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PASSENGER NOISE ENVIRONMENTS OF ENCLOSED TRANSPORTATION SYSTEMS

JUNE 1975

U.S. Environmental Protection Agency
Washington, D.C. 20460

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16. ABSTRACT

To determine the extent to which noise environments of enclosed transportation systems are deleterious to passenger health, an analysis was made of both information collected by past transportation studies and of new data collected for this project. The analysis consisted of identifying trends among various transportation modes, noting areas of data deficiency, calculating the effect of noise exposure on health under various assumptions of travel duration and workplace noise exposure levels, and assessing measurement methodologies.

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PASSENGER NOISE ENVIRONMENTS

OF

ENCLOSED TRANSPORTATION SYSTEMS

JUNE 1975

PREPARED BY

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
WASHINGTON, D.C. 29569

This document has been approved for general availability. It does not constitute a standard, specification, or regulation.

FOREWORD

The Noise Control Act of 1972 (PL 92-574) authorizes the Environmental Protection Agency (EPA) "to disseminate to the public information on the effects of noise, acceptable noise levels and techniques for noise measurement and control." This report is based on a literature survey conducted by Informatics Incorporated, Rockville, Md., under contract to EPA and supplemented by data collelction and analysis by EPA personnel. It is directed toward the following:

(1) Protecting the traveller by identifying high noise areas within transportation modes

(2) Determining the health risk of the interior sound levels (measured with reference to levels identified by EPA as necessary to protect health with an adequate margin of safety)

(3) Delineating areas of data deficiency which require further research and

(4) Identifying transportation modes which require development of a standardized measurement methodology.

The project was conducted by the Technical Assistance and Operations Division, Office of Noise Abatement and Control, EPA. The participation in the project by Judy Ruth a Graduate Student Assistant assigned to the Office of Noise Abatement and Control is noteworthy. Ms. Ruth provided direction to the information-services contractor (Appendix A) and performed the analysis contained in the body of the document. This outstanding effort by Ms. Ruth should provide a most useful reference document to the acoustics community.

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for Noise Control Programs
Office of Noise Abatement & Control

ACKNOWLEDGMENTS

The data base for this document was provided (1) through the measurement efforts of EPA personnel in Regional Offices I, II, III and VII and (2) through the literature search performed by Carl Modig of Informatics Incorporated. Their efforts were a great benefit to this document.

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PASSENGER NOISE ENVIRONMENTS OF ENCLOSED TRANSPORTATION SYSTEMS

Americans are extremely mobile and spend a large percentage of time utilizing transportation systems. Owing to the duration and intensity of individual exposure, it is necessary to examine to what extent such noise exposure damages the auditory system. This report addresses this issue.

The report focuses on the nonoccupational aspects of exposure to noise inside enclosed transportation systems. Thus, noise levels in the cab, cockpit, and locomotive of commercial vehicles, as well as those in off-road and recreational vehicles, were excluded from this investigation.

The study comprised three phases. First, a task was initiated to collect and display (in tabular form) published and unpublished literature concerning the interior sound levels of the following enclosed passenger vehicles:

1. Cars,
2. Commuter buses,
3. Intercity buses,
4. Commuter railroad cars,
5. Intercity railroad cars,
6. Fixed wing aircraft,
7. Helicopters, and
8. Hovercraft.

The result of this compilation is contained in Appendix A. A discussion of possible health and welfare effects and the measurement methodologies employed is also included. The reference listing is accompanied by a key indicating the vehicle and information type encompassed by each article.

Second, a measurement project was undertaken simultaneously to (1) complement by updating the data base derived from the literature survey, and (2) to gain insight into measurement methodology issues and problems. Sound levels were measured inside the following passenger vehicles during various phases of operation:

1. Cars,
2. Commuter buses,
3. Trolley cars,
4. Commuter railroad cars,
5. Intercity railroad cars, and
6. Fixed wing aircraft

These measurements were made by headquarters personnel in the EPA Office of Noise Abatement and Control and by personnel of the EPA Regional Offices I, II, III, and VII while enroute to and from business meetings. The data forms employed are contained in Appendix B.

Third, the data collected under the first two phases provided a base for:

1. Calculation of representative mean interior sound levels of public transportation vehicles,
2. Assessment of the health ramifications of exposure to the interior sound levels of enclosed passenger vehicles,
3. Appraisal of measurement methodologies,
4. Locating areas of data deficiency, and
5. Making recommendations with regard to:
    a. health considerations,
    b. areas requiring further research, and
    c. measurement methodologies.

Since all references, with one exception, report level rather than exposure data, the analysis was directed to translating levels into exposures, assuming several scenarios in order to derive the yearly average $L_{eq(24)}$.

MEAN INTERIOR SOUND LEVELS

Figure 1 illustrates the range of A-weighted interior sound levels collected for each vehicle type and their mean A-weighted interior sound level (averaged on any energy basis). Tables 1 through 17 contain the energy mean A-weighted interior sound levels for vehicles under various operating conditions. Since these energy means are calculated from sound levels collected by many different sources under varying methodologies and conditions, the trends evidenced by the tables may sometimes be biased by certain extraneous or uncontrolled variables, (e.g., road surface, meteorological conditions, vehicle speed). Each table is footnoted to indicate some of the more important variables which have or have not been controlled.

Cars

Based upon the 1970 to 1974 data, there has been a general trend for the interiors of cars to become quieter as a function of model year (Table 1). Car interiors are louder when cruising at 97 km/h (60 mph) than at 48 km/h (30 mph) (Table 2). Little differences were observed between gasoline and diesel engined automobiles. The interiors of diesel engine cars are nearly equal to those of gasoline engine cars at 97 km/h (60 mph) (Table 3).

Commuter Buses

In commuter buses, the mean interior sound level is nearly equal in window seats and aisle seats (Table 4). Seat location affects the level of noise exposure regardless of whether a commuter bus is idling or cruising. Rear seats have a greater mean interior sound level than do middle seats, and middle seats have a greater average interior sound level than do front seats (Table 5). City bus interiors are quieter when cruising at 32 km/h (20 mph) than at 48-64 km/h (30-40 mph) (Table 6).

Intercity Buses

Intercity bus interior sound levels are louder in rear seats than in middle seats and louder in middle seats than in front seats (Table 7). Window and aisle seats have nearly the same mean sound levels (Table 8).

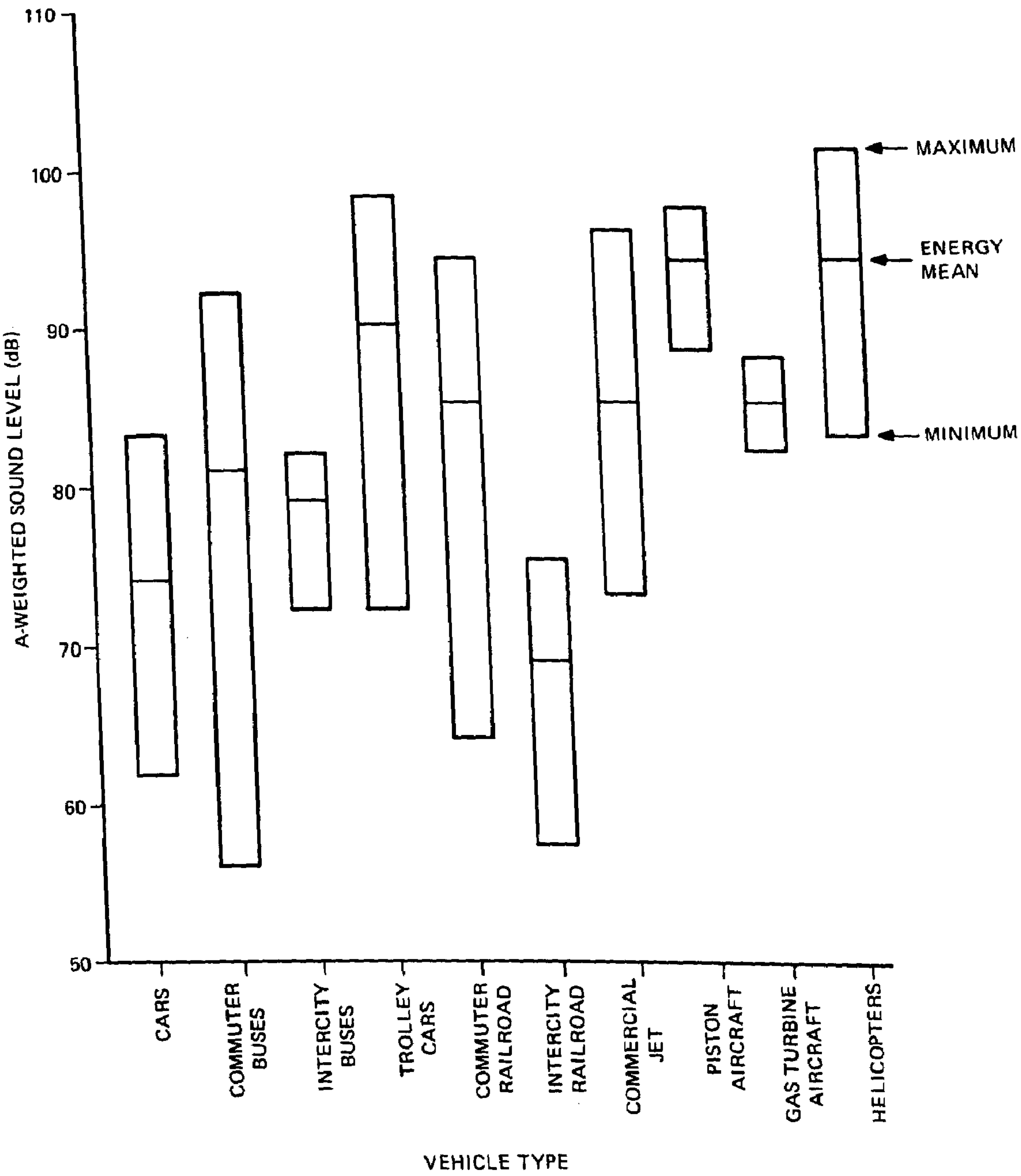

Figure 1. Range of Sound Levels Measured Inside Various Cruising Vehicles

TABLE 1. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CARS CRUISING AT 97 KM/H (60 MPH) BY YEAR OF MAKE AND MEASUREMENT*

	YEAR					ALL YEARS (1970-1974)
	1970	1971	1972	1973	1974	
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	76	76	73	71	72	74
SAMPLE SIZE	38	28	20	41	31	158
RANGE OF SOUND LEVELS	67-80	68-83	67-79	64-78	64-78	64-83

*Road condition is smooth and windows are closed.

TABLE 2. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CARS AS A FUNCTION OF CRUISING SPEED*

	SPEED	
	48 km/h (30 mph)	97 km/h (60 mph)
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	67	77
SAMPLE SIZE	16	24
RANGE OF SOUND LEVELS	61-71	67-83

*Road condition is smooth and windows are closed. The same car models and years of make and measurement are found under both speed conditions.

TABLE 3. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CARS CRUISING AT 97 KM/H (60 MPH) BY ENGINE TYPE*

	ENGINE TYPE	
	DIESEL	GASOLINE
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	74	72
SAMPLE SIZE	12	12
RANGE OF SOUND LEVELS	65-79	64-78

*Road condition is smooth and windows are closed.

TABLE 4. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING COMMUTER BUSES BY LATERAL SEATING LOCATION*

	LATERAL SEATING LOCATION	
	AISLE	WINDOW
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	85	87
SAMPLE SIZE	6	6
RANGE OF SOUND LEVELS	76-90	72-92

*Speed is a controlled variable. All engines are rear mounted diesels and all seats are in the rear.

TABLE 5. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF COMMUTER BUSES AS A FUNCTION OF MODE OF OPERATION AND LONGITUDINAL SEATING LOCATION*

		LONGITUDINAL SEATING LOCATION		
		FRONT	MIDDLE	REAR
MODE OF OPERATION	IDLE	60 dB	64 dB	69 dB
	ACCELERATION	72 dB	76 dB	92 dB
	CRUISE	72 dB	78 dB	86 dB

*All engines are rear mounted diesels.

TABLE 6. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING COMMUTER BUSES AS A FUNCTION OF SPEED*

	SPEED	
	32 km/h (20 mph)	48-64 km/h (30-40 mph)
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	81	89
SAMPLE SIZE	11	5
RANGE OF SOUND LEVELS	68-86	70-92

*All engines are rear mounted diesels.

TABLE 7. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING INTERCITY BUSES BY LONGITUDINAL SEATING LOCATION*

	LONGITUDINAL SEATING LOCATION		
	FRONT	MIDDLE	REAR
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	75	78	83
SAMPLE SIZE	3	3	3
RANGE OF SOUND LEVELS	74-76	77-79	79-84

*All engines are rear mounted diesels. Window seats only.

TABLE 8. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF INTERCITY BUSES BY LATERAL SEATING LOCATION*

	LATERAL SEATING LOCATION	
	AISLE	WINDOW
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	78	77
SAMPLE SIZE	4	6
RANGE OF SOUND LEVELS	74-80	74-79

*Length-wise seating location is a controlled variable.

Commuter Railroad

Commuter railroad cars have a lower average interior sound level above ground than in a subway, regardless of speed or track-bed conditions (Tables 9 and 10). Commuter railroad cars travelling above ground or in a subway have a higher mean interior sound level at speeds of 48-80 km/h (30-50 mph) than at speeds of 80-97 km/h (50-60 mph) (Table 9). Based upon this sample, it is interesting to note, however, regardless of whether commuter railroad cars are travelling above ground or in a subway, their interiors are quieter when the track bed is tie and ballast than when it is concrete (Table 10).

Intercity Railroad

Coach interiors of intercity railroad cars have nearly equal sound levels in the middle and rear seats (Table 11) and higher sound levels in the window seats than in the aisle seats (Table 12).

The interrelationships of interior sound levels, vehicle type and mode of operation are shown in Table 13.

Jet Aircraft

Windows seats of cruising commercial jets have a mean interior sound level which is nearly equal to that of aisle seats, regardless of engine position (Table 14). Average interior sound levels are less in cruising commercial jet aircraft with engines positioned on the wing than in those with engines positioned in the tail, for both aisle and window seats (Table 14). The front and middle seats are quieter than the rear seats, regardless of engine location (Table 15). The effect of the mode of operation on the interior sound levels of commercial jet aircraft is illustrated by Table 16.

The distribution of sound levels measured inside cruising 727 commercial jet aircraft as a function of seating location is illustrated by Figure 2. Multiple linear regression was performed to develop an equation relating the interior A-weighted sound level (L_A) of cruising commercial 727 jet aircraft to their altitude in kilometers (H) and their speed in kilometers per hour (S). The resulting equation is $L_A = 75.07 - 0.76H + 0.01S$. This equation accounts for 76 percent of the variation of the sound levels measured (the correlation coefficient of determination (R^2) is 0.76). Factors affecting the inverse relationship between between interior sound level and altitude are discussed by Bray [1]. He concludes that "changes in the turbulent boundary layer noise in commercial aircraft operating at varying altitudes have been shown to vary according to the density change to the first power."

TABLE 9. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING COMMUTER RAILROAD CARS AS A FUNCTION OF SPEED AND ABOVE-BELOW GROUND POSITION*

	SPEED	
	48-80 km/h (30-50 mph)	80-121 km/h (50-75 mph)
ABOVEGROUND	83 dB	69 dB
SUBWAY (BELOW GROUND)	86 dB	81 dB

*Type of track bed is a controlled variable. Seating location is an uncontrolled variable.

TABLE 10. ENERGY MEAN A-WEIGHTED SOUND LEVEL OF CRUISING COMMUTER RAILROAD CARS AS A FUNCTION OF TRACK BED TYPE AND ABOVE-BELOW GROUND POSITION*

	TYPE OF TRACK BED	
	CONCRETE	TIE AND BALLAST
ABOVEGROUND	82 dB	76 dB
SUBWAY (BELOW GROUND)	86 dB	83 dB

*Speed is a controlled variable. Seating location is an uncontrolled variable.

TABLE 11. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVELS OF CRUISING INTERCITY RAILROAD CARS AS A FUNCTION OF LONGITUDINAL SEATING LOCATION*

	LONGITUDINAL SEATING LOCATION	
	MIDDLE	REAR
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	69	67
SAMPLE SIZE	10	8
RANGE OF SOUND LEVELS	62-75	63-71

*Aisle-window seating location is a controlled variable. Speed is an uncontrolled variable.

TABLE 12. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING INTERCITY RAILROAD CARS AS A FUNCTION OF LATERAL SEATING LOCATION*

	LATERAL SEATING LOCATION	
	AISLE	WINDOW
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	64	70
SAMPLE SIZE	5	13
RANGE OF SOUND LEVELS	62-67	65-75

*Length-wise seating location is a controlled variable. Speed is an uncontrolled variable.

TABLE 13. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL AS A FUNCTION OF TYPE OF LAND VEHICLE AND MODE OF OPERATION

		MODE OF OPERATION			
		IDLE	ACCELERATION	CRUISE	DECELERATION
TYPE OF LAND VEHICLE	CARS	57 dB	72 dB	73 dB	67 dB
	COMMUTER BUSES	67 dB	86 dB	81 dB	72 dB
	TROLLEY CARS	67 dB	79 dB	90 dB	69 dB
	COMMUTER RAILROAD CARS	70 dB	79 dB	86 dB	83 dB
	INTERCITY RAILROAD CARS	66 dB	72 dB	68 dB	60 dB

TABLE 14. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING COMMERCIAL JET AIRCRAFT AS A FUNCTION OF LATERAL SEATING LOCATION AND ENGINE LOCATION*

ENGINE LOCATION	LATERAL SEATING LOCATION	
	AISLE	WINDOW
WINGS	81 dB	82 dB
TAIL	84 dB	86 dB

*Length-wise seating location is a controlled variable.

TABLE 15. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING COMMERCIAL JET AIRCRAFT AS A FUNCTION OF LONGITUDINAL SEATING LOCATION AND ENGINE LOCATION*

ENGINE LOCATION	LONGITUDINAL SEATING LOCATION		
	FRONT	MIDDLE	REAR
WINGS	80 dB	81 dB	83 dB
TAIL	82 dB	81 dB	88 dB

*Aisle-window seating location is controlled for altitude and speed are uncontrolled variables.

