ANNOYANCE OF HELICOPTER IMPULSIVE NOISE

F. d'Ambra and A. Damongeot
S.N.I. Aerospatiale

SUMMARY

Psychoacoustic studies of helicopter impulsive noise have been conducted in order to qualify additional annoyance due to this feature and to develop physical impulsiveness descriptors to develop impulsivity correction methods.

The paper reviews the explored impulsiveness parameters and the subjective evaluation data. The currently proposed descriptors and methods of impulsiveness correction are compared using a multilinear regression analysis technique. It is shown that the presently ISO recommended descriptor and correction method provides the best correlation with the subjective evaluations of real helicopter impulsive noises. The equipment necessary for data processing in order to apply the correction method is discussed.

INTRODUCTION

During the last few years, environmental agencies of different countries have expressed a need to establish and enforce a certification rule for all types of flying vehicles and in particular for helicopters. Among the different problems to be solved in order to promote such a certification rule, the question of representative noise unit is of utmost importance.

Indeed it should obviously:

- Reflect the true annoyance felt by the public
- Allow comparisons with the annoyance due to operations of other types of flying machines
- Reflect truly the efforts that the aircraft manufacturer and operator put in the design and operations of their vehicle to fly more quietly
- Not affect the present units used for aircraft
- Be as simple as possible for data processing

In view of this forthcoming certification scheme of helicopter noise, several countries have undertaken some work on the particular features of helicopter noise in order to assess representative noise units based on corrections to the presently accepted aeronautical noise units. These units already take into account the effect of particular distribution of acoustic energy in the audio frequency range (Noy) and the effect of tone and duration of the noise (EPNL). A new feature which has not yet been taken into account in the noise signature of flying machines is the impulsive type of pressure signals which the majority of helicopter shows in some flight configurations. This impulsive feature is also found in other noise sources of day to day life, like repetitive hammer blows, pneumatic drills, and motorcycles.

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For the motivations previously stated, the work has been conducted in such a way to promote possible correction methods to already existing aeronautical, and to a lesser degree, civil engineering, noise units. A large part of the subjective data which are analyzed originates from psychoacoustic tests performed in France by a joint team of the Helicopter and Aircraft Division of Aerospatiale. Other subjective data and magnetic tape recordings used for psychoacoustic tests performed in other countries have been kindly made available in the framework of ISO and ICAO-WG.B working sessions. These data have also been incorporated to this study.

The paper is divided into four main sections:

(I) Physical impulsiveness parameters: Subjective evaluation methods and results

(II) Data Interpretation: Impulsiveness descriptors and possible methods of corrections

(III) Multilinear Regression Analysis: Quality criteria of the proposed methods

(IV) Instrumentation and data processing

Some aspects of this report have already been presented at the third European Rotorcraft and Powered Lift Aircraft Forum by Dr. S. E. Wright and A. Damongeot (ref. 1). They pertained mainly to the above mentioned sections I and II.

SYMBOLS

I	Impulsive noise signal
R_n	Nonimpulsive noise signal
(I)	Impulsive noise level; PNdB, TPNdB, EPNdB units
(NI)	Nonimpulsive noise level; PNdB, TPNdB, EPNdB units
CF_{Max}, CF_M	Maximum Crest Factor $\frac{(peak)}{(r.m.s)}$
$CF_{0.5}$	Crest Factor during a 0.5 sec time interval
$\overline{CF}_{0.5}$	Mean 0.5 sec Crest Factor during a transient signal
P, P_A	Pressure and "A" weighted pressure time history
$x, \bar{x}$	0.5 sec and mean value of the ISO descriptor
A,B,C	Coefficients of the regression law in dB, dB per unit value of the impulsive descriptor, dB per unit value of the repetition rate
SA,SB,SC	Standard deviation of A,B,C
r, r_e	Multiple correlation coefficients
Se	Overall standard deviation
ΔS	Subjective correction (dB)
ΔC	Computed correction (dB)
f	Pulse repetition rate (Hz)

IMPULSIVENESS PARAMETERS AND SUBJECTIVE EVALUATION METHODS

It has been shown elsewhere (ref. 2) by careful recordings of helicopter noise signals performed either with microphones on the ground and aircraft in hover or in flight (descent or flyover at high speed) or with microphones set in the same reference frame as the helicopter in motion that the impulsiveness content of helicopter noise signals is mainly linked to aerodynamic phenomena on the main rotor and to a lesser extent to the tail rotor. This impulsive character arises when there is either a strong interaction between the main rotor blades and the wake vortices (flight of descent or hover) or when a high aerodynamic speed relative to the tip of the advancing blade is reached (compressibility and/or thickness effect).

Physical Impulsiveness Parameters

The main physical parameters which describe the pressure trace of stationary noise signal in these circumstances are shown in figure 1.

(a) The impulse shape may be different, as illustrated for a light or a heavy helicopter.

(b) The degree of impulsivity can vary widely from a pure random noise to a weak, a medium, and a strong impulsive noise.

(c) The pulse repetition rate - which is equal to the rotor angular frequency times the number of blades - can also vary in a wide range depending on the helicopter weight (rotor diameter and tip speed) and the number of blades used (two to six in present design).

(d) Finally the noise levels, expressed in the presently agreed noise units of PNdB, can vary to a lesser extent at the distances which are actually sought for possible certification scheme. Figure 2, which reproduces noise traces taken at different times during the flyover of a heavy helicopter, shows that, for transient noise signals, there is in addition to the previously stated parameters an evolution of the degree of impulsivity of the noise signal, the trend being that this degree increases before the maximum noise level is obtained, then decreases sharply afterward.

Subjective Evaluation Methods

The principle of a subjective evaluation experiment is to submit to a certain jury the noise signal to be qualified and a reference noise of known annoyance. Broad band noise has been the subject of many subjective evaluations from which the unit of PNdB (Perceived Noise decibel) has been derived. Therefore, it can represent a very good reference, especially if it is taken as the broad band noise of a helicopter.

Elaboration of Impulsive Noise Recordings

In order to be able to change at will the different parameters which were pointed out in the previous paragraph, it is necessary to elaborate the impulsive noise signal to qualify in such a way that one can separate these parameters, while using as much as possible the actual helicopter noise traces. In the French psychoacoustic tests performed, this has been achieved by electrically mixing helicopter broad band noise signals with real helicopter impulse signals, as shown in figure 3. This allows the pulse amplitude and repetition rate to be varied at will so that the four physical parameters, shape, degree, repetition rate, and overall noise levels, could be tested separately.

