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EVALUATION AND ABATEMENT OF NOISE FROM AIRCRAFT AUXILIARY POWER UNITS AND AIRPORT GROUND POWER UNITS

BY:
MICHAEL A. STAIANO
ROBERT A. SAMIS
STEVEN TOTH

7 OCTOBER 1980

PREPARED UNDER:
CONTRACT NO. 68-01-5040
TASK ORDER 006

FOR THE
OFFICE OF NOISE ABATEMENT AND CONTROL
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

APUs and GPUs provide essential service to aircraft during ground operations. Sound levels near these devices range from 80 to 87 dBA at 30 m for APUs, 83 to 103 dBA at 10 m for turbine-engined GPUs, and 71 to 80 dBA at 10 m for piston-engined GPUs. Procedures are provided for: (1) estimating community sound levels due to APUs and GPUs, (2) estimating their exposures in terms of day-night sound levels, and (3) assessing the desirability of noise abatement by comparison to recommended levels for acceptability. Noise abatement options include: operational changes, equipment movement, equipment substitution, equipment quieting, and sound barrier usage.

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SUMMARY

The purpose of this report is to provide a means for assessing the environmental noise impact of aircraft-mounted auxiliary power units (APUs) and airport-based ground power units (GPUs) upon communities adjacent to airports.

Chapter I describes the function, types, and usage patterns for APUs and GPUs. The primary function of these power units is to provide electrical and pneumatic power for aircraft avionics, lighting, air conditioning, and main engine starting. All jet aircraft APUs utilize a turbine engine driven unit while GPUs utilize either turbine or piston driven units. APU usage durations range from 5 minutes to overnight.

A methodology for evaluating community noise exposures generated by APUs and GPUs is described in Chapter II. Sound level information for several power units is provided. Average sound levels around APUs range from 80 to 87 dBA at 30 m. APUs exhibit significant directivity -- as much as 13 dBA for the DC-9. Available data for turbine-engine GPUs of similar rating ranged from 83 dBA to 103 dBA at 10 m. Piston-engine GPU sound levels were found to vary with drive engine power rating -- ranging from about 71 dBA at 10 m for 10 HP drivers to about 89 dBA for 300 HP drivers. Available data indicate that these units also exhibit significant directivity -- as much as 8 dBA. Because APU and GPU noise levels at community locations are a function of distance and

frequency-dependent propagation effects, a method is provided which accounts for these factors. This frequency dependancy can be addressed by characterizing the equipment by engine driver type. Sound attenuation curves with respect to distance for overall A-weighted sound levels are provided to permit the estimation of community levels. The adverse impacts of noise exposures are commonly evaluated through the use of the day-night sound level (DNL). A simplified method is given for estimating DNLs and recommended levels of acceptability are provided.

Chapter III indicates the range, potential sound level reduction, advantages, and disadvantages of various noise abatement options. These options include: operational changes (e.g., curfews and usage reductions), equipment movement (e.g., relocation and re-orientation), equipment substitution (e.g., GPUs for APUs), equipment quieting (e.g., better GPU exhaust mufflers), and use of sound barriers.

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INTRODUCTION

Aircraft require three essential services during airport stopovers. These are provision of:

- Electrical power for avionics, lighting, and other auxiliary equipment
- Pneumatic power for main jet engine starting
- Pre-conditioned air for aircraft cabin heating and air conditioning.

These services are provided by either auxiliary power units mounted on-board the aircraft, airport-based mobile ground power units, or -- increasingly -- stationary centralized systems, operated by airport authorities or, sometimes, by individual airlines.

Unlike the 60 Hz AC electrical power provided by the power utilities, modern jet aircraft require 400 Hz AC power for their electrical systems and therefore need separate generating equipment. Older piston-engined aircraft and most general aviation aircraft use 28.5 V DC power and also need separate generators.

Modern commercial jet transports and executive jets are equipped with an on-board auxiliary power source or unit, commonly referred to as an APU. The auxiliary power unit was incorporated into commercial jet aircraft in order that the aircraft could be relatively self-sufficient on the ground when the main engines are off. When the first commercial jet transports were introduced in 1958, these aircraft (the Boeing 707 and Douglas DC-8) were not equipped with APUs. But by the time the first Boeing 727 was delivered in 1963, the APU was part of the aircraft's design and operating procedure. Since that time, the APU has become standard equipment on all new commercial jet transports.

The auxiliary power unit is driven by a turbine engine, similar to -- but much smaller than -- the aircraft's main jet engines. It generates two forms of power, pneumatic and electrical. The pneumatic power (compressed air) is used for main jet engine starting and for the aircraft's environmental control system (ECS), i.e., heating or air conditioning. In addition, compressed air is used for snow, frost, or ice removal, ground testing of aircraft systems, and general thawing operations. The electrical power is used for the aircraft electrical requirements. The APU is also designed as an emergency back-up electrical power source on two-engine aircraft in order to meet FAA in-flight safety certification standards. Although the utilization rate for APUs may decline in the future, for reasons which are discussed below, it is unlikely that APUs will disappear from aircraft design as long as two-engine aircraft are used. In fact, the current trend towards improved fuel efficiency has bolstered the development of new two-engine aircraft types such as the Boeing 767 and Airbus A310 which are likely to become the predominant aircraft in the world fleet.

The typical APU installation places the unit within the rear portion of the fuselage or tail of the aircraft. Commonly, the intake opening is located along the right side near the base of the vertical stabilizer while the exhaust outlet is placed at the end of the fuselage. The APU intake for the DC-9 is on the bottom rear section of the fuselage and the exhaust just above the right engine pylon. The Boeing 727 has the APU installed in the main landing gear wheel well with the intake located along the undercarriage and the exhaust along the top surface of the right wing a few feet from the

