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Noise Certification of MI-8 Helicopter Family

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The paper presents procedures used in noise certification of the Mi-8 civil helicopters. Unlike the ICAO standard procedure, the average effective perceived noise levels and confidence intervals for them are determined as a line of regressive measured data, and not proceeding from group measurements during the certification process of the Mi-8 helicopter family. In this case the helicopter takeoff weight is used as an independent parameter.

The paper presents the results of the perceived noise level measurements reduced to the declared certification conditions in terms of helicopter flight altitude and airspeed. The standard procedure of data correction takes into account the effect of the flight altitude on the expansion of the sound wave front and sound damping in the atmosphere, as well as the effect of the flight altitude and airspeed on the duration of the noise perception by the observer. In addition to the above effects, the effect of the airspeed on the intensity of the noise produced by the helicopter rotors was also taken into account. The above regressive method was used in determining the above effect in the data analysis.

Mil Mi-8 Family

A non-standard method used to determine the compliance of 13 modifications of the Mi-8 family (Fig. 1) with certification requirements for external noise is presented in the paper. All the helicopters in question have the same 5-bladed main rotors of 21.3-m diameter. Their main difference lies mainly in their takeoff weights, power available from the engines installed in the helicopter, the location of the tail rotor on the tail boom and its dimensions, the composition of the equipment installed.

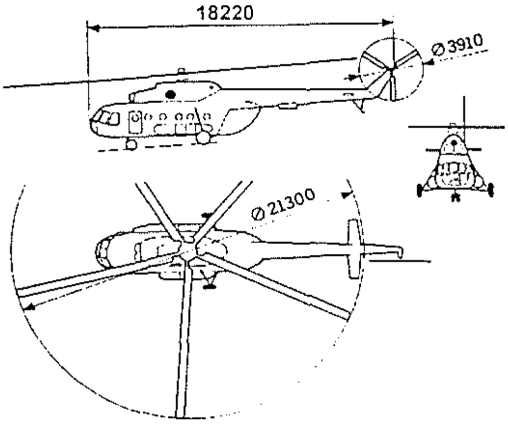

Fig. 1 Mi-8 Helicopter

All the 13 modifications can be divided into three main groups proceeding from their takeoff weight and tail rotor parameters, i.e the factors affecting their external noise.

Group 1 covers 6 modifications of the Mi-8 with the initial takeoff weight equal to 12,000 kgf, powered by two turboshaft engines of 1,500 shp takeoff each, and equipped with a 3-bladed tail rotor, whose blade chord equals 0.27 m.

Group 2 covers 6 modifications of the Mi-8 with the initial takeoff weight equal to 13,000 kgf, powered by two turboshaft engines of 2,000 shp takeoff each, and equipped with a 3-bladed tail rotor, whose blade chord equals 0.305 m.

Group 3 covers 1 modification of the Mi-8 with the initial takeoff weight equal to 13,000 kgf too, powered by two turboshaft engines of 2,000 shp takeoff each, and equipped with a 3-bladed tail rotor, whose blade chord equals 0.27 m.

The tail rotor is located on the port side of the tail boom for all the modifications, and the direction of rotation is also the same for all the modifications. All the modifications of the Mi-8 family have the same performance for external noise certification.

Cruise speed in level flight (ISA)	225 km/h
Speed for best rate of climb and approach speed	120 km/h
Rate of climb at takeoff with forward speed	7 m/s

Statistical Estimate of External Noise Level

The helicopter external noise level is assessed in three flight conditions (Fig.2): takeoff, level flight and approach. It is a random value depending upon quite a large number of parameters, some of which are also random.

