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HELICOPTER NOISE CERTIFICATION AND SENSITIVITY STUDIES ALONG THE PROCEDURAL LINES OF THE NEW ICAO ANNEX 16 / CHAPTER 8 REGULATIONS

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Abstract

This paper discusses the noise-measurement experience gained in the application of the new ICAO Annex 16 / Chapter 8 helicopter noise certification Standard as well as results from recent noise sensitivity studies on two modern-design helicopters. The measurement procedure, the data acquisition and reduction as well as the applied correction procedures are briefly described. Effective Perceived Noise Levels (EPNL) and other noise descriptors are evaluated and related to the present ICAO noise limits. The reproducibility of noise data is demonstrated for one helicopter. The sensitivity of EPNL on variations in test airspeed, rotorspeed, aircraft weight and flight altitude are shown and the need for a source-noise correction is emphasized.

1. Introduction

In November 1981, the International Civil Aviation Organization (ICAO) introduced an "International Standard" on the noise certification of helicopters, as developed and proposed by Working-Group B of the ICAO-Committee on Aircraft Noise (CAN). The pertinent rules, regulations and specification of this Standard are laid down in Chapter 8 and Appendix 4 of ANNEX 16 to the Convention on International Civil Aviation [1]. New helicopters, as of this date, are required to comply with certain noise-rules, whereby their noise under specified flight- and operational conditions is not to exceed a weight-dependent noise-limit.

In preparation for this new Standard, a fair number of helicopters were tested for their noise characteristics through the efforts of research-establishments and national aviation authorities as well as some manufacturers, and the ensuing noise data were taken as the basis for setting appropriate noise limits. Accordingly, a great number of modern civil helicopters are able to comply with the current rules. On account of the rather recent introduction the Standard is presently only applicable to new helicopters and from a certain future date also to derivatives.

Thus, there are two major areas of interest in the context of helicopter noise certification, namely (1) to gain actual field-test-experience in the acquisition, reduction and evaluation of helicopter noise data along the procedural lines of the present ANNEX 16 Chapter 8 specifications, and (2) to test the sensitivity of the certification procedure - the selected noise metric "Effective

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Perceived Noise Level" in particular - on various operational and flight-, as well as aircraft-specific design parameters.

In the following - after a brief description of the new Certification Standard - noise data for two modern helicopters will be presented and assessed against the current noise-limits, and the effect of changing flight-speed, rotor-rotational speed, take-off mass and flight altitude on the noise metric EPNL be demonstrated. Certain conclusions will be drawn on possible improvements and on current areas of uncertainty in the scheme, based not only on the measurement of a (limited) number of test helicopters, but also on experience obtained in field-measurements for noise-certification purposes in the course of over 300 propeller-driven aeroplane noise-tests as conducted by the DFVLR Technical Acoustics Division / Braunschweig.

2. Helicopter Noise Certification Standard - ANNEX 16 Chapter 8/ Appendix 4

The helicopter noise certification Standard spells out the reference noise measurement points and flight procedures, the noise-evaluation measures, - adjustments, -validities and -limits, as well as certain trade-offs.

2.1 Reference Noise Measurement Points and Reference Flight Procedures

The helicopter to be noise tested is required to conduct a series of (a) take-offs, (b) level overflights, and (c) landing-approaches. In each case, the craft must fly over the noise measurement-station which consists of a centrally located microphone - the flight path reference point (C) - and two additional microphones (L and R), symmetrically displaced 150 m to both sides of the flight path as shown in Figure 1 (L ≙ left-hand microphone, R ≙ right-hand-microphone with respect to the flight direction).

The reference flight procedures shall be established with maximum certificated take-off mass, with stabilized rotor speed at the highest normal operating RPM, and with stabilized airspeeds of V_y (the best rate of climb speed) for take-off and approach, and of 0.9 V_H (the maximum speed in level flight at power not exceeding maximum continuous power) for overflight, respectively.

For *take-off* (Fig.1-a) the helicopter shall be stabilized at the maximum take-off power and at the best rate climb along a path starting from the rotation-point located 500 m forward of the flight path reference point (C), at 20 m above the ground.

For *level overflight* (Fig. 1-b) the helicopter must be in cruise configuration and stabilized in level flight overhead the flight path reference point at a height of 150 m.

For *landing approach* (Fig. 1-c) the helicopter shall be stabilized in its landing configuration (e.g. landing gear down) and following a 6° approach path passing overhead the flight path reference point at a height of 120 m.

These specified flight procedures also define the reference flight paths which shall be used for correction purposes to bring the measured data to reference conditions.

