HELICOPTER NOISE REGULATIONS: AN INDUSTRY PERSPECTIVE

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SUMMARY

Regulation standards for external noise of helicopters are being developed. In the United States, the Federal Aviation Agency (FAA) and, on the international scene, the International Civil Aviation Organization (ICAO) are active in this work.

The U.S. helicopter industry has been coordinating its acoustics certification views through the Helicopter Association of America (HAA). Its Committee* on Helicopter Acoustic Certification Standards has prepared this paper.

Helicopter noise measurement programs have been conducted by FAA and ICAO. Noise reduction/economic studies have been prepared and some helicopters have been modified for noise reduction. The problems of new design helicopters meeting a prescribed noise limit have been studied and probable design margins assessed. Laboratory and field studies have been, and are continuing to be, pursued in an attempt to determine appropriate units to measure annoyance associated with blade "slap." Lastly, there is a discussion in progress involving the unique operational capabilities of helicopters and the implications relative to noise regulations and certification.

BASELINE DATA

It is obvious that, before quantitative regulations can be written, data for the current state of the art must be assembled. Programs were undertaken by FAA and ICAO for acoustic measurements. The FAA/Department of Transportation (DOT) tests are reported in reference 1. The noise characteristics of eight helicopters are described in level flyovers, simulated approaches, and hover. Takeoff tests are currently being scheduled on these machines and others that may be available.

Certain conclusions are noted in reference 1 which illustrate differences in noise characteristics of several types of helicopters.

Three general noise classes were apparent depending upon noise-time history during flyover:

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*Especially acknowledging C. Cox, R. Schlegel, and H. Sternfeld, Jr.

(a) Maximum noise at the overhead position and appearing to be tail rotor noise propagated downward.

(b) Maximum noise before the overhead position and caused by main rotor compressibility.

(c) Maximum noise after the overhead position caused by unmuffled reciprocating engines.

A lesson to be learned from this is that there are several noise-making elements in helicopters whose levels, directional aspects, and techniques for modifying are different. Since operation parameters for main rotor, tail rotor, and engine are all intimately interrelated in helicopters, a change in any of the elements involves changes in all the elements. The implications of this interrelatedness must be taken into account in the economic reasonableness, technologically practicable doctrine.

Noise levels during approaches varied with glide slope, and no particular glide slope gave the maximum noise for all helicopters. This suggests that if a particular glide slope is selected for measuring approach noise during certification tests, helicopter A might be benefited and helicopter B could be penalized. It would appear more equitable to allow the applicant to select an approach technique within the airworthiness envelope of his helicopter and use this measured noise as the approach level. This concept is appropriate to helicopters because of the unique flight characteristics.

Current U.S. thinking is to require flyover, approach and takeoff tests to demonstrate compliance with noise levels. The method considered would be to average arithmetically all the data from at least six passes at each test condition after correction and adjustment.

The Committee recommends that before the limit lines are drawn at least the following should be accomplished:

- All available data be adjusted for impulsive noise correction if any adjustment is found necessary.
- Data be adjusted for whatever weather and atmospheric parameters are called for.
- Data should be handled according to whatever test procedures and processing are called for.
- The limits should consider all of the existing fleet.
- All presently scheduled and subsequent tests whose purpose is for data base should be done within the meteorological limits of wind, humidity, etc., and distances proposed for certification testing.

- Correction methods for off-standard conditions should be completely verified before inclusion in the regulations.

- Predictive accuracy (or inaccuracy) must be taken into account.

NOISE REDUCTION/ECONOMIC STUDIES

In a recent working paper of the U.S. Representative to ICAO, the following statements appear:

"In setting a noise level limit, ICAO has previously attempted to determine what is 'economically reasonable, and technologically practicable.'....it has been felt that successful commercial application of a technology by at least one company was prima facie evidence of meeting the ICAO requirements." Our Committee's position is that, for helicopters, it is not true that successful commercial application of a technology by at least one company is prima facie evidence of meeting ICAO requirements for Economic Reasonableness and Technological Practicability (ERTP). Unlike jet transports, which are all designed to pretty much one general requirement - i.e., move people or goods so far, so fast - helicopters are designed to many varied requirements. As examples, external load-industrial category helicopters emphasize sling or hoist payload at low airspeeds. Corporate/executive category helicopters emphasize airspeed in addition to payload. Air taxi operations require high speed, payload and fuel efficiency. Still other helicopters can be designed specifically for high altitude-hot day conditions.

Hence, noise technology in one helicopter type does not guarantee successful application to other types, even those produced by the same company. Tradeoffs between helicopter noise and productivity are not as well understood and predictable as some regulatory agencies' personnel believe.