TABLE 16. MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING COMMERCIAL JET AIRCRAFT AS A FUNCTION OF MODE OF OPERATION*

	MODE OF OPERATION					
	TAXI	TAKE OFF	CLIMB	CRUISE	LANDING	REVERSE THRUSTER APPLICATION
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	75	82	80	85	77	94
SAMPLE SIZE	28	28	28	105	27	21
RANGE OF SOUND LEVELS	63-84	72-92	69-88	73-96	65-83	80-103

*Altitude and speed are uncontrolled variables.

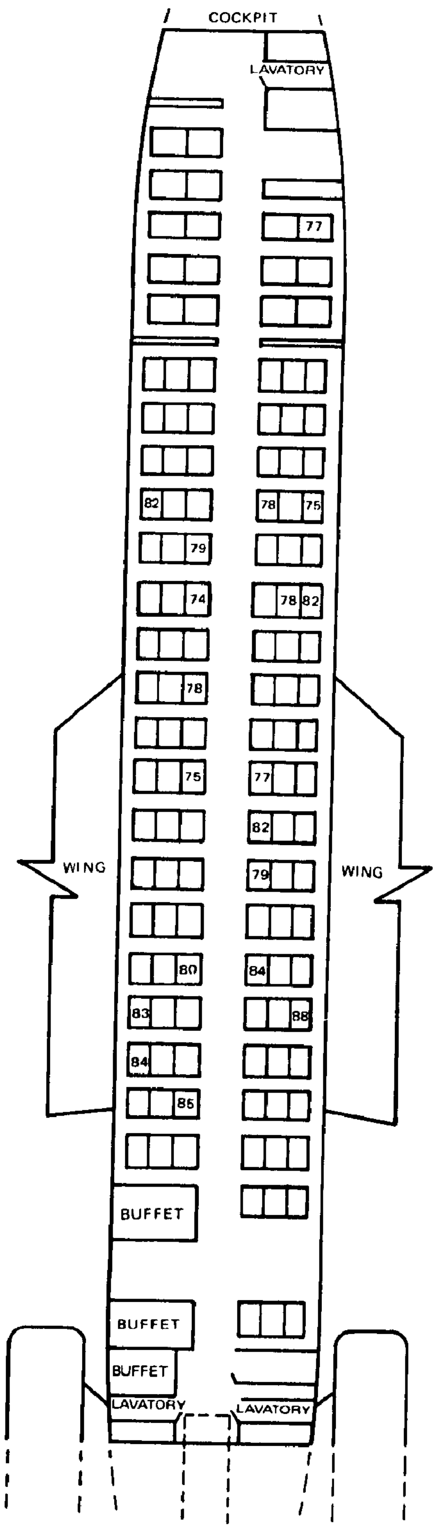

Figure 2. Distribution of A-weighted Sound Levels Measured Inside Cruising 727 Commercial Jet Aircraft as a Function of Seating Location

Other Aircraft

Helicopter and piston engine propeller aircraft have higher mean interior sound levels than gas turbine propeller and commercial jet aircraft (Table 17).

TABLE 17. ENERGY MEAN A-WEIGHTED INTERIOR SOUND LEVEL OF CRUISING AIRCRAFT AS A FUNCTION OF TYPE*

	TYPE OF AIRCRAFT			
	COMMERCIAL JET	GAS TURBINE	PISTON	HELICOPTER
ENERGY MEAN A-WEIGHTED SOUND LEVEL (dB)	85	85	94	94
SAMPLE SIZE	105	13	18	10
RANGE OF SOUND LEVEL	73-96	79-88	88-97	83-101

*Speed and altitude are uncontrolled variables.

HEALTH IMPLICATIONS

Introduction

A maximum yearly average $L_{eq(24)}$* of 70 dB has been identified by EPA as requisite to protect against hearing loss with an adequate margin of safety (2). To determine the extent to which interior transportation noise exposures conform to this identified level, the yearly average $L_{eq(24)}$ is calculated for hypothetical cases which are made to vary by (1) vehicle types, (2) number of hours of exposure to vehicle interiors per year or per workday, and (3) the yearly average workday $L_{eq(8)}$** (Tables 18, 19 and 20).

In formulating these tables, it was necessary to make a number of assumptions. Tables 18 through 21 assume that all the remaining hours of the year have an exposure level low enough to result in a negligible contribution to the yearly average $L_{eq(24)}$, i.e., no greater than an $L_{eq(1)}$ of 60. In Tables 19, 20 and 21, 1 or 2 hours of exposure per workday (5 days per week), is chosen as representative of typical round trip travel time to-and-from work. A wide range of hours of exposure per year (1 to 300 hours per year) to the interiors of aircraft were considered in Table 18, recognizing the wide variance in aircraft travel time incurred by the American public.

Discussion

The maximum permissible number of hours of exposure to commercial jet aircraft, gas turbine aircraft, piston engine aircraft, and helicopters is 252, 216, 36, and 36, respectively, if a maximum yearly average $L_{eq(24)}$ of 70 dB is to be maintained (Table 18).

Table 19 displays the maximum yearly average work $L_{eq(8)}$ permissible if a maximum yearly average $L_{eq(24)}$ of 70 dB is to be maintained, as a function of vehicle type and the number of hours of exposure per workday.

*The yearly average $L_{eq(24)}$ is the yearly energy average A-weighted sound level in decibels relative to 20 micropascals computed over a continuous 24-hour period.

**The yearly average workday $L_{eq(8)}$ is the yearly energy average A-weighted sound level in decibels relative to 20 micropascals computed over a continuous 8-hour period identified with typical occupational exposure.

TABLE 18. YEARLY AVERAGE $L_{eq(24)}$ FOR PEOPLE EXPOSED TO THE INTERIORS OF CRUSING AIRCRAFT AS A FUNCTION OF TWO FACTORS: THE NUMBER OF HOURS OF EXPOSURE, AND THE TYPE OF AIRCRAFT*

TYPE OF AIRCRAFT	NUMBERS OF HOURS OF EXPOSURE PER YEAR												
	1	2	6	12	18	36	72	108	144	180	216	252	300
COMMERCIAL JET	60	60	61	62	62	64	66	67	68	69	69	70	71
GAS TURBINE PROPELLER	60	60	61	62	62	64	66	67	68	69	70	70	71
PISTON PROPELLER	61	62	64	66	68	70	73	75	76	77	78	78	79
HELICOPTER	61	62	64	66	68	70	73	75	76	77	78	79	79

*All remaining hours of the year are assumed to have an $L_{eq(1)}$ of 60 dB.

TABLE 19. THE MAXIMUM YEARLY AVERAGE WORKDAY $L_{eq(8)}$ PERMISSIBLE 5 DAYS PER WEEK IF A MAXIMUM YEARLY AVERAGE $L_{eq(24)}$ OF 70 dB IS TO BE MAINTAINED, AS A FUNCTION OF THE TYPE OF VEHICLE TO WHICH PEOPLE ARE EXPOSED FOR 1 HOUR PER DAY, 5 DAYS PER WEEK*

		MAXIMUM $L_{eq(8)}$ PERMISSIBLE
VEHICLE TYPE** TO WHICH PEOPLE ARE EXPOSED, FOR 1 HOUR PER DAY, 5 DAYS PER WEEK	CARS - 97 km/h (60 mph)	76
	CARS - 48 km/h (30 mph)	76
	COMMUTER BUSES	73
	INTERCITY BUSES	75
	TROLLEY CARS	†
	COMMUTER RAILROAD CARS ABOVE GROUND	74
	COMMUTER RAILROAD CARS IN SUBWAYS	†
	INTERCITY RAILROAD CARS	76
	COMMERCIAL JET AIRCRAFT	†
	PISTON AIRCRAFT	†
	GAS TURBINE AIRCRAFT	†
	HELICOPTERS	†

*All remaining hours of the year are assumed to have an $L_{eq(1)}$ of 60 dB.

†Indicates that it would be impossible to achieve a yearly $L_{eq(24)}$ of 70 dB even if there was no noise exposure in the work environment.

**Cruise condition.

TABLE 20. THE MAXIMUM YEARLY AVERAGE WORKDAY $L_{eq(8)}$ PERMISSIBLE 5 DAYS PER WEEK IF A MAXIMUM YEARLY AVERAGE $L_{eq(24)}$ OF 70 dB IS TO BE MAINTAINED, AS A FUNCTION OF THE TYPE OF VEHICLE TO WHICH PEOPLE ARE EXPOSED FOR 2 HOURS PER DAY, 5 DAYS PER WEEK*

		MAXIMUM $L_{eq(8)}$ PERMISSIBLE
VEHICLE TYPE** TO WHICH PEOPLE ARE EXPOSED, FOR 2 HOURS PER DAY, 5 DAYS PER WEEK	CARS – 48 km/h (30 MPH)	75
	CARS – 48 km/h (30 mph)	76
	COMMUTER BUSES	68
	INTERCITY BUSES	73
	TROLLEY CARS	†
	COMMUTER RAILROAD CARS ABOVE GROUND	68
	COMMUTER RAILROAD CARS IN SUBWAYS	†
	INTERCITY RAILROAD CARS	76
	COMMERCIAL JET AIRCRAFT	†
	PISTON AIRCRAFT	†
	GAS TURBINE AIRCRAFT	†
	HELICOPTERS	†

*All remaining hours of the year are assumed to have an $L_{eq(1)}$ of 60 dB.

†Indicates that it would be impossible to achieve a yearly $L_{eq(24)}$ of 70 dB even if there was no noise exposure in the work environment.

**Cruise condition.

TABLE 21. YEARLY AVERAGE $L_{eq(24)}$ AS A FUNCTION OF TWO FACTORS: THE TYPE OF VEHICLE INTERIOR TO WHICH PEOPLE ARE EXPOSED FOR 1 HOUR PER DAY, 5 DAYS PER WEEK, AND THE YEARLY AVERAGE WORKDAY $L_{eq(8)}$, 5 DAYS PER WEEK*

		YEARLY AVERAGE WORKDAY $L_{eq(8)}$ (5 DAYS PER WEEK)					
		60 dB	70 dB	75 dB	80 dB	85 dB	90 dB
VEHICLE TYPE**	NONE ($L_{eq(1)}$ = 60 dB)	60	65	69	74	79	84
	CARS – 48 km/h (30 mph)	60	65	69	74	79	84
	INTERCITY RAILROAD CARS	61	65	69	74	79	84
	CARS – 97 km/h (60 mph)	62	65	70	74	79	84
	INTERCITY BUSES	65	68	70	74	79	84
	COMMUTER RAILROAD CARS ABOVE GROUND	67	68	71	75	79	84
	COMMUTER BUSES	67	69	71	75	79	84
	COMMERCIAL JET AIRCRAFT	70	71	72	75	79	84
	COMMUTER RAILROAD CARS IN SUBWAYS	70	71	73	75	79	84
	GAS TURBINE AIRCRAFT	70	71	73	75	79	84
	TROLLEY CARS	75	75	76	77	80	84
	PISTON AIRCRAFT	79	79	79	80	82	85
	HELICOPTERS	79	79	79	80	82	85

*All remaining hours of the year are assumed to have an $L_{eq(1)}$ of 60 dB.

**Cruise condition

"EPA has identified an $L_{eq(24)}$ level of 70 dB requisite for protection against hearing loss with an adequate margin of safety" (Reference 1).

Exposure to the interiors of trolley cars, commuter railroad cars travelling in subways, commercial jets, piston engine aircraft, gas turbine aircraft, and helicopters for 1 hour per day, 5 days per week, will make it impossible to achieve a yearly average $L_{eq(24)}$ of 70 dB (Table 19). Increasing the 1-hour exposure to vehicle interiors to 2 hours per day for 5 days per week will decrease the maximum yearly workday $L_{eq(8)}$ allowable if a yearly average $L_{eq(24)}$ of 70 dB is to be sustained (Table 20). Given a 2-hour exposure per day, 5 days per week, to buses and commuter railroad cars travelling above ground, the maximum yearly average work day $L_{eq(8)}$ permissible (if a yearly average $L_{eq(24)}$ of 70 dB is to be maintained) is below the level specified by EPA, i.e., 75 dB (Table 20).

Table 21 and Figure 3 illustrate the effect that compounding the yearly average workday $L_{eq(8)}$ with a 1- or 2-hour exposure to vehicle interiors, 5 days per week, can have on the yearly average $L_{eq(24)}$. Exposure to a yearly average workday $L_{eq(8)}$ of 60, 70, or 75 dB combined with a 1-hour exposure to trolley cars, piston aircraft or helicopters will cause the yearly average $L_{eq(24)}$ to exceed 70 dB (Table 21). The yearly average $L_{eq(24)}$ will also exceed 70 dB if a yearly average workday $L_{eq(8)}$ of 70 or 75 dB is combined with exposure to commuter railroad cars (in subways) commercial jet or gas turbine aircraft for 1 hour per day 5 days per week (Table 20). Exposure to city buses or commuter railroad cars (above ground) for 1 hour per day for 5 days per week will result in a yearly average $L_{eq(24)}$ greater than 70 dB if compounded with a yearly average workday $L_{eq(8)}$ of 75 dB (Table 21). Exposure to a yearly average workday $L_{eq(8)}$ of 80 dB or more, will disallow maintenance of a yearly average $L_{eq(24)}$ of 70 dB, even if no vehicles are traveled in and all remaining hours of the year have an exposure level low enough to result in a negligible contribution (i.e., 60 dB) (Table 21). In the case where the yearly average workday $L_{eq(8)}$ is 80 dB, 1-hour exposure to city buses, trolley cars, commuter railroad cars (above or below ground), commercial jet aircraft, piston aircraft, gas turbine aircraft, or helicopters (5 days per week) will cause 70 dB to be exceeded by a greater amount (Table 21). For 11 of the 13 vehicles, the effect of a 1 hour exposure to their interiors on the yearly average $L_{eq(24)}$ is negligible, if the yearly average workday $L_{eq(8)}$ is 85 or 90 dB (Table 21). The effects of 2 hours of vehicle exposure, 5 days per week, on the yearly average $L_{eq(24)}$ are similar to that of a 1 hour exposure, with the qualification that (1) more vehicle types cause the yearly average $L_{eq(24)}$ of 70 dB to be exceeded and (2) the quantity by which 70 dB is exceeded is increased (Figure 3).

Measurement Methodology

No attempt has been made by the studies surveyed to develop standardized measurement methodologies for any vehicles, excepting rapid transit. [The Transportation Systems Center of the Department of Transportation has developed a methodology for use in its rapid transit noise measurement study (refer to Appendix A, reference 81)]. Because of

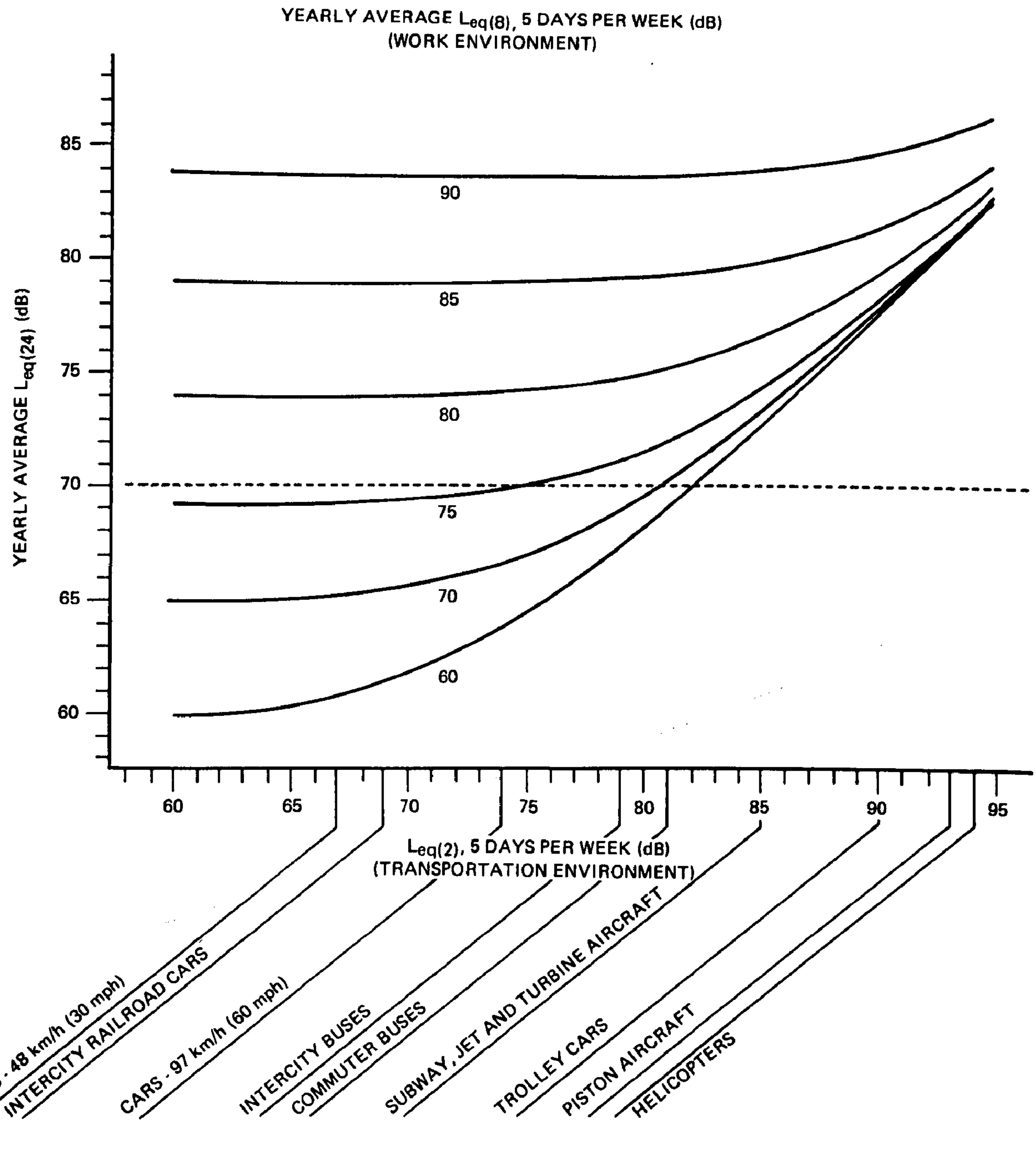

Figure 3. Yearly Average $L_{eq(24)}$ Calculated as a Function of Two Factors: The Yearly Average Workday $L_{eq(8)}$, and the Yearly Average Vehicle Interior Equivalent Sound Level to Which a Person is Exposed for 2 Hours per Day, 5 Days per Week $L_{eq(8)}$*

*All remaining hours of the year are assumed to have an $L_{eq(1)}$ of 60 dB.

