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Comparison of Predicted Engine Core Noise With Proposed FAA Helicopter Noise Certification Requirements

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U. von Glahn and D. Groesbeck
Lewis Research Center
Cleveland, Ohio

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COMPARISON OF PREDICTED ENGINE CORE NOISE WITH PROPOSED FAA HELICOPTER NOISE CERTIFICATION REQUIREMENTS

by U. von Glahn and D. Groesbeck

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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SUMMARY

Calculated engine core noise levels, based on NASA-Lewis prediction procedures, for five representative helicopter engines are compared with measured total helicopter noise levels and proposed FAA helicopter noise certification requirements. Comparisons are made for level flyover and approach procedures. The measured noise levels are generally significantly greater than those predicted for the core noise levels, except for the Sikorsky S-61 and S-64 helicopters. However, the predicted engine core noise levels are generally at or within 3 dB of the proposed FAA noise rules. Consequently, helicopter engine core noise can be a significant contributor to the overall helicopter noise signature and, at this time, will provide a limiting floor to a further decrease in future noise regulations.

INTRODUCTION

In order for the United States to be in the best competitive world position, efficient low noise helicopters must be developed. Uncertainty in the prediction of noise and its control leads to poor performance/noise trades and overly conservative noise design margins that lead to economic penalties. Noisy helicopters can lead to night curfews at airports and heliports, as well as expensive suits by individuals and communities. Also the number of flights during daylight hours can be limited by the use of accumulative noise indices. Finally, helicopter noise can limit certain military stealth operations.

As part of a general program to alleviate community noise problems, the noise associated with helicopters has been receiving increased attention in recent years as the number of operating helicopters has multiplied. Studies, such as that in reference 1, have established that the most objectionable helicopter noise is related to the impulsive and non-impulsive noise generated by the main and/or tail rotors (fig. 1). Because of their dominance, these noise sources have relegated other helicopter noise sources to a secondary position. Consequently, such sources as engine noise and its potential to affect compliance with proposed and future civil helicopter certification requirements has been neglected. In addition to these major helicopter noise sources, noise is also generated by the interaction of the main rotor wake with the fuselage, external protuberances (pods, landing gear, etc.), and the tail rotor.

Effective measures to reduce helicopter noise require independent studies of each noise source in order to ascertain its contribution to system noise and then a total system noise assessment. Once rotor noise has been reduced to acceptable levels, engine noise sources are the most significant noise generators (ref. 2). These sources consist broadly of compressor noise, core noise, and jet noise. Of these, core noise appears to be the most important engine noise source. The compressor generates high frequency source noise that can be effectively reduced by suitable blading design and acoustically treating the inlet duct surfaces. Currently, jet noise is not considered a major noise source for helicopters because of the low jet exhaust velocities. With low jet exhaust velocities, however, core noise can constitute the major engine noise source (ref. 3), and if sufficiently high can cause community annoyance. Core noise is difficult to suppress by wall acoustic treatment because it is dominated by a low frequency combustion noise component.

In the present paper, predicted core noise levels associated with helicopter operation will be examined to determine their significance in complying with the proposed FAA helicopter noise certification requirements.

BACKGROUND

Core Noise

Core noise is considered to consist of that generated by the combustor, turbine, support struts, and internal surfaces. Combustor noise is produced by the unsteady combustion in turbine engines (ref. 2). That is, combustion is unsteady with time varying heat release that in turn produces unsteady pressure fluctuations within the engine. These then propagate downstream from the combustor and give rise to a sound field. The sound field generated by the combustion process is partly attenuated by the turbine, depending on the number of stages, and to a lesser degree by the exhaust nozzle.

Reduction of the unsteady flow (turbulence) in a combustor in order to reduce the source noise may not be practical, since the combustion process depends on a high turbulence level for flame stability and burner performance optimization (ref. 2). Consequently, a performance penalty could be expected with reduced combustor noise.

Turbine noise sources are associated with high frequency generating mechanisms. Thus, tailpipe acoustic wall treatment, in principle, could suppress any objectionable turbine tones or noise levels. However, interactions between the turbine generated noise and the turbulent exhaust flow can result in increased overall noise levels (ref. 2).

Strut or obstruction noise is caused by the flow over a solid surface, resulting in a broadband noise source. In general, the flow velocities are sufficiently low within the engine boundaries that this noise source is considered a second order source. When strut noise does become apparent, it is generally caused by cross flow or rotating flow over an internal support number.

Proposed FAA Helicopter Noise Certification Requirements

As part of the FAA noise certification requirements for aircraft, a noise rule for helicopters has been proposed (ref. 4). The following sections summarize the flight paths and noise measuring stations, and the proposed noise rule.

Flight paths and noise measurement stations. - The proposed helicopter noise certification flights would consist of approach, level flyover, and takeoff noise tests. Simultaneous measurements for each noise test series would include a flight path noise measuring station and two sideline noise measuring stations, one on each side of the path and at a sideline distance of 150 m. The height of the helicopter over the noise measuring station is referenced to the flight path. A six degree angle (flight path) is proposed for the approach test, with a vehicle altitude of 120 m when the helicopter is directly over the flight path noise measuring station. For level flyover, a vertical height of 150 m is proposed for the vehicle flight path over the flight path noise measuring station. Finally, for the takeoff noise test, the measuring station is proposed to be located 503 m from the point at which takeoff power is applied in order to permit the measurement of the noise levels of the helicopter while at the best rate of climb attitude at high engine power and rotor settings.

