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FINAL REPORT ON:

EFFECTS OF NOISE AND VIBRATION ON COMMERCIAL HELICOPTER PILOTS

CASE FILE
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Prepared under Contract NASW-1829

for:

The National Aeronautics
and
Space Administration

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EFFECTS OF NOISE AND VIBRATION ON COMMERCIAL HELICOPTER PILOTS

RESULTS OF PHASE I RESEARCH

7 April 1970

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SUMMARY

The present study sought to determine the effects of appropriate noise and vibration levels on commercial helicopter pilots. The effects were discussed in three dimensions: effects on pilot safety, on pilot performance, and on pilot comfort.

The most important finding of the study was that a great deal of additional evidence is needed before specific effects of the mechanical environment can be defined. Based on available evidence it is concluded that:

- noise levels expected in commercial helicopters do pose a problem for the pilot since they generally exceed accepted damage risk limits. No data are available on the degree of the problem in terms of hearing loss, threshold shift, etc.

- no findings were identified which demonstrate long term or chronic effects of vibration on pilot physical condition

- there is a critical need for a commercial helicopter noise and vibration standard which accounts for combined effects of noise and vibration and which is tailored to the commercial helicopter mission

- the expected relationships between helicopter noise and vibration and pilot fatigue and disorientation point up the need for additional research, development of reliable measurements, and reduction of fatigue and fatigue inducing agents

- the inferred relationships between noise, vibration, and fatigue on the one hand and commercial helicopter accident causal factors on the other demonstrate the need to isolate perceptual-motor factors underlying the causal factors and acquiring valid research data on effects of the environment and fatigue on the perceptual-motor abilities. This assessment is only begun in the present study.

INTRODUCTION

This study presents the findings of an analysis of effects of noise and vibration levels experienced in commercial helicopters on pilot safety, performance, and comfort. The report presents the information currently available on commercial helicopter types and mission (Section 1) and pilot operational requirements (Section 2). These requirements include safety requirements, presented in terms of commercial helicopter accident data, performance requirements or operations conducted by the pilot during actual flight, and comfort requirements or considerations.

In Section 3 helicopter noise and vibration frequencies and amplitudes are reported to describe the mechanical environment. Due to the unavailability of environmental data measured in actual flight of commercial helicopters the noise environment is described based on data available from military counterparts of commercial helicopters. While this approach is admittedly risky it was followed since the military data were all that was available. Vibration levels were inferred from research reports and were not even available from military sources.

Section 4 describes the results of an analysis of research results concerning effects of noise and vibration, at levels presumed for commercial helicopters, on pilot safety, performance, and comfort. Finally Section 5 presents problem areas developed for the analysis conducted in Section 4 and presents recommendations for action to resolve the problems.

1.0 COMMERCIAL HELICOPTER DESCRIPTIONS

The unique flight characteristics of the helicopter have led to its widespread use for both military and commercial applications. During the years 1960 through 1967 the number of commercial helicopters increased from 705 to 1,764 and by the end of 1970 the number is expected to exceed 2,000. The designator "commercial" is applied to all non-military helicopters and includes such applications as industrial cargo transport, pre-construction surveillance, movement of fully erected oil rigs, and passenger transport. It is to this latter usage of the commercial helicopter that this report is addressed and commercial helicopter mission data will be based on passenger transport missions.

1.1 Commercial Helicopter Types

Table 1 describes most of the helicopters currently in operation. These descriptions contain the military counterparts of the commercial designations, the number of commercial aircraft projected through 1970, crew and passenger capacities and performance characteristics.

1.2 Air Passenger Helicopters

During the field trip conducted in this study five helicopter airways companies were contacted and pilot data were collected from each. The intent was to contact pilots having regular flying schedules and to restrict the study to a limited number of helicopter types. In this way flying experiences, schedules, operational practices, and similar variables could be related to known effects of exposure to comparable noise and vibration levels. The five airways companies surveyed and their current helicopter types are as follows:

- New York Airways, New York - Vertol 107-II: multi-rotor, pilot and copilot, 27 passengers
- Air General Helicopters, Boston - Bell Jet Ranger: single rotor, pilot only, 4 passengers
- Chicago Helicopter Airways, Chicago - Sikorsky S-58: single rotor, pilot and copilot, 13 passengers
- SFO Helicopter Airlines, San Francisco - Sikorsky S-61: single rotor, pilot and copilot, 28 passengers

TABLE 1

COMMERCIAL HELICOPTER DATA

COMMERCIAL HELICOPTER	MILITARY COUNTERPARTS					NUMBER THRU 1970	BLADES	ENGINES	ROTOR DIA (ft)	PASSENGERS	CREW	MAX SPEED (mph)	CRUISE SPEED (mph)	RATE OF CLIMB (fpm)	CEILING (ft x 1000)	RANGE (mi)	MAX WEIGHT (lbs x 1000)
	ARMY	NAVY	MARINE	AIR FORCE	COAST GUARD												
BELL JET RANGER 206A	OH-13 SIOUX	UH-13 TH-13		UH-13		365	2	1	35	4	1	150	140	2500	8.8	425	2.9
BELL 204B	UH-1 AH-1G HUEY COBRA	AH-13				142		1	48	8	2	138	120	1660	15.8	330	9.5
BELL 205 A	UH-1 AH-1G HUEY COBRA	AH-13				142		1	48	13	2	138	120	1660	15.8	330	9.5
BOEING VERTOL 107	CH-47 CHINOOK		CH-46			77	3	2	59	25	3	185	155	1750	18.7	230	33.0
HUGHES 500	OH-6A CAYUSE					140		1	26	4	2	143	133	1830	15.9	418	2.4
HUGHES 200/300	TH-55A					1200		1	25	1	1	86	89		11.5	200	1.6
LOCKHEED CL-1026	AH-56A CHEYENNE					?		1	50	30	2	230		3420	26.0	875	16.9
SIKORSKY S-65A			CH-53A	HH-53		0		2	72	67	3	195	172	1625	18.5	256	35.0
SIKORSKY S-64A	CH-54A SKYCRANE					2		2	72			109	127	1300	13.0	278	42.0
SIKORSKY S-61A/B/F/R	CH-3A	SH-3A/D	VH-3A	CH-3B/C HH-3C		59		2	62	28	2	150	140	1300	11.5	276	7.9
SIKORSKY S-62A/B/C					S-62C	56		1	53	10	2	110	98	1300	13.6	276	7.9
SIKORSKY S-58A/B/C/D	CH-34A/C	YSH-34G SH-34G/H LH-34D	UH-34D/E VH-34D		HH-34-F		4	1	56	13	2	130	101	1100	9.6	190	13.0

- LA Airways, Los Angeles - Sikorsky S-61: single rotor, pilot and copilot, 28 passengers

The actual number of aircraft recorded at each company in 1967 was as follows:

● New York Airways	7	Vertol 107
● Los Angeles Airways	1	S-51
	1	S-55
	5	S-616
● San Francisco-Oakland	2	S-62
● Chicago Airways	3	S-58
	3	Bell 206
	4	Bell 47 G/J
● Air General Airways-Boston	6	Bell 47 G/J
	6	Bell 206

The recorded number of revenue passengers carried and passenger miles for each company is presented below for 1963 and 1964.

	Revenue Passengers Carried (X1000)		Passenger Miles (millions)	
	1963	1964	1963	1964
Chicago	50	39	1.1	.8
Los Angeles	167	197	6.9	8.2
New York	240	253	5.0	5.2
San Francisco-Oakland	-	118	-	2.3

2.0 PILOT OPERATIONAL REQUIREMENTS

In this section commercial helicopter missions, equipment, and pilot procedures will be described and discussed. The mission descriptions will be concerned with segmenting a typical mission into its component phases. The pilot operations data will describe helicopter maneuvers and pilot involvement in these maneuvers for each mission phase. The pilot procedures will then be examined and anlayzed to identify the perceptual-motor capabilities required for their effective performance. In Section 4.0 research reports describing the effects of noise and vibration will be presented.

2.1 Mission Data

Missions performed by commercial helicopter airlines engaged in passenger transport were considered in this study. For these companies, a typical mission consists of transporting passengers and materials to scheduled destinations over an average flight time of fifteen to thirty minutes. The mission phases consist of startup and taxi to takeoff point, takeoff and climb to assigned altitude and heading, cruise, entrance into descent pattern, landing, and taxi to passenger station. Some of the helicopter companies land at small stations and do not require taxiing. Some are also permitted to make running landings which do not require hovering prior to ground contact.

The duration of the mission phases will vary as a function of gross weight and weather conditions. The mean number of missions per day ranges from about 12 to 15 with approximately 15 minutes required to complete each flight. The interval between flights varies depending on delays. If, for example, the pilot is delayed at a given point he must minimize his time on the ground at later stops in order to maintain the schedule. Considering that the scheduled interval between flights is approximately 5 minutes there is little time to relax. Pilots average 3.75 hours flight time per day and the majority of them work 5 days per week. At this rate, they will fly an average of 75 hours per month.

Throughout the conduct of these missions pilots are continually subjected to a noise and vibration environment which some investigators describe as intolerable. The precise effects of this environment will be discussed in this report in terms of specific effects on three pilot requirements:

- his safety
- his performance
- his comfort

Before making these evaluations some discussion of these three factors is required. In the general discussion of pilot safety the frequency and severity rates of commercial helicopter accidents will be presented. In the description of performance requirements work load and control considerations will be discussed. In the pilot comfort area the acceptability of work loads and equipment to pilots will be discussed.

2.2 Helicopter Pilot Safety

Table 2 presents statistics on commercial helicopter accidents in general and air taxi accidents in particular for the years 1962 through 1967. Table 3 includes accident rates per 100,000 hours flown for commercial helicopters and fixed wing aircraft.

As indicated in Table 2 the primary cause of helicopter accidents in seventy-five percent of the incidents is pilot error. This table also demonstrates that the most prevelant cause of air taxi helicopter accidents is engine failure with collisions with obstacles next. Table 3 indicates that helicopter accident rates are usually fifty percent greater than fixed wing single engine aircraft accident rates, and from 100 to 500 percent greater than multi engine fixed wing aircraft rates. The severity rate is also much greater in helicopters, equaling about twice the rate for multi engine and single engine fixed wing aircraft in 1967.

2.3 Helicopter Pilot Performance Requirements

Pilot control operations consists of the coordinated interaction of the collective pitch control, the cyclic pitch control, and the pedals which control the pitch of the tail rotor. The collective pitch control lever, located at the pilot's left side, moves upward to increase and downward to decrease pitch. It changes the pitch of all of the main rotor blades equally, generally controlling the altitude and altitude rate of the helicopter. The cyclic pitch control, located between the pilot's legs, is operated by his right hand. It has 360 degrees freedom of movement in the horizontal plane to control turns, banks, and direction of flight. There are two pedals for controlling the pitch of the tail rotor thereby countering main rotor torque. By varying the tail rotor pitch the pilot controls vehicle yaw. Although the collective

TABLE 2

COMMERCIAL HELICOPTER ACCIDENT DATA

	1962	1963	1964	1965	1966	1967
Total accidents	150	183	258	239	311	264
Fatal accidents	14	15	20	16	27	32
Serious accidents	15	18	30	23	41	34
Minor and no injury accidents	121	150	207	200	243	198
Air taxi-passenger accidents	22	6	22	33	22	22
fatal	2	2	2	5	0	3
serious	2	0	5	7	4	3
minor and no injury	18	4	15	21	18	16
Air taxi types of accidents:						
collision-ground or water	2	1	2	2	4	1
-aircraft	0	0	0	0	2	0
-obstacles	1	0	5	3	5	0
engine failure	0	1	7	8	4	6
propeller-rotor failure	0	0	1	3	4	4
Total accidents-pilot error caused:						
all accidents - percent	75				75	74
fatal accidents - percent	57				63	66

TABLE 3

GENERAL AVIATION ACCIDENT RATES
(number of accidents per 100,000 hours)

Type	1962	1963	1964	1965	1966	1967
All accidents						
Helicopter	58.59	47.29	57.72	53.11	62.80	49.07
Single engine fixed wing	40.04	34.43	35.16	33.50	29.56	29.29
Multi engine fixed wing	16.20	14.35	16.06	17.70	13.88	19.91
Fatal accidents						
Helicopter	5.46	3.88	4.47	3.56	5.49	5.95
Single engine fixed wing	3.41	3.40	3.48	3.38	2.87	2.69
Multi engine fixed wing	2.05	2.16	2.42	2.51	1.76	2.99

pitch control does not provide attitude control, it does provide translational motion.

Pilot tasks during the takeoff/climb phase of a mission are typical of control operations throughout the flight and illustrate control requirements. The general operational sequence for this phase is presented below:

1) Increase collective pitch by raising it with left-hand and simultaneously counter increased torque with rudder pedal. As helicopter becomes airborne, manuever cyclic control with right-hand to maintain straight and level attitude (pitch and roll).

2) Continually control yaw with pedals.

3) Slowly adjust collective pitch as hover altitude is acheived. Maintain hover altitude.

4) Maneuver cyclic pitch control so that control response is verified.

5) Increase pedal pressure to verify control response.

6) Scan instrument panel to verify that flight and engine performance gauges are operative and the information is in the normal range.

7) Simultaneously increase collective pitch, apply forward pressure on cyclic control, and adjust pedals to maintain correct airspeed, rate of climb, attitude, and heading.

8) Anticipate cruise altitude and heading. Adjust collective pitch friction to maintain setting, adjust cyclic pitch to maintain attitude, and adjust pedal pressure to maintain heading.

It can be seen that the actuation of one control device will generally require the interaction of the other two for smooth, coordinated maneuvers.

The cruise phase requires less pilot operational control activity than others. Once the helicopter is trimmed for cruise, (collective pitch set at desired position, attitude set by cyclic pitch for cruise and heading controlled with pedals), the condition is maintained until entry for descent/landing. During the cruise phase, the pilot observes other aircraft in the area and monitors the instrument panel. Navigation tasks are minimal owing to the short duration of the flights.

As the flight approaches destination, the pilot advises the air controller and prepares to enter the traffic pattern. He sets up the rate of descent by reducing the collective pitch and, using out-the-window visual cues and cockpit/instrument information, he controls the rate with collective pitch, attitude and ground speed with cyclic pitch, and heading with the pedals. On approaching hover altitude, the pilot reduces altitude rate and ground speed to zero. This coordination maneuver requires simulataneously actuating the cyclic pitch control to reduce ground speed, increasing collective pitch (up) to reduce rate of descent, and adjusting rudder pedal pressure to compensate for torque change. As the helicopter reaches hover, the pilot slowly reduces the collective pitch (down) and adjusts rudder pedal pressure to allow the correct rate of descent for touchdown. On landing gear contact, the pilot reduces the collective pitch to its minimum position to ensure that all wheels are on the ground.

The following sections describe cockpit configurations, pilot equipment data, flight maneuvers, and performance factors.

Cockpit Configurations and Pilot Equipment Data

The cockpit configuration for the Sikorsky S-61 helicopter is illustrated in Figure 1. External visibility is provided by clear plexiglass windshielding around the front and sides, overhead by tinted plexiglass to attenuate bright sunlight, and downward visibility by clear plexiglass panels located at the side of the rudder pedals. The visibility requirements are greater for helicopter than fixed-wing aircraft because of their multi-directional flight capability.

Seats are located side-by-side with the pilot on the right. These seats are constructed of metal frames with bottom and back cushions for comfort; no arm rests are provided. A lap-type seat belt is used at all times; but the shoulder harness is not.

All communications are by voice radio. A headset consisting of earphones and an adjustable microphone boom afford two-way communications. Volume control is located on the earphones; channel selectors on a console between the pilot and copilot. Push-to-talk buttons are located on the cyclic control sticks.

The main control/display panel is located directly in front of the pilot and copilot. The primary flight displays are ordinary aircraft instruments (altitude, airspeed, vertical

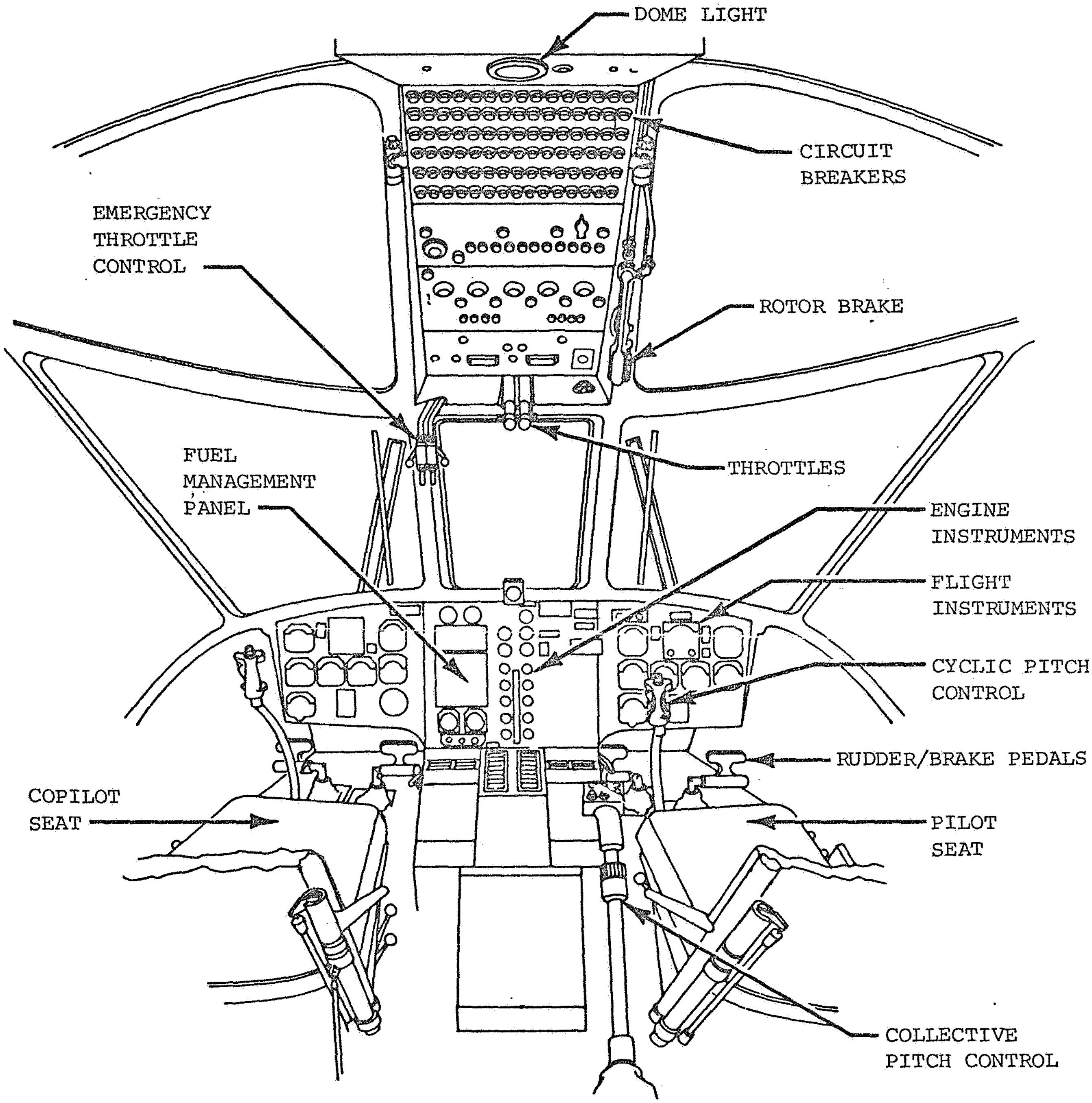


FIGURE 1 COCKPIT CONFIGURATION OF SIKORSKY S-61 HELICOPTER

speed, etc.). These are duplicated for both crew members, the engine performance instruments being centrally located, are shared. There are two auxiliary control panels. One is located overhead between the pilot and copilot and is primarily a warning light panel; but also contains emergency shut-off and lighting controls. The other is located at the pilot's lower right-side and contains electric circuit breakers.

Commercial pilots wear the uniforms designated by their company. These uniforms do not have any special protective qualities such as nonflammability or water resistance. Fire extinguishers are located in the cockpit, behind the pilot's seat and near the floor. A clipboard is used to log flight and rotor time and to record aircraft performance discrepancies.

Cockpit lighting consists of instrument lights, panel edge lights, cockpit utility lights, and a cockpit dome light. Instrument and panel lights are controlled by a rheostat. Utility lights have extension cords and may be handheld. The cockpit dome light has a red and a white lamp, and is used as required.

The main hand controllers are the cyclic pitch control (right hand) and the collective pitch control (left hand). The cyclic pitch stick is located forward of each pilot seat and pivots at the floor to allow for stick displacement in any direction. Each stick is equipped with switches for controlling helicopter trim, automatic flight control systems, and microphone operation.

