# HELICOPTER INTERNAL NOISE CONTROL - THREE CASE HISTORIES

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BELL HELICOPTER TEXTRON

## SUMMARY

Three case histories are described in which measurable improvements in the cabin noise environments of the Bell 214B, 206B, and 222 have been realized. These case histories trace the noise control efforts followed in each vehicle. Among the design approaches considered, the addition of a fluid pulsation damper in a hydraulic system and the installation of elastomeric engine mounts are highlighted. It is concluded that substantial weight savings result when the major interior noise sources are controlled by design, both in altering the noise producing mechanism and interrupting the sound-transmission paths.

## INTRODUCTION

Owners and operators of helicopters today expect comfort levels comparable to those of other transportation vehicles in which they travel. The emphasis on passenger comfort reflects recent market trends. For the third consecutive year, business use of helicopters reached a record high in 1977 with 1219 corporations/executives operating helicopters. This is an increase of 12.7 percent more firms using helicopters than during 1976. Additionally, the number of civil government agencies operating helicopters increased by 9.5 percent over the previous year. The helicopter manufacturer has responded to these trends by quieting derived versions and incorporating noise source control in new designs.

The noise environment within a helicopter cabin is made up of contributions from many sources including the rotors, engine(s), gearing, accessories, and aerodynamic turbulence. The relative amplitude of each of these sources may be, and often is, different for each helicopter type. As a general rule, the high frequency sound components of the engine(s), gearing and accessories are the most disturbing.

For existing helicopter designs and their derivatives, the means used to identify the dominant sources include narrowband spectral analysis of noise and vibration data, detailed mapping of sound transmission paths, and sampling of production vehicles. Peaks in the spectral analyses are related to the physical properties (rotational speed, number of gear teeth, number of blades, etc.) of each potential noise source.

Determining the path by which the sound enters the cabin is often difficult. Airborne sound can enter the cabin through the basic structure, around poorly sealed doors and windows, and through openings, cutouts and ducts. Conventional soundproofing treatment is usually effective in the control of airborne sound, and its benefits vary as a function of the mass or density and thickness of the treatment. On the other hand, sound transmitted to the cabin via the structure often bypasses or flanks the soundproofing. The structure-borne path may also amplify the original sound and create resonances in panels, air cavities and furnishings.

If a resonant or near-resonant condition exists, either at the source or in the structural path, large variations in cabin noise levels can be experienced. In fact, such a variation indicates the probability of resonance. Sampling of a number of production vehicles identifies the magnitude and extent of this problem. The need for corrective action then has justification, particularly if the action necessitates a production change and/or a retrofit.

For new designs, experience gained in previous helicopters can be of significant benefit particularly if the general layout, structure and sound sources are similar. Acoustically weak spots and flanking paths can be designed out and modifications made to the major sources and paths. For designs significantly different from current experience, the manufacturer must rely on in-house developed prediction methods and estimating techniques. An industry-wide need exists for reliable, generally accepted noise prediction methods.

This paper describes three case histories in which the techniques discussed above have been applied to the Bell 214B, 206B and 222 helicopters. Figure 1 illustrates the general configuration and identifies the dominant internal noise source of each helicopter prior to treatment. As can be seen, the offending noise source is different in each of the three designs. For the two derived versions, noise from the hydraulic systems dominates in the 214B, whereas the 206B interior is predominantly influenced by engine gearbox noise. In the newly-designed 222, noise of the hydraulic system and engine is minimal and the level is controlled almost solely by the main transmission.

## CASE HISTORY #1: 214B HELICOPTER

### Configuration

The Bell 214B is a 15-place single-turbine transport helicopter of 6260 kilograms gross weight. It is derived from the 214A helicopter and received FAA certification in January 1976.

### Initial Noise Control

The initial noise control effort involved evaluation of three prototype soundproofing configurations. These treatments consisted of conventional blankets of different thickness and density attached to the cabin roof, aft bulkheads, and side doorposts. Details of the three configurations are

Illustrated in Table 1.

Figure 2 shows typical octave band spectra in the aft cabin for the three configurations. In comparison to the austere treatment, the utility interior reduces high frequency noise 10 to 15 decibels, for doubling of the treatment weight. In the VIP interior, additional thicknesses of material are used, increasing treatment weight by 40 percent. This interior provides additional reduction in the very high frequencies, but has little effect on sound below about 2000 Hertz.

This illustrates a practical limit often encountered when using conventional blanket soundproofing - a point is reached where additional treatment weight no longer yields corresponding noise reduction. Another limiting factor is the difficulty in stitching together the large number of layers.

## Sound Sources

Concurrent with the evaluation of various interior treatments, a program was initiated to control the noise at the source. The primary sound sources inside the 214B are identified in the narrowband spectral analysis of Figure 3. Main and tail rotor noise typically dominates the frequency range below about 500 Hertz. Above 500 Hertz, the spectrum contains a number of pure tones related to gear meshes within the main transmission and drivetrain, and to the dual hydraulic system.

## Hydraulic System Noise Reduction

Because of the amplitude and number of high-frequency tones produced by the hydraulic system, means to reduce this source were investigated. The pump of hydraulic system #1 is driven by an accessory gear on the lower transmission case and generates noise at a fundamental frequency of 787 Hertz. In a similar fashion, the pump of system #2 is driven from the upper case and has a fundamental frequency of 832 Hertz. Both pumps generate a number of harmonic tones related to these fundamental frequencies.

Noise from each pump is transmitted to the cabin by fluid pressure oscillations, referred to as pressure ripple, in the hydraulic lines. Pressure ripple is set up as each piston in the hydraulic pump passes the pressure port. Its magnitude is on the order of 20 kilograms per square centimeter, approximately 1 percent of the steady hydraulic pressure of 210 kilograms per square centimeter. The pressure ripple transmits high-frequency vibratory energy into the structure via the flexible hoses, bypass valves, and hard lines clamped to the aft cabin bulkheads and roof. This structure-borne vibration, in turn, generates sound.

To reduce hydraulic system noise, several approaches were considered. These included vibration isolation of all hydraulic system attachment points, pump modification, and the addition of flow-smoothing devices in the fluid lines to reduce the pressure ripple. Of the three approaches, reduction of the pressure ripple proved to require the least design effort and development.

