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NEW PREDICTION METHODS FOR HELICOPTER NOISE

by

Martin V Lowson

Department of Aerospace Engineering
University of Bristol
Bristol BS8 1TR
England

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Summary

Empirical formulae are given for the prediction of helicopter noise based on the FAA "Rainbow" and fuller ICAO data sets. Formulae are given for noise in EPNdB at the three ICAO measurement locations, together with conversion formulae into SEL and dBA max. Preliminary prediction figures for ground operations are also suggested, and suggestions made for the benefits of optimum flight path on approach noise.

Introduction

The objective of this paper is to present simple methods for the prediction of helicopter noise for use in the estimation of community annoyance, or in initial design studies. Surprisingly, there appears to be no widely accepted method for making simple estimates of helicopter noise. Basic understanding of the noise radiation mechanisms on the helicopter does exist, and there is published data on the noise output of many helicopters. Thanks to the work in support of the ICAO noise certification, there is also a body of data on different helicopters taken in a consistent manner by manufacturers and other bodies. Some estimate of the noise radiation is necessary in order to provide a basis for studies of community response. A prediction method can be developed using this data, in the light of theoretical knowledge of the basic mechanisms. This is the approach taken in the present paper. It is hoped that the results will be of use for direct estimation of noise from helicopters when more sophisticated methods are inapplicable.

2. Basic Data Sources

There are several sources of data which can be used to develop the prediction technique. Perhaps the most complete and consistent data set is that known as the "Rainbow" series of reports prepared by FAA (Refs 1 to 8). The FAA has also produced other data reports in support of the ICAO certification method development which are of direct value in the present work (Refs 9,10). All these results were taken by the same team in a consistent manner. Further, full details of the operating configuration of the helicopter measured is available. This extended Rainbow data set has been used as the basic predictor in the present study. Additional data are available from manufacturer's sources, which was brought together for the relevant ICAO meetings (Ref 11). This data set was taken by individual manufacturer's teams. Although each team was operating to the same notional measurement method, there must be questions about the consistency of data brought together in this way. A further difficulty with this data set is that the information on the helicopter configuration is incomplete, so that some features which are likely to be significant in the noise radiation (eg the tail rotor parameters) are not always available. Nevertheless, this does offer a useful secondary data set for consideration.

The Rainbow report series has been used as the basis for several analyses, notably in Ref 8, which included suggestions for prediction. The data also includes a full data correction method. Many of the direct physical corrections, eg for distance or temperature are small. However, corrections were also made for helicopter flight parameters, notably velocity, which do not have a secure basis. For the present purposes all analysis has been made on uncorrected data.

All the data sources noted above centre around the ICAO noise measurement procedures, which cover the three cases of flyover, approach and take off. A flight path for each condition is prescribed. These flight paths were defined in order to give repeatable and acoustically representative conditions for the noise measurement. The flight conditions were not intended to represent normal operating practice. Measurements were made at three microphones set at 1.2m height above the ground immediately under, and to either side of, the flight path. Fig 1 shows the measurement set up. Data is reported in EPNdB, averaged over the three microphones. EPNdB includes both a tone and duration correction factor. These factors were originally derived for use in fixed wing aircraft noise, and their application to helicopters is questionable. However, all data are given to this standard. The Rainbow report series also presents other measures of the same noise data. This provides a useful basis for developing approximate laws for transforming from one measure to another.*

3. Data Analysis Methods

When the helicopter noise data was originally gathered together for the ICAO certification development, it was found that a feature of the data was the dependence of the noise output on the weight of the helicopter.

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* It is believed that several of the data sets reported by manufacturers in EPNdB were originally taken in other forms such as dBA, and transformed into EPNdB by the use of equivalency factors.

This relationship was built into the noise certification rules adopted by ICAO. The simplest possible prediction rule therefore relates noise output to weight.

Theoretical descriptions of the noise output of a helicopter rotor are available (Ref 12). It is therefore logical to use the dependencies suggested by theory as the basis for a possible prediction rule. The key feature to emerge from the theory is the dependence of the noise radiation on the tip speed (Mach number) of the rotor. Tip speed is therefore a leading parameter for consideration in an improved prediction method.

A recent review paper (ref 12) suggested a series of power laws derived from data presented by Perry and Pike (Ref 13) for the effects of design changes on flyover EPNL. This combines the results from many acoustic predictions for different types of aircraft but, because of its source, is biased towards the larger transport helicopter. The principal laws are as follows:

Rotor tip speed	$V_T^{7.8}$
Aircraft all up weight	W^2
Blade Area	A_B^{-1}
Cruise speed	$V_C^{3.3}$
Blade Number	B^{-1}

From this a prediction law can be developed, and this was given in Ref 12. A prediction law has also been put forward by an SAE committee (Ref 14). Since this technique has been put forward by a reputable body it should be considered in any review of possible prediction techniques. The results from the SAE predictions will be analysed in Section 7 of this paper.

4. Evaluation of Prediction Methods

There are three requirements for an acceptable prediction method; it should :

Be simple to understand and apply
Capture the principal trends suggested by theory
Be consistent with known data

It is difficult to meet these requirements simultaneously. Possible approaches to prediction will be evaluated against these objectives.

The simplest possible approach is one based on AUW alone. As has already been noted, the ICAO rules reflect an AUW to the first power law for the noise radiation. It is therefore of interest first of all to examine the effectiveness of this very simple law. Note that the power laws suggested above also imply a weight to the first power law, since blade area for different helicopters will normally vary in proportion to weight.

Figures 2 to 4 give plots of the noise measured from the complete data set available against AUW in kg. In each case the data point lies at the centre of the label describing the type. It is hoped that this form of presentation will permit a more ready assessment of the issues involved. A first power law would give a straight line on a log plot. It can be seen that in each case the correlation against a simple first power law is not unreasonable.

