EIGHTEENTH EUROPEAN ROTORCRAFT FORUM

A - 06

Paper No 85

INFLUENCE OF DIFFERENT FLIGHT CONDITIONS ON HELICOPTER NOISE CONTOURS ON GROUND

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September 15 - 18, 1992

AVIGNON, FRANCE

ASSOCIATION AERONAUTIQUE AND ASTRONAUTIQUE DE FRANCE

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Abstract

Helicopter exterior noise measurements are presented which were performed for the verification of a noise prediction method in the vicinity of heliports. The test campaign has been supported by the German Federal Environmental Agency (FEA).

The measurement programme covered landing, take-off, and flyover conditions for the Eurocopter BO 105 and the Sikorsky CH 53. In addition, BO 105 hover and turn flight conditions were measured. The noise on ground was measured with 9 microphones, arranged in an array of 600x500 m. By varying the starting/landing point, 17 measurement positions were achieved for each flight condition covering a field of 600x1000 m.

The measurements are evaluated in form of noise contour footprints for maximum noise levels during flyover and time integrated noise levels like SEL. Special view is given to the noise reduction effect of steep approach flight conditions with glide path angles between 9° and 15° and steep take-off procedures.

It can be shown that the prediction methodology of the German Air Traffic Noise Control Act calculates too high noise levels for helicopters. By modification of the noise data base and the flyover time calculation, the accuracy can be considerably increased.

1. Introduction

By definition, noise is undesirable sound; its pressure disturbance can be measured objectively but not its annoyance. Sound measurements are conducted for the development of noise reduction measures as well as a basis for the assessment of the annoyance.

There is a common need to have a model for assessing helicopter noise exposure: For noise oriented planning of heliports, development and application of efficient and safe flight procedures, and as design criteria for the development of quiet helicopters.

Presented at the Eighteenth European Rotorcraft Forum, 15-18 September 1992, Avignon, France

Consequently, it is important for the heliport development, that the resulting noise index is compatible to noise indices of other noise sources in industry and in traffic. Since most noise is rated by using the A-weighted sound level, heliports should be treated in the same way. The advantage is, that heliports can then be included into a general assessment (Ref. 1 and 2).

The current state of the art in assessing heliport noise in Germany is based on a historical development. The German Air Traffic Noise Act provides a calculation scheme for community noise assessment due to aircraft operations. Although originally developed for civil and military airports, helicopters are also included. For helicopter movements on an airport, the accuracy of this procedure was sufficient, since the radiated noise energy is low compared to fixed wing aircraft. However, in the meantime, the calculation scheme is extended to heliports and is planned to be applied to military helicopter bases. Therefore, it is necessary to have available valide data sets of helicopter noise during various flight conditions. Furthermore, there must be a procedure which results in noise assessment levels comparable to those of other noise sources (industry and traffic).

In view of the above, the Federal Environmental Agency and ECD have started a helicopter noise measurement effort with the objectives to

- investigate the helicopter noise characteristics during various flight conditions
- investigate the applicability of the German Aircraft noise calculation procedure to helicopters
- create noise data sets of different helicopter types
- study noise abatement procedures

To meet these objectives, the tests are divided in two measurement campaigns. The first one presented in this paper reports about noise sensitivity tests with respect to various flight condition. The second test period will extend the actual helicopter noise data base.

The paper describes the first noise tests and presents initial results. The measured noise levels are compared with calculated results of the German Air Traffic Noise Control Act. Modifications for the "Act for Application to Helicopters" will be proposed. The paper treats A-weighted as well as energy-equivalent noise levels. Special problems such as rating impulsivity or tonal components are not treated in the paper.

2. Measurement Programme

The measurements have been conducted in August 1991 at the Bundeswehr airport Laupheim. The airport closed during the noise testing period offered a flat grass terrain with low ambient noise levels. The campaign consisted of three measurement days with 10h flight time, 8h for BO 105 and 2h for CH 53.

Acoustic Test Set-up

For the data acquisition, 9 identical microphones, arranged in a array of 500x600 m were used. The signals of the microphones - 1.2 m above ground - were transmitted to a 14 channel tape recorder. Special signal amplifiers, installed on each microphone position compensated the transmission losses due to the long cables. The arrangement is shown in Figure 1.

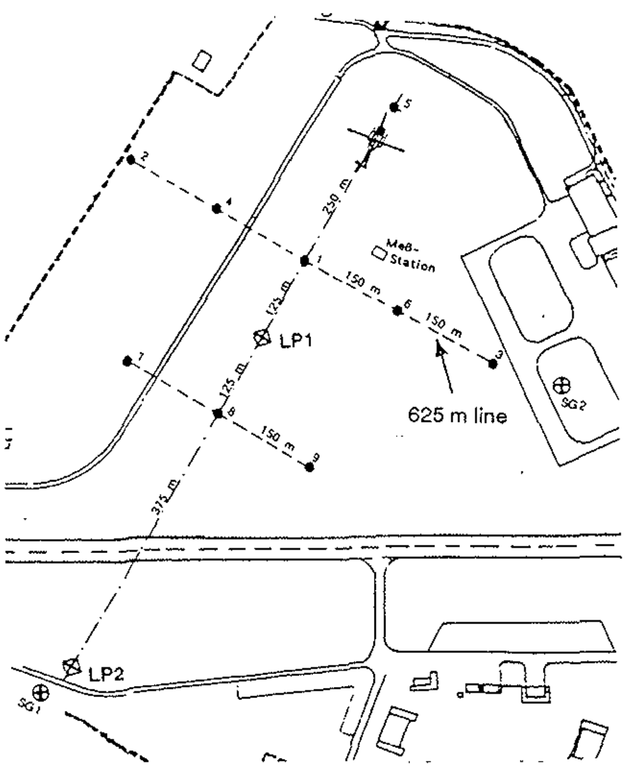


Figure 1: Measurement array: SG1 and SG2 are the positions of the flight path tracking system, LP1 and LP2 are the hover locations for the take-off and approach tests

For the BO 105, the measurement field was enlarged by definition of two landing points (LP1 and LP2). The landing point LP2 was placed in a way that both measurement arrays could be combined to a common one with 17 microphones. Only two microphones correspond to each other (Microphone 5, if landing point LP1 was used, Microphone 8 by using landing point LP2). In the common measurement array, this microphone position was used as a reference position. Figure 2 shows the resulting measurement array for both landing points.

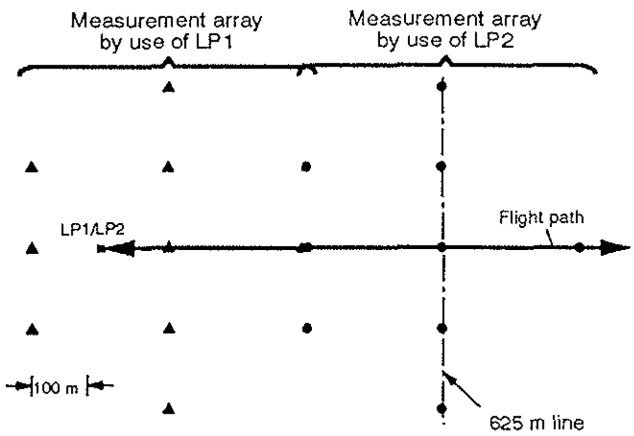


Figure 2: Enlarged measurement array by two landing points LP1 and LP2

Test Helicopters

Two test helicopters were provided for the measurement campaign by the German armed forces:

EUROCOPTER - BO 105 M (Figure 3)

max. take-off weight:	2300	kg
take-off weight during noise measurement:	≈ 2000	kg
fuel consumption:	≈ 180	kg/h
number of blades (main/tail rotor):	4/2	

Figure 3: Approach of a BO 105 to landing point LP1 with support of the visual guidance system.