Vibration isolation would have required replacing all the existing line and hose clamps, and developing elastomeric mounts for bypass valves and possibly the reservoirs. Modification of a pump with variable-spaced piston cylinders, to distribute the fluid oscillations over a random frequency range, would have necessitated extensive prototype design and testing. Reduction of the pressure ripple was the most promising approach.

## Laboratory Tests

Laboratory tests were conducted to evaluate the flow-smoothing capability of five devices, each of which was installed in the flex line immediately downstream of the hydraulic pump outlet. The following devices were evaluated:

1) a pulsation damper consisting of a 300 cubic centimeter spherical volume,

2) a pneumatically charged accumulator,

3) a fluid filter normally used for particle filtration,

4) an "acoustic filter" which provides a dual path for fluid flow, introducing interference effects, and

5) a variable length hose.

Of the devices tested, the pneumatically charged accumulator and the pulsation damper were the most effective. The accumulator reduced pressure ripple by a factor of six. However, its installation in a helicopter would have required a maintenance item to periodically check the pneumatic pressure. The pulsation damper, which reduced pressure ripple by a factor of five, required no such maintenance and was selected as the most practical flow-smoothing device. The relative amplitude of the pressure ripple before and after installation of the pulsation damper can be seen in Figure 4. Also schematically illustrated is the effect of this pressure ripple reduction on noise inside a simulated passenger cabin.

## Flight Test

The pulsation dampers were then installed in the dual hydraulic system of the 214B and evaluated in flight. The installation is illustrated in Figure 5. In system #1, the pulsation damper is mounted to a transmission support member and connected to the pump and hard lines by means of flexible hoses. In system #2, the unit is installed directly at the pump outlet. In both cases, only minor changes are required in the hydraulic hoses and fittings. The entire installation weighs approximately 2.2 kilograms.

Figure 6 depicts the noise reduction realized with the pulsation damper. Sound levels measured with and without the damper are compared. In system #1, the pump fundamental is reduced by about 13 decibels. The first, second and third harmonics are correspondingly lowered by 3 to 6 decibels. In system #2, the quieter of the two systems, the pump fundamental is reduced by approximately

9 decibels and the first and second harmonics are lowered by 3 to 6 decibels.

Reduction of the hydraulic system noise measureably improves the cabin noise environment. The dominance of a number of pure tones is removed, reducing the objectionability and improving speech intelligibility. The A-weighted sound pressure level in the cabin is reduced by an average of 4 dBA. A maximum reduction of 6 dBA is realized in the aft passenger seat locations. Speech Interference Levels are decreased by an average of 6 decibels.

Based on the above improvements, the pulsation dampers are currently being installed on all production 214B's. Additionally, the damper concept has been successfully applied to the Bell 212. Due to differences in routing of hydraulic lines in the 212, the damper is required in only one of the two hydraulic systems. Flight tests have confirmed this and a reduction of about 14 decibels in the pump fundamental has been measured. Modest reductions, an average of 2 decibels, in the A-weighted noise levels and the speech interference levels were also realized.

## CASE HISTORY #2: 206B HELICOPTER

### Configuration

The 206B is a five-place single-turbine corporate, business and utility helicopter with a design gross weight of 1451 kilograms. It is derived from the 206A helicopter and received FAA certification in August 1971.

### Sound Sources

The 206 series helicopters have a history of high-frequency cabin noise originating from the engine gearbox. One unusual characteristic of this noise is that it varies considerably from one vehicle to another. Figure 7 illustrates this variation. Cabin noise levels sampled inside 167 production vehicles are shown. Levels in the 4000-Hertz octave vary from 84 to 95 decibels for the majority of the sample. At the extremes, however, levels as low as 77 decibels are possible and as high as 101 decibels.

Cabin noise sources of the 206B are identified in Figure 8. The 5000-Hz tone which dominates the audible spectrum is traced to the mesh frequency of the power takeoff (PTO) gear and torquemeter (TM) gear inside the engine output gearbox. Other sources that can be traced include the main transmission input pinion gear mesh at 1900 Hertz and the planetary stage gear mesh at 1300 Hertz.

The engine and integral gearbox are located above and behind the passenger cabin, supported by three sets of bipod legs rigidly attached to the gearbox and airframe as shown in Figure 9. The three engine mounting points are on the engine gearbox housing. Gear mesh vibrations propagate down the support legs directly into a bulkhead aft of the passenger seats. Once into the structure, the vibratory energy radiates as noise inside the cabin.

## Engine Gearbox Noise Reduction

Two approaches have been taken to reduce engine gearbox noise. The first involves means of isolating the engine from the airframe. The second approach consists of an investigation by the engine manufacturer aimed at reducing the gearbox vibration at the mounting points.

## Engine Mount Isolation

Three engine mount isolation concepts were investigated. The first involves replacing each of the six engine support legs with a new leg made up of concentric metal tubes separated by an elastomer. The second consists of a circular steel/elastomer washer assembly placed at each of the three engine mounting points. The third concept also uses a washer assembly, but with a rectangular flange which provides greater elastomer area.

Hardware for each mount configuration was fabricated, installed in a test helicopter, and evaluated in flight. The concentric metal tubes proved unsuccessful. During ground run, engine motion was excessive and further evaluation was aborted. However, tests of both the circular and the rectangular washer assemblies were successful. Both concepts measurably reduced the 5000-Hertz gearbox tone and caused no excessive engine motion. Two types of elastomer were evaluated: neoprene rubber and silicon. The rectangular washer assembly with silicon elastomer provided the maximum attenuation.

The internal structure and installation details of the rectangular washer assemblies are shown in Figure 10. Vibrations introduced at the engine pad transmit through a 2 millimeter thickness of elastomer before reaching the metal of the bipod legs. Since the engine must be somewhat rigidly retained, the elastomer thickness is kept to a minimum. However, the frequency of interest is sufficiently high (5000 Hertz) that this relatively thin elastomer provides significant isolation. The flanges of the washer assembly are elongated into a rectangular shape to provide as much elastomer shear area as possible within the physical constraints of the existing mount struts.

Cabin noise measurements with the elastomeric washers installed show 7-10 decibel reduction of the 5000-Hertz tone in the aft cabin area. The noise measured at each passenger location before and after installation is shown in Figure 11. At the left passenger location, which has the highest amplitude before installation of the improved mounts, the tone is reduced by 10 decibels. Levels in the center and right hand seat location are lowered by 9 and 7 decibels, respectively. With the improved mounts the noise is fairly constant across the aft cabin.

