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INM Getting it to work Acoustically

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ABSTRACT

In Australia persons preparing aircraft noise impacts utilising the INM are not normally acoustically trained. Therefore they do not necessarily know what the output means noisewise. It is up to the acoustician to train the INM programmers. Over the last ten years the author has had to get INM to agree with actual measurements thereby overcoming the failings of INM. This paper looks at the various modifications to the NPD dataset that have been required to get INM to work. What about ANM, will it work or is it too expensive?

In Australia aircraft noise exposure around an aerodrome is expressed in terms of ANEF (Australian Noise Exposure) contours depicting an average daily noise exposure [1]. The basis of determining the noise exposure is to consider all aircraft operations in a year divided by the number of operating days.

In Australia the ANEF system utilises a + 6 dB weighting factor for operations during the period of 7pm to 7am and the fundamental acoustic parameter utilised in the assessment procedure is the Effective Perceived Noise Level (EPNL).

From initial work some eight years ago that highlighted issues in terms of the INM [2] we found INM it is not absolutely accurate. We have been given the opportunity of conducting additional testing on various aircraft for calibration against INM, and as such have found a number of issues of concern that are not identified in the INM handbook [3].

All of our investigation work into INM has been related to military operations and because the Australian Department of Defence is looking for accurate information in terms of existing operations and future operations we have been afforded the opportunity of conducting controlled testing of various different aircraft with both line pilots and test pilots and with differential GPS tracking used in such testing [4, 5 & 6].

We have also undertaken assessments with respect to civilian operations and have been conscious of anomalies identified in studies concerning Sydney Airport [7] of which some of our work has been of assistance in resolving one issue.

A number of papers have been issued previously identifying the various INM anomalies specifically associated with helicopters [8, 9 & 10] and general INM anomalies [11, 12, 13 & 14].

The INM issues that require clarification are:

- Lateral attenuation.
- NPD measurements
- NPD crossovers
- temperature/relative humidity absorption coefficients
- average maximum levels.

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

Our early work in terms of considering helicopter operations (for a flight deck trainer relocation) found noise measurements recorded in the field did not agree with the INM predictions.

The INM indicated that doubling the height of a helicopter overflight in a test case resulted in an increase in noise level which defies logic both in terms of measurement and the physical environment.

Having convinced the INM programer that the model had a mistake, further investigations into the algorithms in the program revealed that lateral attenuation was influencing the results, due to the relatively low angle between the flight track and the ground at the receiver point for the first scenario versus the higher altitude lateral attenuation became zero.

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) [15] 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:
>
> $G = 15.09(1 - \exp(-0.00274\ D))$ $0 <= D <= 914$ m
> $G = 13.86$ $D > 914$ 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:
>
> $L = (G/13.86)\ (3.96 - 0.066\ \beta + 9.9\ \exp(-0.13\ \beta))$ $0 <= \beta <= 60$
> $L = 0.0$ $60 < \beta <= 90$
>
> Where L is the total lateral attenuation (dB), and β is the elevation angle to the airplane (degrees)."

Figure 1 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.

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

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

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 [16] that determined ground loss attenuation by use of test engines located relatively close to the ground and aircraft that have engines mounted in the body of the aircraft. Furthermore, it can be seen from the lateral attenuation graph (Figure 2) from AIR 1751, 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.

We trick INM for circuit work by creating a NPD data set with lateral attenuation added back in for set circuit heights.

In 2004 the author presented the above material to the US Aircraft Standards Committee [8] and some two years later INM incorporated a switch to turn off lateral attenuation for helicopters and propeller aircraft.

However lateral attenuation was not turned off for jet aircraft and therefore the anomalies still exist for fixed wing jet aircraft.

A study in relation to Sydney Airport for residential receivers well outside the 20 ANEF zone [7] found that predicted noise levels from INM agreed with measured levels whilst under the flight track, but that at positions to the side (where there was still a relatively low angle from the track to the ground) INM under predicted the noise levels by some 10 dB.

Therefore, be aware in compliance tests of the angle to the flight path.

