Helicopter) - Max Levels

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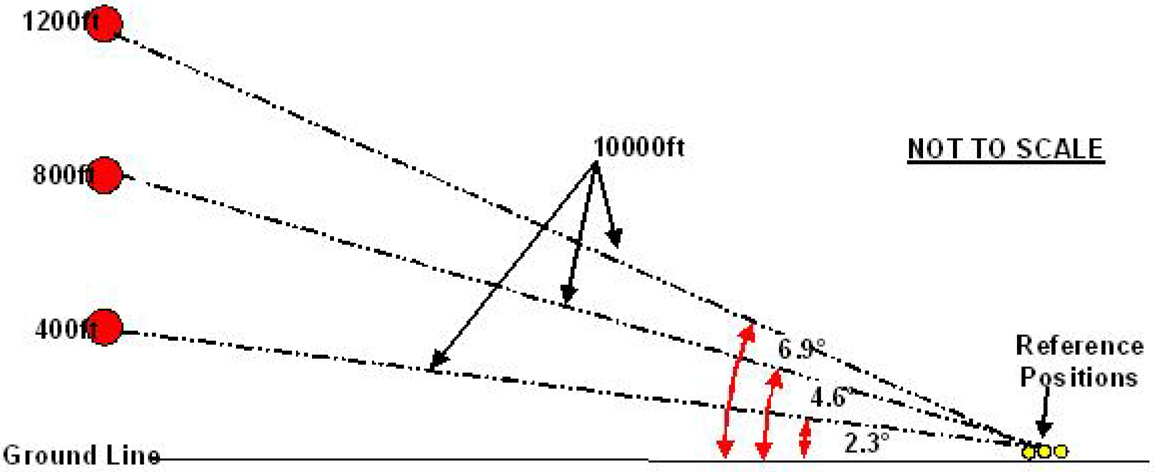
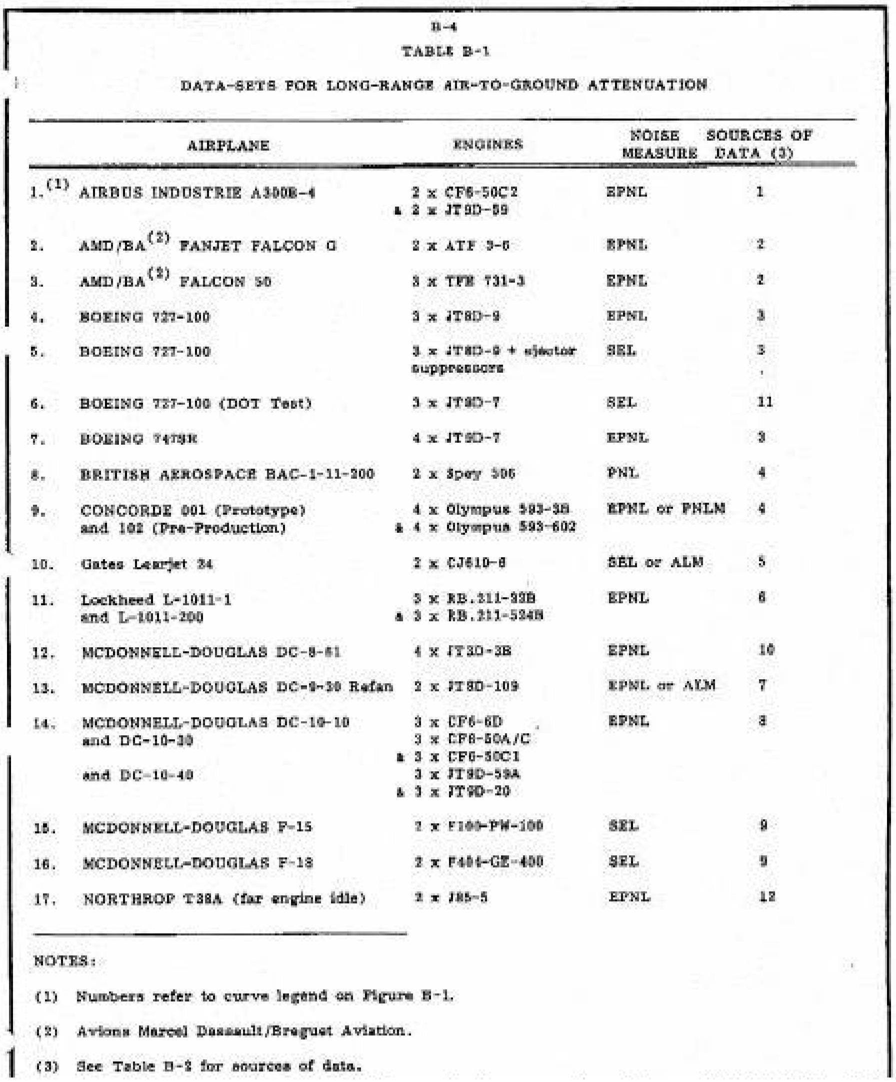