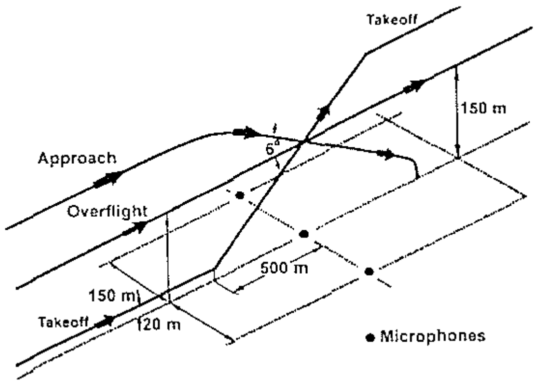

Fig. 2 Pattern for Noise Certification of Helicopters in the Same Weight Category

The latter are those characterizing atmospheric conditions (outside air temperature and pressure, wind velocity and direction), powerplant power rating (gas generator speed), helicopter movement along its flight path (airspeed and flight altitude). Therefore, the existing standards [1,2] treat the external noise level as an interval estimate of mathematical expectation of random effective perceived noise level value (EPNL). This kind of estimation involves a determination of the confidence interval within which the parameter being estimated is located for a pre-selected fiducial probability (reliability).

The estimation of mathematical expectation of random effective perceived noise level value for small sample size and dispersion of the random value unknown beforehand is carried out by using the Student's t-distribution. The helicopter external noise level is determined in units of effective perceived noise level (EPNL) and is found for each flight condition in the following way:

$$EPNL = \overline{EPNL} \pm d \qquad (1)$$

$$d = \frac{t_{psd} \times S}{\sqrt{N}}$$

where:

d is a deviation of the average EPNL value from the boundaries of the confidence interval;

t_{psd} is a parameter of Student's distribution for n=N-1 degrees of freedom and given fiducial probability $p = 1-\alpha/2$, α is the significance level;

N is the local sample size,

S is an estimation of the root-mean-square deviation for a conditional average EPNL values of an $EPNL_i$ random value

$$\overline{EPNL} = \frac{1}{N} \times \sum_{j=1}^{M} (\overline{EPNL'_j})$$

$$\overline{EPNL'} = \frac{1}{3} \times \sum_{j=1}^{3} (EPNL_j) + \sum_{i=1}^{3} C_i \qquad (2)$$

$$S = \sqrt{\frac{\sum_{i=1}^{N} (\overline{EPNL'_i} - \overline{EPNL})^2}{n}}$$

where:

$EPNL_j$ is the EPNL value obtained from the measurement results by the j-th microphone with the helicopter overflying over the terrain check point,

j=3 is the number of the microphones used for measurements in tests,

C_i is correction made to reduce measurement results to the original certification conditions in terms of helicopter flight altitude and speed,

$\overline{EPNL'}$ is the average EPNL value obtained from the measurement results of three microphones for one overfly over the check point.

The $\overline{EPNL'_i}$ values obtained for 6 flyovers refer to one data group as they are reduced to one value of the helicopter takeoff weight being certified and to the same paths and flight conditions.

The existing standards [1,2] define that in assessment of the helicopter noise level the confidence level p of the interval value shall be 0.9 (i.e. 90%), the local sample size of noise levels N shall contain not less than 6 values, and the deviation values of the confidence interval boundaries from the average $\overline{EPNL}$ value shall not exceed 1.5 EPNdB. Only when all the three conditions above are met, the helicopter average effective noise level EPNL is a representative value and could be compared with the existing standards.

For the three groups of the Mi-8 modifications under consideration, the total size of the representative database to be obtained from experiments with application of standard certification procedure for each flight condition being certified, i.e. takeoff, flyover and approach, contains not less that 18 $\overline{EPNL'_i}$ values.

The noise certification procedure presented in the paper allows the required scope of flight testing to be reduced by 2-3 times depending upon the accepted size of the representative data sample, as compared to the standard procedure.