The same technique has been applied to elaborate the transient impulsive noise signals to be tested. The same pulse shape is maintained during the time history of the pressure signal but with a variation of the degree of impulsivity according to the previously mentioned trend: increasing degree before maximum PNL, sharp decrease thereafter.

Method of Comparisons by Pairs

In the French study, the method used to subjectively evaluate impulsive noise is the method of comparison by pairs, illustrated in figure 4. To evaluate given impulsive noise I, five levels of nonimpulsive noise R_n are played twice. The ten pairs (I,R_n) and (R_n,I) are compared at random. For each comparison, the Jury is asked simply "Which noise is the most annoying?" The percentage of the Jury who finds the nonimpulsive noise more annoying is then plotted against the difference in level between the nonimpulsive (NI) and the impulsive noise (I) measured in present subjective noise units: ΔPNdB and ΔTPNdB for stationary signals, ΔEPNdB for transient signals. Two "sensitivity curves" are obtained as shown in figure 5: one relative to (NI) being played before (I), the other relative to (NI) being played after (I). The mean curve is chosen to be the characteristic response curve. The annoyance correction ΔS is then considered to be such that 50% of the Jury find the (I) and (NI) levels equally annoying.

One can notice from figure 5 that the impulsive noise (I) is found more annoying when it is played <u>after</u> the nonimpulsive noise (NI). This trend, constantly noticed throughout the complete study, shows that there is a memory effect which tends to emphasize the last event felt by the Jury as compared to the previous event.

This method of comparison by pairs needs an anechoic chamber and a large jury. But it does not require subjects acquainted to the specific problem to be studied. It qualifies in some way the annoyance felt by a general public not specifically motivated to exaggerate some special features of a noise signal which they would resent due to previous exposures as it could be the case for inhabitants located in the immediate vicinity of a heliport.

Details on the number and selection procedure of the French Jury are specified in reference 1 (about 60 persons retained after audiometer tests).

Method of Pairs Adjustment

It is based on the same principle of comparison between a reference noise and a noise to be qualified, but the subject is allowed to change the reference noise level and play back and forth the two noises to be compared until the equal annoyance of the two noises is reached. The iteration procedure followed by the subject can be recorded and allows a better statistical interpretation of the results obtained.

The subjective evaluation of the impulsive content of noise signals has been evaluated by this method of adjustment in several research centers: Westland Helicopters Ltd., National Physical Laboratory (U.K.), and Bolt Beranek and Newman (U.S.A.). The application of the method does not require an anechoic chamber and it can be conducted with a jury of smaller size. During the course of the experiments, the subjects acquire more experience in the particular features of the noise signals to be tested. In some way, the corrections found for impulsive signals could be closer to the opinion of inhabitants located in the immediate vicinity of an heliport.

Subjective Evaluation Results

Tables I and II provide the subjective results obtained in the French study. The impulse shape used is identified, together with the value of the different impulse parameters previously discussed. The CF_M, $\overline{CF}_{0.5}$, and $\bar{x}$ columns, which specify the degree of impulsivity, will be discussed and identified in the section entitled "Impulsiveness Descriptors and Possible Methods for Corrections."

Table III provides the subjective results of real helicopter transient noise which have been kindly provided by Bolt Beranek and Newman Inc., together with a duplicate of the recordings of the tested noise signals. Parameters pertaining to the degree of impulsivity (CF_M, $\overline{CF}_{0.5}$, $\bar{x}$) have been computed from this tape.

Both types of experimental results show that corrections of 0 to 7 dB have to be added to conventional units of PNdB or EPNdB to reflect the annoyance effect of impulsive noises. As shown in reference 1, the jury responses are statistically meaningful, giving a 90% confidence level of $\pm$1.3 dB.

IMPULSIVENESS DESCRIPTORS AND POSSIBLE METHODS FOR CORRECTIONS

An "impulsive descriptor" is a mathematical expression which is as simple as possible for ease of data processing and which could, as much as possible, provide a good correlation between the value of the descriptor and the subjective correction ΔS.

Stationary Noise Signals: Impulsiveness Descriptors

For stationary subjective data, examination of the jury corrections ΔS as a function of noise levels (90 and 100 PNdB) shows practically no influence of this parameter within this short range of variation. The three other parameters, namely shape, degree, and pulse repetition rate, have been combined into one single descriptor through use of:

- An "A" filtered signal which tends to decrease the effect of the low frequency content of the impulse

- An impulsivity coefficient $\overline{P_A^4} \Big/ \left(\overline{P_A^2}\right)^2$ where P_A is the A filtered sound pressure time history

As shown in reference 1, for a pure periodic pulse train of pulse width a and period T, the unweighted coefficient $\overline{P^4} \Big/ \left(\overline{P^2}\right)^2$ turns out to be equal to be equal to $k \frac{T}{a}$,
where k depends on the pulse shape (rectangle, k = 1; triangle, k = 1.8). If T increases, i.e., if the pulse repetition rate decreases, or if a decreases (i.e., if the "spikyness" increases), then this impulsivity coefficient increases.

Thus shape, degree, and pulse repetition rate are indeed taken into account in this $\overline{P_A^4} \Big/ \left(\overline{P_A^2}\right)^2$ descriptor.

In the framework of the International Standard Organization (ISO) Working Group 2, this topic of impulsiveness descriptor has been brought forth and several impulsiveness descriptors have been submitted for examination. Among the different proposals (Westland Helicopters Ltd., South Africa National Research Institute, France SNI Aerospatiale, U.K. National Physical Laboratory) submitted before their last meeting date (Dec. 5, 1977), the NPL proposal* has been retained and recommended for application to ICAO - Working Group B.

The NPL descriptor is based on the variance of the square of the "A" weighted sound pressure signal divided by the square value of the r.m.s. "A" weighted sound pressure signal:

$$I = \frac{1}{\left(\overline{P_A^2}\right)^2} \cdot \overline{\left(P_A^2 - \overline{P_A^2}\right)^2}$$

It can be shown that the I descriptor is identical to the French descriptor minus one. So this descriptor does take also into account the shape, degree, and pulse repetition rate parameters of impulsive noise. The other descriptors proposed were mainly based on the Crest Factor concept ($\frac{peak}{r.m.s}$). As shown in figure 6, where comparisons are made on the same noise signals between x = 10 Log I and CF = 20 Log ($\frac{peak}{r.m.s}$), the latter descriptor presents a lack of sensitivity.

*With a "short integration time" $\leqq$ 200 μs.