A fuller regression analysis of the data has been undertaken. The direct result is the following power laws for EPNdB:

Flyover: $AUW^{0.95}$, Approach: $AUW^{0.95}$, Take Off: $AUW^{0.97}$

As can be observed from the plots in Figures 2 to 4, the effects at the higher all up weights are controlled by a few types. The *Standard Error of the prediction is around 2dB in each case, and the error in the power law* coefficient is around 0.1. Thus the two figure accuracy indicated in the power law is misleading. In effect the regression gives strong support to the unity power law for noise against weight. Making this assumption allows simple formulae for the noise to be developed from the available data. This data can be treated in two parts. The first is the whole data set as shown in Figures 2 to 4. Although this is a larger data set it seems unlikely to be as reliable as the Rainbow data set. The Rainbow data also has one anomaly, the data from the BV 234. This is the only large twin rotor helicopter tested, and the data indicates that it is not typical of single rotor helicopters, as was concluded also in Ref 15. Thus it seems desirable to use a reduced Rainbow data set excluding the BV 234 for prediction development for single rotor helicopters. Using this data (referred to as Rainbow-) gives the following simple prediction laws.

Flyover: $\text{EPNdB} = 83.5 + 10 \log_{10} (\text{AUW} / 800)$

Approach: $\text{EPNdB} = 86.5 + 10 \log_{10} (\text{AUW} / 800)$

Take Off: $\text{EPNdB} = 83.5 + 10 \log_{10} (\text{AUW} / 800)$

Formula 1. Predictions Based on First Power Weight Law

These laws are shown on Figures 2-4. The numerical values derived for the reduced Rainbow set also apply to the full data set with one exception. Take-off noise is predicted to be about 1dB higher from the full data set than from the Rainbow series. The Rainbow figures are believed to be more representative.

The rms errors from this prediction, in dB, are

Data Set:	Rainbow-	All Data
Flyover:	1.04	2.15
Approach:	1.18	1.70
Take Off:	1.22	2.11

Table 1. RMS Error for First Power Weight Law Predictions (Formula 1)

This level of prediction accuracy is not unreasonable, but it is of interest to see if an improved prediction method can be developed.

5. Effects of Tip Speed

Theory and experiment suggest that tip speed is an extremely significant factor in rotor noise radiation. Inclusion of the effects of tip speed is a natural first step in improving prediction accuracy.

In the laws presented above from Ref 12 it was suggested that a tip speed to the 7.8 power law could be applied. It is likely that noise from a given helicopter will scale with a high power of the tip speed. For the highest speed cases on the advancing blade, say $M > 0.8$, where the noise is dominated by thickness effects, it is certain on both theoretical and experimental grounds that very strong effects of blade Mach number occur. These include effects such "delocalisation" which cause excess noise at tip speeds above $M=0.9$. However, few civil helicopters reach this speed level, and in any case the acoustic effects of high transonic advancing blade speeds are so dominant that there would be no possibility of civil helicopter operations.

Advancing tip Mach numbers are lower at speeds more representative of operations. Effects here are rather different. The intense thickness noise source radiates preferentially forward. This can cause considerable forewarning of the helicopter's approach, and seems likely to be a factor in annoyance. However, several subjective studies, eg Ref 15, have shown that the effects are included within some of the standard measures for noise such as EPNdB. It appears that the additional effects of the forward throw are generally included within an overall duration correction. Standard flyover measures such as those analysed here are likely to be dominated by the noise radiated by the helicopter as it passes overhead. This noise would be a function of rotational tip speed rather than advancing blade Mach number. Thus it is of interest to evaluate the effects of rotational tip speed in a prediction method.

The data has therefore been analysed to indicate the best fit power laws for the noise, having taken account of weight. The key comparative measure is the rms error (ie standard deviation) of the resulting prediction. The results are as follows:

Power Law/rms error

Data Set:	Rainbow-	All Data
Flyover:	5.3 / 0.74	4.8 / 2.06
Approach:	7.0 / 0.53	3.1 / 1.60
Take Off:	5.2 / 1.1	1.1 / 2.08

Table 2. Power Laws and RMS Errors For Prediction Laws Based on Velocity

The merits of the prediction can be determined by comparison of the rms error with the error listed in Table 1. It can be seen that for the Rainbow- data set there is a useful improvement in prediction error by the use of the velocity law. For the full data set there is a small improvement. It seems likely that the full data set contains other errors which mask effects of the improved prediction shown here.

The power laws suggested by the regression analysis are reasonably consistent, with the exception of the full take-off data set. Referring back to Figure 3 it will be noted that there is considerable scatter associated with this set. It was suggested earlier that this could well be caused by inadequate definition of the take-off path for the tests reported. Thus it seems reasonable to discount the full take-off data in developing a prediction method. It seems most reasonable to base the power law selected on the Rainbow- data set. The average value of this is 5.86. Given the errors it is unreasonable to assert accuracies better than one significant figure. Consequently a power law of 6 is recommended for the prediction. This gives the following overall prediction formula, and associated mean and rms errors:

Flyover: $EPNdB = 83.5 + 10 \log_{10} [(AUW / 800) (V_T / 215)^6]$

Approach: $EPNdB = 86.5 + 10 \log_{10} [(AUW / 800) (V_T / 215)^6]$

Take Off: $EPNdB = 83.5 + 10 \log_{10} [(AUW / 800) (V_T / 215)^6]$

Formula 2. Predictions Based on Weight and Tip Velocity to the Sixth Power

Mean/ rms error

Data Set:	Rainbow-	All Data
Flyover:	0.17 / 0.61	0.27 / 2.04
Approach:	0.29 / 0.47	0.46 / 1.62
Take Off:	0.29 / 0.90	-0.34 / 2.47

Table 3. Mean and RMS Errors For Prediction Laws of Formula 2

The errors of these predictions may be compared with the weight only predictions given in Table 1. It will be observed that usefully better accuracy is achieved except for the "all data" Take-Off case. It is thought likely that the full data set is the most likely to contain anomalies, and the overall improvement is therefore thought to justify the use of the improved formula where the best predictions are required. However, for community noise predictions it could well be most appropriate to use the weight only laws presented in Formula 1. Formula 2 is constructed so that, if tip speed is not known, the use of an average speed of 215m/s eliminates the velocity term, and the formula reduces to the weight only laws given previously in Formula 1.