Installation of the elastomeric washers is relatively simple, requiring enlargement of the bolt hole in each support leg, and machining down the shoulder of the trunnion. The washer design is such that the engine is well supported even in the event of elastomer failure or burnout, and no critical misalignment of the engine and driveshafts is possible. Flight tests have shown that engine motion is well within the design limits and the silicon elastomer is

not susceptible to chemical or environmental erosion. A ship set of the mounts weighs less than 0.5 kilograms. Laboratory tests are now being conducted to determine the service life of the improved mounts. They are expected to be fully qualified by July 1978.

## Gearbox Vibration Reduction

The second approach involves studies and tests of gearbox vibration reduction being conducted by Detroit Diesel Allison, manufacturer of the engine. Figure 12 is a schematic of the gas producer and power turbine gear trains, showing the relative positions of the torquemeter (TM) and the power takeoff (PTO) gears. This gear train provides a two-stage speed reduction, converting the 33,290 RPM of the power turbine to 6016 RPM at the power output shaft. The TM and PTO gears are the primary load carrying gears in the output drive train. The 5000-Hertz excitation is generated at the mesh of these two gears.

Analytical studies indicate that both the PTO and TM gears have modes of vibration close to the 5000-Hertz meshing frequency. This possible resonant condition would increase the vibratory energy transmitted to the bearings, to the gearbox housing, and finally through the mounting system.

Hardware changes to the existing gear train are being evaluated on an experimental basis. The modifications and changes under consideration are listed in Table 2. Gear tooth profile modification offers the possibility of reducing the excitation by providing a smoother loading/unloading of each tooth. The damper ring and the spray applied to the gear web are intended to damp out the vibrations transmitted from the gear teeth to the shaft. Changes in the gear resonant frequency by adding mass, the mesh frequency by adding gear teeth, and the gear support stiffness are all designed to reduce any coincidence effects between excitation and resonant frequencies.

This experimental program is currently in progress and final results are not available. It is anticipated that one or more of the above modifications to the engine will lower the high-frequency vibration induced in the engine gearbox. An 8 to 10 decibel noise reduction is expected. Coupled with the improved engine mount, a cumulative reduction of 16 to 20 decibels is possible. This will remove the engine gearing as a dominant noise source in the 206B helicopter and will reduce the wide variation in noise level from one vehicle to another.

## CASE HISTORY #3: 222 HELICOPTER

The two previous case histories pertain to derived versions and deal with solutions to existing noise problems, identified after the helicopter is in production. In a new design, many of these problems can be avoided if attention is paid to noise control throughout the concept, preliminary design and development stages. Such is the case for the Bell Model 222.

## Configuration

The 222 is a 6-8 passenger, twin-turbine helicopter designed specifically for the civil market. It is powered by two AVCO/Lycoming turboshaft engines driving a two-stage spiral bevel, single stage planetary main transmission.

## Design Features

A number of design features are incorporated to reduce cabin noise levels. Double roof construction separates the primary drivetrain noise sources and the cabin area. Provisions are made for a continuous layer of soundproofing below the lower roof. This treatment has a minimum of constrictions or openings. In the hydraulic system, a low-noise pump is specified. All hydraulic lines are kept as short as possible and clamping of lines to panels is avoided. As part of the basic suspension system, the nodalized pylon incorporates elastomeric bearings. These bearings prevent transfer of structure-borne sound from the main power train to the cabin roof. High contact ratio tooth profiles are used extensively in the main transmission. Finally, vendor-purchased accessories such as oil cooler fans, vent/defog blowers and the ECU meet stringent noise specifications or are designed to the lowest practical noise levels.

These design features result in a well-balanced cabin noise environment requiring only minimal conventional soundproofing. The prototype soundproofing treatment weighs only 10 kilograms. It consists of foam/lead foil/foam sheets attached to the inner roof and aft bulkhead. Roof trim panels of 4 centimeters aluminum sheet extend from the aft bulkhead forward and provide a continuous closure over the soundproofing treatment. The treatment density varies along the roof. Densities of 4.88 kilograms per square meter are used in the aft portion directly beneath the main transmission. A lighter density, 2.9 kilograms per square meter, is used in the forward roof.

Figure 13 is a narrowband frequency spectra of the noise in the aft passenger cabin of the 222. In the frequency range above 500 Hertz, the major sound components emanate from the main transmission. The two input pinions' gear mesh is 3200 Hertz. Gear mesh of the planetary stage's spur gears is 1050 Hertz. Harmonics of these gear meshes, lower in amplitude, are also present. Other secondary sources include the hydraulic system and other tones not identifiable at this time.

The forward passenger seats are slightly quieter than the aft ones, but in general the noise field is uniform throughout the cabin. Table 3 compares the A-weighted sound level and the Speech Interference Level (SIL) for each seat location. The sound level in the forward row of passengers averages 85 dBA; 87 dBA in the middle row, and 86 dBA in the aft row. SILs are 76, 77, and 78 db, respectively. These levels vary little with airspeed and gross weight. Speech intelligibility is excellent and passengers can easily converse with each other.

## CONCLUDING REMARKS

The above case histories illustrate use of available techniques to control helicopter interior noise levels. Different techniques, it is shown, are required for each type design. Existing or derived designs with noise problems can often be improved and require detailed knowledge of the source characteristics and sound paths. New designs can often benefit from these experiences, particularly in savings of weight required for soundproofing treatments.

Figure 14 illustrates the weight savings benefit. Cabin noise levels of the 214B, 206B, and 222 with different interiors are compared. Maximum levels of the three designs with no soundproofing are approximately the same. The "best seat" levels, however, are lower in the 222 by 6-8 dBA. Less soundproofing weight (10 kilograms) is required in the 222 to reach A-weighted levels of 84 to 89 dBA and SILs of 75 to 81 dB. The percentages of useful load required for soundproofing to reach equivalent cabin noise inside the 214B, 206B and 222 are 1.6%, 3%, and 0.7%, respectively.

The low soundproofing weight penalty of the 222 reflects the early application of noise control in the design. Another important benefit is that future improvements in noise level appear to be possible for modest increases in the interior weight.