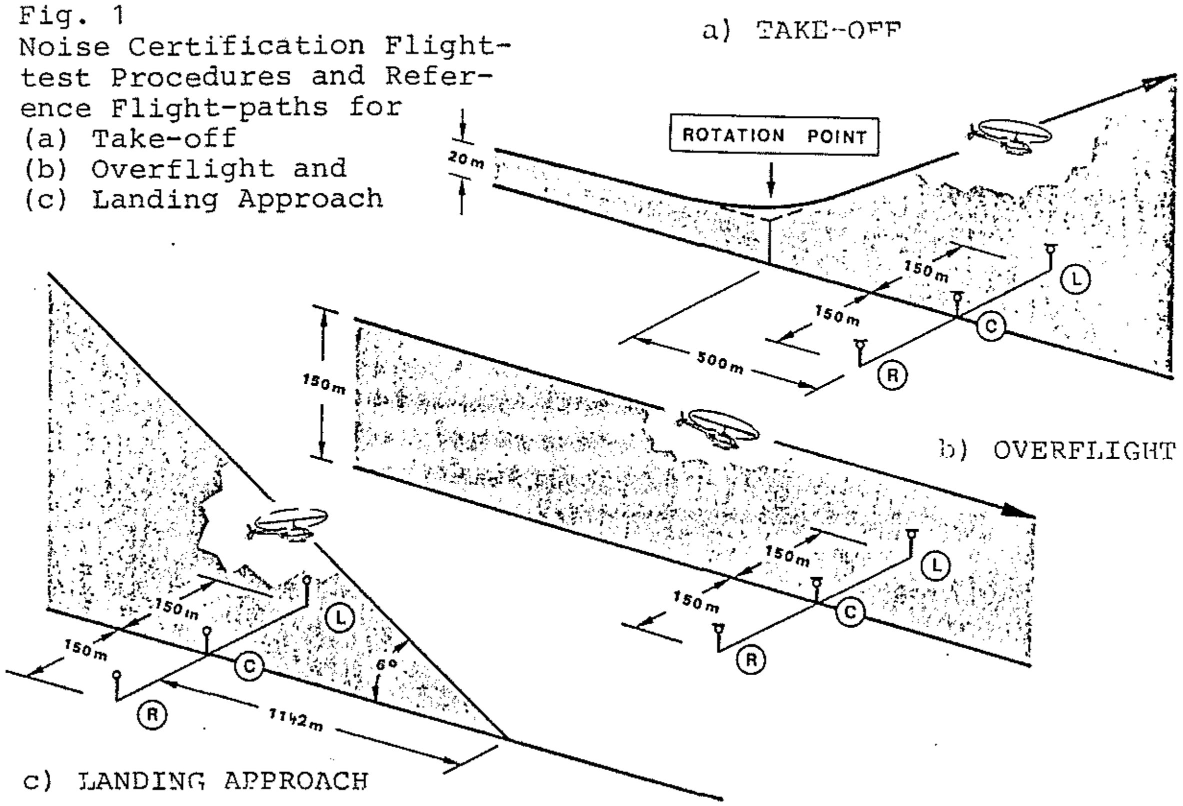

Fig. 1
Noise Certification Flight-test Procedures and Reference Flight-paths for
(a) Take-off
(b) Overflight and
(c) Landing Approach

2.2 Noise Evaluation Measure

Since the overflight noise signature of a helicopter varies strongly with time, both in intensity and spectral content, there was a need to select a single-number noise-descriptor for the subjective response to aircraft noise. A very appropriate descriptor, or noise evaluation measure, - at least for the time being - is the "Effective Perceived Noise Level, EPNL" in units of EPNdB, as described in ANNEX 16 / Appendix 4 [1] which is a good measure of the annoyance caused by accounting for maximum overflight intensity, tonal content and the subjectively perceived noise-duration of the noise-signal.

2.3 Noise Data Adjustment

In addition to the reference flight paths for the three test procedures, certain atmospheric reference conditions are defined. Since all reference conditions hardly ever occur simultaneously, certain test-windows are allowed, as listed in Table I.

Adjustments of data, if outside the above test-windows, *must* be conducted by the noise-certification applicant, and *can* be conducted - if he so desires - if inside the test-windows. The adjustments, as presently mandatory in the ANNEX, pertain to atmospheric sound attenuation in case the temperature/humidity differs from reference conditions and/or the distance from the helicopter to the microphone is affected due to a deviation of the actual flight path from the reference flight-path. Also, the true airspeed in the presence of head or tailwind enters the correction process in terms of over-ground-speed for the "Duration-Correction"-adjustment.