The essence of the procedure is as follows: to obtain the required statistical estimates, a regression equation for $\overline{EPNL}$ whose parameter is the value of the tested helicopter takeoff weight

(m) is used instead of group (point) sample of measurements:

$$\overline{EPNL} = a_0 + a_1 \times m + a_2 \times m^2 \qquad (3)$$

Polynomial coefficients a_0, a_1, a_2 are found by using the least square method for the total EPNL database within the whole range of the tested helicopter takeoff weight changes. In this case, the sample size should contain not less than 6 EPNL values and it should be such that the deviation of the average EPNL value should not exceed 1.5 EPNdB. The value of the helicopter conditional average effective perceived noise level (EPNL) for the flight condition under consideration is obtained from Equation 3 when it is substituted by the takeoff weight being certified (m_o), i.e.

$$\overline{EPNL} = a_0 + a_1 \times m_0 + a_2 \times m_0^2 \qquad (4)$$

The probability values of the helicopter noise level is defined by Equation 1, and the deviation of the confidence interval boundaries from the helicopter average noise level is found proceeding from Student's distribution for a random $EPNL_i$ value:

$$d = t_{psd} \times S_E \times S_m \qquad (5)$$

Where

n=N-k-1, and k is the power of regression Equation 3,

$$S_E = \sqrt{\frac{\sum_{i=1}^{N}(EPNL_i - \overline{EPNL})^2}{n}} \qquad (6)$$

For k=2

$$S_m = \sqrt{\frac{1}{N} + \frac{(m_0 - \overline{m})^2}{\sum_{i=1}^{N}(m_i - \overline{m})^2}} \qquad (7)$$

Here

m_i is the current value of the helicopter takeoff weight in tests,

m_o is the initial takeoff weight value to be certified, $\overline{m}$ is the average takeoff weight value in tests from each sample.

Thus, Equations 3-6 allow the value of the helicopter average effective perceived noise level and the boundaries of the confidence interval (±d) for each of the three flight conditions to be estimated for a given confidence probability. However, it is necessary first of all to reduce the measurement results to the initial certification conditions in accordance with Equation 2.

Correction of Experimental Data

The standard procedure used to correct the data [1,2] takes into account the influence made by the deviations in helicopter flight altitude and speed from the initial (certification) values on the EPNL value. The deviations in helicopter flight altitude and speed from the initial (certification) values affect the value of the sound pressure spectral level being measured, and, thus, the value of the helicopter tone corrected perceived noise level (PNLT) value. This influence manifests itself through an expansion of the sound wave front and through the sound damping in the turbulent atmosphere, as well as through a changed time of the observer exposure to PNTL.

$$\overline{EPNL'}_{exp} = \overline{EPNL}_{ch} + \delta_1 + \delta_2 + \delta_3 \qquad (8)$$

Here δ_j are corrective functions:

δ_1 takes into account the influence of the differences existing in the air temperature, humidity and the distance between the observer and the helicopter in tests conditions and initial conditions on the value of the maximum tone corrected perceived noise level (PNTLM);

δ_2 takes into account the influence of the changes in the distance between the helicopter and the checkpoint and the helicopter speed on the change in the noise exposure time.

$$\delta_1 = PNLTM_{thd} - PNLTM_{mes}$$
$$\delta_2 = -7.5\,lg\left(\frac{H_{meS}}{H_{init}}\right) + 10\,lg\left(\frac{\overline{V}_{mes}}{V_{init}}\right) \qquad (9)$$

Here

H is the helicopter altitude above the point of noise measurement;

V is an average airspeed along the path leg corresponding to the time when the upper 10 TPNdB of the noise level in the measurement point are heard.

The corrective function δ_3 in Equation 8 is an additional one relative to the standard correction procedure [1,2] and it takes into account the influence of the helicopter speed on the intensity of the noise level produced by its rotors. It is known [3] the PNLT values versus speed is nonlinear and non-monotonic, and it corresponds qualitatively to the power required versus speed. This dependence is characterized by a relatively small gradient of the noise level change at small changes in speed, therefore the δ_3 value becomes tangible only within quite a wide range of speed changes. In this paper, a regression procedure of data analysis was used:

$$\delta_3 = PNLT_{init} - PNLT_{mes}$$
$$PNLT_V = b_0 + b_1 \times V + b_2 \times V^2 \qquad (10)$$

Where

$PNLT_{initial}$ and $PNLT_{measured}$ are the values of the noise level perceived which are found by using regression Equation 10 for helicopter speeds in tests and initial certification conditions respectively. Regression Equation 10 was derived from the results helicopter tests obtained in level flight and corrected in compliance with Equation 9.