Sikorsky CH 53 (Figure 4)

max. take-off weight:	18000	kg
take-off weight during noise measurement:	≈ 12350	kg
fuel consumption:	≈ 800	kg/h
number of blades (main/tail rotor):	6/4	

Figure 4: Sikorsky CH 53

Meteorological Data

Wind speed, wind direction, temperature, and humidity were measured by the Laupheim airport tower, situated in a distance of 750 m from microphone 1 (Figure 1). Except the first measurement day, wind speed was below 5 kt in average. On the first day, where only horizontal flyover procedures have been conducted, the wind speed was between 5 to 15 kt parallel to the flight path direction.

Flight Path Tracking System

For flight path data acquisition, a tracking system of the German armed forces was used. The system is based on the measurement of the Radar-Doppler effect of a moving object. The flight path data were actualized 4 times each second. The system provided the position of the helicopter in polar coordinates and the flight speed in kts.

Measurement Procedure

For an optimum use of the flight time, the test programme avoided flights without acoustic data acquisition. This means that

- flyovers were conducted in south-north direction and vice versa, and
- each approach measurement was immediately followed by a take-off condition.

In approach flight conditions, a visual flight path guidance system (VASI) was used. The BO 105 flew to both landing points, LP1 and LP2, whereas the CH 53 only used LP2.

A matrix of all measured fly-over, approach and take-off flight conditions for the two Helicopters is shown in Figure 5. In addition, noise measurements in hover condition were conducted. Furthermore, for the BO 105, turn flight measurements with two different bank angles in each direction were carried out.

Because the pilot was advised to hover above the landing point LP1 - within the microphone area - the planned horizontal and vertical flight speeds could not maintained during the whole flight procedure due to acceleration/deceleration effects.

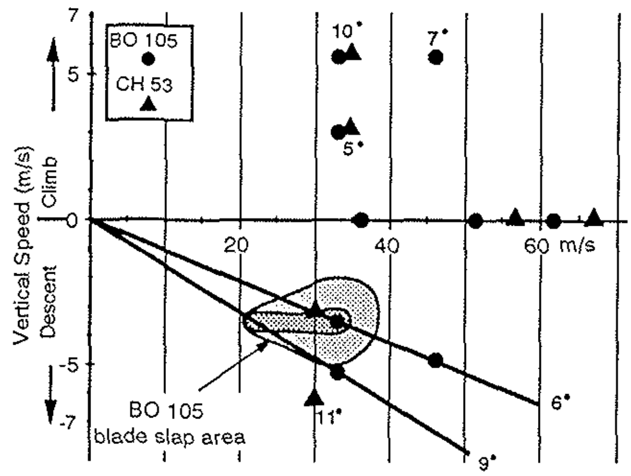


Figure 5: Test matrix for the BO 105 and the CH 53

In addition to the tests described in Figure 5, some flight conditions were measured without prescribed flight path. First, the pilots were told to fly typical approach and take-off procedures. In a second test series, the pilots tried descent and take-off flight paths with high flight path angles.

Acoustic Data Analysis

For each flight, the data of all 9 microphones were digitized in parallel. Afterwards 1/3 octave band spectra were calculated in 0.5 sec time steps. From these all further evaluations have been done. Corrections of the atmospheric conditions and flight path deviations were applied in accordance with the ICAO regulation Annex 16, Chapter 8. (Ref. 3)

Approaches and take-offs for the BO 105 made it possible to evaluate ground noise contours covering 600 m x 1000 m. For the above mentioned reference microphones, the noise level differences were in the range of 0.5 to 1 dB. Only measurements of the test conditions without prescribed flight path showed deviations of up to 2 dB.

The results of the data evaluation for each microphone position were:

- **A-weighted maximum noise levels L_{Amax} :**
  For each helicopter flyover the highest measured A-weighted noise level was analysed for each microphone position

- **Sound Exposure Level SEL :**
  Single noise events like the flyover of a helicopter are described by the SEL (Single Event Level). SEL sound pressure level is the integration of all noise energy during the flyover related to a time period of one second. The SEL can be described as the constant dB(A)-level which, if maintained for a period of one second, would produce the same A-weighted sound energy to the receiver as the actual event itself.

3. Measurement Results

3.1 Approach Tests

Approach flight tests have been conducted for 3 flight conditions with prescribed glide path and 2 conditions without fixed glide path. Figure 6 shows the noise contours for the maximum levels L_{Amax} together with the altitude and velocity during the descent flight. Approach 1 (6° glide path angle at 65 kt) which corresponds to ICAO noise certification approach procedure, shows the most extensive noise contour on ground of all conditions measured. It can be seen in Figure 5, that this approach lies directly in the intensive blade slap area of the BO 105.

Approach 2 has the same glide path angle like Approach 1 but at higher flight velocity. The noise level below the flight path far of the hover point is about 5 dB lower compared to Approach 1. Near the hover point the noise contour of Approach 2 increases as the pilots had to slow down for the final approach. Hereby the helicopter flew into the blade slap area which increases the noise around the landing point.

The third measurement in Figure 6 is a steep approach condition without prescribed flight path. The angles of this approach varies from 10° to 12° in the first phase of the approach and increased up to 15° during the end phase. The 85 dB(A) contour is the smallest of all measured approaches. However during transition from horizontal flight to descent flight the helicopter generated blade slap noise which enlarged the 80 dB(A) contour.

No Blade Slap was generated during Approach 3 (Figure 7a) with a glide path angle of 9° at 65 kt speed. Because of the absence of blade slap and the steep glide path angle, the 80 dB(A) noise contour for maximum flyover noise is significantly smaller than for the 6° approach and the typical approach which is shown in addition in Figure 7b. The glide path angles of the typical approaches were between 7° and 10°.