	REF. CONDITION	PERMISSIBLE TEST WINDOW
ATMOSPHERIC CONDITIONS		
ATMOSPH. PRESSURE	1013 h Pa	not defined
AMBIENT TEMPERATURE*	25 °C (ISA+10) 15° alternatively	2° to 35 °C**
RELATIVE HUMIDITY*	70%	20 % to 95 % **
WIND SPEED*	0 km/h	up to 19 km/h up to 5 km/h crosswind at flyover
FLIGHT AND/OR OPERATIONAL CONDITIONS		
VERTICAL FLIGHT PATH DEVIATION	0 m	± 10 m
LATERAL FLIGHT PATH DEVIATION	0 °	± 5° from vertical
AIRSPEED DEVIATION	0 km/h	± 9 km/h
HELICOPTER MASS	max.certificated mass for take-off or landing	- 10 % to + 5 %
ROTOR RPM	100 %	± 1 %

• measured 10 m above ground level

** excluding conditions with sound attenuation rate more than 12 dB/100 m for 8 kHz 1/3-octave band

Table I Reference and Permissible Test Conditions

No source-noise correction is presently required, in contrast to the noise certification procedure for propeller-aircraft. The source noise, however, is definitely affected by operational and atmospheric parameters - for example through the main-rotor advancing blade tip Mach-number. Test results to illustrate this pronounced effect will be presented in section 4.

The ANNEX states, that "test-conditions and procedures shall be closely similar to reference conditions", without being too specific on how much deviation after all is acceptable (Chapter 8: Section 8.7.3). However, adjustments and/or corrections of test-towards-reference-conditions shall not exceed 4 EPNdB on take-off, or 2 EPNdB on overflight or approach (Chapter 8: Section 8.7.4). Thus, in a strict sense, the airspeed could conceivably differ by much more than ±9 km/h from the reference air speed, as long as corrections - not too well defined as they presently are - are less than 4 EPNdB for the take-off procedure, for example.

Very little information on the effect of various operational and flight parameters on the final EPN-level is at hand, and therefore future adjustments to the permissible test-windows (in terms of a widening or narrowing) cannot be excluded. One major objective of the test reported under section 4 of this paper is specifically directed towards understanding and quantifying said influences.

2.4 Test Result Validity

Each test-flight produces one EPN-level at each of the three micorphones. ANNEX requires to arithmetically average the 3 EPNL-values to arrive at one flight-characteristic EPN-level. ANNEX further states that a minimum of 6 valid test flights (for each procedure) are to be conducted, the EPNL-values of which are further averaged to obtain (in a statistical sense) the mean, and the standard deviation of the mean, to establish a 90 % confidence-limit not to exceed ±1.5 EPNdB.

Statistical evaluation of aircraft noise is usually hampered by the extremely small number of available data points. To obtain 6 valid flight-noise levels for 3 different flight-procedures is a lengthy and time-consuming undertaking, and to request many more data points in order to improve the statistical confidence in aircraft noise testing, is simply not feasible.

Now, in the problem at hand, one assumes, that the 6 (EPNL-) values are part of a normally distributed sample-population, where - unfortunately - the true mean, μ, and the true standard-deviation, σ, is not known. Known is only a *measured* mean $\bar{x}$ and standard deviation s, based on 6 sample points. In order to be "90 % sure" (i.e. have a 90 % confidence-level or, alternatively, to accept a 10 % error-probability), that the measured arithmetic average of the 6 data points lies within 1.5 dB of the true mean, one may employ the Student-distribution (t-distribution), which takes into account the actual sample-size for any desired confidence level or error-probability. Fig. 2 illustrates the widening and flattening of the "normal"-distribution when having substantially less than infinitely many data points for the case of a 90 % confidence level. Since the ANNEX specifies the confidence limit $u_p \equiv |\bar{x} - \mu|$ to be equal or less than 1.5 dB, one may derive the maximum permissible standard deviation s as function of the sample size (i.e. number of valid, data-producing, test flights) to obtain a $u_p \leq 1.5$ dB. Fig. 3 shows the results, indicating that for the case of interest, i.e. $N = 6$, the standard deviation of the data sample could be as large as 1.82 dB, a number rather readily achievable in typical tests.

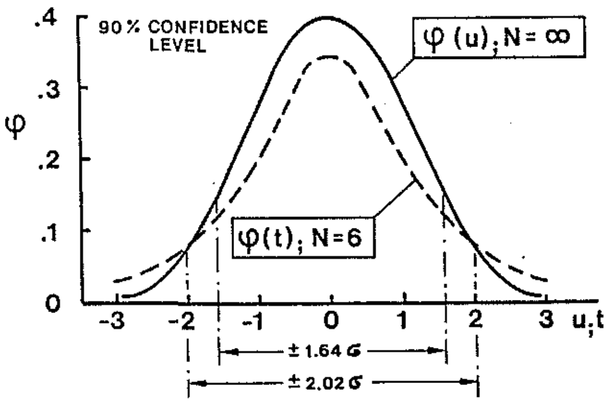

Fig. 2 Normal Distribution ($\varphi(u)$) for an Infinitely Large Sample ($N = \infty$) and t-Distribution ($\varphi(t)$) for a Sample Consisting of $N = 6$ Data Points and Corresponding Confidence Ranges in Terms of Multiples of the Standard Deviation σ to Obtain a 90%-confidence Level