The collective pitch lever is located to the left of each crew member's seat. The lever is equipped with a friction lock which holds it in a fixed position. A switch box is mounted on each lever for controlling landing lights, loading lights, and hydraulic servo systems.

Two tail rotor pedals are used to control the pitch of the tail rotor blades to vary the thrust which counteracts main rotor torque. The pedals are equipped with toe operated brakes for wheel braking.

The principal indicators and displays of the S-61N are those associated with engine operation and flight control. The ranges of values associated with primary displays are presented in Table 4.

TABLE 4

SIKORSKY S-61N DISPLAYS AND RANGES

DISPLAY	UNITS	MAX.	NORM. OP. RANGE	PRECAUTIONARY RANGE	MIN.	TOTAL RANGE
Airspeed	knots	131	15-131	0-15	0	131
Engine power turbine speed	percent	110	100-104	104-110 91-100	91	19
Rotor speed	percent	111	10--111	91-100	91	20
Power turbine inlet temp.	deg. C	704/ 677	300-635	635-704	300	404
Gas generator tachometer	percent	102	56-100	100-102	53	49
Torque	percent	112/ 95	0-86.5	86.5-95	0	112
Fuel press.	PSI	995	210-795	795-995	160	835
Engine oil temperature	deg. C	121	0-121	-	-54	175
Engine oil pressure	PSI	75	20-60	60-75	8	67
Transmission oil temp.	deg. C	145	40-120	120-145	-15	160
Transmission oil pressure	PSI	120	35-90	90-120	25	95
Servo hydraulic pressure	PSI	1600	1300-1600	-	1300	300

Flight Maneuvers and Associated Pilot Perceptual-Motor Factors

In this section pilot procedures are described in terms of basic flight maneuvers. For each maneuver the critical operational elements and associated perceptual-motor abilities required for each one are described.

The perceptual-motor factors are included to facilitate the evaluation of research findings and the application of these findings to the helicopter situation. Specific perceptual-motor factors are described in Table 5. Certain of these descriptions were developed by Parker et al. (1965). In Table 6 perceptual-motor abilities are identified for helicopter operation control task elements. These elements are basic operations required to control the vehicle.

TABLE 5

PERCEPTUAL-MOTOR FACTORS

PERCEPTUAL FACTORS

Visual acuity the ability to resolve visual detail.

Perception of distance and depth the ability to distinguish relative differences in distance and to make absolute distance judgements.

Perception of form and pattern the ability to identify or recognize shape, form, and pattern.

Perception of motion the ability to detect relative motion.

Movement analysis the ability to analyze velocity, acceleration, and higher derivative characteristics of target motion.

Movement prediction tracking the ability to predict position through time.

Perceptual speed the ability to make rapid comparisons of visual detail.

Time sharing the ability to obtain and use information presented within more than a single display.

MOTOR FACTORS

Arm-hand steadiness the ability to make precise and steady arm-hand movements of the type which minimize strength or speed.

Finger-wrist speed the ability to make rapid pendular and/or rotary wrist movements involving rapid repetitive jabbing movements in which accuracy is not critical. Does not depend on precise eye-hand coordination.

Finger dexterity the ability to make rapid, controlled manipulative movements of small objects with the fingers.

Manual dexterity the ability to make skillful controlled arm-hand manipulation of longer objects.

Position estimation the ability to move a limb to a specified position when the position must be estimated rather than reproduced from an immediately experienced limb position.

Response orientation the ability to choose and perform the proper movement or direction of movement from several alternatives.

Speed of arm movement the ability to make discrete gross arm movement at maximum speed.

Multi-limb coordination the ability to coordinate the movements of two hands, two feet, or combination of hands or feet simultaneously.

Reaction time speed with which a person can react to a stimulus.

TABLE 6

PERCEPTUAL-MOTOR FACTORS RELATED TO CENTRAL TASK ELEMENTS

No.	CENTRAL TASK ELEMENT	PERCEPTUAL-MOTOR ABILITY
1	Fore/aft cyclic control for: • airspeed attainment • rate of change of speed • maintain ground speed constant	manual dexterity response orientation manual dexterity manual dexterity movement prediction perceptual speed
2	Combined fore/aft and lateral cyclic control	multi-limb coordination manual dexterity response orientation
3	Combined fore/aft cyclic control and throttle control	multi-limb coordination finger-wrist speed manual dexterity response orientation
4	Very fine cyclic control	manual dexterity finger-wrist speed position estimation speed of arm movement
5	Aft cyclic control	position estimation
6	Finely controlled swiftly executed cyclic control	arm-hand steadiness finger-wrist speed speed of arm movement reaction time manual dexterity
7	Fine control of collective pitch	speed of arm movement arm-hand steadiness position estimation
8	Throttle control	finger-wrist speed manual dexterity position estimation
9	Spatial-angular judgements	visual acuity distance-depth perception form-pattern perception motion perception time sharing
10	View flight area	distance-depth perception movement analysis movement prediction-tracking

One difficulty with this approach, however, is the failure to account for the objective of the specific tasks and the other tasks which may be performed simultaneously or immediately preceding or following a specific task. For example, control of RPM might involve the same motor abilities during takeoff or landing, however, the interaction of this task with on-going perceptual tasks must make the RPM task intrinsically different for the two operations. The molecular view of pilot procedures, wherein abilities are derived for individual tasks, is therefore not sufficient to describe the performance requirements placed on the pilot. A better approach is to combine the information presented in Table 6 with an analysis of perceptual-motor abilities associated with maneuvers. The results of this synthesis are presented in Table 7.

TABLE 7

CENTRAL TASK ELEMENTS ASSOCIATED WITH MANEUVERS

MANUEVERS	CENTRAL TASK ELEMENT NUMBER (TABLE 6)
Vertical takeoff to a hover	1 3 4 8 10
Hovering	7 10
Hovering turn	7 8 10
Straight and level flight	1 4 10
Turning	2
Normal approach to a hover	1 7 8
Landing from a hover	1 3 4 5 6 7 8 9 10

As indicated in Table 7 the landing maneuver is the most complex in terms of number of central task elements involved. Landing in this context subsumes all techniques for landing including normal landing, steep landing, running landing, forced landing, and confined area landing. The takeoff maneuver is second in complexity and includes normal takeoff, maximum performance, running, and confined area takeoff.

2.4 Helicopter Pilot Comfort Requirements

The factors in the helicopter pilot's environment which have been demonstrated as influencing his comfort are as follows:

- Physical environment
    - noise levels
    - vibration levels
    - temperature
    - cockpit ventilation - presence of fumes
    - lighting - photic stimulation
- Equipment design
    - seat and restraint system design
    - provisions for arm, head, leg rests
    - control-display design, arrangement, location
- Operational environment
    - work-rest cycles
    - work loads
        difficulty
        duration
        criticality of operations

3.0 THE COMMERCIAL HELICOPTER NOISE AND VIBRATION ENVIRONMENT

The first prerequisite in any assessment of the effects of noise and vibration on helicopter pilots is to clearly define the noise and vibration environments encountered in operational commercial vehicles. A second requirement is to establish the duration of pilot exposure to specific levels.

The major problem encountered in the conduct of this study was the fact that noise and vibration and exposure duration information for commercial helicopters is almost totally unavailable. The only exceptions to this unavailability of specific commercial helicopter data are vibration and noise levels for the Vertol 107 obtained from the Boeing Company. Helicopter companies in general could provide no measures of noise and vibration levels obtained in actual flight but rather asserted that the actual levels were well within the minimum levels specified by applicable military standards.

In order to achieve an approximation of noise and vibration levels prevalent in commercial helicopters we have relied heavily on information published by military sources relevant to the military counterparts of the commercial vehicles. Thus the noise and vibration levels recorded in a CH-46A helicopter, the Marine Corps counterpart of the Vertol 107, are available and are presented for each flight phase in Table 8.

It is interesting to note that maximum noise levels were obtained during flight segments which also yielded minimum vibration amplitude (130 kt cruise and turn) and that fairly high vibration levels were measured during phases yielding minimum noise levels (liftoff, hovering turn, touchdown). Since helicopter noise and vibrations are ascribed to the same predominent source, the main rotor, the inverse relationship of levels is difficult to explain.

Since no other data are available on noise <u>and</u> vibration within commercial helicopters the mechanical environments of these vehicles will be described separately for noise and vibration. The following sections describe what is currently known concerning existing noise levels and vibration levels for commercial helicopters or for military counterparts.

TABLE 8

NOISE, VIBRATION, AND EXPOSURE DATA
FOR THE CH-46A (VERTOL 107) HELICOPTER (Dean 1964)

Flight Phase	Noise Level in db	Vibration Amplitude in RMS g	Approximate Time
Liftoff	107	.325	minimum
Hover	113	.195	unrestricted
Rapid climbout	113	.254	36 sec to 1,000 ft
Normal climbout	112	.201	60 sec to 1,000 ft
120 kt cruise	111	.162	2 hrs
120 kt turn	112	.195	
130 kt cruise	114	.184	1 hr 42 min
130 kt turn	114	.168	
Normal descent	114	.204	less than 3 min
Deceleration	110	.244	about 3 min
Rapid descent	112	.410	less than 1 min
Hovering turns	107	.293	
Touchdown	107	.247	minimum

3.1 Commercial Helicopter Noise Levels

Since helicopter manufacturers state that noise and vibration levels for their vehicles are designed to meet military standards, these shall be considered first. The majority of helicopter manufacturers in this country use MIL-standard A-8806A as the design guide for maximum levels of noise across the frequency spectrum. Maximum noise levels specified by MIL-A-8806A for octave frequency bands are depicted in Table 9. This table also presents maximum levels of industrial noise specified by the Walsh-Healy Act (1969) for 4 hour daily exposure.

TABLE 9

MAXIMUM ACCEPTABLE NOISE LEVEL AT NORMAL CRUISE POWER (LONG DURATION) AND SHORT DURATION AS DEFINED BY MIL-A-8806A AND MAXIMUM LEVELS SPECIFIED BY THE WALSH-HEALY ACT (1969)

	MIL-A-8806A		
Frequency bands (Hz)	Short duration limits (db)	Long duration limits (db)	Walsh-Healy (db)
37.5 - 75	118	104	120
75 - 150	118	104	115
150 - 300	118	104	105
300 - 600	112	96	97
600 - 1200	106	90	94
1200 - 2400	100	86	90
2400 - 4800	94	75	88
4800 - 9600	94	75	95
Overall	120	106	

Noise level data were obtained for 3 of the 4 helicopters of interest in this study, the S-58, 107, and Bell Jet Ranger. Actually these data were recorded in the U.S. Army counterparts of three aircraft, the CH-34C, CH-47A, and OH-13H respectively (Gasaway and Hatfield, 1963, Camp 1965).

A general description of noise sources in each of these aircraft is presented below:

CH-34C (S-58) In this aircraft noise emanating from two sources, the transmission and the engine exhaust, are more pronounced within the cockpit. There has been some reduction of acoustical energies generated by the main rotor and anti-torque rotor due to the increased number of blades which results in less intense rotor noise. The engine is mounted in the helicopter nose directly beneath the pilot compartment. Internal noise exposures are directly influenced by acoustical energies generated by engine exhaust, torque-distribution shaft, main transmission, and main rotors.

Noise levels for cruise and hover conditions are presented in Table 10 and depicted in Figure 2. The long and short duration limits of MIL-A-8806A are also presented in this table. The table demonstrates that in all frequency bands except one, the recorded noise levels during cruise conditions exceed the long duration limits of the military standard. At no frequency band do hover noise levels exceed short duration MIL-A-8806A limits.

CH-47A (Vertol 107) The noise generated internally within the CH-47A is a mixture of many complex noise components. Figure 3 demonstrates noise levels at different station locations within a CH-47A during normal cruise. The engines were generating 350 psi of torque and the rotors were rotating at 230 rpm. The aircraft was flying at an altitude of 500 feet and at an airspeed of 100 knots (IAS). Plottings of the over-all noise levels show that at positions directly beneath the forward and aft transmission the level of the noise is found to be most intense. Noise plottings of the lower frequency band of 37.5 to 75 Hz indicate positions where noise emanating from disturbances created by the rotors is found to be most intense. The noise plottings of the acoustical energy produced within the higher frequency ranges, especially from 1200 through 4800 Hz are indicative of noise generated by the forward and aft transmission and gear-distribution systems. For instance, at positions directly beneath the forward and aft transmission units the noise in the higher frequency ranges was found to be most pronounced. In fact, the noise plottings indicate that the level of the over-all noise at these internal locations is largely determined by the amount of acoustical energy produced by the transmission and related systems within the aircraft.

Figure 4 illustrates similar noise plottings taken at the same internal positions. However, during these measurements the aircraft was operating on the ground and the engines were producing only 150 pounds of torque. When less torque is applied to the transmission systems, and subsequently the rotors, the level of the noise produced by the transmissions remains basically the same, except for the forward transmission system. As noted from these measurements, the noise generated by the forward transmission system is not as intense during low power ground operations as it is during higher power cruise conditions. In contrast, noise emanating from the aft transmission system remains basically the same throughout both phases of operation. (Gasaway and Hatfield 1963 page 73)

Figure 5 illustrates Vertol 107 data received from Boeing. Table 11 presents noise level data obtained from the Army report and from Boeing data. As indicated in this table the noise levels recorded during cruise operations exceed MIL-A-8806A limits at three frequency bands.

OH-13H (Bell Jet Ranger) The internal noise levels of the OH-13H are basically similar during most phases of flight. One particular factor that may have a direct influence on the intensity and frequency spectrum of the internal noise is whether the cockpit doors are on or off. Due to the type of doors used on the OH-13H, they must be either on the aircraft and closed during flight, or completely removed. Usually during hot weather the doors are removed and during cold weather operation the doors are usually attached and closed. Figure 6 illustrates the amount of internal noise generated within the OH-13H during ground and hover maneuvers (doors on and doors removed). Figure 7 shows noise generated at the head level of the left occupant in the OH-13H during a cruise at 500 feet altitude and at 55 knots (IAS). During this maneuver the engine was operating at 3,200 rpm and 22 inches of manifold pressure. The main rotor had a blade passage frequency of 11.9 times per second and a tip speed of 656.1 feet per second (0.587 Mach). The anti-torque rotor had a blade passage frequency of 53.3 times per second and a tip speed of 477.6 feet per second (0.427 Mach). (Gasaway and Hatfield 1963 page 21)

Table 12 presents noise levels obtained for the Jet Ranger under varying flight conditions. It is evident that for short duration phases no levels exceeded the appropriate MIL-A-8806A limits. (Columns A, B, and C). However, for cruise operations noise levels exceeded those presented by the MIL-standard at most frequencies.

TABLE 10

NOISE LEVELS FOR THE CH-34C (S-58) HELICOPTER

	Noise Levels (db)			MIL-A-8806A	
Frequency Bands (Hz)	A	B	C	Short Duration	Long Duration
20 - 75	108**	110**	108	118	104
75 - 150	106**	105**	110	118	104
150 - 300	103	103	103	118	104
300 - 600	101**	101**	100	112	96
600 - 1200	95**	95**	95	106	90
1200 - 2400	96**	92**	92	100	86
2400 - 4800	92**	87**	85	94	75
4800 - 10,000	82**	78**	78	94	75

A - Normal cruise, 2,450 RPM, 80 kts IAS (U.S. Army-Gasaway and Hatfield 1963)

B - Cruise (Boeing Vertol 1961)

C - Hover (Boeing Vertol 1961)

** Exceeds MIL-A-8806A Long Duration Limits (only A and B)

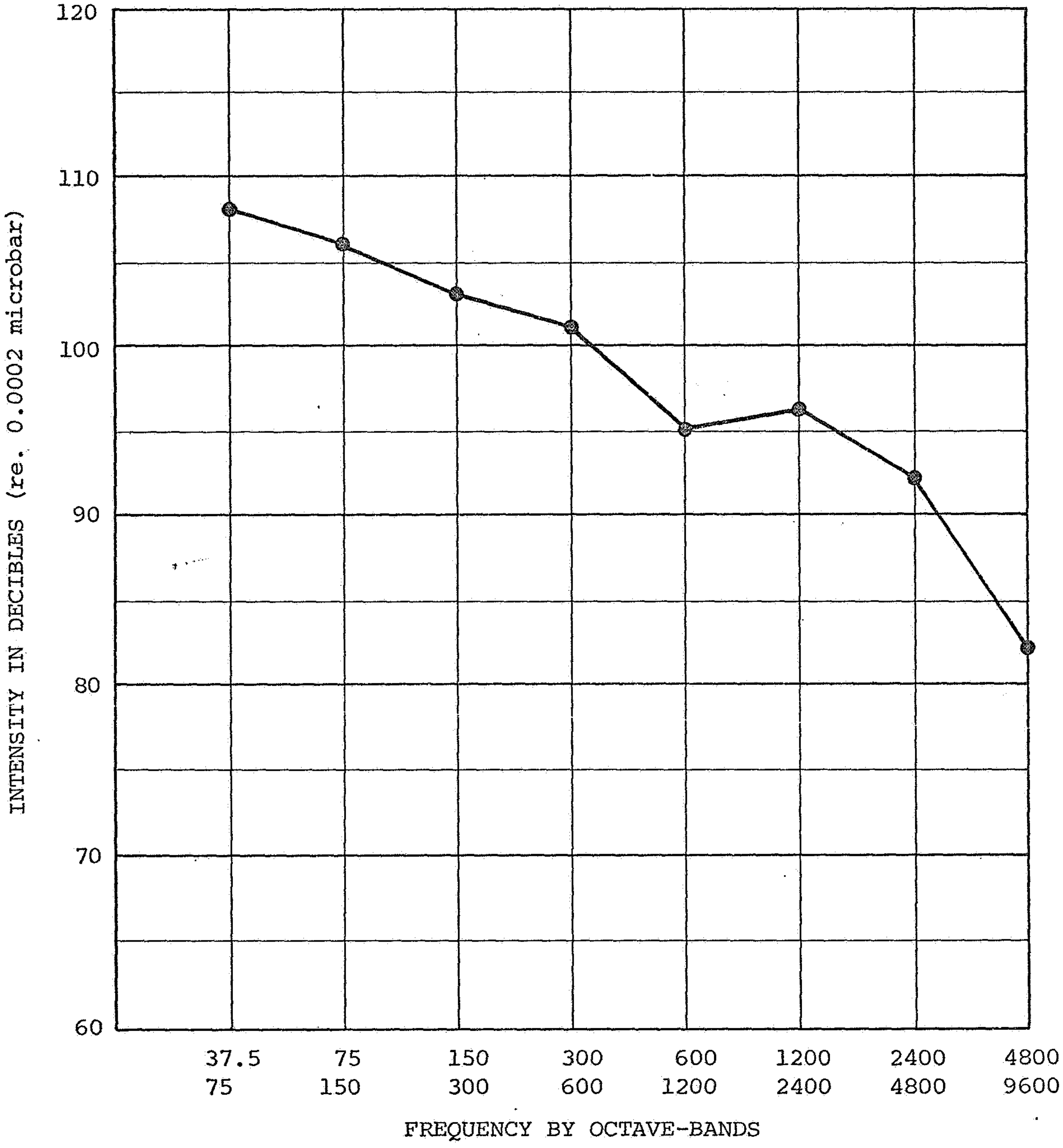


FIGURE 2 INTERNAL NOISE OF CH-34C HELICOPTER DURING NORMAL CRUISE, 2450 RPM, 80 KNOTS IAS

TABLE 11

NOISE LEVELS FOR THE CH-47A (VERTOL 107)

	Noise Levels (db)			MIL-A-8806A	
Frequency Bands (Hz)	A	B	C	Short Duration	Long Duration
20 - 75		100	106**	118	104
75 - 150			97	118	104
150 - 300			91	118	104
300 - 600			94	112	96
600 - 1200	98		90	106	90
1200 - 2400	99	104**	83	100	86
2400 - 4800	93	112**	74	94	75
4800 - 10,000			65	94	75
Overall	106	113**		120	106

A - Ground operations (U.S. Army-Gasaway and Hatfield 1963)

B - Cruise at 500 ft altitude, 350 PSI torque, 100 kts IAS (U.S. Army-Gasaway and Hatfield 1963)