"EPA has identified an $L_{eq(24)}$ level of 70 dB as requisite for protection against hearing loss with an adequate margin of safety" (Reference 1).

this lack of standardized measurement methodologies, different investigators have employed different methodologies for the same vehicle type. Therefore, the data collected by different studies is sometimes incomparable and is often difficult to collapse. These problems are evident in the footnotes to Tables 1 through 17 and were even more clear when the data were being organized and tabulated. A lack of specificity regarding operation parameters (i.e., speed, road condition, or microphone location) resulted in deletion of data points during creation of the tables. Also, the observed differences in mean sound levels as a function of recorded differences in operation variables, such as road conditions, may have been biased by differences in uncontrolled variables such as vehicle age or mileage.

The problem extends beyond that of combining or comparing the results of two or more studies. Drawing conclusions regarding the results of even a single survey can be hindered by an incomplete sample design. This would be less likely to occur if guidance in the form of standardized methodology was available.

These problems illustrate the need for the development of standardized measurement methodologies. Proposed methodologies should include specifications by vehicle type of:

1. Noise descriptor(s) including noise exposure descriptors (such as L_{eq}, or L_{dn}),
2. Modes of operation,
3. Other variables of vehicle operation,
4. Environmental variables,
5. Vehicle description,
6. Microphone location(s), and
7. Other intruding noise sources.

Tables 22 through 24 list the variables which have been used by the studies surveyed. These variables should be considered in developing standardized methodologies. Two draft proposals have been developed by the International Standards Organization (ISO) on the methods of making sound level measurements inside aircraft and motor vehicles (3, 4). The proposals were not designed to enable the investigation of variables affecting interior vehicle sound levels, rather, they specify constant levels of maintenance for most of these variables. These constant levels could be recommended for variables not under investigation. The draft proposals also make recommendations regarding microphone placement.

Data Deficiency

A sufficient number of interior A-weighted sound levels were collected to enable confident calculation of representative mean levels for the vehicle types studied. The data

TABLE 22: VARIABLES SPECIFIED IN THE INTERIOR MEASUREMENT METHODOLOGIES OF CARS AND BUSES

1. NOISE DESCRIPTORS:
   a. A-weighted sound level
   b. C-weighted sound level
   c. Overall sound pressure level
   d. Octave band sound pressure level

2. MODE OF OPERATION, THEIR DURATION AND GEAR:
   a. Idle
   b. Acceleration
   c. Cruise
   d. Deceleration

3. OTHER VARIABLES OF VEHICLE OPERATION:
   a. Speed
   b. Auxiliary equipment (on or off)

      - Air vent
      - Air conditioner
      - Heater
      - Defroster
      - Windshield wipers
      - Radio

   c. Number of windows opened and closed
   d. If closed are the windows sealed?

4. ENVIRONMENTAL VARIABLES:
   a. Road condition
   b. Road material
   c. Number of passengers

5. VEHICLES DESCRIPTION:
   a. Manufacturer
   b. Model
   c. Year of make

TABLE 22: VARIABLES SPECIFIED IN THE INTERIOR MEASUREMENT METHODOLOGIES OF CARS AND BUSES

d. Tire condition
e. Mileage
f. Engine location (front or rear)
g. Diesel or gasoline consuming engine

6. MICROPHONE LOCATION:
   a. Its row number
   b. Total number of rows
   c. Window, middle, aisle, or other (specify) seat

TABLE 23: VARIABLES SPECIFIED IN THE INTERIOR MEASUREMENT METHODOLOGIES OF RAILROAD CARS

1. NOISE DESCRIPTORS
   a. A-weighted sound level
   b. C-weighted sound level
   c. Overall sound pressure level
   d. Octave band sound pressure level
   e. 1/3 octave band sound pressure level
   f. L_{eq}, L_{01}, L_{10}, L_{50}, L_{90} and L_{99}

2. MODES OF OPERATION AND THEIR DURATION
   a. Idle
   b. Acceleration
   c. Cruise
   d. Deceleration
   e. Brake application-air release from brake compression

3. OTHER VARIABLES OF VEHICLE OPERATION
   a. Speed
   b. Doors opening or closing
   c. Auxiliary equipment (on or off)

      - Air conditioner
      - Heater

   d. Number of windows opened and closed
   e. If closed are they sealed?

4. ENVIRONMENTAL VARIABLES
   a. Rail (jointed or welded)
   b. Trackbed (concrete and/or ballast or suspended)
   c. Track surface (ground or unground)
   d. Coupling (direct or indirect fixation)
   e. Track condition (geometry, loose joints, and/or contaminated ballast)
   f. Tunnel, at-grade; or elevated (specify on earth berm or bridge)
   g. Curve or straight
   h. Switches or crossovers
   i. Number of passengers

TABLE 23: VARIABLES SPECIFIED IN THE INTERIOR MEASUREMENT METHODOLOGIES OF RAILROAD CARS (CONT)

5. VEHICLE DESCRIPTION
   a. Propulsion (electric, diesel electric or other - specify)
   b. Car type (roomette, coach, etc.)
   c. Year of make
   d. Do doors seal properly?
   e. Are the wheels flat?
   f. Are wheels rubber or steel?
   g. Do brakes squeak?
   h. System and line

6. MICROPHONE LOCATION
   a. Its row number
   b. Total number of rows
   c. Window, middle, aisle or other (specify) seat
   d. Height roughly at that of a seated passenger

TABLE 24: VARIABLES SPECIFIED IN THE INTERIOR MEASUREMENT METHODOLOGIES OF AIRCRAFT

1. NOISE DESCRIPTORS
   a. A-weighted sound level
   b. C-weighted sound level
   c. Overall sound pressure level
   d. Three-band preferred octave speech-interference level (PSIL)
   e. Octave band sound pressure level

2. MODES OF OPERATION AND THEIR DURATION
   a. Taxi to or from runway
   b. Take off (acceleration)
   c. Climb
   d. Cruise
   e. Landing (Deceleration)
   f. Reverse thruster application

3. OTHER VARIABLES OF OPERATION AND ENVIRONMENT
   a. Speed
   b. Altitude
   c. Auxiliary equipment (on or off)

      - Air vent closest to microphone
      - Neighboring seat's air vent

   d. Number of passengers
   e. Number of windows opened and closed

4. VEHICLE DESCRIPTION
   a. Manufacturer - make
   b. Model
   c. Year of make
   d. Number, type and position of engines

5. MICROPHONE LOCATION
   a. Its row number
   b. Total number of rows
   c. Window, middle, aisle or other (specify) seat
   d. Number of rows from galley

base was not adequate to quantify the sensitivity of these average sound levels to the variables of microphone location and vehicle description, operation, and environment. This deficiency resulted from inconsistencies in the collection of data regarding these variables. Standardized measurement methodologies would alleviate this situation by providing a list of the important variables for which values should be specified.

Recommendations and Conclusions

The hypothetical scenarios developed herein indicate combined exposure to occupational noise and interior transportation noise may result in exposure levels exceeding the levels identified by EPA as requisite for protection against hearing loss with an adequate margin of safety (i.e. $L_{eq\ (24)}$ of 70 dB). For instance, it was calculated that 1- or 2-hour exposure to some of the investigated vehicle types will result in a yearly average of $L_{eq\ (24)}$ greater than 70 dB when combined with exposure to a yearly average workday $L_{eq\ (8)}$ of 60, 70, or 75 dB (Table 21 and Figure 3). Also, if the exposure to the yearly average workday $L_{eq(8)}$ is 80 dB or greater, the $L_{eq(24)}$ will always exceed 70 dB, even if there is no vehicle exposure.

These calculations of exposure levels are based on assumptions regarding the typical daily time period during which Americans are exposed to the interiors of various transportation modes. Since these calculations indicate that there is a risk of hearing loss associated with the hypothesized exposure durations, it is important to determine the number of Americans actually represented by these exposure durations. A review of multimodal trip generation studies should be examined to determine their applicability to noise exposure forecasting. This task might be supplemented by a random sample of the U.S. population to estimate realistic exposure durations as functions of various vehicle types.

Available information indicates that the levels of noise exposure in off-road vehicles, recreational vehicles are generally higher than those experienced in the passenger areas of the other discussed vehicles. As illustrated in Figure 4, the energy mean A-weighted sound level in truck cabs is 90 dB, when measured at the right ear of the truck operator with closed windows under various modes of vehicle operation (5). Measurements made by EPA personnel in locomotives yielded an energy mean A-weighted sound level of 91 dB. The A-weighted sound levels to which motorcycle operators are exposed range from 90 to 115 dB depending on engine displacement (6). Operators of snowmobiles are exposed to A-weighted sound levels which range from 98 to 114 dB, with an energy mean of 110 dB (7). A-weighted sound levels measured on pleasure out-board motor boats range from 73 to 96 during cruise and from 84 to 105 dB during acceleration, depending on horsepower (8). Therefore, it is recommended that the study of interior transportation sound levels be extended to occupational exposures, off-road ana recreational vehicles, because of the higher sound levels experienced on these vehicles equal exposure durations.

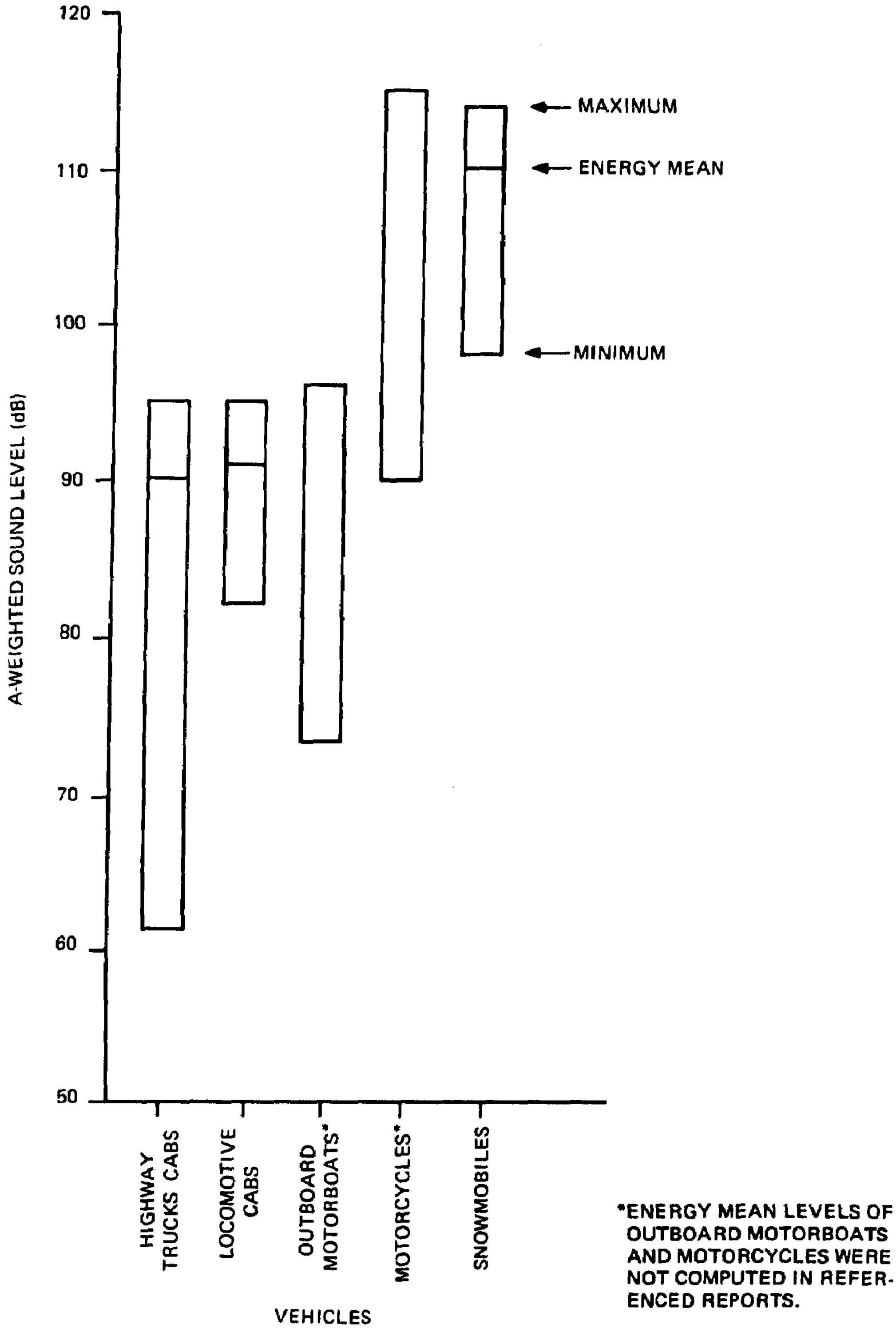

Figure 4. Range of A-weighted Sound Levels Measured Inside Occupational Locations in Vehicles, and at the Operator Position of Off-road and Recreational Vehicles.

The lack of established methodologies for measuring interior sound levels has contributed to the incompatibility of data collected by different sources. It is therefore concluded that standardized measurement methodologies should be developed to provide guidance to and facilitate the consistency of studies of interior transportation sound levels. These guidelines would help alleviate the deficiency of data regarding the effect of operation and location variables on the sound levels measured inside vehicles. General considerations for this methodology development are contained in the test. Once these methodologies are developed, studies should be implemented to remedy the present gaps in the data base.

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(6) U.S. Environmental Protection Agency. "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," Document No: NTID 300.13, December 31, 1971, p. 178.

(7) U.S. Environmental Protection Agency. "Control of Snowmobile Noise, Volume I: Technology and Cost Information," Document No: 550/9-74-003A, June 1974, pp. 18-19.

(8) U.S. Environmental Protection Agency. "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," Document No: NTID 300.13, December 31, 1971, p. 180.

APPENDIX A

Passenger Noise Environments in Vehicles:

A Data Compilation

PASSENGER NOISE ENVIRONMENTS IN VEHICLES: A DATA COMPILATION

Final Compilation

December 6, 1974

Office of Noise Abatement and Control
U.S. Environmental Protection Agency

Under Contract 68-01-2229

by

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INTRODUCTION

This is a compilation of measurements of passenger noise environments in various enclosed vehicles that are now used for transportation in the United States. It includes cars, buses, rapid transit, railroads, commercial airplanes, general aviation airplanes, helicopters, and hovercraft.

The scope of this compilation excludes:

- Non-enclosed vehicles (motorcycles, snowmobiles);
- Recreational vehicles (small boats, snowmobiles, off-road motorcyles);
- Occupational settings (cockpit noise, truck cab noise), except in such cases as light planes, where the operator and the passengers are exposed to essentially the same noise;
- State-of-the-art vehicles ("people movers," prototypes, experimental vehicles);
- Foreign (vehicles not in use in the U.S.).

The data have been extracted from numerous published and unpublished references, which have been assembled into a document collection (companion volumes 2-10). The tables of this compilation have been designed to permit meaningful comparisons between data from different sources. Most of the data are single measurements of noise levels in a particular vehicle, at a particular location within the vehicle, while the vehicle is operating in a particular way. In general, such data are entered as follows:

79(28)

Noise level ↗ ↖ Number of reference from which the datum is taken.

In addition, some statistics representing many measurements were available; these have been included in the tables properly identified by footnote or comment.

Octave band data and frequency distributions in graphical form have not been brought into the compilation itself, but their location in the document collection has been referenced where possible.

It is hoped that this accumulation of measurements, from different sources, will enable central tendencies and ranges of deviation to be established. It also should allow the identification of problems in measurement technique that might otherwise go undetected -- for example, when two investigators ostensibly measure the same equipment in the same operation, but come up with different numbers.

Data presently being collected by EPA staff will add to the compilation, and the tables were designed with such additions in mind.

The collection of references (volumes 2-10) has been scanned for other types of information on noise inside vehicles -- data on noise exposures, health and welfare effects, measurement methodologies, identification of contributing noise sources, and abatement methods. The List of References (p. 4-14 in this volume) contains a key to the types of information contained in each reference. The key was designed to cover more types of vehicles than are presently represented in the document collection. In addition, Table 1 (p. 18) references in detail the location of data on exposures and discussions of health and welfare effects.

To our knowledge, this compilation is the first effort to assemble data on noise inside vehicles on so comprehensive a scale. Although the format of some tables may need to be redefined, the scope of vehicle types broadened, and new tables added, we believe that the present compilation will prove to be a useful tool for assessing the general problem.

REFERENCES

Key to Information Categories

Vehicle Type	Data Type
A. Car	1) Interior noise levels as a function of vehicle type and mode of operation.
B. Bus	2) Interior noise exposure as a function of vehicle type and trip length. Time histories of noise levels which could be used in calculating exposure.
C. Rapid Transit	3) The health and welfare effects of interior noise as they relate to vehicle type and mode of operation.
D. Railroads	4) Measurement methodologies employed as a function of vehicle type.
E. Fixed Wing Aircraft	5) Identification of major noise sources contributing to interior noise by vehicle type and mode of operation.
F. Helicopter	6) Modifications to attenuate interior noise in terms of vehicle type.
G. Boat	
I. Motorcycle	
J. Snowmobile	
K. Other (includes Hovercraft)	

Examples:

A1	Noise levels inside cars.
E (1-6)	All types of data and information on aircraft
(A-D) (1), C2	Noise levels in cars, buses, rapid transit, and railroads. Also some exposure on time-history information on rapid transit only.

Those foreign documents included because of their particular interest are so marked.