For the level flyover tests, the reference speed proposed is 90-percent of either maximum level flight speed with maximum continuous power or the never-exceed speed, whichever is lower. The microphones would be located 1.2 m above the ground.

Proposed noise rule. - The proposed FAA helicopter noise certification requirements (ref. 4) are given in figure 2. The requirements are based on the collected data of reference 1. In general, the noise level varies with 10 log W for all certification requirements, the exception being at the low end of the gross weight scale. For approach noise, which has the highest allowable levels, the proposed noise limits vary between 87 and 107 EPNdB. For level flyover noise, which has the lowest allowable levels, the proposed noise limits vary between 85 and 105 EPNdB. The takeoff noise limits fall halfway between the two preceding sets of limits.

ACOUSTIC DATA BASE

In the present study, measured helicopter total noise data from reference 1 are used for comparison with predicted core noise levels and proposed FAA helicopter noise certificaton requirements. In reference 1, the measured helicopter noise levels are given for eight helicopters, two of which were powered by piston engines. These latter data are not included herein, the present study being limited to turbine engine powered helicopters. A brief description of the helicopter/engines included herein is given in the following table.

Helicopter manufacture	Engine	No. of engines	Test gross weight, W, kg
Hughes 500C	Allison 250-C20A	1	839
Bell 212 (UHIN Huey)	Pratt and Whitney PT6T-3	2	4354
Sikorsky S-61 (SH-3B)	General Electric T58-GE-8B	2	8492
Sikorsky S-64 (CH-54B)	Pratt and Whitney JFTD-12A-5A	2	19456
Boeing Vertol 114 (CH-47C, Chinook)	AVCO-Lycoming T55-L-11	2	18594

In addition to the preceding helicopters, a Bell 206L was also included in reference 1; however, the approach flight path was not the same as that for the other helicopters. Consequently, this set of data are not included herein. It should be noted that the Bell 206L is very similar to the Hughes 500C, having a somewhat larger gross weight (1768 kg) and a slightly more powerful Allison engine (20 more shaft horsepower).

The purpose of the tests of reference 1 was to obtain a data base for the development of the regulatory standards. Consequently, acoustic data were obtained at the proposed FAA measuring stations for approach and level flyover certification requirements. Data were also obtained at a hover condition (wheels 1.53 m above ground level), but are not included herein. No data were obtained for the takeoff condition. For the approach condition, glide slopes of 3°, 6°, and 9° were used for the acoustic measurements. Because the proposed certification requirements specify a 6° glide slope, only these acoustic data are included herein.

The following approach and level flyover helicopter airspeeds at the FAA measuring stations given in reference 1 were used herein:

Manufacturer	Nominal Airspeed, m/s	
	Approach	Level flyover
Hughes 500 C	26.8	58.3
Bell 212	30.8	56.7
Sikorsky S-61	30.8	59.3
Sikorsky S-64	30.8	49.0
Boeing Vertol 114	30.8	72.7

For both flight conditions, the helicopter engine centerline was assumed to be parallel to the ground.

ENGINE CHARACTERISTICS

The helicopter nominal full-power engine characteristics are given in the following table:

Engine	Maximum combustor-to-ambient pressure ratio, $P_{3,m}/P_{3,m}$	Maximum temperature ratio across combustor, $T_{4,m}/T_{3,m}$	Maximum combustor mass flow, $\dot{m}_m$, kg/sec
Allison 250/C20A	7.0	2.36	1.54
Pratt and Whitney PT6T-3	7.2	2.60	2.90
Gen. Electric T58-GE-8B	8.2	2.29	5.70
Pratt and Whitney JFTD-12A-5A	6.8	2.90	23.0
AVCO-Lycoming T55-L-11	8.5	2.25	10.24

In order to provide input into core noise prediction procedures for less than full power engine operation, the preceding engine parameters were examined for similarity. The P_3/P_a and $\dot{m}$ terms were plotted in terms of engine speed based on available data from small turbofans, such as the AVCO-Lycoming YF-102 and Pratt and Whitney JT15D engines (refs. 3 and 5, respectively). It is assumed herein that the turboshaft engines for helicopters would exhibit similar trends. The $P_3/P_{3,m}$ and $\dot{m}/\dot{m}_m$ variations with fan speed are shown in figure 3 for the YF-102 and JT15D engines. The relationship between fan and core speed is shown in figure 4. Single curves are drawn through the data of figures 3 and 4 and are assumed to apply to the helicopter turboshaft engines included herein. It should be noted that the data shown in figures 3 and 4, which are for relatively small turbofan engines, are very similar to data for very large turbofan engines (not included herein). The temperature ratio shown in the preceding table did not vary appreciably for the engine speeds of interest. Hereinafter, engine speeds noted are in percent of core speed.

CORE NOISE PREDICTION

Spectra

The spectral shape used for the prediction of core noise is that given in reference 6 and identified as the "spectral envelope". This spectral envelope is a broader spectrum than that frequently ascribed to combustor noise only. The peak of the spectrum is assumed to be at 400 Hz statically and is assumed to be shifted in flight by a Doppler shift in frequency.

Overall Sound Pressure Levels

The noise level statically is obtained from reference 7 and is given by:

$$\mathrm{OASPL}_{120^\circ} = K - 20 \text{ Log } R + 10 \log \left\{\dot{m}[(T_4 - T_3)(P_3/P_a)(T_a/T_3)]^2\right\} \qquad (1)$$

where K, in SI units, is assumed to be 51 for turboshaft engines. The K-value used for turboshaft engines is the average for turbojet and turbofan engines, as suggested in reference 6. The value of R is the azimuthal distance from the helicopter to the ground at each directivity angle. The variation of OASPL with directivity angle, taken from reference 7, is given in figure 5; the values shown are dB values relative to the OASPL at $\theta = 120^\circ$, this angle generally is considered to be the peak core noise angle.