2.5 Maximum Permissible Effective Perceived Noise Levels

The maximum permissible (not to be exceeded) noise levels in terms of the Effective Perceived Noise Level, EPNL for the three test procedures (take-off, overflight and approach), are shown in Fig. 4. The measured, properly corrected and averaged final EPNL value for each individual test procedure is then assessed against the noise

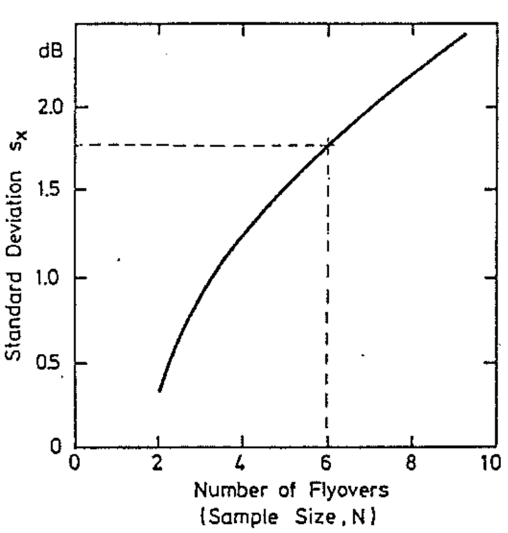

Fig. 3 Permissible Standard Deviation to Achieve 90%-Confidence Level not Exceeding ±1.5 dB

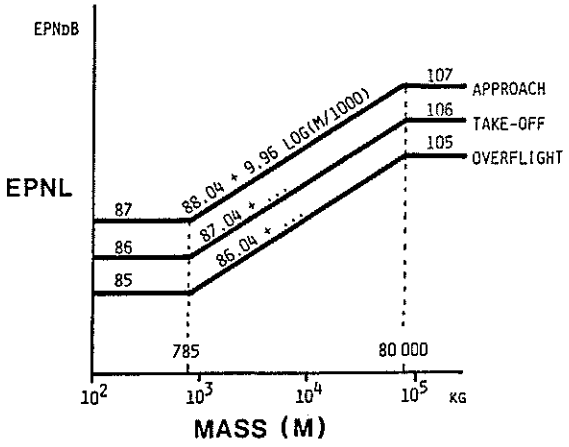

Fig. 4 Helicopter Noise Limits (ANNEX 16 / Chapter 8)

limit as a function of the helicopter-mass, specified as maximum certificated take-off or landing mass.

3. Certification Noise Measurements

3.1 Test Helicopters

Tests were conducted in strict compliance with current regulations of Chapter 8 / Appendix 4 to obtain "noise-certification levels", on two modern-design helicopters, namely a MBB BO 105 and a MBB / Kawasaki BK 117. These helicopters - photographs appear in Fig. 5 - have the specifications listed in Table II.

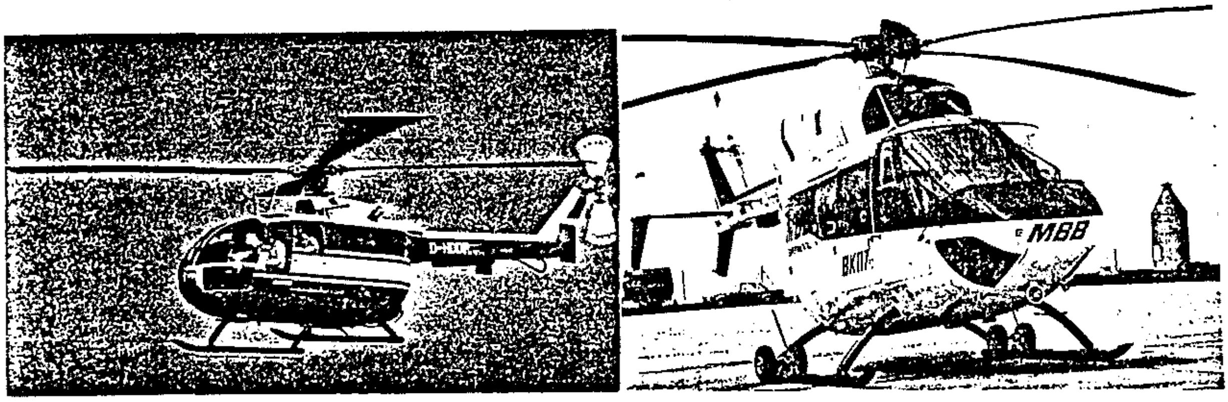

Fig. 5 Test Helicopters BO 105 and BK 117

3.2 Test Procedural Aspects

Tests were conducted at the Braunschweig Airport (EDVE). The test site terrain was flat and covered with short-cut grass. The flight-path ground track was oriented from East to West parallel to the concrete runway. Visual cues (2m x 10m orange coloured ribbons) served to mark the flight-path center-line and to define the rota-