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22.	Ibid., 198 (April 1971), 42, 50.	
23.	Ibid., 198 (May 1971), 16, 24.	
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27.	Ibid., 199 (Aug. 1971), 23, 26.	
28.	Ibid., 199 (Sept. 1971), 26, 30.	
29.	Ibid., 199 (Nov. 1971), 16, 20, 26.	
30.	Ibid., 199 (Dec. 1971), 18, 24, 26.	
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32.	Ibid., 200 (Feb. 1972), 32, 34.	
33.	Ibid., 200 (March 1972), 12, 22, 24.	
34.	Ibid., 200 (April 1972), 50, 56, 60.	↓

REF NO.	CITATION	INFORMATION CATEGORIES (see key)
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36.	_Ibid._, 201 (July 1972), 26, 28, 39.	↓
37.	_Ibid._, 201 (Aug. 1972), 35, 44.	↓
38.	_Ibid._, 201 (Sept. 1972), 18, 26.	↓
39.	_Ibid._, 201 (Nov. 1972), 46, 50.	↓
40.	_Ibid._, 201 (Dec. 1972), 30, 35.	↓
41.	_Ibid._, 202 (Jan. 1973), 30, 40, 42.	↓
42.	_Ibid._, 202 (Feb. 1973), 52, 62, 68.	↓
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44.	_Ibid._, 202 (April 1973), 58, 66, 72.	↓
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48.	_Ibid._, 203 (Aug. 1973), 16, 20, 24.	↓
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51.	_Ibid._, 204 (Jan. 1974), 22, 38.	↓
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94.	Camp, Robert T., Jr., Noise Spectra of the U.S. Army U-21A Aircraft. USAARU Letter Report, December 26, 1967.	E(1, 3)
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101.	URS/Coverdale & Colpitts, Inc. <u>A New Car for Amtrak.</u> (pp. 42-53 only). November 1, 1973.	D(1, 5, 6)
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106.	Berry, Charles A.; Eastwood, Herbert K. "Helicopter Problems: Noise, Cockpit Contamination and Disorientation." Aerospace Medicine, 31(3) (March 1960), 179-190.	F(1,3)
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108.	Modig, C. Set of field measurements made in cars, buses and aircraft Nov. 22 - Dec. 2, 1974. Unpublished data.	(A, B, E)1
109.	Hinterkeuser, Ernest G.; Sternfeld, Harry, Jr. Civil Helicopter Noise Assessment Study Boeing Vertol Model 347. Boeing No. D210-10752-2. Final report prepared for NASA under contract NAS 1-12494. May 3, 1974.	F6 (external)
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111.	Federal Aviation Administration. General Aviation Activity Survey, 1972. FAA Office of Management Systems, Information and Statistics Div., July 1974.	E(2) (no noise data, but data on avg. trip lengths & durations)
112.	U. of Va., Dept. of Engineering Science and Systems. Unplublished data on three aircraft. Private communication. November 26, 1974.	E1

REF. NO.	CITATION	INFORMATION CATEGORIES (see key)
113	Gruesbeck, Marta G.; Sullivan, Daniel F. Noise levels in five feeder-line type commercial aircraft. One-page excerpt from Aircraft Motion and Passenger Comfort Data from Scheduled Commercial Airline Flights. Memorandum Report 403212, May 1974. (P. 26.)	E1
114	Cooper, B. K. (Tracor, Inc.). Noise Measurements in Grumman Gulfstream II. May 26, 1972.	E1
	and Grumman Aircraft Co., data taken in 10 Gulfstream aircraft. No date.	

GENERAL COMMENTS ON MEASUREMENT METHODOLOGY

1. There are no widely accepted measurement standards for noise vehicles, except for standards applicable to commercial truck cabs, which are outside the scope of this report. However, there is a body of common practice reflected in the literature.

2. It is common practice to use the "slow" response on the sound level meter, and all data in this compilation, if they were taken by reading a meter, were taken with the meter set on "slow." It is also common practice to report the reading as a single number if the noise is so steady that the meter needle does not fluctuate more than ± 1 decibel over several seconds. When the needle fluctuates by more than several decibels some investigators evidently report the central tendency and others evidently report the result as a range between two numbers. Most readings are taken on the A-weighted scale.

3. There is general agreement on measuring noise at the ear level of various seat positions, but some measurements are taken in the empty seat at center-of-head position, some with the meter one foot in front of the occupant of the seat, some at both right and left ears, etc. In addition, only a few investigators have also measured noise close to the window or exterior shell to simulate levels experienced by a passenger resting his head against window or cabin wall.

4. (Recommendation.) Measurement of attenuation of the exterior shell of surface vehicle types such as cars and buses has been neglected. Since intrusion of background noise is an important factor in the urban traffic setting, more measurements should be taken in this area. Even taking into account the problem of audibility of warning devices like horns and sirens, more may perhaps be done to attenuate noise from outside the vehicle.

5. (Recommendation.) Vehicle types vary greatly in the degree to which noise in the passenger compartment is steady or fluctuates. Moreover, vehicle noise in specific vehicle types varies in steadiness with mode of operation (start, accelerate, stop, etc.). Noise levels taken with a hand-held meter are sufficient for the case of steady, continuous noise (cruise mode), and will also suffice for preliminary orienting measurements of other noise types. However, when fluctuating or intermittant noises are found of high enough level to

warrant examination in detail, laboratory analysis of tape recorded data should be the rule. Such measurements have already been made by DOT's Transportation Systems Center for rapid transit vehicles (e.g., Refs. 79-81, 107) and by the Consumers Union for cars (data promised to Informatics, but not yet received.)

GENERAL COMMENTS ON HEALTH AND WELFARE EFFECTS

1. A key to discussions in the literature is given in the table on the following page (Table 1).

2. Most discussion of hearing damage risk has been in terms of a comparison between cruise noise levels in a given vehicle and criteria curves (if octave band data, e.g. the military) or the 90 dBA OSHA single number standard. Few calculations of exposure in L_{eq} are yet found in the literature, either those calculated from time histories, or those obtained by using "typical" levels for different vehicle operations combined with an assumed trip length. A set of Wyle estimates of the latter type is given verbatim in Table 2.

3. There is a need for more data on speech interference as opposed to hearing damage risk. This situation is caused in part by the relative ease of taking A-weighted levels, as opposed to taking the octave band data necessary to calculate SIL or PSIL. Wyle estimates of speech interference, generalized for basic vehicle types, is given in Table 3.

4. A question remains whether, (at least for some vehicles,) the combined noise and vibration effects should be considered in assessing the health and welfare effects, rather than considering the noise effects alone. Most experts polled informally by this author discounted effects of vibrations typically found in commercial vehicles. One expert did not. Some work now in progress may shed more light on this question.

TABLE 1.

Summary Table: Location of data on Exposure and discussions of Health and Welfare Effects

(Ref. No. /Pages)

	CARS	BUSES	RAPID TRANSIT	RAILROADS	FIXED WING AIRCRAFT	HELICOPTERS	OTHER (including helicopters)
<u>Exposure Data</u>							
L_{eq}	8/227	8/227	63, 64, 79, 80, 81, 107, 104	8/227	8/227	8/227	8/227
Graphical time histories			63, 64, 79, 80, 81, 107, 104		8/20		
. <u>Health and Welfare discussion</u>		6/19	6/19	6/19	2/3-5, 6/19, 8/227, 61/1347, 70/4, 71/4, 76/1135-7, 84/12-16, 94/3-5, 90/9-10,	106/182-4, 93/3-4, 97/3-5, 8/227, 89/2-7, 98/3-4, 99/8-9, 100/16-20, 91/2, 93/3-4	
Hearing damage risk (PTS, TTS, Walsh-Healy)	8/227	8/227	8/227 64/App. E, 75/896, 104	8/227			
Speech interference	8/228-9	8/228-9	8/228-9 104/645, 649	8/228-9	2/5, 8/228-9, 70/5, 71/4-5, 84/9	106/184, 8/228-9, 85/2-4, 103b/1-2	
Performance (Reaction time, disorientation, fatigue)					2/5, 84/16	106/185	
Other (1) Combined noise/vibration effects						1/351, 61/1347	
(2) Annoyance			63/10, 75		84/16	.85/2	

TABLE 2.

EXTRAPOLATIONS ON RELATIVE HEALTH AND WELFARE EFFECTS (HEARING DAMAGE RISK) OF VARIOUS VEHICLES.

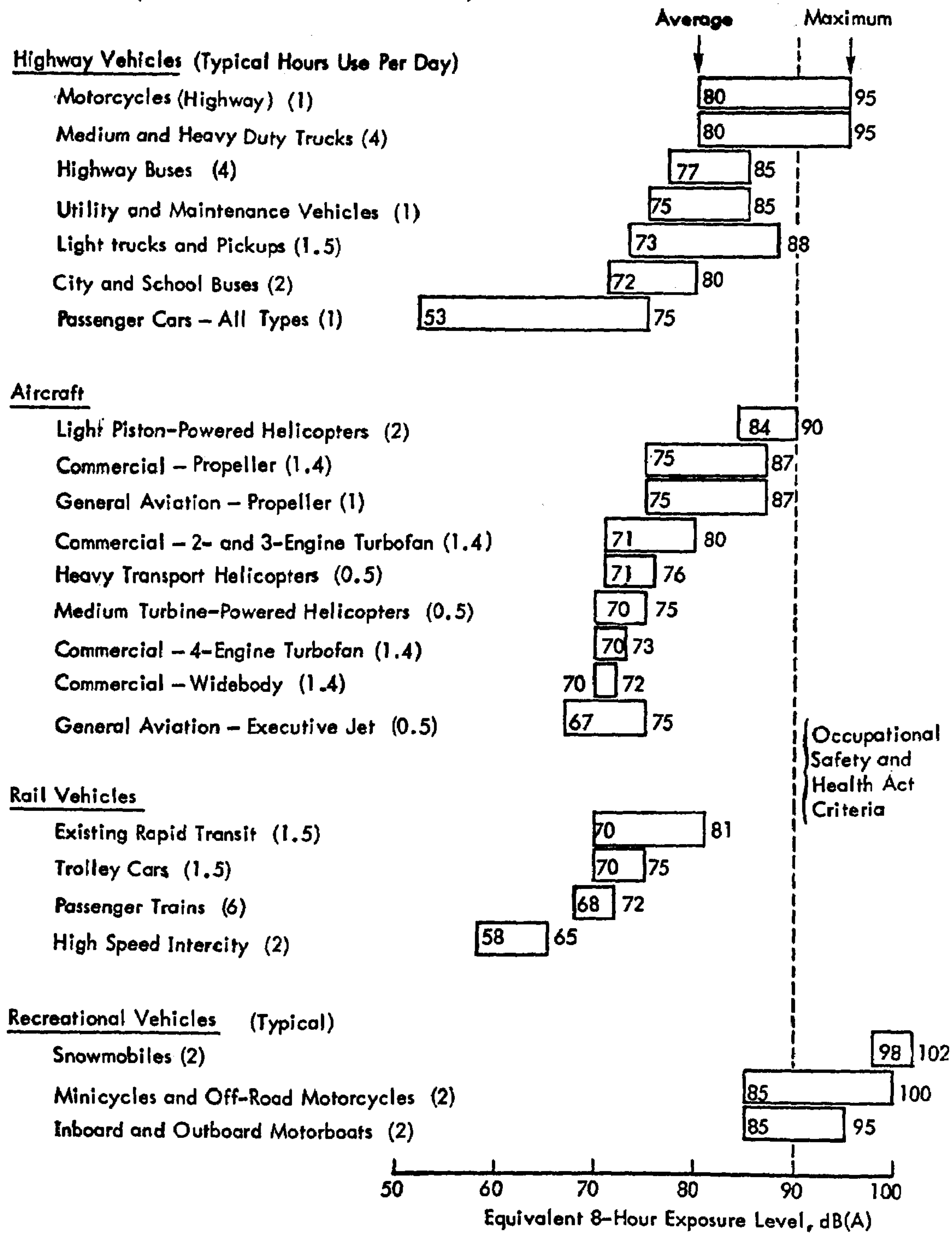

Figure 4-4. Potential Hearing Damage Contributions from Transportation System Categories in Terms of Equivalent 8-Hour Exposure Levels, for Passengers or Operators

Source: Ref. 8 U.S. Environmental Protection Agency. Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines. NTID300.13 Prepared by Wyle Laboratories. December 1971. p. 227

TABLE 3

GENERALIZED ESTIMATE OF RELATIVE HEALTH AND WELFARE EFFECTS (SPEECH INTERFERENCE) OF VARIOUS VEHICLE TYPES.

Typical Passenger Separation Distances and Speech Interference Criteria Compared to Average Internal Noise Levels for Major Transportation Categories

	Talker–Listener Separation Feet	Speech Interference Limits * dB(A)	Average Internal Noise Levels dB(A)
Passenger Cars	1.6 to 2.8	73 to 79	78
Buses	1 to 1.7	79 to 85	82
Passenger Trains	1 to 1.7	79 to 85	68 to 70
Rapid Transit Cars	1 to 1.7	79 to 85	82
Aircraft (Fixed Wing)	1.1 to 1.7	79 to 84	82 to 83
V/STOL Aircraft	1.1 to 1.7	79 to 84	90 to 93

* Maximum noise levels to allow speech communication with expected voice level at specified talker–listener separation distances.[7]

Source: Ref. 8. U.S. Environmental Protection Agency. Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines. NTID300.13 Prepared by Wyle Laboratories. December 1971. p. 229.

CARS. MEASUREMENT.

1. Of all vehicles, we have the best data for cars.

   The data shows that when driven at high speeds with the windows open, the central tendency of the noise level is harder to find (more fluctuation), particularly on the C-weighted scale or at the driver's left ear. (Ref. 108)

   Also the C-weighted noise level consists of a base level (measurable to ± 1dB) plus upward deflections of 2 to 4 dB (and occasionally up to 7 dB) for small bumps in the road. Otherwise, provided the test run was on level smooth road, measurements should be repeatable to ± 1 dB for the cruise.

2. The data also shows that the measurement positions 4" R of the driver's right ear (Popular Science method) and in the passenger's seat ear-high (Consumers Union) are for all practical purposes equivalent and that these data sets may be merged. * The differences between the measurement positions, on the basis of trials with 7 cars of various types and ages, was 0 - 1 dBA (windows closed) and 0 - 2 dBA (windows open). These differences are acceptably small relative to the general degree of precision obtainable in the measurements as a whole (road smoothness, accelerator fluctuations, errors reading meter, etc.). (Ref. 108. The author undertook these field measurements primarily to demonstrate that these two data sets could be merged, in order to get data from different sources on identical makes and models.)

3. The data on effects of opening the windows is sufficient to establish a significant difference in noise levels (Refs. 9 & 108). However, the reliability could be increased somewhat by testing more cars and by using a wind screen on the microphone, especially for the left ear measurements. It will probably never be possible to get well-behaved repeatable measurements for the windows open condition, especially for driver's left ear. For one thing, 4" left of ear puts the microphone closer to being outside the car in some cars than others.

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* Informatics was still waiting receipt of the Consumer Union data set at time of writing of the final report.

4. Some preliminary measurements on several cars suggest that at typical freeway conditions (with windows closed, at 97 km/h (60 mph) on smooth road), playing the radio over the heater fan can add 4 to 9 dBA to the basic noise level, depending on driver preference as to audibility of spoken speech on the radio. The fan alone, set at "high", can add 0 - 2 dBA, with an increase of 1 dBA typical.

5. Several types of additional measurements could be made to enhance our understanding of car noise:
   (1) Effect of snow tires
   (2) Octave band data sufficient to obtain speech interference ratings (SIL). This data set exists and has been promised to Informatics, but had not been received at the time of writing the final report.
   (3) Noise levels in the back seat.
   (4) Noise peaks from passing or being passed. Effect of high-density freeway traffic.
   (5) More data on (and a better method of characterizing) rough vs. smooth roads.
   (6) More data on the attenuation of the exterior shell.

6. Data in the Reference Collection (Refs. 12 - 60) taken at 48 km/h (30 mph) on rough roads shows that road surface is a critical variable in measurement, for this noise typically equals or exceeds noise on smooth roads at 97 km/h (60 mph). (This 48 km/h (30 mph) data was not put in the tables.)

   One possible way to achieve comparability between measurements of different investigators would be to require one measurement condition to be on concrete-surfaced Interstate Highways at 89 km/h (55 mph), on the presumption that these roads are relatively identical because they were built to a single federal standard.

7. Based on a sample of two models, diesel-engined cars are slightly louder (2 -3 dB at idle, 1 - 3 dB at speed) than their gasoline-powered equivalents.

8. The Mazda should be measured to ascertain the spectral characteristics of its "hmmmmmm."

CARS. HEALTH AND WELFARE.

1. There has been no discussion in the literature on health and welfare effects of noise in cars. However, some observations may be made from our data.
   Of all vehicles, cars rank among the lowest as a potential health and welfare problem. (Paradoxically, we presently have the best data on cars.)

2. Although most cars are "safe" at freeway speeds (70-80 dBA) from the standpoint of conventional hearing damage risk criteria, it is easy to see that various combinations of factors (rough road, window open, playing radio) could expose driver and passengers to levels in the 85-90 dBA range.

3. When the Consumers Union octave band data is received, it will be possible to assess bettter speech interference effects. It should be noted that cars are privately operated vehicles, where it is not desirable to have a minimum level of background noise to assure some speech privacy between non-adjacent seats. The optimum design solution from an acoustical point of view would include more attenuation in the exterior shell, but this approach apparently conflicts with safety, as pointed out in the general comments section earlier. The conflict may not be as great as one might think, however, since the efficacy of horns and sirens as warning devices is now under closer scrutiny. (See full version of Ref. 69 when it is released.)

CARS --CRUISE-- "PERSONAL CARS" at 97 km/h (60 mph) All levels in dBA; smooth road; condition: new except as noted; ( ) = Ref. No.; windows closed; all auxiliary equipment off.