6. Other Effects

Several other possible parameters can be considered for prediction purposes, and these have been tested against the available data. Blade number is certainly a plausible parameter to use in the predictions, and applies directly to the related case of propeller noise. Examination of the data showed a significant reduction in accuracy by using the blade number parameter suggested in Section 3. This is thought to be due to the low fundamental frequency of the main rotor. Regions of the spectrum where cancellation of main rotor discrete frequency noise due to blade number effects might be expected are confined to regions of about a 100Hz or below, and will not affect subjective response. Several high frequency noise radiation sources are due to interaction of edges with turbulence, either inflow or boundary layer induced. Under these conditions increase of blade number might well be expected to increase the noise, rather than reduce it as suggested.

The potential use of a cruise speed correction has also been studied against the data available. It has been found that prediction accuracy was reduced by inclusion of such a factor. This is believed to be due to relative insignificance of advancing blade effects in the measured data, for reasons which were discussed above.

The final feature of significance is the effect of the tail rotor. Theory and subjective experience suggests that the effect of the tail rotor can be important, even dominant. It is noteworthy that the recent NOTAR helicopter due to McDonnell Douglas, has noticeably lower levels of noise. This benefit is particularly pronounced on flyover. An examination of the data was made to see if an improvement could be made by incorporating the effects of the tail rotor. It was found that the statistical effects of including tail rotor models was fairly small even for the Rainbow data set. A useful improvement in prediction accuracy could be achieved including an allowance for the tail rotor for the flyover case, but other cases were not clear cut. Broad brush data of the present type is not well suited to drawing out effects of design detail. Experimental programmes specifically tailored to the problem are necessary. An empirical estimate for the effects of the tail rotor which appeared to have some predictive capability was to assume that both main and tail rotor had equal contributions to the noise. Thus the constant term in the flyover formula for the main rotor noise was reduced by 3dB, and an additional noise source due the tail rotor calculated via:

$$EPNdB_{TR} = 80.5 + 10 \log_{10} [(AUW / 800) (V_{T(TR)} / 215)^6 \; (4/B_{TR})]$$

Formula 3 Proposed Formula for the Effects of the Tail Rotor on Flyover Noise

where

$V_{T(TR)}$ is the tip velocity of the tail rotor (m/s)
B_{TR} is the number of tail rotor blades

Note that the final correction will be zero if the main and tail rotor have the same tip speed (for a four blade tail rotor). The effect of blade number appears on both theoretical and experimental grounds to be of more significance for the tail rotor, and is retained in the formula above. It was found that this approach gave useful improvements in prediction accuracy for flyover noise of helicopters with quiet tail rotor configurations, such as the Fenestron or NOTAR designs, and for those cases where there were notable differences between the speeds of the main and tail rotors.

7. SAE Predictions

A draft prediction method for helicopter noise has been put forward by a committee of SAE (Ref 15). It is of obvious relevance to the present objectives to test these SAE predictions against the available data. The SAE method is based on the use of the parameter P defined by

$$P = \frac{W}{\pi R^2} - \frac{R}{152} - \frac{M_T}{1 - (M_T + M_F)}$$

where

W is AUW
R is blade radius
M_T is tip Mach number
M_F is advancing blade tip speed

This formula is partially based on theoretical considerations. The first term is argued to represent a disc loading law. Since R appears in the numerator of the next term, it can be seen that the overall law offered is in fact on the basis of blade loading. Also the theoretical Mach number laws have a higher power than proposed here. The formula as presented corresponds approximately to a cube law with M_T at typical rotor tip Mach numbers. The theoretical basis for these laws is therefore questionable.

The SAE calculation procedure uses this parameter to develop constants for a prediction technique based on regression analysis. It is not entirely clear which helicopter noise data was included in the regression analysis, although the data must inevitably include much of the information used in the present work. The SAE method predicts noise to a slightly different case than that selected for ICAO predictions. Maximum noise levels are predicted for single points under the flight path, at distances of 150m from the helicopter. These are then corrected to Sound Exposure Level values by a further linear relation for which the coefficients are given as a result of a regression analysis. As will be demonstrated later in this report, the Sound Exposure Levels should correspond quite closely to the EPNdB values used in the ICAO data (except for a possible constant term). Predictions based on the SAE method have been made for all data available, and mean and rms errors calculated. The results are given in Table 4 below.

Mean/ rms error

Data Set:	Rainbow-	All Data
Flyover:	0.89 / 0.88	0.47 / 2.14
Approach:	1.94 / 0.97	1.34 / 1.60
Take Off:	-0.17 / 1.61	-1.47 / 2.47

Table 4. Mean and RMS Errors For SAE Prediction Laws

Comparing with Table 1, it can be seen that the SAE method provides very little, if any, improvement in rms prediction error over the weight law alone. In comparison with Formula 2 it is significantly inferior for the Rainbow- data set, and slightly inferior for the whole data set. It is concluded that the SAE method is not a suitable prediction method for the present purposes.

The SAE report also gives a prediction method for noise from a hovering helicopter near the ground. This is based on less data than for flyover etc. However, it is of interest that it is suggested that values of LA_{max} for flyover, take-off, and hover can be combined in a single prediction formula within the limits of confidence of the data.

8. Comparisons of Prediction with Experiment

Comparisons of the results from the present predictions using Formula 2 with the complete measured data set are shown in Figures 5 to 7. In effect Figures 2 to 4 already compare the data with the simplest possible first power weight law (although with axes exchanged). Thus the scatter on the graphs of equivalent conditions may be directly compared. As before, the plots feature the name of each helicopter type. The Rainbow series helicopters are noted by an asterisk in front of their name.

8.1 Errors

The full data set appears to contain considerable scatter which is a function of factors outside the considerations of the present report. It is certainly likely that measurement errors are non-trivial. Several trials have been run to look at repeatability of helicopter noise measurement data. Ref 12 reports on an extensive comparison carried out under the auspices of FAA on the Bell 206L helicopter.

