Problems with the INM: Part 3 – Derivation of NPD Curves

Steven Cooper, Steven

The Acoustic Group, Sydney, Australia

ABSTRACT

The standard procedure used in the US for derivation of aircraft noise power distance (NPD) curves is to conduct a measurement at one position and extrapolate those results by general acoustic formula with corrections for atmospheric attenuation at standard atmospheres. Initial work undertaken for helicopters operating from military bases in Australia found different rates of attenuation for slant distances less than 1,000ft versus that for slant distances greater than 2,000ft. The position of the aircraft when creating the maximum level at a receiver location is not physically at the slant distance used on an NPD curve for that same position. SAE/FAA procedures for conducting/calibrating NPD curves from field measurements do not exist and from FAA advice, no such work has been carried out. Examination of military jet aircraft and military helicopter operations in Australia, with DGPS positioning and atmospheric attenuation corrections identified in the previous papers has resolved this issue. The NPD derivation investigations are discussed.

INM & NPD CURVES

The Integrated Noise Model ("INM") is a computer program used throughout the world for producing noise exposure contours around an airport. To generate an INM contour it is necessary to identify the aircraft types to be operating at the subject airport, the flight tracks and power settings of aircraft utilising those tracks, the direction of aircraft operations (along such flight paths), and the number of movements.

The INM database (inside the program) incorporates various aircraft descriptors with different types of engines that are in service and a set of noise data curves that show for the various operating modes of take-off, landing and overflights, the noise received from the relevant aircraft under different thrust (power) settings for standardised receiver distances (locations on the ground) (Figure 1). These noise data curves are described as Noise Power Distance (NPD) curves. The NPD curves can be in dB(A) maximum level, dB(A) SEL, PNLTM and EPNL units.

If the NPD curves are not right then the output of INM cannot be right.

INM also includes a database of 70 odd spectral classes representing average noise spectra for groups of aircraft, which is not an area The Acoustic Group (TAG) has examined in great detail. However, from the limited field measurements conducted by TAG a number of spectral groupings for helicopters would appear to have the wrong spectral classification.

For working out dB(A) contours INM only requires either the dB(A) maximum level or the SEL NPD values by way of an empirical relationship (INM Handbook (V6) Section 8.3.3) between the maximum level and the time dependent level.

$$LAMAX = SEL - 7.19 - 7.73 \log\{ D / 1000\} \qquad (1)$$

Where D is in feet

Similarly, the ANEF contours can be derived from either PNLTM or EPNL NPD curves by the relationship of:

$$PNLTM = EPNL + 1.12 - 9.34 \log \{ D / 1000\} \qquad (2)$$

INM cannot derive ANEF contours from dB(A) data.

DEVELOPING NPD CURVES

Examination of the curves in typical NPD graphs shows that, as the distance from the aircraft increases then the resultant noise level decreases. As the distance from the aircraft of the receiver increases there is also additional attenuation as a result of atmospheric attenuation.

On a conceptual basis, there is no issue with attenuation over large distances for the maximum dB(A) level or PNLTM, although dependent upon the spectral characteristics, different rates of attenuation for different aircraft could be expected.

The time dependent component of an NPD curve (SEL and EPNL) from equations 1 and 2 indicates a relationship to the maximum noise level can be validated from the synthesis of a triangular waveform representing the noise level over time.

The generalised concept contained in SAE AIR 1989 utilises the dB(A) measurement of the aircraft at one receiver position. By deducting the atmospheric and distance attenuation component, one can obtain a base maximum sound level at source. Extrapolation of the maximum level results by 6dB per doubling of distance for the required receiver location is subject to the nominated atmospheric corrections to obtain a maximum level at the relevant NPD point. The maximum level with the above formulae can be used to derive the time dependent value for each NPD reference position.

As a result of TAG's engagement in the development of the NPD curves that work in INM to produce ANEF contours for the Defence airfields with a significant helicopter component, extensive communication between the authors of the INM Handbook, the program developers and members of the US aircraft noise committee has taken place. The NPD development work has progressed over the last few years that permit the Author to provide a greater insight into how NPD curves can be developed.

Our Early Work

TAG's early work on NPD curves for Defence involved the testing of helicopters. The speed of such aircraft is relatively slow (when compared with fighter jets). The vertical distance from the helicopter to the receiver was less than 3,000ft. Therefore, the matter of atmospheric attenuation as identified in the previous paper (*Problems with the INM: Part 2*), was not significant with respect to the measured results, but was an issue with respect to the extrapolation of the data to greater distances.

Initially, there was difficulty in finding a procedure for development of an NPD curve from field measurements. The FAA provided advice which did not accord with SAE documentation and in some cases considered a theoretical derivation of the NPD curves based on different thrust settings. But this procedure did not apply in a practical sense for helicopter operations where the variation in noise is not related directly to thrust but to the pitch of the blades, the rate of descent/ascent, and the air speed of the helicopter. SAE AIR1989 nominates generalised equations for SEL and A-weighted maximum values from helicopter parameters but does not consider PNLTM or EPNL values.

Most NPD curves for helicopters that were available were in dB(A) values and very little information was available in PNLTM or EPNL data. What helicopter information was available appeared to be related to certification testing which represents an entirely different scenario to normal operations that would apply at an operating aerodrome.

On being given the task of generating helicopter NPD curves the assessment found a number of critical components had to be satisfied.

Firstly it was essential to obtain the services of a highly qualified pilot who could fly consistent flight tracks, the same profile and utilise the same power settings. In the end the only way to obtain consistent results was to have the use of military test pilots who satisfy all those requirements and would consistently fly whatever tracks or profiles were requested. If you want to conduct NPD testing you have to have the highest possible calibre of pilot or otherwise you are wasting your time.