(All measurements made 4" to right of drivers right ear)

MAKE	MODEL	WEIGHT (lbs)	PRICE ($)	A-Weighted Sound Levels in Measurement Year 1970	1971	1972	1973	1974	1975	COMMENTS
Buick	Riviera			68 (13)						
Pontiac	Grand Prix			68 (13)						
Pontiac	LaMans Safari					68 (42)		70 (51)		
Chevrolet	Monte Carlo			68 (13)						
Ford	Thunderbird			67 (13)						
Olds	Toronado			72 (13)						
Plymouth	Barracuda 340			75 (15)						
AMC	Javelin SST			76 (15)						
Volvo	144-S			78 (16)			70 (49)			
Audi	100-LS			76 (16)			71 (49)			
"	Fox						74 (48)			Foreign
Peugeot	504			78 (16)			68 (49)			Compacts
Saab	99						73 (49)			
Citroën	Special			75 (16)						
Datsun	510			77 (17)						
Fiat	124S			79 (17)						
Simca	1204			80 (17)						
Toyota	Corona (1973 Mark II)			76 (17)			73 (48)			
				76 (108)						136,794 km/h (85,000 mi) part worn snow tires
Datsun	1200			79 (18)						
	610						75 (48)			
Toyota	Corolla			77 (18)			75 (58)			
VW	Bug			80 (18)						
Ford	Pinto				78* (19)	76 (32)		70 (58)		
Chevrolet	Vega (1974 Vega LX)				83* (19)	76 (32)		69 (58)		
Ford	Maverick V8			71 (20)			67 (46)	70 (55)		
"	" V6						72 (46)	71 (59)		
AMC	Hornet V8			74 (20)			71 (42)	70 (55)		
	Gremlin X				77 (32)	71 (32)		73 (58)		
Plymouth	Valiant			74 (20)			71 (46)	70 (55)		
Chevrolet	Nova V8						70 (46)	68 (55)		
Austin	Marina						76 (48)			

* = after 10,000 miles driving

MAKE	MODEL	WEIGHT (lbs)	PRICE ($)	A-weighted Sound Levels by Measurement Year 1970	1971	1972	1973	1974	1975	COMMENTS
Dodge	Colt				76 (23)			73 (53)		Size of Vega & Pinto
Plymouth	Cricket				80 (23)					
Opel	1900				71 (23)			73 (53)		
"	(74 Mantra)				79 (5)					
Ford	Capri V6				75 (23)	74 (36)		77 (53)		
Dodge	Demon V8				76 (24)		71 (42)			76,444 km/h (47,500 mi) new tire
	(73: Dart Sport)						73 (108)			
Pontiac	Ventura II V8				73 (24)					Expensive 2+2, "GT" Type
Mercury	Comet V8				75 (24)		68 (42)			
Dodge	Challenger			80 (26)						
Mercury	Cougar			75 (26)						
Pontiac	Firebird			74 (26)						
VW	Superbeetle				78 (28)			74 (58)		Like Toyota Corolla, Datsun 1200
Fiat	128				76 (28)					
Subaru	ff-1-1300G				79 (28)					
Opel	1900				74 (29)					Medium price 4-door imports
Peugeot	304				75 (29)					
Renault	R-12				79 (29)					
Citroën	DS-21				73 (30)					Luxury
Jaguar	XJ-6				69 (30)					
Mercedes Benz	250				74 (30)					
Chevrolet	Chevelle - Malibu 6			69 (31)		70 (31)	69 (41)			Intermediate size
"	Laguna					69 (42)	69 (41)			
Ford	Gran Torino 6			72 (31)		70 (31)	68 (41)			
Plymouth	Satellite 6			74 (31)		72 (31)	70 (41)			
AMC	Matador 6					72 (31)	70 (41)	70*(51)		
"	Rebel 6			75 (31)						
"	Hatchback						71 (55)			
Buick	LeSabre					69 (35)				
"	Century Luxus						65 (45)			
	Century Regal						67 (108)			32,187 km/h (20,000 mi) half worn

MAKE	MODEL	WEIGHT (lbs)	PRICE ($)	A-Weighted Sound Level By Measurement Year 1970	1971	1972	1973	1974	1975	COMMENTS
Mercury	Monterey					69 (35)				
"	Montego MX						64 (45)	67 (51)		
Oldsmobile	Delta 88 Royale					67 (35)				Standard
Chrysler	Newport Royal					69 (35)				
Dodge	Charger 6							70 (51)		
"	Cornet Custom						67 (45)			
Fiat	124 Sport Coupe					74 (36)				
Datsun	240/Z					73 (36)				Sports cars
Renault	15					79 (37)				
Fiat	128 SL 1300					78 (37)		78 (58)		
Mazda	RX-3					73 (37)				
	RX-4							72 (59)		
Ford	LTD						64 (43)	67 (52)		
Chevrolet	Caprice						64 (43)	67 (52)		
"	Camaro SS			71 (15)						
AMC	Ambassador						68 (43)	71 (52)		
Plymouth	Fury Gran Sedan					72 (108)	66 (43)	70 (52)		1972: snow tire on rear;
Pontiac	Grand Am						64 (43)			
Dodge	Colt							73 (58)		
Subaru	DL							74 (58)		
Datsun	B-210							75 (58)		
VW	Dasher							71 (59)		
Ford	Mustang			77 (15)				73 (53)		
BMW	3 L Bavarian					75 (108)				96,561 km 60,000 mi. half worn radia
	2L 2002						70 (108)			24,140 km 15,000 mi.-pa worn radials.

CARS -- CRUISE -- VANS at 97 km/h (60 MPH)

Smooth road; all levels dBA at operator's right ear; condition: new; ( ) = Ref. No.; all auxillary equipment off.

MAKE	MODEL	WEIGHT (lbs.)	PRICE ($)	A Weighted Sound Levels by Measurement Year						COMMENTS
				1970	1971	1972	1973	1974	1975	
Ford	Clubwagon				76 (25)					
Chevrolet	Sport van				76 (25)					
Dodge	Sportsman				76 (25)					
International	Travelall				71 (25)					
Concord	(Dodge chassis)									Recreational Vehicles
	front							77 (54)		
	rear							76		
Diamond	(Dodge chassis)									
	front							78		
	rear							77		
Shasta	(Chev. chassis)									
	front							79		
	rear							79		
Tioga	front							81		
	rear							79		
Winnebago	front							78		
	rear							74		
Starcraft	front							78		
	rear							74		

CARS -- CRUISE -- 4 - WHEEL DRIVE VEHICLES
97 km/h (60 mph)

Smooth road· all levels dBA at operator's right ear
condition: new· ( ) = Ref. No. ; all auxiliary equipment off.

MAKE	MODEL	WEIGHT (lbs)	PRICE ($)	A-Weighted Sound Levels By Measurement Year 1970	1971	1972	1973	1974	1975	COMMENTS
International	Scout				82 (27)		74 (47)			
Jeep	Wagoneer				75 (27)		73 (47)			
	Cherokee							73 (57)		
Ford	Baja Bronco				82 (27)		78 (47)			
Chevrolet	Blazer				78 (27)		71 (47)	73 (57)		
Plymouth	Trail Duster							75 (57)		
Dodge	Ramcharger							77 (57)		

CARS -- CRUISE -- PICK-UP TRUCKS at 97 km/h (60 mph)

Smooth road; dBA levels at operator's right ear; condition: new; ( ) = Ref. No.; all auxiliary equipment off.

MAKE	MODEL	WEIGHT (lbs)	PRICE ($)	A Weighted Sound Levels by Measurement Years 1970	1971	1972	1973	1974	1975	COMMENTS
Chevrolet	Cheyenne Super 20					74 (33)				
Diamond	-----Camper Unit					76 (40)				
Ford	F250 Ranger XLT					78 (40)				
						74 (33)				
Rover	-------Camper Unit					73 (40)				
International	1210 Custom					74 (33)				
Monitor	------Camper Unit					76 (40)				
Dodge	Adventurer					71 (33)				
Chevrolet	L. U. V.					79 (36)				
Datsun	PL 620					75 (36)				
Ford	Courier					78 (36)				
Toyota	Hi-Lux					78 (36)				
Jeep	J-4000					77 (40)				
Four Winds	---Camper Unit					77 (40)				
Dodge	D-200					72 (40)				
Winnebago	----Camper Unit					82 (40)				

CARS -- CRUISE -- STATION WAGONS at 97 km/h (60 mph)

Smooth road; all levels dBA approx. 4" to R. of operator's right ear; condition: new; ( ) = Ref. No.; all auxiliary equipment off.

MAKE	MODEL	WEIGHT (lbs)	PRICE ($)	A-Weighted Sound Levels by Measurement Year 1970	1971	1972	1973	1974	1975	COMMENTS
Buick	Estate Wagon			73 (12)						
Chrysler	Town & Country			75 (12)						
Dodge	Monaco			75 (12)				68 (56)		
Mercury	Colony Park			70 (12)				64 (56)		
Chevrolet	Suburban Carry-all			76 (14)						
International	Travelall D-1000			71 (14)						
Kaiser	Jeep Wagon			73 (14)						
AMC	Matador V8				74 (21)		72 (44)			Intermediate Size
Dodge	Coronet V8				73 (21)		68 (44)			
Mercury	Montego V8				72 (21)		66 (44)			
"	Villager						66 (44)			
AMC	Ambassador				68 (22)			69 (56)		
Ford					69 (22)					
Chevrolet					73 (22)					
Plymouth					69 (22)					
Pontiac	Safari						68 (44)	67 (56)		
"	LeMans						68			
Chevrolet	Vega						77 (56)			
Ford	Pinto						75 (56)			
Toyota	Corolla						78 (56)			
Toyota	Land Cruiser				77 (108)					61,799 km (38,400 mi.) half worn mud tires

CARS -- CRUISE -- MOSAIC OF VARIOUS SPEEDS FOR VARIOUS SOURCES

Windows closed; auxiliary equipment off; condition: new, except as noted; ( ) - Ref. No.; Smooth road.

MAKE	MODEL	YEAR	A Weighted Sound Level (at cruise speed) 24 km/h (15 mph)	48 km/h (30 mph)	64 km/h (40 mph)	80 km/h (50 mph)	(Comparison of two Refs.) 97 km/h (60 mph)	97 km/h (60 mph)	105 km/h (65 mph)	113 km/h (70 mph)	123 km/h (80 mph)	COMMENTS
Austin	America	1971	68 (5)					80 (5)				
Capri	Sport Coupe	↓	67 ↓	66 (23)			75 (23)	75 ↓				Ref. 5: microphone position not mentioned. Assumed to be dBA.
Dodge	Colt (2-door)		62	69 (23)			76 (23)	76				
Plymouth	Cricket		66	66 (23)			80 (23)	76				
Datsun	510 (2-door)		60					78				
Fiat	850 Sport Coupe		69					80				
AMC	Gremlin		66	65 (32)			77 (32)	78				
Opel	1900 Sport Coupe		68	65 (23)			74 (29)	79				*Ref 19: After 16,100km/h (10,000mi)
Ford	Pinto		69	67 (19)			*78 (19)	82				
Renault	R10		66					78				*Ref 9: various ages
Saab	99E (4-door)		61					72				
Toyota	Corona (4-door)		67					78				
Chevrolet	Vega GT		71	*68 (19)			*83 (19)	79				
VW	Super Beetle	↓	64 (↓)	69 (28)			78 (28)	79 (↓)				
Oldsmobile	F-85	1965			71 (9)*				76 (9)*			
Ford	Galaxie (Conv.)	1966			77 ↓				82 ↓			
Oldsmobile	Cutlass	1967			70				72			Ref. 9: Plus 0 to 2 dBA if fan is on. Microphone position at operator's ear. Smooth blacktop road.
Chevrolet	3/4 Ton Truck	1970			71				80			
AMC	Ambassador	1970			72				79			
VW	Bug	1970			78		80 (18)		81			
VW	Squareback	1971			79				84			
Ford	Torino	1971			71 (↓)				78 (↓)			
Mercedes	220	1973		64 (50)	66 (50)	67 (50)	68 (50)			74 (50)	78 (50)	
Peugeot	504	1973		64 (50)	66 (50)	68 (50)	70 (50)			72 (50)	78 (50)	
Buick	Century Royal	1973		61 (108)			67 (108)					32,187 km/h (20,000 mi)
BMW	2L 2002	1973		63 ↓			70 ↓					24,140 km/h (15,000 mi)
Dodge	Dart	1973		64			73					76,444 km/h (47,500 mi)
Toyota	Corona Mark II	1970		67			76					136,794 km/h (85,000 mi)
Plymouth	Fury	1972		67			72					32,287 km/h (20,000 mi)
BMW	3L Bavaria	1972		71 (↓)			75 (↓)					96,561 km/h (60,000 mi)

CARS

Differences Between A-weighted and C-weighted Sound Levels (windows closed)

	SOUND LEVELS AND DIFFERENCES (Δ)												
	48 km/h (30 mph)						97 km/h (60 mph)						
	Right ear			Left ear			Right ear			Left ear			
	dBA	dBC	Δ	dBA	dBC	Δ	dBA	dBC	Δ	dBA	dBC	Δ	
Car No. 1	61	86	25	64	86	22	67	89	22	70	89	19	1973 Buick Century
2	71	91	20	72	91	19	75	91	16	77	92	15	1972 BMW - Bavarian
3	63	84	21	64	87	23	70	86	16	72	87	15	1973 BMW-2002
4	70	94	24	71	95	24	77	96	19	80	97	17	1972 Toyota Land Cruiser
5	64	91	27	67	90	23	73	94	21	76	94	18	1973 Dodge Dart
6	67	89	22	68	89	21	76	95	19	77	96	19	1970 Toyota Corona Mark II
Arithmetic Average			23			22			18			17	

Note: (1) On C-weighted scale readings, momentary upward fluctuations caused by bumps are disregarded
(2) All data from Ref. 108.
(3) All auxillary equipment <u>off.</u>

CARS -- CRUISE -- "PERSONAL AUTOMOBILES"-- DIESEL vs GASOLINE

Conditions: new, windows closed, accessories off. Smooth road.

REF.	MAKE	MODEL	YEAR	SPEED km/h (mph)	SOUND LEVEL dBA DIESEL	SOUND LEVEL dBA GAS	COMMENTS
50	Mercedes	220, 220 diesel	1973	48 (30)	65	64	Measured near
				64 (40)	67	66	Operator's
				80 (50)	69	67	Right ear
				97 (60)	72	68	
				113 (70)	76	74	
				123 (80)	79	78	
	Peugeot	504, 504 diesel	1973	48 (30)	65	64	
				64 (40)	69	66	
				80 (50)	70	68	
				97 (60)	72	70	
				113 (70)	74	72	
				123 (80)	79	78	

CARS

Relative Effect of Open Windows on Interior Sound Level as a Function of Speed. 48 vs. 97 km/h (30 vs. 60 mph). (ref. 108)

	48 km/h (30 MPH) SOUND LEVELS dBA			97 km/h (60 MPH) SOUND LEVELS dBA		
	Windows Closed	Windows Open	Δ (dBA)	Windows Closed	Windows Open	Δ (dBA)
4" R. of R. ear						
Car No. 1	61	70	9	67	78	11
2	71	72	1	75	83	8
3	63	66	3	70	80	10
4	70	72	2	77	82	5
5	64	66	2	75	79	4
			arithmetic avg - 3.4			arithmetic avg - 7.6
4" L. of L. ear of driver						
1	64	75	11	70	89	19
2	--	--	--	77	95	18
3	64	71	7	72	82	10
4	71	73	2	80	86	6
5	67	72	5	76	90	14
			arithmetic avg - 6.2			arithmetic avg - 13.4

CARS

Relative Effect of Open Windows on Interior Sound Level as a Function of Speed. -- 64 km/h vs. 97 km/h (40 vs 60 mph)

(Ref 9 pp 24-25)

(All measurements approx. 4" R. of R. ear of driver.	64 km/h (40 MPH) SOUND LEVELS, dBA		Δ (dBA)	97 km/h (60 MPH) SOUND LEVELS, dBA		Δ (dBA)
	Windows Closed	Windows Open *		Windows Closed	Windows Open	
1965 Oldsmobile F-85	71	78	6	76	84	8
1966 Ford Galaxie (Conv.)	77	78	1	82	84	2
1967 Oldsmobile Cutlass	70	78	8	72	82	10
1970 3/4 Ton Chevrolet Truck	71	79	8	80	86	6
1970 American Motors Ambassador	72	73	1	79	82	3
1970 Volkswagen (Bug)	78	82	4	81	87	6
1971 Volkswagen (Square Back)	79	81	2	84	92	8
1971 Ford Torino	71	72	1	78	85	7
			arithmetic avg. 3.8			arithmetic avg. 6.2

* Open = both front windows and both vents

BUSES. MEASUREMENT.

1. City buses and inter-city buses require different measurement techniques. The "cruise" operation is the most important one to measure, from a health and welfare standpoint, for inter-city buses. It is less important for city buses, whose noise is usually a combination of "idle," "accelerate to 24-32 km/h (15-20 mph)" or "accelerate to 48-56 km/h (30-35 mph)," and "coast-throttle-coast-throttle" types of operations. (Ref. 108, plus informal communication with author of Ref. 66.)

2. For standard transmission buses, gear as well as speed should be noted for "cruise" conditions, as was done in Ref. 4. Almost all city buses have automatic transmissions and rear engines; most school buses do not. They should not be lumped together as done in Ref. 8/227.

3. Reference 4 made the following observations on the effect of various conditions on noise levels in the two buses being tested:
   a. Traffice noise added 1 to 6 dBA.
   b. Increases of 8 to 12 dBA were experienced when travelling on rough pavement.
   c. Uphill grades burdened the engine and increased the noise by 3-4 dBA.
   d. Squeaking seat brackets on one bus increased the noise level by 7 dBA.

4. A set of measurements should be taken to establish the absorption effect of a full load of passengers vs. an empty bus.

BUSES. HEALTH AND WELFARE.

1. With the exception of the Wyle estimates, there has been little or no discussion in the literature of the effects of noise in buses or passengers.

   However, it seems clear from the data that:

   a. The levels in intercity buses, combined with avg. duration of trip, make noise on these buses a potential problem. (L_{eg} (8) up to 85 dB per Ref. 8/227)

   b. Noise on city buses is less of a problem to passengers than that on intercity buses. It is intermittant, with frequent dips to 60 dBA, and trip duration is much shorter.

2. The problem of lack of data on noise in school buses should be corrected. Trip time histories as well as cruise noise levels should be collected.

CITY BUSES - CRUISE

Windows closed, constant speed. W = window seat. A = aisle seat. Bus empty except as noted.

REF/PAGE	CITY	TYPE	SEATING	ENGINE TYPE	ENGINE POSITION	SPEED km/h (mph)	SOUND LEVELS dBA Measurement Position Front W	Front A	Middle W	Middle A	Rear W	Rear A	Not Specified	dBC Front W	Front A	Middle W	Middle A	Rear W	Rear A	Other or Not Specified	Comment
6 & 7	Amarillo		19	Gas	Front		72		78		70			102		106		102			Not empty
↓	Houston		53	Diesel	Rear		70		78		74			94		94		95			
	Wash. DC		55	Diesel	Rear		71				77			94				95			
	NYC		51	Diesel	Rear			78							98						
																				Overall spl	
74*	Wash. DC	1961 GM 3 yrs. old	51	Diesel V-6200 hp	Rear	80(50) 48(30) 24(15)														88 85 85	Measured 1/3 from front, octave band data at 74/144
8/117													72 to 80								
66 + 77	Wash. DC	1963 GM		Diesel 6V71	Rear	32(20)		56			76** 78	76** 78									Front: author's estimate
67 + 77	S.F.	1969 GM		8V71	Rear	32(20)		60 to 64			82 86	80 84									
67 + 77	S.F.	1969 GM		Diesel 8V71	Rear	48-64 (30-40)		69 to 70			89 92	87 90									
108	Washington	1964 GM		6V71	Rear	32 (20)		71-72													Driver's window and rear window slightly open, bus full of people.