NPD MEASUREMENTS

Following a lateral attenuation investigation we were requested to provide NPD curves for helicopter operations so that an ANEF contour map could be produced in relation to a naval airfield. INM contains NPD data in relation to the A-weighted results but not the EPNL results that are required for an ANEF.

There is no material set out in the INM handbook or ICAO Annex 16 [17] to identify the measurement procedures for an NPD curve. Accordingly we set about conducting testing utilising microphone locations under the centre line to encompass the standard NPD reference locations between reference slant distances of between 200ft and 2,500ft.

The field measurement results for the first three helicopter types tested did not concur with the dB(A) NPD curves indicated in INM and the regression lines indicated different slopes for slant distances below a 1,000ft versus distances above 2,000ft.

Our methodology for deriving the NPD curves is attached as Table 2 and indicates that it is not a simple matter of standing underneath an aircraft overflight to determine such curves.

It became apparent at the aforementioned US Aircraft Standards Noise Committee that NPD curves had not been calibrated or checked in the US and that in the main the curves were derived from measurements of a helicopter 500ft above the microphone location for a landing/takeoff or overflight, or 1,000ft for fixed wing aircraft from which the curves were derived on a theoretical basis.

Testing on another three different helicopter types (used by the Army) found similar anomalies.

NPD CROSSOVERS

The INM has a range of NPD curves for various operations. In relation to military aircraft they are derived from the Omega 10 output file of NoiseMap [19].

You may not have the full range of power settings for an aircraft being used. INM has limitation as to extrapolating data outside the supplied NPD curves.

If you derive your own NPD curves for an INM exercise and seek to just scale down (or up) the power settings then make the curves the same. However there can be changes in the rate of decay of the curve for different power settings when the spectra change.

INM nominates a standard 160knot speed for the aircraft and says the maximum level doesn’t change. However that is not the case. For example using a military helicopter (S76) we find that at 108 knots versus 150 knots the tail rotor high frequency changes dramatically. The NPD curves have a different shape. If you group the relevant curves (of the same parameter) together they can cross over.

Sometimes NPD data can be expressed as Departure for various power settings and then separate data for cruise and endurance flights. If the data for different modes are all added together and placed say as Departure curves they can cross over.

Beware of cross overs.

When NPD curves in the same set cross over INM crashes!

ATMOSPHERIC ATTENUATION

Field measurements in terms of aircraft operations where there is a significant distance between the aircraft and the receiver location have negligible high frequency noise components. The ICAO Annex 16 sets out attenuation coefficients in dB per 100m for various ranges of temperature and relative humidity. For frequencies above 1,000 Hz atmospheric attenuation plays an important part in terms of the noise level determined at the receiver locations, whilst for frequencies above 5,000 Hz atmospheric attenuation by way of the tables is significantly greater than distance attenuation due to spherical radiation.

Field measurements of helicopters have indicated spectral information received at ground level for the higher frequencies to be significantly different than that recorded at smaller slant distances.

We formed the view that there may very well be an issue in terms of the atmospheric absorption coefficients and that whilst there have been various studies to look at different absorption ratios between various standards, the methodology was basically using again a theoretical approach and looking at the differences that prediction models would attain by use of different sets of absorption coefficients.

In industrial noise assessments one is used to measuring or utilising sound power calculations and then determining the resultant contribution at residential areas. When one is dealing with a significant sound power source that can occur on industrial premises we have found from our experience that high frequency levels tend to be higher at receiver locations than predicted by computer models and general textbooks.

If one considered an aircraft generating a constant noise level and had the opportunity to keep that aircraft producing such level on a takeoff up to say 20,000ft then on working backwards from the spectrum recorded at ground level (knowing the relative humidity and temperature at the time) one could determine whether the atmospheric attenuation tables were relatively accurate or not.

The use of a twin engine military fighter jet was the subject of NPD testing at a remote location in one of our deserts that permitted microphones to be located out to 12 nautical miles from the start of roll. Testing conducted with the aircraft on the ground at full power level resulted from measurements 200m behind and to the side of the aircraft (see Figure 3) a nominal sound power level of 174 dB(A).