Secondly it was necessary to determine the position of the aircraft in 0.5 second increments and synchronise the noise measurements with the aircraft position. Ultimately a Digital Global Positioning System (DGPS) measurement procedure was used by hiring satellite time to synchronise additional satellites with the DGPS receivers that were time aligned with the multitrack tape recorder. The testing required availability of an operational military base for an entire day. Nearly 2000 metres of microphone and preamplifier cabling to a central recording system was used, in addition to remote recording systems.

The processing of the data was extensive because it required the determination of the position of the aircraft every 0.5 second and to relate that to the 1/3 octave spectrum for each microphone location for the relevant 0.5 second interval.

When that processing was complete the attenuation attributed to the atmospheric conditions prevailing at the time of test were subtracted from the measured data and the results were adjusted to normalised standard atmospheric conditions. It was then necessary to determine regression line analysis for the measurement data without atmospheric attenuation components to permit an extension of the NPD curve to the outer standardised distances which could not be measured using the subject helicopters.

A theoretical exercise of utilising an over-flight at 150 metres and the standard calculations from SAE AIR 1989 could not agree with the measurement results. For the helicopter testing (six helicopter types) different rates of attenuation were observed on the regression lines for slant distances less then 300 metres, when compared with slant distances greater than 600 metres (Figure 2).

In the course of comparing predicted versus measured results the issue of lateral attenuation was identified as discussed in the first paper *(Problems with INM: Part 1)*. At the SAE A12 Helicopter Noise Working Group meeting in March 2004 the Author set out the basis of how NPD curves were derived from field measurements with the paper concentrating on the discrepancy associated with lateral attenuation. Discussions which followed the meeting revealed that the general trend in the US was to conduct measurements of helicopters in their relevant operating mode 500 feet above microphones and extrapolate the results on the basis of 6 dB per doubling of the distance and ICAO atmospheric corrections to derive the resultant NPD curve. The discussions revealed that so far as the committee member were aware no validation exercises had been carried out in the US on helicopter NPD curves at the various normalised distances. Therefore no checking of the assumed 6dB per doubling of the regression lines had occurred as there were no test programs for validation of NPD curves.

Some members of the working group indicated interest in the investigations. General agreement was obtained that the lateral attenuation could give rise to excessive absorption and the FAA representative confirmed that the lateral attenuation algorithms were incorrect for helicopters. The latest version of INM (issued in 2006) permits switching lateral attenuation off.

The NPD maximum level assessment at that point in time (2004) could be described as:

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 temperature and relative humidity
5. Synchronise Noise Data with DGPS
6. Correct for no atmospheric attenuation
7. Recalculate dB(A) levels
8. Line of fit through points
9. Using a maximum time splice to calculate the atmospheric correction to further distances
10. Minus atmospheric correction off line fit data

Should only the L_A maximum level be required, then the theoretical development of regression analysis is relatively simple provided the same power settings of the aircraft under test are maintained.

Consideration of the time weighted acoustic indices for INM or an N70 does present some difficulty in extrapolation of the data out to the greater slant distances. Obviously whilst the maximum noise level reduces for greater distances, the time period increases and therefore can dramatically affect the calculated SEL/EPNL results.

Field measurements of helicopter operations have consistently revealed a build up and decay of the time signal with different frequency spectrum at different parts of the overflight. Therefore, an equilateral triangle for the time signal, as assumed in the INM handbook, may not necessarily be achieved.

Figure 3 and Figure 5 show the flight profile with the dB(A) and PNLTM levels recorded at a monitoring microphone for helicopter type 5. In all examples the maximum dB(A) and the PNLTM occur at the same point in time, although for the 200ft and 1,000ft overflights the maximum level occurs after the helicopter has passed the microphone location.

On each of the overflight graphs in Figure 3 and Figure 5 are shown four points relative to the microphone locations which correspond to the 1/3 octave band spectra shown in Figure 4 and Figure 6. The spectra, before and after the microphone, are significantly different. Due to the different spectral characteristics, it could be audibly determined if the helicopter was approaching to the receiver or departing from the receiver.

Another issue for helicopters is that NPD curves used in INM are normally represented by a series of thrust (or power) settings. This concept does not actually work with helicopters, particularly when the speed is increased. At higher speeds the tail rotor becomes a dominant noise source that increases the level of high frequency emission. On plotting two different speeds of an overflight for helicopter type 5 on an NPD graph, due to the increase in the high frequency components for the greater speed the curves can cross over (Figure 6). When NPD curves in the same mode cross over in INM the program output is meaningless.

At the AHS Helicopter Noise Workshop (Cooper June, 2005) the preliminary findings on the atmospheric attenuation (based on helicopter tests) was presented, with discussion of different concepts for developing NPD curves that had been investigated. Further testing with a high speed military jet (see previous paper, *Problems with INM: Part 2*) and a fourth generation helicopter has provided further avenues for evaluating the suggested NPD concept.

Jet Aircraft NPD Measurements

For this exercise testing was first conducted at a Defence airfield in Queensland but experienced problems with ambient noise and interference from other aircraft operating in the immediate area.

Testing was then conducted at a different Defence airfield with a low ambient noise level. The new site offered miles of open area, therefore permitting test positions up to 12 nautical miles from the far end of the runway and a flight program specifically designed for the test.

Due to operational priorities the test pilot originally tasked for the job was cancelled at the last minute. A less experienced line pilot was provided. Not all the proposed test flights were flowing precisely, however, the essential flights/profiles were achieved with a few minor variations between test runs as shown in the flight profiles in Figure 7.

Aircraft operating at higher speeds than helicopters introduce a few more interesting factors in deriving NPD curves and consequently, more data processing. This work has required a re-evaluation of the previous processing procedures outlined earlier in this paper.