No summary results from the test as a whole are given in the report, but standard deviations for each sub-series of tests are listed. From these an estimate of overall repeatability can be made. Equivalent information is given in the individual Rainbow reports. The standard deviations for the EPNdB data are, in dB:

	B206	SA365	SA355	SA350	S76	B222	H500D
Flyover	0.5	1.2	0.5	0.5	1.0	0.7	1.2
Approach	1.0	0.5	0.9	0.5	0.6	0.4	0.4
Take-Off	0.6	0.5	0.6	0.7	1.0	0.5	0.7

Table 5 Standard Deviations Measured in FAA Helicopter Noise Tests

The data above have been found by averaging the errors reported at individual microphones for each flight case. The figures are given here to one significant figure accuracy. No specific conclusions about the sources of error can be made. It becomes clear on analysing the data that the errors are essentially random. Flight series which produce rather consistent results at one microphone produce considerable variations at another microphone. In the original reports attempts were made to correct the data for known deviations such as speed and height. In many cases the rms errors worsened, and there seems little justification for accepting the corrected data as more representative.

From the above data, an average level of *measurement* error is 0.7dB. This is not significantly different to the *prediction* errors for the Rainbow set as a whole using Formula 2, (see Table 3). It seems very possible that the errors in the wider data set are also due to problems in measurement of an exceptionally complex source rather than in prediction.

The results of formula 2 suggest that the noise effects of take-off and flyover are essentially equivalent. The same conclusion was reached in the SAE document Ref 14. There it was also suggested that hover noise levels could be combined with peak levels from the take-off and flyover cases. In both the SAE method and in formula 2 the difference of the approach noise from the other two cases is found to be 3dB. This is certainly a point of interest for certification considerations. ICAO regulations specify targets in which the approach is only 1dB larger than for flyover, with the take off case a further dB lower. It would appear that the regulations are an inadequate reflection of the noise generating characteristics of typical helicopters.

9. Relation to Other Measures

$$\mathrm{SEL} = \mathrm{EPNdB} - 3$$

Formula 4. Relation of SEL to EPNdB

Analysis of the data suggested that the above formula gave a reasonable correlation between SEL and EPNdB, with an rms error of 0.70 dB. The constant is given to the nearest 0.5 dB.

In the SAE report (Ref 15) a correlation is given between SEL and the A weighted maximum sound level. This correlation is fundamental to the prediction procedure suggested. SEL is found to depend on $\mathrm{LA}_{max}{}^{N}$, where the power law N has a value between 0.7 and 0.83 dependent on the flight condition. Analysis of the SAE predictions suggests that this power law formula is the principal source of the prediction errors in comparing with the current data.

The relation between SEL and LA_{max} is unlikely to be simple. SEL will be governed by duration corrections which will depend on flight configuration. For example, the Take-Off and Flyover cases could be expected to have rather different relations for these two parameters. A further significant factor is the directivity of the rotor noise. It would be anticipated that any substantial forward throw of the noise would have a strong effect. It seems unlikely that these factors can be reflected in a prediction which depends only on a power law of the maximum sound level.

An analysis of the data in the Rainbow report series has been undertaken to throw further light on this point. The data which is relevant to the issue is limited, but it does appear that trends in the relation of EPNL to LA_{max} exist, dependent on both helicopter type and on phase of flight. It is not possible from the limited data available to make any firm suggestions for the effect of different helicopter types. However, an approximate relation between EPNL and LA_{max} can be given as

$$\mathrm{LA}_{max} = \mathrm{EPNL} - F$$

Where

F = 11 for Approach or Flyover
F = 13 for Take-off

Formula 5. Approximate Relations Between LA_{max} and EPNL

These approximate formulae allow the formulae given for EPNL to be reinterpreted to give maximum noise levels if desired.

10. Ground Operations

Data is also given in the Rainbow series on noise levels resulting from various ground operation conditions. This data has been used in an attempt to provide a prediction for the relevant dBA levels. The average dBA level at 150 m over hard ground for various aircraft are given in the Table below. Data for the Bell 206L has been taken from Ref 12.

	Hover IGE	Flight Idle	Ground Idle	Hover OGE
H 500D	75.7	71.2	61.8	
AS 350D	81.9	69.8	56.2	
AS 355F	79.8	77.1	64.2	79.8
SA 365N	77.8	76.5		83.9
Bell 222	71.2	68.2	61.6	79.5
S 76A	78.5	67.6	58.0	
BV 234	78.9	75.0	70.3	87.4
B 206L	76.8	70.8	57.4	
Average (Less 234)	77.4	71.6	59.9	82.5

Table 6 Average dBA Levels for Various Ground Operation Cases

There is no strong trend with either weight or tip velocity. These results are not entirely surprising since the actual operating conditions under such cases as "flight idle" are likely to vary considerably from helicopter to helicopter. Hover in ground effect is likely to be dominated by the effects of recirculation and may well involve other features of both the aircraft and the conditions under which the hover occurs.

Hover noise levels are likely to be related to the noise during take-off and flyover. SAE (Ref14) suggested that all of this data could be regarded as belonging to a single set. Table 7 compares the average dBA values for OGE hover with the figures for centreline LA_{max} found in the Rainbow tests. It will be seen that there is some, although limited, correlation. The number of samples is small, and the LA_{max} measure is liable to be controlled by the appearance of local directional maxima in the helicopter noise field, so that greater scatter is inevitable than in integral measures which provide some averaging.

	Hover OGE dBA	Take-Off LA_{max}	Flyover LA_{max}
AS355F	79.8	76.8	82.6
SA 365N	83.9	86.1	77.7
Bell 222	79.5	73.6	79.9
BV234	87.4	84.3	79.2

Table 7. Comparison of Hover Levels with Flight Cases

In the absence of more specific data it appears reasonable to use the present predictions for take-off/flyover as an approximation for the hover case.

A further important point which did emerge from the FAA tests was the critical effect of the ground on the noise radiated. The difference between propagation over hard and soft ground was as much as 10dB even over 150m. This is an unexpected result, and appears to require special consideration in development of a community noise prediction model. Examination of the data for the effects of soft ground reveals wide variations. Some of this may result from strong directionality effects, since the data given in Table 6 is an average value. Data taken for the two soft ground locations used also show considerable variations, often over 6dBA on average. There is no obvious explanation for the substantial effects of ground condition found. Temperature varied considerably over the day, but there was no observed effect of time of day on the results, as would be expected from refraction gradients. This issue will require additional data, and further study, before any clear recommendations can be put forward.