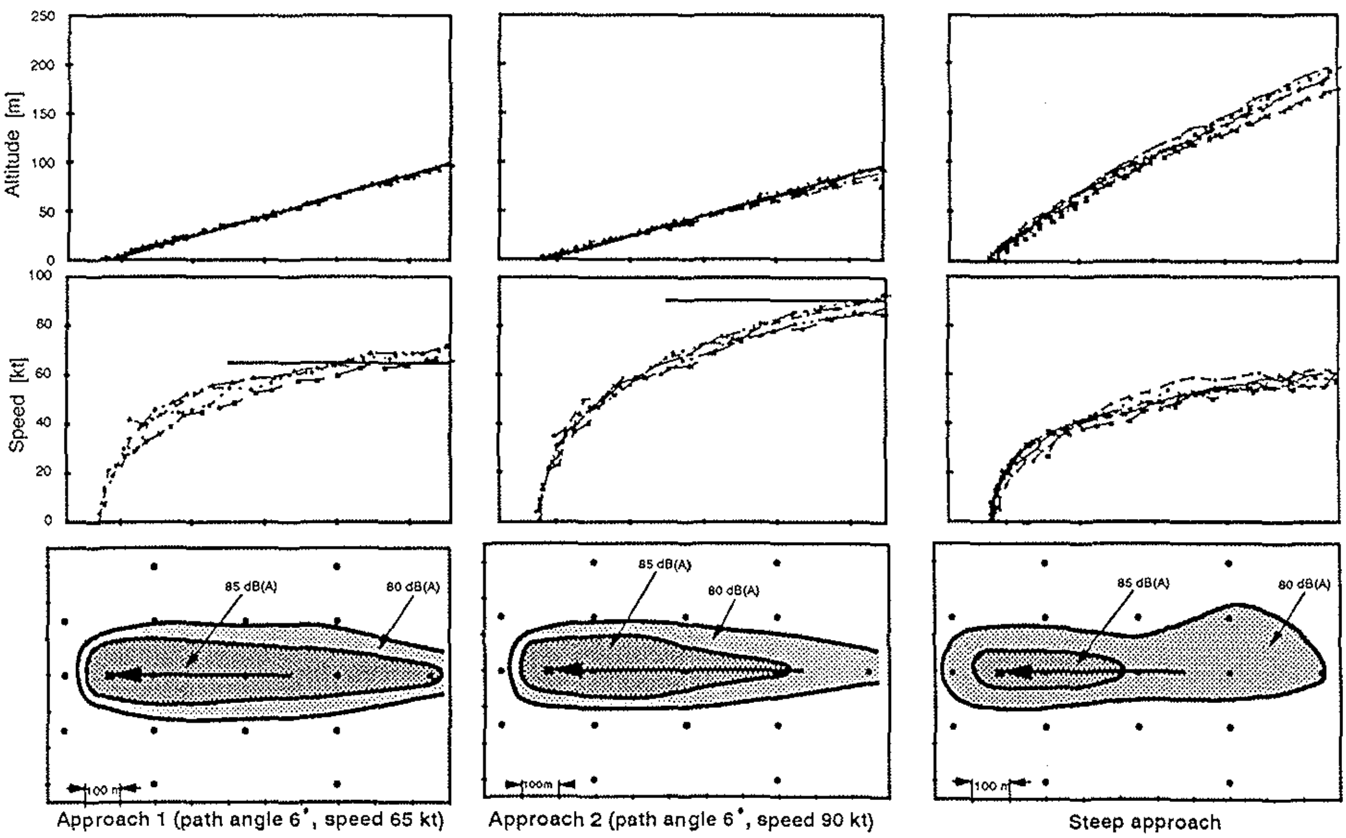
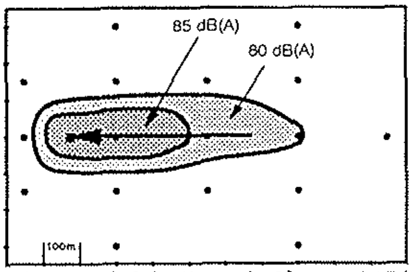
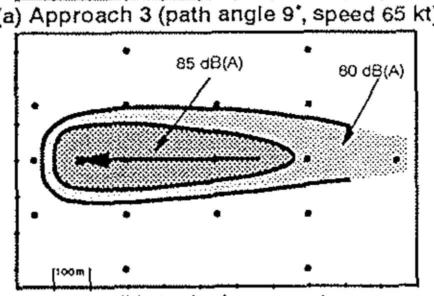


Figure 6: BO 105 L_{Amax}-contours for approach



(a) Approach 3 (path angle 9°, speed 65 kt)



(b) typical approach

Figure 7: BO 105 approaches: L_{Amax}-ground contours

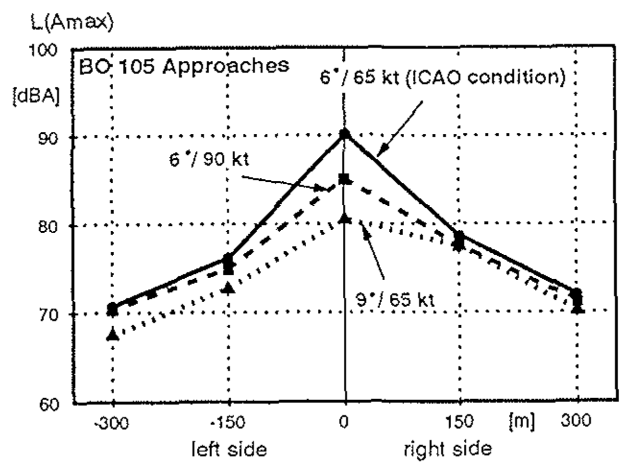
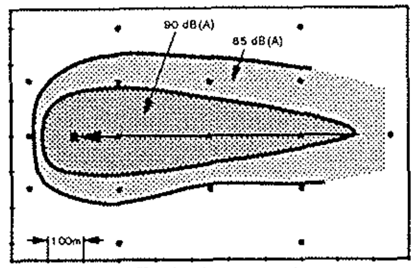


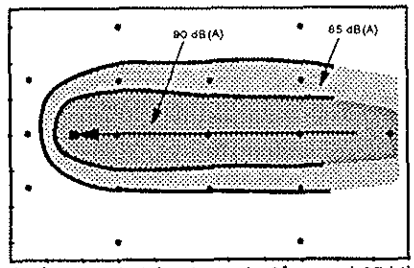
Figure 8: BO 105: L_{Amax}-levels for the approach conditions (microphone line 625 m ahead of the landing point)

The noise reduction dependency on approach flight condition can also be identified from the L_{Amax} signals of the 625 m microphone line (see Figures 2 and 8). If the 6° approach is flown with 90 kt instead of the ICAO- reference condition (65 kt), a L_{Amax} reduction of 5.5 dB was measured on the centerline. Reduction up to 10 dB(A) are achieved if the 9°/65 kt approach is considered. On the sideline microphones, no significant noise reduction is noticed.

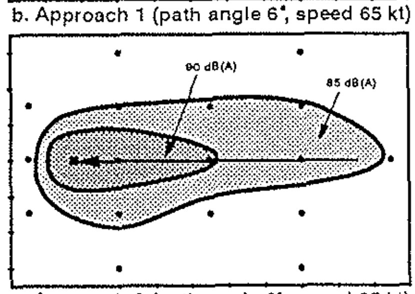
Similar contour shapes as in the case of the L_{Amax} measurement can be noticed for SEL-results. In Figure 9, SEL contour plots are presented for the ICAO noise certification approach with 6°, 9° and typical approach. The comparison between ICAO and 9° approach shows a significant reduction in SEL.



a. Typical approach



b. Approach 1 (path angle 6°, speed 65 kt)



c. Approach 3 (path angle 9°, speed 65 kt)

Figure 9: SEL-contours for BO 105 approaches

Contrary to the BO 105, the CH 53 helicopter generates impulsive noise at higher glide path angles. Noise measurement results for the 6° and 11° approaches are shown in Figure 10 for the 625 m microphone line. At sideline microphones, the 11° approaches show the same noise levels comparable to or even louder than the 6° approaches, especially on the advancing blade side. Here the L_{Amax} and SEL of the approaches with 11° are up to 3 dB(A) louder than those of the 6° approaches. Only due to the greater flyover height, the centerline microphone position shows lower noise level for 11° approaches. A difference in a maximum noise level of about 6 dB could be theoretically expected, whereas the measured difference was only 4.5 dB.