Figure 2. Relative Angles for a Slant Distance of 10000ft



B-4

TABLE B-1

DATA-SETS FOR LONG-RANGE AIR-TO-GROUND ATTENUATION

	AIRPLANE	ENGINES	NOISE MEASURE	SOURCES OF DATA (3)
1.⁽¹⁾	AIRBUS INDUSTRIE A300B-4	2 x CF6-50C2 & 2 x JT9D-59	EPNL	1
2.	AMD/BA⁽²⁾ FANJET FALCON G	2 x ATF 3-6	EPNL	2
3.	AMD/BA⁽²⁾ FALCON 50	3 x TFE 731-3	EPNL	2
4.	BOEING 727-100	3 x JT8D-9	EPNL	3
5.	BOEING 727-100	3 x JT8D-9 + ejector suppressors	SEL	3
6.	BOEING 727-100 (DOT Test)	3 x JT8D-7	SEL	11
7.	BOEING 747SR	4 x JT9D-7	EPNL	3
8.	BRITISH AEROSPACE BAC-1-11-200	2 x Spey 506	PNL	4
9.	CONCORDE 001 (Prototype) and 102 (Pre-Production)	4 x Olympus 593-3B & 4 x Olympus 593-602	EPNL or PNLM	4
10.	Gates Learjet 24	2 x CJ610-6	SEL or ALM	5
11.	Lockheed L-1011-1 and L-1011-200	3 x RB.211-22B & 3 x RB.211-524B	EPNL	6
12.	MCDONNELL-DOUGLAS DC-8-61	4 x JT3D-3B	EPNL	10
13.	MCDONNELL-DOUGLAS DC-9-30 Refan	2 x JT8D-109	EPNL or ALM	7
14.	MCDONNELL-DOUGLAS DC-10-10 and DC-10-30 and DC-10-40	3 x CF6-6D 3 x CF6-50A/C & 3 x CF6-50C1 3 x JT9D-59A & 3 x JT9D-20	EPNL	8
15.	MCDONNELL-DOUGLAS F-15	2 x F100-PW-100	SEL	9
16.	MCDONNELL-DOUGLAS F-18	2 x F404-GE-400	SEL	9
17.	NORTHROP T38A (far engine idle)	2 x J85-5	EPNL	12

NOTES:

(1) Numbers refer to curve legend on Figure B-1.

(2) Avions Marcel Dassault/Breguet Aviation.

(3) See Table B-2 for sources of data.

Figure 3. List of Aircraft for lateral Attenuation Data (SAE AIR 1751, 1986)

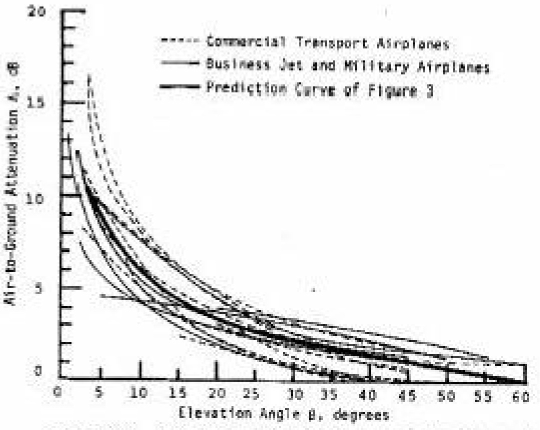


Figure B-2. Prediction curve for long-range air-to-ground attenuation compared with average lateral attenuation curves of Figure B-1.

Figure 4. Lateral Attenuation (SAE AIR 1751, 1986)

Table 2. NPD Curves for Normal Operations and Circuit Work

TROOP HELICOPTER		Slant Distance (ft)									
		200	400	630	1000	2000	4000	6300	10000	16000	25000
MAX - dB(A)	**Departure**	83.5	78.4	75.0	71.3	65.1	57.9	52.4	45.9	38.6	31.1
	Departure (2)	83.5	78.4	75.5	72.9	69.7	66.1	62.1	57.0	50.6	43.6
	Approach	90.9	87.0	84.2	81.3	76.2	70.4	65.8	60.9	55.3	49.0
	Approach (2)	90.9	87.0	84.7	82.9	80.9	78.6	75.6	72.0	67.3	61.6
	Overflight 65%	91.6	85.7	81.6	77.3	70.2	62.0	55.7	48.6	40.8	33.0
	Overflight (2) 65%	91.6	85.7	82.1	78.9	74.9	70.1	65.5	59.7	52.8	45.6
PNLTM - dB	**Departure**	98.4	93.6	90.2	85.9	78.9	69.9	63.7	57.3	50.2	42.0
	Departure (2)	98.4	93.6	90.7	87.5	83.6	78.1	73.5	68.4	62.2	54.6
	Approach	105.4	101.7	98.7	95.3	90.0	83.8	78.8	73.2	67.0	60.1
	Approach (2)	105.4	101.7	99.2	97.0	94.6	92.0	88.5	84.2	79.0	72.7
	Overflight 65%	103.5	97.5	93.3	88.9	82.1	73.9	68.1	61.4	53.7	44.9
	Overflight (2) 65%	103.5	97.5	93.8	90.5	86.7	82.1	77.9	72.5	65.6	57.5