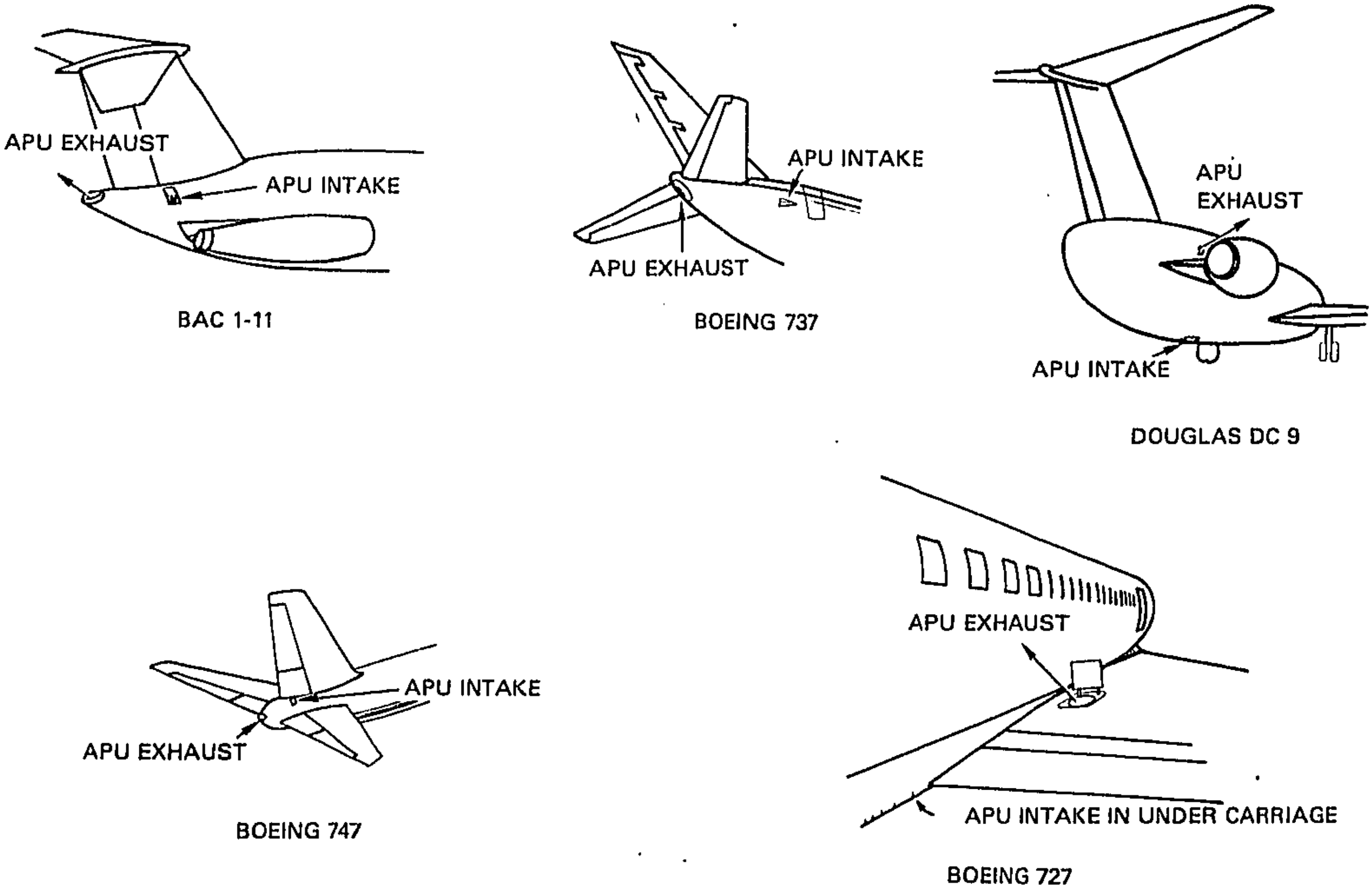


FIGURE I-1. SAMPLE AIRCRAFT APU INSTALLATIONS fuselage. The Boeing 707 and Douglas DC-8 commercial aircraft did not come equipped with an APU, but a few operators have since installed them; also in an aft location. Sample APU installations are illustrated in Figure I-1.

APUs were originally designed for military applications which did not include acoustical design considerations. The initial commercial applications relied upon these existing designs. Air carriers soon sought some attenuation for the releif of enplaning and deplaning passengers and ground crews. These initial acoustical treatments consisted of damping inlet and turbine body sound radiation, use of sound absorbing material, and exhaust muffling. These actions reduced sound levels by about 5 dBA. Additional reductions of APU sound levels are reported to require either new technological advances or significant aircraft flight performance penalties caused by increased installed APU weight.

APU USAGE

The concept of the self-sufficient aircraft that would not be dependent upon airport facilities for ground equipment support gained ascendency with the introduction of short and medium range jet transports. The use of APUs eliminated the need for an extensive inventory of ground service equipment dispersed at every airport from which a carrier operates. The APU eliminates the need for as many as three ground service vehicles: the engine starter, air conditioning units, and electric power generator. Aside from reducing airlines' labor and maintenance costs, the use of an APU also reduced ramp clutter and inadvertent damage to the airframes. Gate turn-around time was also shortened. This time-saving feature became particularly important for short-haul operations which require high aircraft utilization. The APU will continue to offer certain advantages permitting operational flexibility. These are:

- Multiple operations are not impeded by ground power facility availability
- Route and schedule changes can be made independently of ground equipment distribution

- Aircraft dispatch reliability is improved because the APU can be used to serve as a substitute electrical source if ground-based equipment is temporarily inoperative.

Two developments in recent years have altered the near universal reliance upon APUs. The first dramatic change was the tripling of aviation fuel prices following the oil embargo of 1973. APUs can consume 35-80 gal/hr of jet fuel depending upon the APU type, aircraft, and power requirements. Air carriers in their efforts to cut operating costs have attempted to limit the duration of APU usage. The second development enabled air carriers to cut down on APU usage on a permanent basis. Advances in the application of certain electrical engineering principles have permitted the development of fixed, centralized 400 Hz electrical ground power system. Fixed 400 Hz electrical power at the airport terminal gate can now substitute for the continuous operation of the APU for electric power. Previously a few airports had installed individual 400 Hz electric motor-generator sets at each gate, but this was quite costly. The new centralized power system requires only one electric motor-generator and one back-up power source to support up to ten gates. The fixed, centralized system is made possible by a line drop compensator (LDC) which automatically adjusts the required voltage for reactive voltage drops in lines connecting the generator to the load. These fixed, centralized electric power systems are gaining widespread acceptance and installation at major air carrier basing facilities.

Some airlines are also looking into installing fixed, centralized air conditioning hook-ups at terminal gates which would eliminate a second function performed by the APU. The sole remaining function, engine starting, requires only ten or fifteen minutes of APU usage prior to departure.

Auxiliary power unit usage patterns depend upon the flight schedule, weather, aircraft type, and the availability of fixed and mobile ground equipment. Generally, APUs operate about one hour for every airborne flight hour. Almost all of the APUs' operational time occurs on the ground. Average APU usage is about 2,500 hours per year. Short haul flights with several brief stopovers will use their APUs about the same amount of time as long-haul flights with extensive layovers.

Some large air carriers have instructed their personnel to turn off their APUs if a stopover is longer than 45 minutes. Other carriers have just recommended that their pilots use their own judgement in order to minimize APU usage. The carriers which developed the fixed time limit rule largely based the rule upon the cost of jet fuel and the fuel consumption rate of APUs. Since these rules were developed, the price of fuel has increased substantially which would suggest even these guidelines are out of date.

Auxiliary power units may be used continuously for short stopovers of 45 minutes or less. When a fixed, centralized electric power system is available, the APU is only used for 10-15 minutes prior to departure for engine starting and air circulation during passenger loading.

A couple of recent surveys provide an indication of auxiliary power unit usage patterns. One study observed Eastern and Allegheny (now U.S. Air) Airlines' APU usage patterns at Boston's Logan Airport.[1] Both Allegheny and Eastern reported that APUs were used 68 percent of the total time that aircraft were stationed at the terminal gates. Allegheny used the APUs on board their DC-9 and BAC 1-11 aircraft on average 14.4 minutes per daytime flight. Apparently, APUs were operated continuously throughout the night on aircraft parked at the gates. Due to this practice, daytime APU usage composed only 35 percent of the total APU operational time despite the fact that 91 percent of the flights occur during the daytime. Eastern, on average, operates its DC-9 727, and L1011 APUs only 5.1 minutes for daytime flights and slightly over an hour for its nighttime flights. Surveys were also conducted by AiResearch several years ago and were summarized by the Office of Air and Waste Management of the U.S. EPA.[2] These and other sources are used to develop the information presentation in Table I-1 for various aircraft types and operating requirements. APU use is also required to support various maintenance activities which usually are undertaken at night. Every aircraft undergoes routine and/or special purpose maintenance at least every third night.