Two modifications of the Mi-8 which can be referred to Groups 1 and 2 took part in flight noise tests. The takeoff weight of the helicopter belonging to Group 1 varied in tests within 11,000-12,000 kgf, while that belonging to Group 2, within 13,000-14,000 kgf. During the tests conducted the helicopters flew over the three points in which external noise was measured 25 times in total (instead of 54 times required by the standard certification procedure): 7 takeoffs, 9 level flights and 9 approaches. Regression Equation 3 was derived from the database common for both helicopters. And the common database in this case was formed with due account of the experimental results on the contribution made by the tail rotor to the total external noise produced by the helicopter (see Ref.3)

For single-rotor helicopters, the external noise is primarily produced by their main and tail rotors. The acoustical radiation from the turboshaft engines manifests itself in the measured spectra of sound pressure in the area of high frequencies (over 4 kHz) and it does not affect greatly the effective perceived noise level (EPNL) value. Therefore, helicopters having the same initial takeoff weights and performance in certification flight conditions (takeoff, level flight, approach) whose main and tail rotors have the same dimensions and tip speeds will have the same external noise levels.

A different location of the tail rotor (on the helicopter starboard or port side) affects the value of the external noise level only in the point of measurement located to the side of the flight path but the averaged EPNL value (for three points of measurement) does not virtually vary.

A change in the tail rotor blade chord with other dimensions and tip speed remaining the same can result in a change in the helicopter external noise level, if the tail rotor thrust coefficient changes (C_T/σ) [4]. A wider tail rotor blade chord for the Mi-8s belonging to Group 2 as compared to that for the Mi-8s belonging to Group 1 results in a higher rotor solidity ratio (δ). However, the increase in the original takeoff weight from 12,000 kgf to 13,000 kgf causes a higher main rotor torque reaction and, as a consequence, a higher tail rotor thrust required to counteract that moment. As a whole, the tail rotor blade loading for the helicopters belonging to

$$\left(\frac{C_T}{\sigma}\right)_1 = \left(\frac{C_T}{\sigma}\right)_2 = idem$$

Groups 1 and 2 remains practically the same:

Therefore the wider tail rotor blade chord for the Group 2 helicopters will not result in a higher helicopter external noise level.

As for the helicopters, belonging to Group 3 having the original takeoff weight equal to that of the Group 2, helicopters (13,000 kgf) and the tail rotor with "narrow" blades inherent in the Group 1 helicopters, the tail rotor blade loading increases as compared to that of the Group 1 and 2 helicopters. It is known [4] that the power the noise produced by of the helicopter rotor is proportional to loading parameters squared $(C_T/\sigma)^2$. Bearing in mind that for single-rotor helicopters of Mi-8 type the external noise level is greatly determined by the noise produced by the tail rotor [3], increased tail rotor blade loading will result in an increase in the helicopter external

$$\Delta = 20\, lg \frac{(C_T/\sigma)_3}{(C_T/\sigma)_1} \qquad (11)$$

noise level by a value:

Therefore the external noise level for the helicopter belonging to Group 3 was determined in the same way that was used for the Group 1 and 2 helicopters but with due corrections (Eq. 11).

Measurement Results

The tables below show the results of the statistical assessment of the external noise level for different modifications of the Mi-8 type helicopters. There $EPNL_N$ is the maximum helicopter external noise level, $\Delta EPNL = EPNL - EPNL_N$ is an increment (+) or decrement (-) in actual helicopter noise level relative to the standard value, d is the deviation of the confidence interval boundaries from the average EPNL value, $t^{\#}$ is Student's distribution parameter, $S^{\#}$ is the estimate of the root-mean-square deviation for a conditional average noise level.