As the ambient background level in the field without the aircraft was in the order of 25 dB(A) it comes at no surprise that at every monitoring location all personnel could hear when the aircraft having obtained 20,000ft turned the afterburners off.

On reverse engineering the ground level measurements to a sound power source we found that for measurements with the slant distance in the order of 500 to 1,000ft there was agreement with a constant sound power level, but for the 15,000ft slant distance the sound power level of the same aircraft was more than 500 dB(A) – see Figure 4.

When faced with the issue of significantly less attenuation than predicted, the original source information upon which the standard formulas and text books utilise for atmospheric attenuation is Harris [18]. That work occurred some time ago where the attenuation/100metres was a theoretical conclusion, not measurements in a laboratory having dimensions in the order of 300 or 400 metres. The measurement procedure did not have actual measurement data for the distancesup to 100 metres. The attenuation coefficients expressed in terms of attenuation per 100 metres under different temperature and relative humidity were obtained from experimental work utilising a stainless steel spherical chamber of 1.9 metres diameter.

Testing of a new military helicopter conducted in the desert location for the purpose of adding it to the NPD database utilised a similar concept in terms of overflights at different heights (much less than 20000ft agl) under different weather conditions to the twin engine military jet to reveal similar issues of concern.

Utilising the measurement data for the specific testing of a sound power versus measured levels for aircraft at different heights suggested that the equations should have been more of a power curve that would be frequency dependent, by comparing the measured results with the theoretical attenuation coefficients – see figures 5 & 6.

In a general sense the frequency anomaly would be relatively small when dealing with dB(A) parameters but if one is seeking to conduct validation of aircraft noise exposures in terms of the NPD dataset then this issue becomes of importance in that one is assessing the EPNL results to derive an ANEF of which the frequency component of the aircraft noise spectrum plays a significant part of the resultant noise level.

AVERAGE MAXIMUM NOISE LEVELS

The methodology used in Australia for assessing noise control as a result of aircraft noise intrusion is to utilise the arithmetic average of the maximum noise level generated by an aircraft type in the process of an overflight or a takeoff or a landing [1]. For a building site one considers the maximum noise level allocated to each of the different aircraft types under their operating scenario and then to utilise the maximum of those levels.

INM can produce a maximum noise level contour from the input data used to develop an ANEF but that does not represent a representative aircraft type or the arithmetic average of such aircraft.

An international or major domestic airport will have many flights per day and therefore utilise standard flight tracks it is relatively easy to determine the average maximum level both from INM and physical measurements.

However for military operations one can experience high noise levels for relatively few flights. There can also be multiple tracks and different types of procedures into an aerodrome, and circuit training. Hence the derivation of the highest average maximum level for military aerodromes is much different to normal domestic/international aerodromes where one is used to just take offs and landings.

For example military jets utilise an initial and pitch procedure that can bring groups of aircraft in over the airfield for example say the control tower and then peel off one at a time into the crosswind leg to then join the downwind leg and line up for landing with appropriate separation distances. This operation is clearly different to a straight in approach either as a visual approach or an ILS approach.

Accordingly in considering a military airport operation we have utilised INM to identify all of the individual flight tracks/operations that are determined on the daily average basis, to then take the number of flights (greater than 0.5 per day on a specific flight track/profile) and then to group all of those flight track combinations to derive the arithmetic average level for that mode.

By definition the average level for a mode should have some movements generating a higher noise level than movements generating a lower noise level.

Following the derivation of the average maximum level for each mode one then determines the highest average maximum level for all modes at the relevant site.

Therefore the occasional aircraft type which is not a regular user of the airport on a daily basis is excluded by that methodology, whereas the default matter of maximum noise levels generated in INM would not exclude that aircraft.

ANM

INM has a few problems. Some of the issues described above are coming to the surface. What happens when communities find the noise plans use for planning purposes are based on inaccurate noise predictions?