Stationary Noise Signals: Correction Methods

Once an impulsiveness descriptor has been chosen, a correction method can be easily built using a best fit technique between the subjective corrections ΔS and the computed corrections ΔC. In the ISO N 356 proposal, the recommended correction law is

$$\Delta C_{(dB)} = 0.8\ (x - 3)$$

$$\text{where } x = 10 \text{ Log } I$$

This correction is limited to the range of

$$0. < \Delta C < 5.5 \text{ dB}$$

and held constant at 5.5 dB for larger values of x. It is to be noted that for $x = 3$ and $I \approx 2$, the noise signal is purely broad band.

This correction method applied to the French subjective data provides a standard deviation of ± 1.3 dB.

Transient Noise Signals: Impulsiveness Descriptors and Correction Methods

In the ISO N 356 recommended procedure, the impulsiveness descriptor remains the same as in the stationary case. The I Descriptor is computed at each 0.5 sec time interval, the correction $\Delta C_{0.5}$ is added to the L_{TPN} giving a L_{ITPN} time history from which the corrected EPNL is computed. This procedure is synthetically presented in figure 7.

At the last ISO Working Group 2 meeting, another procedure has been proposed to ISO members (ref. 3). As presented synthetically in figure 8, the impulsiveness descriptor is based on a "A" weighted Crest Factor CF, and the impulse repetition rate (f) is taken as a complementary descriptor.

Two possible impulsiveness correction methods were presented which are briefly sketched in figure 9.

In the first one, the "A" weighted Crest Factor is computed every 0.5 sec of the transient signal and a correction law is applied to L_{TPN}, giving a L_{ITPN} time history from which the corrected EPNL is computed.

An alternate method presented was to compute an overall correction Δ_o to the EPNL which is based on the "A" weighted maximum Crest Factor CF_{Max}* measured during the transient noise signal.

The correction laws proposed in the two cases are linear as function of Crest Factor and pulse repetition frequency (f):

$$\Delta_{dB} = A + B \cdot (CF) + C \cdot f$$

*[Max (peak)]/[Max (r.m.s)], each factor measured independently.

and the A, B, and C coefficients are obtained in each case by a multilinear regression analysis using the subjective corrections ΔS of table III (nine experiments) as input data.

Procedures Discussion

The use of a multilinear regression technique to obtain a best fit correction method is indeed a very good approach, provided that a large number of experiments is taken into account in the computation process of the coefficients of the regression law. Otherwise, the correction law obtained may very well fit the experimental data which are used as input, while putting, on some parameter, a weight through the regression law coefficient which does not reflect its true importance. More precisely, at a time when manufacturers are trying to increase the number of blades of their rotors (ex., Hughes Aircraft Company, Quiet Helicopter Program) in order to decrease the noise, it is very important to know if the pulse repetition rate (f) has to be an independent parameter, and if it is the case, what values should be chosen for its regression coefficient C and its accuracy.

In order to answer these questions, a multilinear regression analysis has been performed on the complete set of available data presented in tables I, II, and III, using as possible descriptors the two previous Crest Factors $CF_{0.5}$ and CF_{Max}, the ISO descriptor x together with the pulse repetition rate f.

MULTILINEAR REGRESSION ANALYSIS

The method used in this analysis is briefly sketched in figure 10. The method is identical to the multilinear regression analysis used in appendix A of reference 3. Regression coefficients A, B, and C are computed using on one hand the subjective corrections ΔS as stated by the juries and impulsiveness parameters (I.D. = x, $CF_{0.5}$, CF_M) and pulse repetition rate f on the other hand. That is to say, the correction law assumed is

$$\Delta C = A + B \cdot (I.D.) + C \cdot f$$

and A, B, and C are computed to minimize

$$|\Delta C - \Delta S|$$

In addition to the overall standard deviation S_e which results from the best fit technique, and of the multiple correlation coefficient r, the present study defines also the standard deviation SA, SB, and SC for the coefficients A, B, and C.

These standard deviations on the regression coefficients define the accuracy provided on these coefficients A, B, and C by the method of analysis. They show, in a simple manner, the confidence level that one can grant to each parameter (I.D., f) taken into account. For example, it is possible that the multiple correlation coefficient r be statistically significant for a given confidence level, and that, at the same time, one obtains a standard deviation on one of the coefficients as large as the value of this coefficient itself. Obviously, in this case the parameter related to this coefficient has no real significance. These quality criteria have been summarized in figure 10.

Application of the Regression Analysis

- For the CF_{Max} and $CF_{0.5}$ descriptors, the procedure underlined in reference 3 has been followed. It is first necessary for a transient signal to define a mean value of the descriptor $CF_{0.5}$. For this purpose, $CF_{0.5}$ is computed at each 0.5 sec time interval from the "A" weighted noise signal, and a "first" correction $\Delta CF_{0.5}$ is computed

$$\Delta CF_{0.5} = CF_{0.5} - 12 \quad (\Delta CF_{0.5} > 0)$$

- A corrected PNLT is then computed

$$PNLT_{corr.} = PNLT + \Delta CF_{0.5}$$

which is used in the integration process to compute the $EPNL_{corr.}$

A mean 0.5 sec Crest Factor for the complete signal is obtained by the following expression:

$$\overline{CF}_{0.5} = (EPNL_{corr.} - EPNL) + 12$$

- A mean value of the ISO impulsiveness descriptor x has also to be computed in order to conduct the regression analysis. This mean descriptor $\bar{x}$ is computed following the same procedure as in the case of the $CF_{0.5}$ descriptor.

The EPNL correction is first computed following the ISO N 356 recommended method. Then $\bar{x}$ is deduced from this correction setting.

$$EPNL_{corr.} - EPNL = 0.8\,(\bar{x} - 3)$$

- The values of CF_{Max}, $\overline{CF}_{0.5}$, and $\bar{x}$ are indicated for each recording used in the subjective evaluation methods in tables I, II, and III. It is to be noted that throughout this regression analysis a good consistency has been maintained in the hypothesis in order to get comparable results:

- The corrections at each 0.5 sec are applied from x = 3 ($\Delta C = 0$) and $CF_{0.5} = 12$ which represent the values of a pure broad band noise signal.

- The maximum correction at each 0.5 sec is 5.5 dB in each case.

- The regression analysis is conducted for the three descriptors in two cases:

(a) Taking into account the pulse repetition rate (f) as an independent parameter.

(b) Discarding the pulse repetition rate f in the regression law.

Regression Analysis Results

Table IV summarizes the results obtained in this regression analysis. The following remarks can be drawn from this table.

(a) The overall standard deviation is minimum (1.4 dB) when the ISO recommended method is used.