In order to determine the flight effects from the static values of OASPL, the Doppler factor, $(1 - M_0 \cos \theta)^{-1}$ was used in reference 7. The resultant inflight OASPL is given as follows:

$$\mathrm{OASPL}_F - \mathrm{OASPL}_S = -40 \log (1 - M_0 \cos \theta) \qquad (2)$$

Perceived Noise Levels

Perceived noise levels (PNL) were calculated for the appropriate engine power settings at approach and level flyover conditions. The PNL values, plotted as a function of time, were then integrated to a level 10 dB down from the peak PNL in order to obtain EPNL values for the various helicopters and flight conditions.

Calculated core noise levels were adjusted for the number of engines by adding 10 log N to the calculated single engine PNL and EPNL. An arbitrary 3 dB also was added to the calculated PNL and EPNL in order to account for ground reflections inherent in the measured data. In figure 6, the core noise EPNL is shown as a function of airspeed for the Boeing

Vertol 114 helicopter, for level flyover and approach. Similar trends occurred for the other helicopters included herein.

A core noise map illustrating the combined effects of core speed (power setting) and flight speed is shown in figure 7 for the Boeing Vertol 114 helicopter. The map covers the anticipated operating conditions for approach. The general acoustic trends are a reduction in core noise level with increasing forward speed and with decreasing core speed (power). Similar results were obtained for the other helicopters included in this study and for the level flyover condition.

RESULTS

Perceived Noise Levels

In order to obtain the effective perceived noise levels (EPNL) for the core noise associated with the various helicopter engines, the predicted perceived noise levels (PNL) were plotted as a function of time before and after the overhead measurement station (figs. 8 and 9). This procedure is analogous to plotting the PNL as a function of distance along the flight path relative to the overhead measurement station.

Level flyover condition. - It is apparent from figures 8(a), (b), and (c) that the total noise levels, which are dominated by rotor noise (ref. 1), for the Boeing Vertol 114, Bell 212, and Hughes 500C greatly exceed the predicted core noise levels, even when the latter are for 100-percent core speed (maximum power). Upstream of the overhead measuring station (positive time), the predicted core noise levels at 100-percent core speed are near the measured total noise levels. This, however, may be coincidental, because the engine operating conditions for the tests are not available. Also shown in figure 8 are the predicted core noise levels for 91-percent core speed. It appears reasonable to assume that the measured noise levels were obtained in the range of 91- to 100-percent core speed.

For both the Sikorsky S-61 and S-64, the predicted core noise curve was very similar in shape to the trends in measured total noise levels; however, the measured levels were shifted toward more negative times compared with the predicted core noise curves. If the core speed had been near 86-percent of full core speed, the conclusions drawn between measured and predicted noise levels would be similar to those observed for the data shown in figures 8(a) to (c).

Approach conditions. - The measured total noise levels and predicted core noise level curves are shown in figure 9. In general, the trends of the variation of PNL with time for the approach condition are similar to those discussed for the level flyover condition.

Spectra

The spectra for the overhead measurement station are shown in figure 10 for both the level flyover and approach conditions. In general, the spectral data confirm the observations made in the discussion of the PNL trends. Because only one microphone was used for the measurements rather than an array along the flight path, the absolute measured spectral values are believed to be relatively less accurate than the calculated SPL curves. The measured data shown do not appear to be corrected for ground reflections, as evidenced by the large dips and rises in the spectra at the lower frequencies (<500 Hertz). Consequently, the accuracy of the measured absolute SPL values are suspect.

COMPARISON OF CALCULATED CORE NOISE WITH PROPOSED FAA HELICOPTER CERTIFICATION REQUIREMENTS AND MEASURED TOTAL NOISE

The proposed FAA helicopter noise rules for level flyover and approach conditions are shown in figure 11, together with the predicted core noise levels and the measured helicopter total noise levels.

Measured Total Noise Levels

The Hughes 500C, Bell 212, and Boeing Vertol 114 helicopters measured noise levels, shown by the circle symbols in figure 11, exceed the proposed FAA helicopter noise certification requirements, due to their high rotor noise components, by up to 5 EPNdB. The total measured noise levels for the Sikorsky S-61 and S-64 helicopters are below the proposed noise rule levels by as much as 4 EPNdB.

Predicted Core Noise Levels

Level flyover and approach. - The predicted core noise levels for the helicopters are also shown in figure 11 (square symbols). The core noise levels shown were calculated for a 100-percent core speed. In general, the level flyover predicted core noise levels are lower than the proposed FAA noise rule by about 3 EPNdB. The Sikorsky S-64 predicted core noise level, however, is 6 EPNdB below the proposed rule. For the approach condition, the predicted core noise levels are at the proposed FAA certification rule.

It should be noted that the predicted core noise levels and the measured total helicopter noise levels are substantially the same for the two Sikorsky helicopters. This can be due to several factors: (1) imprecise measured noise levels because of insufficient acoustic instrumentation (i.e., use of only a single microphone, etc.), (2) engines not operating at 100-percent core speed for the test flights; consequently, the predicted core noise levels should be lower than those indicated in figure 11, (3) the core noise correlation used from reference 7 may have to be modified to be applicable to helicopter turboshaft engines and (4) a combination of these factors.