Australia is a bit more critical than the US in relation to aircraft noise limits, as our acceptable noise limits for residential use are lower (US Ldn 65 versus Australia' ANEF20 that approximates Ldn 55).

The US Department of Defence does not use INM they use NoiseMap and claim it is more accurate. However there is little validation of that system either.

It is anticipated that within two years INM will be discontinued and replaced by a three dimensional noise source model. The first 3d prediction model appeared for helicopters more than 12 years ago and various groups in the US are working on obtaining datasets for rotary and fixed wing aircraft.

However there is one very significant issue with the Aircraft Noise Model – the cost of obtaining the source data.

The method utilises flying aircraft between two towers (cranes) that have microphones located 300ft above the ground, as well as standard ICAO tpre testing locations. To change over from INM requires a massive amount of testing or some form of yet undetermined conversion.

CONCLUSION

When some eight years ago we started to investigate or validate INM material with respect to aircraft operations at Defence aerodromes it was apparent that most of the persons involved in preparing INM contours, whilst being appropriately and/or highly competent in operating the model, did not necessarily have acoustic training to understand or comprehend the outputs of their work.

Just as we have had the benefit of their expertise in running and/or modifying INM to agree with acoustic measurements they too have had the benefit of input from acousticians to assist in modelling defence aerodromes.

As a result of this interaction and identifying the need for verification, noise and flight path monitoring systems have been or are being established at military aerodromes around Australia as discussed in another paper.

The reader should be aware that INM is not perfect and one needs to utilise the knowledge of acousticians experienced in aircraft assessments as an adjunct to the preparation of INM.

The anomalies set out above appear at the present time to represent the significant acoustic deficiencies that has been found as a result of the validation process required for military aerodromes.

The author acknowledges permission from the Australian Department of Defence to refer to previous studies and acknowledge the assistance of Mr E Wegner from the Department of Defence, Mr G Moss and Mr K Lin from GHD, and staff at the Acoustic Group that have significantly contributed in the investigations leading to the above material.

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19 “NoiseMap”, Version 7.353, Wasmer Consulting, Florida

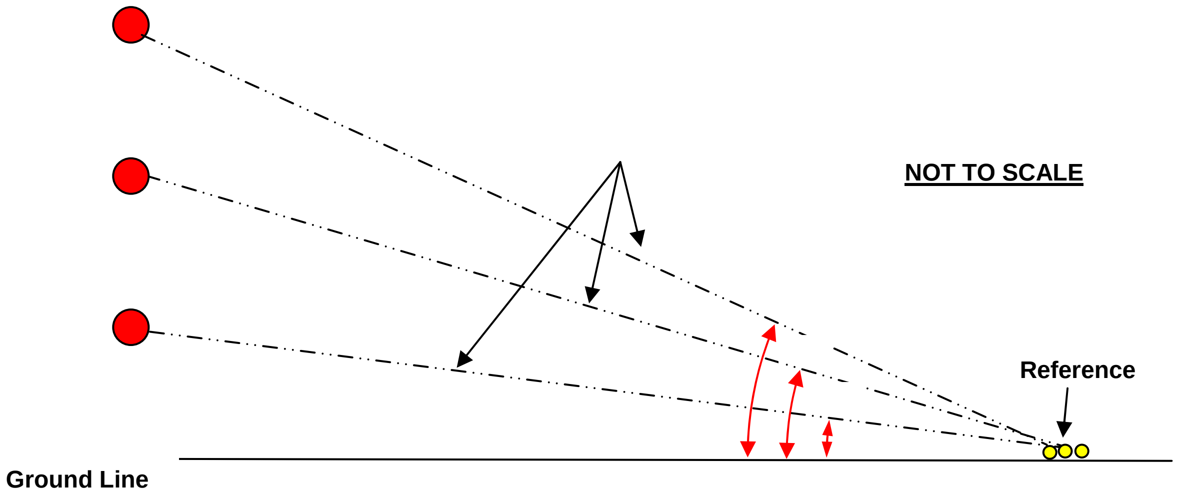

Figure 1. Relative Angles for a Slant Distance of 10000ft

TABLE 2: dB(A) NPD ANALYSIS PROCEDURE
1 - Cull DGPS data to 0.5 second intervals
2 - Convert DGPS data to origin point
3 - Convert DGPS data relative to each monitoring location
4 - Correct Noise Data with ambient
5 - Sync Noise Data with DGPS
6 - Correct for no atmospheric attenuation
7 - Recalculate dB(A) levels
8 - Line of fit through points
9 - Using an average maximum time splice calculate the atmospheric correction to further distances
10 -minus correction off line fit data