As can be seen from the previous discussion, for approach flight conditions, a direct dependency between steepness of glide path and noise contour cannot be expected. Whereas the BO 105 has intensive noise emission at moderate glide path angles around 6°, the CH 53 shows high noise levels at quite steep approaches which are often recommended for noise abatement.

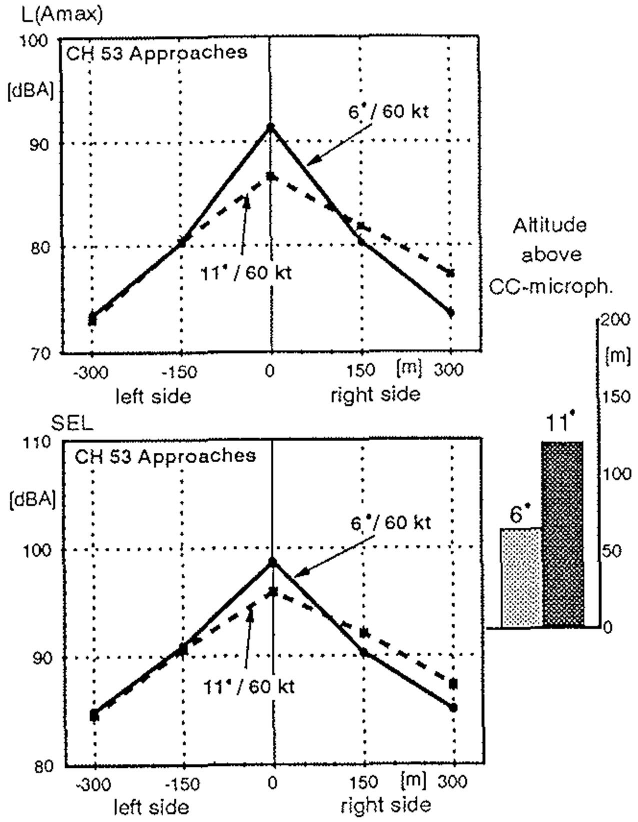


Figure 10: CH 53: L_{Amax}- and SEL-levels for approach conditions (microphone line 625 m ahead of the landing point)

This shows the necessity of extensive helicopter noise measurement for the definition of appropriate noise abatement approach procedures.

3.2 Take-off Tests

All take-offs were started from a hover condition in ground effect. Then the helicopter accelerated to the planned vertical and horizontal flight speed. This acceleration phase took place mainly above the microphone array. A constant flight speed was reached outside the measurement array.

The most significant take-off measurement results for the BO 105 are shown in Figure 11. Noise contours are provided together with flight path data for a prescribed take-off procedure with 10° flight path angle, typical take-offs and steep take-offs.

Because of the high flight path angle of the 10° take-off, the noise contours are small compared to the typical 6° take-off. The steep take-off is described by a short vertical climb phase and a subsequent climb phase with about 10° path angle.

The noise contours of take-off conditions with 5° and 7° flight path angles are not reported here because of their similarity to the typical take-off.

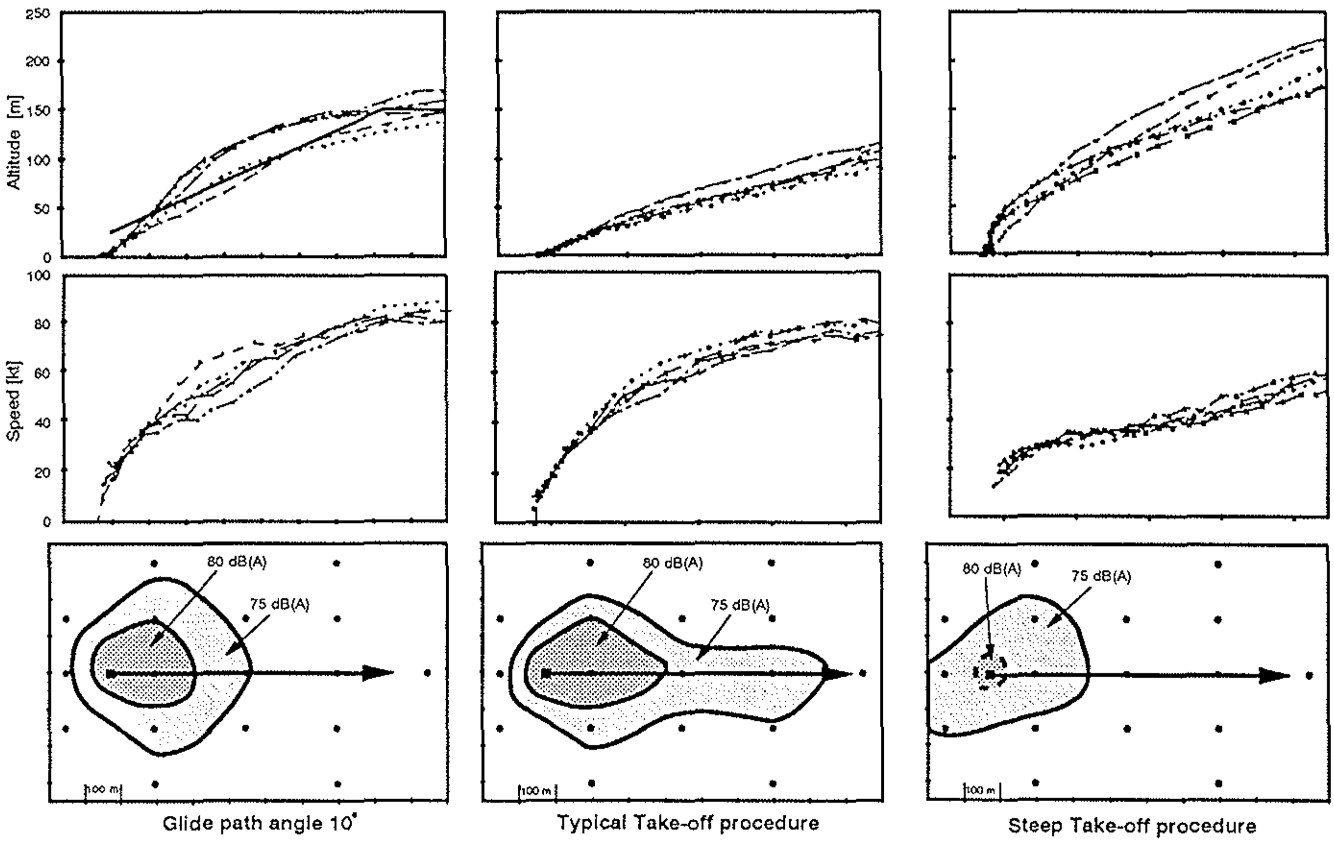


Figure 11: BO 105 L_{Amax}-contours for take-offs

The increased height above the microphones due to the vertical climb phase of the steep take-off leads to a significant noise reduction at the centerline microphone positions. This is shown in Figure 12 for the 625 m microphone line (Fig. 2). The bars on the right hand side of Figure 12 indicate the attained height above the centerline microphone.