Table 1. Group 1 Helicopters
TOW = 12,000 kgf

Flight condition	*EPNL* EPNdB	*d* EPNdB	$t^{\#}$	$S^{\#}$ EPNdB	$EPNL_N$ EPNdB	$\Delta EPNL$ EPNdB
Takeoff	94.8	0.7	2.015	0.9	100.8	-6.0
Level flight	93.7	0.8	1.734	1.6	99.8	-5.9
Approach	96.5	1.3	1.895	1.8	101.8	-5.3

Table 2. Group 2 Helicopters
TOW = 13,000 kgf

Flight condition	*EPNL* EPNdB	*d* EPNdB	$t^{\#}$	$S^{\#}$ EPNdB	$EPNL_N$ EPNdB	$\Delta EPNL$ EPNdB
Takeoff	94.7	0.8	2.015	0.9	100.1	-6.4
Level flight	94.7	0.6	1.734	1.6	100.1	-5.4
Approach	96.9	1.4	1.895	1.8	102.1	-5.2

Table 3. Group 3 Helicopters
TOW = 13,000 kgf

Flight condition	*EPNL* EPNdB	*d* EPNdB	$t^{\#}$	$S^{\#}$ EPNdB	$EPNL_N$ EPNdB	$\Delta EPNL$ EPNdB
Takeoff	95.8	0.8	2.015	0.9	100.1	-5.3
Level flight	95.8	0.6	1.734	1.6	100.1	-4.3
Approach	98	1.4	1.895	1.8	102.1	-4.4

The data obtained for the external noise level for the helicopters of Mi-8 type show that these noise levels do not exceed the standard restrictions for all the flight conditions under consideration, i.e. takeoff, level flight, approach. At the same time, the average deviation of the average noise level from the confidence interval boundaries does not exceed ±1.5 EPNdb specified by the standard.

Figs. 3, 4, 5 compare the external noise levels obtained for helicopters of Mi-8 type with the results obtained from the certification noise tests conducted for a number of single-rotor helicopters published in the reports of the ICAO CAEP [5]. It can be seen that the external noise levels produced by helicopters of Mi-8 type in all flight conditions are in a good agreement with those obtained for helicopters of different foreign companies.

Concluding Remark

The results obtained from the data processing and analysis have allowed us to establish that the Mi-8 family helicopters meet the ICAO standard requirements [1] in terms of external noise levels while the noise levels themselves are lower than those specified in the requirements: they are from 5.3 to 6.0 EPNdB and from 4.3 to 6.1 EPNdB at takeoff and in flypast respectively. The average noise level deviation from the boundaries of the confidence interval does not exceed the value of 1.5 EPNdB specified by the standard.