11. Flight Path Effects on Helicopter Noise

The potential effects of operating technique on noise radiation are well established. It should also be noted that the ICAO approach case for certification was chosen to reflect a particularly intense noise radiation condition for most helicopters, and is not typical of operations.

In Ref 10 a detailed study was reported of the benefits of operating effects to reduce approach noise. Bell Helicopters have laid down quiet operating procedures for their helicopters, and the benefits of this were evaluated for the B206L. The data support choosing a typical approach level 3dB lower than ICAO certification figures for the B206L, as indicated in Table 8. The test program was flown by experienced test pilots, and although the results do show the benefits of operating procedures on noise output, they also demonstrate the sensitivity of the noise produced during approach to small changes in the flight conditions.

	Rainbow Data		Ref 16	Ref 16
Helicopter Type	Benefit EPNdB	Approach Type	"Best" vs 6°	Normal vs 6°
B206L	3	Bell Quiet Approach	2.1	1.2
R22			2.4	2.2
H500D	2.3	9°	0.8	1.3
AS 350	1.8	9°		
A109A			3.7	3.0
BK117			0.9	0.4
B222	3.2	12°	1.6	0.2
SA365N	<0.5	9°	2.7	4.0
S76A	3.9	9°	3.0	3.8

Table 8 Approach Path Benefits on Noise

Some further data on other potential low noise approaches are given in other reports in the Rainbow series. These are also summarised in Table 8. The figures given here are an average from various measurement points for each flight condition. In each case the benefit from the best approach path over the standard 6° case is noted. Analysis of the data suggests that the effects of the lower noise approaches are more pronounced at centreline locations where noise during the 6° case is high.

In Ref 16 data was given on a wide range of tests carried out by in the FAA/HAI helicopter flight operations noise tests. These figures are also shown in Table 8. The figures correspond to an average figure for reduction in SEL at left centre and right microphones, corrected for distance by use of data from the cockpit altimeter. Two sets of figures are given, the reduction for a "best" low noise approach path, and a second set for the variation from the 6° certification path to a "normal" approach. The data shows that for some helicopters the normal approach produces less noise than the "best" low noise approach. It is unclear how much this is a real effect and how much is due to statistical variations. The variation in results from equivalent tests during the Rainbow series on the same helicopter may also be noted.

What is certainly clear is that choice of approach path can have major effects on the noise radiated. Generally the quietest approaches at low speeds involve high rates of descent, typically between 1000 and 1500 fpm, and approach angles of 9° or more. Many helicopters can operate safely at approach angles of 15°, and noise would be expected to be low in such operating regimes.

An analysis has also been made of possible side to side variations in noise. No systematic effect was found in the case of flyover or take off. However, on approach a strong effect was found. The actual results for the difference in noise level right side - left side are shown in the table below

Type	B222	S76	H500	B206	AS350	SA365
R-L	2.7	3.1	2.7	4.8	-2.3	-2.8

Table 9 Differences in Helicopter Noise from Side to Side

Note that the last two machines have rotors turning in the opposite direction to the others listed. Typically approach noise is 3dB louder on the advancing side.

12. Conclusions

Analysis of data from carefully controlled tests against ICAO certification conditions has provided the basis for an empirical model for the prediction of helicopter noise. It is found that the majority of the variation in noise for different types of helicopter can be captured by a weight law. There is also some effect of rotor tip speed, but the dominant effects of tip speed on rotor noise expected from theoretical considerations are not borne out by data on complete helicopters.

The formulae presented appear to offer a reasonable basis for simple empirical predictions. Comparisons with previous empirical predictions have also been presented. Error margins in helicopter noise measurement are sufficiently large to prevent more precise models to be developed from a purely data based approach.

Preliminary data is also given on the noise from ground running, and the strong effects of operating procedures on the noise output demonstrated.

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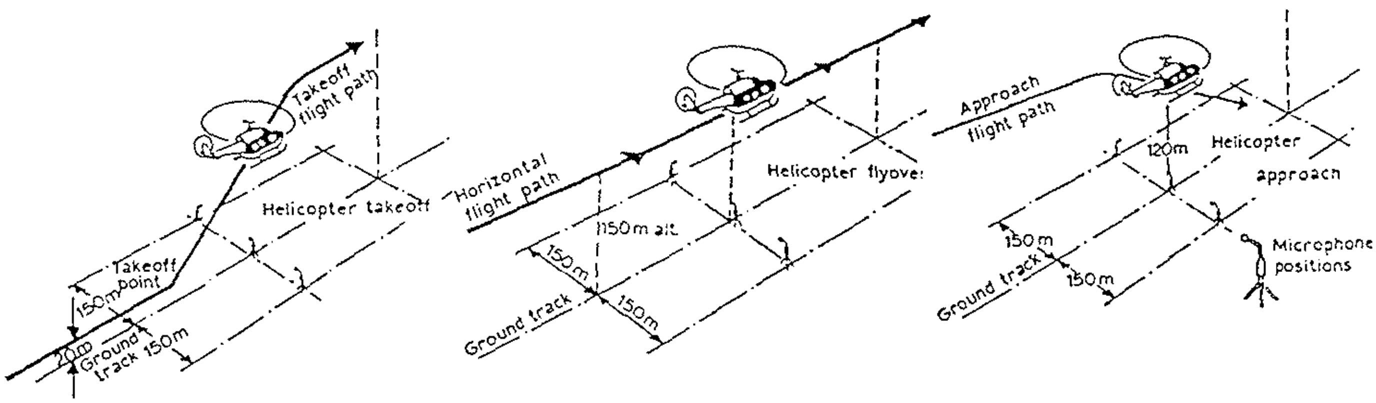