The only study published to date by the FAA which addresses the economic impact of noise reduction on helicopter noise is reference 2. This study concluded that a vehicle noise reduction of 2.5 EPNdB could be achieved on most helicopters by engine duct treatments with only a 2 to 3 percent increase in vehicle life cycle cost. It was additionally concluded that rotor noise reduction methods were not cost-effective means for reducing helicopter noise.

A detailed review by the Committee has shown the study to be technically lacking in several important areas, resulting in the incorrect conclusions that not only engine noise reductions can measurably reduce helicopter noise, but also that 2-3 dB reductions can be made with a modest increase in life cycle cost. The Committee's findings did substantiate the conclusion that means for reducing rotor noise were generally very costly to the vehicle's life cycle cost. The results of some actual aircraft noise reduction programs are herein presented to substantiate these findings.

CRITIQUE OF REFERENCE 2*

The study has its major weaknesses in (a) the incorrect identification and reduction of helicopter predominant sound sources, (b) an inaccurate cost analysis, particularly for light helicopters, (c) an incomplete weight trending analysis, (d) the exclusion of impact analysis of some major factors such as range, payload, marketability and vehicle suitability and (e) non-applicability to tandem helicopters.

Relative to the noise analyses used: (1) Tail rotor noise is shown to be significantly underpredicted, resulting in its exclusion as a major noise source. In fact, many helicopters flying today have predominant contributions of their tail rotor to the vehicle's PNL and EPNL. (2) The main rotor noise analysis assumes an unrealistically rapid rolloff of rotor broadband noise. This incorrectly emphasizes the importance of other noise sources such as the engine in the important mid-frequency region. A recently completed study for NASA (ref. 3) substantiates this conclusion. (3) The engine analysis used significantly overpredicts engine noise by underpredicting the rolloff of core engine noise above 1000 Hz by 7-8 dB per octave.

All of the above result in the incorrect conclusion that turbine exhaust treatments, rather than rotor noise reduction (main and tail) are required to reduce the perceived noise level of helicopters.

As far as the cost analysis is concerned: (1) Quantity of aircraft is not considered. (2) Adjustments to cost data, such as inflation, changing overhead rates, new technology costs, development costs and recertification cost are not stated and/or included. (3) Estimates are not correlated with statistical data. (4) Using the study's estimates, the costs for nine current models was underpredicted by 15 to 350 percent, while the costs for five other models were overpredicted by from 23 to 83 percent. Inaccuracies of over ± 2 to 1 were therefore seen.

With regard to the weight analysis used: (1) The selection of driving weight parameters is incomplete and the majority of the trending equations are incorrect. (2) The significant influence of mission requirements (such as altitude/temperature criteria and single engine ceiling requirements) is ignored. (3) Far too much dependence is placed on main rotor size and power rating. (4) Input data used are for older military aircraft. No data are included for light helicopters which represent the bulk of the fleet. (5) Engines are assumed to be "rubberized" such that engine weight is incorrectly considered a linear function of small power changes. In reality an engine cannot generally be resized in small increments, requiring the next larger size available engine to be used.

Relative to the performance analysis used: (1) Installed power relationships are too generalized, as they do not account for installation losses which can be significant. (2) Forward flight power required relationships are very

*The views expressed are those of the Committee and are not necessarily those of NASA.

much dependent on individual manufacturer's design philosophy and, therefore, cannot be generalized in the manner of reference 2. (3) The specific fuel consumption data used does not apply to modern-day turboshaft engines.

SPECIFIC NOISE REDUCTION CASES

Analysis

A Sikorsky S-61N 8840 kg (19 500 lb) gross weight helicopter was analyzed by Committee members to determine the impact on direct operating cost of applying state-of-the-art noise reduction technology to reduce its cruise flyover noise. The best analytical techniques available to Sikorsky were used for this study and were updated with actual weights, performance and cost data to provide the most realistic models possible.

The result of this study is shown in figure 1 as the dotted line and is compared with the reference 2 results (normalized to Direct Operations Cost (DOC)) for main rotor reductions and engine silencers. It should be noted that the engine silencing curve of reference 2 demonstrating the limited penalty associated with noise reduction, shows no correlation with the total vehicle curve. Rather, the total vehicle results more closely correlate with the reference 2 rotor curve (which was concluded to be impractical) even though tail rotor, main rotor and engine noise reduction was generally required to achieve the required noise reductions. A 2-dB noise reduction resulted in a 13-percent increase in DOC while a 3-dB noise reduction resulted in a 70-percent increase in DOC.

Hardware

Several helicopters have been modified for reduced noise and demonstrate the economic impact of the application of current state-of-the-art technology.