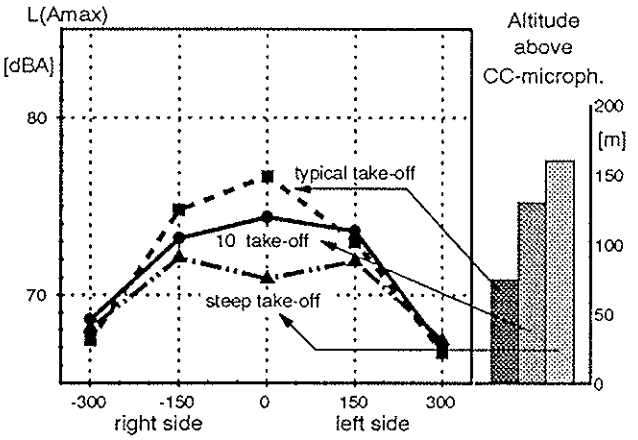


Figure 12: BO 105: L_{Amax}-levels for take-off procedures (microphone line 625 m away from the landing point)

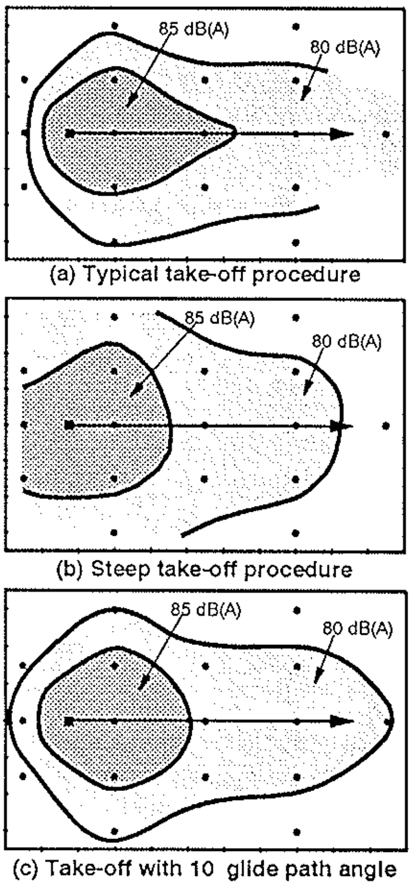


Figure 13: SEL-contours of BO 105 take-offs

The maximum flyover noise levels during take-off are directly dependant on the steepness of the take-off flight path. So the measurement results could lead to the conclusion that a very steep take-off with a short phase of vertical climb starting from the hover point would be the best way to fly with low neighbourhood noise annoyance. However, in this flight condition the helicopter will stay a long time close to the hover point which increases time integrated noise levels like the SEL-level.

Figure 13 shows SEL-noise contours for the steep take-off (a) compared to the typical take-off (b). As expected, in flight path direction, the 80 dB(A)-SEL-contour of the typical take-off is smaller than the steep take-off due to the increased height above the microphones. But around the hover point, the noise contour of the steep take-off is significantly larger.

A low noise 10° take-off procedure for the BO 105 representing a compromise between low maximum noise levels and acceptable SEL-noise contours, is described in Figure 13 (c).

Measurement results for the CH 53 helicopter are presented in Figure 14. The difference to the BO 105 noise levels during take-off is in analogy to the weight difference of the two helicopters around 7 to 8 dB(A).

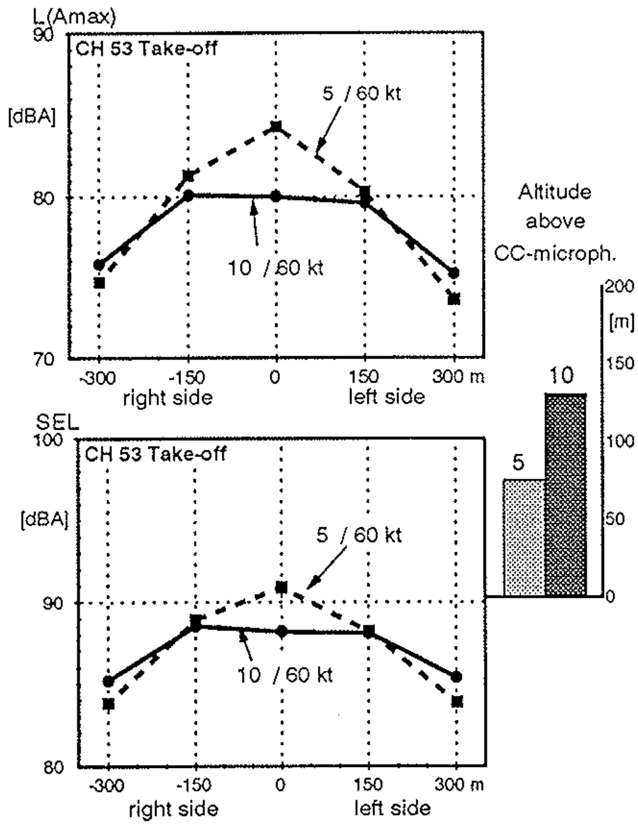


Figure 14: CH 53: L_{Amax}- and SEL-levels for take-off conditions (microphone line 625 m ahead of the landing point)

The take-off results at the outside microphone positions show higher noise levels in the case of the steep flight path angle. The helicopter is louder during the steep take-off and this can be noticed at these microphones, because there is only less distance effect between the two flight paths. The same effect can also be noticed for the BO 105 in Figure 12: Here the noise at the outside microphones are louder for the steep take-off than for the typical take-off.

3.3 Turn Flight Conditions

Right and left turns have been flown to get a first insight in the acoustic characteristic of turns. Two different turn flight condition were selected:

- Radius 100 m and 65 kt flight speed leads to 48° bank angle
- Radius 200 m and 75 kt flight speed leads to 37° bank angle

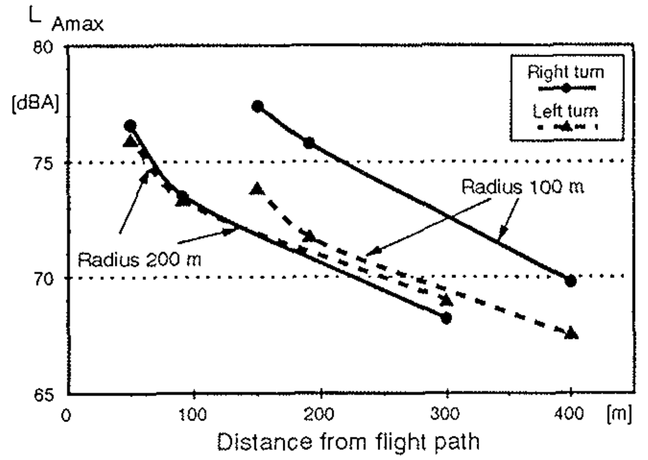


Figure 15: L_{Amax}-levels for BO 105 turn flight conditions

In Figure 15, the measured L_{Amax} levels are provided for microphone positions on the outside range of the curves. The data indicates, that the right turns with high bank angle are about 3 dB(A) louder than the corresponding left turn. This effect cannot be noticed for the turn with the lower bank angle. Here, right and left turn nearly yield the same noise levels.