C - Boeing Vertol 1968

** Exceeds MIL-A-8806A Long Duration Limits (only B and C are applicable)

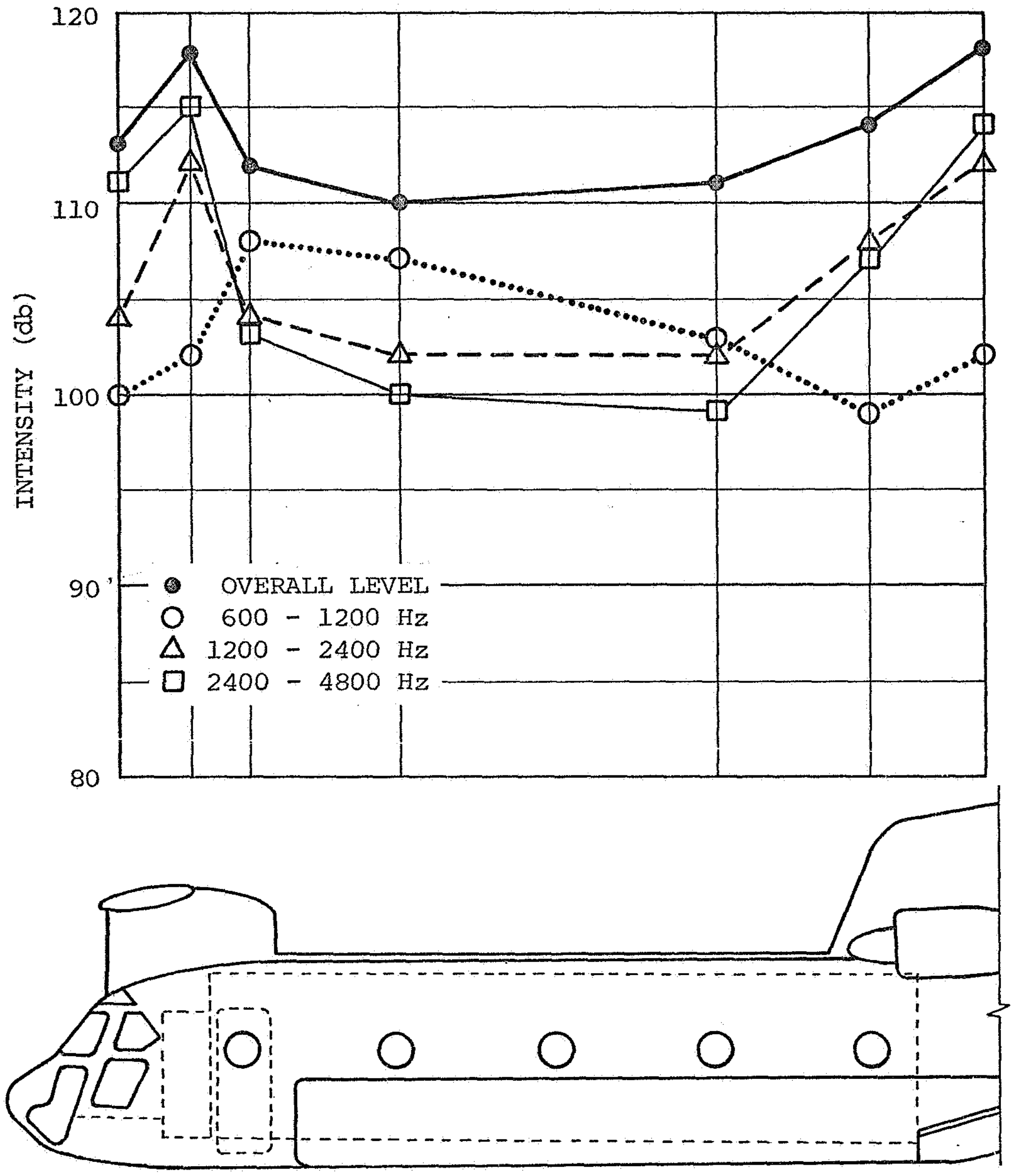


FIGURE 3 INTERNAL NOISE OF CH-47A HELICOPTER DURING NORMAL CRUISE AT 500' ALTITUDE, 350 PSI TORQUE, 100 KNOTS IAS

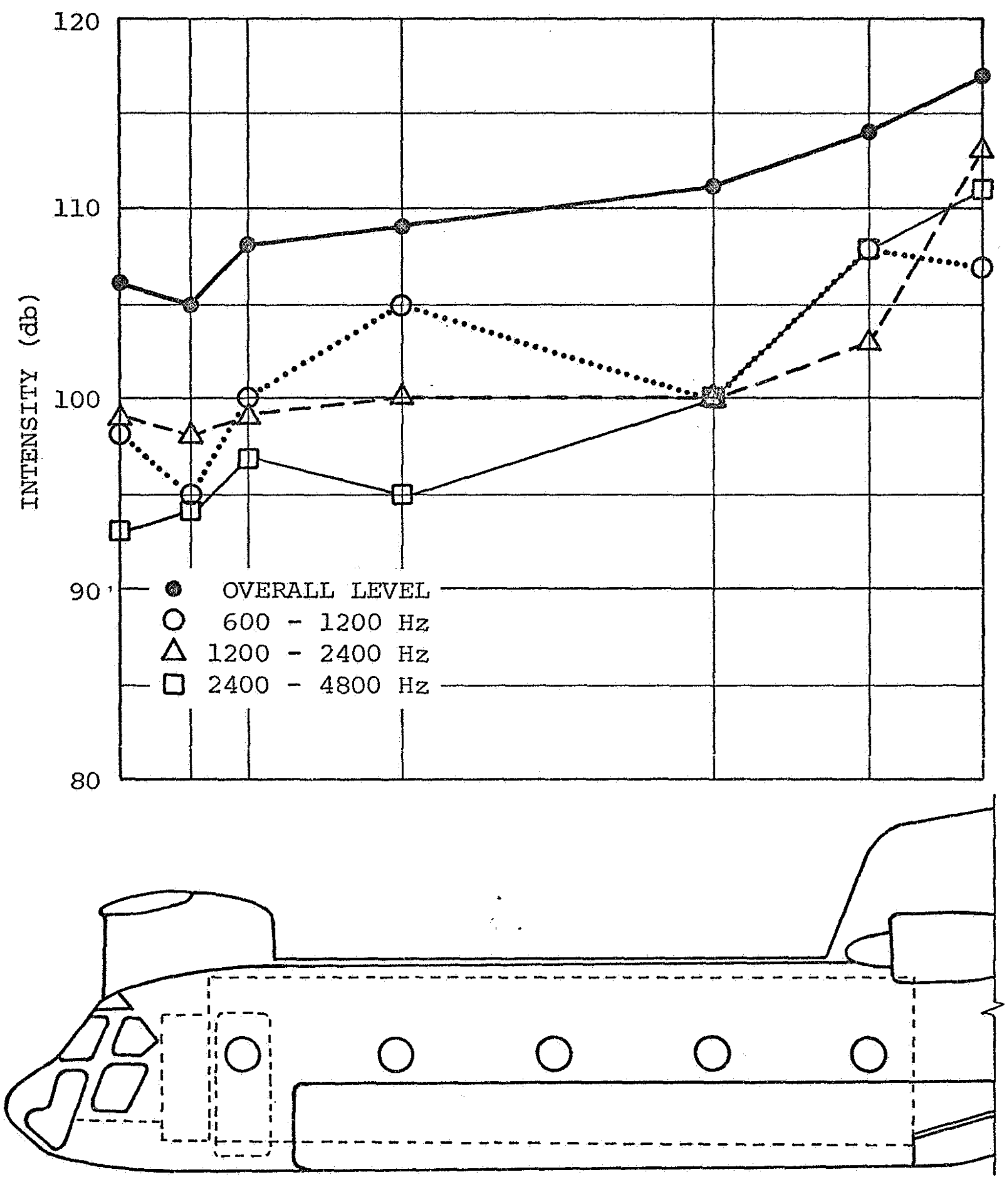


FIGURE 4 INTERNAL NOISE OF CH-47A HELICOPTER DURING GROUND OPERATIONS, 150 PSI TORQUE

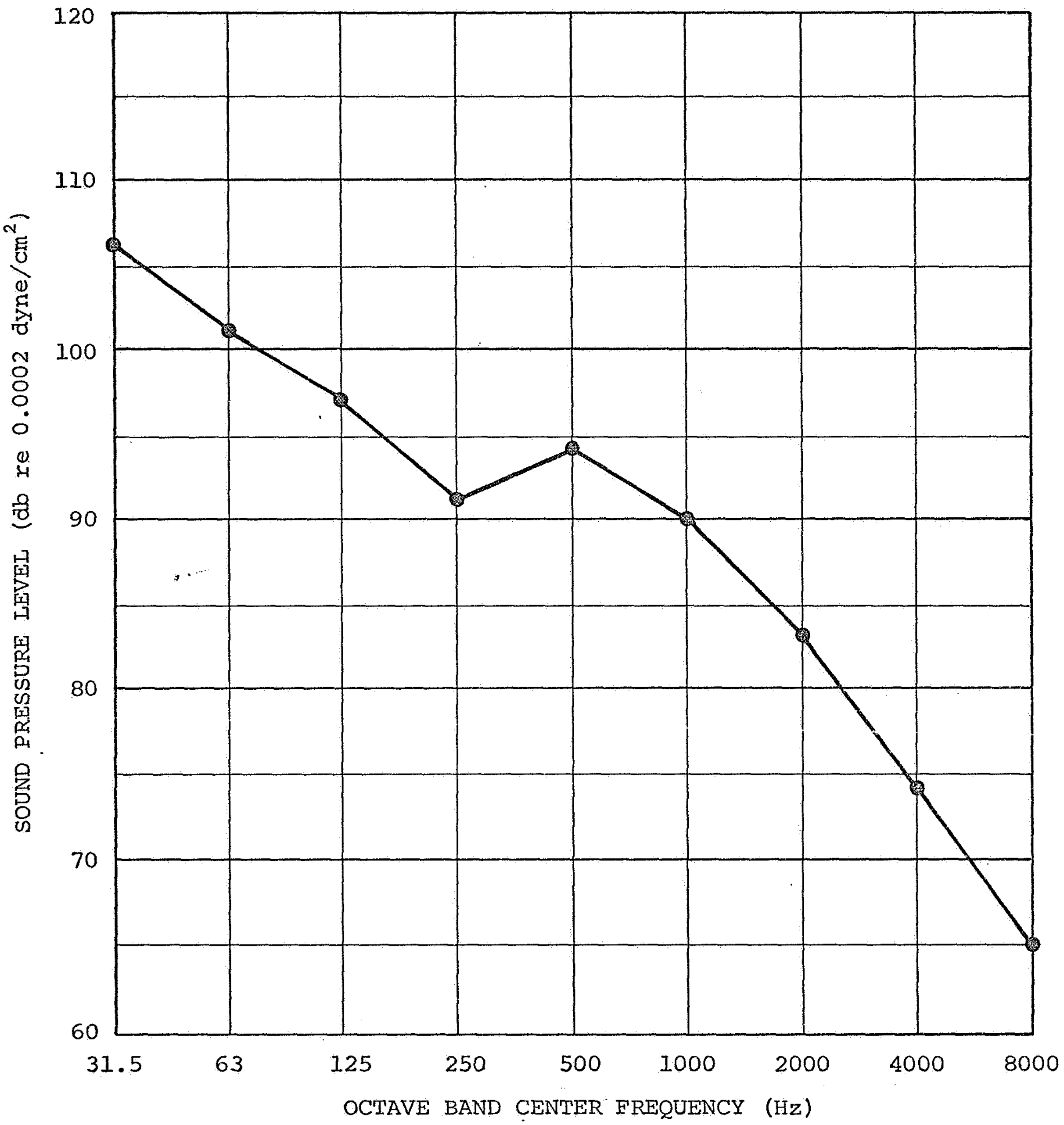


FIGURE 5 COCKPIT NOISE LEVELS VERTOL 107

TABLE 12

NOISE LEVELS FOR THE OH-13H (BELL JET RANGER) HELICOPTER

Frequency Bands (Hz)	Noise Levels (db)									
	A	B	C	D	E	F	G	H	MIL-A-8806A	
									Short	Long
20-75	97	103	115	109**	105**	104	115**	116**	118	104
75-150	110	105	115	110**	110**	97	105**	107**	118	104
150-300	110	108	110	111**	117**	97	94	97	118	104
300-600	101	102	110	97**	100**	90	94	96	112	96
600-1200	97	97	100	93**	90	89	97**	97**	106	90
1200-2400	95	96	90	94**	88**	82	93**	94**	100	86
2400-4800	89	90	90	92**	80**	79**	88**	90**	94	75
4800-10,000	79	81	85	93**	75	74	83**	83**	94	75

A - Ground operations - door open - 3100 RPM (U.S.Army - Gasaway & Hatfield 1963)

B - 3 Foot hover, door closed, 3200 RPM (U.S.Army - 1963)

C - Hover (Boeing Vertol - 1961)

D - Normal cruise 500 ft. altitude, 3100 RPM, 55 kts IAS (U.S. Army - 1963)

E - Normal Cruise (Boeing Vertol - 1961)

F.- Engine RPM 2300 (U.S.Army - Camp 1965)

G. Engine RPM 3100 (U.A.Army - Camp 1965)

H. Engine RPM 3200 (U.S.Army - Camp 1965)

** Exceeds M-A-8806A long duration limits (only measures applicable are D,E,F,G, and H)

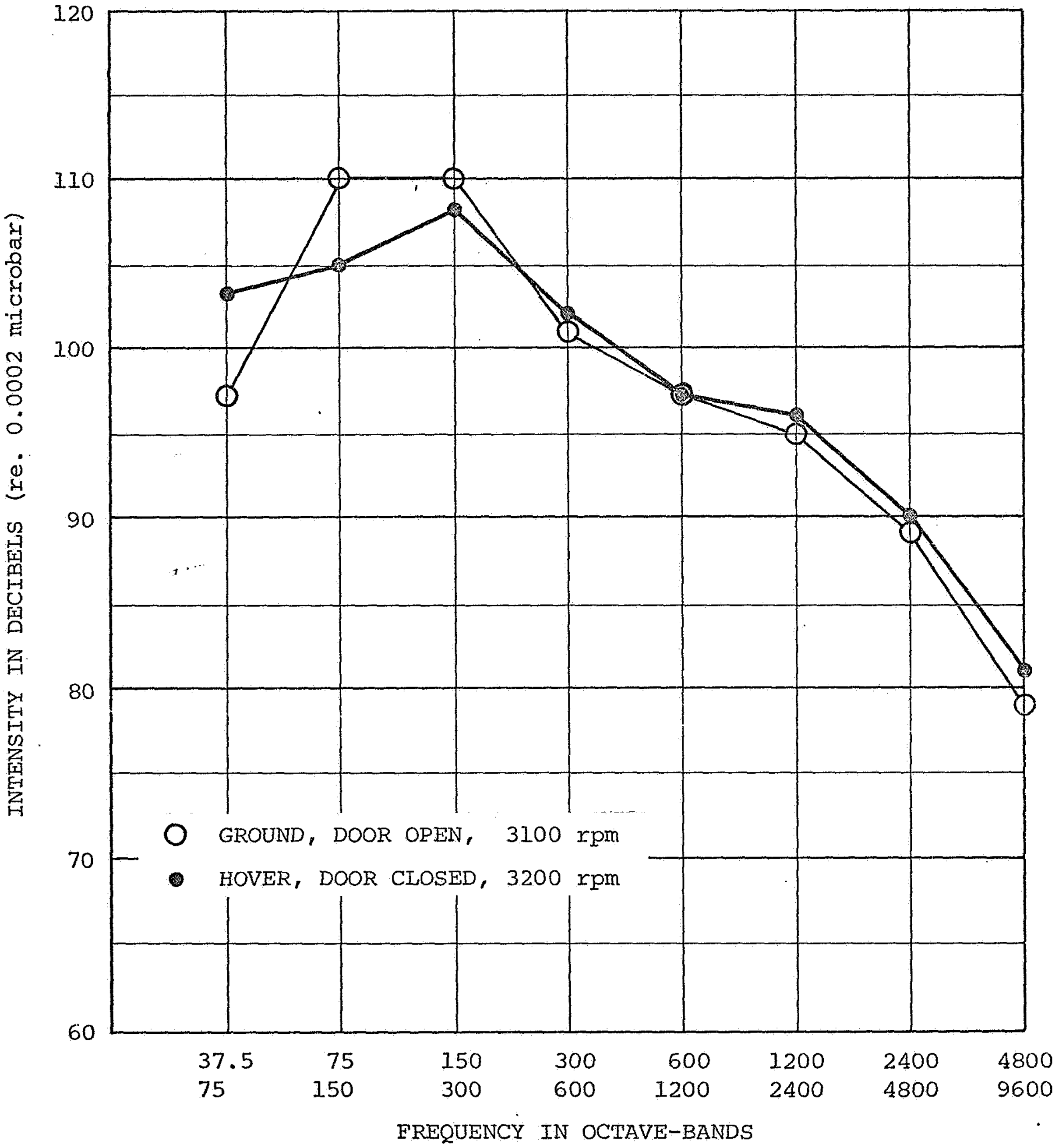


FIGURE 6 INTERNAL NOISE OF OH-13H HELICOPTER DURING GROUND OPERATIONS AND A 3' HOVER

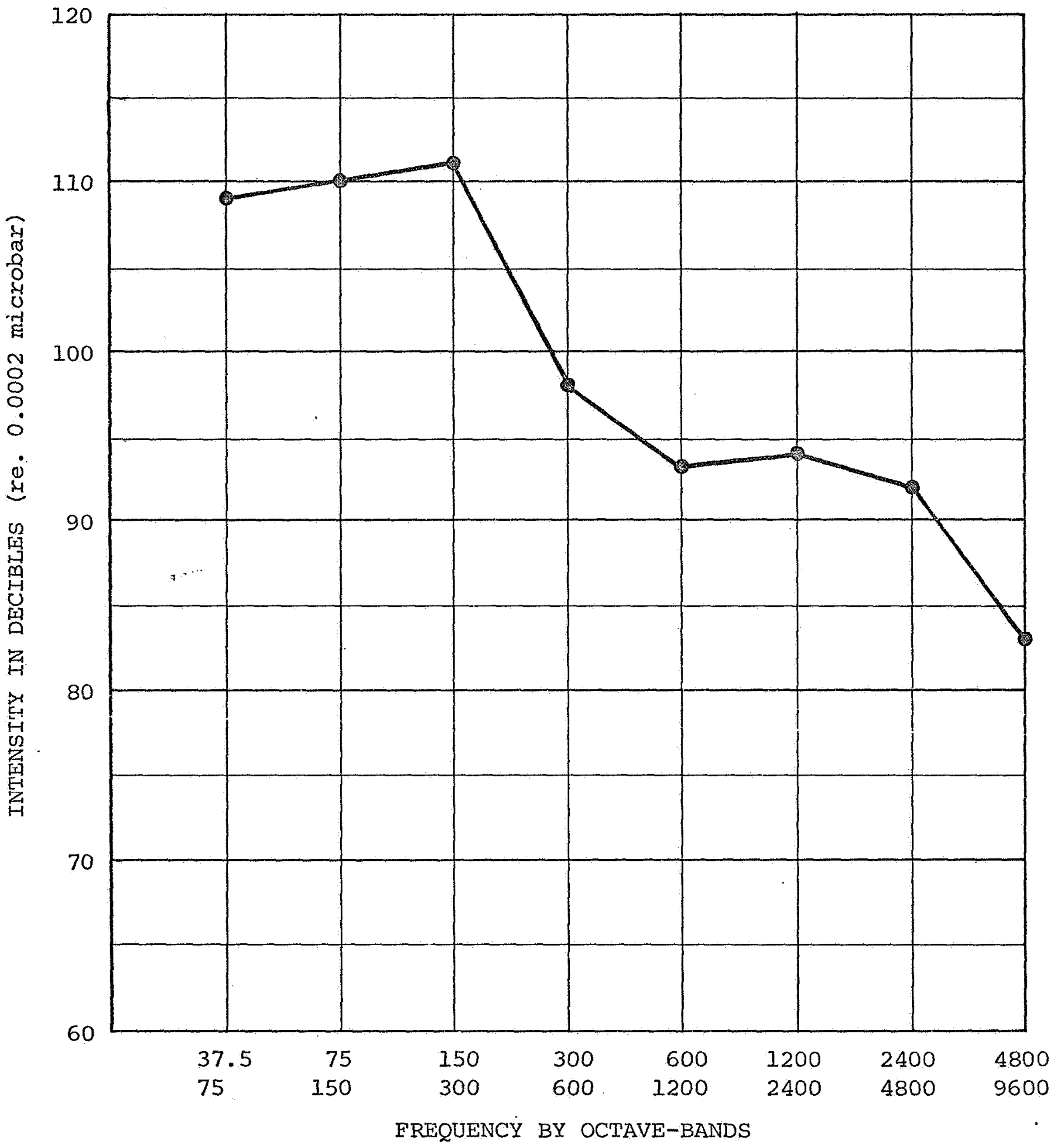


FIGURE 7 INTERNAL NOISE OF OH-13H HELICOPTER DURING NORMAL CRUISE AT 500' ALTITUDE, 3100 RPM, 22" MP, 55 KNOTS IAS

3.2 Commercial Helicopter Vibration Levels

Helicopters are subjected to the full range of mechanical vibration resulting from mass unbalance, rotor runout, torsional vibration, whirl vibration, and critical shaft conditions. Vibration problems of helicopters derive from a multitude of sources, most of which are aerodynamic in nature (Roach 1968).