In the case of Boeing Vertol model 347 helicopter, which resutled from modifications to the CH-47 helicopter, a noise reduction in the order of 12 PNdB was achieved. The following changes were incorporated:

Changed from three- to four-bladed rotors.
Reduced rotor rpm.
Increased height aft pylon 0.76 m (30 in.).
Increase length fuselage 2.79 m (110 in.).

The total increase in weight empty was approximately 1590 kg (3500 lb). Since the aerodynamic performance of both aircraft is similar, this weight comes directly out of payload. Allowing 75 kg (165 lb) per passenger plus 15.9 kg (35 lb) baggage, the reduction comes to 18 passengers. At a maximum seating density of 52 passengers, the reduction in potential passengers, and hence, revenue, is 35 percent.

Another helicopter modified for reduced noise, the Hughes OH-6, will also be addressed here. In reference 4, a reduction of 10 dB (OASPL) (from

90 to 80) is stated as being accompanied by a reduction in payload from 295 kg (650 lb) to 267 kg (590 lb), or 28 kg (60 lb) for 10 dB. This is a reduction of noise of 10 dB with a payload reduction of about 10 percent. However, the report states that it was an idealized "perfect" muffler; i.e., it did not reduce power, it did not increase fuel consumption, it did not weigh anything, but it did reduce noise. A practical case in the same reference shows that for 10 dB noise reduction, the payload drops from 295 kg (650 lb) to 159 kg (350 lb) which is a reduction of 46 percent. A large part of the penalty is in the power-robbing aspect of the muffler, but it does represent the real world.

Another helicopter to be considered is the Hughes 269C as modified for police work. The standard version has a gross weight of 930 kg (2050 lb), and a payload of 286 kg (630 lb) with full fuel. The never-exceed speed V_{NE} for the standard version is 175 km/h (109 mph). The quieted version has a gross weight of 873 kg (1925 lb) and a payload of 229 kg (505 lb) with full fuel; V_{NE} in the quiet mode is 113 km/h (70 mph). Thus, the quieted version payload is about 60 percent of the standard version. This is for a reduction in noise of from 3 to 8 dB (either dBA or PNdB) for the various flight conditions. Further, the quieted version has a minimum operating speed and a minimum operating altitude over the terrain of 152 m (500 ft). These latter limitations come about because of the reduced rotor rpm. Here again, the real world is more severe than theory.

Two major points result from the above: (1) One cannot generalize noise-economic studies, which must be made on specific models by the respective manufacturers, and (2) The cost of noise reduction is significant, and has shown a range of payload and DOC penalty from 3 to 23 percent impact per PNdB of reduction. The payload reduction associated with reduction in noise for the CH-47C and the OH-6A is 35 to 46 percent and on another aircraft this reduction in payload exceeds 70 percent for a reduction as low as 3 PNdB.

As a result, noise standards must not be established which require significant reductions over current design helicopters until such time as the technology is developed to economically achieve the required reductions. This technology development requires a substantial financial commitment comparable to that spent to develop economically viable quieting means for fixed-wing aircraft.

NOISE TRENDS AND POSSIBLE NOISE LIMITS

Figure 2 shows noise levels of 16 current helicopters and possible noise limits under consideration in the United States and internationally. The levels are taken from DOT/FAA noise measurements, ICAO/CAN Working Group B data, and U.S. industry supplied data. Several trends are evident. Helicopter noise levels vary directly with gross weight. Larger variations in noise level occur in cruise flyover than in a 6^{o} approach for a given size helicopter. Also, noise levels of the quieter designs are generally higher during approach than in cruise flyover.

Possible noise limits under consideration by the FAA and within ICAO Committee on Aircraft Noise (CAN) Working Group B differ in stringency and variation with gross weight. The FAA's possible limits are the most stringent, particularly for the approach condition. If such limits were in effect, one-half of the helicopters shown in figure 2 would not comply for the flyover condition. For the approach condition, over 70 percent would not comply.

The upper line, labeled HAA, in figure 2 has been proposed by U.S. industry as a possible noise standard. It represents levels that "place a lid" on the noise of future designs and derivative versions. At the same time, the standard penalizes those helicopter types which are the noisiest. With such a standard, 25 to 30 percent of the helicopters shown in figure 2 would not comply. In view of the present understanding of rotor sound generation, the accuracy of noise prediction, and the limited change possibilities of derivative helicopters, this standard is believed a more rational initial step.

PREDICTION ACCURACY

The development of standards and the establishment of noise limits must consider the accuracy of helicopter noise prediction as well as the repeatability of the data. The manufacturer must have a high level of confidence of meeting these limits since the certification test is conducted near the end of the development program. This has been recognized by DOT/FAA (refs. 5 and 6) in the development of noise standards for fixed-wing aircraft. For these aircraft, the confidence level of noise prediction is high because of the extensive resources expended over the past decade. Tolerances range from 2 EPNdB up to 5 or 6 EPNdB.