HELICOPTER MODEL	BO 105	BK 117
MANUFACTURER	MBB	MBB/KAWASAKI
MAX.C.T.O. WEIGHT (kg)	2300	2850
NBR. OF ENGINES	2	2
TAKE-OFF POWER (kW)	2 x 298	2 x 404
MAX. CONT. POWER (kW)	2 x 287	2 x 404
MAX. HORIZONTAL SPEED (km/h)	233	257
NEVER EXCEED SPEED (km/h)	268	277
BEST RATE OF CLIMB SPEED (km/h)	117	120
BEST RATE OF CLIMB (m/s)	7	9
NBR. OF MAIN ROTOR BLADES	4	4
ROTOR DIAM. (m)	9.82	11.0
ROTOR SPEED RPM (100%)	424	383
BLADE TIP SPEED (m/s)	218	221

ISA, sea level

Table II Test Helicopters Specifications

tion point for take-off. For landing-approach tests a visual approach slope indicator was set at the prescribed 6° slope.

Half-inch-condenser microphones (Brüel&Kjaer type 4166) were mounted for grazing sound-incidence 1.2 m above ground. Flight paths were tracked by means of 2 kino-theodolites (Askania) with an accuracy of ±0.3 m and three-dimensional coordinates provided for each 1/2 second time interval. For correction purposes the helicopter position along the flight path must be related to the noise as recorded at the various measurement stations through time synchronization. This was accomplished by the kino-theodolite system transmitting synchronization-signals with the photograph sequence frequency. Atmospheric data were measured close to the measurement array 10 m above ground level.

Noise related operational data of the helicopter (Rotor-RPM, Torque, Indicated Airspeed) were recorded ad-hoc by the accompaning test-engineer on board, and - in addition - documented by a photograph of the cockpit instrument panel taken at the midpoint of each test run.

3.3 Results

The acoustic certification data for the BO 105 and the BK 117 helicopters are shown in Table III, together with several other noise metrics. The following comments are in order: Both helicopters can easily comply with the noise limits for take-off and approach,

TEST PROCEDURE	AIRCRAFT	NUMBER OF FLIGHTS	EPNL $\pm u_p$ (EPNdB)	NOISE LIMIT (EPNdB)	NOISE EXCESS (EPNdB)	PNLTM (TPNdB)	OASPL(max) (dB)	L_A(max) (dB(A))	EPNL - L_A(max) (dB)
TAKE-OFF	BO 105	8	89.1±0.2	90.6	-1.5	89.9	83.2	76.7	12.4
	BK 117	6	88.8±0.8	91.5	-2.7	85.3	79.8	72.1	16.4
OVERFLIGHT	BO 105	6	90.4±0.2	89.6	+0.8	93.0	84.9	79.9	10.5
	BK 117	6	92.5±0.4	90.5	+2.0	91.6	87.9	78.9	13.6
APPROACH	BO 105	4	90.6±0.9	91.6	-1.0	90.8	83.2	78.6	12.0
	BK 117	6	90.2±0.9	92.5	-2.3	90.8	85.1	78.0	12.2

Table III Noise Certification Data and Other Noise-Metrics while showing excess-noise for the overflight test procedure. Trade-off rules in both cases, however, make these aircraft to fullfil ANNEX 16 requirements. Staying within the prescribed confidence-level limits of ±1.5 dB in general field practice also seems to be no problem, since u_p ranges from 0.2 dB to 0.9 dB at most. It should be noted that only 4 valid flights were evaluated for the BO 105 / approach procedure.

Table III also shows a column with the difference in level of EPNL and L_A(max). For rough estimates an additive factor of 13 dB is frequently employed to determine EPNL from a measured maximum A-weighted overflight level in aircraft noise assessment. The appropriate listing in Table III shows these differences to range from about 10 to 16 dB, with a mean of 12.9 dB and a standard deviation of ±2.1 dB.

A comparison of the BO 105 data with results of earlier measurements, partly obtained within the framework of ICAO-CAN cooperation through DFVLR/BMV (Germany) and TSC/FAA (USA) is shown in Table IV.