Air conditioning and heating is provided for the comfort of the passenger. The aircraft does not require this service during nighttime maintenance when only a few people are on board the aircraft only for short periods of time. When the outside temperature is significantly warmer or colder than normal indoor temperatures, the aircraft will require pneumatic power for the environmental control system. During hot weather about an hour

TABLE I-1

AIRCRAFT AUXILIARY POWER UNIT USAGE PATTERNS

AIRCRAFT TYPE/OPERATING REQUIREMENT	APU DUTY CYCLE DURATIONS (minutes)	
	range	typical
short-medium haul/short stopover	5-60	continuous during stopover
short-medium haul/long stopover	30-120	80
long haul/long stopover	85-295	155
all types/nighttime hangar maintenance	-	60
all types/summertime cabin temperature conditioning	-	60*
all types/wintertime cabin temperature conditioning	-	60**
all types/jet engine starting	5-20	10

*prior to take off

**every four to five hours

may be required to cool down and stabilize the aircraft's interior temperature after an extended period of inoperation by the ECS. Similarly, cold weather may require the use of APU to drive the air cycle equipment.

APU INSTALLATIONS

Three major aerospace manufacturers produce auxiliary power units for commercial jet aircraft but one manufacturer overwhelmingly dominates the field. AiResearch, a division of Garrett, produces a series of APUs which are utilized on all Boeing 727, 737, and 747, McDonnell-Douglas DC-9, and DC-10, Airbus A300, and British Aerospace BAC 1-11 aircraft, as well as on several general aviation aircraft. AiResearch also produces an APU which can be installed on Boeing 707 and McDonnell-Douglas DC-8 aircraft, no commercial passenger carriers have availed themselves of this option. Solar Turbine, a division of International Harvester, produces an APU which can be installed on the Boeing 707, DC-8, BAC 1-11, and various business jets or turboprops. Hamilton Standard, a division of United Technologies, produces the APU for the Lockheed L1011 aircraft. Table I-2 presents a summary of the APU specifications by aircraft types.

GROUND POWER UNITS

The electrical power, engine starting, and air conditioning service can also be provided by airport-based ground power units (GPUs). Normally GPUs are owned and operated by each air carrier and employed in conjunction with or as substitutes for APUs depending upon the individual carrier's practices and equipment status. Ground power units can be driven by:

- Turbine engines, functioning similarly to the aircraft-mounted APUs for electrical and pneumatic power service
- Piston engines (either diesel or gasoline), such as driving an electric generator or air compressor to fill an air storage tank for engine starting
- Electrical motors, such as a 60 Hz AC motor driving either a 400 Hz or 28.5 V DC generator.

GPUs are available in a variety of configurations: trailer-mounted, truck-mounted, self-propelled, or stationary mounted. (A typical, trailer-mounted GPU is illustrated in Figure I-2.)

REFERENCES

[1]Miller, N. P. and Eldred, K. M., Environmental Impact Analysis of the Proposed Commuter Pier at Logan Airport's Southwest Terminal: Noise, BBN Report No. 4085 for the Massachusetts Port Authority, Boston, Massachusetts, March 1979.

[2]Deimen, James M. Aircraft Emissions at Selected Airports 1972-1985, Ann Arbor, Michigan, U.S. EPA; Standards Development and Support Branch, Emission Control Technology Division, Office of Air and Waste Management, Technical Report No. AC 77-01, January 1977.

TABLE I-2

AUXILIARY POWER UNIT SPECIFICATIONS

MANUFACTURER	MODEL	AIRCRAFT APPLICATIONS	NORMAL AIR FLOW (lb/min)	MAXIMUM RATED POWER (HP)	POWER SHAFT SPEED (RPM)	FUEL CONSUMPTION (lb/hr)
AiResearch	GTCP30	G/A	29-42	70	59,000	73-105
	GTCP36	G/A	50-58	50	58,000	115
	GTCP85-98	B727-200	128	100	40,700	280
	GTCP85-98 DCK	DC-9	102-130	100	40,700	280
	GTCP85-115 CK	BAC 1-11	130	40	40,700	280
	GTCP85-129	B737	103	100	40,700	240
	GTCP331-200A	B757/767	265	200	n/a	n/a
	GTCP660-4	B747	480	300	20,000	1,005
	TSCP700-4B	DC-10	385	189	35,300	565
	TSCP700-5	A300	385	189	35,300	565
Solar Turbine	T62-T40C	B707 B720 DC-8 DC-9 BAC 1-11 G/A	50-75	90	61,250	140
Hamilton Standard	738080-20	L1011	n/a	n/a	n/a	n/a

G/A denotes general aviation aircraft

n/a denotes data not available

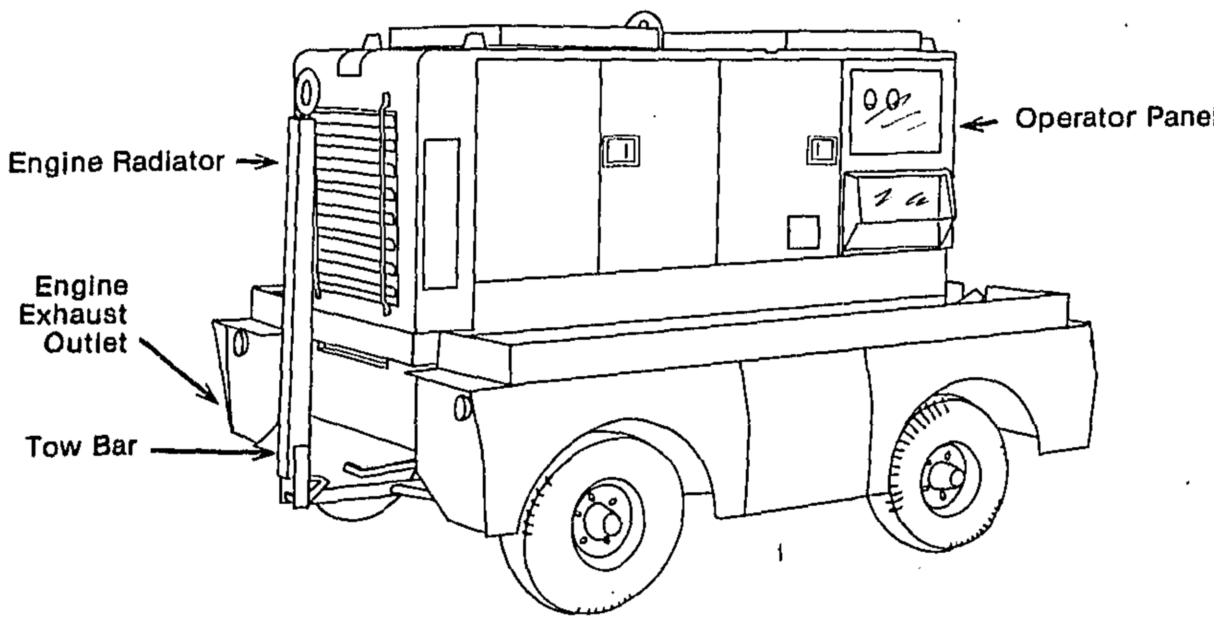


FIGURE I-2. TYPICAL TRAILER-MOUNTED GPU (HOBART 90G20P 400 Hz AC, PISTON-ENGINED, ELECTRICAL GENERATOR)