(b) The multiple correlation coefficient r is much higher (>0.75) when the ISO recommended method is used, while it is barely significant at 1% confidence level with the CF_{Max} or $\overline{CF}_{0.5}$ descriptor.

(c) Discarding the pulse repetition rate - which has a low regression coefficient C with a very high (44 to 75%) relative standard deviation (SC/C) - improves very much the standard deviation SA which influences directly (dB) the level of the correction ΔC.

Table V provides a direct comparison of the quality criteria of the regression analysis in the six cases treated. From this table one can conclude that:

- The pulse repetition rate should be discarded as an independent parameter

- The ISO recommended procedure provides on a statistical basis the best available method at the present time

These conclusions are more clearly illustrated in table VI which represents the computed results obtained from application of the regression laws without repetition rate dependency on the psychoacoustic tests conducted on the real helicopter noise signals of reference 3. Comparing computed corrections ΔC with the Jury subjective evaluations lead to the following remarks:

- CF_M and $\overline{CF}_{0.5}$ give high penalties (2.3 and 1.8 dB) for the reference noise supposedly nonimpulsive

- Overall standard deviation between the computed and the subjective results is 1.1 dB for the ISO method, 1.5 dB for the $CF_{0.5}$ method, and 1.7 dB for the CF_M method of correction

INSTRUMENTATION AND DATA PROCESSING

Procedure

In the ISO N 356 recommended method, the impulsiveness descriptor I is defined as follows:

1. The acoustic signal is weighted through a filter "A," then sampled at a frequency of 5000 Hz.

2. The digital values "v_i" thus obtained are processed, every 0.5 sec, in two steps:

- The mean square "s" of v_i at each 0.5 sec (i.e., the square of the signal r.m.s value), is first computed.

$$s = \frac{1}{n} \sum_{i=1}^{n} v_i^2 \qquad n = 2500$$

- The impulsivity descriptor I is then

$$(1)\quad I = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{v_i^2 - s}{s} \right)^2 = \frac{1}{n} \frac{1}{S^2} \sum_{i=1}^{n} \left(v_i^2 - s \right)^2$$

It has been proved mathematically in reference 4 that this procedure leads to the value of the previously proposed French descriptor minus one, the latter descriptor being defined as:

$$(2)\quad CI = \frac{\overline{v_i^4}}{\left(\overline{v_i^2}\right)^2} \qquad I = CI - 1$$

So in principle, either expressions 1 or 2 can be used for the impulsivity descriptor computation process.

Instrumentation and Cost

The procedure previously underlined implies the use of:

- the "A" weighting and antialiasing (0 to 2000 Hz) filters

- an analog/digital converter ($\pm$10 volts; 11 bits + sign) associated with a 5000-Hz timer controlling the signal sampling

These instruments are quite inexpensive (≈$400).

The timer is synchronized with the 1/3 octave analyzer used to compute each 0.5 sec the 24 levels of the 1/3 octave spectrum needed for PNL computation.

Two cases have then to be considered (see fig. 11):

Case 1: The laboratory in which the data processing is to be performed uses a 1/3 octave analyzer coupled to a 5000 Hz real time computer for the I task in normal operations of PNL and EPNL computations. In this case, the computer has enough storage capacity to store 5000 sampled values (two time intervals of 0.5 sec, ΔT_{i-1}, and ΔT_i with 2500 values v_i at each time interval) and enough performance to compute the I value (5000 multiplications, 2500 subtractions, and few divisions) of the ΔT_{i-1} time interval during the time allowed (0.5 sec) for the "v_i" acquisition of the next ΔT_i time interval.

Case 2: The 1/3 octave analyzer is coupled to a lower performance computer not allowing real time computation of the I task at the frequency of 5000 Hz. In this case a complementary "mini computer" is necessary to store the 5000 sampled values and compute at each 0.5 sec the I value of the previous 0.5 sec time interval. This type of mini computer is at the present time available commercially at a low price compared to the other equipment necessary for pure EPNL computations. For example, in France, the AMSI type ALPHA LSI 4/90 which has the floating point computation capability (2 K - RAM, 8 K ROM - PROM) is sold in France at approximately $5000 which is to be compared with the $20 to 30 000 needed for a 1/3 octave analyzer.

GENERAL CONCLUSIONS

This study has essentially shown that:

(1) Impulsive noise needs to be corrected in order to represent the annoyance really felt by the public.

(2) Corrections up to 7 PNdB or EPNdB have been found by representative Juries in several countries, with a standard deviation of $\pm$1.3 dB.

(3) Among the proposed impulsiveness descriptors and correction methods, the recommended ISO N 356 procedure provides the best correlation between subjective and computed corrections.

(4) There is no special need to add to the proposed ISO N 356 procedure an additional correction term based on pulse repetition rate.

(5) The standard deviation obtained between computed and subjective annoyance of real helicopter noises is ± 1.1 dB which is comparable to the standard deviation of the jury subjective responses.

(6) The instrumentation and computing hardware necessary for data processing are available on the market at a small price compared to the cost of the equipment needed for EPNL data processing.

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4. Damongeot, A.: Instrumentation for Measuring the Impulsivity Indicator, ISO/TC-43/SC-1/WG2, proposed by N.P.L. or France.