It is apparent, however, that if the rotor noise is reduced, core noise is one of the major barriers to further total helicopter noise reductions. Should future noise rules at even lower levels than currently proposed come into effect - for example, consider proposed heliport levels near 85 EPNdB - core noise, in the absence of rotor noise will provide a severe barrier toward achieving such a noise level, particularly for the heavier helicopters.

Take-off condition. - The proposed FAA helicopter noise rule for take-off prescribes a measuring station 503 m downstream of the initial start of climb. No altitude at the measuring station is specified because each helicopter has a climb rate depending, in part, on its weight and engine performance characteristics. Discussions with several representatives in the helicopter industry indicated that an altitude range of 100 to 200 m could be expected over the measuring station. This brackets the altitudes at the measuring stations for approach and level flyover (120 and 150 m, respectively). It was also indicated that, at the measuring station, a forward speed of about 41 m/s for helicopters is a good estimate. Consequently, the core noise levels for the take-off conditions are of the same order as those for the approach and level flyover conditions. On these bases, it can be assumed that, in the absence of measured data, the relative differences between measured total noise levels and predicted core noise levels for takeoff are similar to those given for the approach and level flyover conditions.

CONCLUDING REMARKS

On the basis of analytical calculation of core noise levels for current representative helicopter engines, it has been shown that, in general, core noise levels are within 3 EPNdB of proposed FAA helicopter certification requirements. Because of an assumed constant applicable for turboshaft engines in the core noise prediction, the predicted core noise levels are valid only to ±5 dB. It is a strong possibility, however, that the core noise levels used herein are reasonable. Consequently, it is not improper to state that once rotor noise has been reduced to acceptable levels engine core noise will provide a limiting floor to further helicopter noise reductions.

Because core noise spectra are associated with low frequencies (peak frequency near 400 Hz), exhaust duct acoustic treatment to attenuate this noise is difficult. Such treatment, aside from adding considerable thickness to the walls, adds significant weight to the helicopter thereby reducing the payload. In addition, use of bulk wall treatment materials can be subject to acoustic deterioration and fire hazards by fuel contamination during engine startup.

The presence of a fuselage as a sound barrier between the engine noise sources and the ground has been advanced as an engine noise suppression device. However, studies of engine-over-the-wing concepts, such as reference 8, have shown that only high frequency noise is attenuated by the presence of a barrier. Thus, in the flyover plane, engine core and jet noise, which are low frequency noise sources would not be attenuated significantly by the presence of a fuselage. In fact, the presences of a solid surface near a jet can result in low frequency noise generation or amplification. Compressor and turbine noise, being high frequency noise sources, would be reflected or shielded by a fuselage. The benefits of high frequency noise reduction by the shielding effects of a fuselage would not be evident at sideline locations.

In view of all the preceding considerations, there is a need for research to be conducted to better understand the prediction and control of engine core noise which is a potentially important noise source relative to proposed FAA helicopter noise certification requirements.

APPENDIX - SYMBOLS

c_a	ambient sonic velocity, m/sec
f	1/3-octave-band center frequency, Hz
EPNL	effective perceived noise level, EPNdB
K	constant in internally-generated noise prediction, dB re 20 $\mu N/m^2$
$\dot{m}$	mass flow rate, kg/sec
M_o	flight Mach number, V_o/c_a, dimensionless
N	number of engines
OASPL	overall sound pressure level, dB re 20 $\mu N/m^2$
P	total pressure, N/m^2
PNL	perceived noise level, PNdB
R	source-to-observer distance, m
SPL	1/3-octave-band sound pressure level, dB re 20 $\mu N/m^2$
T	total temperature, K
V_o	flight speed, m/sec
W	gross takeoff weight
θ	directivity angle measured from inlet, deg

Subscripts:

a	ambient
F	flight
m	maximum
S	static
120°	evaluation at $\theta = 120°$
3	combustor inlet
4	combustor exit
θ	local directivity angle

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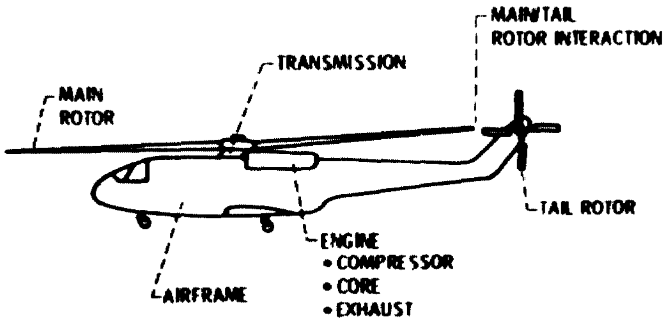


Figure 1. - Helicopter noise sources.