No information concerning vibration levels in commercial helicopters was discovered in the literature. Table 8 presented amplitude levels for the military counterpart of Vertol 107 and these generally range from .2 up to .41 g for short duration flight phases and from .16 to .18 for longer (cruise) intervals.

Reports are only in approximate agreement concerning the overall range of vibration frequency and amplitude of general interest in helicopter studies. For example, Hornick (1961) concluded that, "dominant helicopter vibration ranges from 3-80 cps with greatest amplitudes at frequencies below 10-20 Hz." He cites Russian estimates of 10-70 Hz with amplitudes ranging from 0.4 mm for 70 Hz to 2.5 mm for 10 Hz. Other reports cited by Hornick express greatest concern for the lower frequency region in which the higher amplitudes occur. Guignard (1960) mentions vibration below 20 Hz McClements (1951) notes, "rotor-induced vibration in the S-51 to have peaks at 3-4, 10, and 20 Hz." Guignard and Irving (1960) mention heavy vibration below 10 Hz.

Among the broadest range of values indicated for helicopters, and hence the most encompassing, are the frequencies and amplitudes depicted in Figure 8. These data are from a report by Goldman and von Gierke (1960) after Getline (1955), and indicate a frequency range of 3 to 100 Hz with accelerations of approximately 0.009 to 4 g. For purposes of this report the Goldman and von Gierke parameters suffice to frame a general helicopter vibration response area, beyond which we may assume helicopter vibration frequencies and amplitudes are either rarely encountered or are of little practical importance.

In addition to the above, it is also helpful to delineate a sub-area of frequencies and amplitudes related both to main rotor effects and to the limits of a widely followed design guide such as MIL-H-8501A. A recent report by Calcaterra and Schubert (1968) helps to determine the former. It considered helicopter gross weights ranging from 2,000 to 80,000 lbs, thereby including S-61 commercial helicopters at 19,000 lbs, the Jet Ranger at 2,900 lbs and the Vertol 107 at 53,000 lbs, and indeed most others, save the small lightweight types.

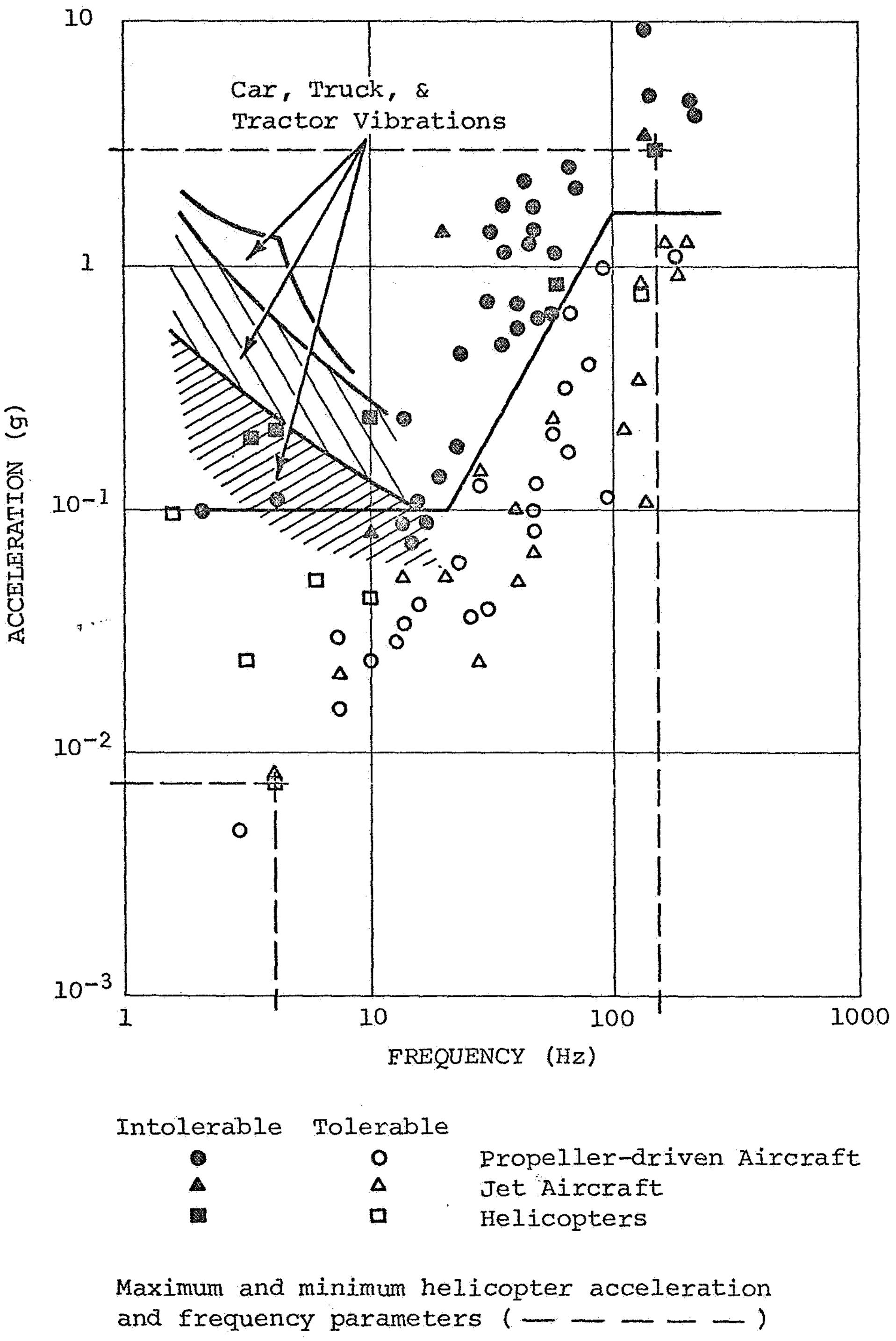


FIGURE 8 VIBRATION PARAMETERS FOR VARIOUS TRANSPORT DEVICES
(Adapted from Goldman and von Gierke, 1960; after Getline, 1955).

The report states that, "vibratory helicopter rotor-induced forces contain energy at frequencies which are harmonics of the blade passage frequency and typically occur in the range 10 to 30 Hz."

Turning to MIL-H-8501A, vibration at the pilot, crew, passenger, and litter stations during rapid or slow acceleration or deceleration is limited to 0.3 g for frequencies up to 44 cps. This limit will serve as an upper dominant acceleration boundary. For a lower limit, Hornick's (1961) estimate for 3 Hz, 0.05 g, will suffice.

The selected values of dominant helicopter acceleration and frequencies, 10 to 30 Hz and 0.05 to 0.3 g are obviously not intended to be definitive statements for precise application. Their utility is in two areas.

1. As helicopter-bound reference data against which to compare the more general vibration literature.
2. As a general approximation of dominant helicopter vibration parameters to be used in the absence of more specific data.

For a particular helicopter one may well find important vibration responses in the 3 to 10 Hz frequency band, for example, and should make use of such data when available.

4.0 EFFECTS OF COMMERCIAL HELICOPTER NOISE AND VIBRATIONS

The effects of the noise and vibration environment on helicopter pilots is presented for combined effects of noise and vibration and for each of the factors, noise and vibration, individually. Effects are presented at these levels: safety considerations include estimates of the likelihood that prolonged exposure to helicopter noise and vibration levels will result in physiological damage or impairment. Safety effects also include implication of the mechanical environment as potential causal factors of accidents. Performance considerations include the effect of noise and vibration on the pilot's ability to make maneuvers and control the vehicle. Comfort factors comprise the pilots subjective reactions to the helicopter mechanical environment.

4.1 Combined Effects of Commercial Helicopter Noise and Vibration

4.1.1 Effects on Pilot Safety

No evidence is available concerning the combined effects of helicopter noise and vibrations on the physiological well being of the pilot. Effects of noise and vibration treated singly will be described in separate sections (4.2.1 and 4.3.1). In this section the concern is with the degree to which helicopter noise and vibration act as contributing factors to helicopter accidents. While no direct causal relationship has been established between aircraft mechanical environment and accidents, the environment can be considered a contributing factor through its relationship with pilot fatigue, which results in degradation in performance of critical maneuvers and increases the liklihood of disorientation.

Specific causal factors for commercial helicopter accidents linked to pilot error, and frequency of occurrence of each for the years 1965-67 are presented in Table 13.

TABLE 13

SPECIFIC CAUSAL FACTORS FOR COMMERCIAL HELICOPTER PILOT ERROR ACCIDENTS

	Frequency of Occurrance (Percent)		
Cause	1965	1966	1967
Pilot error accidents	--	75	74
Fatal Pilot error accidents	--	63	66
Failure to see and avoid	10	11	9
Failure to maintain RPM	11	13	7
Improper flight control	11	8	20
Poor judgment	10	5	2
Selection of unsuitable terrain	3	4	3
Misjudged clearance	5	5	5
Misjudged, distance	2	2	9

As indicated by this table about three fourths of all commercial helicopter accidents are attributed to pilot error. Of all accidents two thirds are due to pilot error and involve at least one fatality. Primary specific causal factors are failure to see and avoid, poor control, and poor judgment. While it is difficult to demonstrate that such errors resulted from the noise and vibration environment, it is well known that performance degradation such as these are often associated with pilot fatigue.

In order to isolate potential pilot performance degradation which could have influenced the accident causal factors identified in Table 13, the major causal factors were analyzed for underlying perceptual-motor factors. This analysis comprised an assessment of operational requirements associated with each accident causal condition and the identification of perceptual-motor factors from those listed in Table 5 for the operational requirements. The results of this analysis are presented in Table 14. From this table it is evident that the most important perceptual-motor factors, in terms of their possible contribution to accidents are as follows:

- Visual acuity
- Perception of distance and depth

- Perception of motion
- Movement analysis
- Movement prediction - tracking
- Finger-wrist speed
- Manual dexterity
- Response orientation
- Speed of arm movement
- Multi limb coordination

In addition to degradation in performance attributable directly to degradation of specific perceptual-motor abilities, the possibility of accidents in helicopters can be attributed to two interrelated conditions of the pilot - fatigue and disorientation.

TABLE 14

PERCEPTUAL-MOTOR ABILITIES ASSOCIATED WITH ACCIDENT CAUSAL FACTORS

Causal Factor	Associated Perceptual-Motor Factor
Failure to see and avoid	Visual acuity Perception of distance and depth movement analysis Movement prediction Reaction time
Failure to maintain RPM	Finger-wrist speed Manual dexterity Response orientation
Improper flight control	Multi limb coordination Response orientation Speed of arm movement
Midjudgments - distance and clearance	Perception of distance and depth Visual acuity Tracking

Fatigue

One of the most vexing problems in the assessment of pilot performance is in determining the role to be assigned to fatigue. This is true of both the physical exhaustion type and the somewhat more elusive psychological stress category. The problem is recognized by Guignard (1965) who notes the widely held belief that vibration contributes to the lowering of performance by fatigue, although the specific mechanisms by which it does so are largely unknown.

Indirect measures of fatigue, such as vigilance performance and error score trend analysis, are often suspect because it is difficult to determine the degree to which subjects may be compensating for the fatigued state by increased determination and energy expenditure.

Fatigue is a complex problem which is often oversimplified, and which refuses to yield to "isolated measures of function, e.g., visual acuity" (Frazier, 1955), (see also Lyman and Levedahl, 1958). Nevertheless, Frazer holds that fatigue is capable of objective definition and measurement, and that it "affects high-grade performance long before there are signs of physiological exhaustion...."

Before leaving this topic some preliminary findings of an on-going study (Gabriel, et al.) should be mentioned. A research team of Douglas Aircraft and Navy Aeromedical Department scientists are assessing air crew performance as a function of flight duration in a simulator. They have limited their operational definition of fatigue to "degradation in performance or effective state resulting from previous work" as opposed to anxiety or physical stress due to illness or adverse environments. Briefly stated, their study objectives are:

1. To investigate a number of potentially sensitive measures selected from physiological areas.
2. To evaluate Barlett's hypothesis (which states that fatigue will be reflected by increased variability of performance, perceptual breakup, and reports of discomfort, in that order).
3. To determine if sleep/recovery data offers promise as a method for studying the effects of fatigue.

Preliminary results have confirmed Barlett's hypothesis of increased variability and perceptual break-up and have indicated some reliable physiological differences. Among these are significant differences in heart rate, respiration rate, and basal skin resistance as a function of work period. The authors note, however, that experimental conditions "did not seem to overly fatigue the subjects", and performance results are not conclusive.

Although work on the measurement, monitoring, and performance effects of fatigue is still quite recent and exploratory, it is encouraging that some tentative results are beginning to appear. More definitive and reliable data in these areas will fill a chronic gap in applied research knowledge for a variety of problem areas.

Fatigue and Commercial Helicopter Noise and Vibration

While many investigators state that one of the primary effects of noise and vibration is to increase the likelihood of fatigue the precise nature of this influence remains to be determined. On a psychological level the annoyance and discomfort generated by the mechanical environment should result in fatigue which increases in intensity over exposure time. In terms of physical effects the fact that many helicopter vibration frequencies equal the resonance frequencies of the whole body and parts of the body should also increase the chances of fatigue. In a survey of 27 commercial helicopter pilots at San Francisco/Oakland Airlines conducted in the present study, 26 percent of the pilots commented on the fact that helicopter noise and/or vibration results in fatigue.

Commenting on the interrelationship of helicopter noise and vibration and fatigue, Steinfeld (1961) had this to say:

> "Maintenance of reasonable noise levels in the cockpit area of the modern helicopter is not to be regarded as a luxury. Pilot fatigue and tolerance to other ambient conditions, including vibration, cannot be divorced from the noise level"

The incidence of fatigue is a function not only of the environment impinging on the human operator but also of the workload to which he is subjected and the duration of exposure to the environment and workload. While fixed wing aircraft are inherently stable and will seek level flight if left alone, the helicopter is inherently highly unstable. To maintain proper attitude and flight profile in rotary winged aircraft requires an endless series of minor corrections involving use of both hands and feet. The levels of alertness, information processing, and control are therefore much more demanding in helicopters than in fixed wing craft.

Commercial helicopter pilots average about 10 to 15 flights per day with a flight averaging 15 minutes. The interval between flights is about five minutes, therefore the daily exposure of the pilots to the mechanical environment and workloads is about five hours. Ten times during these five hours, the pilots must make the precise control adjustments and critical judgments associated with takeoff and landing. The physical and mental exertion associated with these repetitive maneuvers must be highly fatiguing.

Fatigue and Spatial Disorientation

Pilot fatigue has been demonstrated to be a major contributing factor to spatial disorientation. This is a greater problem in rotary wing aircraft because both hands and feet must be constantly alert in anticipation of the slightest change in aircraft attitude. (Giesecke et al. 1960) Disorientation of pilots has been cited as the third most important causative factor in helicopter accidents, after mechanical failure and crashing into obstacles (Kiel and Blumberg 1963). Disorientation incidents are most frequent in straight and level flight (20 percent of the total) with descending turn, climbing turn, and hover following in that order (12, 11, and 10 percent respectively). Disorientation is usually associated with IFR flight conditions and adverse weather, particularly fog, rain, or low overcast (Ogden et al. 1966). While commercial pilots fly only VFR, they are subjected to unpredicted adverse weather conditions during flight and are therefore susceptible to disorientation. A study of the severity of the disorientation problem for helicopters conducted by the Army, indicated that while only 3.4 percent of accidents recorded from 1 July 1957 to 31 December 1963 (total of 1202) were attributed to disorientation, 30.7 percent of fatal accidents were linked to pilot disorientation.

4.1.2 Effects of Noise and Vibration on Helicopter Pilot Performance

The only study which reported effects of helicopter noise and vibration on pilot performance (Dean et al. 1964) subjected subjects to random complex vertical vibrations similar to those found in the CH-46A (Vertol 107) with frequencies ranging from 4 to 120 cps and amplitudes of .162 to .41 g RMS. Noise levels ranged from 107 to 114 db. Subjects flew seven 40 minute simulated flights in a 6 hour period. Results indicated no adverse effects on tracking performance, meter reading ability, and visual acuity.

Although the experiment reported by Dean et al. (1964) indicates a considerable amount of effort, it is inadequate in a number of respects and is invalid for our purposes. For example, original pilot complaints were based on lateral vibration. This vibration was attenuated and the complaints shifted to vertical vibration, which had become "more perceptible" following the attenuation. Flight tests were conducted wherein 10 vibration channels were recorded for 3 directions of motor - vertical, lateral, and longitudinal. These were sampled at four locations: on the cockpit floor, and at the pilots' seat, helmet, and heel slide. Noise was recorded at the pilot's head and in the intercom system. For 120-knot cruise, maximum overall noise was 111 db (112 dbs during rapid descent); overall vibration was 0.162 RMS-g vertically at the seat (0.410 RMS-g during rapid descent).

After collecting vibration data on 10 channels, only the vertical was used in the simulator. The authors state that the other channels "were not necessary for simulation", providing only supplementary information. This contention seems curious in two respects: first, lateral vibration had been the original problem and helicopters do vibrate in more than one axis. Second, multiple axis vibration might well produce performance degradation effects, even though single axis vibration would not. Few, if any, data are available on this issue, and the report ignores the problem without explanation.

Still another problem is that of trial duration. Seven 40-minute flights followed by 10-minute rest periods comprised a 6-hour experiment day. Each 40-minute flight consisted of four evenly spaced performance periods of 7-minutes duration, for a total exposure of 28 minutes. Three 4-minute rest periods separated each 7-minute trial. Therefore, subjects were exposed to a daily total of about 3 hours and 16 minutes of simulation, well laced with 4 and 10-minute rest periods.

This structuring represents neither the 1.5-hour daily missions flown by company test pilots, or the 6 hours-a-day operational experience of the Marines, who were the aircraft's ultimate users. Although the latter's flying consists of "short-duration flights with short breaks for refueling, loading, and unloading," Marine Corps pilot experience would presumably be much more uneven in work/rest cycles than the experimental conditions reflected. Why then was not some worst case condition used as a check? Indeed, Broadbent's (1953, 1954, 1957) experiments on noise performance degradation typically used exposure duration of one and one-half hours; in most cases finding improved performance or no degradation during the first 5 minutes. During 7-minute trials in the simulation study, compensatory effects were not only possible, they were quite likely to have occurred.

In addition to the above problems, validity questions also arise from the nature of the performance tasks used. In the experiment, subjects tracked a pitch and roll display with their right hand, and responded to warning lights, a circular scale meter, and a Landolt ring display with their left.

Given sufficient task complexity and display stimulus/response rates, man-in-the-loop simulation of this type can yield valid results, even though close fidelity to real world pilot tasks is missing. The important requirement is to base the simulation on comparably difficult problems and work loads. In the subject experiment, however, adequate data about display sensitivity, signal rates, or subject work loads are not given. One cannot determine, therefore, if the tasks are valid measures of helicopter pilot performance.

The specified data suggest that experimental conditions would be only marginally suitable for extrapolation to real world performance. Taken separately, the tasks were evidently quite simple. Reading a pointer on a circular scale, which normally rests at zero, is not difficult. Turning off warning lights is a simple task when decision making is not involved. This also applies to many tracking and Landolt C ring orientation tasks, although the 1-minute of visual angle used for some of the Landolt gap trials would provide a sufficiently difficult acuity problem.

Since the performance tasks were basically simple and straightforward, they probably did not provide an adequately complex test of pilot performance. If they were presented at rates which mirrored the difficulty level of real world tasks, the authors should have said so.

The above report was singled out for dissection, not because it is a particularly poor example; indeed it has many virtues as well as faults. Rather, it indicates both the kind of work that needs to be done, and explains why reliance cannot be placed on that which has already been attempted.

More examples of simulation study results would be cited. For the present, it will suffice to summarize some of the basic difficulties.

1. Few, if any, of the reported experiments on helicopter pilot performance use simultaneous multiple axis vibration. Most used only vertical sinusoidal vibration.

2. In none of the experiments has both the pilot and display panel been vibrated independently at representative frequencies, intensities, and directions. Usually, only the subject is vibrated; the display remaining stable.

3. Rarely, if ever, are actual pilot scan patterns, task loads, decision processes, or stresses adequately considered.

4. Only recently has general physiological and psychological fatigue been given the attention it deserves. Much more needs to be done to assure the reliable collection and identification of fatigue data before performance effects can be evaluated.