4. Discussion of the Public Noise Regulation

4.1 German Air Traffic Control Act

Helicopter noise during flyover can be calculated with a good accuracy by high sophisticated prediction codes. However, these codes require large effort for high resolution input data establishment and noise calculation. Therefore, simple noise prediction models have been developed for heliport noise assessment which are mainly based on measurement results.

One of them, used in Germany, is described in the "Instructions for the Calculations of Noise Protection Areas (AzB)" (Ref. 4). It is based on the summation of the maximum A-weighted noise level L_{Amax} during flyover and a correction for the flyover duration using an estimation of the 10-dB-down-time t_{10}. The time duration t_{10} is the time interval between the first and the last instant at which the A-weighted sound level is within 10 dB of the maximum value (Figure 16).

The corresponding L_{Amax}-level for an individual point is calculated by aircraft data sets and by the distance vector perpendicular to the flight path. Based on the resulting level, the equivalent continuous A-weighted sound level L_{eq} for a defined number of flights within a time period T (here: 6 months) is calculated.

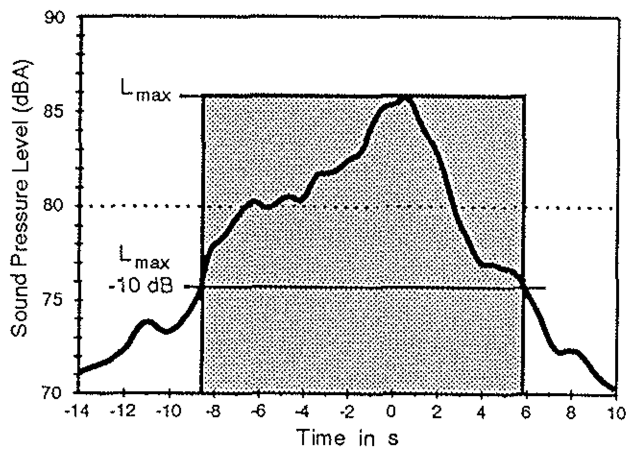


Figure 16: Flyover noise level based on the maximum noise level and duration of the noise event

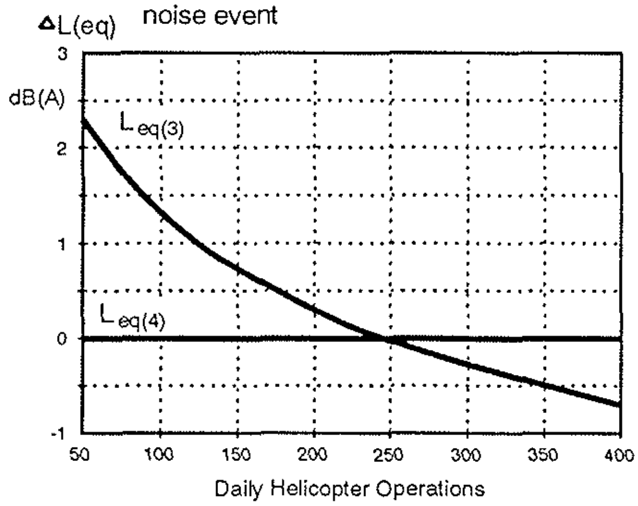


Figure 17: Differences of $L_{eq(q=3)}$ and $L_{eq(q=4)}$ versus number of flights

For the L_{eq}-calculation, the influence of the time integration of noise events is given by the equivalence parameter q. The parameter specifies the level difference, if the duration of the noise or the number of noise events is doubled. In international standards, an equivalence parameter q=3 is used, whereas the German Air Traffic Noise Act requires a value of q=4. In Figure 17, the resulting difference between both equivalence parameters is shown as a function of the number of flights.

For characterisation of the different aircraft, data sets are available dividing aircraft in different classes and flight conditions. Helicopters are classified into only two weight classes, below and above 2500 kg take-off weight, with a difference of 10 dB in noise level. These data sets are applied for noise prediction of all flight conditions.

The resulting noise levels for an airport or a military helicopter base calculated from the corresponding data will be compared with limits based on statistical annoyance tests. In Germany, two limits are used: Zone 1 means a L_{eq} above 75 dB(A), zone 2 above 67 dB(A). The levels represent a compromise between the community annoyance and the need for aircraft operations.

For civil heliports, the "Instructions for Calculations" are applied in the same manner, but with an equivalent factor of 3 instead of 4. The resulting L_{eq}-value will be compared with the recommended noise level criteria for residential and commercial zones summarized in Table 1. Both criteria mean a very strong restriction in the number of helicopter movements near populated areas - the use of q=3 at least for low flight numbers.

Type of district	L_{eq} - limit dB(A)	
	day	night
Rural residential, zones of hospitals	45	35
Suburban residential	50	35
Urban residential	55	40
Urban residential with some business	60	45
City (business, trade, administration)	65	50
Industrial area	70	70

Table 1: German criteria for equivalent continuous noise levels recommended for different types of district

Considering the significant dependency of helicopter noise on flight condition - differing strongly from the corresponding fixed wing characteristics - a more accurate description of helicopter noise data will lead to a higher sensitivity of noise prediction. In addition, inadequate restrictions of helicopter operations will be avoided.

4.2 SEL-equivalent value

The result of all neighbourhood noise assessment schemes, like the German air traffic noise act as well as the day-night level used in USA and Australia, is the equivalent continuous sound level L_{eq} during the measurement period. The best way to get L_{eq}-levels is to measure it directly. However this requires long measurement times and many measurement points. Therefore, prediction methods based on aircraft noise data are established to calculate L_{eq}-levels (Ref. 4 and 5). One method is described in the "Instruction for Calculation of Noise Protection Areas" in the German Air Traffic Control Act.

Single noise events like the flyover of a helicopter are best measured by the SEL (Single Event Level). SEL is especially useful when dealing with an environment in which a number of different types of noise events occur. These may differ because of various aircraft operating or because of different flight conditions and flight paths of these aircraft.

The L_{eq} can be readily calculated from the SEL levels as follows:

$$L_{eq} = \frac{q}{0.3} \cdot \log\left(\frac{1}{T} \cdot N \cdot 10^{(SEL \cdot 0.3/q)} \right)$$

where N describes the number of operations and T is the measurement period. The equivalence parameter q indicates how much the sound pressure level increases by doubling the number of noise events. If energy equivalence is measured, the parameter has to be 3.