TABLE I.   214B PROTOTYPE INTERIOR TREATMENTS
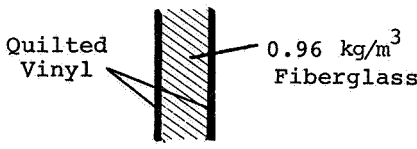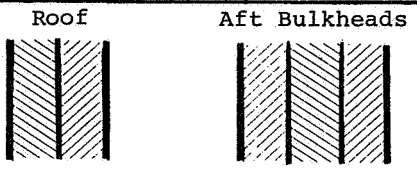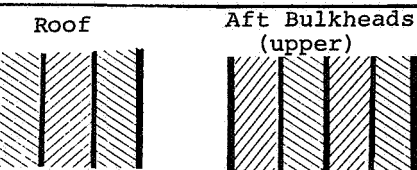
| Interior Treatment | Treatment Weight | Blanket Composition |
|---|---|---|
| Austere | 17 kg | Quilted Vinyl — 0.96 kg/m$^3$ Fiberglass |
| Utility | 31 kg | Roof / Aft Bulkheads |
| VIP | 43 kg | Roof / Aft Bulkheads (upper) |

TABLE II.   206B ENGINE GEARBOX EXPERIMENTAL MODIFICATIONS

| Design Approach | Modification |
|---|---|
| Reduce Excitation | • Modify gear tooth profile (increase crown) on TM and PTO gears |
| Damping | • Attach damper rings to gear webs <br> • Apply damping compound to gear webs |
| Change Resonant Frequency | • Add mass to TM and PTO gears <br> • Change mesh frequency by increasing number of teeth on both gears <br> • Increase stiffness of gear case |

TABLE III.  PROTOTYPE 222 CABIN NOISE AND SPEECH
INTERFERENCE LEVELS

|  | Left Side | | Center | | Right Side | | Average | |
|---|---|---|---|---|---|---|---|---|
|  | dBA | SIL | dBA | SIL | dBA | SIL | dBA | SIL |
| Forward Row | 85 | 77 | 82 | 75 | 87 | 77 | 85 | 76 |
| Center Row | 87 | 77 | 86 | 77 | 87 | 79 | 87 | 77 |
| Aft Row | 84 | 77 | 86 | 77 | 89 | 81 | 86 | 78 |



214B

DUAL HYDRAULIC
SYSTEM

206B

ENGINE OUTPUT
GEARING

222

MAIN
TRANSMISSION
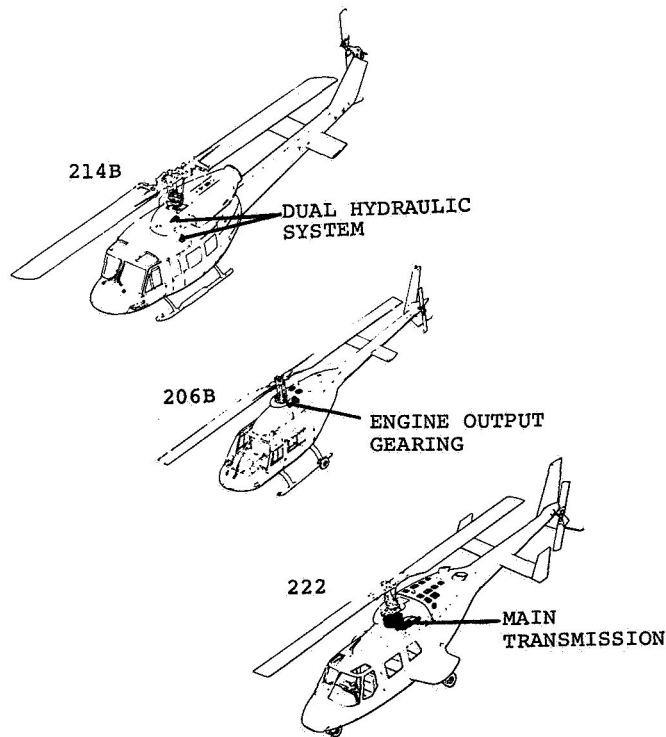
Figure 1.- Dominant internal noise sources of the
Bell 214B, 206B and 222 helicopters.
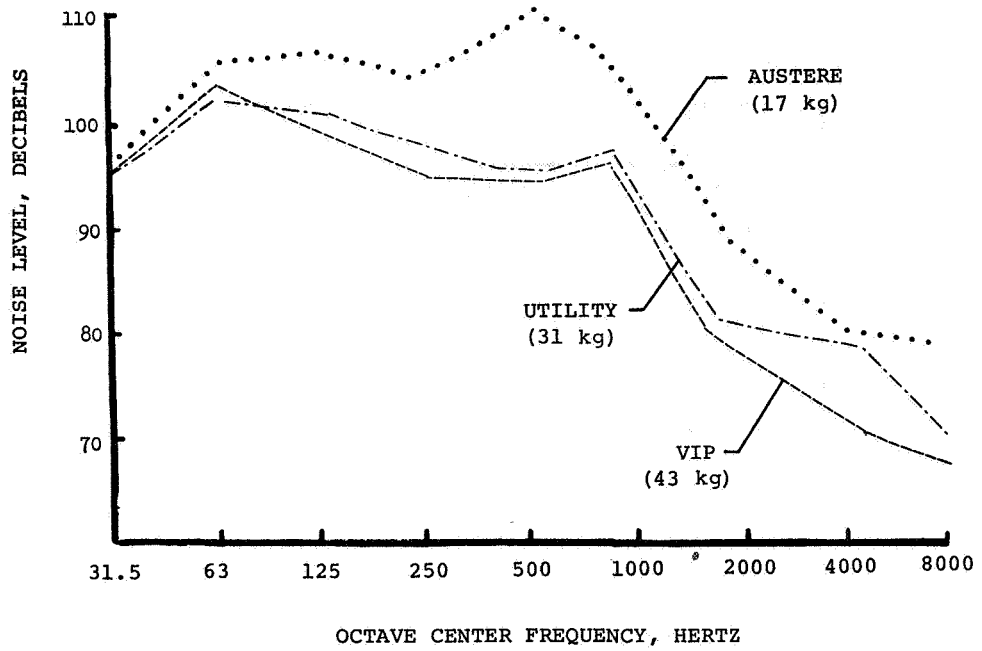
Figure 2.- Effect of 214B prototype interior treatments.
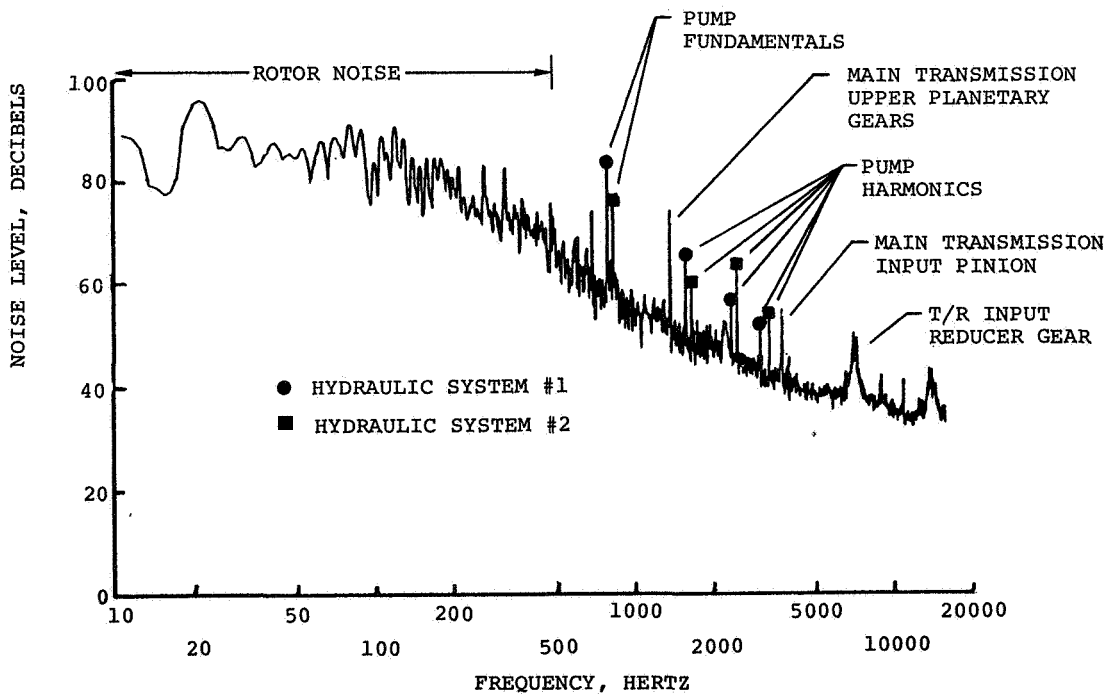