5. In most cases the overall ambient environment is ignored in simulation studies. Cockpit lighting, temperature, noxious fumes, noise and vibration all should be considered if truly valid data are to be derived.

In summary, unless the above variables are accounted for in experimental designs, the findings and conclusions of studies purporting to determine the effects of noise and vibration on pilot performance will have limited meaning.

Effects of Noise and Vibration on Specific Operations

Table 15 includes perceptual-motor factors where research data indicate that an effect of noise and vibration has or has not been demonstrated and, for those abilities where findings do not exist, estimates are presented of the expected presence or absence of a degrading effect.

This table serves to underscore the almost complete unavailability of research results which are meaningful for the helicopter situation, since effects are reported from data in only 15 of 44 cases and since these perceptual-motor abilities were selected primarily because of their relevance to helicopter flying. Due to this insufficiency of research findings, expected effects are indicated in the table which are based on the authors' best estimate of the probability of noise and vibration adversely affecting the abilities. This best estimate is again based on an assessment of the essential behavioral factors associated with each ability and the probability that performance of operators requiring the ability will be degraded by noise and vibration.

If performance degradation is judged severe enough to degrade performance of the associated operation a "yes" indication is entered in the appropriate column (noise or vibration) of Table 15. If performance degradation is not judged severe, a "no" is entered in the column.

As indicated on Table 15, degrading effects of vibration are reported or expected for 13 of the abilities; while for noise the number is 15. Noise and vibration have been found to, or are expected to simultaneously affect 11 of the abilities. A comparison of the abilities affected by noise and/or vibration with their associated central task elements (Table 6) indicates that vibration will adversely affect performance of all 10 task elements. Noise will affect all except elements 2 and 3, which comprise fore/aft cyclic control and throttle control. Noise and vibration will jointly affect seven of the task elements including 1, 4, 5, 7, 8, 9, and 10.

TABLE 15

REPORTED AND EXPECTED EFFECTS OF VIBRATION AND NOISE ON PERCEPTUAL-MOTOR ABILITIES AND RELATED TASKS

Abilities	Vibration Effects	Noise Effects
* Visual acuity	yes-data	yes-expected
* Perception of depth	no-expected	no-expected
Perception of form	yes-expected	yes-expected
* Perception of motion	yes-expected	yes-expected
* Movement analysis	yes-expected	yes-data
* Movement prediction-tracking	yes-data	yes-data
Perceptual speed	no-expected	yes-data
Arm-hand steadiness	yes-expected	no-expected
* Finger-wrist speed	no-expected	no-expected
* Manual dexterity	yes-expected	no-expected
Position estimation	yes-expected	yes-expected
* Speed of arm movement	no-expected	no-expected
* Response orientation	no-expected	no-expected
* Multi-limb coordination	no-expected	no-expected
* Reaction time	no-data	yes-data
* Whole body orientation	yes-data	yes-expected
Speech perception and communication	yes-data	yes-data
Time sharing	yes-expected	yes-data
* Vigilance task monitoring	yes-expected	yes-data
Time estimates	no-expected	yes-data
Short-term memory	no-expected	yes-data
* Decision making	yes-expected	yes-data

*Abilities associated with accident causal factors

Table 15 also demonstrates that of the 14 abilities which are associated with accident causal factors, 8 are known or expected to be affected by vibrations. For noise, the number is 7 while for noise and vibration, the number is 9. Abilities which are expected not to be affected by noise or vibration include depth perception, finger-wrist speed, speed of arm movement, response orientation, and multi limb coordination. However, no data exist to verify these expectations and the effects of noise and vibration on these abilities is largely unknown.

4.1.3 Effects of Noise and Vibration on Helicopter Pilot Comfort

During the conduct of the present study, 27 helicopter pilots were interviewed at San Francisco/Oakland Airways. The opinions of these pilots are summarized in Table 16.

As indicated by the table, 89 percent of the pilots complained of noise and vibration levels in helicopters, with 74 percent objecting to vibration and noise individually. Twenty six percent commented on the relationships between noise and vibration and fatigue. A total of 58 per cent of the pilots requested improved ear protection, improved blade tracking, and better seats. Finally 26 percent of the interviewees objected to the detrimental effect of noise on communications.

TABLE 16

SUMMARY OF COMMERCIAL HELICOPTER PILOT COMMENTS

PILOT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Σ	%	X̄
GENERAL OBJECTION TO NOISE	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓			✓		✓	20	74	
GENERAL OBJECTION TO VIBRATION	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓		✓	✓	20	74	
VIBRATION AND FATIGUE										✓		✓											✓					3	11	
NOISE AND FATIGUE														✓				✓		✓		✓						4	15	
NOISE AND COMMUNICATION	✓	✓			✓		✓			✓									✓				✓					7	26	
EAR PROTECTORS USED OR REQUESTED			✓				✓		✓						✓				✓		✓		✓					7	26	
IMPROVED TRACKING REQUESTED	✓	✓				✓	✓														✓		✓					6	22	
IMPROVED SEATS, ADJUSTMENT, CUSHION		✓		✓	✓						✓							✓			✓			✓		✓		8	30	
OTHER	A	B			C							D	E				FG							HI		JK				
TOTAL HELICOPTER HRS FLYING TIME (100's)	45	32	45	45	36	25	25	81	100	45	27	75	44	20	23	80	16	85	75	25	22	85	21	61	15	28	23			45-
MONTHLY FLYING TIME (AVERAGE) HRS	60	80	70	13	70	55	60	60	60	65	60	60	60	55	65	20	60	65	70	50	55	75	65	65	80	75	40			60-
DAYS ON/OFF PER MONTH	18 12	18 12	18 12	V	18 12	18 12	18 12	18 12	18 12	18 12	18 12	18 12	18 12	18 12	19 11	V	18 12	18 12	18 12	17 13	18 12	18 12	18 12	18 12	18 12	18 12	18 12			18 12
NUMBER OF ACCIDENTS	1	0	-	1	0	0	0	0	2	0	0	0	2	0	0	0	-	-	0	0	0	-	1	0	0	0	0	7		
HRS ON GROUND PER MONTH WITH ROTOR ON	75	30	50	-	65	20	57	80	80	120	50	30	120	45	65	2	40	50	60	50	20	60	20	50	20	50	80			51+
AGE	-	-	35	33	30	31	31	48	35	-	26	38	29	-	-	-	35	46	39	30	30	-	29	40	24	31	29			33+

89%

26%

16-58%

OTHER COMMENTS

A	Sound Proofing Requested
B	Poor Ventilation - Requires Open Windows
C	Instrument Panel Vibrates
D	Headache Due to Vibration
E	Tenseness Due to Noise
F	Ringing in Ears Due to Noise
G	High Frequency Hearing Loss
H	Manufacturer Should Publish Noise and Vibration Data
I	Flight Training to Reduce Vibration Should be Considered
J	Back Problems Due to Vibration
K	Flying Hours Are Too Long
-	No Data
V	Variable

(See the appendix for the raw data)

4.2 Effects of Noise on Helicopter Pilots

4.2.1 Effects on Pilot Safety

The Life Science Research Office of the Federation of American Societies for Experimental Biology has asserted that noise levels in several rotary-winged aircraft often exceed 110 db (1969). The authors of this report prepared for the Army add that this level "approaches the threshold of pain (140 db), interferes with speech communication, and produces transient and permanent auditory damage". They further add that "no standards on the level of noise and risk of auditory injury (damage risk criteria) have been accepted by both medical and engineering authorities". (pg. 21). Such statements add little and cause added confusion in assessing the possibility of detrimental effects of the noise environment on helicopter pilot well being. To state that helicopter noise levels often exceed 110 db which "approaches the threshold of pain...interferes with speech communication, and produces transient and permanent auditory damage" is to overlook the fact that for four of the eight octave bands used, the limits recommended by MIL-A-8806A exceed 110 db for short exposure exposure.

Damage Risk Criteria

The task of relating noise exposure data to damage risk criteria has been a long standing problem. Although research interest in such criteria extends more than 20 years, they are still a source of disagreement amoung experts. Nevertheless, generally useful guidelines are available with which to quantify predictions on damage risk.

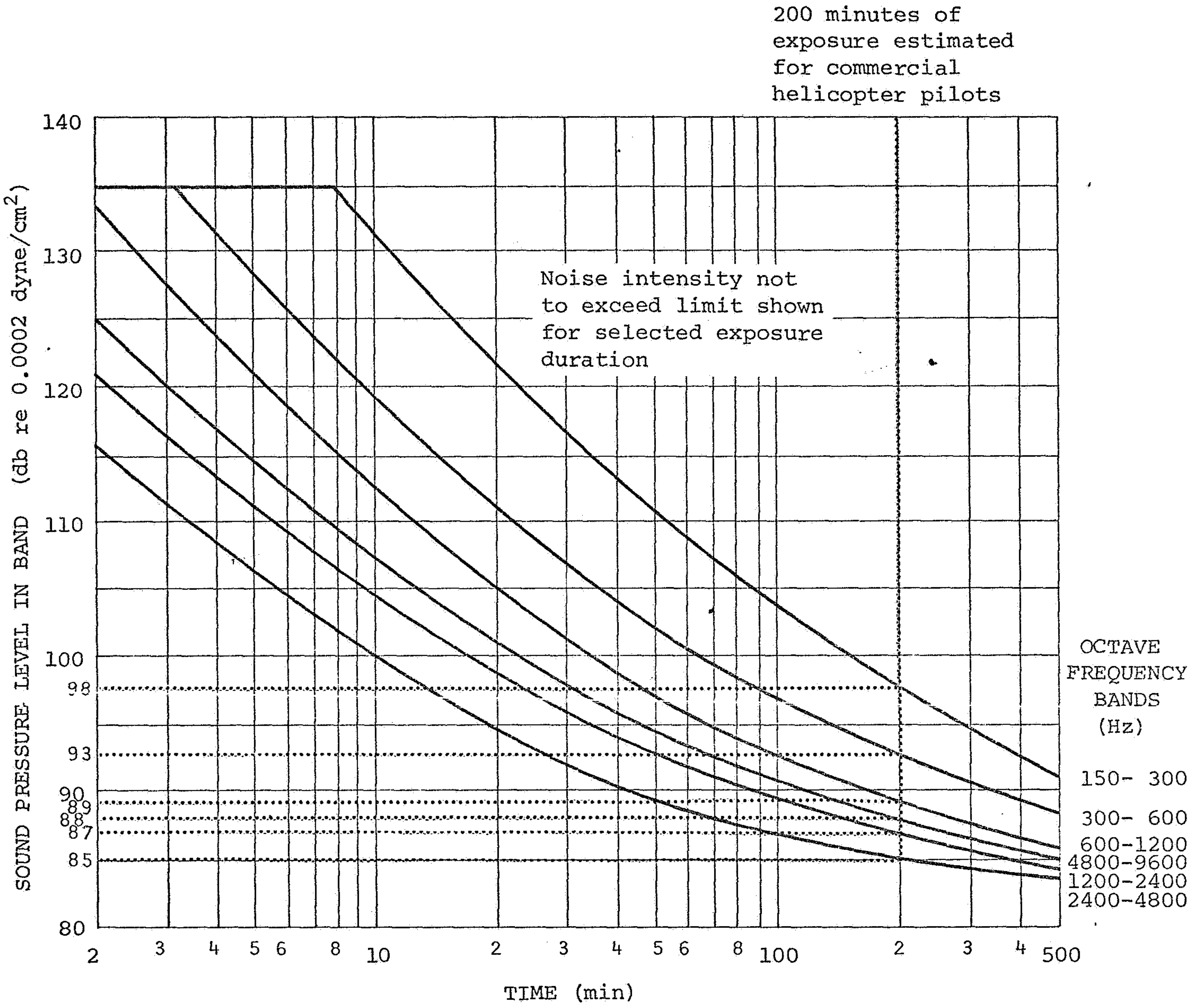
Kryter (1965) reported that in 1955, a group known as CHABA (now the NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics) was asked by the Armed Services for advice on establishing damage risk criteria for noise exposure. Group members assessed the literature and made recommendations which later resulted in the writing of Air Force Regulation 160-3 (1956). Since that time, additional findings have indicated some disagreement with the earlier effort and a new attempt at the same objective was initiated. Under the Chairmanship of Kryter, Working Group 46 was formed.

Its thirteen members included representatives from the Air Force, Army, Navy and National Research Counsel, and its recommendations were released in January, 1965. Damage risk criteria based on these recommendations are emphasized in the present report.

The left ordinate of Figure 9 depicts Working Group 46's recommended damage risk levels for exposure to broad band noise. Daily exposure time in minutes (along the abscissa) can be roughly estimated from the commercial helicopter pilot experience previously reported. In round average figures this totals about 36 minutes of exposure at maximum power and 150 to 200 minutes of exposure at cruise power. Time on the ground, either in or out of the aircraft, is excluded from consideration for simplicity, as are the attenuating effects of whatever earphones may be used. Even though such factors are not trivial, insufficient reliable data are available at this time to warrant conjecture about them.

Note that the most restrictive frequency curve in Figure 9, 2400-4800 Hz, requires that sound intensity be kept at or below 85 db for a daily exposure of 200 minutes. This compares to approximately 98 db for the lowest octave band, 150-300 Hz. These data are listed in Table 17 where it is also shown that acceptable (MIL-A-8806A) cruise power noise levels exceed Working Group 46's recommendations in three of the six octave bands being compared. Moreover, we have already indicated that the noise intensity levels in helicopters under field conditions are likely to be greater than those given in the table by 5 db or more.

Figure 10 depicts the damage risk levels recommended by Rosenblith et al. (1953). These levels are comparable with those specified by Kryter except at higher frequencies, where these are significantly higher.



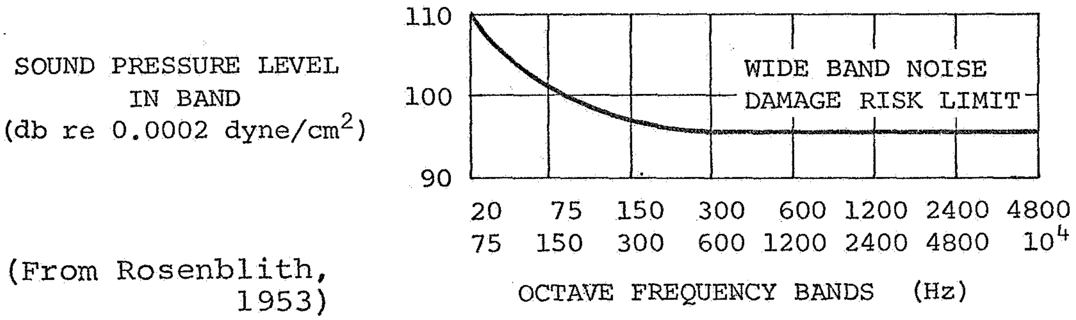
To apply these data: (...........)

1. Locate the average daily duration of exposure on the abscissa. (We have chosen 200 minutes as a rough estimate of commercial helicopter pilot exposure.)
2. Find the intersection of the selected exposure time and any octave band, and read the recommended maximum noise intensity on the ordinate.

(Adapted from Kryter, 1965)

FIGURE 9. DAMAGE RISK CONTOURS FOR DAILY EXPOSURE TO CERTAIN OCTAVE BANDS OF NOISE

(From Kryter, 1965)



(From Rosenblith, 1953)

These data depict earlier (and less precise) damage risk limits than are recommended by Kryter (1965) and are shown only for comparison. For any octave band of interest, the maximum allowable noise intensity can be found on the left ordinate. For the higher frequencies, the typical maximum intensity is shown to be about 95 dB.

FIGURE 10. DAMAGE RISK (DR) CRITERION FOR STEADY NOISE AND FOR LIFETIME EXPOSURES

Table 17 presents a comparison of damage risk levels with those specified by MIL-A-8806A for long duration flight (cruise). These data indicate that the exposure allowed by the MIL standard exceeds noise levels recommended as damage risk levels for four of the eight octave bands. Thus either the standard is not restrictive enough or the damage risk levels are not to be adhered to.

Table 18 compares helicopter noise levels with the damage risk levels.

TABLE 17

MIL-A-8806A - MAXIMUM ACCEPTABLE NOISE LEVEL AT NORMAL CRUISE POWER (LONG DURATION) COMPARED TO MAXIMUM INTENSITY LEVELS RECOMMENDED FOR 200 MINUTES OF DAILY EXPOSURE (ESTIMATED AVERAGE EXPOSURE OF COMMERCIAL HELICOPTER PILOTS)

MIL-A-8806A DATA		KRYTER'S DAMAGE RISK LEVELS †	ROSENBLITH'S DAMAGE RISK KEVELS
OCTAVE FREQUENCY BANDS (Hz)	MAX. ACCEPTABLE NOISE INTENSITY LEVEL (db)	RECOMMENDED MAX. NOISE INTENSITY FOR 200 MIN. OF DAILY EXPOSURE	
OVERALL	106		
37.5 - 75	104		110
75 - 150	104 +		101
150 - 300	104 *+	98	97
300 - 600	96 *+	93	95
600 - 1200	90 *	89	95
1200 - 2400	86	87	95
2400 - 4800	75	85	95
4800 - 9600	75	88	95

* Noise levels which exceed Kryter's recommended Damage Risk Levels

\+ Noise levels which exceed Rosenblith's Damage Risk Levels

† Adapted from Kryter
(See also Figure 9 DAMAGE RISK CONTOURS FOR BROAD OCTAVE BAND EXPOSURE)

TABLE 18

NOISE LEVELS AT CRUISE POWER
COMPARED WITH DAMAGE RISK LEVELS

Noise Levels (db)

Frequency			Jet	Damage Risk Levels	
Bands (Hz)	S-58	107	Ranger	Kryter	Rosenblith
20-75	108	106	109		110
75-150	106●	97	110●		101
150-300	103*●	91	111*●	98	97
300-600	101*●	94*	97*●	93	95
600-1200	95*	90*	93*	89	95
1200-2400	96*●	83	94*	87	95
2400-4800	92*	74	92*	85	95
4800-10,000	82	65	93*	88	95

* Helicopter noise level exceeds damage risk level specified by Kryter

● Noise levels exceed Rosenblith's damage risk levels

As indicated by this table, the noise levels recorded during cruise conditions exceeded Kryter's damage risk levels in five of six octave bands for the S-58, 2 of 6 bands for the 107, and in all six octave bands for the Jet Ranger.

For Rosenblith's levels the limits are exceeded at 4 of 8 bands by the S-58, at none of the bands for the 107, and at three bands by the Jet Ranger.

Although the evidence is preliminary, insofar as it reflects actual operating conditions, duty cycles, and exposure levels, it indicates that commercial helicopter crewmen are commonly exposed to noise intensity levels which are hazardous to their hearing.

Though we refer to Kryter's (1965) and Rosenblith's (1963) damage risk criteria reports for comparison to helicopter noise exposure, they are by no means the final word, as Bell (1966) advises, "Expert opinion on maximum safe intensity level ... is anything but unanimous (Sterner, 1952; Eldredge, 1960; Bonney, 1962). Some of the several criteria proposed are not precise limits and can be regarded only as general guides." McCormick (1964) confirms this view in his text on human factors engineering. He summarizes the problem in this statement.

> "It would be convenient if one could say that noise levels above some value are "harmful" and those below are "safe" for people to work in (but things are not quite that simple). Various people have expressed opinions on this point, and at least one survey of experts has been conducted (Sterner). In that survey intensity levels above 100 were almost universally considered not to be safe and those below 90 were generally considered not to be harmful, in terms of the definition of "harmful" used (levels above which even brief repeated exposure introduces the probability of permanent deafening effect). Various other experts have ventured opinions that the "danger zone" starts somewhere between 80 and 90 db, although it is probable that most of these estimates were predicted on the existence of continuous and extensive exposures, rather than "brief, repeated" exposures as used in the above study."

Permanent threshold shift (PTS)

Loss in acuity first occurs in the 3000-6000 Hz band, usually at 4000 Hz. As hearing becomes progressively worse, loss at these frequencies increases and lower frequencies are involved (Bell,1966).

In general, impairment of hearing tends to be maximal at the end of 10 years' exposure, and then to remain constant for 30 years (Glorig and Davis, 1961). Note, however, Bell's (1966) comments on the effects of aging. Moreover, it is not safe to conclude that one who has worked in a noisy environment for 10 or more years is immune to further loss (Lawrence, 1963). It has been said that the rate at which noise-induced hearing loss is experienced is proportional to the amount of hearing remaining to be lost (Herman, 1965).