Figure 3 and Figure 5 show that the maximum noise level of a relatively slow helicopter over-flight does not occur directly over the monitoring microphone. When the speed of the aircraft is increased, this discrepancy becomes even larger. To provide accurate positioning of the aircraft, a sampling rate quicker than 0.5 seconds for the DGPS would be required, particularly in the case of a military jet with a speed in excess of 400 knots.

To further complicate the matter, the speed of the aircraft, if faster than the speed of sound, must be taken into account to determine the "real" position of the aircraft considering the time it takes for the sound to travel from the source to the receiver versus where the aircraft was at the time the sound was received at the microphone. Such testing is a little bit more challenging than testing a Cessna 152 training aircraft.

Figure 7 shows the difference in assessment locations of the maximum noise level to two receiver points for a high-speed overflight with the aircraft on maximum power. Figure 8 shows the critical NPD curve for this aircraft. Such operations generate the maximum noise impact.

In dealing with an NPD curve that is utilised in INM, the assessment point is expressed in terms of the slant distance which, in Figure 7, is significantly less than the actual distance at which the maximum level occurs. Therefore, in determining the corrections for atmospheric attenuation, the actual distance of the aircraft to the receiver for the normalisation process of the maximum level needs to be utilised. This distance is greater than the nominal "slant distance" used in the INM calculations.

For the time dependent parameters:

1. identify the individual ⅓ octave spectra in time,
2. determine the actual position of the aircraft to the receiver location,
3. perform the various adjustment/corrections to obtain standard atmospheres,
4. recalculate the resultant noise level over time at the relevant ground position to derive the NPD value for that location.

This exercise occurred for multiple flights for normal takeoffs (afterburner to a certain height), landings, flyovers (at different heights) and take-offs with full afterburner up to 18000ft. The analysis occurred over a few months. Then one has to go back to the DGPS data and construct the flight profiles, determine the speed of the aircraft and the power settings of the aircraft (also obtained by the DGPS tracking pod mounted on the aircraft) to provide the INM flight profile input files for validation purposes.

An INM was constructed for the test flight procedures and then refined as the test flights were a bit different to normal airport operations (our testing had displaced take-off and "landing points" that was different to INM's normal procedure) in that the aircraft never actually landed on the runway but utilised ICAO certification procedures using intersections of profiles.

With the atmospheric attenuation corrections discussed in the previous paper (*Problems with INM: Part 2*) and multiple INM runs to provide a model to agree with the testing, NPD curves were obtained that agreed with the measurement results under the flight path. The measurements and the analysis procedure outlined above does not accord with the US NPD concept of extrapolation from a nearfield measurement point as shown by the comparison of NPD curves in Figure 8.

To examine the lateral attenuation (for constant power) issues, an additional 9 monitoring stations were placed to the side of the runway. Due to other pressures, analysis of the obtained data has not yet been completed.

Another Helicopter NPD Test

Testing for a new helicopter to be used by Defence (designated type H) was conducted in South Australia late last year and used some of our previous testing procedures.

NPD test flights for normal operations and certification procedures revealed different curves.

The temperature and humidity conditions at the time were different to the military jet testing and provided different atmospheric attenuation adjustments as shown in the previous paper (*Problems with INM: Part 2*).

The spectral characteristics of this helicopter do not have the low frequency components exhibited with large two blade helicopters and this made the analysis of the time dependent components easier.

Testing of a stationary helicopter (with main rotors at flat pitch idle) utilising the sound intensity technique found at ground level the high frequency components were a negative vector whilst at elevated levels (above the rotor) there was a positive vector. How this relates to the NPD results has not been yet examined but this is likely to be another side issue for TAG to explore as part of the on-going helicopter noise investigations.

CONCLUSIONS

The preparation of NPD curves is not for the faint hearted. The required rigorous testing and analysis procedures are very demanding and time consuming.

To date there is little guidance as to the required procedures. Obtaining such information from the relevant authorities in the US is a very difficult and frustrating task.

Extensive work with helicopters over the years to identify the difference between certification, normal and fly-neighbourly techniques has revealed, in some cases, quite dramatic differences in noise emission.

The concept of noise abatement profiles is one of generalised, not very specific, procedures. The successful use of DGPS tracking for normal INM flight profile assessments (successfully used in our NPD testing and now being used in the US by SAE-A21 members) is a valuable tool for future airport noise modelling.

However, regardless of whether N70s, SEL or ANEFs are used, they all rely upon accurate NPD data stored in the INM.

The purpose of this paper is to demonstrate a method for NPD testing and to identify a number of traps for the unwary. There are still further side issues to explore but they are outside the Defence contract scope.

During the course of research for the project, TAG obtained some helicopter NPD data from various organisations. However, that data, derived from calculation and not actual field measurements, cannot agree with the TAG field measurement results.

It is most interesting that the technical challenges in generating accurate NPD curves, when placed in the INM (with and without lateral attenuation turned off) agree with field measurements have been most interesting. The work has generated spirited conversations with the overseas learned colleagues from the helicopter noise assessments field who look forward each year for the next instalment of the research work.

This research work required enormous time involvement by TAG staff in field measurements and processing the massive amounts of data, with the assistance of various Defence personnel in providing the aircraft and facilities used in our studies, and the INM modelling team at GHD (Canberra).

REFERENCES

Integrated Noise Model, US Department of Transportation, Federal Aviation Administration

Fleming, Olmstead, D'Aprile, Gerbi, Gulding, Bryan & Mirsky, *Integrated Noise Model (INM) Version 6.0 User's Guide*, September 1999 US Department of Transportation, Federal Aviation Administration.