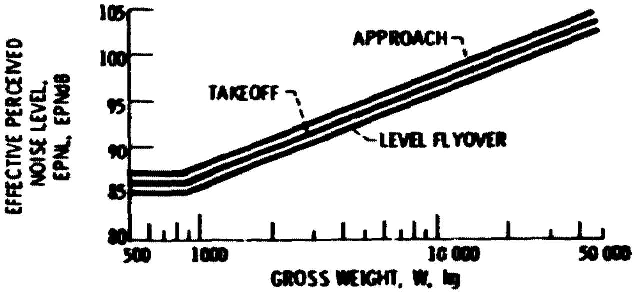
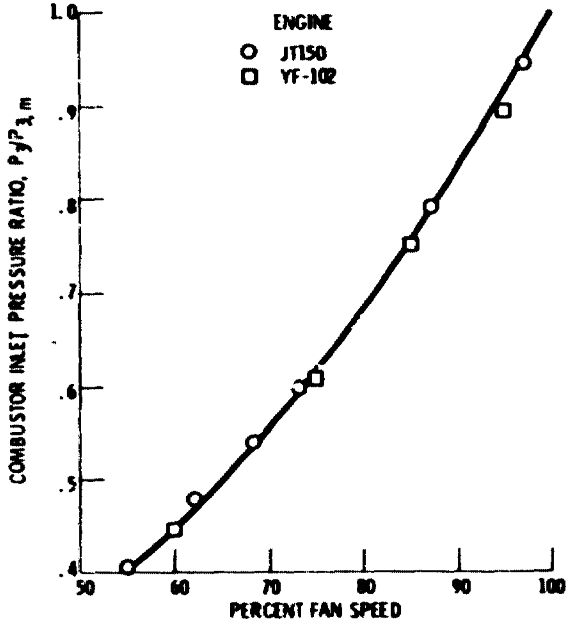
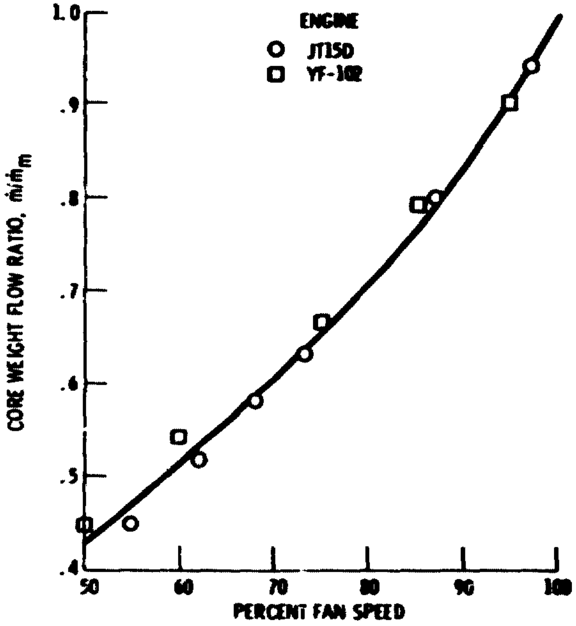


Figure 2. - Proposed FAA helicopter noise certification requirements.



(a) VARIATION OF COMBUSTOR INLET PRESSURE RATIO WITH FAN SPEED.

Figure 3. - Variation of engine parameters with engine speed.



(b) VARIATION OF CORE WEIGHT FLOW RATIO WITH FAN SPEED.

Figure 3. - Concluded.

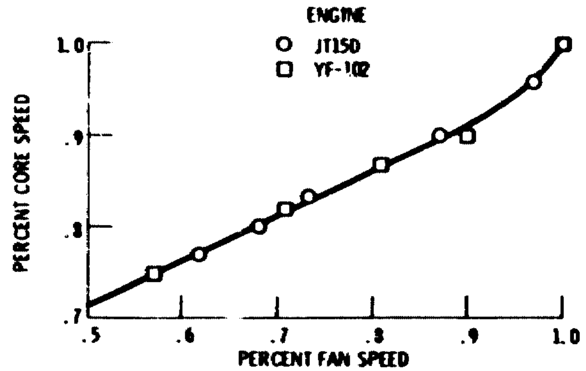


Figure 4. - Variation of core speed with fan speed.

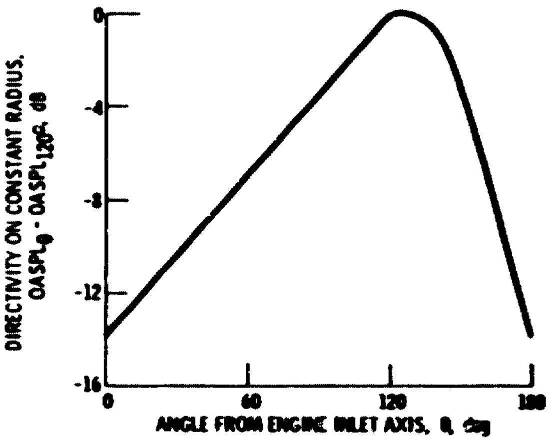


Figure 5. - Core noise static directivity (ref. 7).

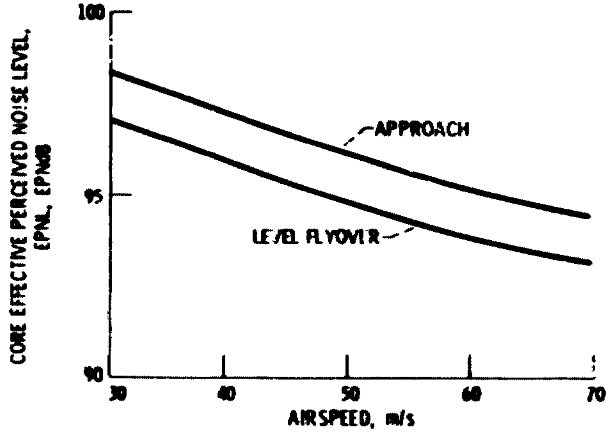


Figure 6. - Variation of predicted core noise with airspeed for Boeing Vertol 114 helicopter. 100-percent core speed.