II. EVALUATION OF COMMUNITY NOISE EXPOSURES

The purpose of this chapter is to provide a guide for determining the desirability for noise abatement of APUs or GPUs. This guide consists of a number of steps. Available sound level data near APUs and GPUs are presented. A means of projecting the sound levels to community locations is then provided, followed by presentation of a method for estimating the noise exposure level in the community which considers not only the APU or GPU sound level but also the duration and the time of day of operation. Finally, standards and recommended levels, upon which the final evaluation can be made, are provided for comparison to the estimated exposure levels. This procedure is illustrated in Figure II-1; it is intended to be as simple as possible and still allow for flexibility on the part of the user. (A glossary is provided as Appendix A in which the terms used in this chapter are defined.)

The purpose of this guide is to provide a self-contained basis for making evaluations of community noise exposures. However, sound level data are not available for all aircraft types and for all GPUs. The sound level data provided in this chapter can be supplemented by data from other sources, such as data measured by equipment manufacturers or by the user himself. Guidelines for the measurement of sound from APUs are given in Appendix C. Examples are provided at various points in this chapter which are intended to illustrate how the guide may be adapted.

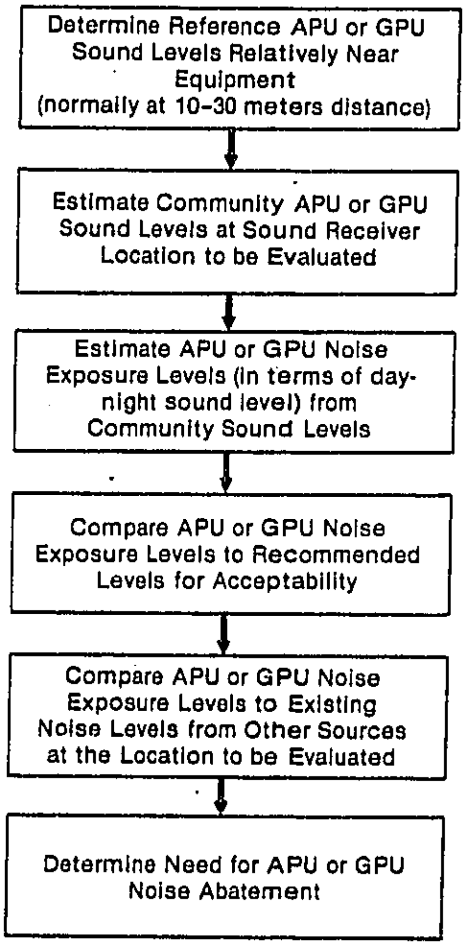


FIGURE II-1. COMMUNITY NOISE EVALUATION PROCEDURE

SOUND LEVELS NEAR APUs and GPUs

The sound from a noise source diminishes with increasing distance from the source and varies as a function of angular location around the source. This latter effect is called directivity. In the following paragraphs APU and GPU sound levels are provided at a specified reference distance.

APU Sound Levels

Sound levels for APUs are provided at a reference distance of 30 m from the APU installation on the aircraft. This information is provided by aircraft type in Table II-1. Directional sound levels are referenced in accordance with Figure II-2 (for which the forward direction of the aircraft is referenced at 0^{o}). Note that APU sound levels vary considerably around the aircraft -- by as much as 13 dBA for the DC-9.

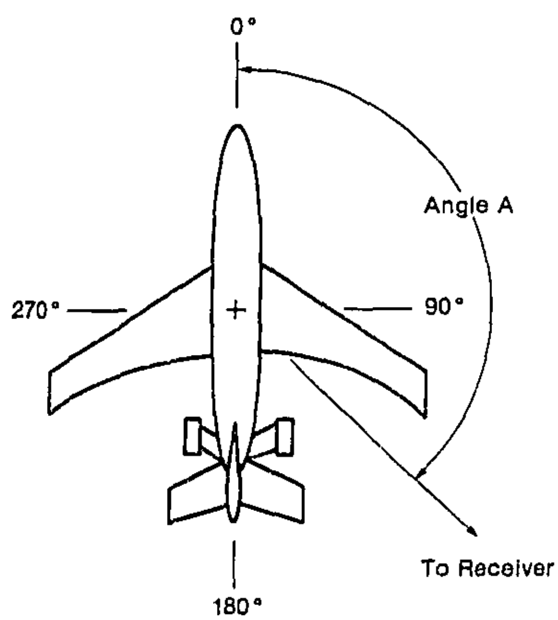


FIGURE II-2. AIRCRAFT REFERENCE ANGLE, A

TABLE II-1

REFERENCE APU SOUND LEVELS (RL) AT REFERENCE DISTANCE (RD) OF 30 m

AIRCRAFT TYPE	APU SOUND LEVEL (RL) AT 30 m (RD) in (dBA)								
	Average	Direction with Respect to Aircraft Reference (Angle A, Figure II-2)							
		0^{o}	45^{o}	90^{o}	135^{o}	180^{o}	225^{o}	270^{o}	315^{o}
A300	81	-	-	80	-	81	-	81	-
B727	81	78	78	78	85	82	82	82	76
B737	80	-	-	81	-	-	-	78	-
B747	87	-	-	84	88	84	89	86	-
BAC 1-11	84	-	79	84	88	83	85	81	76
DC-9	82	-	-	77	-	86	-	73	-
DC-10	-	-	-	-	-	-	-	-	-
L1011	80	-	84	80	78	77	80	79	79

Dash (-) denotes data not available.

Sources: See Appendix B.

The International Civil Aviation Organization (ICAO) has established guidelines for noise from APUs, as Attachment E to ICAO Annex 16. These guidelines specify that sound levels from an aircraft APU not exceed 90 dBA at a rectangular perimeter around the aircraft when measured in accordance with the Society of Automotive Engineers (SAE) Aerospace Recommended Practice, ARP 1307, Measurement of Exterior Noise Produced by Aircraft Auxiliary Power Units During Ground Operation. (The ICAO guidelines and the SAE standard are both provided in Appendix C.)

GPU Sound Levels

Noise from GPUs is primarily determined by the type of drive device (turbine engine, piston engine, or electric motor). Available sound level data for turbine-engined GPUs, averaged around the units, is presented in Table II-2 for a referenced distance of 10 m. Sound levels from piston-engined GPUs vary with drive engine power. Sound levels for both gasoline- and diesel-engined GPUs can be determined from Figure II-3 for a reference distance of 10 m. Sound levels, including directivity, for a diesel-engined, 400 Hz AC generator are provided in Table II-3. Note that all GPU sound levels are referenced to the distance from the geometric center of the device. Directivity is referenced as shown in Figure II-4.