Figure 3.- Frequency spectra of 214B cabin noise.
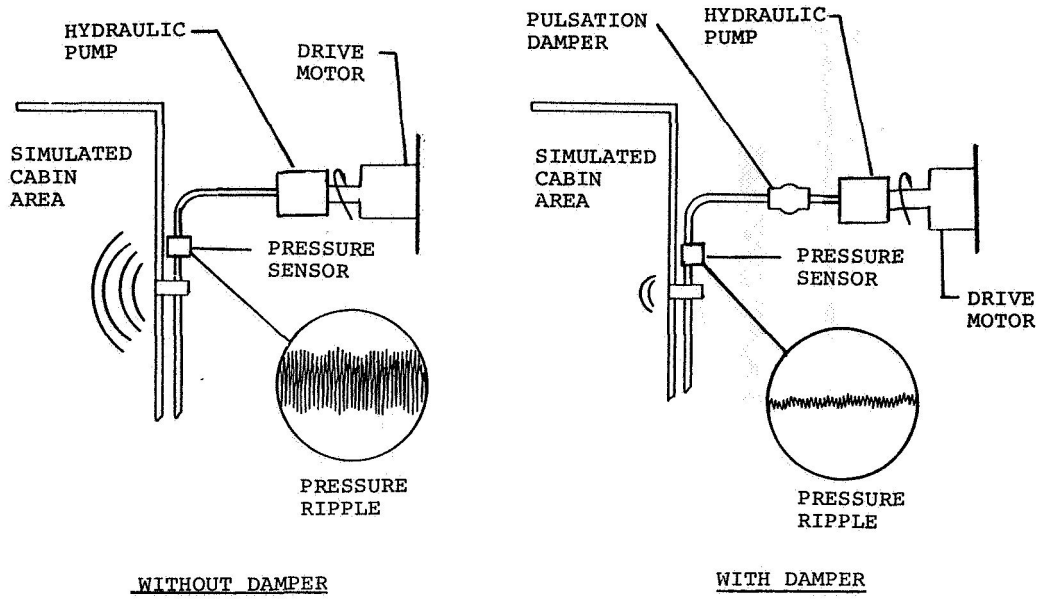
Figure 4.- Laboratory setup and effect of pulsation damper
on hydraulic system pressure ripple.
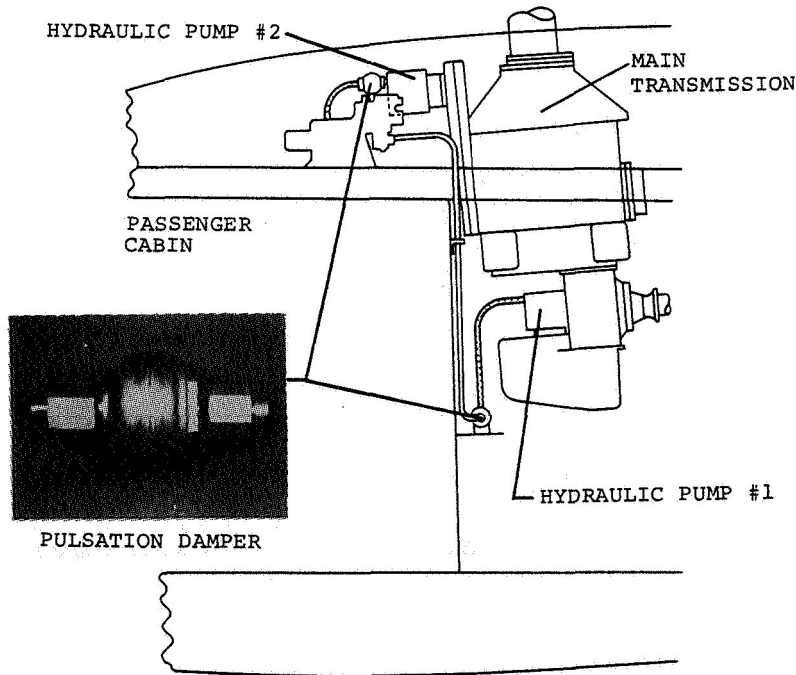