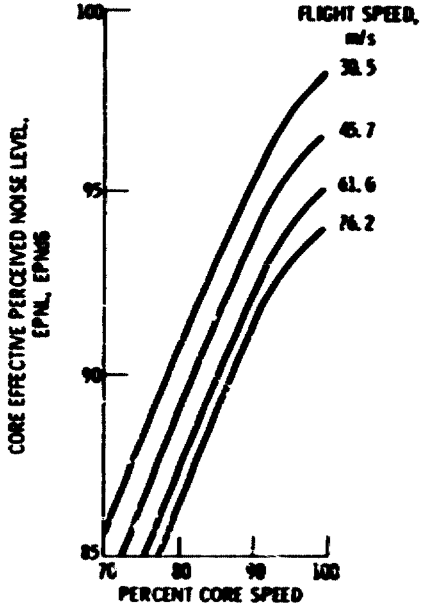
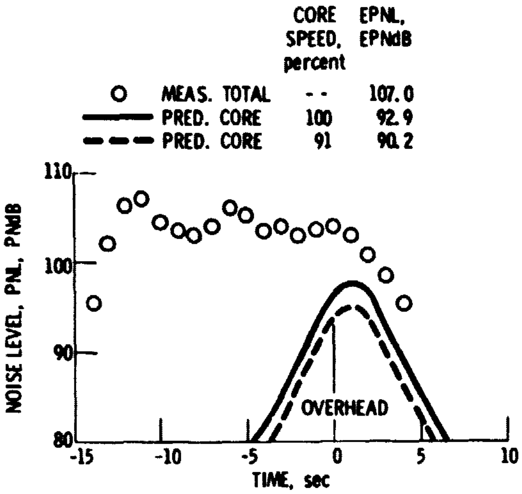
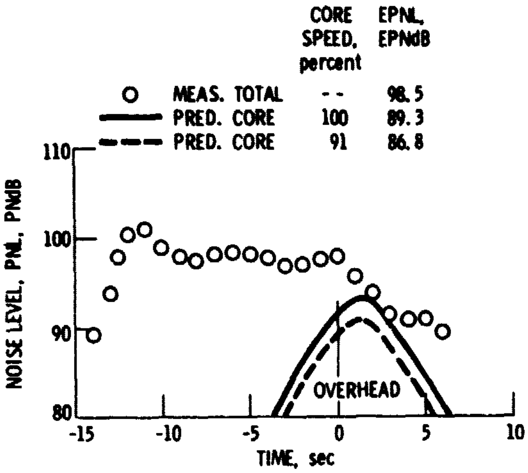


Figure 7. - Variation of predicted core noise with core and flight speeds for Boeing Vertol 114 helicopter. Approach condition.



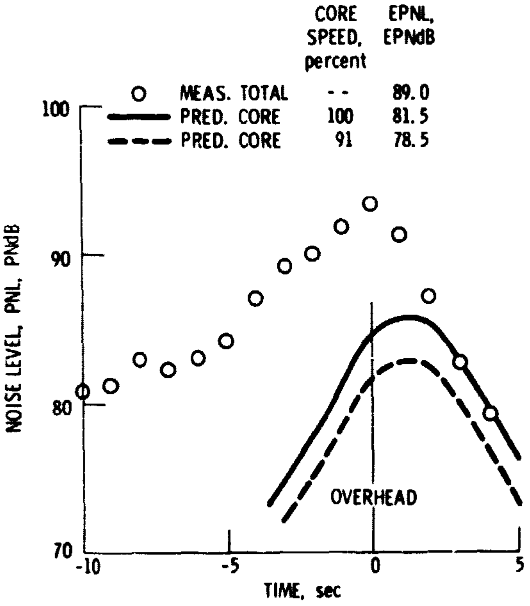
(a) BOEING VERTOL 114; FLIGHT SPEED, 72.7, m/s.

Figure 8. - Variation of PNL with time for level flyover.



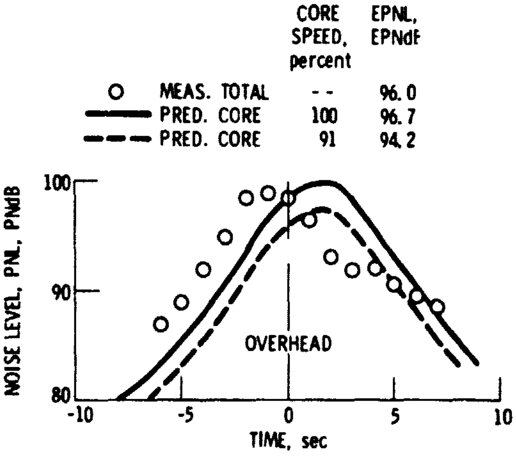
(b) BELL 212; FLIGHT SPEED, 56.7, m/s.

Figure 8. Continued.



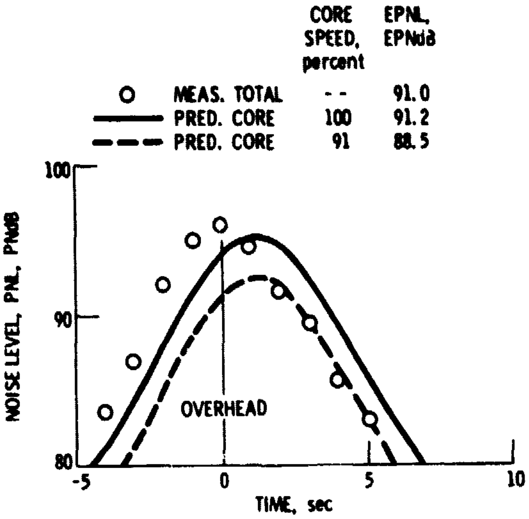
(c) HUGHES 500 C; FLIGHT SPEED, 58.3, m/s.