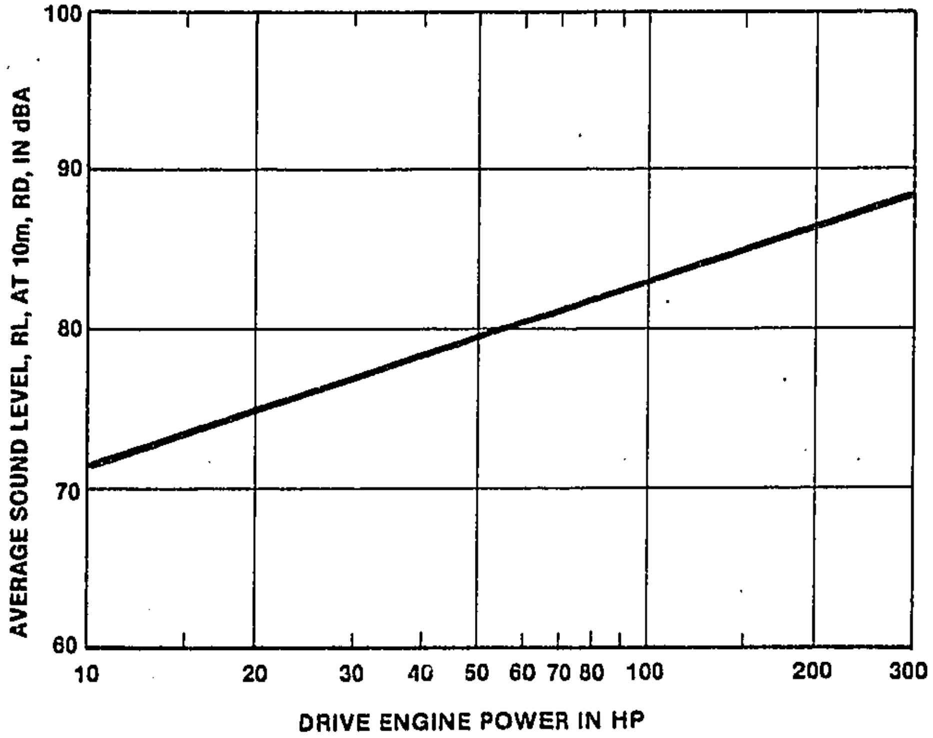
TABLE II-2

REFERENCE GPU SOUND LEVELS (RL) AT REFERENCE DISTANCE (RD) OF 10 m FROM GEOMETRIC CENTER OF UNIT -- AVERAGE SOUND LEVELS FOR TURBINE-ENGINED EQUIPMENT (Turbine Engines Rated At Approximately 200 HP)

GPU TYPE	GPU SOUND LEVEL (RL) AT 10 m, RD (dBA)	
	Range of Averaged Levels	Arithmetic Mean of Averaged Levels*
Turbine-Engined	83-103	95

Source: See Appendix B.

*Arithmetic mean of average sound levels around 3 similar units--for worst case estimates, assume extreme of range, 103 dBA.



SOURCE: See Appendix B

FIGURE II-3. REFERENCE GPU SOUND LEVELS (RL) AT REFERENCE DISTANCE (RD) OF 10 m FROM GEOMETRIC CENTER OF UNIT -- AVERAGE SOUND LEVELS FOR PISTON-ENGINED EQUIPMENT

TABLE II-3

REFERENCE GPU SOUND LEVELS (RL) AT REFERENCE DISTANCE (RD) OF 10 m FROM GEOMETRIC CENTER OF UNIT -- HOBART 90G20P (Trailer-Mounted, 90KVA, 400 Hz AC Ground Power Unit With GM 4-71 Diesel Engine Rated at 152 HP at 2100 RPM)

GPU TYPE	GPU SOUND LEVEL, RL, AT 10 m, RD (dBA)								
	Average	Direction with Respect to GPU Reference (Angle A, Figure II-4)							
		0^o	45^o	90^o	135^o	180^o	225^o	270^o	315^o
Piston-engined	87	91	89	85	83	84	84	85	89

Source: See Appendix B.

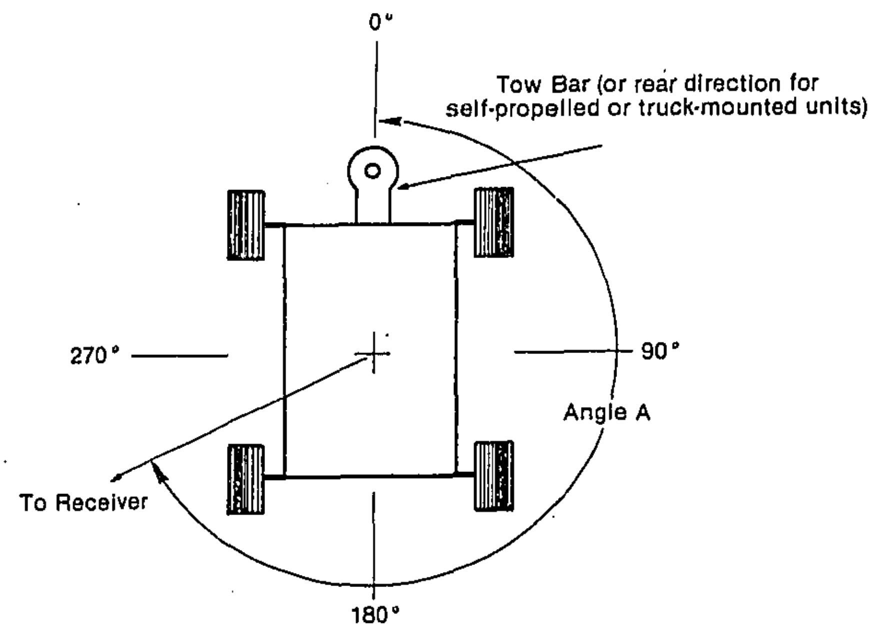


FIGURE II-4. GPU REFERENCE ANGLE, A

ESTIMATION OF SOUND LEVELS IN THE COMMUNITY

At distances greater than about 10 m from a noise source, the decrease in sound from the source is due not only to the geometric spreading of the sound but also the increasing effects of the absorption of sound in air and the attenuation of sound due to a variety of atmospheric effects and ground cover. In Figure II-5 sound attenuation curves are provided for average frequency spectra for piston-engined equipment (Curve P) and for turbine-engined equipment (Curve T). (The derivation of these curves is discussed in Appendix D.)