> "The full relationship between temporary threshold shift and permanent loss is not quite clear. The greater the permanent loss at any frequency, the smaller will be the TTS at this frequency (Glorig, 1961b). The results of a ten-year follow-up study to determine the relationship between temporary and permanent hearing loss, from average daily noise levels of 90 db overall, have recently been reported by Sataloff, Vasallo & Menduke (1965). A noise that does not cause temporary loss rarely, if ever, causes permanent impairment in the same individual. Noise-induced temporary shift and permanent impairment run parallel, though on a differing time-scale (Glorig, Ward & Nixon, 1962). The shift in db resulting from an 8-hour exposure closely parallels the permanent loss at the end of 10 years' exposure (Glorig, 1958, Glorig, Ward & Nixon, 1962). For the average individual habitually exposed to loud noise, it may be predicted that the ultimate hearing level at 4000 Hz will be equal to the temporary level found two minutes after 5 hours' continuous exposure to the noise in question (International Organization for Standardization, 1963a)." (Bell, 1966).

Another well-known report on helicopter noise problems is that of Metcalf and Witwer (1958). These authors were primarily concerned with passenger compartment noise in Marine Corps troop transport helicopters (HR2S-1). They found that the passenger compartment measured between 114 and 122 db in flight with an average at about 119 db. The pilot's area registered 108 db. These intensity levels resulted in a measurable hearing loss in all frequencies, averaging about 22 decibels for unprotected passengers. Further, the authors note that all of the predominant peak frequencies of recorded noise fell within the normal speech range (i.e. 500 to 3000 Hz), and would be expected to interfere with hearing.

Figure 11 depicts some representative helicopter noise data from the cited literature. It includes a curve for MIL-A-8806A normal cruise power limits, and damage risk recommendation data from both Kryter (1965) and Rosenblith (1953). These data support Sternfield's view, that the maintenance of reasonable noise levels in the cockpit of the modern helicopter is a necessity, not a luxury. For example, Berry and Eastwood's composite envelope of helicopter noise is generally higher than recommended damage risk limits. MIL-A-8806A limits plot higher than Kryter's 200-minute exposure curve in three of the six octave bands on which comparative data are available. Interference with pilot speech is likely, and so on. Rather than continuing to point out the obvious, however, the figure must be used or not on its own merits. Vivid comparative data are only as meaningful as the bedrock of evidence supporting them and we have already noted some of the questions remaining to be answered in this broad field.

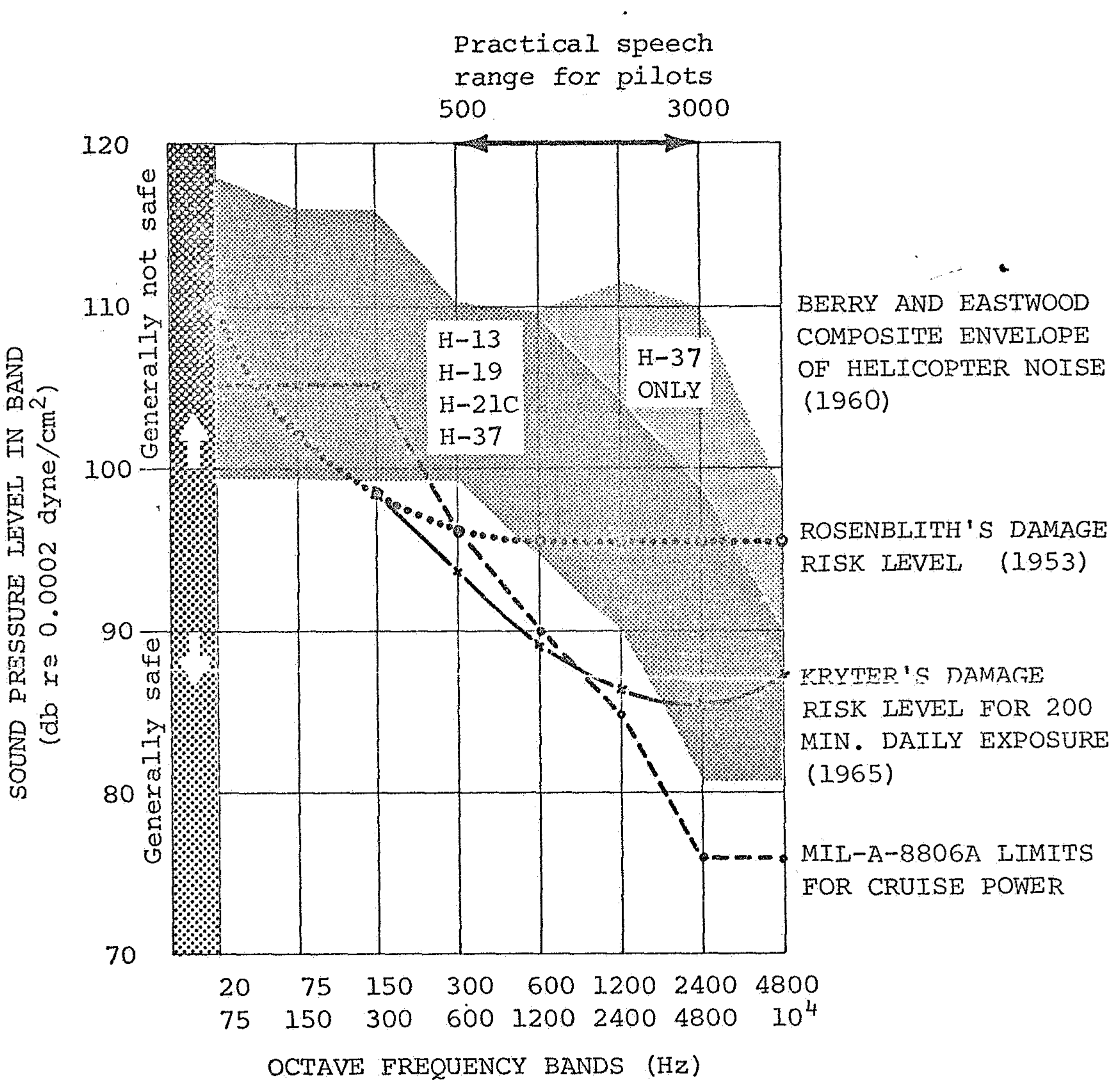


FIGURE 11 COMPARISON OF REPRESENTATIVE HELICOPTER NOISE DATA WITH DAMAGE RISK CRITERIA

An important consideration in the determination of damaging effects of helicopter noise is the minimum time required for recovery after each exposure. These recovery times are plotted as a function of noise intensity and duration of exposure in Figures 12, 13, and 14. If a standard helicopter flight takes 15 minutes, it will take about 3 minutes to recover from noise levels of 95-100 db in the 300-600 Hz band (reported in the S-58 and the Jet Ranger) and 6 minutes to recover from noise levels of 100-103 db for the same band (S-58). In the frequency band 600-1200 Hz it will take 7 minutes to recover from 95-100 db noise (S-58). In the band 1200-2400 Hz it will require 6 minutes to recover from a noise level of 90 to 95 db. (S-58 and Jet Ranger). Based on these data it can be stated that the 5 minute interval between flight used by most air taxi companies is adequate provided the pilot is subjected to relative quiet (less than 85 db) during the period. For ground operations, Figure 4 indicates that the overall noise level in the CH-47A is about 106 db while Figure 6 shows that the overall level in the OH-13H, with door open, has been recorded at 97 db.

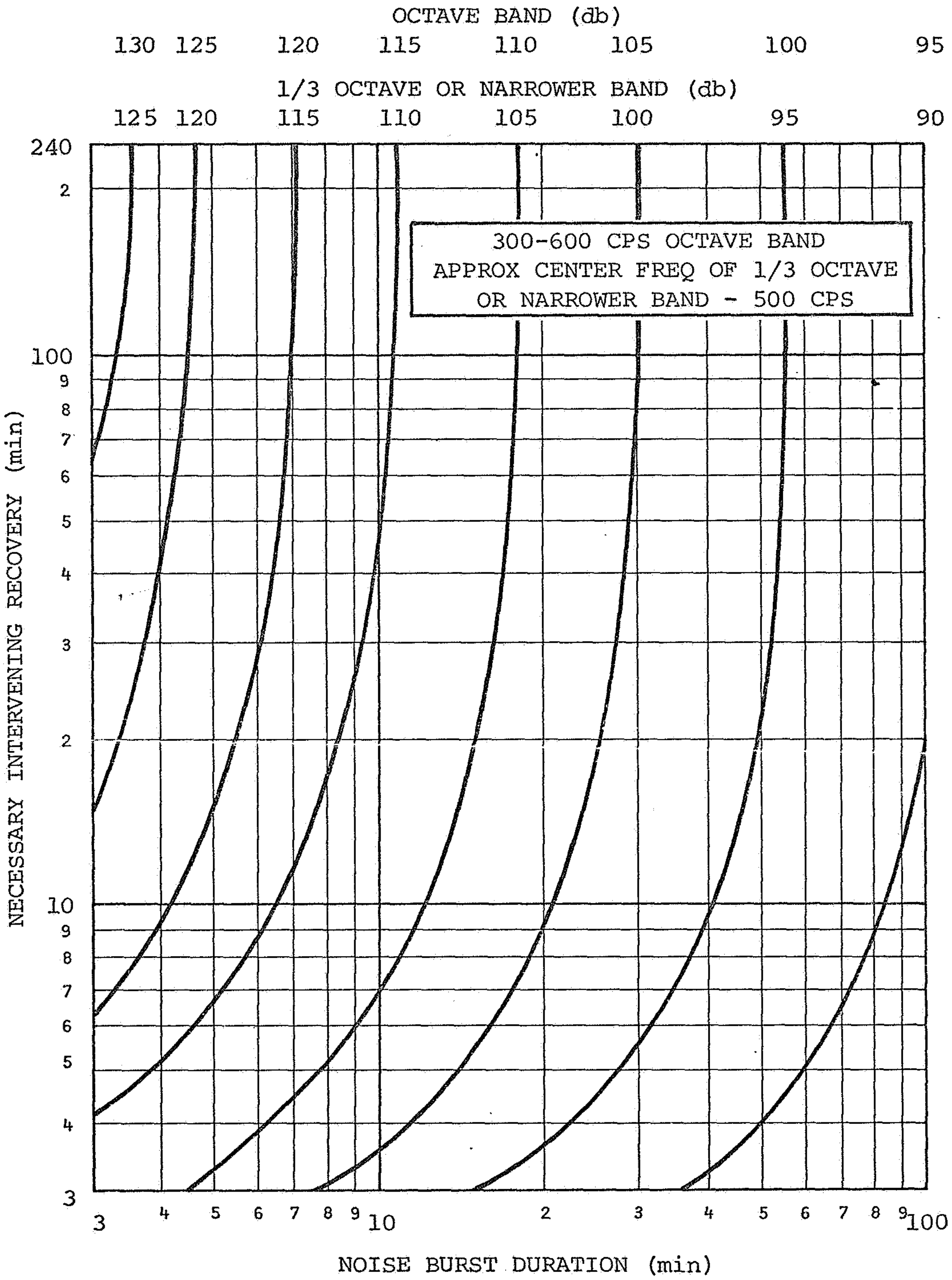


FIGURE 12 DAMAGE RISK CONTOURS FOR LONG-BURST-DURATION INTERRUPTED NOISE PARAMETER: BAND SPL.

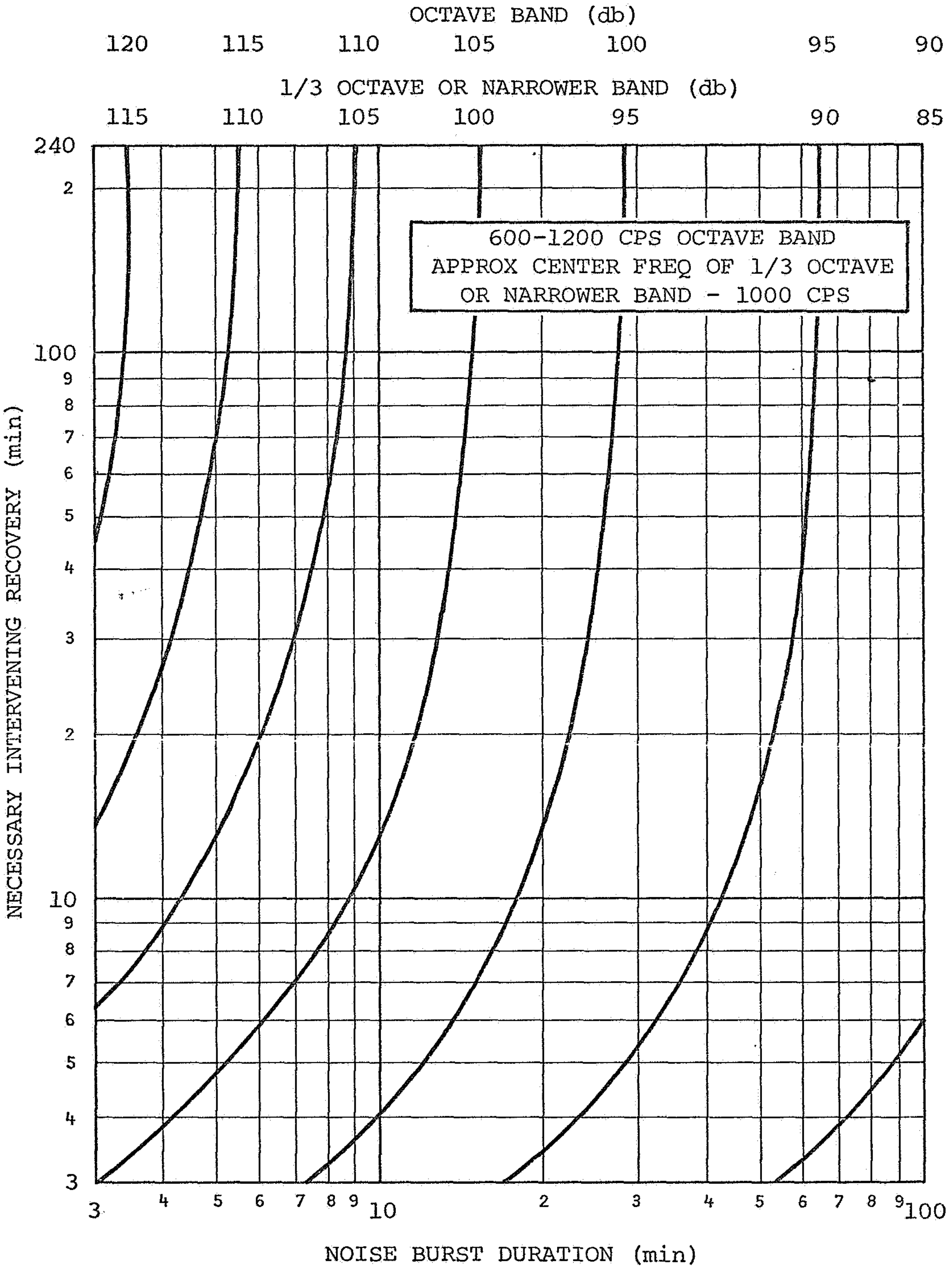


FIGURE 13 DAMAGE RISK CONTOURS FOR LONG-BURST-DURATION INTERRUPTED NOISE PARAMETER: BAND SPL.

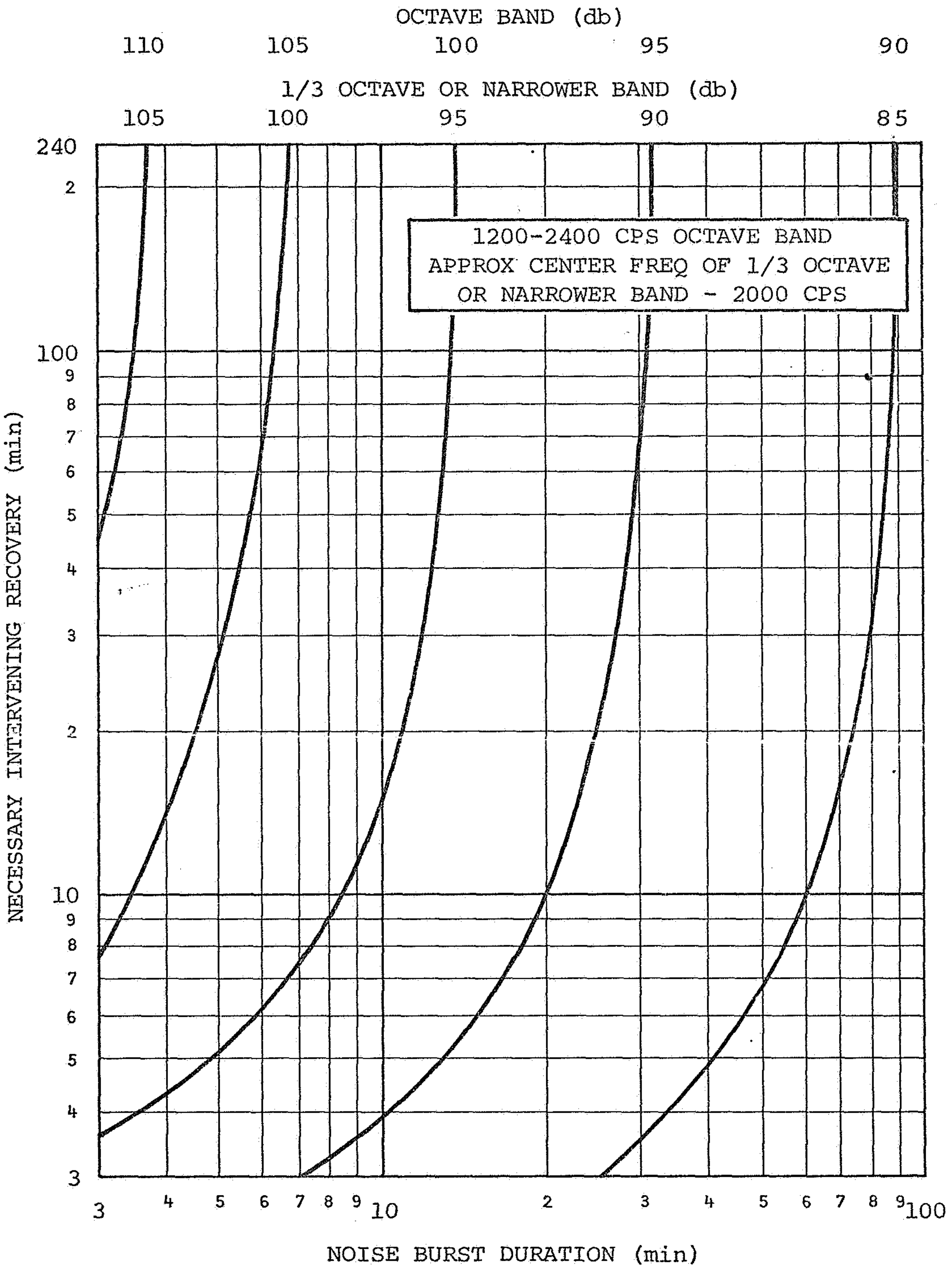


FIGURE 14 DAMAGE RISK CONTOURS FOR LONG-BURST-DURATION INTERRUPTED NOISE PARAMETER: BAND SPL.

4.2.2 Effects on Pilot Performance

Direct Performance Effects

Under certain conditions high intensity noise (90-100 db) adversely affects human performance. Extensive research, particularly that done in the 1950s by such well known experimenters as Broadbent and Jerison makes this quite clear. Even so, accurate predictions of noise degradation effects for a given individual on a given day are difficult to make. Some important complicating factors are:

- the nature and difficulty of the performance task;
- the frequency, intensity, bandwidth, and duration of offending noise;
- the intermittency, modulation, or abruptness (startle effects) characterizing the noise;
- susceptibility of the subject;
- inappropriateness of noise for the task in hand; and,
- adaptability of the subject and his compensatory response.

Studies of noise effects on performance exemplify both supporting and disclaiming evidence concerning the performance degradation effects of noise. Those averring degraded performance are marked by variables which are more analagous to the helicopter pilots' experience. They are based on complex tasks, long duration exposure, and high intensity broad band noise. Conversely, these studies reporting either no degradation or improved performance often exhibit simplistic tasks and short exposure durations. Among the reasons given for improved performance are the stimulating and arousal effects of noise, the masking of other auditory distractions, and increased subject motivation.

In Miller's (1957) study, the question asked was essentially this - Does a 111 db noise intensity level interfere with the recall of simple learned items? It is not too surprising that Miller found no interference, even though longer exposure and a more difficult recall task might have reversed the finding. His subjects were exposed to noise only while they recited or wrote short word lists. It is quite possible that compensation processes were at work for them, such as those found by Morgan (1907). Indeed, Miller's subjects did complain of mild irritation, distraction, and general disturbance. They were affected by the noise, therefore, but not enough to manifest performance degradation.