Figure 8. - Continued.



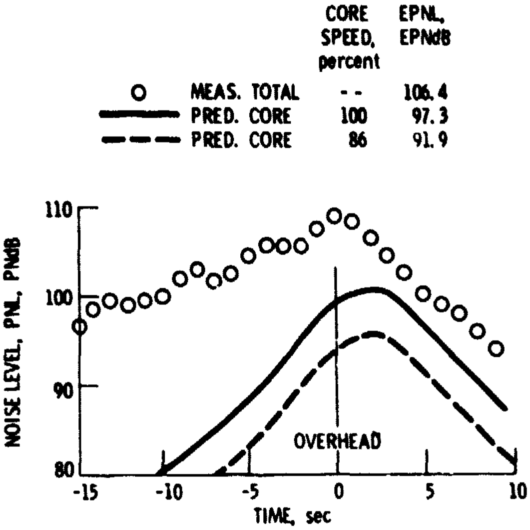
(d) SIKORSKY S-64; FLIGHT SPEED, 49, m/s.

Figure 8. - Continued.



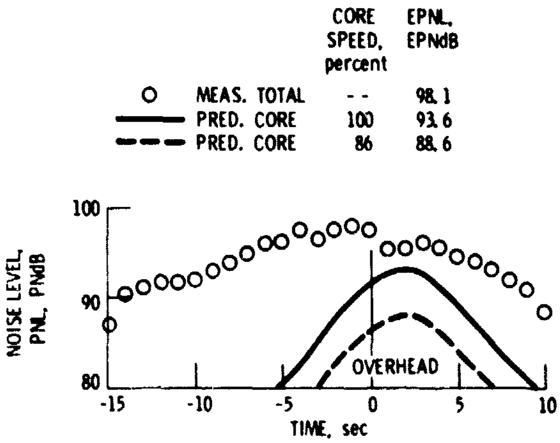
(e) SIKORSKY S-61; FLIGHT SPEED, 59.3, m/s.

Figure 8. - Concluded.



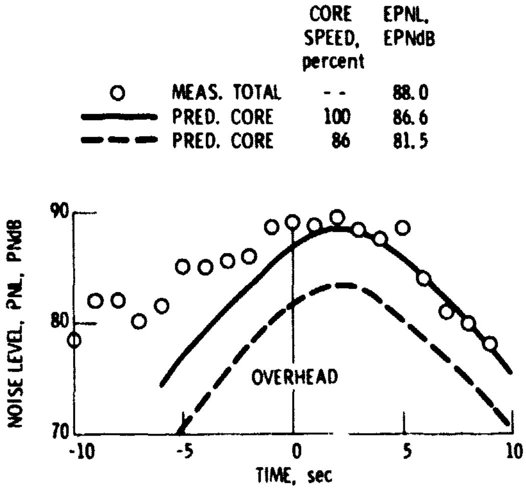
(a) BOEING VERTOL 114; FLIGHT SPEED, 30.8, m/s.

Figure 9. - Variation of PNL with time for approach condition.



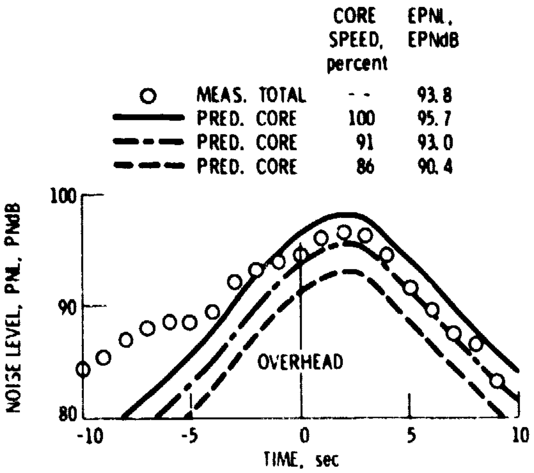
(b) BELL 212; FLIGHT SPEED, 30.8, m/s.

Figure 9. - Continued.



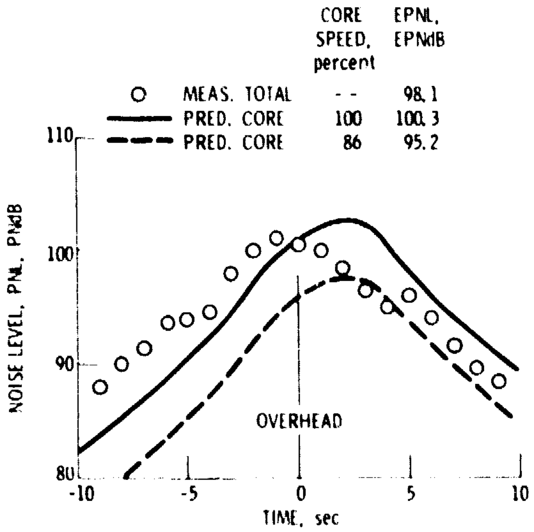
(c) HUGHES 500 C; FLIGHT SPEED, 26.8, m/s.

Figure 9. - Continued.