Such is not the case for helicopters. The state of technology of helicopter noise prediction is not as advanced as that for jet transports and propeller-driven airplanes. To assure compliance, a helicopter manufacturer's design would have to be targeted below the noise rule requirement by tolerance margins of up to 5 EPNdB for derivative and growth versions, and 10 to 12 EPNdB for new designs that are substantially different for current experience. This is illustrated in figure 3. Coupled with this is the fact that no prediction method exists for the approach and takeoff conditions.

LIMITED CHANGE POSSIBILITIES OF DERIVATIVES

Under the acoustical change provision of FAR Part 36 aircraft noise standards, the noise level of derived versions must not exceed that of the "parent" aircraft if the parent's noise level is above the limits. This provision is being considered for the helicopter noise rule. This means that future derivatives of the helicopters exceeding the limits in figure 2 cannot "grow" in the traditional manner.

The helicopter industry follows a unique design/product improvement cycle in developing derived versions and in designing new ones. Since the helicopter derives its lift and control from constantly powered rotating blades, a continuous flow of power is required from the engine to the rotors. This flow is accomplished by means of a complex transmission/drive train system which must transmit high torque loads during all helicopter flight regimes. The expense of developing and testing the components of this transmission/drive train/rotor system represents a significant factor in the overall cost of the helicopter. For this reason the design/development cycle many times calls upon previously developed components to meet the requirements of a newly designed helicopter.

After a new helicopter type is certificated and in production, new or updated requirements of the helicopter operator must be met. The manufacturer must decide on a new product or modification of an existing one. Because of the high cost of components and qualification testing of a helicopter, the decision to modify an existing product is more often the choice. Thus, derived versions of a helicopter design are constantly being developed, using as many of the original drive train/rotor system components as possible.

Typically, helicopter derivatives are growth versions with higher payload and/or range capability and increased gross weight. For the same rotor tip speeds, the gross weight effect increases the noise level. To offset this, rotor tip speeds of all growth versions, if the parent design is noncompliant, would have to progressively decrease.

Reducing rotor tip speeds has several very practical limits. Torque levels in the transmission and drive train increase. With previously developed components, torque limits can be quickly reached. Hence, in those designs that are torque-limited, derivative versions would not be possible under the acoustical change provision. Lowering rotor tip speeds also directly affects the lifting capability and control of the vehicle. It is not possible to generalize this effect since each design starts from a different baseline. However, experience has shown that performance and controllability tend to be degraded.

Any retroactive provisions which apply to current helicopters or to future production of existing designs would curtail the growth of the helicopter industry. Unlike fixed-wing aircraft noise control, it has been demonstrated that retrofit and modifications to existing helicopter designs result in unacceptable performance and safety degradation (refs. 2, 4, 7, and 8).

ROTOR IMPULSIVE NOISE

The matter of rotor impulsive noise generates quite a bit of controversy due to the very subjective nature of people's response to it. The term, as used here, applies to any rotor signature having as one of its characteristics a high crest factor, regardless of the physical cause of the noise. It should be understood that impulsive noise is not associated with any one helicopter configuration or flight condition. It may be due to intersections between blades and vortices shed by other blades or rotors. Examples of this are tandem rotor helicopters, or single rotor helicopters in descent. Impulsive noise may also be associated with high advancing tip Mach Number on any configuration.

Figure 4 illustrates typical spectra of impulsive rotors. It is the preponderance of high-amplitude higher harmonics that create the sound often referred to as "bang" or "slap."

There is no question that an impulsive rotor is more annoying than a non-impulsive rotor. There is considerable room for debate, however, as to the units which best measure the annoyance. The unit of Effective Perceived Noise Level (EPNL) has been selected by both FAA and ICAO as the basic unit for helicopter noise regulation. The debate centers on whether EPNL adequately measure impulsive noise, or whether an additional adjustment, in the form of a penalty, is required.

Several descriptors for impulsive rotor noise have been proposed and some of these were evaluated in an FAA report (ref. 9).

One of the leading contenders is

$$\Delta = -6.875 + 13.75 \log CI \qquad 0 \geq \Delta \geq 5.5 \tag{1}$$

where

$$CI = \frac{\frac{1}{N} \sum_{j=1}^{n} V_i^{\,4}}{\left[\frac{1}{N} \sum_{j=1}^{n} V_i^{\,2}\right]^2} \tag{2}$$

and

N = the number of samples of V_i obtained in each 0.5 second by high-speed digitizing of the signal

V_i = voltage sampled at ith time increment

Two forms of the above have been proposed: one in which the signal is low-pass filtered at 2000 Hz prior to high speed digitizing, and one in which the signal is "A"-weighted prior to digitizing.