** Lower number: arithmetic avg. of 5 control bus measurements;
Top number: arithmetic average of 5 ELP-bus measurements;

* Auxiliary equipment off.

CITY BUSES - IDLE

Windows closed. Air conditioning off. Lighting (power inverter) on. Bus in gear.

REF/PAGE	CITY	TYPE	SEATING	ENGINE TYPE	ENGINE POSITION	SOUND LEVELS FRONT dBA	FRONT dBC	MIDDLE dBA	MIDDLE dBC	REAR dBA	REAR dBC	NOT SPECIFIED	COMMENTS
TEST CONDITIONS													
	Wash. D.C. area:												
62/10	[AB & W	All GM:											
	Shirley	Std		Diesel	Rear	61		65		70			Buses empty
	Express	EIP*		6V71		59		65		71			
	(Va.)]												
		EIP		8V71	Rear	60		64		71			
ACTUAL OPERATIONAL CONDITIONS													
108	Wash., D.C.	GMi.c. body by Flixable		6V71	Rear	60▲		61-62	86	64 67▲	83-87 88▲		▲ Window seats except ▲ = aisle seat Metro No. 6829 Rear 1 = 2/3 back
108	Wash., D.C.	GMC		6V71	Rear			63-65	82-84	69 68▲	87 87▲		Rear 2 = on back seat, extreme rear Metro No. 6451. Driver's window & window near rear slightly open.

*EIP buses had anti-noise and anti-pollution hardware.

CITY BUSES - ACCELERATION

Windows closed. Air conditioning off. Lighting (power inverter on.
0 to 48 km/h (0 to 30 mph) full throttle (automatic transmission).

REF./PAGE	CITY	TYPE	SEATING	ENGINE TYPE	ENGINE POSITION	MAX. SOUND LEVEL (dBA) Front	Middle	Rear	Not Specified	COMMENTS
TEST CONDITIONS										
62/10	Wash. D.C. area AB & W / Shirley Express (Va.)	GM std.		Diesel	Rear	72	75	81		2 vehicles of each type measured.
		GM EIP*		6V71		71	76	83		
		GM EIP		8V71	Rear	71	74	81		
66 & 77	Wash. D.C.	GM Std		6V71	Rear			84***		Avg. 5 buses $S^2 \approx 10$**
		GM EIP (1963)						84		Avg. 5 buses $S^2 \approx 10$
67 & 77	San Francisco, Cal.	GM Std		8V71	Rear			92-93***		4 buses, various parts of rear seats, $S^2 \approx 3$
		GM EIP (1969)						88-90		4 buses, various parts of rear seats, $S^2 \approx 12$
										Background noise: 45 dBA.
ACTUAL OPERATIONAL CONDITIONS							dBA dBC	dBA dBC		
108	Wash., D.C.	1968 GM with body by Flix-able		6V71	Rear		75▲ 100▲	81 96		▲ Window seats except ▲ = aisle seat. Metro No. 6829. Bus full of people. Accel to 24-32 km/h (15-20 mph). Accel to ca. 48 km/h (30 mph) with bumps.
108	Wash., D.C.	1964 GMC		6V71	Rear	72	78 92	79 94		Metro No. 6451. Bus full of people.

* EIP = GM - developed anti air and noise pollution kit, factory installed on many buses.

** S^2: square of the stand. deviation.

*** Arithmetic mean

INTERCITY BUSES -- CRUISE

All rear-mounted diesels; windows closed; constant speed; buses in use (at least partially full) except Ref. 4. empty. A= Aisle seat. W= Window seat.

REF. (date of meas.)	Speed km/h (mph)	MAKE	MODEL	YEAR	Seats	SOUND LEVELS, dBA FRONT W	FRONT A	MIDDLE W	MIDDLE A	REAR W	REAR A	not spec.	SOUND LEVELS, dBC FRONT W	FRONT A	MIDDLE W	MIDDLE A	REAR W	REAR A	not spec.	Sound Levels, Overall dB FRONT	MIDDLE	REAR
6 + 7	*				40				80							98						
↓					46		78	79		79				96	96		98					
↓					46	74	74						78	98								
(speed not mentioned)					43	74		77		84			96		96		99					
↓					39	76			77	84			96			97	97					
↓					40			78							102							
8/117	*											72 to 80**										
4	24(15)[1] 48(30)[2] 80-89 (50-55)[3]	Superior	Standard Army Ambulance Bus, 6 cyl., 501 cu. in. engine	c. 1970	44															101 104 103	102 102 103	103 108 106
	24(15)[1] 48(30)[2] 80-89 (50-55)[3]	Ward	Army Ambulance Bus, 6 cyl., 292 cu. in. engine		25															103 109 113		105 107 114

* Speed not mentioned. ** Generalized Wyle Data.

1. 3rd Gear, 2. 4th gear. 3. 5th gear. 4. 3rd gear. 5. 4th gear. 6. 4th gear.

RAPID TRANSIT. MEASUREMENT.

1. Transit vehicles present measurement problems because the level fluctuates like that of the city bus, and also because each system has slightly different sets of cars, rail types, and percentages of tunnel in the line. Data should be tape recorded and analyzed later.

2. The presence of passengers has significant effect on noise levels measured according to Reference 73.
Another source says passengers have a "minor" effect "compared with the spread of the data" between lines and between measurements on the same line. (Ref. 3/14)

3. DOT's Transportation Systems Center has been developing a "standard measurement methodology" for rapid transit noise, but the measurement point within the car has not yet evidently been fixed (maximum noise over the trucks, Ref. 64 pp. 19-21 vs. noise 1/3 from end of the car, Ref. 81 pp. 2-3 to 2-8). This method uses a tape recorder and later laboratory analysis of many 1/8 sec. samples. Measurements in Chicago were made at the center of the car (Ref. 104, p. 641) and also were tape recorded.

4. In addition to the measurements entered in the following tables, more data exists in Ref. 3 and Ref. 104, pp. 647-8, as well as a general discussions of measurement methodology problems.

5. No. of cars in the train may be a significant variable in tunnels; the influence of this variable has evidently not yet been checked by investigators.

RAPID TRANSIT. HEALTH AND WELFARE.

1. Noise exposure values (L_{eq}) of 71 to 78 dBA have been measured on a run on Boston's Red Line, and L_{eq} = 84-85 on Boston's Green Line. (Ref. 64 App. E.) This source also gives the exposures in terms of percentage of the allowable OSHA limit. Noise levels in the Chicago CTA had arithmetic means of 81 dBA on the A-train and 80 in the B train, with significant time percentages above 90 dBA. It was concluded that these exposures constituted hearing damage risks for some passengers, as well as crews (Ref. 104/649, 650-652).

2. Severe interference with speech was noted in the Chicago lines tested. "Normal" communication was effective

   25% of the time on ballasted track
   17% on elevated track
   7% in tunnels.

   Shouting was necessary 60% of the time to make communication feasible. (Analysed in terms of PSIL and Webster's criteria). (Ref. 104/649-650).

RAPID TRANSIT - CRUISE ***- AT GRADE or ELEVATED

Cars empty unless otherwise noted.

REF. (Date of meas.)	SYSTEM & LINE	WHEEL- STEEL RUBBER	TRACKBED CONCRETE TIE & BALLAST	SPEED km/h (mph)	SOUND LEVEL dBA	SOUND LEVEL OVERALL	SOUND LEVEL dBC	LOCATION OF OCTAVE BAND OR 1/3 O.B. DATA (Ref/Page)	COMMENTS
72	BART (S.F.)	S	C (elevated)	97 (60)	64	90		(72/145)	
		S	T&B (at grade)	97 (60)	72	96		(72/145)	
73	NYC - I.R.T. Flushing	S	C (elevated)	48 (30)	89	97		(73/12)	
* 6 & 7	NYC (1970-71)	S			70		96		
	Fort Worth (1970-71)	S			76		94		
74	Boston - (1964)	S	Elevated. Rail on wooden Sleepers	48 (30)		95		(74/55)	60 sec on straight, level track. Meas. in center of car. Multiple runs until data consistent
**64	Boston - Red Line (1972)	S	T&B, new.		Middle / End			(64/Appendix E)	Peak rms noise level. Also vibration data (64/22). Also noise data on outside p/at Form between cars.
			Welded rail, concrete ties	82 (51)	69 / 72				
			C (welded rail, bridge desk	74 (46)	75 / 78				
			T&B, old. wood ties. Non-welded rail	71 (44)	78 / 81				
			T&B, old, wood ties, Non-welded. ELEVATED	58 (36)	74 / 78				
*81/Fig. A4	Boston - Red Line	S	T&B, old, Welded rail		CAR TYPE I / II				Car Type I "Bluebirds" built 1963; Type II "Silverbirds" built 1970 (Air conditioned) Measured at height of seated passenger, 1/3 of distance from end of car.
	Kendall - Charles		ELEVATED		80 / 72				
	Charles - Park		"		79 / 70				
	(see page 2, continued)								

*** Called "plateau" by DOT/TSC.
** Air conditioning off.
*Cars in use with unspecified No. of passengers.

RAPID TRANSIT - CRUISE***- AT GRADE or ELEVATED, continued   Cars in use (partially full of passengers).

REF. (Date of meas.)	SYSTEM & LINE	WHEEL- STEEL RUBBER	TRACKBED CONCRETE TIE & BALLAST	SPEED km/h (mph)	SOUND LEVEL dBA CAR TYPE I	SOUND LEVEL dBA CAR TYPE II	OVERALL dBC		LOCATION OF OCTAVE BAND OR 1/3 O. B. DATA (Ref/Page)	COMMENTS
	(Boston Red Line, contd.)									
*81/FigA4 cont'd.	Andrew		At grade		81					
			↓		78					
					81					
	(various segments)				83					
					77					
	Fields Corner				79					
	South shore extension	S	T&B, new. Welded rail, concrete ties.							
			-at grade			70				
			-elevated			77				
*81/FigA3	Boston Orange Line	S	T&B, ELEVATED							
	Everette		↓			80				
						82				
	(various segments)					80				
	North Station					75				
	Dover					82				
						81				
						73				73 dBA: reduced speed zone
						83				
						87				
	Forest Hills					83				
*81/FigA2	Boston Blue Line	S	T&B, At grade							
	Airport-Wood Island		↓			83				
	Wood Island					85 {94}				{ } level when going through underpass
						86 {92}				
						87 {94}				
	Wonderland					84 {93}				
8/144					72 to 90				(8/144)	Generalized data from Wyle

*** Called "plateau" by DOT/TSC

RAPID TRANSIT - CRUISE - IN TUNNEL

All cars empty except as noted. Windows closed.

REF. (Date of meas.)	SYSTEM + LINE	WHEEL STEEL RUBBER	TRACKBED CONCRETE TIE&BALLAST	SPEED km/h (mph)	SOUND LEVEL dBA	Overall	dBC	LOCATION OF OCTAVE BAND OR 1/3 O.B. DATA (Ref./Page)	COMMENTS
72	Bart (S.F.)	S	C	97 (60)	80	97		(72/145)	
73		S	C	97 (60)	86	93		(73/14)	
72	BART (S.F.)	S	C	64 (40)	78	92		(72/145)	
72	Paris - Metro	R	T & B	64 (40)	82	94		(72/145)	
72	Paris - RER Line	S	T & B	80 (50)	75	86		(72/145)	
73	Montreal	R	T & B	72 (45)	83	92		(73/14) EMPTY CAR	
					85	91		(73/12) EMPTY CAR	
					77	89		(73/12) - FULL CAR	
73 ↓	NYC - I.R.T. Flushing	S	T & B	48 (30)	83	94		(73/13) ↓	Some car data too, but probably not enough for meaningful comparisons.
	NYC - B.M.T.	S	T & B	48 (30)	88	97			
	NYC - I.N.D.	S	C	48 (30)	91	98			
	NYC - I.R.T. 7th Ave.	S	T & B	48 (30)	88	100			
	NYC - Shuttle	S	C	48 (30)	85	94			
	NYC - PATH	S	T & B	32 (20)	83	97		(73/14)	Old line (1904, new cars 1962)
	Newark, N.J.	S	T & B		83	100			
6 + 7 ↓	NYC	S			75		96		
	Philadelphia				87		99		
	Forth Worth				86		98		
74 ↓	Toronto (1964)	S	C	24 (15)		82		(74/55) ↓	60 sec on straight, level track
				48 (30)		85			Measured in center of car
	Chicago - Dearborn St. (1964) & State St.	S	Wood ties on concrete	24 (15)		86			Multiple runs until constant
				48 (30)		92			data obtained.
	NYC - BMT (1964) 1960 cars	S	T & B	24 (15)		87			
				48 (30)		94			
	Philadelphia (1964)	S	Wood ties on concrete	24 (15)		--			
				48 (30)		98			

RAPID TRANSIT - CRUISE* IN TUNNEL - CONTINUED.

					SOUND LEVELS				
					dBA CAR TYPE I	dBA CAR TYPE II	OVERALL	dBC	
81/FigA4	Boston Red Line	S	T&B, non-welded rail						Car Type I "Bluebirds" built 1963; Type II "Silver-birds" built 1970. Air conditioned. Ref 80/p. (2-3) Measured at right of seated passengers, 1/3 of distance from end of car.
	Haward--Central				89	79			
	Central--Kendall				80	79			
	Park--Washington				83	70			
	S. Station--Broadway				84	75 **			
					89	81			
	Broadway--Andrew				88	81			Cars in use, (partially full of passengers).
					dBA				
81/FigA2	Boston Blue Line	S							
	Bowdoin--Govt. Center				85				
	Govt. Center--State				87				
	State--Aquarium				87				
	Aquarium--Haverick				93				
	Haverick--Airport				83				

** before and after curve.
* Also called "plateau" by DOT/TSC; = "steady state" level read between stations.

RAPID TRANSIT - IDLE IN STATION

REF.	SYSTEM & LINE	AIR COND. ON?	SOUND LEVEL dBA	SOUND LEVEL Overall	SOUND LEVEL dBC	LOCATION OF OCTAVE BAND DATA (Ref/page)	COMMENTS
81/Fig. A-1	Boston Blue line	No	71-72*				Cars partially full. All Boston data.
	Orange line	?	69-70*				Meas. at height of seated passenger 1/3
	Red line	No	66*				of distance from end of car.

* Avg. estimated by eye from time histories for several dozen stations for each line. For almost all stations, the level is the average level. The few exceptions vary by approximately 2 to 3 dB.

RAPID TRANSIT

BOSTON GREEN LINE

Car empty; air conditioning off. (Ref 79/App F)

Statistical summaries of time histories of 2 trips including stops: at-grade, bridge, subway route sections. dBA.

LINE	TYPE	SAMPLES (8/sec.)	AVG	STD. DEV.	L_{eq}	L_{01}	L_{10}	L_{50} MEDIAN	L_{90}	L_{99}	RANGE	WALSH-HEALY EXPOSURE	MEAS. PT.
Riverside to North Station	21,641 m (71,000 ft.) of "old" rail bed. Partly subway & party at grade.	19,200	82	5.3	85	92	89	84	73	70	32	6%	End (over front trucks 76 cm (30") from side of car, height of seated passenger's ear.
North Station to Riverside		20160	82	5.3	84	91	88	83	73	70	39	3.6%	

Additional Notes:

1) Single electric, 14 m (46-ft) car, representative of existing fleet: 1973-design PCC type built in 1951.

2) Also measured for the same run were:
   Journal box acceleration;
   Track gage & track midchord profile; vibration data.

3) One-third octave band data for 12 locations: pp F-17 ff. Includes one "wheel squeel" point (106 dBA @ 18 km/h (11 mph); pure tone peaks near 600 & 4000 Hz.

4) Speed never exceeded 64 km/h (40 mph).

RAPID TRANSIT

BOSTON REDLINE

(Ref 64/App E)

Statistical summaries of time histories of 3 trips including stops; at-grade, bridge, subway route sections. dBA.

LINE	TYPE	SAMPLES (8/sec.)	AVG	STD. DEV.	L_{eq}	L_{01}	L_{10}	MEDIAN	L_{90}	L_{99}	RANGE	WALSH-HEALY EXPOSURE	MEAS. PT.
S. Shore Extension	New rail bed Welded rail Concrete ties Neprene pads At grade	4200	70	2.9	71	78	74	70	67	63	20	0	Midcar
		4200	71	4.9	74	83	77	72	64	59	28	0	End (over rear trucks)
Ashmont Extension	Old rail bed Non-welded rail Wood ties Ballast 25% Subway	3840	70	4.7	73	83	80	70	65	63	25	0	Midcar
		3840	71	8.0	76	85	81	73	60	58	36	0	End (over rear trucks)
S. Shore Proper	Old rail bed Non-welded rail Wood ties on Ballast 95% Subway	7362	72	5.9	76	84	81	72	66	63	25	0	Midcar
		7362	71	8.6	78	86	83	72	61	58	31	0	End (over rear trucks)

RAILROADS. MEASUREMENT.

1. More data is required to make conclusions either about levels or about measurement techniques themselves.

2. There has been little discussion in the literature of measurement techniques, especially when compared to the activity in rapid transit measurement.

3. Compared to rapid transit, measurement is simplified because "cruise" is the predominant mode.

RAILROADS. HEALTH AND WELFARE.

1. There are no discussions in the literature.

At grade unless otherwise noted. A - Aisle seat, W - Window seat.
All cars in use (i.e., at least partially full), unless otherwise noted.

COMMUTER RAILROADS -- CRUISE

SOUND LEVELS

REF. (date of meas.)	TYPE	OPERATOR	PROPULSION	SPEED km/h (mph)	END of Car (over tracks) AISLE dBA		WINDOW dBA		not spec. dBA		MIDDLE of Car AISLE dBA		WINDOW dBA		not spec. dBA		OTHER not specified dBA		COMMENTS
					dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	
6 + 7	Coach (PATCO)	Port Authority Transit Co.	Electric	121 (75)													74	92	
																	72	84	
																	66	85	Underground (subway)
	Silverliner Coach	Penn Central	Electric	64 (40)													73	92	Underground (subway)
8/139	Coach		Electric	121 (75)													74		This is probably PATCO data again.

INTERCITY RAILROADS -- CRUISE

At grade, unless otherwise noted. A = Aisle seat. W = Window seat. All cars in use (i.e., at least partially full), unless otherwise noted.