If there are different noise sources k (e.g. different helicopters) flying with different distributions D_i on flight paths i, the L_{eq} calculation changes to

$$L_{eq} = \frac{q}{0.3} \cdot \log\left(\sum_i D_i \cdot \sum_k 1.5 \cdot N_{ik} \cdot \frac{1}{T} \cdot 10^{(SEL \cdot 0.3/q)} \right)$$

The factor 1.5 is used if there are only flights during day time (6.00h to 22.00h). If the above definition is set equal to the definition of L_{eq} in the German Air Traffic Noise Control Act (AzB), the result is

$$\frac{1}{T} \cdot 10^{(SEL \cdot 0.3/q)} = A_{i,k} = \frac{1}{T} 10^{L_{Amax} \cdot 0.3/q} \cdot t_{10}$$

$A_{i,k}$ is the sound of the helicopter k on the flight path i. Based on the L_{eq} calculation of the Noise Control Act (AzB), a level similar to the SEL can be derived for comparison with measurements:

$$SEL_{AzB} = \frac{q}{0.3} \cdot \log\left(10^{L_{max} \cdot 0.3/q} \cdot t_{10} \right)$$

The formulation contains some simplifications which are valid for the comparison with the measurements: Only one helicopter type is considered and no corrections for lateral flight path deviation are regarded as all these deviations are already taken into account in the correction of the measurement results.

Finally, the SEL equivalent value for L_{eq} calculations in accordance to German regulations yields

$$SEL_{A,zB} = L_{Amax} + \frac{q}{0.3} \cdot \log(t_{10})$$

If the measurements are analysed with an equivalent parameter of q=3, the SEL reads

$$SEL_{(A,zB,q=3)} = L_{Amax} + 10 \cdot \log(t_{10})$$

This function means: The single event level according to the noise assessment procedure is calculated by the level L_{Amax} held constant over a duration time t_{10} (Figure 16). By application of this procedure, a deliberate overestimating of the real L_{eq} in the neighbourhood noise is incorporated in order to safely define noise protection zones. This can be shown by Figure 18: Here measured SEL-levels of BO 105 and CH 53 flight conditions are compared to the SEL-equivalent values according to the above formulation. The L_{Amax}-values and t_{10}-durations are taken from the same measurements. This procedure is applied by German local authorities for heliport certification. It can be seen that the formulation of the SEL by L_{Amax} and t_{10} ends up with 3 to 5 dB(A) higher SEL-equivalent values compared to the direct measured SEL.

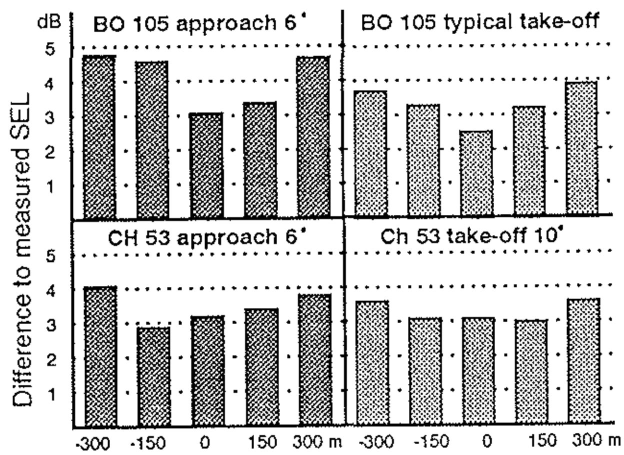


Figure 18: Deviations of SEL-equivalent values with measured SEL values

Some countries favour noise assessment models which are based direct on SEL-measurements, like it is the case in the Helicopter Noise Model (HNM, Ref. 5). But it must be noted that there is also no realistic noise radiation model for SEL-levels. The calculation from a measured point to another point in the neighbourhood has to be done also via a flyover time duration or, like it is done by the HNM, by definition of lateral attenuation coefficients for extrapolation routines based on measured data in different distances. However, if no flyover time is regarded the model will not be able to take in account any change in flight speed. Therefore, the model based on L_{Amax} and flyover duration offers some advantage in application of the model to heliports.

4.3 <u>Comparison of the prediction scheme with measurement</u>

In the calculation procedure an estimation for the t_{10} duration is given:

$$t_{10} = \frac{5 \cdot s}{\left(V + \frac{s}{30}\right)}$$

where s means the distance perpendicular to the flight path and v is the flight velocity.

Figure 19 presents a comparison of measured t_{10} durations with the above formulation. Except of the CH 53 approaches, the prediction equation calculates always too high values.

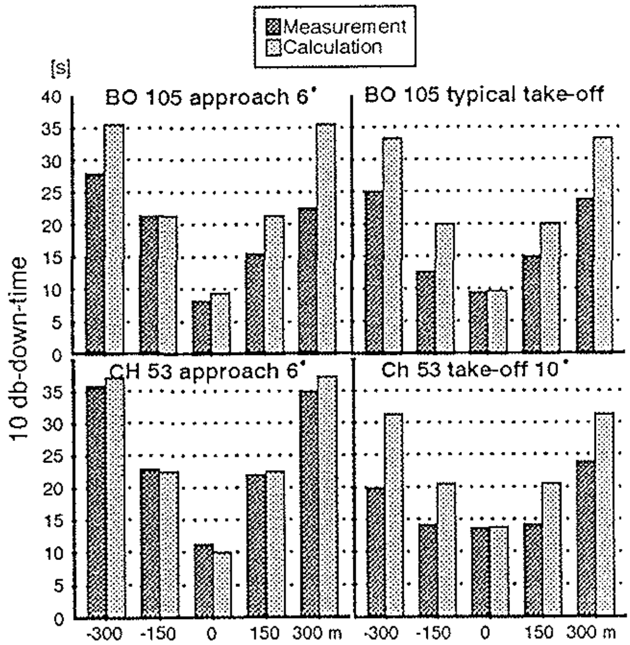


Figure 19: Comparison of measured 10-dB-down-times with prediction formulation

Prediction of the SEL-equivalent levels derived in chapter 4.2, are compared with measured SEL-values in Figure 20. The data sets are normally based on a flight path angle of 11° for take-off and approach with a flight speed of 30 m/s. However, for a better comparison, the actually measured values were used.

The prediction model overestimates again the SEL-measurements. Only the BO 105 approach with 6° glide path angle which is one of the loudest flight conditions of the BO 105, shows a lower difference between calculation and measurement.

These differences are based on too high tabulated noise levels and fly over durations, as well as the prediction scheme itself, as shown in Figure 18. Consequently, the over-prediction provides larger airport noise protection zones than measured, however there is no direct restriction to helicopter operations. The protection zones lead to restriction in housebuilding and to noise protection measures on existing buildings. As such a conservative approach seemed to be reasonable and there were no sufficient helicopter noise data available during the establishment of the model, an overestimation was accepted.

However, if one considers that the actual noise assessment method is used for small heliports which are compared to other noise sources, an overestimation of the helicopter noise should be avoided. Taking into account that a 10 dB difference in noise levels means a change in helicopter operation numbers by a factor of 10 (for q=3), it is evident that the prediction scheme in its current state will discriminate heliports.