SAE 1845, Procedure for the Calculation of Airplane Noise in the Vicinity of Airports, issued March 1986

SAE AIR 1989, Helicopter External Noise Estimation, May 1989

Cooper, S, Problems with the INM: Part 1 – Lateral Attenuation, Acoustics 2006, New Zealand

Cooper, S, The INM program is a much better program than HNM for helicopter modelling, but …. SAE-A21 Helicopter Noise Working Group, Las Vegas 2004

ICAO International Standards and Recommended Practices, Environmental Protection Annex 16 to the Convention & International Civil Aviation (Amendment 7), Vol 1, Aircraft Noise Third Edition 1997

Cooper S, *Derivation & Use of NPD Curves for the INM*", Helicopter Noise Workshop, American Helicopter Society Conference, June, 2005

ICAO Committee on Aviation Envrionmental Protection, Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft, June 2003

Cooper, S, Problems with the INM: Part 2 – Atmospheric Attenuation, Acoustics 2006, New Zealand

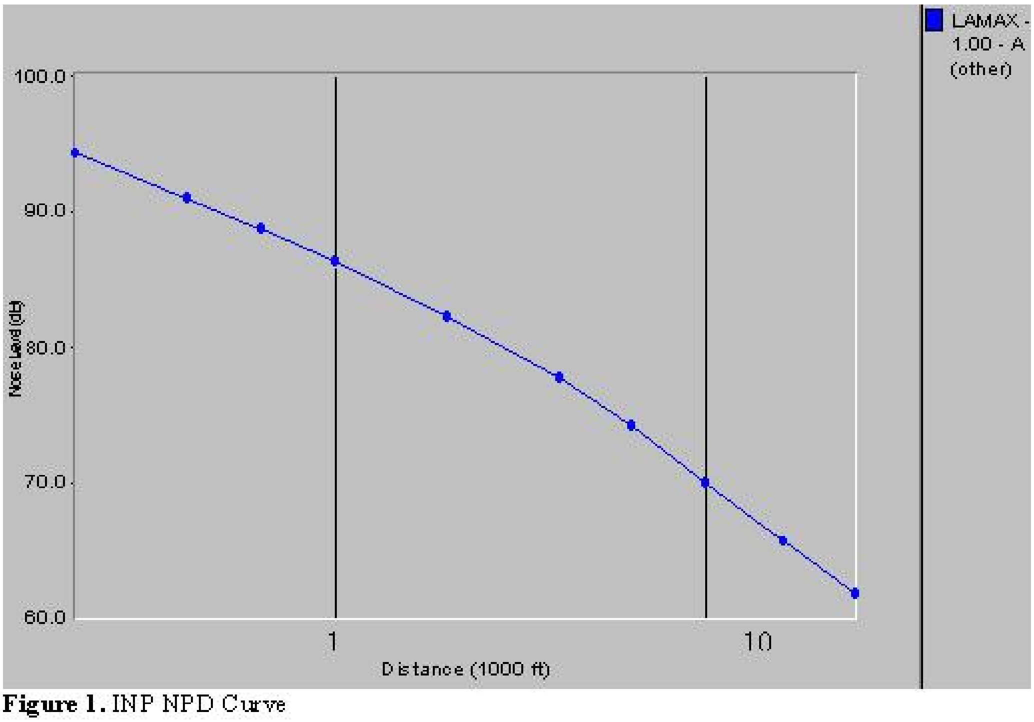

Figure 1. INP NPD Curve

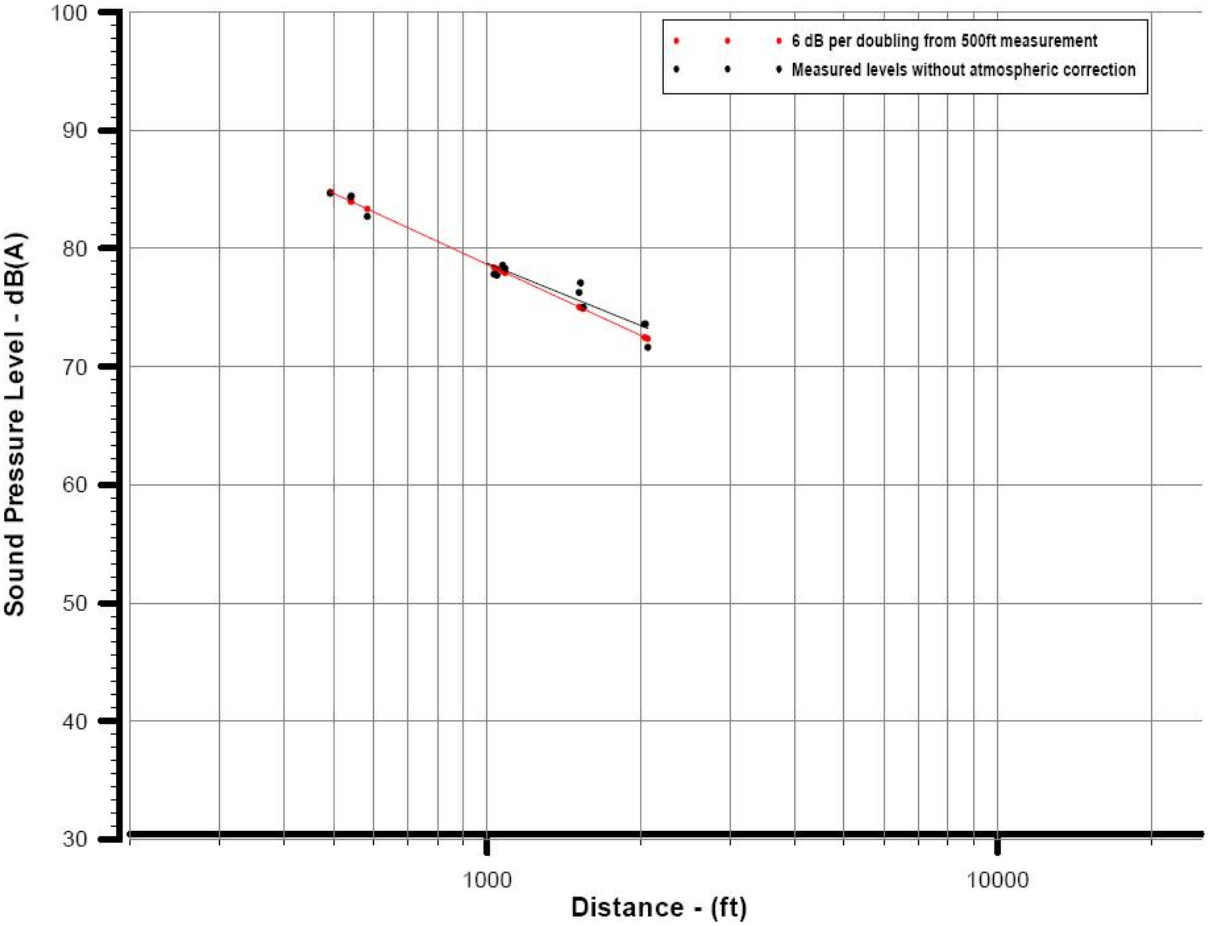

Figure 2. Helicopter Type 5 – Max Level without Atmospheric Correction

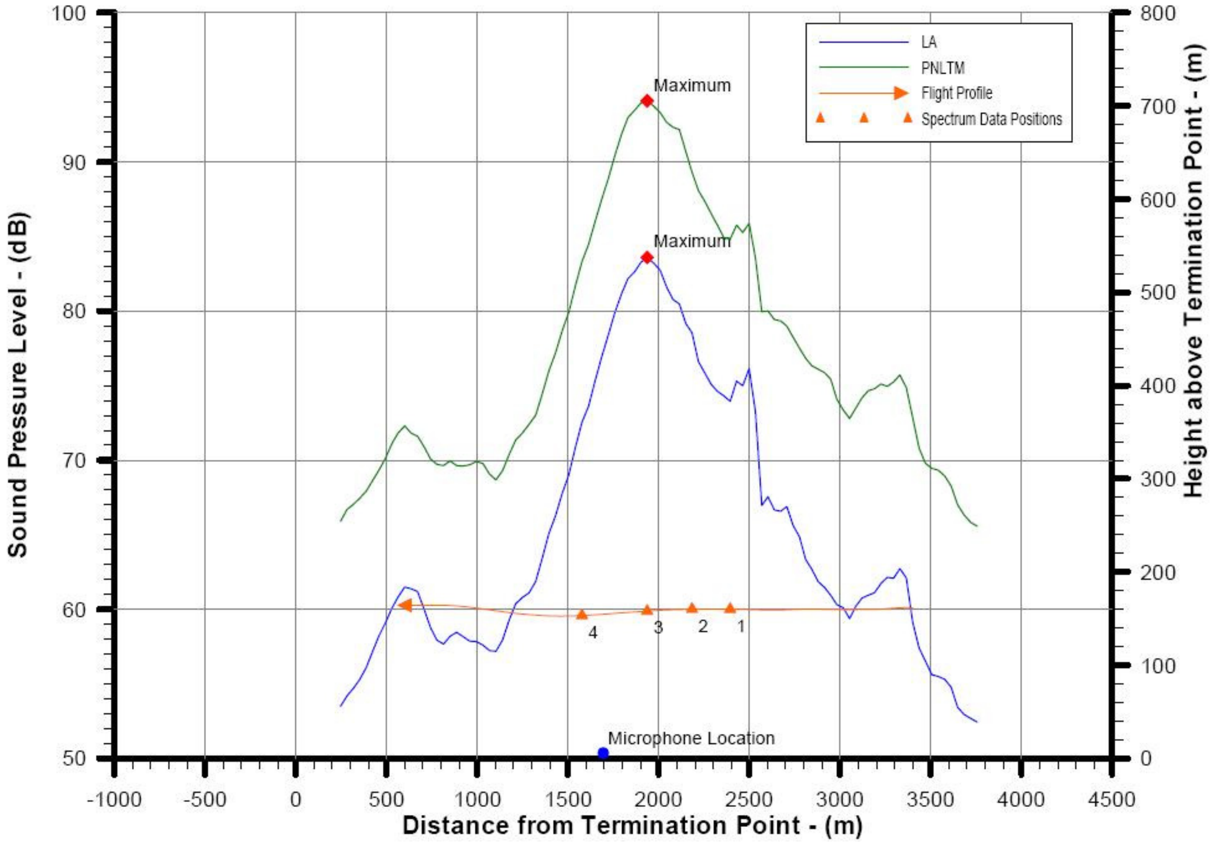

Figure 3. Helicopter Type 5 Flight Profile with dB(A) and PNLTM – Overflight 500 ft AGL