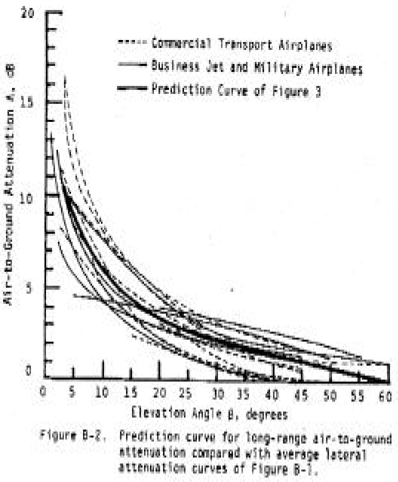

Figure 2: Lateral Attenuation (SAE AIR 1751, 1986)

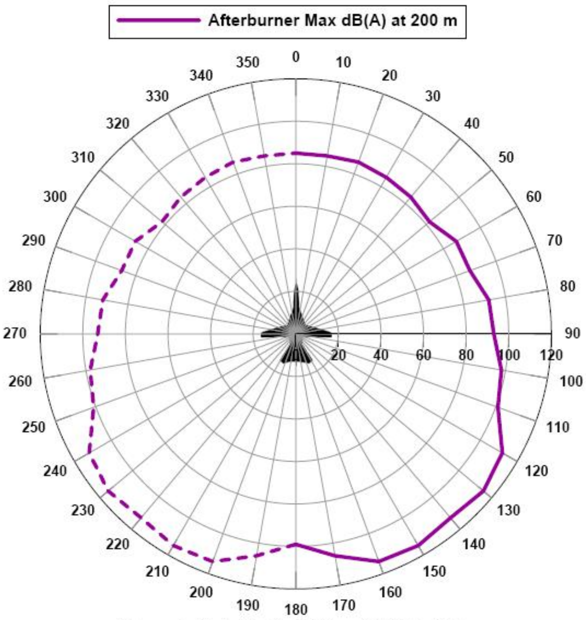

Figure 3. Twin Engine Military Jet Polar Plot

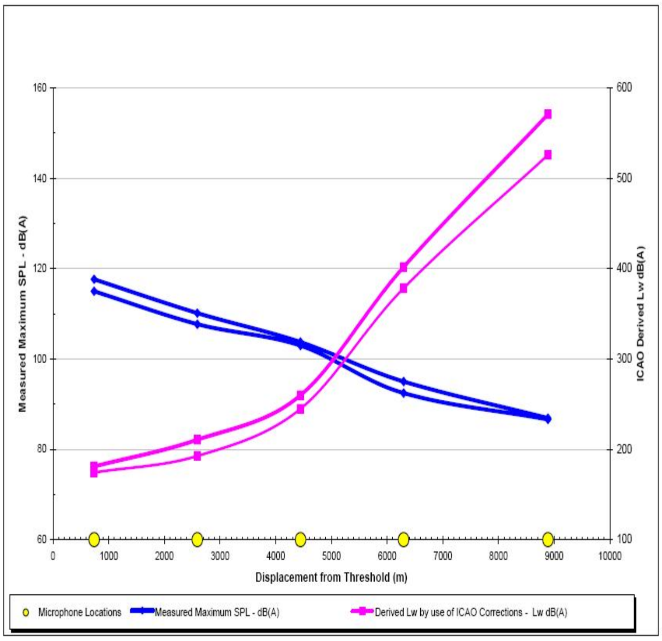