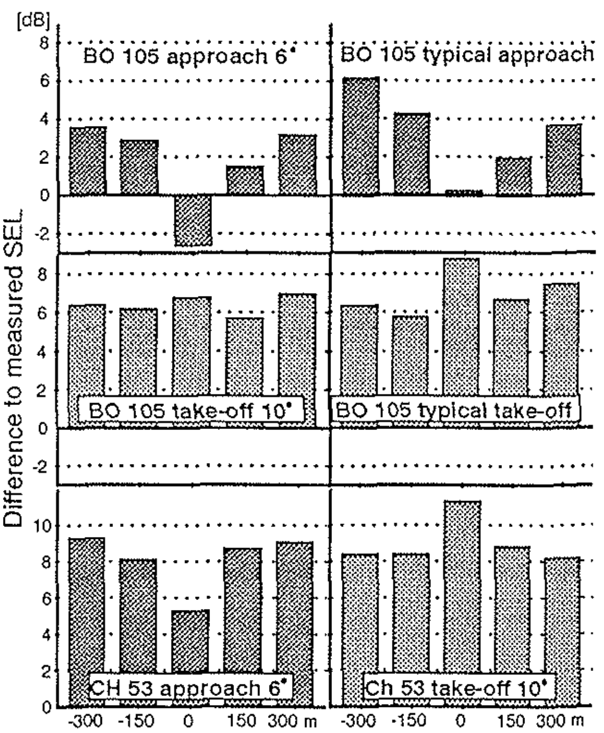


Figure 20: Differences of predicted SEL-equivalent values with measured SEL-values (calculated in accordance to the Air Traffic Control Act)

A first improvement would modify the prediction scheme, as follows:

- Separate data sets for take-off and approach
- Noise certification flight conditions for data set generation should be used are as far as available. The noise spectra are evaluated by averaging the noise on the advancing and retreating side.
- The duration prediction scheme is changed to

$$Approach:\quad t = \frac{3\cdot s}{V+\frac{s}{20})}$$

$$Take-off:\quad t = \frac{2.5\cdot s}{\left(V+\frac{s}{10}\right)}$$

Especially for take-off, the duration prediction is shorter than the 10-dB-down-time. However, as described in Figure 18, if the calculation of the SEL equivalent value is based on the 10-dB-down-time, the duration is overestimated.

The differences between the modified model and the measurements are illustrated in Figure 21. Compared to the original model, a significant improvement in the noise prediction is achieved. As the approach noise data set is based on the 6°-approach, the typical approach (7° to 9°) shows higher deviations. This again confirms the strong dependency of noise emission characteristics (particular Blade Vortex Interaction (BVI) occurrence) on the approach flight condition. Due to the lack of BVI, this effect is not as significant for take-off conditions. Hence, the differences between prediction and measurement for the typical take-off do not differ strongly from those of the 10° take-off, utilized for generating the modified data set.

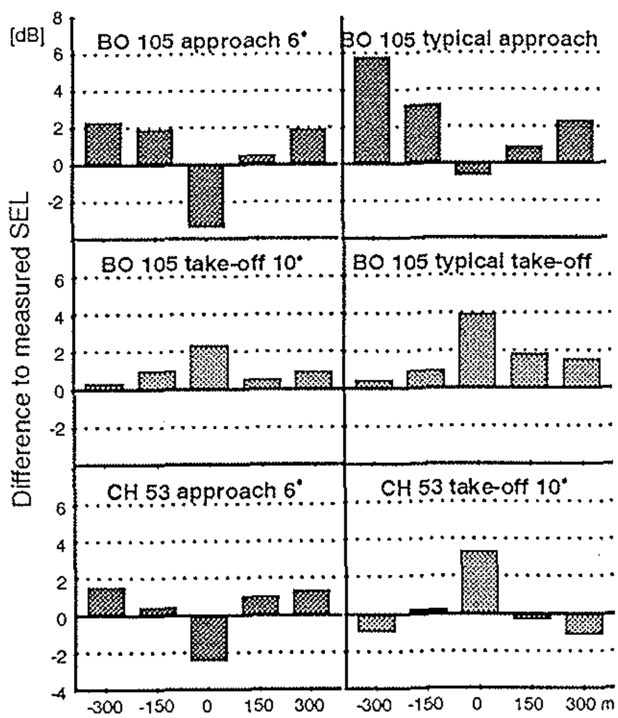


Figure 21: Differences of predicted SEL-equivalent values of the modified model with measured SEL-values

But even with the modification, the model in the current form does not fully represent the noise radiation characteristics of helicopters. Whereas during take-off the centerline microphones are estimated higher than measured, in approach condition the noise on the centerline is underestimated. At the sideline microphones, the deviations are in the range of similar noise assessment models like the Helicopter Noise Model (HNM, Ref. 3).

This can also be seen from the noise contour prediction in Figure 22. The extension of the predicted noise contours to the side regions complies well with the measured data, whereas on the centerline, an overestimation is noticed. A special problem exists in the vicinity of the landing point where the hover noise emission must be considered. Since the current model is originally made for airplanes, hover is unknown in the prediction method. However, it can easily be incorporated by using a pertinent data set and an appropriate duration time. The resulting SEL value must then be added to the flyover level for all positions around the hover point.

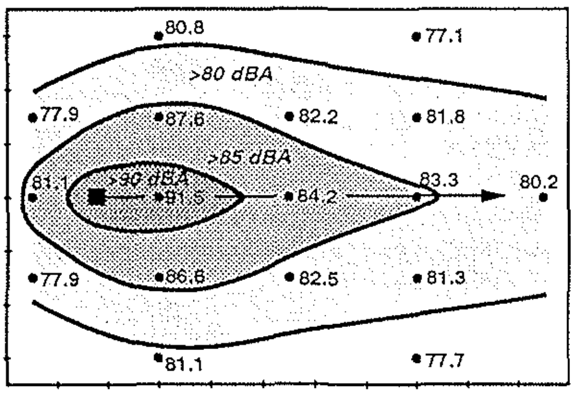


Figure 22: Comparison between measurement and prediction of the noise ground contour for 10° take-off with the modified model

Conclusion

The first measurement programme for noise contour calculation led to the following accomplishments:

- For approach condition, noise emission generally is not dependant on glide path steepness. Only near centerline, steep approaches use to be quieter due to distance effect. Here, noise reductions up to 10 dB(A) were achieved.
- For take-off conditions, $L_{A_{max}}$ is significantly reduced by steep flight paths. However, SEL levels are increased for steep take-offs near the starting point as there the acceleration of the helicopter is low and therefore the flyover duration increases.
- On the outside microphones the distance effect of steep path angles vanishes. Therefore, if the helicopter only passes at the side of populated areas, flight procedures with steep path angles are not automatically the best noise abatement procedure.

The measurement results have been compared with the German aircraft noise assessment model of the Air Traffic Noise Control Act which is mainly oriented towards prediction of noise protection zones of large airports. Therefore, the model requires adaption to specific helicopter noise phenomena. Especially typical flight conditions like hover or BVI must be considered.

In order improve the Act for helicopter application, first modifications were proposed. It could be shown that with these improvements, a significant increase of prediction accuracy could be achieved.

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