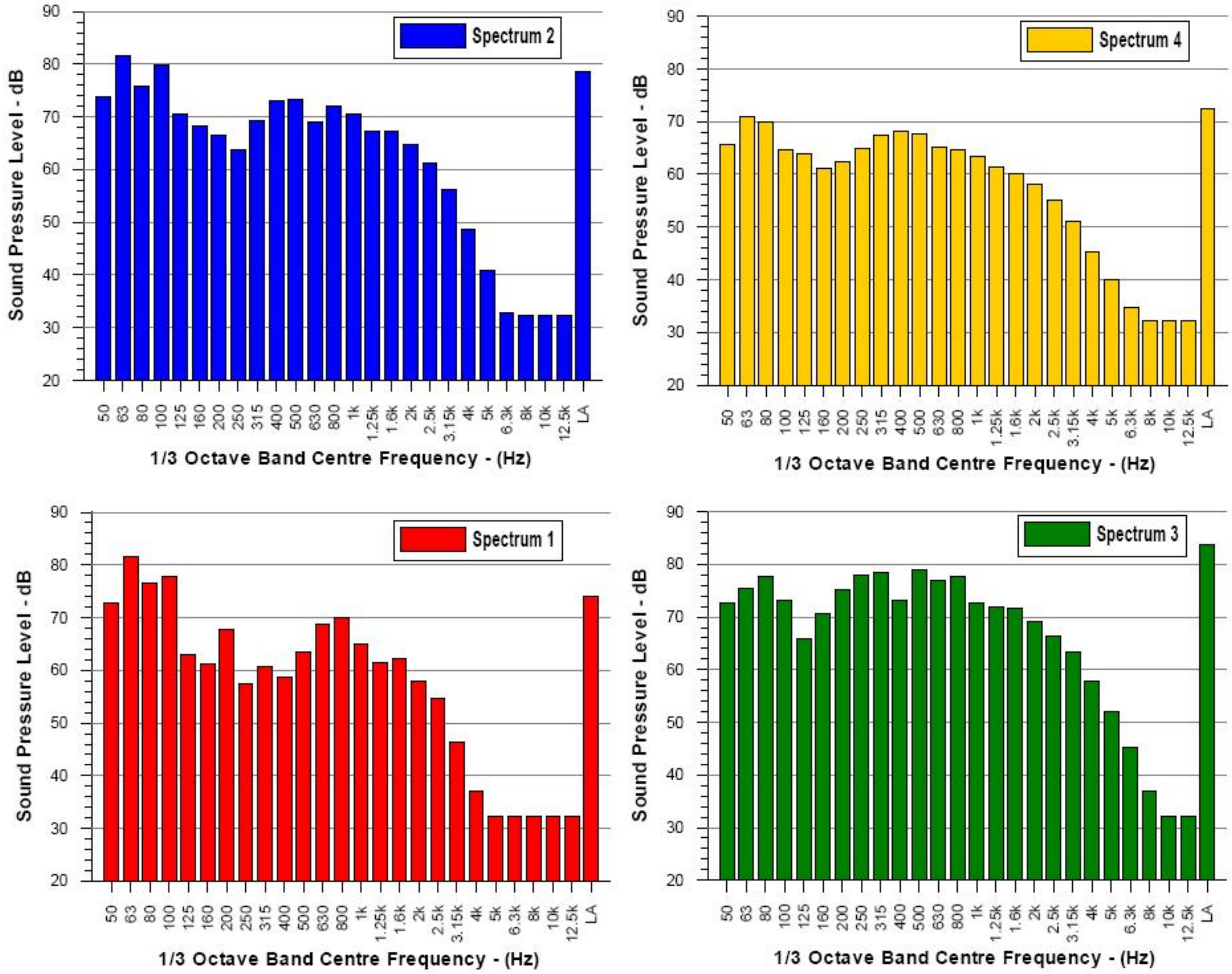

Figure 4. Helicopter type 5 Spectrum Corresponding to Points in Figure 3 – Overflight 500ft

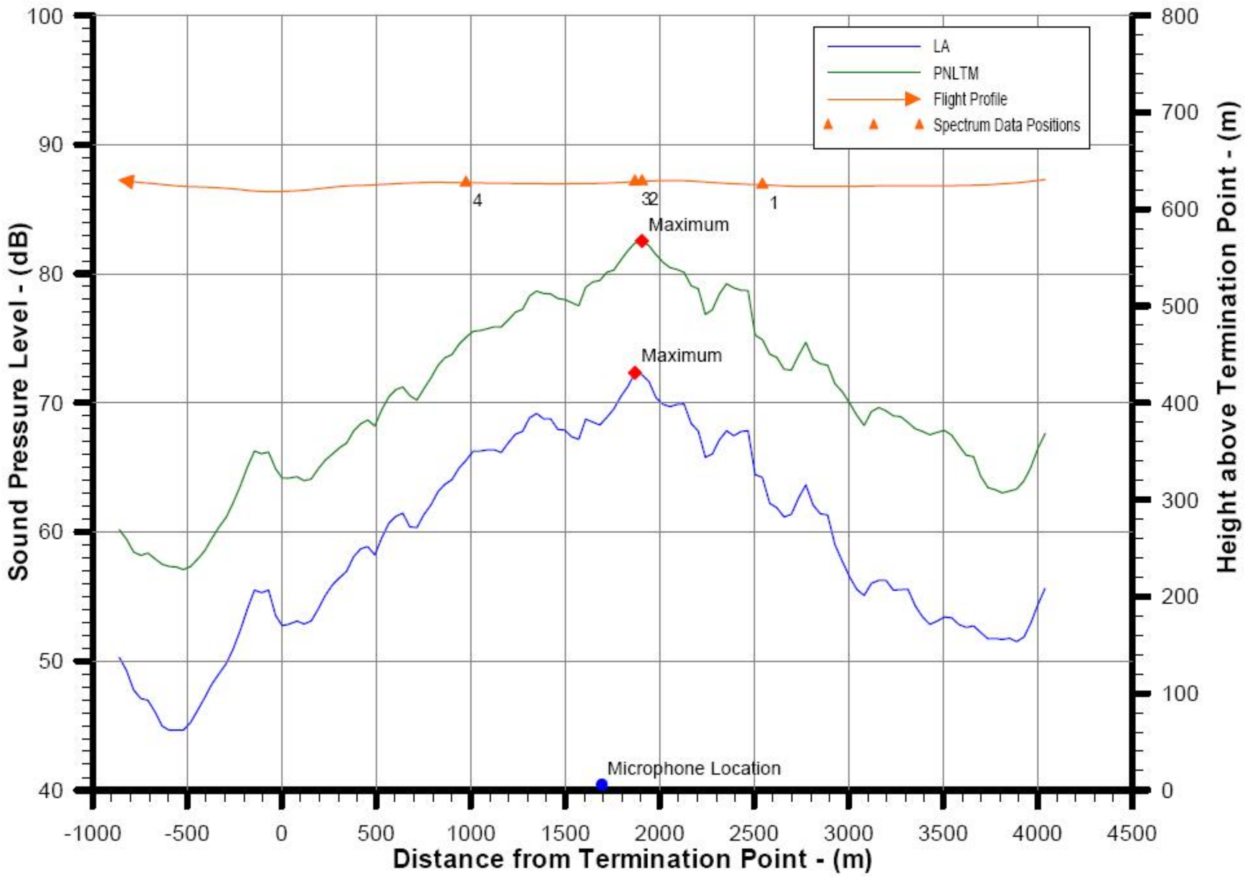

Figure 5. Helicopter Type 5 Flight Profile with dB(A) and PNLTM levels – Overflight 2000ft AGL