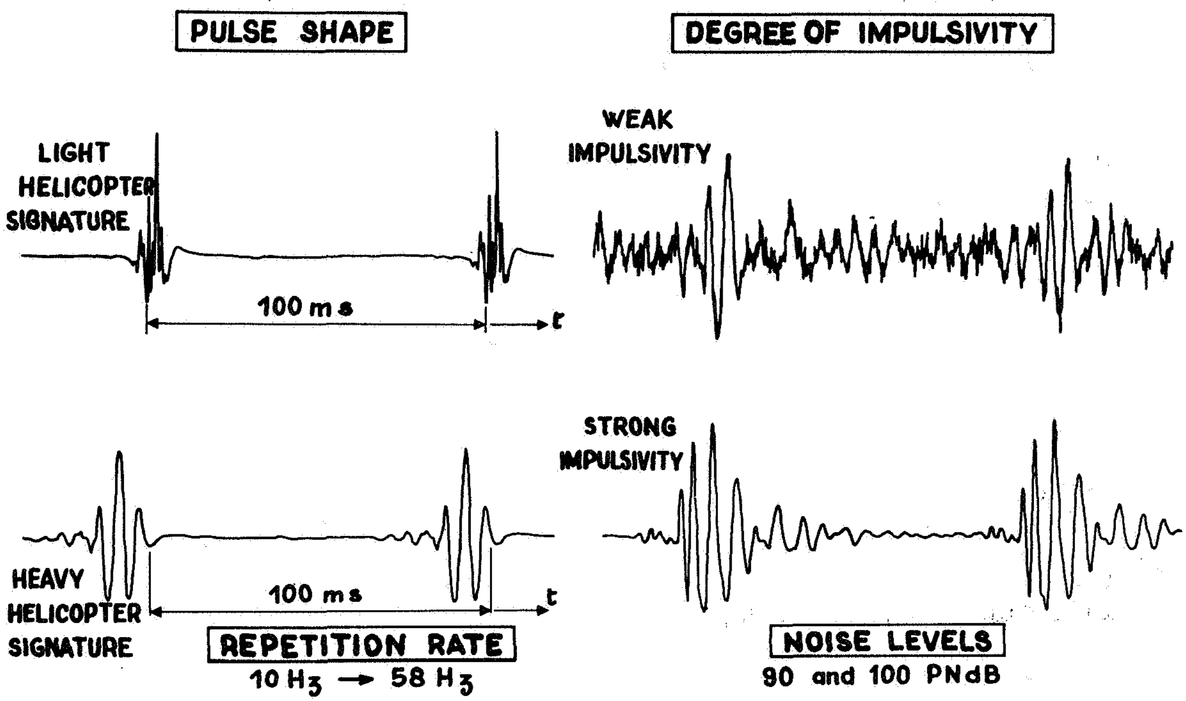


Figure 1.- Impulsiveness parameters.

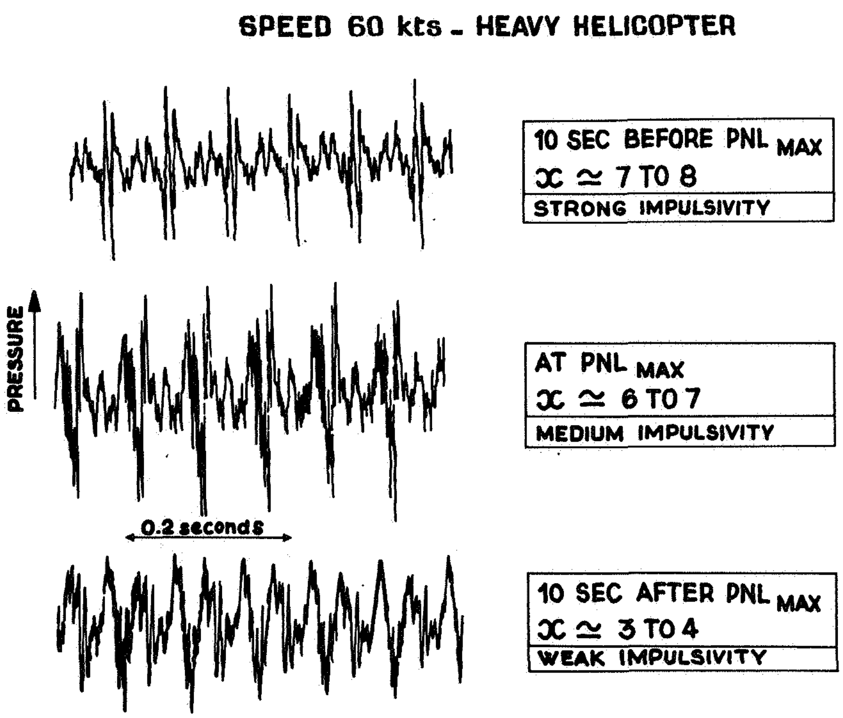


Figure 2.- Evolution of impulsiveness degree during helicopter flyover.

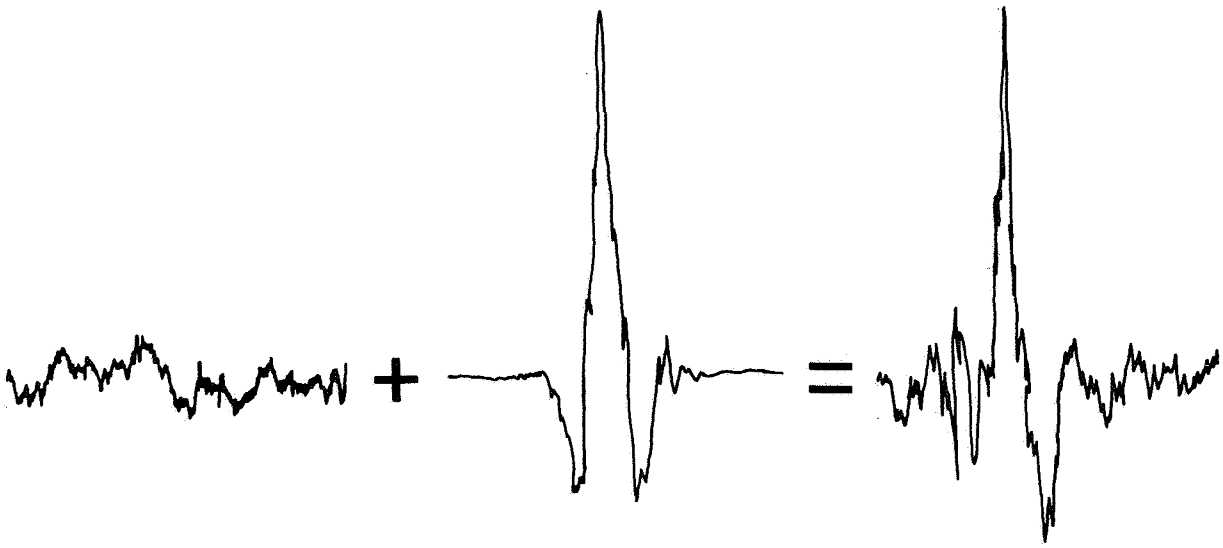
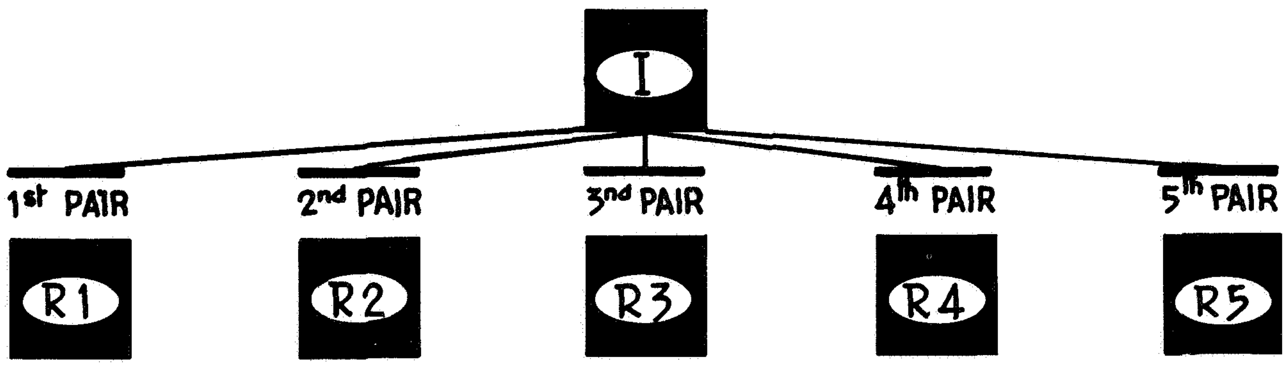


Figure 3.- Generation of helicopter noise signal.