Another proposed approach uses the difference between the maximum peak A-weighted sound pressure level and the maximum A-weighted sound pressure level as measured by analog devices. These measurements may be based on the peak values during the run, or performed every 0.5 second as in the previous method.

A conclusion of the reference 9 study is: "All of the impulsiveness descriptors...when applied to the EPNL values for actual flyovers, improve correlation with the average judged response. None, however, provides a correlation that is statistically significantly different from zero at the 1-percent level...."

Reference 9 further states that: "Correlation between main rotor blade passage frequency (the pulse repetition rate) and averaged judged response is higher than that provided by all of the impulse measures except the French method" (eqs. (1) and (2).)

Reference 9 also concludes: "Descriptors formed by combining repetition rate with each of the impulsiveness measures are all significant at the 1-percent level accounting for 75 to 87 percent of the variance in averaged judged response."

So, we even see a disagreement among proponents of the impulse penalty as to whether impulse level or repetition rate is more important. This latter position is at variance with at least two other studies (refs. 10 and 11) which find repetition rate to be barely significant.

Use of methods such as those described above implies that the data analysis for helicopter certification may be considerably more involved than that required for airplanes. Such complexities should not be introduced unless the current method is clearly proven to be inadequate. This is not the case. Figure 5 shows the EPNLs of successively impulsive flybys obtained by increasing the advancing tip Mach Numbers of a helicopter while holding the airspeed relatively constant. Figure 5 also presents the time histories of the first and last runs showing that the EPNL of the impulsive data is greater than that of the non-impulsive data because the levels are higher and the time duration greater.

The results indicate that the last run had an increase of 8 PNdB due to level, and 5 PNdB due to exposure time, for a total increase of 13 EPNdB over the first run.

The HAA Committee finds that EPNL, by itself, is a realistic and sensitive enough measure of blade impulse noise without further embellishment.

CERTIFICATION TO OPERATIONAL CATEGORIES

The Noise Control Act of 1972 relates, among other things, to the promotion of "an environment for all Americans free from noise that jeopardizes their health and welfare." Thus, the thrust of the Act is toward the protection of people.

The philosophies of present aircraft certification standards establish a noise limit which may not be exceeded if type certification is to be achieved. This philosophy was developed in conjunction with fixed-wing aircraft. Such aircraft are generally operated from airports, and airports are generally located in centers of population.

Helicopters, however, can operate from totally unprepared fields and perform much of their useful work in sparsely populated areas. HAA statistics show that over 70 percent of helicopter operations are conducted in areas occupied by few, if any, people. The search for and production of new energy sources, and other raw materials, are prominent in these non-noise sensitive regions.

While all studies to date do not show the same penalties for quieting, all studies show that some penalties result when helicopters are made quieter. Fuel economy is worsened, power is reduced, weight increases, greater costs are incurred, all in various degrees, when quieting is required.

Therefore, the Committee feels that it is rational to direct attention to the unique operational abilities of helicopters when writing noise regulations. The regulations should not preclude certification on the sole basis of inability to meet noise criteria. Rather, inability to meet noise criteria should result in limitation of operational areas. The regulations should permit "dual" certification if requested: a quiet mode, complying with all regulations, including noise, and a more efficient mode (not meeting the noise criteria) having operational constraints as part of the certification.

HAA is in the process of questioning the helicopter operating members as follows:

Do you favor a helicopter noise certification criterion which, all other aspects considered equal,

( ) Requires all helicopters to be certificated with a performance which produces noise levels based upon operation in congested areas?

or

( ) Uses a certification noise level based on operation in congested areas but allows relaxation when operations are to be conducted in sparsely populated areas?

Fifty-eight responses have been received of which 57 favored the second criterion. The other respondent favored the first for new designs and the second for existing designs.

FAR 36 now has a statement: "No determination is made, under this part, that these noise levels are, or should be, acceptable for operation at, into, or out of any airport." This certainly recognizes the probable existence of local opinion and local regulations about the operations of noisy vehicles. It further appears that administrative channels are in existence for implementing local controls and approval of helicopter operations. FAR 133 Rotorcraft External-Load Operations, Para. 133.31(f) allows rotorcraft external load operations over congested areas if those operations are conducted without hazard to persons or property on the surface. The operator must develop a plan and coordinate the plan with the FAA district office, and get agreement with local officials relative to air traffic control, etc.

If, in the above, "hazard" is construed to include noise damage or annoyance, the "plan" of FAR 133.31(f) can include, for example, a minimum altitude and a path so as to minimize noise on the ground.