FLIGHT PROCEDURE	EPNL (EPNdB)			Δ EPNL (MAX.)
	DFVLR (1981)	DFVLR (1978)	TSC/FAA (1978)	
TAKE-OFF	89.1	88.4	89.1	0.7
LEVEL FLYOVER	90.4	89.6	88.4	2.0
LANDING APPROACH	90.6	90.9	91.7	1.1

Table IV Comparison of Effective Perceived Noise Levels of the BO 105 Helicopter Obtained Through Different Tests, Test-sites, and Measurement-groups

The agreement of the properly corrected EPN-levels is very satisfactory, considering that the measurements were in fact conducted by different laboratories at different locations (USA and Germany) and at different times (viz. different atmospheric conditions). The maximum deviation of 2 dB surprisingly occurs for the overflight procedure, while for take-off and approach the maximum difference reduces to about 1 dB. Regarding only the DFVLR-results obtained on the identical helicopter, the agreement (i.e. reproducibility) is better than 1 dB for each of the three flight-procedures.

Flight test experience has also shown, that the lateral deviation tolerance from the reference flight path track seems rather tight. Fig. 6 shows both ground plane tracks and altitude profiles for the take-off procedure of the BK 117-helicopter in several test flights (including those that were ultimately not taken for further evaluation). Lateral deviation sometimes exceeds the tolerable 5°-from-the-vertical over the important part of the flight path. Thus it seems particularly

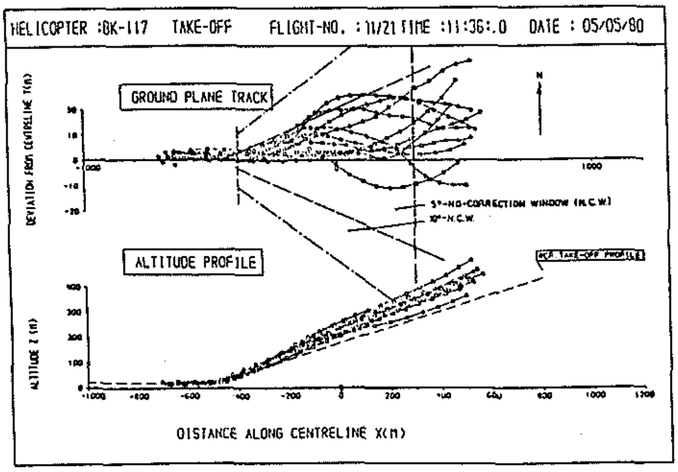

Fig. 6
Take-off Flight Path Tracks (Lateral Deviations at Enlarged Scale)

difficult for the pilot, to maintain the reference flight path in the presence of wind, especially during the take-off procedure. No well defined correction-procedure within the EPNL-computation is at hand, such that a widening of the tolerance, e.g. up to ±10° from the vertical has been suggested, causing probably very little effect on the final results, since a three-microphone-average is taken.

4. Noise Sensitivity Studies

Correction of noise data towards reference conditions, on the one hand, and the definition of tolerable test-windows, on the other hand, require an understanding of the sensitivity of the various noise-metrics, the EPNL in particular, on flight-, configuration-, and operational parameters. Appropriate studies were conducted employing one or both test-helicopter(s).

4.1 Effect of Flight Altitude

Level flyovers at 0.8 V_H were conducted with the BO 105 helicopter at different flight-altitudes between 75 m and 300 m. Results appear in Fig. 7 together with several suggested correction-schemes, i.e. (a) the "inverse-square-distance-law" (-6 dB per doubling of distance), (b) the "inverse-distance-law" (-3 dB per doubling of distance), and (c) the ANNEX 16 distance correction which combines the "inverse-square-distance-law" for spherical spreading and the "inverse-distance-law" for the adjustment of the "Duration-Correction", yielding a relation similar to the "inverse-distance-law".

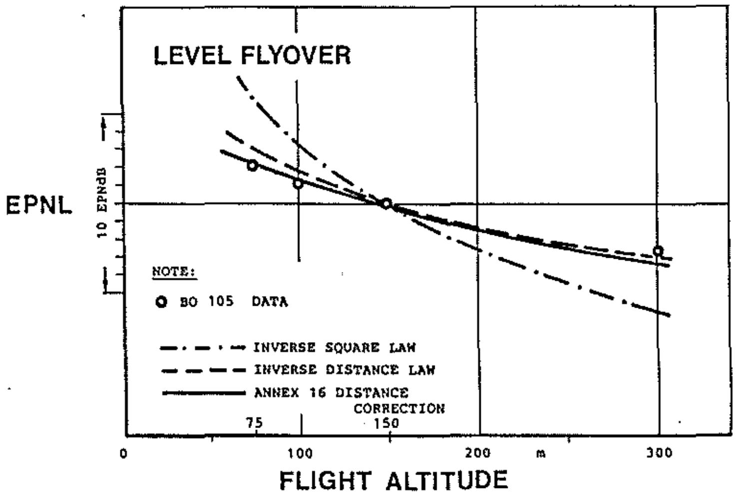

Fig. 7 Flight Altitude Effect on EPNL

The diagram shows the expected decrease in the EPN-level with increasing flight altitude, and demonstrates the ability of the ANNEX 16 distance correction procedure to correct the basic 150 m data over a wide range of flight altitudes.