I : IMPULSIVE NOISE TO EVALUATE
FIXED CONDITIONS : NOISE LEVEL, DEGREE OF IMPULSIVITY(x), PULSE SHAPE, PULSE REPETITION RATE

R : NONIMPULSIVE COMPARISON NOISE AT 5 DIFFERENT NOISE LEVELS R1 TO R5 EACH PAIR (I, R_n) EVALUATED TWICE : ORDER (I, R_n) and (R_n, I)

Figure 4.- Subjective evaluation method comparison by pairs.

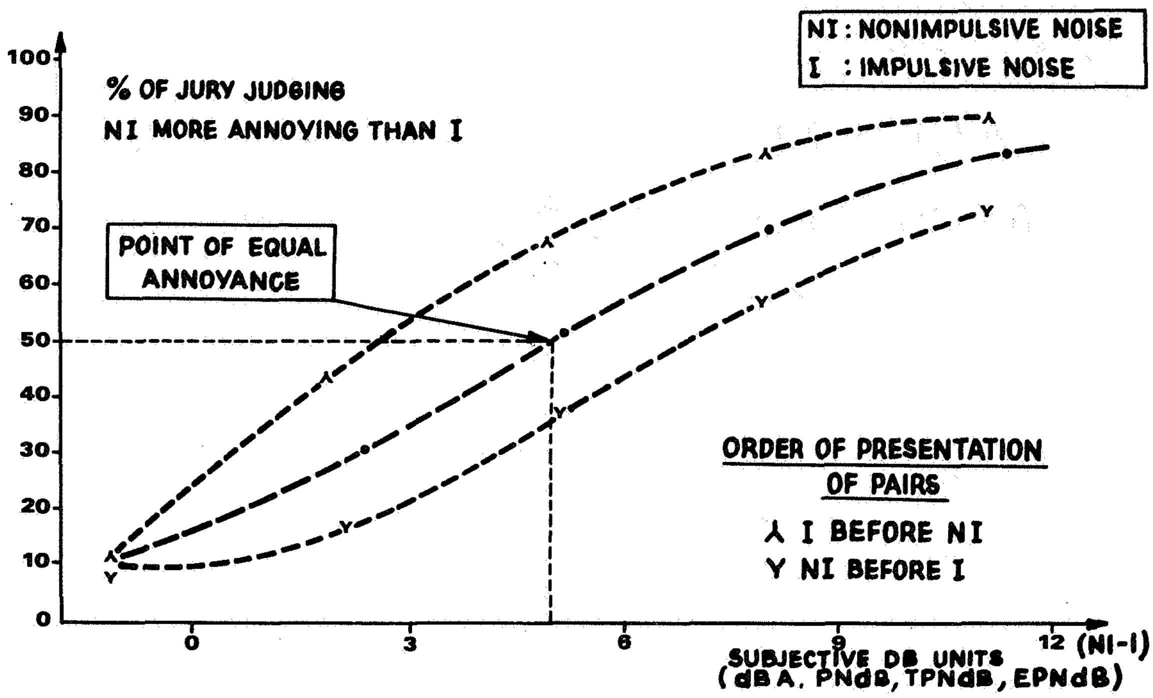


Figure 5.- Jury response curve.

$$CF = 20 \log \frac{PEAK}{RMS} \quad ; \quad x = 10 \log I \text{ with } I = \frac{\overline{V_i^4}}{(\overline{V_i^2})^2} - 1$$

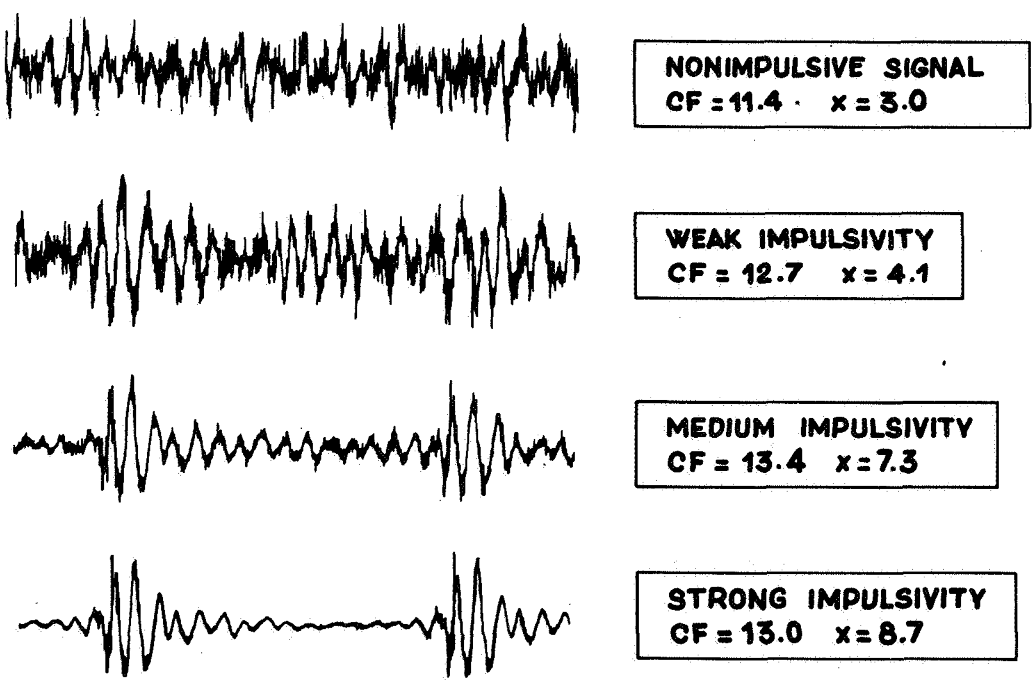


Figure 6.- Impulsiveness descriptors comparison.