Use of Sound Attenuation Curves for APUs

The basic procedure for estimating community sound levels consists of: determining or obtaining a reference sound level for the noise source at a reference distance; determining the increase in sound attenuation from

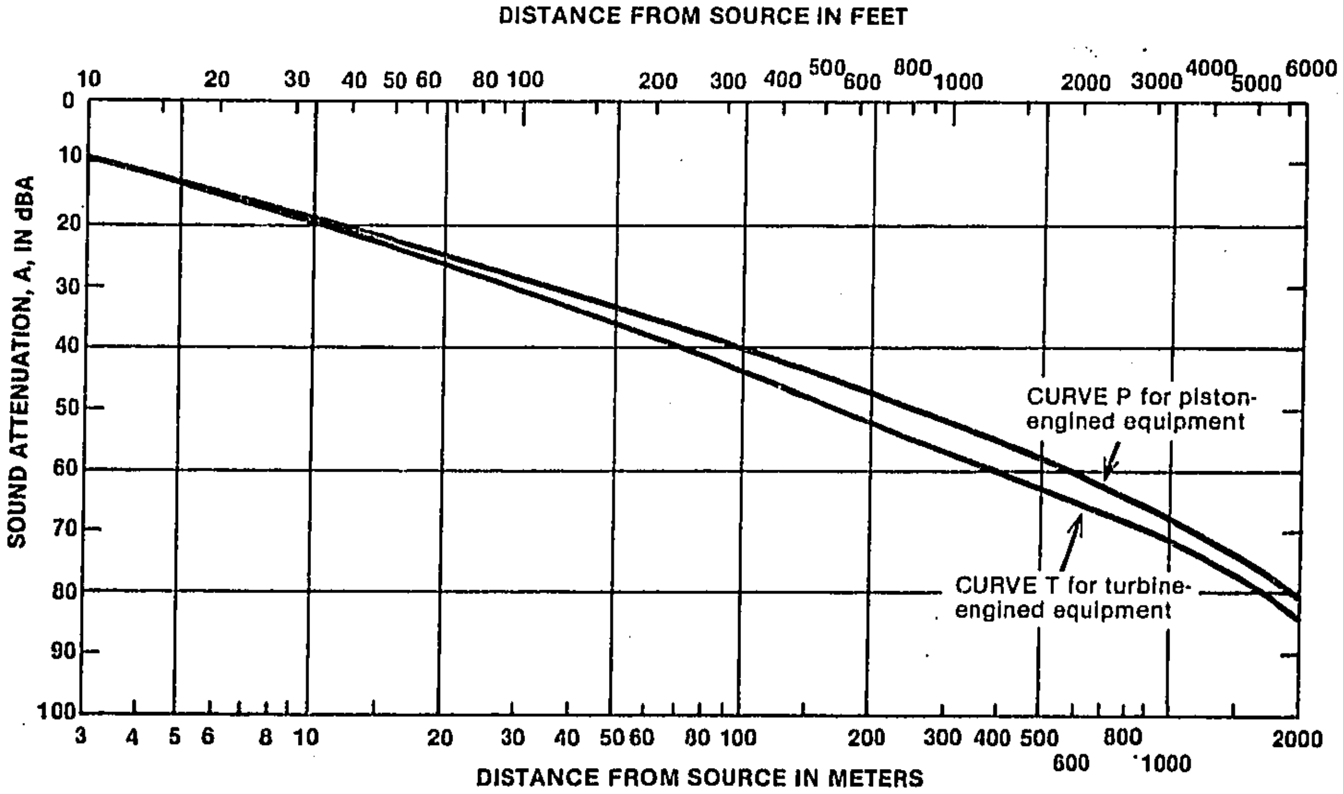


FIGURE II-5. SOUND ATTENUATION CURVES

the noise source between the reference distance and the distance of the community; and reducing the reference sound level by that added attenuation. This procedure is defined in Figure II-6 and Example 1 illustrates its application. Figure II-6 can also be used for other sound level data -- such as the ICAO guideline as illustrated in Example 2. However, use of this procedure with sound level data measured much closer than 30 m from the APU is not recommended. Note that all APU installations are turbine-driven. Therefore, Curve T is used for APU noise estimations.

Example 1

A Boeing 737 is parked on a runway apron as shown in Figure Ela. What is the sound level in the nearby residential community?

Solution:

1. The aircraft type is B737 and its orientation is known, Angle A = 135^{o}.

2. Referring to Table II-1, sound levels are not available for B737s at 135^{o} so the average sound level is used RL = 80 dBA at RD = 30 m.

3. From Figure II-5 using Curve T for turbine-engined equipment, the attenuation, A_{RD}, to reference distance, RD, is A_{RD} = 31 dBA. (See Figure Elb.)

4. The location to be evaluated is that point in the residential area closest to the APU (for the worst possible situation), CD = 500 m.

5. From Figure II-5 using Curve T for turbine-engined equipment, the attenuation, A_{CD}, to the receiver location being evaluated is A_{CD} = 63 dBA. (See Figure Elb.)

6. The typical sound level, CL, experienced by a receiver at the evaluation location is

$$CL = RL + A_{RD} - A_{CD}$$

$$= 80 + 31 - 63 = 48 \text{ dBA} = CL,$$ the desired information.