Figure 4. Twin Engine Military Jet – Departure with Afterburners

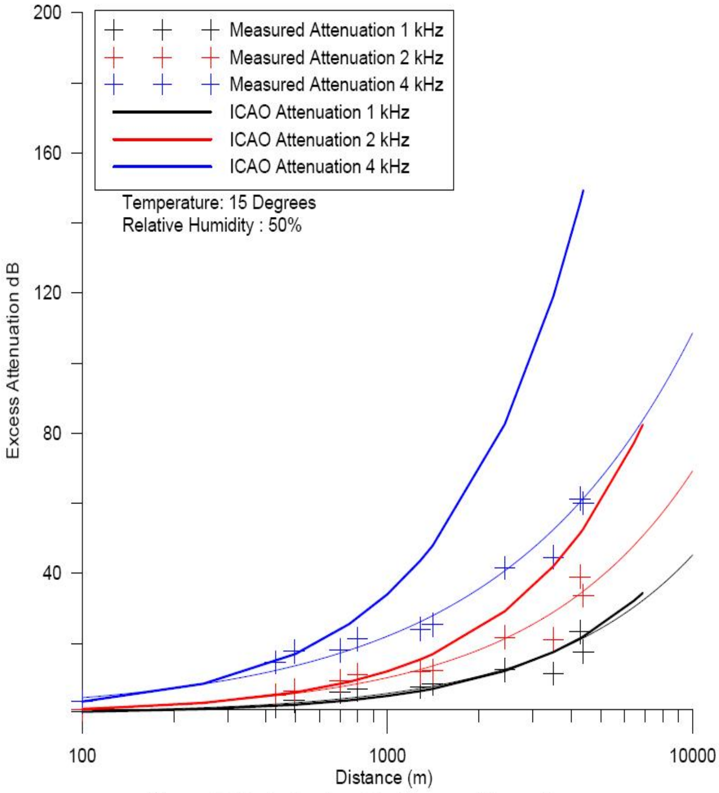

Figure 5. Twin Engine Jet - Excess Attenuation

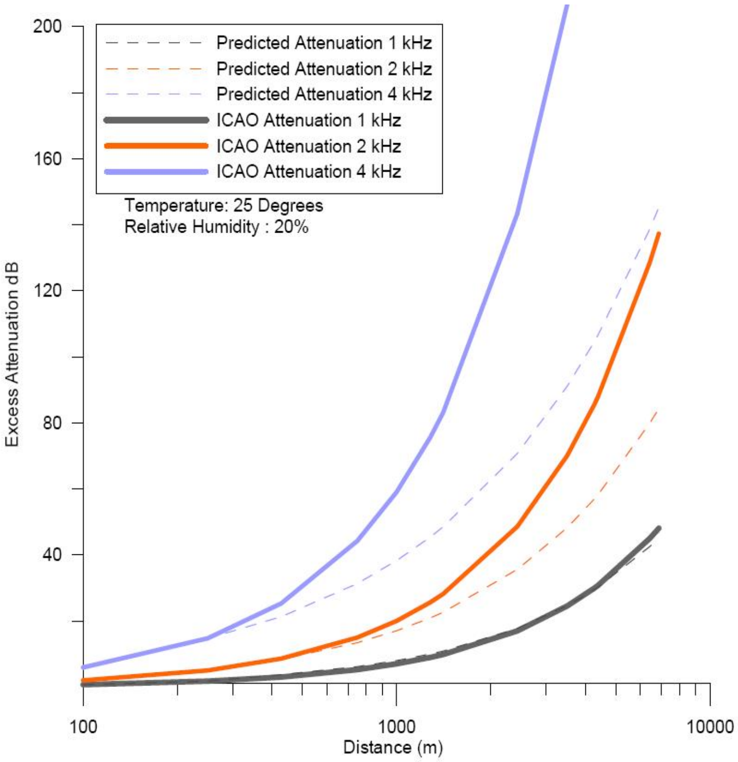

Figure 6. Helicopter - Excess Attenuation