CONCLUSIONS

(1) Helicopters, as noise generators, are more complicated than fixed-wing aircraft. This fact does in no way excuse helicopters from noise regulations. The fact does, however, indicate that there should be a different regulatory and operational attitude toward helicopters than to fixed-wing aircraft.

(2) These differences impact upon the ERTP doctrine making generalizations unreliable when applied to a variety of helicopters.

(3) Hardware experience has indicated greater performance and economic penalties than published theory would indicate.

(4) The relatively primitive and incomplete state of the art of helicopter noise prediction methods, particularly for new designs, cries out for generous noise limits, and increased funding for further study.

(5) If the traditional, successful industry policy of derivative design is not recognized by the regulatory agencies, there will be severe economic implications, curtailing industry growth.

(6) The question of rotor impulsive noise and the units with which it shall be expressed promises to make testing and data reduction more complicated and costly than is necessary, at least for the initial body of regulations. EPNL, by itself, appears to be an adequate and practical descriptor for this decade.

(7) The ability of helicopters to operate where no other vehicle can demands reasoned consideration. If we insist upon levels of quiet (appropriate for cities) when operating in the wilderness, we shall be needlessly, and inefficiently, constrained by a man-made wall of unreason.

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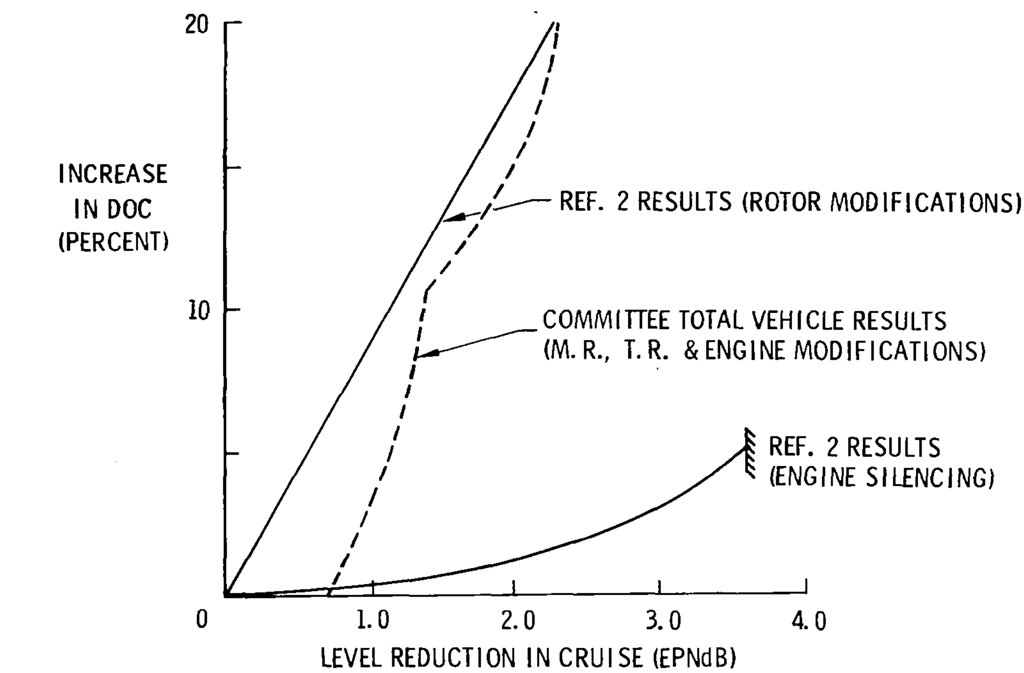

Figure 1.- Comparative trade-off results.