Figure 1. ICAO Measurement Set Up

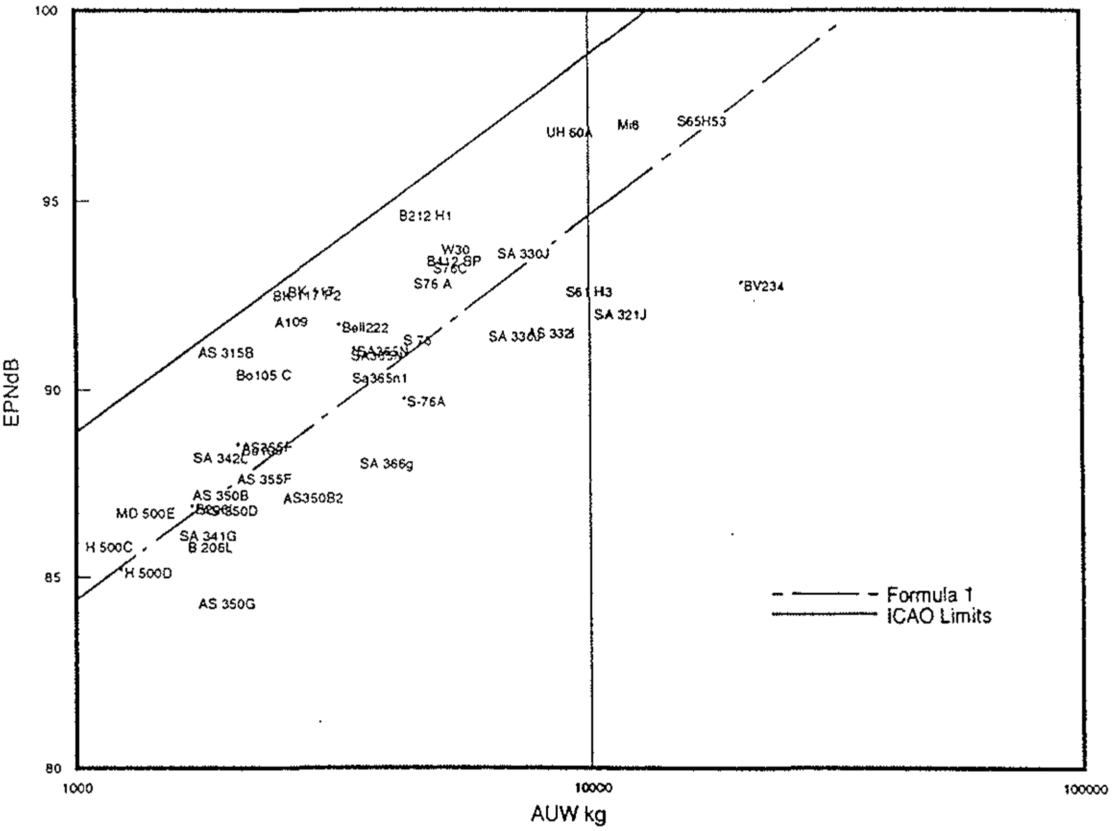

Figure 2. Flyover Noise vs AUW

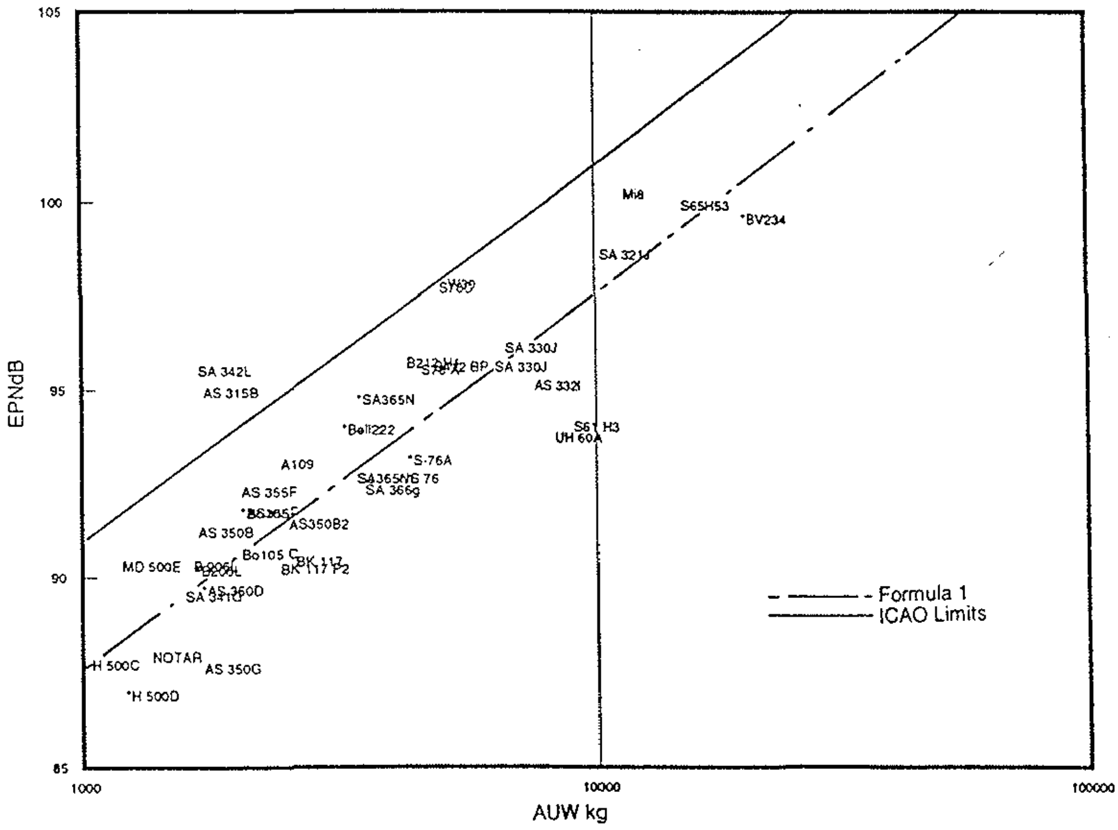