Figure 5.- Pulsation damper and installation schematic.
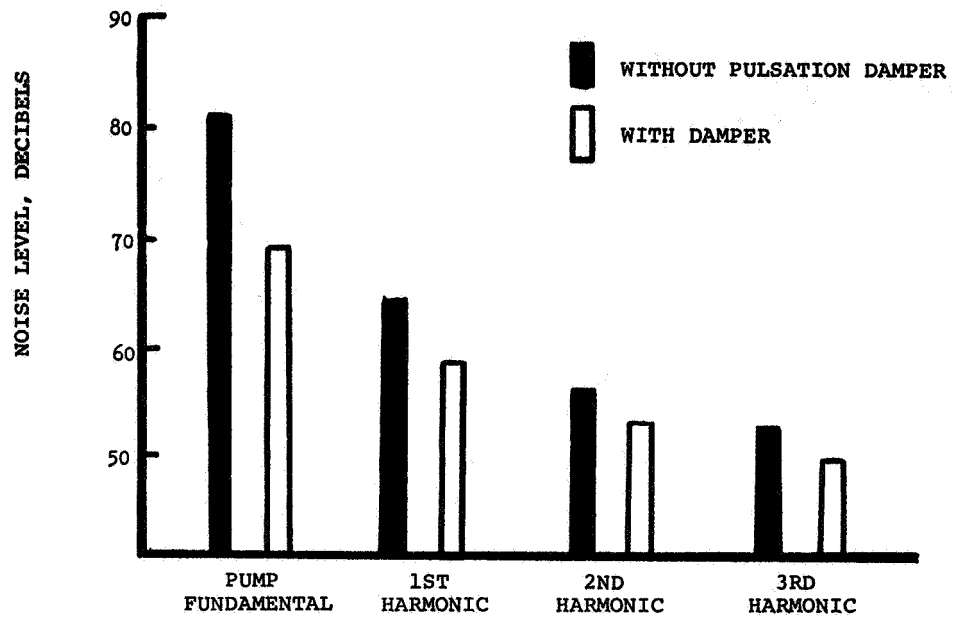
(a) System #1.
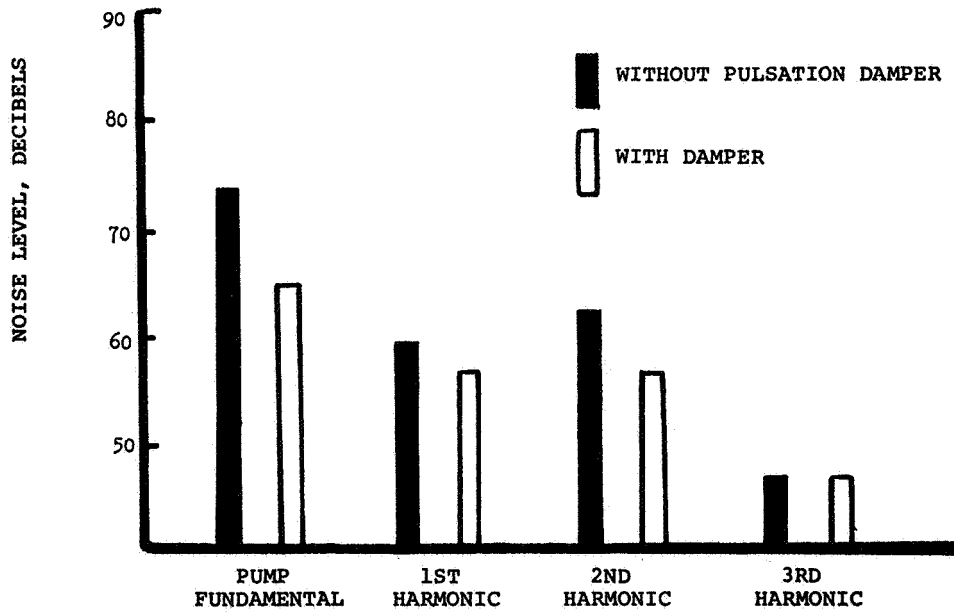


(b) System #2.

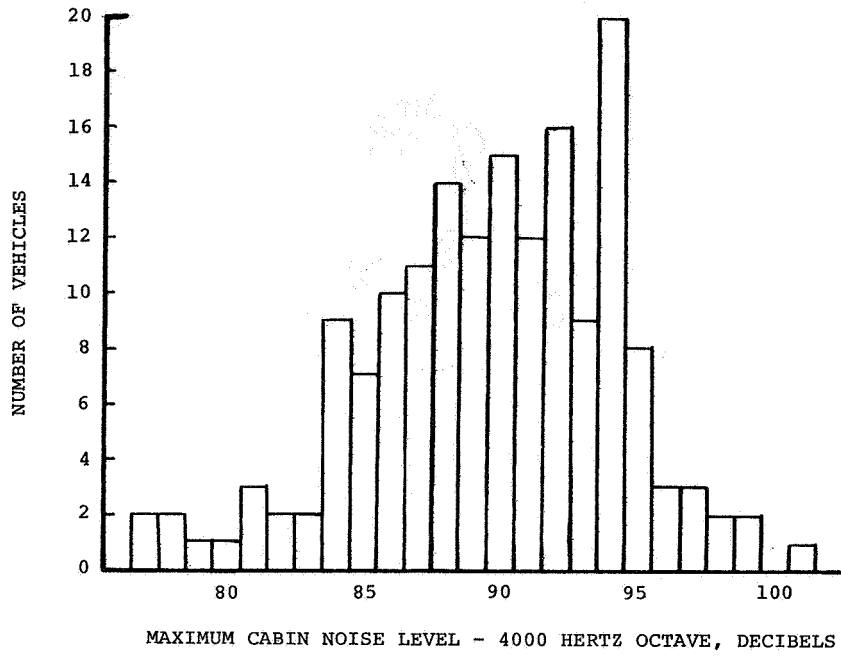Figure 6.- Effect of pulsation damper on hydraulic system noise sources.