References

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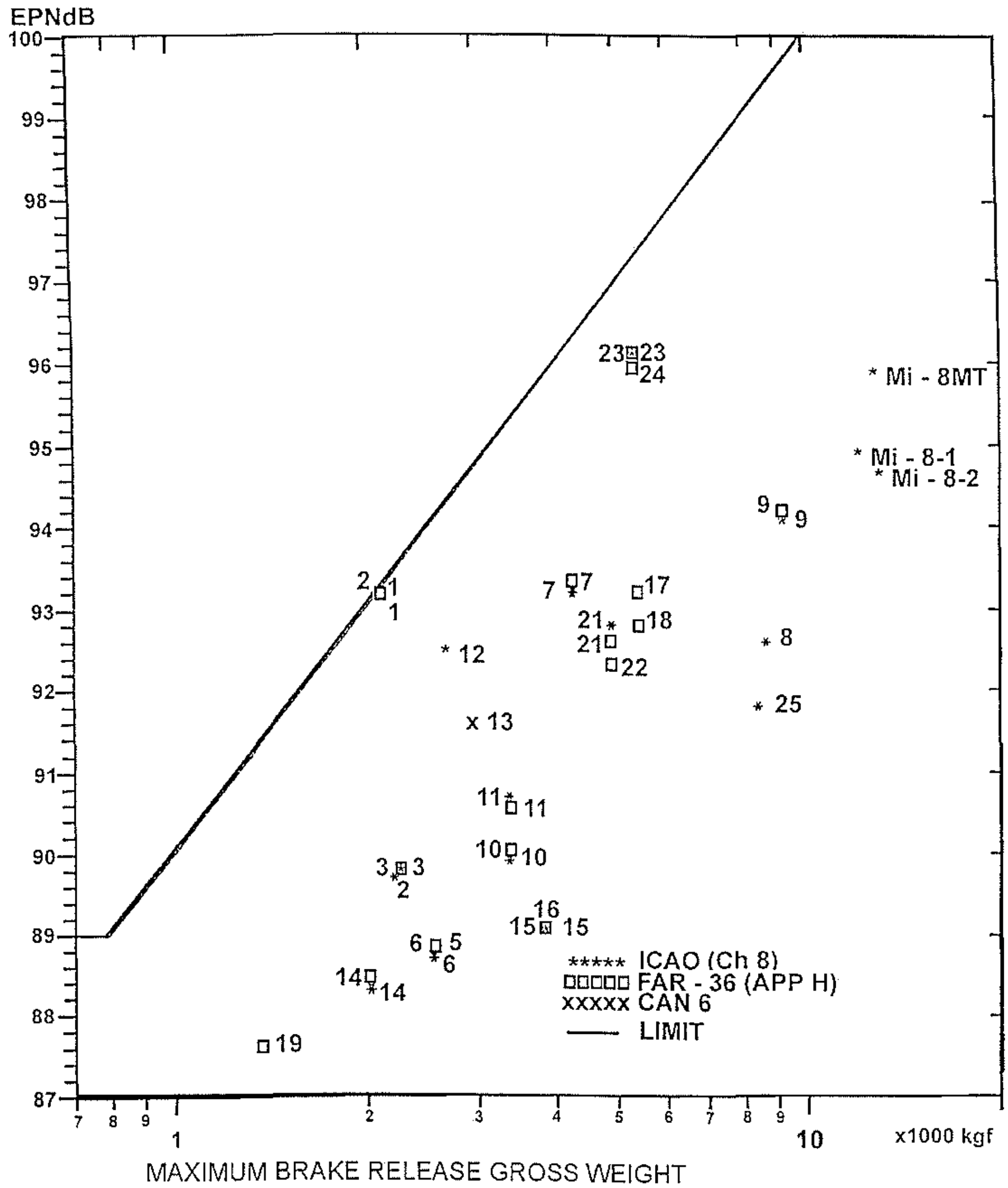
3. V.F. Samokhin, M.G. Rozhdestvensky. External Noise of Single-Rotor Helicopter. AGARD-CP-552, 1995.

4. A.G, Munin, V.F. Samokhin, R.A. Shipov et al. Aviation Acoustics. Community Noise of Subsonic Passenger Aircraft and Helicopters. Edited by Munin. Russia, Moscow, Mashinostroyenie, 1986.

5. Helicopter Certification Noise Level Data. ICAO, HTISG/WP, Sept. 1994.



1 - AS 350 BA
2 - AS 350 B1
3 - AS 350 B2
4 - AS 355 F2
5 - AS 355 F2R
6 - AS 355 N
7 - AS 365 N2
8 - AS 332 L1
9 - AS 332 L2
10 - BK 117 B2
11 - BK 117 C1
12 - A 109 C
13 - A 109 K2
14 - 206 L4
15 - 230 (Wheels)
16 - 230 (Skid Gear)
17 - 412 SP
18 - 412 HP
19 - 500 ER
20 - 520 N
21 - S 76 A
22 - S 76 A(STS)
23 - S 76 C
24 - S 76 C(STS)
25 - A S 332 L