Figure 3. Approach Noise vs AUW

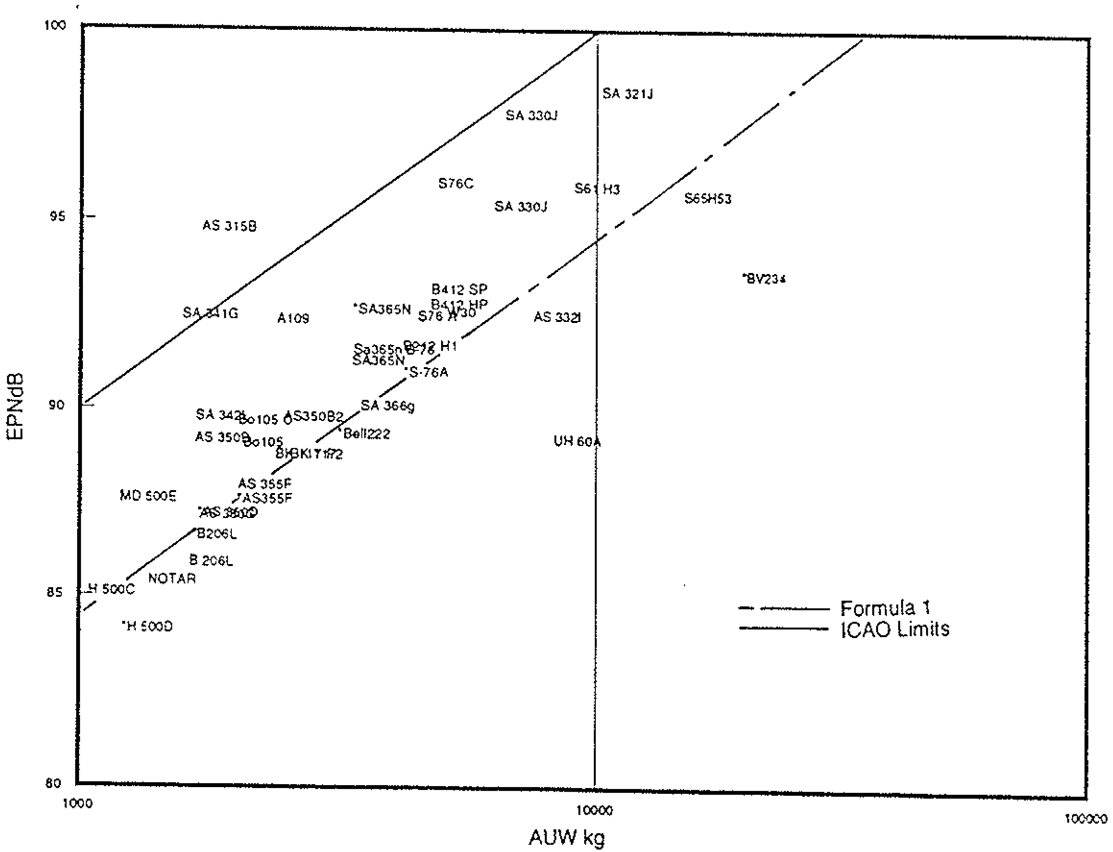

Figure 4. Take-Off Noise vs AUW

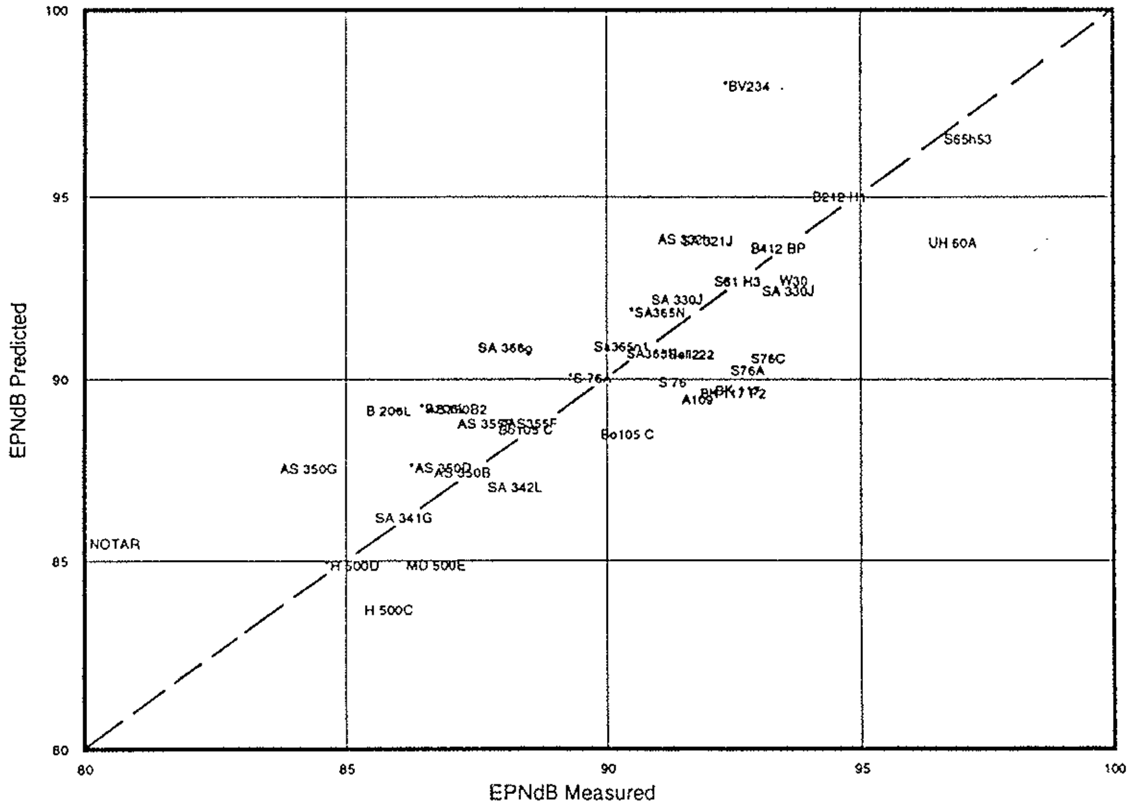

Figure 5. Flyover Prediction vs Data