4.2 Effect of Aircraft Weight

Several experiments on the BO 105 helicopter with drastically reduced flight-weight were conducted to check that particular influence on the EPN-level during take-off, overflight and approach. Table V lists the changes in level, when the weight is lowered from the maximum certificated take-off weight of 2300 kg to 1800 kg.

In all cases the effect is very minute, exhibiting no discernible effect for the overflight-procedure, and an effect on the order of 1 dB for the two other procedures, with the lower levels pertaining to the lower weight.

FLIGHT PROCEDURE	WEIGHT (kg)	EPNL ± u_p (EPNdB)
TAKE-OFF	2300	89.1±0.2
	1800	88.0±0.2
OVERFLIGHT (.8V_H)	2300	89.0±0.1
	1800	89.1±0.1
APPROACH	2300	90.6±0.6
	1800	89.3±0.3

Table V Weight Effect on Effective Perceived Noise Level (BO 105 Test Helicopter)

4.3 Effect of Flight Speed

For the case of horizontal overflight at 150 m altitude, the effect of the flight-speed on EPNL was investigated on both test helicopters. Fig. 8 shows the result. The sensitivity curves indicate an exponential increase with flight speed for both helicopters; the "certification-speed" of 0.9 V_H is indicated in each case. The shape of the curve seems to be typical for modern helicopters with high advancing-blade-tip Mach-numbers. Especially in the blade-tip Mach-number range between 0.8 and 0.9 the growing influence of impulsive noise-components, such as "thickness-noise" and "high-speed impulsive noise" is evident. Compressibility effects - then occuring - cause significant changes in both the noise-level and the directivity characteristic. This effect becomes more obvious, if EPN-levels are plotted vs. advancing-blade-tip Mach-number (Fig. 9).

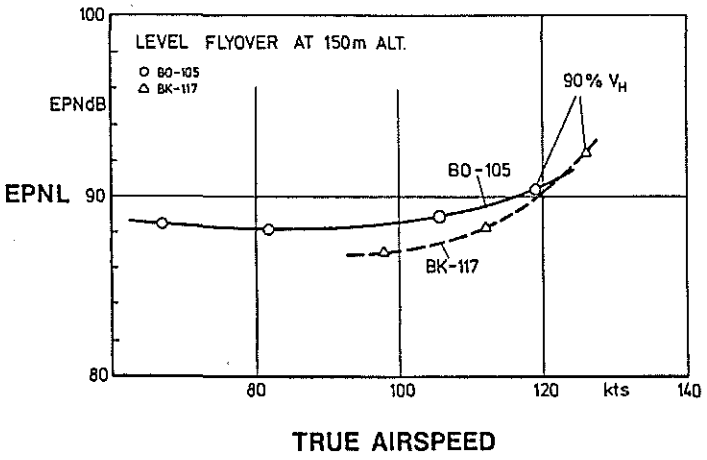

Fig. 8 Flight-speed Effect on EPNL

The tests on the BK 117 were conducted for an initial aircraft configuration exhibiting high tail rotor loading at maximum level flight speed. This effect is assumed to be one of the main reasons for the steep slope of flyover-noise versus speed during the first tests. On the final production configuration the tail rotor has been deloaded by increasing the endplates' incidence angle, which is expected to decrease the noise intensity at high level-flight speeds.

4.4 Effect of Rotor Rotational Speed and Forward Velocity

Maintaining rotor rotational speed (in terms of percent nominal speed) but varying forward speed and plotting the resulting EPN-levels vs. advancing blade-tip Mach-number indicates a characteristic noise-sensitivity curve for each rotor rotational speed: Thus, the 95%-RPM curve appears in the Mach-number range of about 0.75 and 0.80, while the 102 % curve appears in the 0.80 to 0.85 Mach-number range, causing 3 EPNdB higher levels for otherwise identical flight speeds (Fig. 10).

Accordingly, the Chapter-8-required flight test speed of 0.9 V_H could be achieved with rotor-speeds from 95 % to 102 % with corresponding level changes of 3 EPNdB. Thus, ANNEX 16 allows RPM-tolerances of ±1 % only, tolerating in this case approximately 0.5 EPNdB variations.