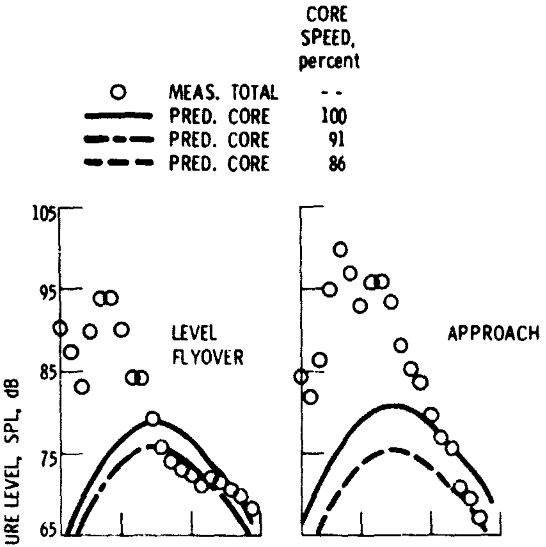
(d) SIKORSKY S-61; FLIGHT SPEED, 30.8, m/s.

Figure 9. - Continued.

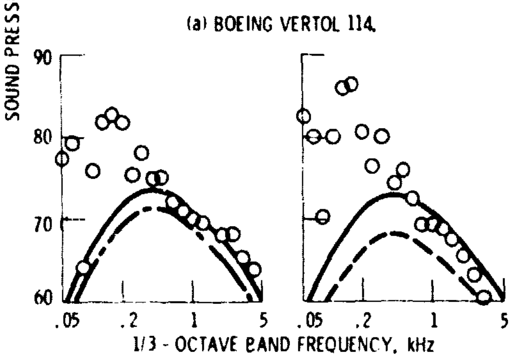


(e) SIKORSKY S-64; FLIGHT SPEED, 30.8, m/s.

Figure 9. - Concluded.

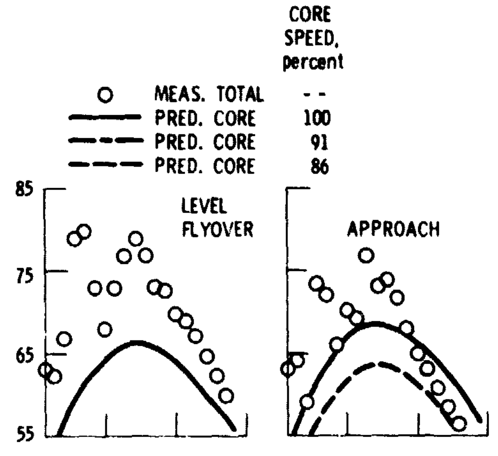


(a) BOEING VERTOL 114.

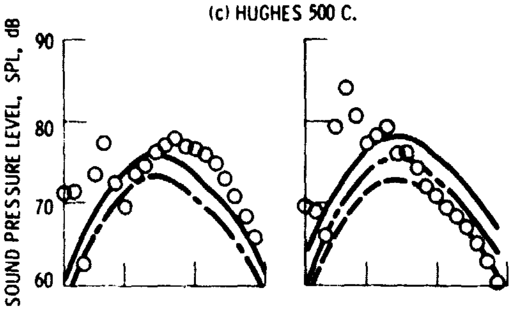


(b) BELL 212.

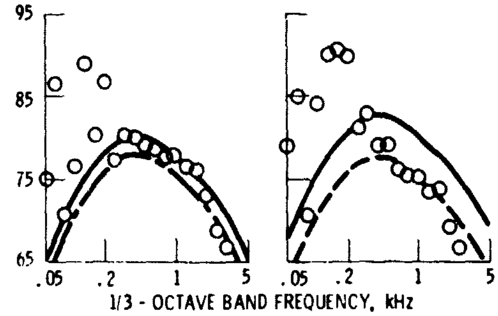
Figure 10. - Comparison of measured total helicopter noise spectra with predicted core noise spectra. Helicopter at overhead position.



(c) HUGHES 500 C.

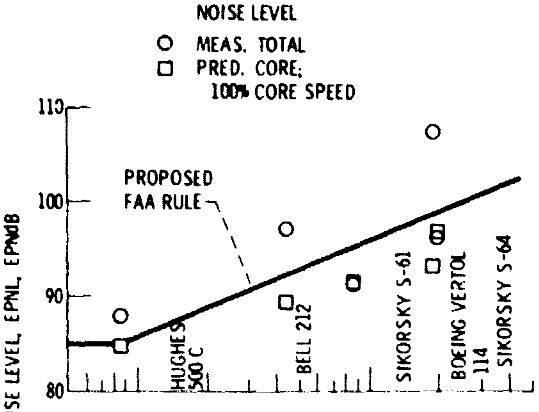


(d) SIKORSKY S-61.

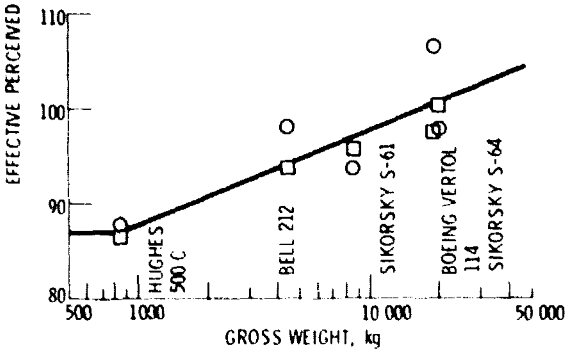


(e) SIKORSKY S-64.

Figure 10. - Concluded.



(a) LEVEL FLYOVER.



(b) APPROACH.

Figure 11. - Comparison of proposed FAA helicopter noise certification requirements with measured total helicopter noise and predicted core noise levels.