The general literature on noise is admittedly much more extensive than our few examples suggest. Since there are a number of excellent summaries available (e.g., Roth and Chambers, 1968; Guignard, 1965; Bell, 1966; and von Gierke, 1965), there is no need to attempt to duplicate them. Table 19 lists some of the effects of noise on nonauditory performance which are indicated in the literature. These effects are isolated for the 14 perceptual-motor factors which are associated with commercial helicopter accidents. Of the 14 abilities, data were available on 7 and all results indicated degredation in performance.

TABLE 19

REPORTED EFFECTS OF NOISE

Perceptual-motor Ability	Effect	Investigator
Visual Acuity	Degraded	Broadbent DE 1953
Perception of Depth	No Evidence	
Perception of Motion	No Evidence	
Movement Analysis	Degraded	Jerison and Wing 1957
Movement Prediction-Tracking	Degraded	
Finger Wrist Speed	No Evidence	
Manual Dexterity	Degraded	Laird 1933
Speed of Arm Movement	No Evidence	
Response Orientation	No Evidence	
Multi limb Coordination	No Evidence	
Reaction Time	Degraded	Broadbent 1957
Body Orientation	No Evidence	
Vigilance	Degraded	Broadbent 1953 Jerison 1954
Decision Making	Degraded	Jerison 1954

Temporary threshold shift (TTS)

The International Organization for Standardization defines TTS as "an evaluation of the hearing threshold level following exposure to noise which shows a progressive return toward the pre-exposure threshold level and ultimate recovery in less than 10 days". Bell (1966) advises that most recovery occurs within an hour or two of the end of exposure; and, therefore, audiograms made on an exposed person are likely to vary as a function of elapsed time.

The extent of TTS depends, of course, on the composition and intensity of noise responsible, and individual susceptibility. For any person, the phenomenon is reliable. Significant shifts do not generally occur, however, unless a continuous steady noise greater than 78 db is experienced (Glorig, Ward, and Nixon, 1961). Others have shown that pre-exposure to 15 minutes of broadband noise at 78 db can modify TTS reaction to more intense levels (Trittipoe, 1959). Within limits, the amount of shift produced by noise at a constant intensity is greater in the high frequencies.

Recovery from TTS does not separate cleanly from permanent hearing loss caused by long term noise exposure, or from that caused by normal presbycousis (aging). Ward (1957) advises that the time required for recovery from TTS is generally related to the length of noise exposure that induced it. Some studies suggest that with increasing duration of exposure, there is less and less recovery from TTS and increasing permanent loss. Ward indicates further that the extent of TTS, following a day's exposure to continuous noise, is surprisingly close to the magnitude of permanent hearing loss, following 10 years of exposure to similar noise.

A complicating factor, however, both in recovery from TTS and in projecting permanent hearing loss, is normal presbycousis. Bell (1966), for example, recognizes the difficulty in separating the effects of aging from occupational noise exposure. He states that the major break in audibility curves for men occurs around age 32, after which normal hearing loss advances in discrete steps of approximately 15 years.

4.2.3 Effects on Pilot Comfort

McCormick (1964) stated that while the effects of noise upon human performance are not yet well established, both research and common everyday experience confirm the fact that noise can be subjectively annoying to people. While the specific characteristics that cause noise to be considered as annoying are not yet adequately known, in general terms it is fairly well established that annoyance is associated more with high frequencies, high intensity, intermittency, and reverberation.

With respect to frequency, it seems that higher frequencies are generally more annoying than middle or lower ranges, whether the sounds in question are pure tones or bands of noise.

When considering intensity independently of frequency, experiments substantially confirm the common belief that loud noises are more bothersome than quiet ones and that intermittent or irregular noises are more annoying than steady noise. Reverberation is also a source of annoyance, the impression being that of a ringing quality to the noises or of the noises being drawn out. The use of acoustic material frequently reduces the amount of reverberation.

Figure 15 depicts subjective judgments of noise levels at specific frequencies. The relationships of these levels to the noise levels recorded in S-58, 107 and Jet Ranger aircraft is presented in Table 20.

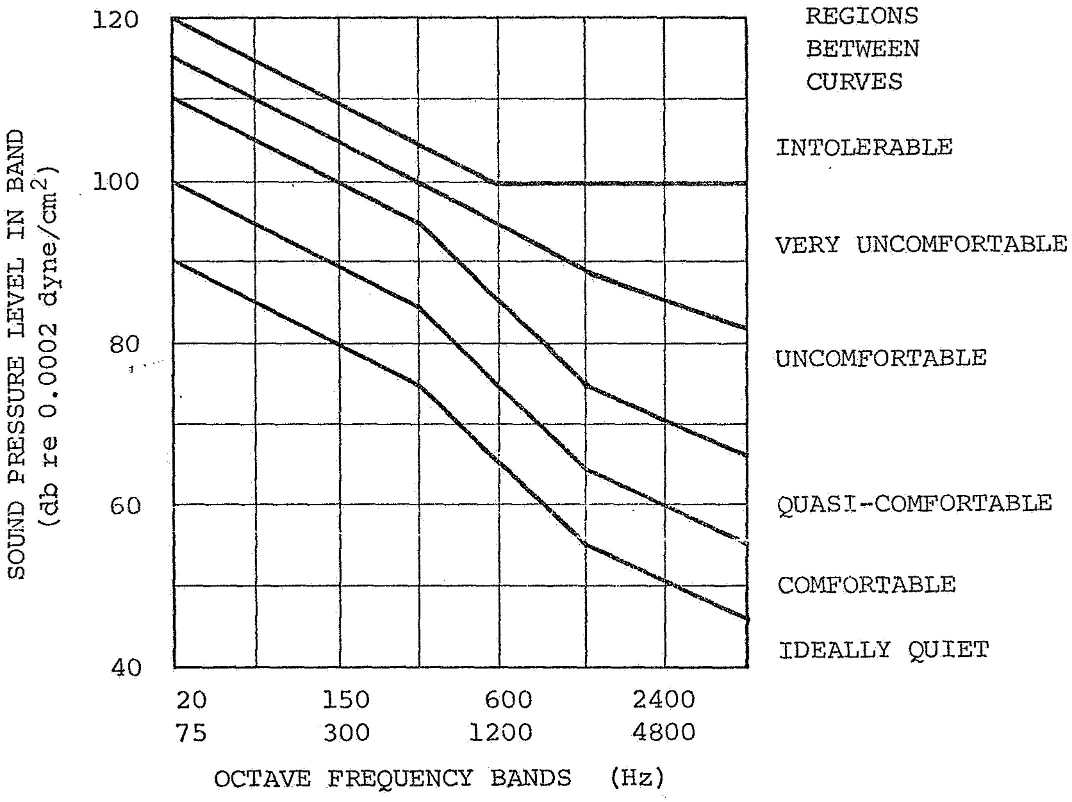


FIGURE 15 GRAPHICAL RELATION BETWEEN JUDGMENT OF COMFORT INSIDE THE CABINS OF COMMERCIAL TRANSPORT AIRCRAFT AND THE OCTAVE-BAND PRESSURE LEVELS
(Lippert and Miller, 1951; after Rosenblith)

TABLE 20

COMFORT ESTIMATES FOR COMMERCIAL HELICOPTERS

Frequency Band	S-58	107	Jet Ranger
20-75	Quasi-Comfortable	Quasi-Comfortable	Quasi-Comfortable
75-150	Uncomfortable	Quasi-Comfortable	Very Uncomfortable
150-300	Uncomfortable	Quasi-Comfortable	Intolerable
300-600	Very Uncomfortable	Uncomfortable	Uncomfortable
600-1200	Very Uncomfortable	Uncomfortable	Uncomfortable
1200-2400	Very Uncomfortable	Uncomfortable	Very Uncomfortable
2400-4800	Very Uncomfortable	Uncomfortable	Very Uncomfortable
4800-10,000	Very Uncomfortable	Quasi-Comfortable	Very Uncomfortable

4.3 Effects of Vibration on Helicopter Pilots

As recently as January 1969, a report published by the Life Sciences Research Office of the Federation of American Societies for Experimental Biology asserted that further study is urgently needed on the effects of vibration on helicopter pilots. Specific areas needing additional research include the effects of vibration frequency, comparative analysis of sinusoidal vs random vibration, and effects of duration of exposure. Phillips, (1963) in describing helicopter vibrations stated that there is ample evidence that these vibrations are not random and are far from sinusoidal. Actually the helicopter vibrations are a composite of many frequencies with the amplitude varying as an inverse function of frequency. In the fact of this assertion, 15 of 16 studies surveyed, which were concerned with vibration effects on pilots of helicopters or fixed wing aircraft, used sinusoidal vibration (Weisy et al. 1965, Parks and Snyder 1961, Mozell and White 1958, Shoenberger 1967, Fraser et al. 1961, Dennis 1960, Garrill and Snyder 1957, Hornick 1961, Magid and Coermann 1960, Rubenstein 1968, Lyton 1962, Cattermann et al. 1962, Lange and Coermann 1962, Chaney and Parks 1964 and Buckout 1964.) As demonstrated by the study conducted by Weisy et al. (1965), the effects of vibration on human performance vary over a wide range with sinusoidal vibration as compared with random vibration.

In determining the helicopter vibration frequency Phillips (1963) has stated that the dominant frequency is governed by the number of blades of the rotor. The range is normally 3 to 20 Hz which is particularly deleterious since it encompasses the resonant frequencies of the body and parts of the body.

The body resonances within this range include:

Axial Compression of the Spine	11-14 Hz	(Guignard & Irving 1960)
Hand	17-25 Hz	(Dieckmann 1957 Latham 1957)
Eyeball	10-70 Hz	(Borschchevsky et al. 1958)
Muscles of the Face	10-30 Hz	(Guignard 1965)
Whole Body	5 Hz	

The effect of vibration with respect to body resonance is that the induced motion of the resonating organs may cause physical damage due to unnatural displacement of body parts relative to one another. The induced motion, particularly of the hand and eye could conceivably degrade visual performace of the pilot.

4.3.1 Effects of Helicopter Vibration on Pilot Safety

As stated by von Gierke (1965) there is no generally accepted criteria for minimum vibration in use in this country. Standardization efforts are still in beginning stages. What is most clear is the total absence of any clearly demonstrated vibration induced permanent symptoms. Also, the effects of exposure time and of repeated exposures to vibrations is completely unknown (von Gierke 1965).

A review of vibration literature resulted in only one investigation which reported chronic problems associated with exposure to the helicopter vibration environment (Seris and Auffret 1965). In this study, back problems were reported in 87.5 percent of the cases after one or two years exposure. The general tone of the comments elicited from commercial helicopter pilots surveyed in the present study appears to be one of annoyance with helicopter vibration rather than a consensus of service disability. In the Seris and Auffret study, pain beginning with the 300th hour of flying time appears to be severe, according to subjective comments. No such reports were evident from the survey taken in this study which included pilots with an average helicopter exposure of approximately 4,500 hours.

In brief, it can be stated that the present study has failed to identify any reliable evidence for long term or chronic adverse effects of helicopter vibration on pilots.

4.3.2 Effects of Helicopter Vibration on Pilot Performance

As indicated above, the vast majority of research reports on the effects of vibration on helicopter pilot performance have utilized sinusoidal vibration which is not typical of the forces encountered in actual flight. Individual findings for such performance facts as tracking, visual acuity, orientation, speech intelligibility, and reaction time, are presented below.

Tracking

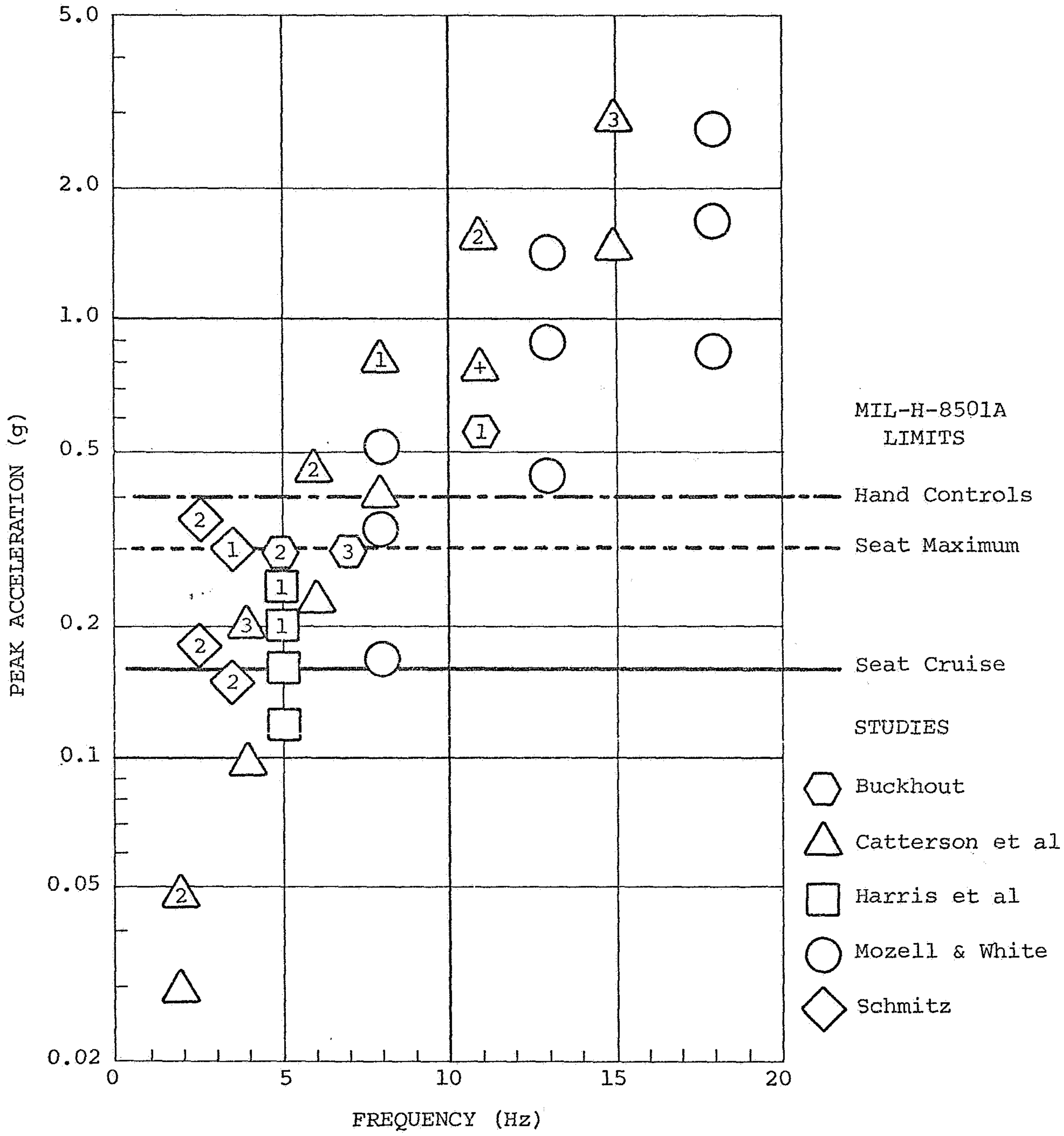
The results of several studies which lie within the general area of helicopter activity are shown in Figure 16. On the effects of vibration within the range of frequencies (10-30Hz) and accelerations (0.05 - 0.3 g) of greatest concern in this report, there is, unfortunately, a divergence of opinion. Roth and Chambers (1968) cite a number of reports which indicate significant error score increases for accelerations of 0.1 g in the frequency range 1 to 30 Hz. Others, (Dean et al., 1964) have found improvement on a tracking task under moderate vibration. Still others report varied findings (e.g., Mozell and White, 1958; Hornick and Lefritz, 1966).

Commenting on the diversity of findings, Roth and Chambers (1968) attribute some of the conflict to differences in method. There has been little or no standardization of important independent variables in the many experiments. In some studies both man and display are vibrated, but not in others. Amplitudes are not always held constant for a given frequency band. The nature of the display, and hence the tracking task, differs across experiments. Given these conditions it is not surprising that results do not agree. Nevertheless, a few tentative conclusions can be drawn from the Roth and Chambers review.

- Transverse vibration degrades tracking performance more than vertical vibration.

- Steady-state vibration over comparatively long periods degrades tracking performance.

- Immediate post-vibration tracking ability has been found to be worse than performance on preliminary tests.



Empty symbols indicate no effect
Low numbers indicate greatest decrement for each study
High numbers indicate least decrement for each study

These data suggest that some performance decrements will occur within the specified limits.

FIGURE 16 TRACKING TASKS: MIL-H-8501A VIBRATION LIMITS MATCHED TO THE DECREMENTAL EFFECTS OF VIBRATION ON TRACKING TASKS FOUND IN FIVE INDEPENDENT STUDIES.

(Adapted from Harris and Shoenberger, 1965.)

- Other factors, such as stress, motivation, and fatigue are believed to operate, but have not yet been reliably measured.

- On simple motor tasks, those which require the maintenance of intensity, e.g., the strength of grip or speed of tapping, are not generally affected by vibrations. Precision of muscular coordination, on the other hand, is degrading.

Visual acuity

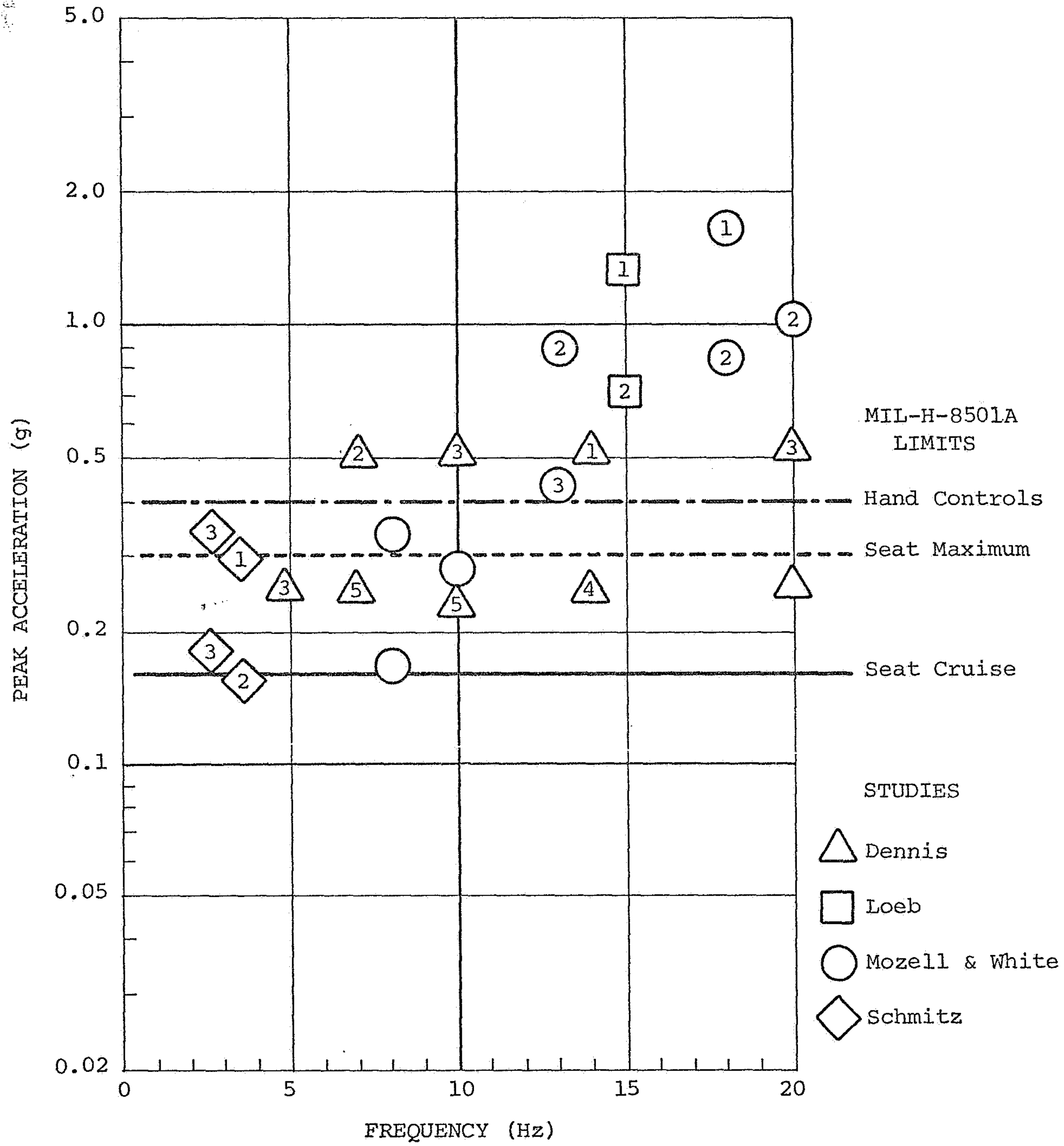
Visual acuity is degraded during vertical sinusoidal vibration at frequencies above 15 Hz, particularly in the frequency bands of 25 to 40 Hz and 60 to 90 Hz (Coermann, 1940). Within a limited range, the decrement in acuity increases as amplitude increases in vibration reaching the head. This is the result of mechanical body resonances. Reduction in acuity in the range of 20 to 40 Hz is attributed to passive movement of the eyes produced by resonance of the soft tissues of the face and scalp (Dennis, 1965); 60 to 90 Hz is in the eyeball resonance zone. Though there is ample evidence showing that visual decrement does occur, variability across subjects is sometimes pronounced.