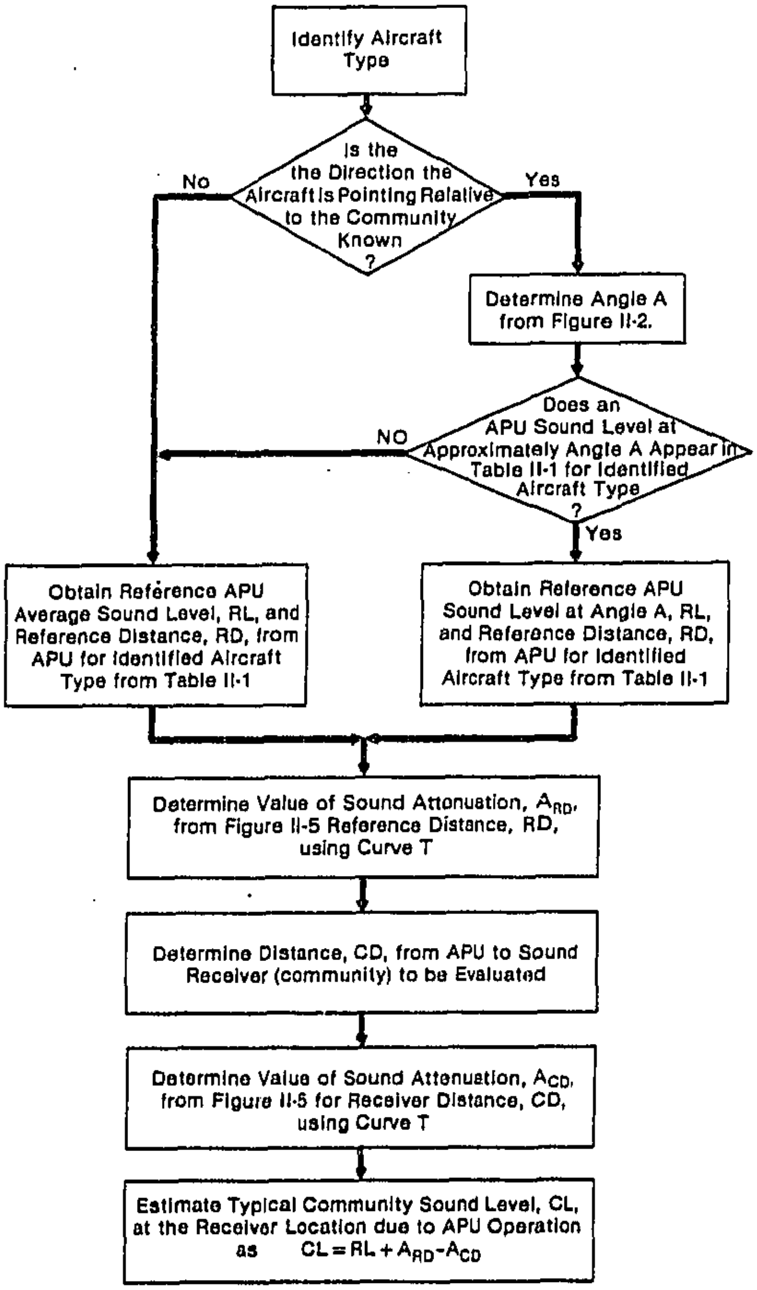
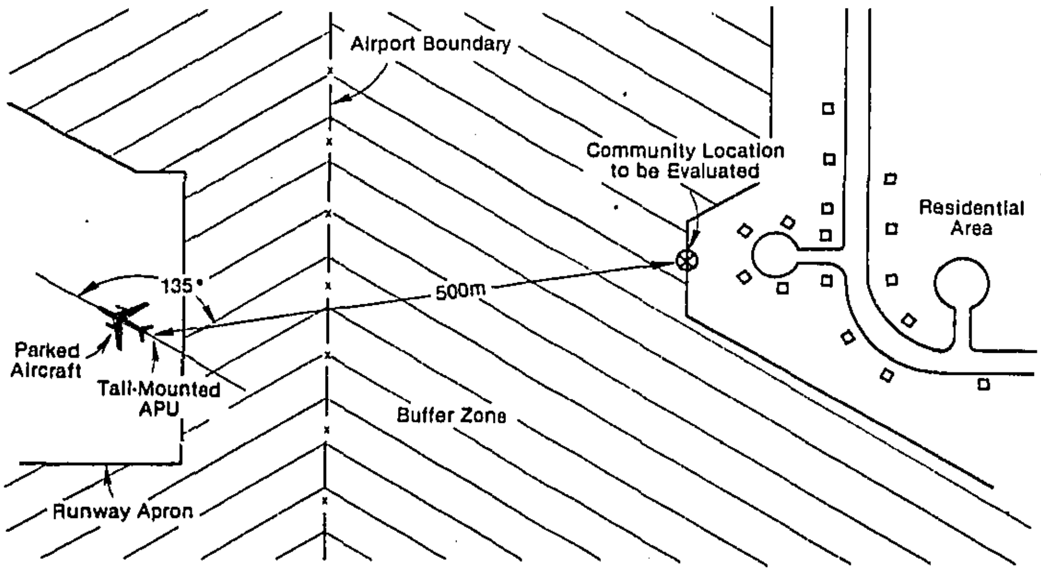
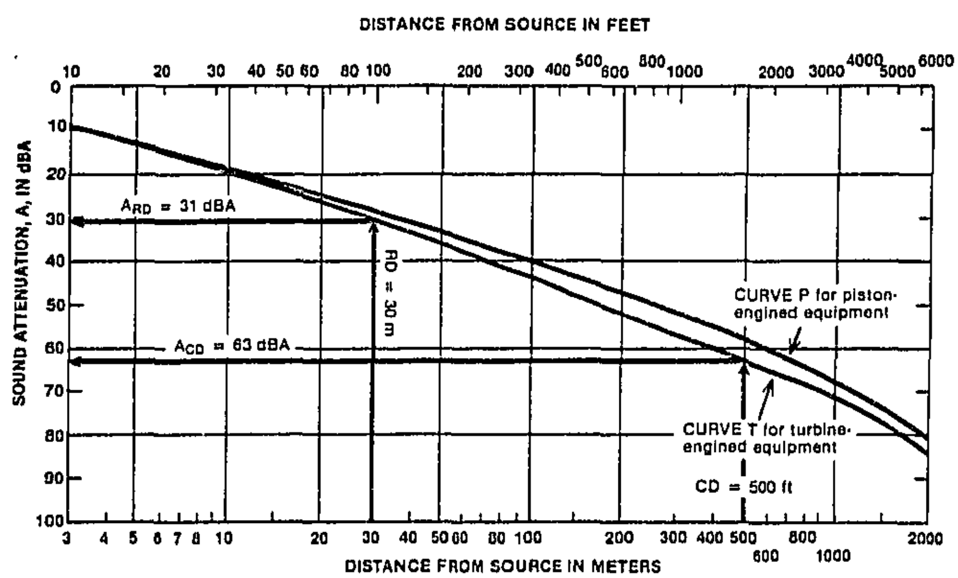


FIGURE II-6. APU COMMUNITY NOISE ESTIMATION PROCEDURE



(a)



(b)

FIGURE E1. EXAMPLE 1

Example 2

For an aircraft with a tail-mounted APU conforming to ICAO Annex 16 guidelines, what is the greatest sound level a receiver 3000 ft. from the aircraft would be likely to experience?

Solution:

1. Since sound attenuates with distance, the location on the ICAO rectangular perimeter which just meets the ICAO 90 dBA requirement and is farthest from the APU will indicate the direction of the greatest noise. For an aircraft with a tail-mounted APU, this "farthest" plausible location is the corner point of the rectangle, as shown in Figure E2a.

2. Since the aircraft will just conform to ICAO, RL = 90 dBA.

3. For the corner point, the reference distance is

$$RD = \sqrt{20^2 + 20^2} = 28.3 \text{ m.}$$

4. From Figure II-5 using Curve T for turbine-engined equipment, the attenuation, A_{RD}, to the reference distance, RD, is $A_{RD} = 30$ dBA. (See Figure E2b.)

5. The receiver distance, CD = 3000 ft.

6. From Figure II-5 using Curve T for turbine-engined equipment, the attenuation, A_{CD}, to the receiver location is $A_{CD} = 71$ dBA. (See Figure E2b.)

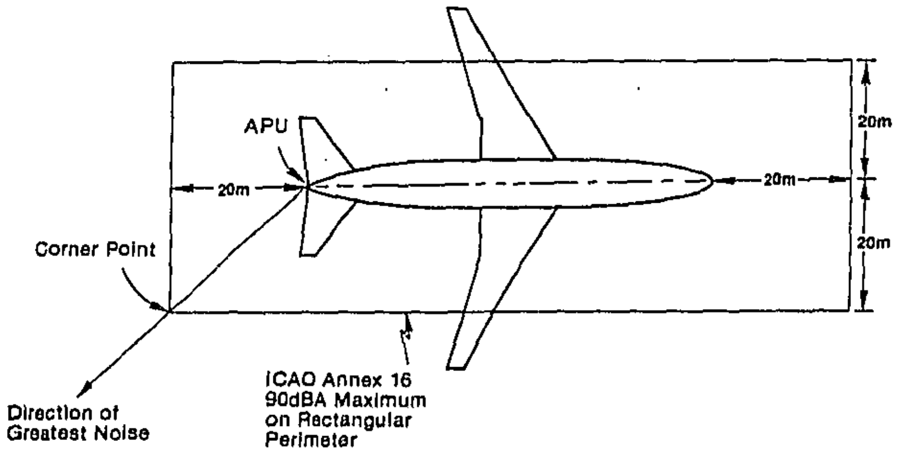
7. The greatest sound level the receiver is likely to experience is