■ ISO N 356 RECOMMENDED METHOD

- COMPUTE I DESCRIPTOR AT EACH 0.5 SEC.
- APPLY AT EACH 0.5 SEC. A CORRECTION ΔC TO THE L_{TPN}.

  $\Delta C_{(dB)} = .8(x - 3) \quad 0 \leq \Delta C \leq 5.5$

  WHERE $x = 10 \text{ Log } I$
- COMPUTE THE EPLN FROM THE CORRECTED L_{ITPN} TIME HISTORY

Figure 7.- Impulsiveness correction methods.

• ISO RECOMMENDED DESCRIPTOR

I → BASED ON THE VARIANCE OF THE SQUARE OF THE "A" WEIGHTED TIME HISTORY.

• DESCRIPTOR MENTIONED TO ISO

- CF → BASED ON THE CREST FACTOR OF THE "A" WEIGHTED PRESSURE TIME HISTORY.
- IMPULSE REPETITION RATE (f) MENTIONED AS A POSSIBLE COMPLEMENTARY DESCRIPTOR

Figure 8.- Impulsiveness descriptor.

■ CORRECTION METHOD MENTIONED TO ISO

- COMPUTE $CF_{0.5}$ DESCRIPTOR AT EACH 0.5 SEC.
- APPLY AT EACH 0.5 SEC. A CORRECTION Δ TO THE L_{TPN}

  $\Delta_{dB} = A + B\ CF_{0.5} + Cf \qquad 0 < \Delta \leq 5.5$

  A, B, C OBTAINED FROM REGRESSION ANALYSIS OF PSYCHOACOUSTIC DATA.
- COMPUTE THE EPNL FROM THE CORRECTED L_{ITPN} TIME HISTORY

ALTERNATE METHOD

- OVERALL CORRECTION Δ_O APPLIED TO EPNL BASED ON CF_{MAX}
- $\Delta_O = A + B\ CF_M + Cf$

  WHERE A, B, C ARE COMPUTED FROM PSYCHOACOUSTIC DATA BY REGRESSION ANALYSIS TECHNIQUES

Figure 9.- Impulsiveness correction methods.

INPUT

- SET OF PSYCHOACOUSTIC DATA

  JUDGED RESPONSE : (Δ S)

  IMPULSE DESCRIPTOR (I.D.)

  IMPULSE REPETITION RATE (f)
- LINEAR CORRECTION LAW ASSUMED :

  $\Delta C = A + B(ID) + C\ (f)$

COMPUTE

A, B, C. REGRESSION LAW COEFFICIENTS

TO MINIMIZE $|\Delta C - \Delta S|$

QUALITY CRITERIA

- MULTIPLE CORRELATION COEFFICIENT $r > r_e$ FOR SIGNIFICANCE AT 1°/o LEVEL
- OVERALL STANDARD DEVIATION S_e : MINIMUM
- STANDARD DEVIATION ON COEFFICIENTS A, B, C : SMALL

Figure 10.- Multilinear regression analysis.

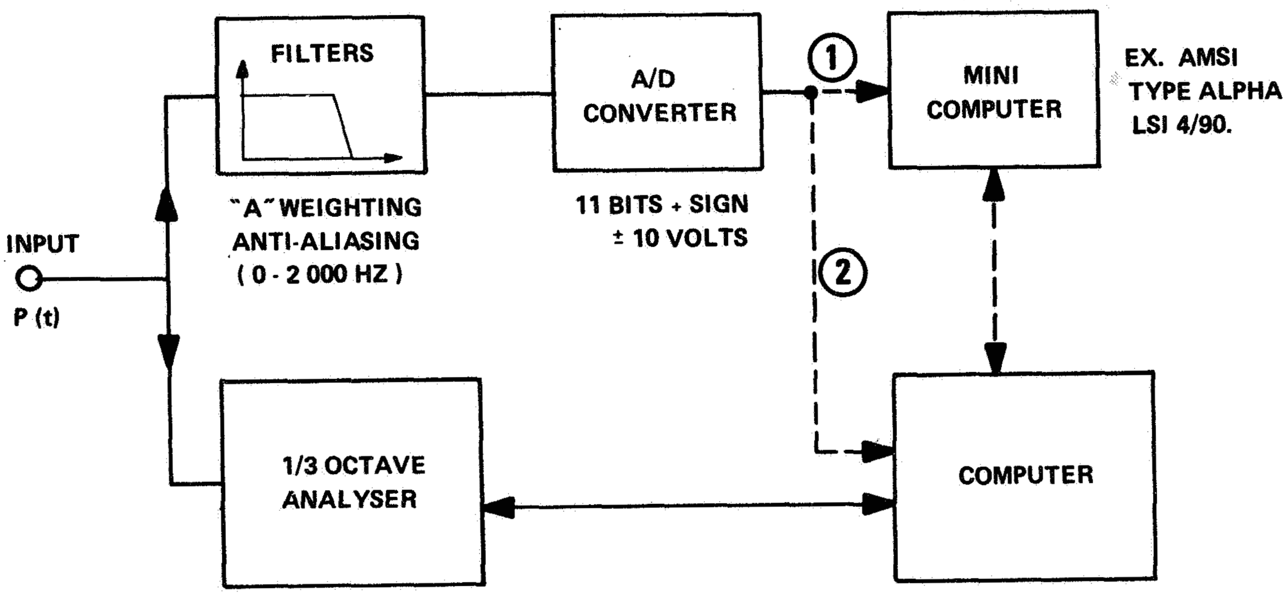


Figure 11.- PNL, EPNL computer system with impulsivity corrections.

TABLE I.- PSYCHOACOUSTIC TEST DATA - STATIONARY NOISE SIGNALS*

TEST N°	TYPE OF HELICOPTER	FREQ. HZ	CF_M	$CF_{0.5}$	$\bar{x}$	ΔS PNdB
201	HEAVY - N.I. (REF.)	17.5	12.9	12.4	3.3	0
202	LIGHT - N.I. (REF.)	17.5	15.2	12.9	3.6	0
206	HEAVY - 100 PNdB	10	14.7	14.8	9.5	5.6
210	LIGHT - 100 PNdB	10	14.9	13.8	4.0	0.9
211	LIGHT - 100 PNdB	10	19.4	20.3	9.6	4.2
212	LIGHT - 100 PNdB	10	20.3	22.	9.6	5.4
213	LIGHT - 90 PNdB	10	15.4	14.7	5.6	2.8
214	HEAVY - 90 PNdB	10	14.1	12.4	3.6	0.1
215	LIGHT - 90 PNdB	17.5	16.1	14.9	8.8	4.4
216	LIGHT - 90 PNdB	25	14.7	15.9	9.0	6.4
217	LIGHT - 90 PNdB	35	16.7	14.8	8.4	5.8
218	MOTORCYCLE - N.I. (REF.)	30	13.9	13.7	4.0	0
220	MOTORCYCLE 1	58	14.6	13.2	7.9	7.0
221	MOTORCYCLE 2	24	19.4	16.6	9.8	3.2