A recent review of visual performance under vibration by Harris and Schoenberger (1965), indicates that some performance decrements start to occur at 10 Hz and above in the region below 0.3 g (See Figure 17). It is interesting, and can be seen in the figure, that Dennis (1960) found some reduction in performance at 10 Hz with an amplitude of approximately 0.25 g, although Mozell and White (1958) did not.

Roth and Chambers (1968) discuss a variety of reports which show that visual acuity is degraded by vertical, wholebody vibration in the range 0.1 to 0.75 g at frequencies used, 8 to 50 Hz, and the double amplitudes, 0.05, 0.1, and 0.16 inches, are within the range of helicopter experience, the results must be used with caution.

Orientation and Vertigo

Eastwood and Berry (1960) found that vibration can produce decrements in both vision and balance, which may result in the complete disorientation of helicopter pilots.



Empty symbol indicates no effect
Low number indicates greatest decrement for each study
High number indicates least decrement for each study

These data suggest that some visual performance decrements will occur within the specified limits.

FIGURE 17 VISUAL ACUITY TASKS: MIL-H-8501A VIBRATION LIMITS MATCHED TO THE DECREMENTAL EFFECTS OF VIBRATION ON VISUAL ACUITY TASKS.

(Adapted from Harris and Shoenberger, 1965.)

This condition was described following interviews with 17 pilots who reported disorientation experiences in H-5, H-13, H-19, H-21, and H-34 aircraft. The authors are among the few who have noted the dependence of a helicopter pilot on the readibility of his flight instruments. Others more often mention the complexity of motor coordination tasks or the importance of external visibility for helicopter landings.

In addition to the above report, a number of personal communications indicate that rotor shadow flicker effects, reflected light from rotors, the passage of white clouds, and other vision considerations cause chronic problems. Epileptic seizures are a danger for some unsuspecting pilots. Because disorientation may be a major contributor to helicopter accidents, we recommend that it be thoroughly investigated along with other visual problems.

Speech

It has been demonstrated by some investigators that speech is degraded by vibration. Teare (1963) reports that speech disturbance is worst at forcing frequencies between 3 and 15 Hz. Within this band, intelligibile speech is said to become very difficult at acceleration amplitudes exceeding 0.5 g. Teare's findings are supported by Nixon (1962) who found that listeners rated vibrated talkers as being of poorer quality than non-vibrated counterparts. von Gierke (1965) however reported that speech intelligibility is little effected by vibration.

Reaction Time

Reaction time does not appear to be seriously affected by moderate vibration. In a study of speed and accuracy of reading digits, Dennis (1960) found a nonsignificant increase in reaction time at a low level of vibration (0.25 g at 5-27 Hz). Dean et al.,(1964) found a nonsignificant improvement in reaction time in an investigation which used simulated helicopter noise and vibration levels.

Summary

The effects of helicopter vibration on the 14 perceptual motor abilities associated with accident causal factors are indicated in Table 21. Of the 14 abilities, results were obtained on 5, and of these, 2 demonstrate no effect, while 3 have contradictory evidence - degradations and no effect.

TABLE 21

EFFECTS OF VIBRATION ON PRECEPTUAL-MOTOR ABILITIES

Perceptual - Motor Ability	Effect	Investigator
Visual Acuity	Degraded	Rubenstein & Taub 1967 Dennis 1960 Garrill & Snyder 1957 Rubenstein 1968 Hornick & Lebritz 1961 Lange & Coermann 1962
	No Effect	Dean et al. 1964 Hornick 1961
Perception of Depth	No Evidence	
Perception of Motion	No Evidence	
Movement Analysis	No Effect	Dean et al. 1964
Movement Prediction -Tracking	No Effect	Dean et al. 1964 Holland 1967
	Degraded	Buckout 1964 Weisz et al. 1965 Hornick and Lebritz 1966
Finger Wrist Speed	No Evidence	
Manual Dexterity	No Evidence	
Speed of Arm Movement	No Evidence	
Response Orientation	No Effect	Schoenberger 1967
Multi Limb Coordination	No Evidence	
Reaction Time	No Effect	Hornick and Lebritz 1966 Mozell and White 1958
	Degraded	Hornick 1961
Body Orientation	No Evidence	
Vigilance	No Evidence	
Decision Making	No Evidence	

4.3.3 Vibration Effects on Comfort

The variability of subjective opinions of vibration tolerability and acceptability is demonstrated in Table 22 where vibration amplitudes are cited which have been related to comfort levels in different studies.

TABLE 22

VIBRATION AMPLITUDES (IN G RMS) FOR COMFORT
LEVELS CITED BY THREE INVESTIGATORS (A, B, AND C)

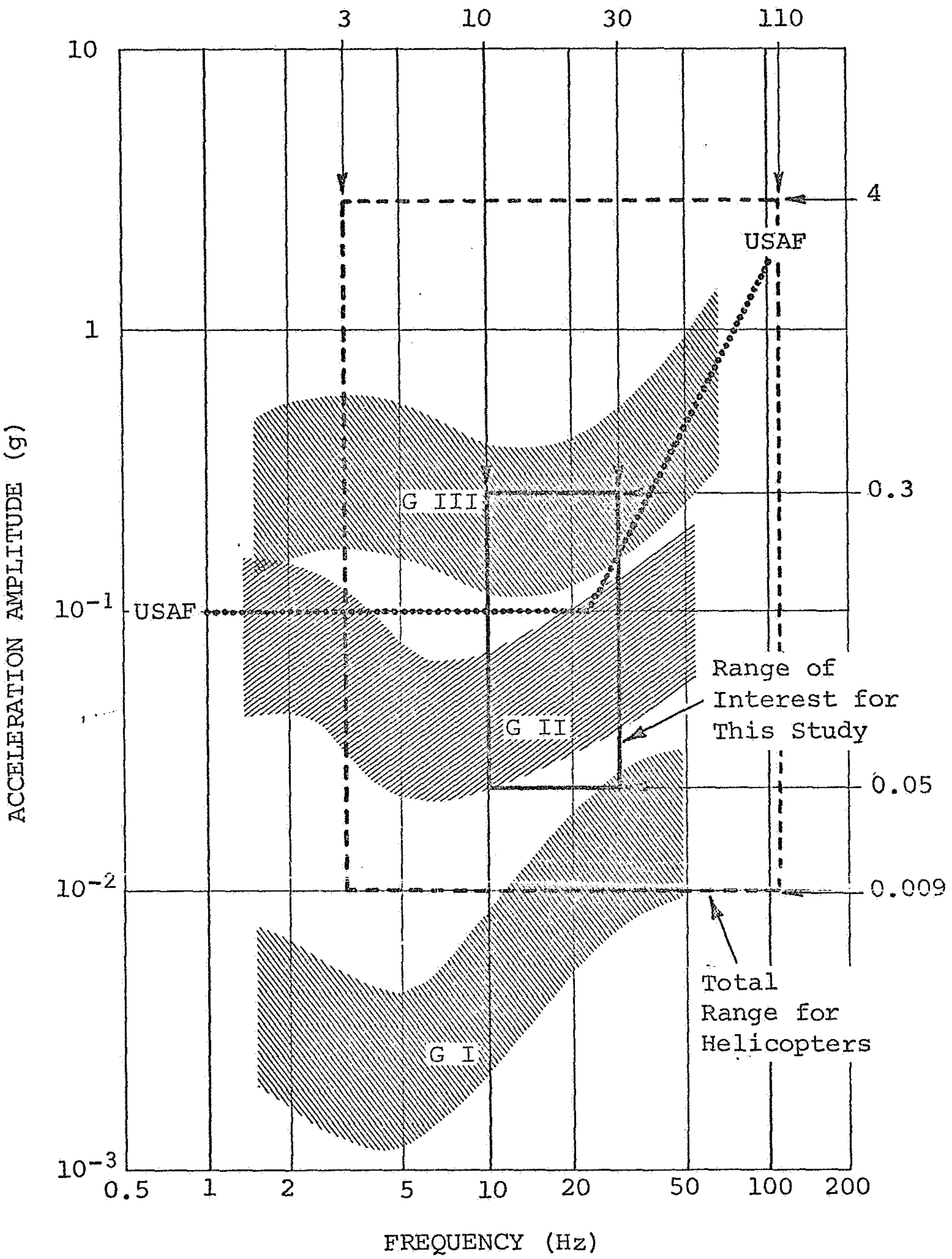
		10Hz			15Hz			20Hz	
	A	B	C	A	B	C	A	B	C
Levels		Studies			Studies			Studies	
Perceptible	.003	.01	-	.005	.01	-	.009	.01	-
Definitely Perceptible	-	.04	.15	-	.03	.3	-	.03	.2
Annoying	.04	.1	.3	.06	.09	.5	.05	.1	.5
Extremely Annoying	-	.4	.4	-	.3	.6	-	.3	.7
Intolerable	.2	.8	.6	.2	.9	.9	.2	1.0	.9

A - Goldman 1957

B - Garrill and Snyder 1957

C - Parks 1961

The relationship of Goldman's (1957) levels of tolerability with helicopter levels is presented in Figure 18.



G I - Goldman (1957): Threshold of perception*
G II - Goldman (1957): Threshold of unpleasantness
G III - Goldman (1957): Threshold of intolerability
USAF - United States Air Force (WADC): Long-term tolerance limit for military aircraft

* The breadth of Goldman's curves represents ± one standard deviation from the mean

This figure indicates that helicopter vibrations often fall within the zones of unpleasantness and even intolerability.

FIGURE 18 DOMINANT AND GENERAL RANGE OF HELICOPTER VIBRATIONS RELATED TO GOLDMAN'S DATA ON SUBJECTIVE ESTIMATES OF TOLERABILITY.

5.0 PROBLEM AREAS AND RECOMMENDATIONS

In this section recommended solutions to problems concerning the effects of noise and vibrations on commercial helicopter pilots will be formulated. The problems are of two general types - problems associated with pilot safety, performance, and comfort and research problems. The first class of problems comprise those areas where commercial helicopter noise and vibration levels affect pilot safety, performance, and comfort to a degree that modifications are required. Modifications include changes in equipment design, procedures, monitoring policies and practices, and training. Research problems include areas where relevant evidence is unavailable, unreliable, inconclusive or invalid.

5.1 Problems and Recommendations Associated With Effects of Noise and Vibration

Safety Problems

Problem 1

While the findings of this study failed to demonstrate any evidence for long term or chronic adverse effects of vibration alone and of noise and vibration combined on the physiological status of helicopter pilots, such evidence is more available for effects of noise. It can be assumed that standard curves depicting damage risk levels indicate the sound pressure levels for frequency bands over time which are considered maximum. A noise source which exceeds these limits will potentially cause ear damage. For the time period selected as representative of pilot daily exposure to the noise environment (200 minutes) it was demonstrated that noise levels in military counterparts of commercial helicopters exceed the damage risk levels at many of the recorded frequency bands (Table 18). The degree to which the damage risk levels are exceeded by noise levels of specific helicopter samples is depicted in Table 23.

TABLE 23

AMOUNT IN db BY WHICH HELICOPTER NOISE LEVELS EXCEED DAMAGE RISK LEVELS (FROM TABLE 18)

		Helicopter	
Frequency (Hz)	S-58	107	Jet Ranger
20-75	-	-	-
75-150	5	-	9
150-300	5	-	14
300-600	8	1	4
600-1200	6	1	4
1200-2400	9	-	7
2400-4800	7	-	7
4800-10,000	-	-	5

In an attempt to reduce the noise environment in the Vertol-44 Miller et al. (1959) reported that the effect of such design modifications as applying skin damping tape to fuselage, adding acoustical blankets, double windows and bulkheads, enclosing the drive shaft and ventilation ducts, and adding floor carpeting and foam padding, resulted in a 5 db reduction of low frequency noise and a 22 to 26 db reduction at higher frequencies.

As stated by Berry and Eastwood (1960), standard headset earphone covers attenuate ambient noise as follows:

Frequency Band (Hz)	Attenuation of Noise Level (db)
300 - 600	7
700 - 1200	13
1200 - 2400	20
2400 - 4300	30

Therefore, use of the earphones should reduce the noise problem significantly in the 300 to 4300 Hz range. Below 300 Hz the 5 db reduction accomplished through design changes reported by Miller et al. eliminates the disparity between recorded noise levels and damage risk limits for the S-58 helicopter sampled, but not for the Jet Ranger. For the latter aircraft, the noise level will continue to exceed the damage risk level at frequencies between 75 and 300 Hz even after a 5 db reduction. Special noise reduction procedures should be developed specifically for the Jet Ranger and specifically at frequencies between 75 and 300 Hz.

Recommendation 1

Implement steps to reduce the noise levels in all commercial helicopters such that levels measured at the pilots ear are less than appropriate damage risk limits. Reduction should involve mandatory use of earphones and design modifications as reported by Miller at al. (1959).

Problem 2

Commercial helicopter companies have no noise and vibration standards of their own and usually rely on military specifications for guidelines concerning levels of noise and vibration. However, the military specifications were developed for noise and vibration individually (they present limits for noise without accounting for combined or additional effects of vibration, etc.) and were designed for missions different from the commercial helicopter situation.

The degree to which helicopters meet even the military specifications is doubtful. The military counterpart of the S-58 produces noise levels which exceed the appropriate specifications (MIL-A-8806A) levels at 7 of 8 frequency bands tested. The number of bands where this is true for the 107 and Jet Ranger is 3 and 8 respectively. The degree to which MIL-A-8806A limits are exceeded is presented in Table 24.

TABLE 24

AMOUNT IN db BY WHICH HELICOPTER NOISE LEVELS EXCEED LIMITS IMPOSED BY MIL-A-8806A FOR CRUISE CONDITIONS

Frequency Hz	S-58	107	Jet Ranger
20-75	4	2	5
75-150	2		6
150-300			7
300-600	5		1
600-1200	5		3
1200-2400	10	18	8
2400-4800	17	37	17
4800-10,000	7		18

As indicated by this table noise levels recorded in sample helicopters exceeded appropriate MIL-A-8806A levels in 18 of 24 cases with the degree of difference increasing as a direct function of frequency (at higher frequencies). The greatest disparity is evident in the 2400 to 4800 Hz range.

Since such a disparity could be attributed to excessive noise levels, to an inadequate or unrealistic standard, or to both causes, the adequacy of MIL-A-8806A was determined by comparing its recommended levels with damage risk limits. The results of this comparison, presented in Table 25, indicate that at four frequencies the standard exceeds limits for damage risk with the greatest disparity occurring at the 150-300 Hz band. At higher frequencies the standard was assumed adequate since it did not exceed damage risk levels.

TABLE 25

AMOUNT BY WHICH MIL-A-8806A EXCEEDS DAMAGE RISK LEVELS (in db)

Frequency (Hz)	MIL-A-8806A Excess Over Damage Risk Levels (db)
20 - 75	-
75 - 150	3
150 - 300	7
300 - 600	3
600 - 1200	1
1200 - 2400	-
2400 - 4800	-

It can, therefore, be assumed that the standard is inadequate at lower frequencies and that helicopter noise levels are excessive at higher frequencies.

Recommendation 2

Develop a noise and vibration standard specific for commercial helicopter mission and flight durations.

Problem 3

The five minute rest period between commercial helicopter flights is adequate for recovery of threshold shift if the pilot is subjected to relative quiet during the period.

Recommendation 3

Ensure that during the 5 minute rest period on the ground that the noise level at the ear does not exceed 85 db.

Performance Problems

Problem 1

Over the past three years the failure on the part of the pilot to see and avoid has accounted for about 10 percent of all commercial helicopter accidents. While the connection between this failure on the part of the pilot and basic underlying perceptual-motor abilities is inferred rather than demonstrated, it is assumed that see and avoid capability is dependent on such abilities as visual acuity, depth perception, motion perception, analysis, and prediction, and reaction time. The degree to which each ability enters into the see and avoid situation has not been defined.

Given that these perceptual-motor abilities influence the see and avoid function to some unspecified degree, the degree to which the noise and vibration environment encountered in helicopters acts as a contributing factor in helicopter accidents can be inferred by determining effects of the environment on performance of the abilities. Actually this inference can only be approximated in this study due to the lack of applicable research. Based on the present evidence, all that can really be stated is that of the 6 perceptual-motor abilities associated with the see and avoid operation, 5 are known to be or are expected to be adversely affected by the noise and vibration environment of commercial helicopters.

Recommendation 1

Consider requirements for automatic detection capability to alert pilots to impending collision with other aircraft or obstacles.

Problem 2

In 1967 alone 27 percent of all commercial helicopter accidents were attributed to pilot error in maintaining RPM or following flight control procedures. These errors have been associated with five perceptual-motor abilities. Noise and vibration are known to adversely affect two of these abilities: manual dexterity and tracking. The effects of vibration on these abilities is inconclusive in the case of tracking where different investigators report contradictory findings, and is only inferred in the case of manual dexterity. The effect of noise on the abilities is expected to be minimal for manual dexterity and is known to be detrimental for tracking. These findings relate to direct effects of noise and vibration. Perhaps the major effect of these environmental factors is their effect on pilot fatigue which itself has probably a great effect on tracking and manual dexterity.

Recommendation 2

Consider requirements to reduce fatigue and fatigue inducing properties of noise and vibration. Reduce accuracy requirements on control where manual dexterity and tracking are required by increasing display size, modifying stick response characteristic, adding additional detents to controllers such that a stick position can be maintained without constant application, and consider improvements in control/display relationships such as use of quickening and direct feedback.

Comfort Problems

A total of 89 percent of helicopter pilots interviewed at San Francisco/Oakland Airlines reported that noise and/or vibration levels were excessive in their helicopters. Twenty-six percent of these pilots felt that there was a direct relationship between noise and vibration on one hand and fatigue on the other. These data indicate that whether or not there is a real problem in terms of effects of noise and vibration, the vast majority of pilots who are subjected to the environment felt that a problem exists.

As indicated in Table 20, the noise levels associated with the military counterparts of commercial helicopters when compared with comfort levels from the literature were judged to be uncomfortable or very uncomfortable in 17 of 24 cases and were intolerable in one situation (Bell Ranger at 150-300 Hz frequency range). There is good comparison between the frequencies where noise levels are judged uncomfortable and the frequencies where the levels exceed damage risk limits (Table 18). This indicates that the criteria for comfort is related to the criteria for damage risk.

5.2 Research Problems and Recommendations

The primary finding of this study is that the effects on pilots of noise and vibration levels experienced in commercial helicopters cannot be adequately defined without additional research. Areas where additional findings are required include the following:

(1) Noise and vibration levels must be recorded during actual flight in operating commercial helicopters performing representative commercial helicopter missions. The vehicles selected for this investigation should include samples at various stages of maintenance (just returned from maintenance, mid-point time from maintenance, about to go into maintenance) and age.

(2) More research is required on the combined effects of noise and vibration. These studies should use actual levels of noise and vibration recorded in commercial helicopters, flight duration comparable to helicopter missions, and task difficulty levels as close as possible to the helicopter situation.

(3) A better definition of perceptual-motor abilities underlying helicopter operations is required. Additional information is needed to define the abilities which are associated with causal factors for accidents and the degree to which each ability operates as a contributing factor.

(4) A critical need exists for the development of a quantitive measure and predictor of fatigue in helicopter pilots. The relationship between the environment and fatigue must be clearly demonstrated before any meaningful assessment can be made of the requirements to reduce noise and vibration.

(5) The degree to which pilot disorientation operates as a causal factor for commercial helicopter accidents must be established.

(6) The appropriate work/rest cycles which minimize the danger of physical impairment and performance degradations which are associated with accidents must be determined.

(7) Longitudinal studies of helicopter pilots are required where audiograms and medical checkup data are repeated over some long period of continual operation.

(8) Longitudinal studies should also be implemented to assess the adequacy of recommended design or procedural modifications.

(9) The adequacy of noise and vibration attenuation devices must be established in terms of their effectiveness in reducing excessive levels versus their production and implementation costs.

(10) Modifications to controller dynamics and display formats and sizes must be based on requirements for assisting the pilot to perform specific operations in the noise and vibration environment.

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