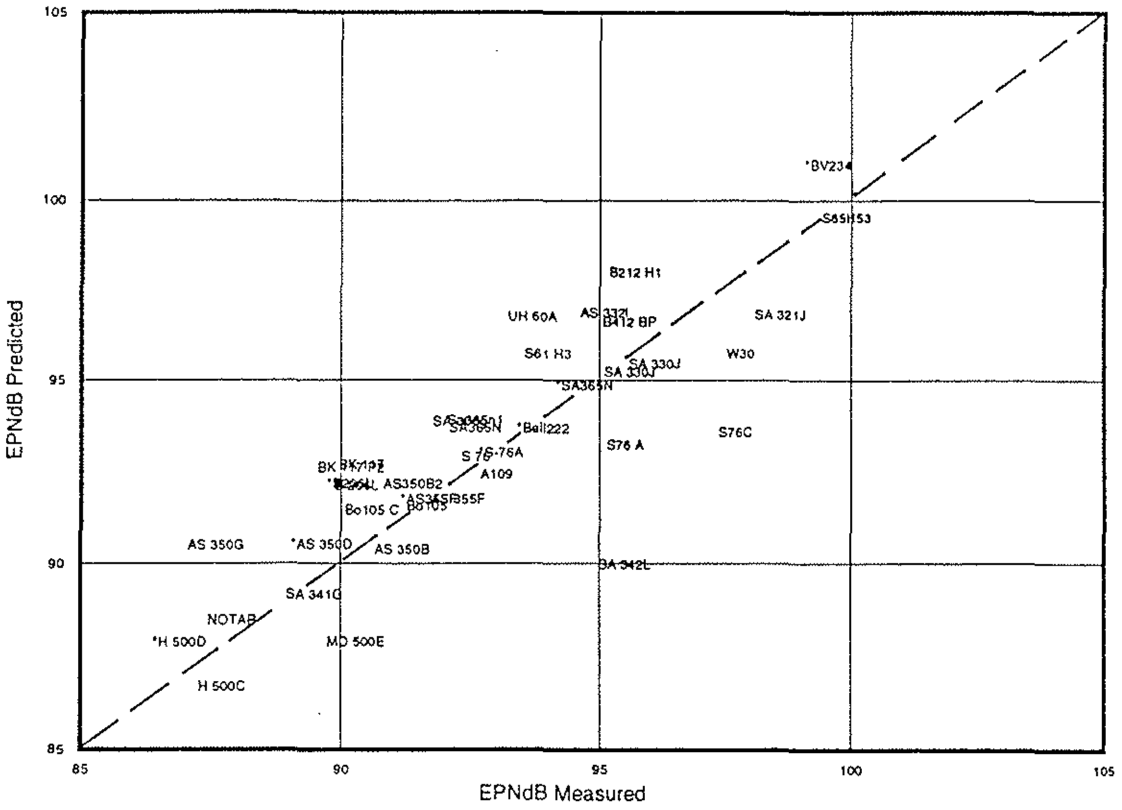

Figure 6. Approach Prediction vs Data

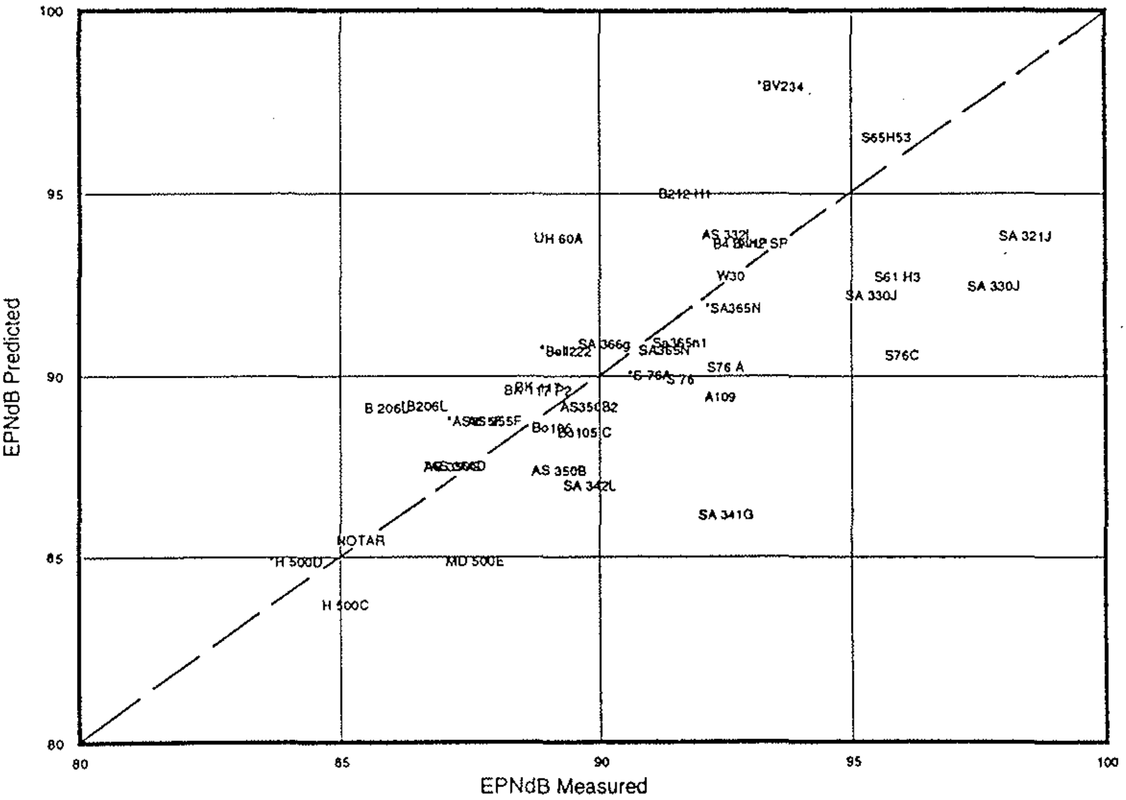

Figure 7. Take-Off Prediction vs Data