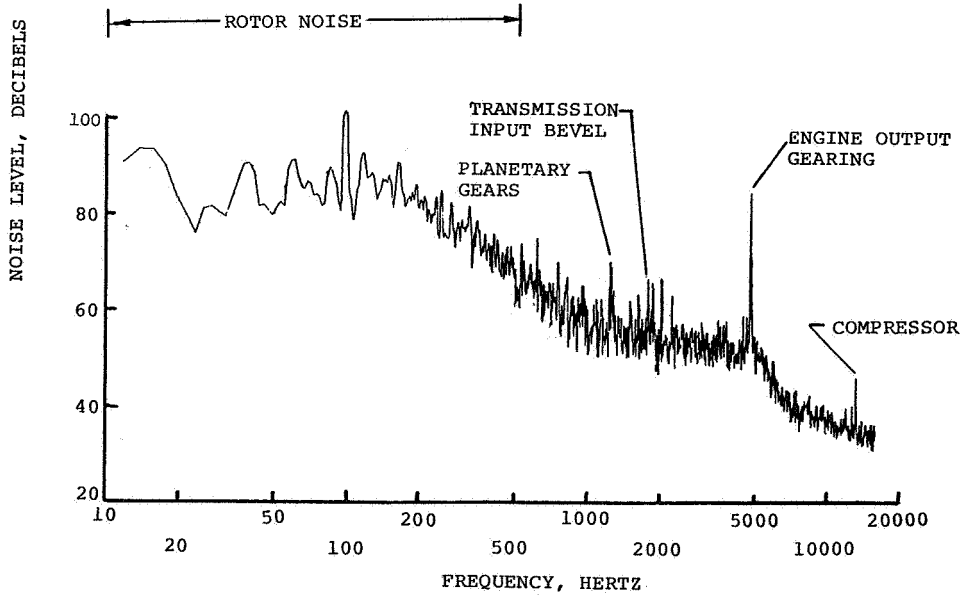Figure 7.- Noise sampling of 206 series helicopters.



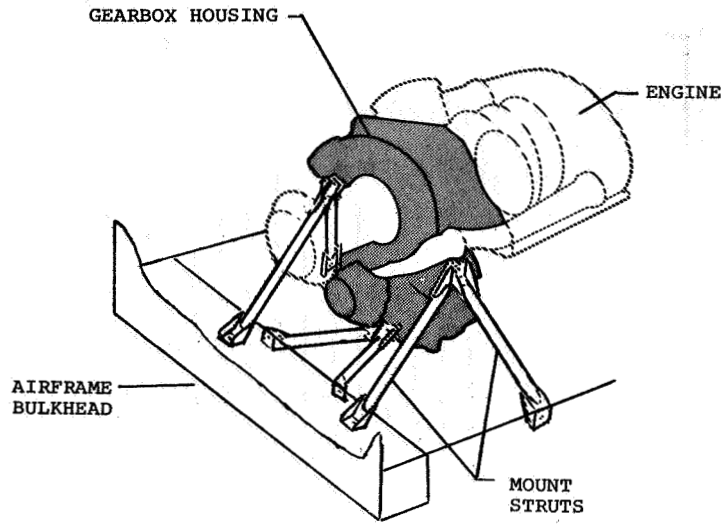Figure 8.- Frequency spectra of 206B cabin noise.

GEARBOX HOUSING

ENGINE

AIRFRAME
BULKHEAD
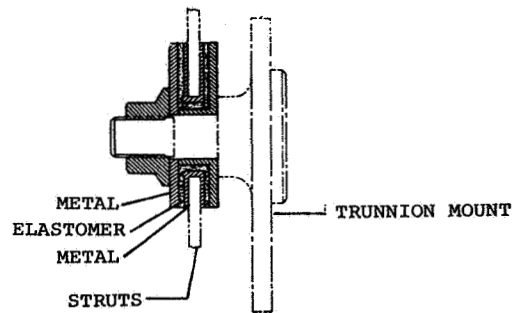
MOUNT
STRUTS

Figure 9.- 206B engine mount assembly.

WASHER ASSEMBLY

TRUNNION MOUNT

STRUTS
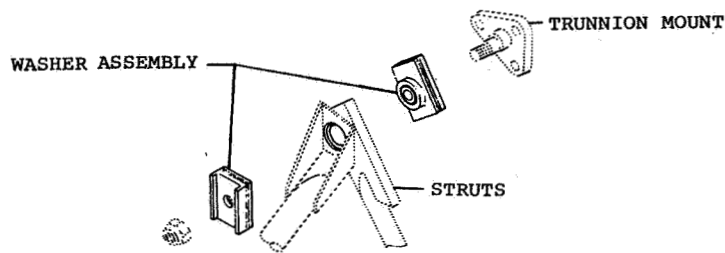
(a) Exploded view of mount assembly.

METAL
ELASTOMER
METAL

TRUNNION MOUNT

STRUTS

(b) Cross section of installed mounts.

Figure 10.- 206B improved engine mounts.

654

CABIN NOISE LEVEL - 4000 HERTZ OCTAVE, DECIBELS

STANDARD ENGINE MOUNTING

WITH IMPROVED ENGINE MOUNTS

100

90

80

70

LEFT
SEAT

CENTER
SEAT

RIGHT
SEAT
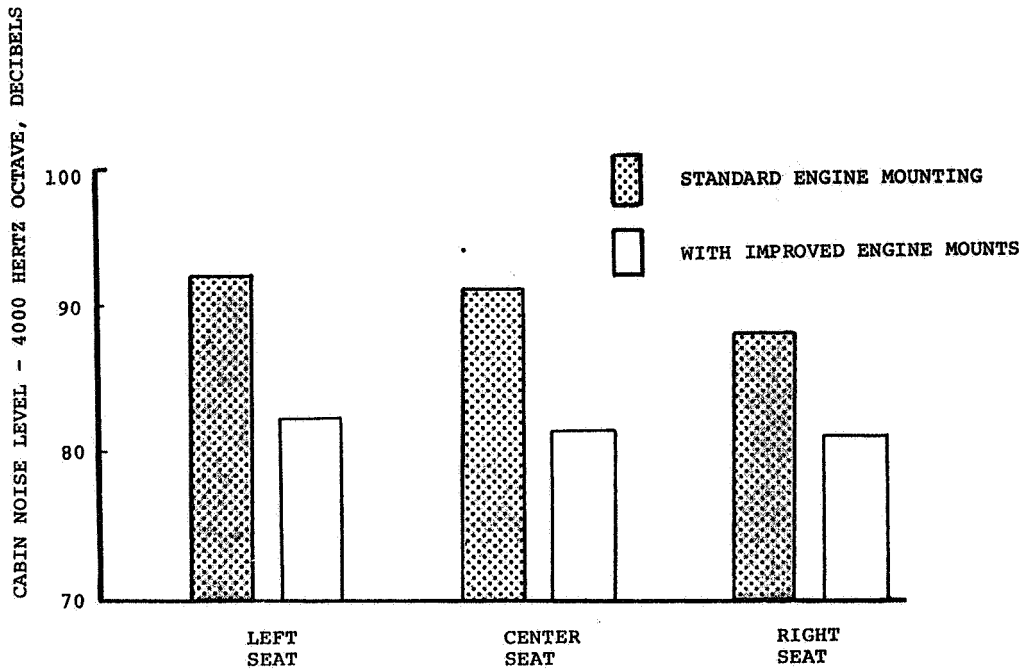
Figure 11.- Effect of engine mounting on 206B cabin noise levels.