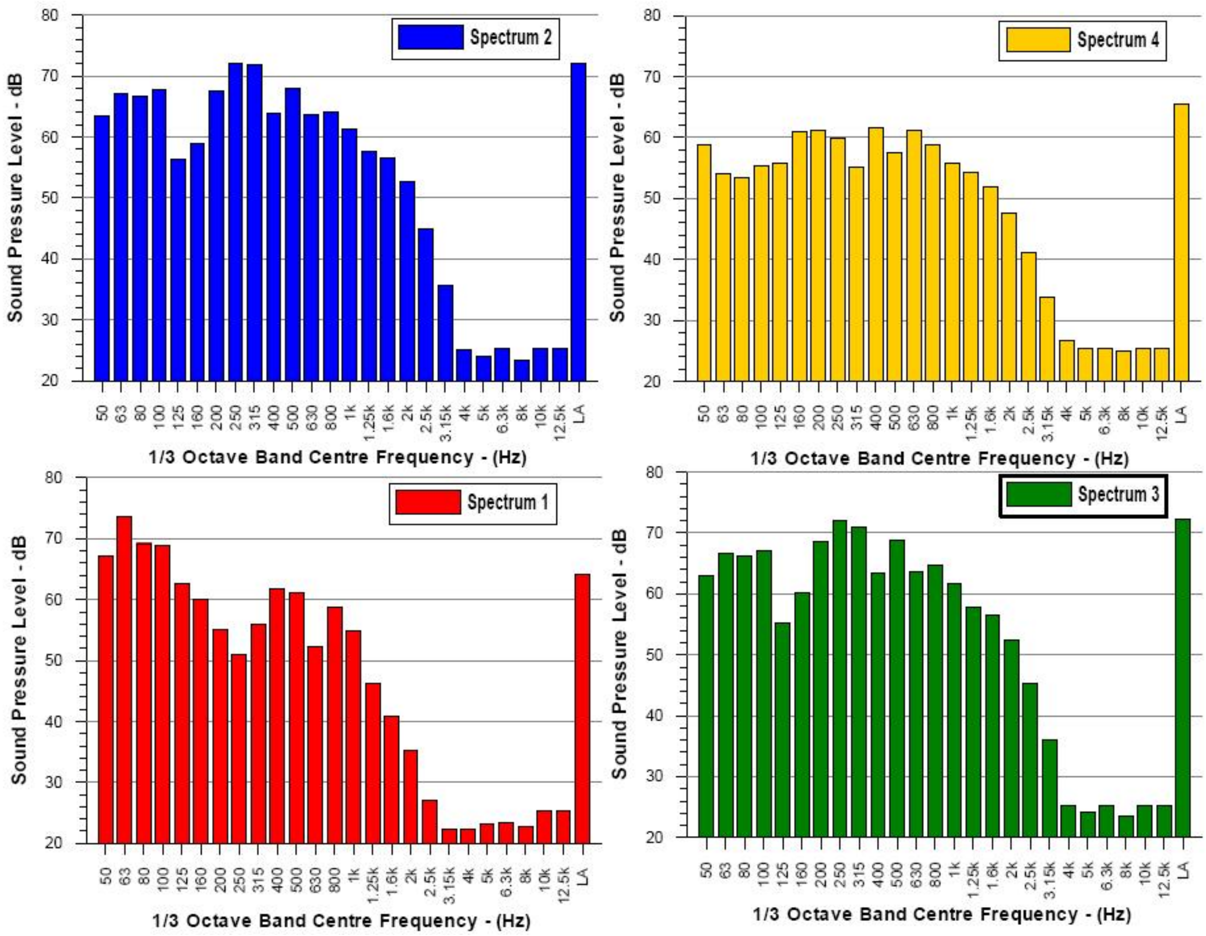

Figure 6. Helicopter Type 5 Spectrum Corresponding to Points in Figure 5 – Overflight 2000ft