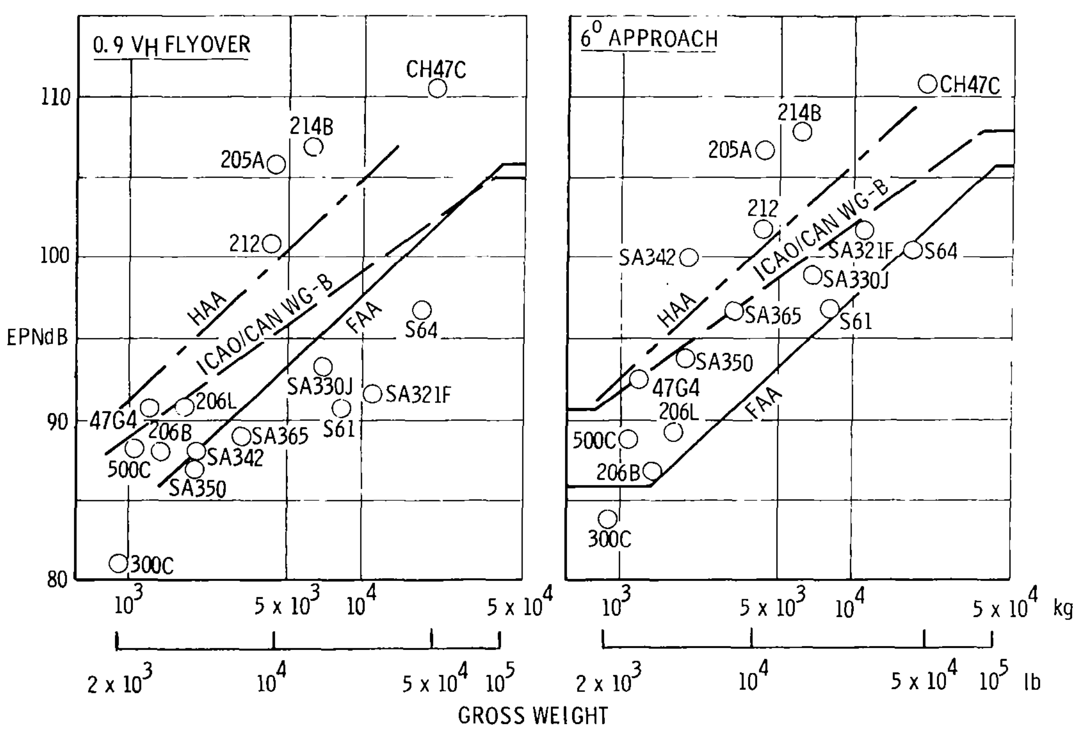

Figure 2.- Helicopter external noise trends and noise limits under consideration (ISO impulsivity included).

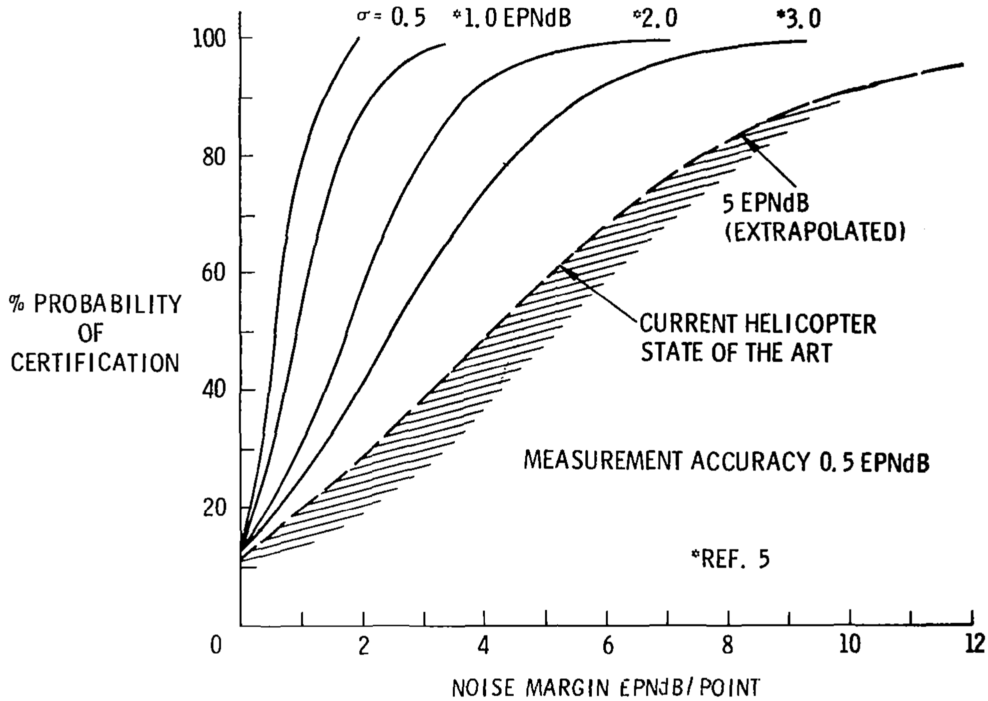

Figure 3.- Required design noise margin EPNdB/point.