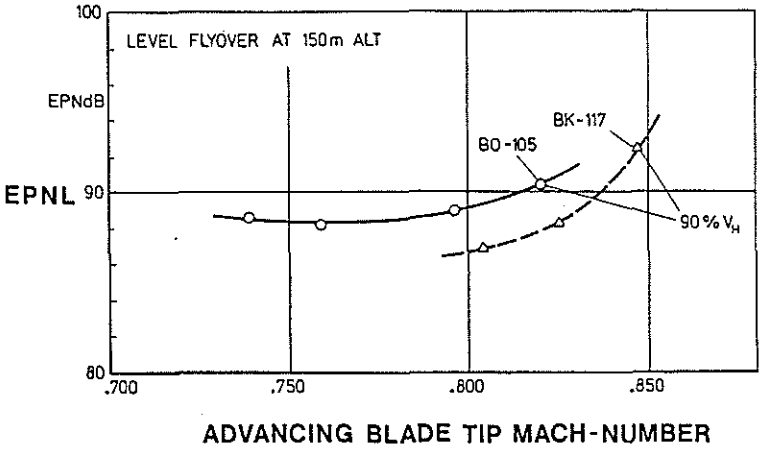

Fig. 9 Mach-number Effect on EPNL

5. Concluding Remarks

The current noise-certification procedure for helicopters, as laid down as a Standard in ANNEX 16/Chapter 8 is a fairly well-founded step towards regulating helicopter-noise for keeping within bounds the acoustic annoyance it causes on the ground.

Although the Standard rather precisely regulates the test and data-reduction procedures, there are still some uncertainties that potentially affect the final Effective Perceived Noise Level. Some tolerances - it seems - could be loosened, e.g. that for test-weight (since weight-changes of up to 20 % have shown a relatively small effect on EPNL), or that for lateral flight-path deviation (which represent an unjustified burden on the pilot), or the altitude tolerance for level overflight (since accurate corrections are readily available); others should perhaps be narrowed such as that for the rotor-rotational speed in combination with the flight-speed, or appropriate source-noise corrections should be made mandatory; however no accurate correction scheme for advancing blade-tip Mach-number is available at present* (as there is non for the temperature-effects on source-noise, for that matter), and more basic research in this area is needed on many more helicopters, especially on those operating at near sonic blade-tip speeds and those that are prone to generate impulsive noise.

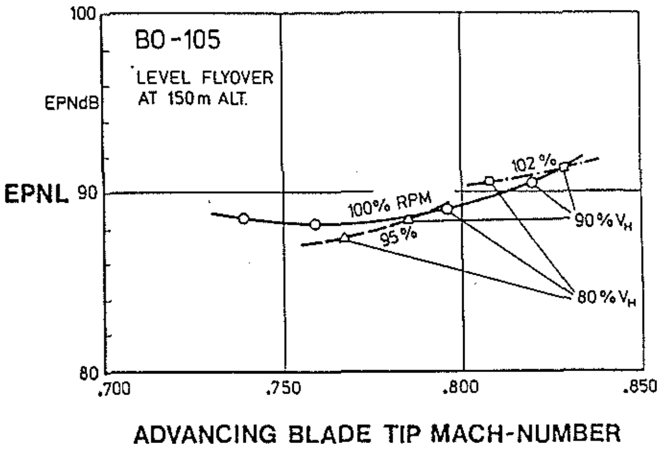

Fig. 10 Effect of Rotor Rotational Speed and Foreward Velocity on EPNL

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* It should be mentioned that even for the relatively "easy case" of propeller-noise there is no accurate helical-blade-tip-Mach-number correction available, and helicopter aeroacoustics is still more complicated.

Other areas of uncertainty, not only in helicopter noise-certification, but in aircraft noise research quite in general, pertain to the reliability and reproducibility of noise data when obtained by either different and independently operating measurement crews during the very same, identical overflight event, or when obtained, even with the same crew, at different times and/or locations on the same aircraft. Matters become still more complicated, if an acoustical change is to be investigated, such as an alternate rotor-blade geometry on a particular helicopter. Here, the statistical validity and the accuracy achievable in field-tests must be well understood and accounted for. Another area of concern relates to the effect of ground-reflection, when an acoustic signal bounces off the ground before reaching the microphone at 1.2 m above the surface, and interferes with the direct wave. The problem is well known - but far from being solved - also in propeller aircraft noise research and/or certification.

Noise-regulations, in a sense, are a motivator for the manufacturer to design and build a quiet product. However - since it is the manufacturer's obligation to prove compliance with the noise regulations, he must put substantial - and time-consuming - effort into the development of advanced rotorcraft noise technology, with the consequential need to generate sufficiently accurate physical models for noise prediction, to develop noise-orientated design principles and to provide techniques for the assessment of the economic impact of such designs. Thus, introduction and enforcement of noise regulation must take both the manufacturer's technical possibilities, and the public's desire for a quiet environment into account and must therefore try to balance these perhaps somewhat conflicting aspects.

Aerospace vehicle noise certification - development, introduction and application - is a continuing process and is likely to require adjustments when in the course of time more experience is gained by all concerned.

References

[1] International Civil Aviation Organization (ICAO):

"Environmental Protection", ANNEX 16 to the Convention on International Civil Aviation, Volume I 'Aircraft Noise' First Edition - 1981, Montreal, Canada