GEAR CASE

GAS PRODUCER TURBINE INPUT
$\left(\begin{array}{c} 50,920 \text{ RPM} \\ 17 \text{ TEETH} \end{array}\right)$

TORQUEMETER GEAR
$\left(\begin{array}{c} 10,027 \text{ RPM} \\ 83 \text{ TEETH} \end{array}\right)$

POWER TAKEOFF GEAR
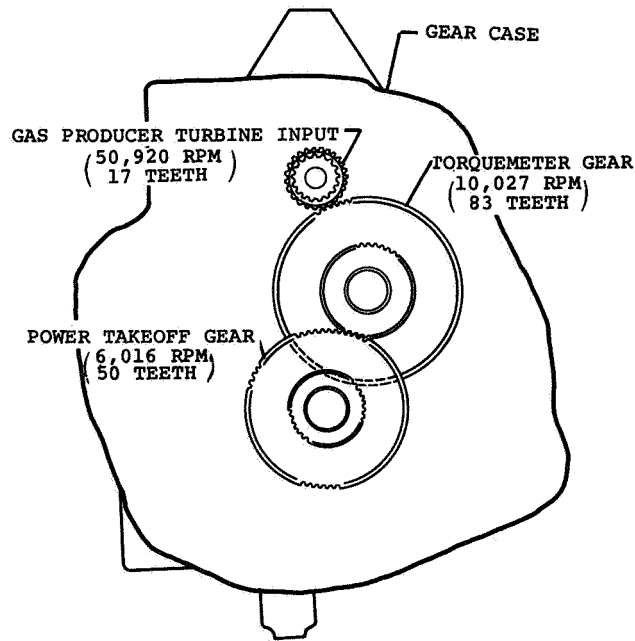$\left(\begin{array}{c} 6,016 \text{ RPM} \\ 50 \text{ TEETH} \end{array}\right)$

Figure 12.- Relative positions of engine torquemeter (TM)
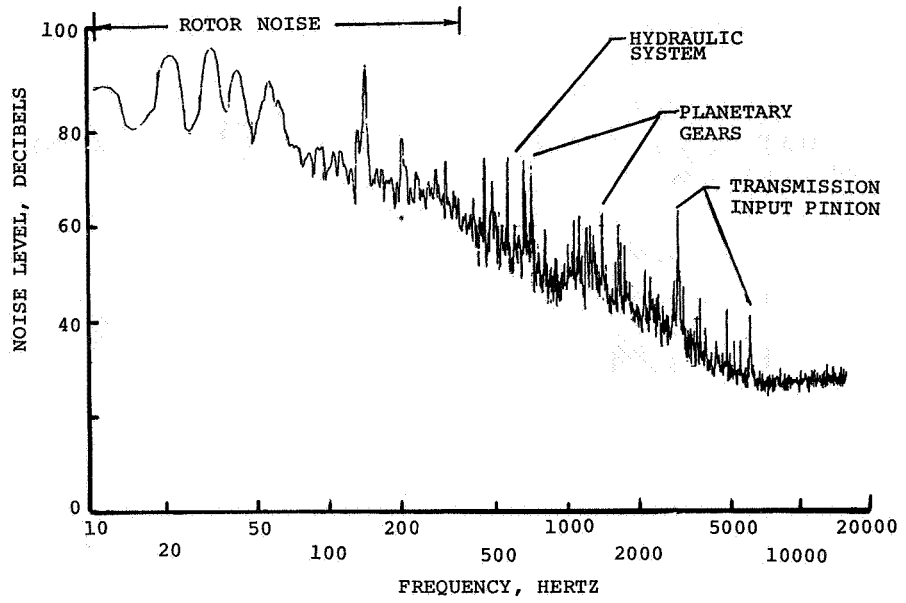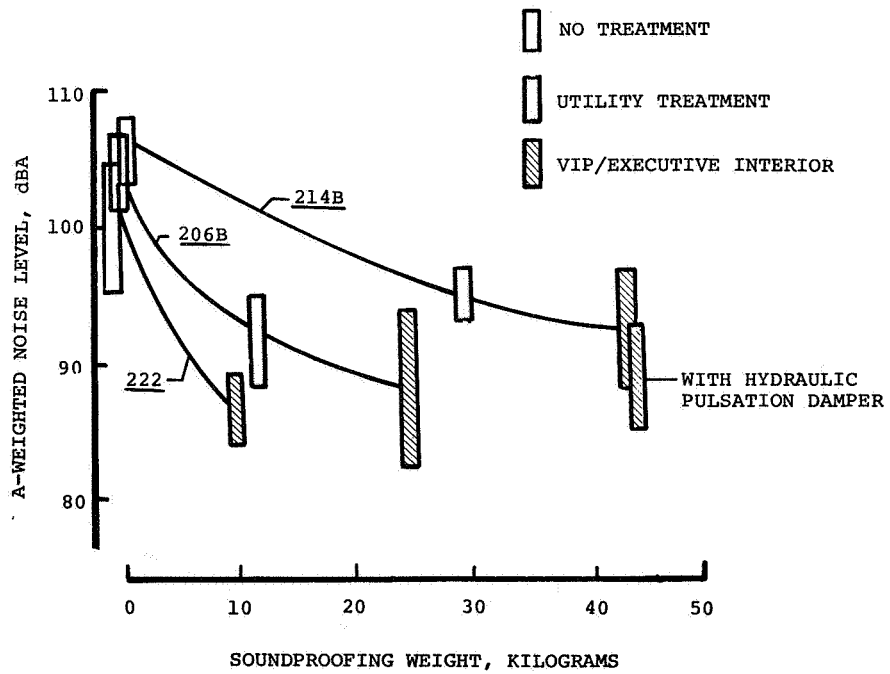and power takeoff (PTO) gears.

655

Figure 13.- Frequency spectra of 222 cabin noise.



Figure 14.- Cabin noise levels versus soundproofing weight.

656