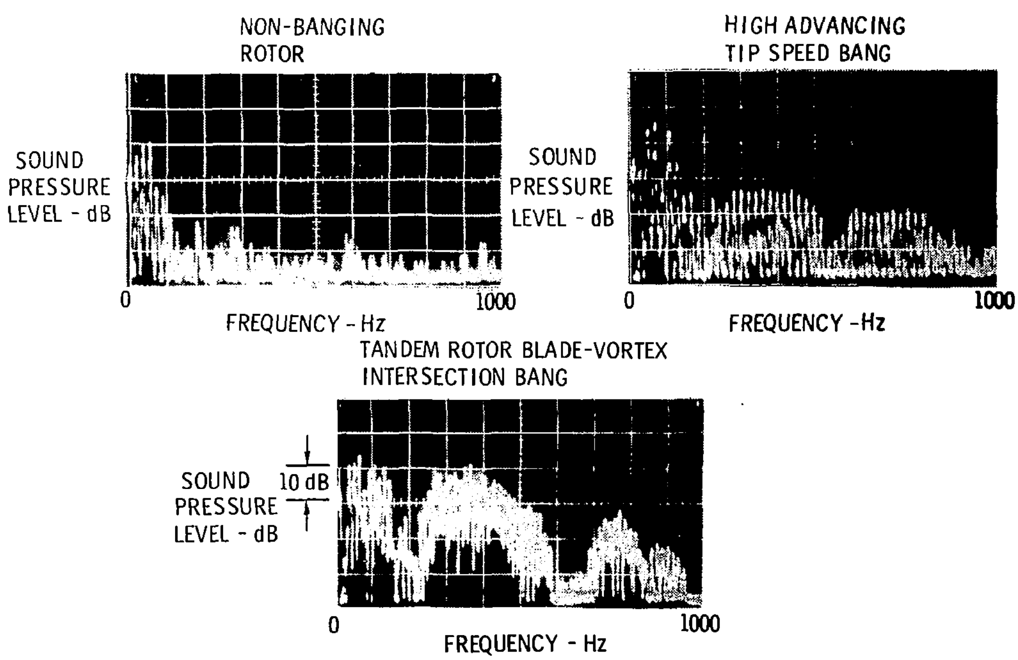

Figure 4.- Narrow band spectra - rotor noise.

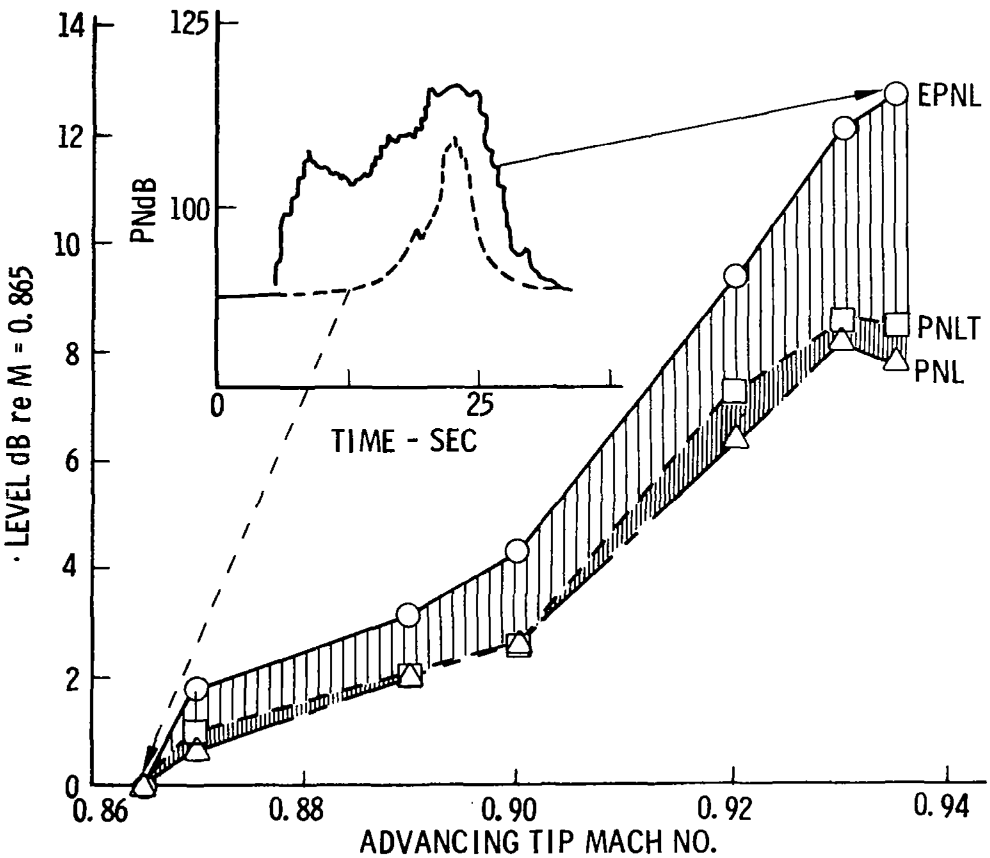

Figure 5.- Effect of impulse noise on measurements.