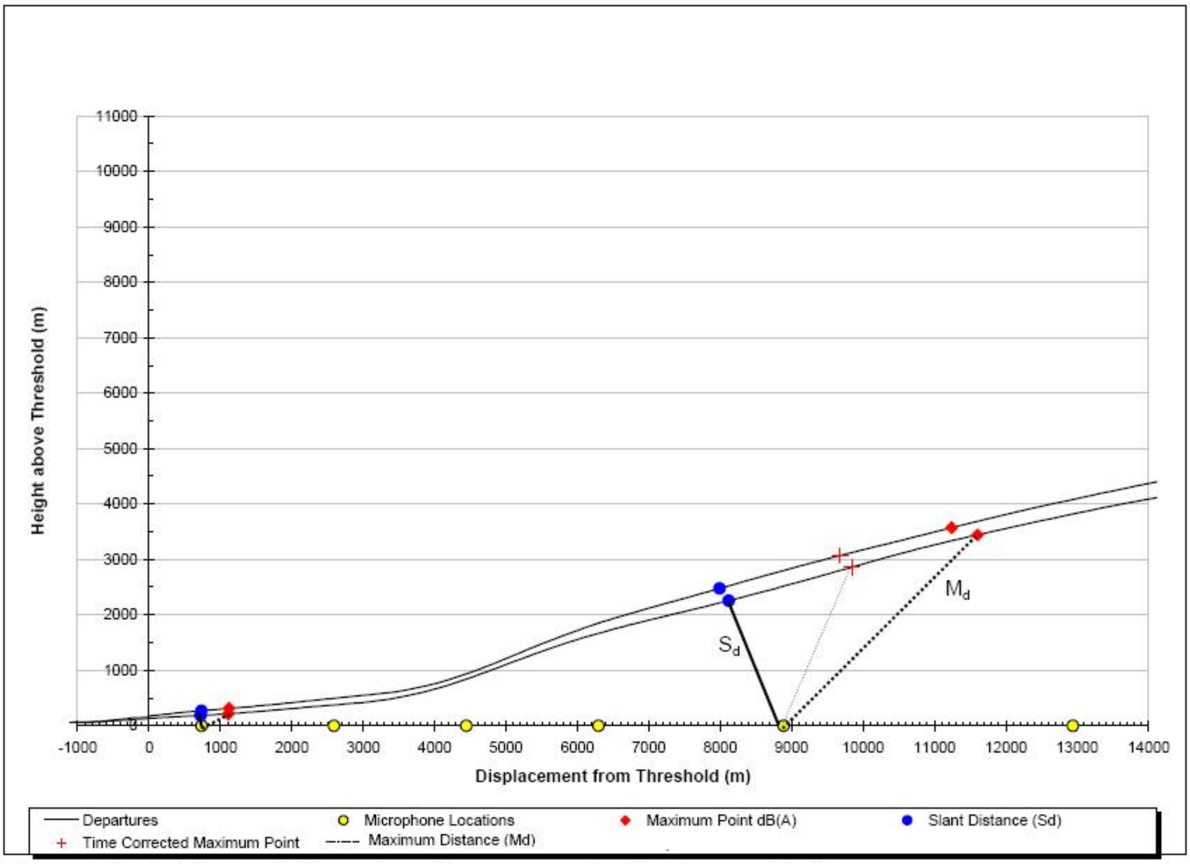

Figure 7. Twin Engine Military Jet – Departure with Afterburners Profile

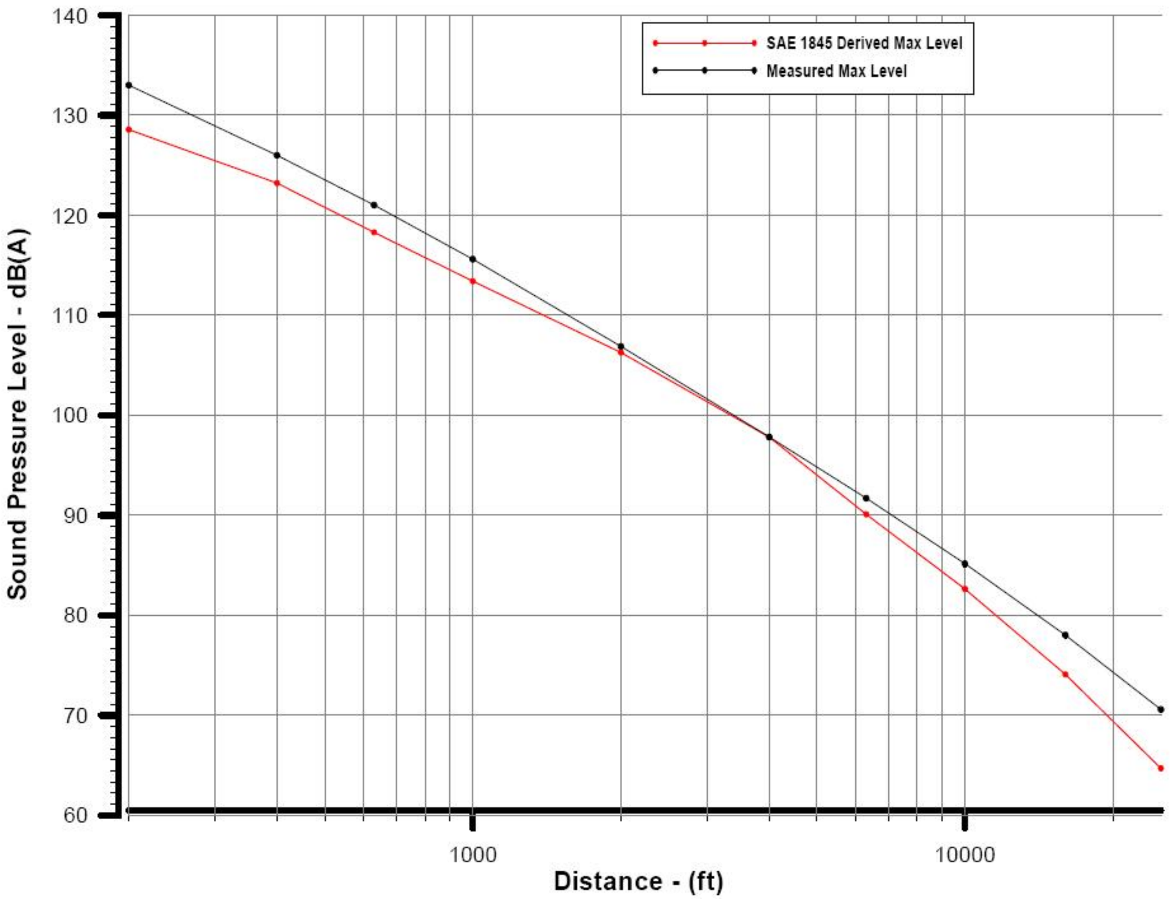

Figure 8. Twin Engine Military Jet – NPD Max Level