* FRENCH STUDIES, COMPARISON BY PAIRS

TABLE II.- PSYCHOACOUSTIC TEST DATA - TRANSIENT NOISE SIGNALS*

TEST N°	TYPE OF HELICOPTER	FREQ. HZ	CF_M	$\overline{CF}_{0.5}$	$\bar{x}$	ΔS EPNdB
101	FLYOVER - 70 Kt - N.I. (REF.)	17.5	12.5	12.3	3.5	0
102	H. LIGHT - 70 Kt - 95 EPNdB	10	15.8	15.2	6.1	4.2
103	HEAVY - 70 Kt - 95 EPNdB	17.5	14.3	14.5	4.1	2.1
104	FLYOVER - 148 Kt. N.I. (REF.)	17.5	13.8	13.5	4.1	0
105	H. HEAVY - 148 Kt - 95 EPNdB	17.5	15.8	17.8	9.0	1
106	H. HEAVY - 70 Kt - 95 EPNdB	17.5	13.7	13.1	3.8	4
107	H. HEAVY - 70 Kt - 95 EPNdB	17.5	14.8	15.6	7.0	2.3
108	H. HEAVY - 70 Kt - 95 EPNdB	17.5	15.7	15.7	6.2	2.5
109	H. HEAVY - 70 Kt - 100 EPNdB	17.5	15.9	15.8	6.5	2.1

• FRENCH STUDIES, COMPARISON BY PAIRS

TABLE III.- PSYCHOACOUSTIC TEST DATA - TRANSIENT NOISE SIGNALS*

B.B.N. N°	TYPE OF HELICOPTER	FREQ. HZ	CF_M	$\overline{CF}_{0.5}$	$\overline{x}$	ΔS EPNdB
214	S.61 (REF.) - 115 Kt - LEVEL	17	14.3	12.7	3.5	0
215	S.64 - 60 Kt - LEVEL	18.6	14.4	14.1	4.6	2.7
216	CH47.C. - 150 Kt - LEVEL	12.5	17.6	15.8	8.3	7.0
217	CH47.C. - 60 Kt - LEVEL	12.5	17.3	16.9	8.3	5.5
218	B.212 - 105 Kt - LEVEL	11	14.3	15.0	6.8	3.2
219	B.212 - 61 Kt - LEVEL	11	19.4	15.8	7.0	3.1
220	47.G. - 6° APPR.	12	17.7	16.1	7.1	3.5
221	S.61 - 6° APPR.	17	15.6	14.6	6.4	3.8
222	B.206 L - 6° APPR.	13	21.4	15.8	7.0	3.6

* B.B.N. STUDIES, METHOD OF ADJUSTMENT

DATA COMPUTED FROM B.B.N. MAGNETIC TAPE COPY.

TABLE IV.- REGRESSION ANALYSIS RESULTS - 32 PSYCHOACOUSTIC TEST DATA

I.D. IMPULSE DESCRIPTOR		A	± SA	B	± SB	C	± SC	S_e dB	r
CF_M	(a)	– 6.50	2.77	0.52	0.16	0.08	0.04	1.9	0.55
	(b)	– 4.01	0.36	0.44	0.16	–	–	2.0	0.44
$\overline{CF}_{0.5}$	(a)	– 7.14	2.71	0.57	0.16	0.09	0.04	1.8	0.58
	(b)	– 4.12	0.35	0.47	0.17	–	–	2.0	0.46
$\overline{x}$ (ISO)	(a)	– 2.43	0.90	0.74	0.12	0.04	0.03	1.4	0.77
	(b)	– 1.84	0.26	0.75	0.12	–	–	1.4	0.75

* CH47C PULSE RATE (f) AT 12.5 HZ

ΔS = A + B (I.D.) + C.f

r > 0.46 SIGNIFICANT AT 1 % LEVEL

(a) PULSE REPETITION RATE TERM INCLUDED

(b) PULSE REPETITION RATE TERM DROPPED

TABLE V.- QUALITY CRITERIA OF DIFFERENT IMPULSIVENESS DESCRIPTORS

DESCRIPTORS (I.D.)		SA dB	SB/B %	SC/C %	S_e dB	r
CF_M	(a)	2.8	31	50	1.8	0.55
	(b)	0.4	36	–	2.0	0.44
$\overline{CF}_{0.5}$	(a)	2.7	28	44	1.8	0.58
	(b)	0.4	36	–	2.0	0.46
$\overline{x}$ (ISO)	(a)	0.9	16	75	1.4	0.77
	(b)	0.3	16	–	1.4	0.75

$\Delta S = A + B\ (I.D.) + C.f$

SIGNIFICANCE AT 1 % LEVEL $\longrightarrow r > 0.46$

(a) PULSE REPETITION RATE TERM INCLUDED

(b) PULSE REPETITION RATE TERM DROPPED

TABLE VI.- COMPARISONS BETWEEN COMPUTED AND SUBJECTIVE IMPULSIVENESS CORRECTION - TRANSIENT NOISE SIGNALS*

B.B.N. N°	TYPE OF HELICOPTER	FREQ.	ΔC EPNdB			ΔS JURY
			CF_M	$\overline{CF}_{0.5}$	$\overline{x}$ (ISO)	
214	S.61 (REF.) - 115 Kt - LEVEL	17	2.3	1.8	0.8	0
215	S.64 - 60 Kt - LEVEL	18.6	2.3	2.5	1.6	2.7
216	CH47.C. - 150 Kt - LEVEL	12.5	3.7	3.3	4.4	7.0
217	CH47.C. - 60 Kt - LEVEL	12.5	3.6	3.8	4.4	5.5
218	B.212 - 105 Kt - LEVEL	11	2.3	2.9	3.3	3.2
219	B.212 - 61 Kt - LEVEL	11	4.5	3.3	3.4	3.1
220	47.G. - 6° APPR.	12	3.8	3.4	3.5	3.5
221	S.61 - 6° APPR.	17	2.9	2.7	3.0	3.8
222	B.206 L - 6° APPR.	13	5.4	3.3	3.4	3.6
	STANDARD DEVIATION		1.7	1.5	1.1	

* B.B.N. STUDIES, METHOD OF ADJUSTMENT.