REF. (date of meas.)	TYPE	OPERATOR	PROPULSION	SPEED km/h (mph)	SOUND LEVELS: END of Car (over: AISLE dBA	AISLE dBC	WINDOW dBA	WINDOW dBC	not spec. dBA	not spec. dBC	MIDDLE of Car: AISLE dBA	AISLE dBC	WINDOW dBA	WINDOW dBC	not spec. dBA	not spec. dBC	OTHER not specified dBA	OTHER not specified dBC	COMMENTS
6 + 7	Intercity Coach	Penn Central	Diesel electric and Electric	97-129 (60-80)									75	91					
													74	94					
													71	93					
	Metroliner Coach	Penn Central	Electric	203(126)			71	92											
					67	90	70	92											
	Intercity Coach-roomette	Penn Central	Diesel electric and Electric	97-129 (60-80)							62	91			62	91			
															57	84			
	Coach	Atchison, Topeka & Santa Fe R. R.	Diesel electric	97-129 (60-80)	70	94			70	95	64	88							
											64	91							
	Hi-level Coach				63	93	69	96					66	93					
					63	90	66	91											
							65	92											
	Roomette	Southern R. R.	Diesel electric	97-129 (60-80)					64	85									
8/139	Coach		Diesel electric						60	82							60-75		Min-max, depending on rails, etc. Wyle data.

FIXED WING AIRCRAFT. MEASUREMENT.

1. A methodology for large commercial planes is given in Ref. 84 p. 7. The measurement position is one foot in front of the passenger, with window or aisle seat specified. Measurements immediately next to the window averaged 4-10 dBA higher (Refs. 84, 108) than those taken at the passenger's usual head position in the window seat. It is a matter of judgement whether a standard methodology should require adjacent-to-window measurements, but it is true that a sleeping passenger, on long flights, may rest his head very close to the window.
   A methodology for recording sound in light aircraft cockpits for later analysis or playback is described in Ref. 2, Ref. 70, and others. Distinctions based on seat positions in larger light aircraft are discussed in Ref. 102.

2. In all references, measurements have been made at ear-level.

3. At "cruise" noise is generally steady except for increased in noise in jets, due to occasional beat frequencies of 4-10 dBA amplitude (engines out of phase) (82/20).

4. In large commercial aircraft, the passenger does not usually have access to knowledge of engine settings as he take measurements. Instead, he must assume that because of pilot and route standarization, settings fall into a fixed range for each plane operation/load. He then takes repeated measurements on various flights to determine that range. He should note altitude of cruise when taking cruise noise measurements.
   In light planes, however, both altitude (or rate of climb) and engine settings (and air speed) can and should be noted to specify method of operation.

5. The cruise noise measurement is the single most important noise indicator in estimating exposure. However, on many short haul flights, a significant portion of the trip is spent climbing to altitude, switching altitude or descending, so noise measurements for those modes should also be taken. Here the best that can be done is to get a range of typical values, unless a tape recorder is used.

6. A design measurement methodology for the contribution of noise from the boundary layer is given in Ref. 83.

7. In light aircraft measurements have been taken in various measurement positions with little difference in results so long as as microphones were not too close to windows. There is some difference on the 6-10 seat planes from front to rear, however (Ref. 102/6).

8. For light plane cruise, one source found little difference in readings taken from below 914 m (3000 ft.) up to 2438 m (8000 ft.) Ref. 102/6).

FIXED WING AIRCRAFT. HEALTH AND WELFARE.

1. McClelland played back sound tape-recorded in a light plane cabin to subjects in a sound proof booth and measured TTS, speech interference, and effect of mental task performance for a 1-hr exposure (Ref. 2) TTS[2] ranged from 3.7 dB to 11.6 dB, depending on frequency. Speech discrimination scores, 98.4% in quiet, dropped to 60.4% in noise. Three additional normal hearing subjects were exposed to noise for 3 hours. By the end of the 2nd hour, TTS had reached the Damage Risk Criterion at several frequencies; by the end of the 3rd hour; at all frequencies from 125 through 300 H_z. The effect of mental tasks seemed to be to heighten the amount of TTS obtained.

2. The spectral energy distributions of noise in 16 piston-engine light planes tested are remarkably similar, and the noise from the plane used in the tests in Ref. 84 closely approximated the average overall level and the average levels per octave band.

3. U.S. Army TB MED 251 of 25 January 1965 requires use of ear protection when certain octave band levels are exceeded, and is applied in numerous references (e.g. Ref. 90, 94, 99) to various military aircraft, only a few of which have direct commerical equivalents.

AIRCRAFT TYPE: Convair 880

( ) = Ref. No.

Approx. No. of Passengers ____
No. of Engines 4
Type Turbo jet
Position of Engine Wings

	SOUND LEVELS																	
	FRONT				MIDDLE				REAR				OTHER					
	Aisle		Window		Aisle		Window		Aisle		Window		Window Seats					
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m(ft) 3048 (10,000) 7620 (25,000) 10666 (35,000) (83)															65 63 62	90 94 94	Front Middle 355 kts. 3048 m. Rear
															72 68 [illegible]	92 95 97	Front Middle 515 kts. 7620 m. Rear
															64 62 60	89 91 84	Front Middle 460 kts. 10, 666 m. Rear
(61) 35, 000													80(61)				"Window"
Cruise Alt. unspecified)											82(7)	93(7)					
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ____

AIRCRAFT TYPE: Boeing 737

( ) = Ref. No. Data from Ref. 113 avg of several flights, various conditions

Approx. No. of Passengers ______
No. of Engines 2
Type Jet
Position of Engine Wings

OPERATION \ SOUND LEVELS	FRONT SEATS Aisle dBA	FRONT SEATS Aisle dBC	FRONT SEATS Window dBA	FRONT SEATS Window dBC	MIDDLE SEATS Aisle dBA	MIDDLE SEATS Aisle dBC	MIDDLE SEATS Window dBA	MIDDLE SEATS Window dBC	REAR SEATS Aisle dBA	REAR SEATS Aisle dBC	REAR SEATS Window dBA	REAR SEATS Window dBC	OTHER Not Specified dBA	OTHER Not Specified dBC	OTHER Not Specified PSIL		NOTES
Takeoff													90±5 (113)				
Climb													84±5 (113)				
Cruise Altitude m(ft) 7315 (24,000)	80 (84)	86 (84)			82 (84)	92 (84)			84 (84)	92 (84)	86 (84)						From Fig. 3, Ref. 84
Cruise (alt. not spec.)													77±5 (113)				
Descent													75±5 (113)				
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ______

AIRCRAFT TYPE: Boeing 727

( ) = Ref. No. (All data from Ref. 8 from p. 20)

Approx. No. of Passengers ____________
No. of Engines 3
Type jet
Position of Engine rear

OPERATION	SOUND LEVELS: FRONT Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER dBA	OTHER dBC	OTHER PSIL	NOTES
Takeoff	76(9)	86(8)					79(8) 78(8)	97(3)			83(8)	103(8)				
Climb	78(8)	87(8)					83(8) 75(8)	88(8)			81(8)	96(8)				
Cruise Altitude m(ft) 4877(16,000)	83-85 (84)	83-92 (84)	86(84)	90-93 (84)												Data taken from figure 3, Ref. 84.
6096(20,000)	82(84)	87(84)			84(84)	92(84)	84(84)	93(84)	85-87 (84)	93-94 (84)	87-88 (84)	97-99 (84)				
7315(24,000)							86	96								
8534(28,000)	78-82 (84)	85-89 (84)									85(84)	93-97 (84)				
Cruise (alt. not spec.)	80(61) 80(8)	87(8)	83(8) 83(8) 78(8)	95(8) 95(8) 88(8)	83 83(7) 78	95 95(7) 88	82(7) 82(8) 83(8)	94(7) 93(8)			83(7) 83 85(6) 86(8)	97(7) 97 97(8)	89(61)			Ear near window
Descent							78(8) -80 85(8)	95(8)								
Landing							72-78 (8)									
Reverse thrust																
Taxi	74(8)	86(8)					70(8) 74(8)	89(8)			78(8)	93(8)				

Other data in Refs: (8/21) - Generalized Data

AIRCRAFT TYPE: Boeing 720B

( ) = Ref. No.

Approx. No. of Passengers ______
No. of Engines ______
Type ______
Position of Engine ______

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff							94 (8)										
Climb							84 (8)										
Cruise (ft)																	
Cruise (alt. not spec.)							83 (3)										
Descent							86 (8)										
Landing							73-79 (8)										
Reverse thrust							70 (8)										
Taxi																	

Other data in Refs: (8/21 Generalized Wyle data)

AIRCRAFT TYPE: 707

( ) = Ref. No.

Approx. No. of Passengers ____

No. of Engines 4

Type Turbo jet & Turbo fan

Position of Engine Wing

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff																	
Climb																	
Cruise (ft) Alt (1000ft)																	
Cruise (alt. not spec.)					73 (7)	81			77 (7)	85							
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ____

AIRCRAFT TYPE: L-1011

( ) = Ref. No.

Approx. No. of Passengers ______

No. of Engines 3

Type Jet

Position of Engine Wing & tail

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff					77(84)	97(84)										
Climb					77(84)	92(84)										
Cruise altitude m (ft) 10058 (33,000)	78-82	86-92			78-81	88-91			80-81	90-93	82-85	95-101	86-90	97-101		From Fig. 4, Ref. 84.
Cruise (alt. not spec.)																
Descent																
Landing																
Reverse thrust																
Taxi					72(84)	83(84)										

Other data in Refs: ______

AIRCRAFT TYPE: DC-10

( ) = Ref. No.

Approx. No. of Passengers ____________
No. of Engines 3
Type Jet
Position of Engine 2 on wings, 1 on tail

SOUND LEVELS / OPERATION	FRONT SEATS				MIDDLE SEATS				REAR SEATS				OTHER				NOTES
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff											87(84)	103					
Climb			83(84)	95							82(84)	99					
Cruise Altitude m (ft) 7620 (25,000)	78-80 (84)	88-90 (84)	78-81 (84)	87-90 (84)					78-80 (84)	88-90							From Fig. 4, Ref. 84
10,668 (35,000)			73-75 (84)	83-88 (84)									78-79 (84)	85-90 (84)			Other: "Ear near window"
Descent																	
Landing																	
Reverse thrust																	
Taxi											74 (84)	92					

Other data in Refs: ____________

AIRCRAFT TYPE: DC-9

( ) = Ref. No.

Approx. No. of Passengers ________
No. of Engines 2
Type Turbo Fan
Position of Engine Rear

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff (108)											93	106				
Climb									89	102	89	102				
Cruise Altitude m;(ft.) 7315 (24,000)									87	99	86	98				
Cruise (alt. not spec.) (7)	83 82 80	86 86 86			79 78 76	85 91 84	82	95	91 91	104			85 85 87	96 95 98		Rear of airplane) middle seat
Descent (108)									82-83		84-85					
Landing (108)											86	98				
Reverse thrust (108)											97					
Taxi									76	92	79	95				

Other data in Refs: 108: All "Rem" data from seat beside engines.

AIRCRAFT TYPE: DC-8

( ) = Ref. No.

Approx. No. of Passengers ______

No. of Engines 4

Type Turbo jet

Position of Engine Wing

OPERATION	SOUND LEVELS: FRONT Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER dBA	OTHER dBC	OTHER PSIL	OTHER Middle	NOTES
Takeoff							100 (8)										
Climb							82-85 (8)										
Cruise Altitude m(ft.) 10668 (35,000) (61)			80 (61)														
Cruise (alt. not spec.)							80-92 76-81 80 (8)									77-88 (8)	Seat 64A
Descent							78 68 (8)										
Landing							70-65 (8)										
Reverse thrust																	
Taxi							63-65 (8)										

Other data in Refs: (8/21 generalized Wyle data)

AIRCRAFT TYPE: BAC 1-11

( ) = Ref. No.

All data Ref. 108

Approx. No. of Passengers 75
No. of Engines 2
Type Turbo Fan
Position of Engine Rear

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff											91	101					Rear seats 15A & 15B
Climb									82	92	84-85	96-97					
Cruise Altitude m(ft.) 5486-6096 (18-20,000)					81	88			82	91-92	83	94					Middle: Seat 13C (closer to rear 1/3)
Cruise (alt. not spec.)																	
Descent	78	84	78	88					76-78	90	78-79	94-95					Front: seats 2D & 2E
Landing											81						
Reverse thrust											93						
Taxi					79	89					82		95				

Other data in Refs:

AIRCRAFT TYPE: YS-11A

( ) = Ref. No. All data from Ref. 113, avg of several flights.

Approx. No. of Passengers 60
No. of Engines 2
Type Turbo prop
Position of Engine Wings

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window		Not Specified			
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff													88 ± 5			
Climb													83 ± 5			
Cruise Altitude m (ft.)																
Cruise (alt. not spec.)													79 ± 5			
Descent													72 ± 5			
Landing																
Reverse thrust																
Taxi																

Other data in Refs:

AIRCRAFT TYPE: Fairchild Hiller FH-227

( ) = Ref. No.

All data from Ref. 113, avg. of several flights.

Approx. No. of Passengers 50
No. of Engines 2
Type Turbo prop
Position of Engine Wings

	SOUND LEVELS															
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window		Not Specified			
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	NOTES
Takeoff													80 ± 5			
Climb													80 ± 5			
Cruise																
Cruise (alt. not spec.)													80 ± 5			
Descent													80 ± 5			
Landing																
Reverse thrust																
Taxi																

Other data in Refs: __________

AIRCRAFT TYPE: Nord 262 (French)

( ) = Ref. No.

All data from Ref. 113, avg. of several flights.

Approx. No. of Passengers 29

No. of Engines 2

Type Turbo prop

Position of Engine Wings

	SOUND LEVELS															
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window		Not Specified			
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	NOTES
Takeoff													92 ± 4			
Climb													87 ± 3			
Cruise																
Cruise (alt. not spec.)													86 ± 3			
Descent													83 ± 5			
Landing																
Reverse thrust																
Taxi																

Other data in Refs: __________

AIRCRAFT TYPE: DeHaviland Twin Otter

( ) = Ref. No. (Data from Ref. 113 avg. of several flights, various conditions.)

Approx. No. of Passengers 12-22
No. of Engines 2
Type Turbo prop
Position of Engine Wing

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff													95 ± 10 (113)				
Climb													88 ± 3 (113)				
Cruise																	
Cruise (alt. not spec.)			86(7)	103 (7)	85(7)	103 (7)	85(7)	103(7			87(7) 82(7)	101 (7) 99(7)	87 ± 2 (113)				
Descent													88 ± 4 (113)				
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: __________

AIRCRAFT TYPE: Beech 99

( ) = Ref. No. All data from Ref. 112. Avg. of 30 flights, various loads and altitudes.

Approx. No. of Passengers 8-12
No. of Engines 2
Type Piston
Position of Engine Wings

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Approx. middle of cabin				
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		NOTES
Takeoff													88-96				
Climb													90-94				
Cruise																	
Cruise (alt. not spec.)													87-92				
Descent													78-82				
Landing																	
Reverse thrust																	
Taxi													68				

Other data in Refs: ____

AIRCRAFT TYPE: Volpar Beech (a "stretch" B-99)

( ) = Ref. No.

All data from Ref. 113, avg. of several flights.

Approx. No. of Passengers 15
No. of Engines 2
Type Turbo prop
Position of Engine Wings

SOUND LEVELS / OPERATION	FRONT				MIDDLE				REAR				OTHER				NOTES
	Aisle		Window		Aisle		Window		Aisle		Window		Not Specified				
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff													89±3				
Climb													84±4				
Cruise																	
Cruise (alt. not spec.)													86±2				
Descent													78±4				
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ______

AIRCRAFT TYPE: Mooney MK21

( ) = Ref. No.

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Ear level bet. front seats				
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise																	
Cruise (alt. not spec.)													91		77	108 (2) 109 (76)	dBA & PSIL calculated from octave band data.
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: Octave bands Ref. (2/slide 3)

AIRCRAFT TYPE: Cessna Cardinal RG (1974)

( ) = Ref. No.

Approx. No. of Passengers 5 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

	SOUND LEVELS															
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	NOTES
Takeoff			97 (102)													
Climb																
Cruise																
Cruise (alt. not spec.)			96 (102)													75% Cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs: ______

AIRCRAFT TYPE: Cessna Skyhawk (1974)

( ) = Ref. No. (a type of 172)

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

	SOUND LEVELS															
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	NOTES
Takeoff			94 (102)													
Climb																
Cruise																
Cruise (alt. not spec.)			93 (102)													75% Cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs: ______

AIRCRAFT TYPE: Cessna 172

( ) = Ref. No.

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

	SOUND LEVELS																				
	FRONT				MIDDLE				REAR				OTHER								
	Aisle		Window		Aisle		Window		Aisle		Window		between pilot and co-pilot								
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	NOTES				
Takeoff			100 (102)																		
Climb																					
Cruise																					
Cruise (alt. not spec.)			92 (102)														1973 model, 75% cruise, ∠ 914 m (3000 ft.)				
																109 (76)	2300 rpm, 100 IAS (indicated as speed)				
Descent																					
Landing																					
Reverse thrust																					
Taxi																					

Other data in Refs:

AIRCRAFT TYPE: Mooney Ranger (1974)

( ) = Ref. No.

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

	SOUND LEVELS															
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	NOTES
Takeoff			97 (102)													
Climb																
Cruise Altitude m (ft.)																
Cruise (alt. not spec.)			92 (102)													75% cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs: ______

AIRCRAFT TYPE: Mooney Chaparral (1964)

( ) = Ref. No.

Approx. No. of Passengers 3 +pilot
No. of Engines 1
Type Piston
Position of Engine Front

OPERATION	SOUND LEVELS: FRONT Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER dBA	OTHER dBC	OTHER PSIL		NOTES
Takeoff			102 (102)														
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)			92 (102)														75% cruise, < 914 m (3000 ft)
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ______

AIRCRAFT TYPE: Bellanca Super Viking (1974)

( ) = Ref. No.

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff																
Climb					95 (102)											25 in M.P.; 2500 rpm
Cruise Altitude m (ft.)																
Cruise (alt. not spec.)					97 (102)											75% cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs: __________

AIRCRAFT TYPE: Rockwell Commander 112 (1974)

( ) = Ref. No.

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff			97 (102)													
Climb																
Cruise Altitude m (ft.)																
Cruise (alt. not spec.)			95 (102)													75% cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs:

AIRCRAFT TYPE: Cessna 310 (1974)

( ) = Ref. No.

Approx. No. of Passengers 5 + pilot
No. of Engines 2
Type Piston
Position of Engine Wings

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff			99 (102)								95-97 (102)						
Climb																	
Cruise Altitude m (ft.)																	75% cruise
Cruise (alt. not spec.)			97 (102)						93-95 (102)							104	75% cruise, <914 m (3000 ft.) 2300 rpm, manifold 24, model yr unknown, 310G.
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs:

AIRCRAFT TYPE: Piper Seneca

( ) = Ref. No.