Fig. 3. Helicopter Certification Level Data, Take-off

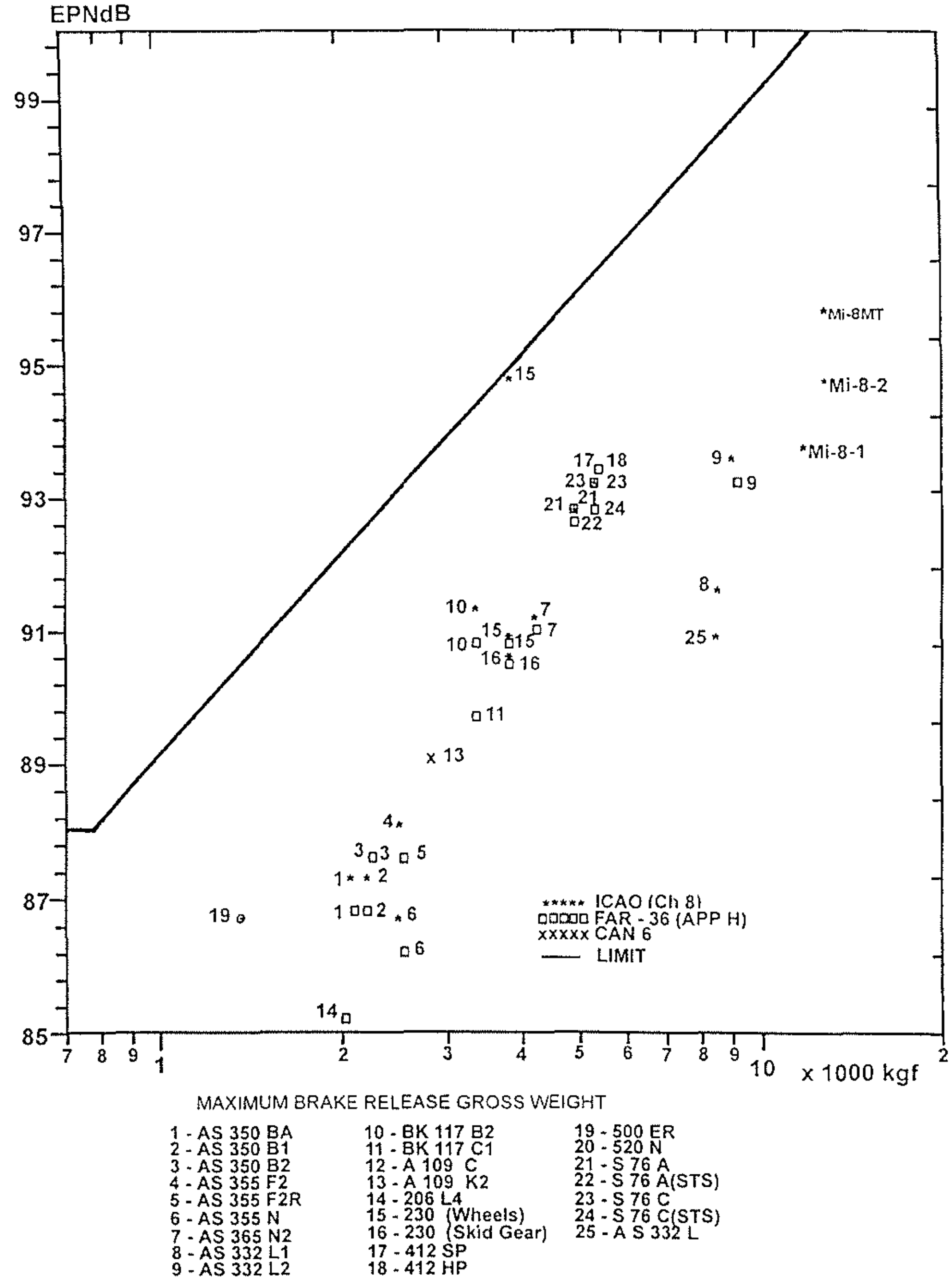
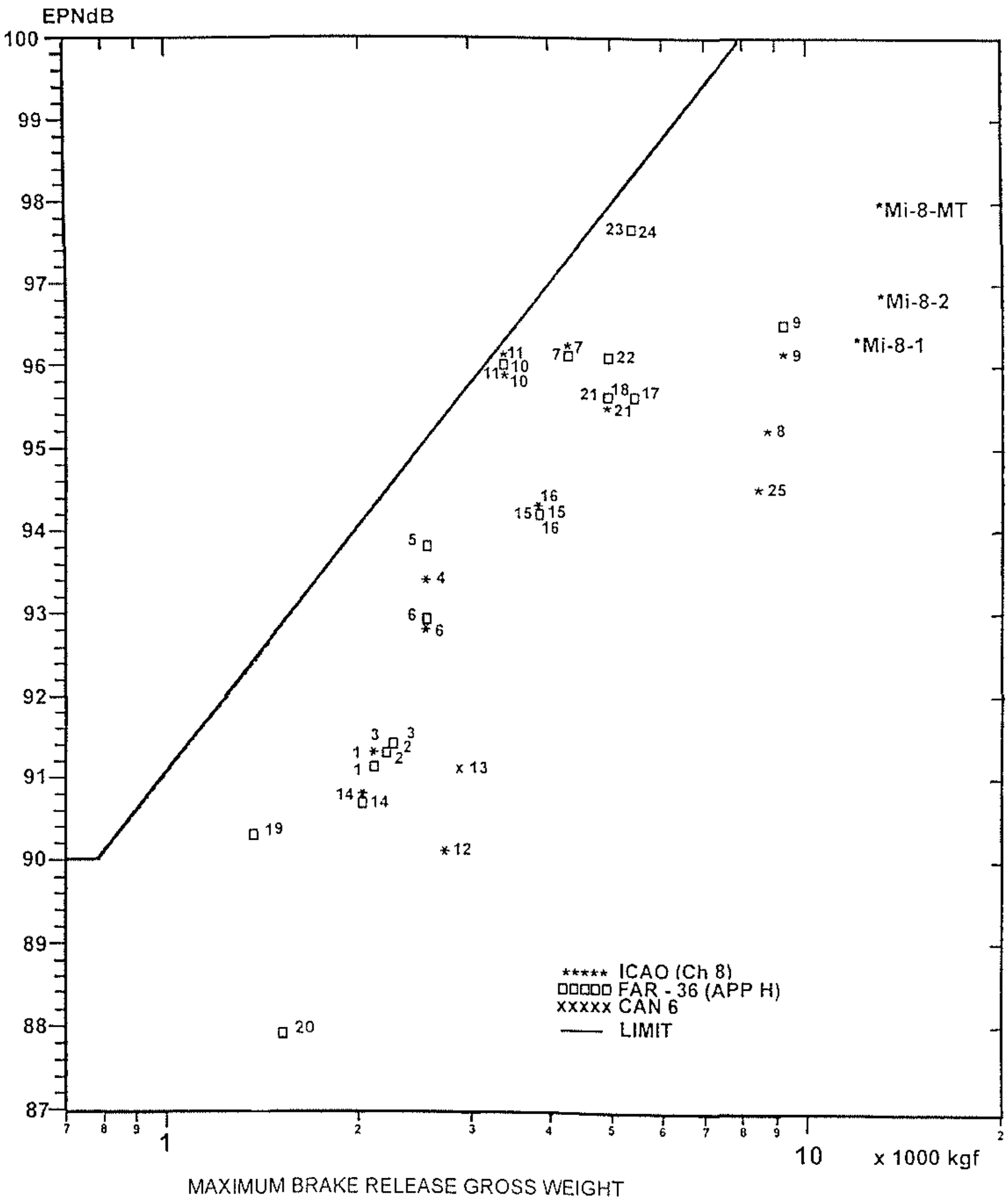


Fig. 4. Helicopter Certification Level Data, Overflight



1 - AS 350 BA
2 - AS 350 B1
3 - AS 350 B2
4 - AS 355 F2
5 - AS 355 F2R
6 - AS 355 N
7 - AS 365 N2
8 - AS 332 L1
9 - AS 332 L2
10 - BK 117 B2
11 - BK 117 C1
12 - A 109 C
13 - A 109 K2
14 - 206 L4
15 - 230 (Wheels)
16 - 230 (Skid Gear)
17 - 412 SP
18 - 412 HP
19 - 500 ER
20 - 520 N
21 - S 76 A
22 - S 76 A(STS)
23 - S 76 C
24 - S 76 C(STS)
25 - A S 332 L

Fig. 5. Helicopter Certification Level Data, Approach