(2) Indicates circuit height 120 metres AGL

Source (Cooper 2004)

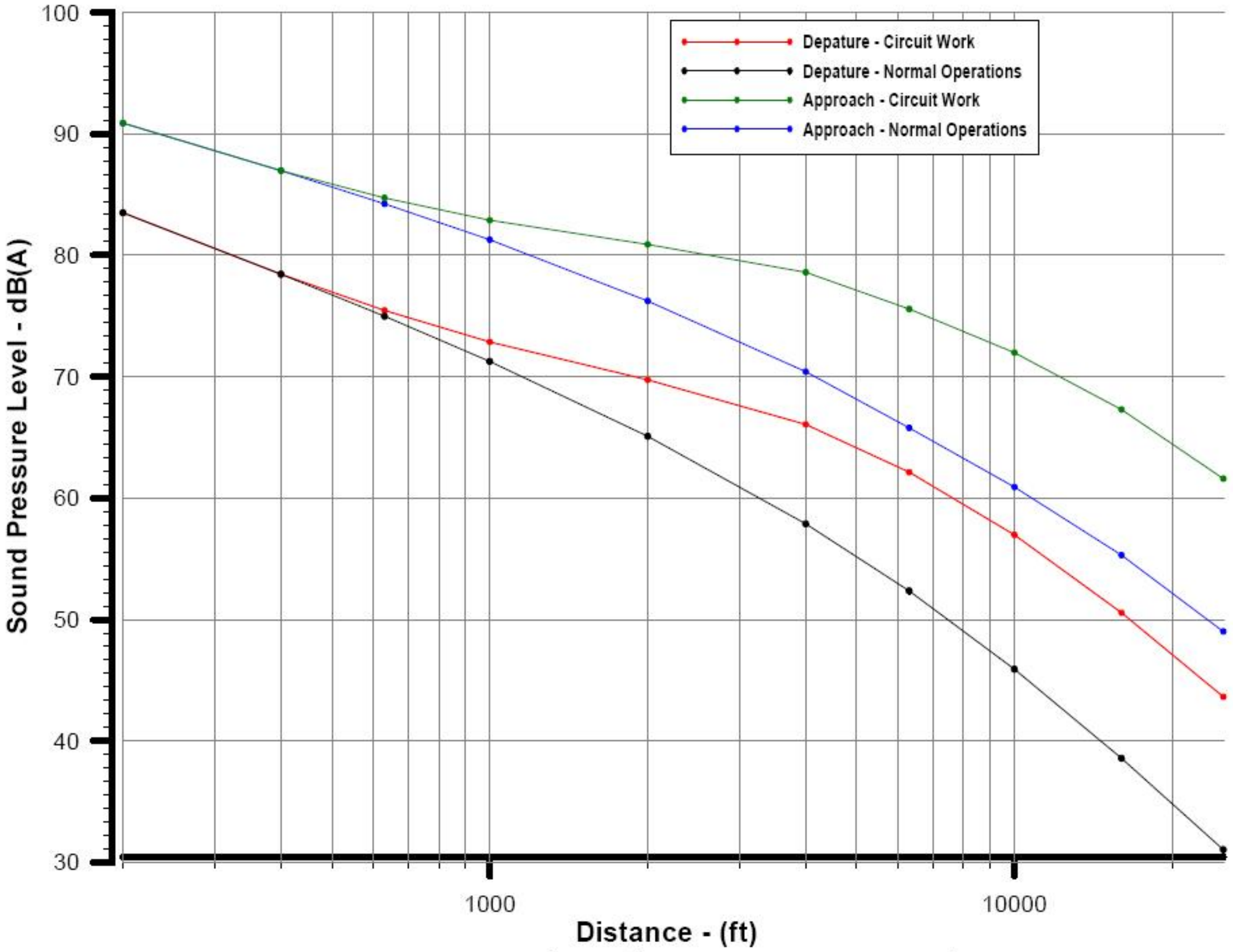


Figure 5. Troop Carrying Helicopter – NPD Max Level