Approx. No. of Passengers 5 + pilot
No. of Engines 2
Type Piston
Position of Engine Wings

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window					
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff			98 (102)				95 (102)				94 (102)					
Climb																
Cruise Altitude m (ft.)																
Cruise (alt. not spec.)			93 (102)				88 (102)				93 (102)					75% cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs:

AIRCRAFT TYPE: Cessna Centurion (1974)

( ) = Ref. No.

Approx. No. of Passengers 4 or 5 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

OPERATION	SOUND LEVELS: FRONT Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER dBA	OTHER dBC	OTHER PSIL	NOTES
Takeoff			95 (102)													
Climb																
Cruise Altitude m (ft.)																
Cruise (alt. not spec.)			94 (102)													75% cruise, < 914 m (3000 ft.)
Descent																
Landing																
Reverse thrust																
Taxi																

Other data in Refs: ____________

AIRCRAFT TYPE: Cessna Skylane (1974)

( ) = Ref. No.

Approx. No. of Passengers 3 + pilot
No. of Engines 1
Type Piston
Position of Engine Front

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window						
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		NOTES
Takeoff			94 (102)														
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)			93 (102)														75% cruise < 914 m (3000 ft.)
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs:

AIRCRAFT TYPE: Piper J-3

( ) = Ref. No.

Approx. No. of Passengers ________
No. of Engines ________
Type ________
Position of Engine ________

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. pilot & Co-pilot				
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																107 (74)	2100 rpm 70 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ________

AIRCRAFT TYPE: Piper Colt

( ) = Ref. No.

Approx. No. of Passengers

No. of Engines

Type

Position of Engine

	SOUND LEVELS																	
	FRONT				MIDDLE				REAR				OTHER					
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-Pilot					
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall		NOTES
Takeoff																		
Climb																		
Cruise Altitude m (ft.)																		
Cruise (alt. not spec.)																106 (74)		2500 rpm 105 manifold or IAS
Descent																		
Landing																		
Reverse thrust																		
Taxi																		

Other data in Refs:

AIRCRAFT TYPE: Piper Cherokee

( ) = Ref. No.

Approx. No. of Passengers ____________
No. of Engines ____________
Type ____________
Position of Engine ____________

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-pilot				
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																115 (74)	2350 rpm 115 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ____________

AIRCRAFT TYPE: Piper Tripacer

( ) = Ref. No.

Approx. No. of Passengers ____
No. of Engines ____
Type ____
Position of Engine ____

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-pilot				
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																105 (74)	2250 rpm 112 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ____

AIRCRAFT TYPE: Cessna 182

( ) = Ref. No.

Approx. No. of Passengers

No. of Engines

Type

Position of Engine

OPERATION	SOUND LEVELS																		NOTES
	FRONT				MIDDLE				REAR				OTHER						
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-pilot						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall			
Takeoff																			
Climb																			
Cruise Altitude m (ft.)																			
Cruise (alt. not spec.)																104 (74)			2300 rpm 22 manifold or IAS
Descent																			
Landing																			
Reverse thrust																			
Taxi																			

Other data in Refs:

AIRCRAFT TYPE: Helio

( ) = Ref. No.

Approx. No. of Passengers

No. of Engines

Type

Position of Engine

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-pilot				
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																106 (74)	2600 rpm 22 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs:

AIRCRAFT TYPE: Apache 160

( ) = Ref. No.

Approx. No. of Passengers ____________
No. of Engines ________
Type ________
Position of Engine ____________

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-Pilot				
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																103 (74)	2250 rpm 22 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: 74/1134

AIRCRAFT TYPE: Commanche 250

( ) = Ref. No.

Approx. No. of Passengers ______
No. of Engines ______
Type ______
Position of Engine ______

OPERATION	SOUND LEVELS: FRONT Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER Bet. Pilot & Co-pilot dBA	OTHER Bet. Pilot & Co-pilot dBC	OTHER Bet. Pilot & Co-pilot PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																100 (74)	2200 rpm 22.5 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: 74/1134

AIRCRAFT TYPE: Beech E185

( ) = Ref. No.

Approx. No. of Passengers ____
No. of Engines ____
Type ____
Position of Engine ____

OPERATION	SOUND LEVELS: FRONT Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER Bet. Pilot & Co-Pilot dBA	OTHER dBC	OTHER PSIL	OTHER Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																106 (74)	1900 rpm 24 manifold or IAS
Cruise (alt. not spec.)																	
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: ____

AIRCRAFT TYPE: Cessna 140

( ) = Ref. No.

Approx. No. of Passengers ____________
No. of Engines __________
Type ____________
Position of Engine ______________

OPERATION	SOUND LEVELS — FRONT — Aisle dBA	FRONT Aisle dBC	FRONT Window dBA	FRONT Window dBC	MIDDLE Aisle dBA	MIDDLE Aisle dBC	MIDDLE Window dBA	MIDDLE Window dBC	REAR Aisle dBA	REAR Aisle dBC	REAR Window dBA	REAR Window dBC	OTHER — Bet. Pilot & Co-pilot dBA	dBC	PSIL	Overall	NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																103 (74)	2250 rpm 103 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: 74/1134

AIRCRAFT TYPE: Bonanza "H"

( ) = Ref. No.

Approx. No. of Passengers ____
No. of Engines ____
Type ____
Position of Engine ____

	SOUND LEVELS																
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Bet. Pilot & Co-pilot				
OPERATION	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		NOTES
Takeoff																	
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)																102 (74)	2200 rpm 22 manifold or IAS
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: 74/1134

AIRCRAFT TYPE: Cessna Super Skymaster (1974)

( ) = Ref. No.

Approx. No. of Passengers 4 + pilot
No. of Engines 2
Type Piston
Position of Engine 1 Front + 1 Pusher rear

SOUND LEVELS

SOUND LEVELS / OPERATION	FRONT				MIDDLE				REAR				OTHER				NOTES
	Aisle		Window		Aisle		Window		Aisle		Window						
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff			97 (102)														
Climb																	
Cruise Altitude m (ft.)																	
Cruise (alt. not spec.)				94 (102)													75% cruise, < 914 m (3000 ft.)
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: __________

AIRCRAFT TYPE: Cessna 150

( ) = Ref. No.

Approx. No. of Passengers 1 + Pilot
No. of Engines Single
Type Piston
Position of Engine Front

SOUND LEVELS / OPERATION	FRONT				MIDDLE				REAR				OTHER				NOTES
	Aisle		Window		Aisle		Window		Aisle		Window		Pilot's head			Over all	
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff			95 (102)														
Climb																	
Cruise Altitude m (ft)																	
Cruise (alt. not spec.)			91 (102)													105	1972 model, 75% cruise, < 914 m (3000 ft) 2400 rpm 105 IAS
													94* (76)			111 (76)	
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs:

AIRCRAFT TYPE: GRUMMAN GULFSTREAM II

All data from Ref. 11r
NOTE: DATA IN DBC COLUMNS ARE OVERALL SPL.

Approx. No. of Passengers ____
No. of Engines 2
Type Jet
Position of Engine ____

OPERATION	SOUND LEVELS																NOTES
	FRONT				MIDDLE				REAR				OTHER				
	Aisle		Window		Aisle		Window		Aisle		Window		Lavatory				
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL		
Takeoff																	SN 103. Eight passengers in cabin.
Climb																	
Cruise - Alt. m (ft.)																	
9449 (31,000)		69		69				79									Mach 0.75
10058 (33,000)								75				74		85			Mach 0.85
11887 (39,000)				67				69						84			Mach 0.75
Cruise (alt. not spec.)																	
Descent																	
Landing																	
Reverse thrust																	
Taxi																	

Other data in Refs: o.b. data in ref. 114

AIRCRAFT TYPE: GRUMMAN GULFSTREAM

All data from Ref 114.

Approx. No. of Passengers ____
No. of Engines 2
Type Turboprop (?)
Position of Engine ____

OPERATION	SOUND LEVELS: FRONT Aisle	FRONT Window SIL	FRONT Window Over all	MIDDLE Aisle	MIDDLE Window SIL	MIDDLE Window Over all	REAR Aisle	REAR Window SIL	REAR Window Over all	OTHER Galley dBA	OTHER Galley dBC	OTHER SIL	OTHER Over all	NOTES
Takeoff														
Climb														
Cruise Altitude m (ft) 620 (25,000)		60 -70	99 -110		60 -69	97 -110		59-64	100 -107			70 -85	106 -114	Sample of 10 aircraft. Air Cond. on "normal" 195 kts IAS or 285 TAS (cruise power) Levels are maximum levels.
		66 avg.	104 avg.		64 avg.	105 avg.		61 avg.	104 avg.			77 avg.	109 avg.	Arithmetic averages
Cruise (alt. not spec.)														
Descent														
Landing														
Reverse thrust														
Taxi														

Other data in Refs: o.b. data in Ref. 114.

HELICOPTERS. MEASUREMENT.

1. Comparison of vehicles. A major factor in analyzing the data collected is that noise levels in commercial helicopters cannot be inferred from data gathered in their military equivalents, even though commercial types have generally been the direct offspring of military types (Ref. 85/2, 103a, 105). In addition, noise levels in one commercial type may vary from specimen to specimen, because different soundproofing options are offered by the manufacturer, and the customer may also elect to have a soundproofing "kit" installed by a third party vendor (Ref. 103a). Nevertheless, we have included military data, mostly for interest and purposes of comparison, and partly because there is little commercial data.

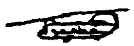
HELICOPTERS. HEALTH and WELFARE

1. Choice of units. In Reference 109/10, it is stated that the A weighted sound level may not represent the measure of human response to helicopter noise, since the low frequencies characteristic of rotor noise are de-emphasized.

2. Much work done by the military emphasizes hearing damage risk (Refs 89, 91 - 93, 95, 97), while some civil works emphasize speech interference (Ref. 85). The explanation is probably threefold: (a) military helicopters are noisier, (b) commercial flight durations are short--usually under ½ hour, (c) military crews communicate with each other via intercom using headsets.

HELICOPTERS - CRUISE

Measured in passenger compartments, except as noted.

Ref. (Date)		Military Commerical	Equiv. Designation Comm.	Military / Popular Name	"Make"	Sound Levels dBA	dBC	Over-all	SIL	PSIL	Mode of Operation	Comments	Octave Band or 1/3 of data in Ref.
85		C	S-61		Sikorsky	93		105	80.3	86.3		93 PNdB	No
(1972)													
		C	S-58							85			
		C	S-58T							75		1970 a.c. with commercial	
		C	S-65-40							75		interior.	
		C	S-200							(68)		Design goal for 1980 s a.c.	
86					Boeing								
(1968)		M		CH-21C Shawnee	Vertol			114	91*		74 km/h (40 knots)	Gasaway, center mid-section	Yes
								113			130 km/h (70 knots)		
(1963)		M		CH-37B Mojave				116	107*		139 km/h (75 knots)	Gasaway & Hatfield	
(1969)		M		CH-47C Chinook		106	114	117		98*	185 km/h (100 knots) @ 235 prop	Camp. Center mid-section	
		M		OH-6A Cayuse		94	106	107		87*		Camp. & Boris Small cabin. Diffuse field.	
(1963)		M		OH-23D Raven				107	86*		111 km/h (60 knots) @ 6500 rpm 325 prop. rpm	Gasaway & Hatfield	
(1968)		M		UH-1D Iroquois (Huey)		98	106	107		91*	162 km/h (90 knots) @6600 rpm	Camp. pilots position	
						97	108	111			" " "	" L. side of transmission	
								109				with soundproofing blankets	
(1963)		M		" "				109			148 km/h (80 knots)@6600 rpm	Gasaway & Hatfield Pilots position	
(1963)		M		UH-19D Chickasaw	Sikorsky			110	93*		@2400 rpm, manifold 29	Gasaway & Hatfield Center forward	
87		C	Vertol 347		Boeing Vertol	82-83					301 km/h (187 mph) knots	95 PNdB-$\frac{12}{\text{or } 13}$ ≅ 82-83 dBA	No.
8/54		C				86-100					"Light utility, 2-7 seats"	Generalized Wyle data	(8/57-58)
						83-96					"Medium weight, 10-15 seats"		
						85-104					"Heavy transport, 20-50 seats"		
6 & 7		C	206A		Bell	90	109				(Turbine engine)	2 a.c. ? 2 trips on one	
						89	104					a.c. ?	

* Calculated from octave band levels: PSIL = 1/3 (L500 + L1000 + L2000)

SIL = 1/3 [L (600-1200) + L (1200-2400 + L (2400-4800)]

HELICOPTERS - CRUISE (continued). Measured in passenger compartments, except as noted.

Ref. (Date)	Military / Commerical	Equiv. Designation: Comm.	Equiv. Designation: Military / Popular Name	"Make"	Sound Levels: dBA	dBC	Over-all	SIL	PSIL	Mode of Operation	Comments	Octave Band or 1/3 of data in Ref.
105	C	BO-107	CH-46	Boeing Vertol	87			65		222 km/h (120 knots)	Calculated from O. B. data	Yes
					93			71		"		
				Bell	101		106	89*		Max levels of 3 seat positions Min levels during hover & max. forward air speed. (calculated from maxima in each octave band and minima in each octave band. Actual max. A-weighted level probably somewhat lower.)	Light (GW less than 6000 lb) turbine helicopter. Probably or 4-places	Yes
106 (1960)	C	Vertol-44	H-21C	Boeing Vertol	87.1		105	70*		"various flight conditions"	Commercial equiv. of military	Yes
								67		from (106/184)	CH-21C (see above)	
	M		H-21C	"			108	93		" " "	Military, for comparison With "soundproof	
							117			" " "	without "	
(1958)	M		HR-2S-1				119					

HOVERCRAFT -- CRUISE

REF	MANUFACTURER'S NAME	DESIG.	DESCRIPTION	SOUND LEVEL			OCTAVE BAND DATA (Ref/pg)	COMMENTS
				dBC	dBA	OVER-ALL		
112	———	HM2	50 passenger			85-86	———	British
88	Vosper	VT1-001	———		80	99	88/243	British
			Small fan-driven		88	104		
			Large air propeller-driven		92			
			Small water propeller-driven		93	106		
			Small air propeller-driven		95	108		

HOVERCRAFT

TYPE: HM-2 (British, used in Florida)

( ) = Ref. No.

All data from Ref. 112

Approx. No. of Passengers 50

No. of Engines ______

Type ______

Position of Engine ______

OPERATION	SOUND LEVELS															NOTES
	FRONT				MIDDLE				REAR				OTHER			
	Aisle		Window		Aisle		Window		Aisle		Window		Passenger Cabin			
	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC	PSIL	
Takeoff													82-84			Rising on water 30-50 sec. duration
Climb																
Cruise Altitude - m (ft)													85-86			Approx. 65 km/h (35 knots)
Cruise (alt. not spec.)																
Descent													78			Lowering to surface of water
Landing													72			
Reverse thrust																
Taxi													80			on water

Other data in Refs: ______

APPENDIX B

Data Forms

AIRCRAFT

1. NAME: 2. DATE
3. OFFICE PHONE #:
4. DEPARTURE TIME:
5. ARRIVAL TIME: AND PLACE:
6: AIRLINE: 7. FLIGHT #:
8. MAKE, MODEL, & YEAR OF AIRCRAFT:
9. FORM OF PROPULSION (JETS, TURBO PROP, OR PISTON PROP):
10. TOTAL # OF ENGINES:
11. LOCATION OF ENGINES (WINGS, TAIL, AND/OR FRONT):
12. SOUND LEVEL (USE SLOW RESPONSE) & DURATION OF VARIOUS MODES OF OPERATION:

	dBA	dBC	DURATION (SPECIFY UNITS)	SPEED (SPECIFY UNITS)	ALTITUDE (SPECIFY UNITS)
a. taxi to runway	____	____	________		________
b. take-off (acceleration)	____	____	________		________
c. climb	____	____	________		________
d. cruise	____	____	________	________	________
	____	____	________	________	________
e. landing (deceleration)	____	____	________		________
f. reverse thruster application	____	____	________		________
g. taxi to terminal	____	____	________		________

13. SEATING LOCATION:
    a. total # of rows (including first class):
    b. your row #:
    c. window, middle, aisle or other (specify) seat?:

14. WINDOW CONDITION:
    a. is the window nearest to you open?:
    b. total # of windows open?:
    c. total # of windows closed?:
    d. if closed, are they sealed?:

15. AIR VENT CONDITION:
   a. is your air vent open?:
   b. are your neighbors' air vents open?:

16. GALLEY FAN:
   a. is the galley (kitchen) air exhaust fan on?:
   b. if so, how many rows are you from the galley fan?:

17. TYPE OF SOUND LEVEL METER:

18. ADDITIONAL COMMENTS:

CAR, BUS, RAPID TRANSIT-SUBWAY, TROLLEY, OR TRAIN

1. NAME:
3. OFFICE PHONE #:
4. DEPARTURE TIME: AND PLACE:
5. ARRIVAL TIME: AND PLACE:
6. VEHICLE TYPE (CAR, BUS, RAPID TRANSIT-SUBWAY, TROLLEY, OR TRAIN):
7. VEHICLE MAKE, MODEL, & YEAR:
8. SOUND LEVEL (USE SLOW RESPONSE) & DURATION OF VARIOUS MODES OF OPERATION:

	dBA	dBC	DURATION (SPECIFY UNITS)	SPEED SPECIFY UNITS)	IF SUBWAY, INDICATE ABOVE (A) BELOW (B) GROUND	IF TRAIN SPECIFY CAR TYPE
a. idle						
b. acceleration						
c. cruise						
d. deceleration						

9. YOUR SEATING POSITION:
   a. total # of rows:
   b. your row #:
   c. window, middle, aisle or other (specify) seat:

10. WINDOW CONDITION:
    a. is the window nearest to you open?:
    b. total # of windows open:
    c. total # of windows closed:
    d. if closed, are they sealed?:

11. AUXILIARY EQUIPMENT (SPECIFY EITHER ON, OFF, OPENED, CLOSED OR NONE):

a. air vent:
b. air conditioner:
c. heater:
d. defroster:
e. windshield wipers:
f. radio:

12. TYPE OF SOUND LEVEL METER:

13. ADDITIONAL COMMENTS:

U.S. GOVERNMENT PRINTING OFFICE: 1975– 210-810:36