$$CL = RL + A_{RD} - A_{CD}$$

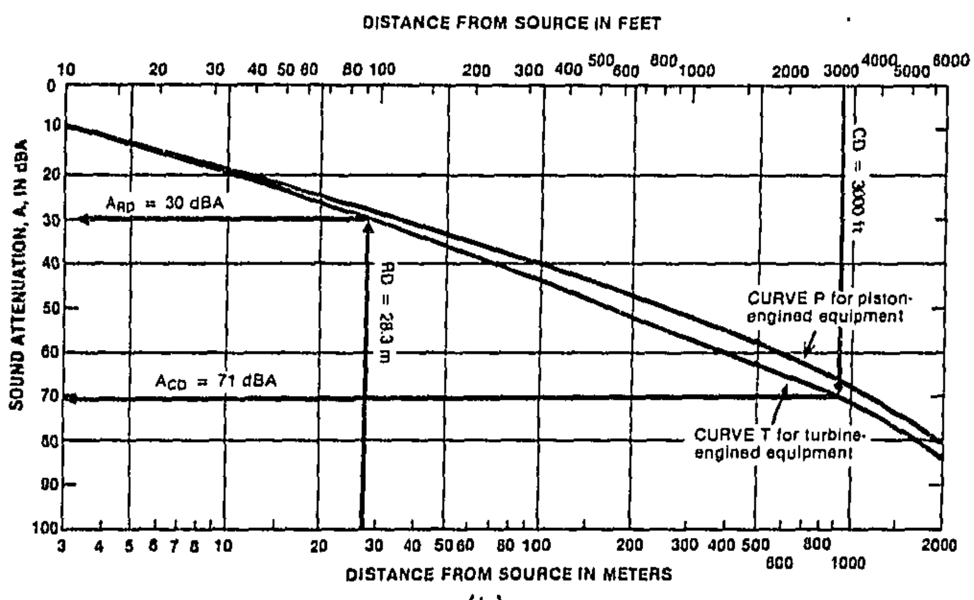
$$CL = 90 + 30 - 71 = 49 \text{ dBA} = CL.$$

Use of Sound Attenuation Curves for GPUs

The procedure for GPU estimations is much the same as that for APUs although care must be taken that the proper curve for drive engine type is selected. This procedure is described in Figure II-7. Example 3 illustrates the application of Figure II-7. As for APUs, other sources of data can be applied in this estimation procedures; this is illustrated in Example 4. In the case of GPUs, sound levels measured much less than 10 m from the center of the GPU are not recommended for use in this procedure.



(a)



(b)

FIGURE E2. EXAMPLE 2

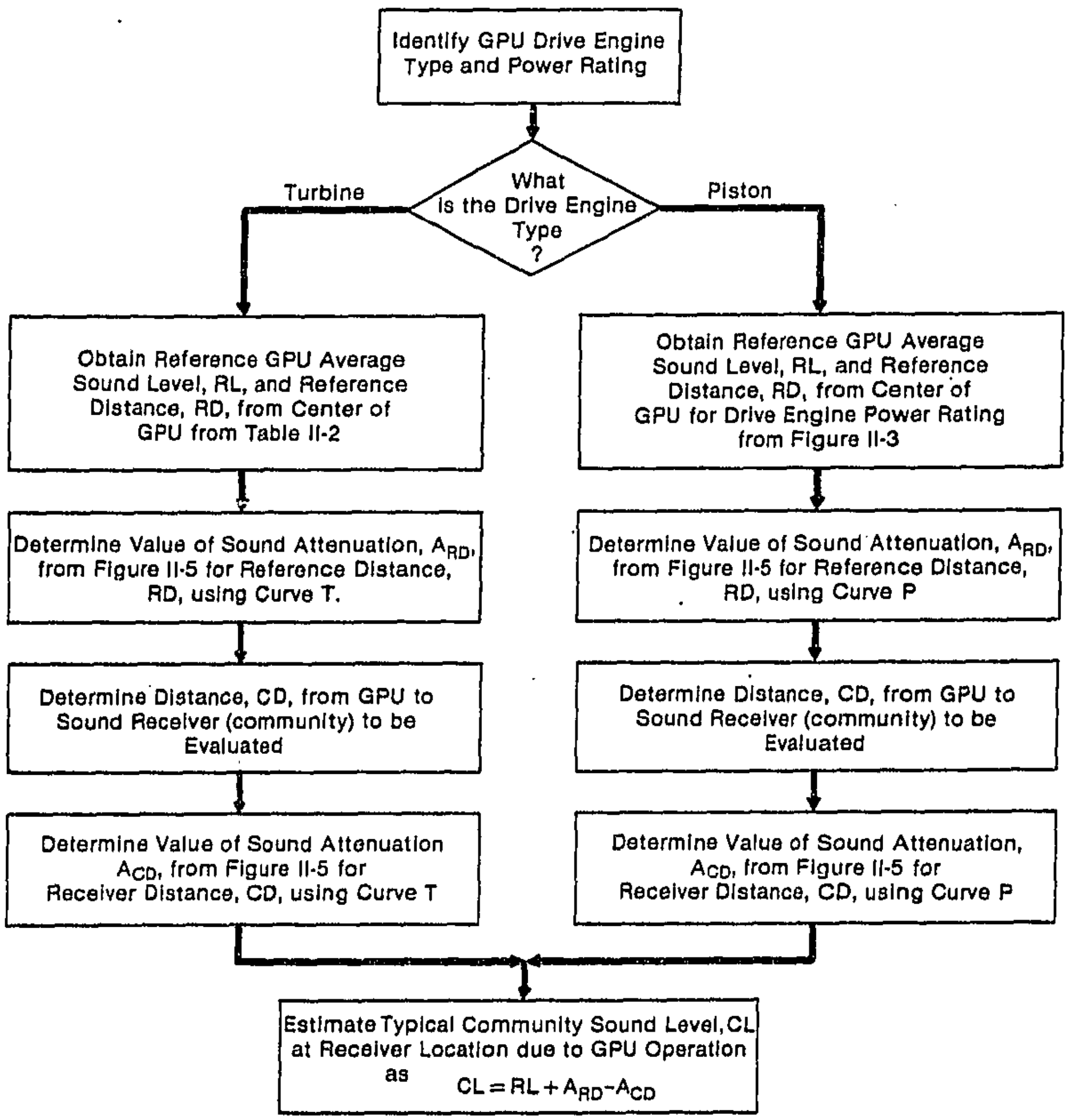


FIGURE II-7. GPU COMMUNITY NOISE ESTIMATION PROCEDURE

EXAMPLE 3

What is the community noise level at 1 mile due to an air conditioning supply driven by a 200 HP gasoline engine?

Solution:

1. The gasoline engine is a piston engine and its power rating is 200 HP.

2. From Figure II-3 for 200 HP drive engine, the average sound level, RL, is RL = 87 dBA at RD = 10 m.

3. From Figure II-5, the attenuation, A_{RD}, to reference distance, RD, is A_{RD} = 20 dBA. (See Figure E3).

4. The receiver distance, CD = 1 mi.

5. From Figure II-5 using Curve P for piston-engine equipment, the attenuation, A_{CD}, to the receiver location is A_{CD} = 77 dBA.

6. The community noise level due to the GPU is

$$CL = RL + A_{RD} - A_{CD}$$

$$CL = 87 + 20 - 77 = 30 \text{ dBA CL}.$$

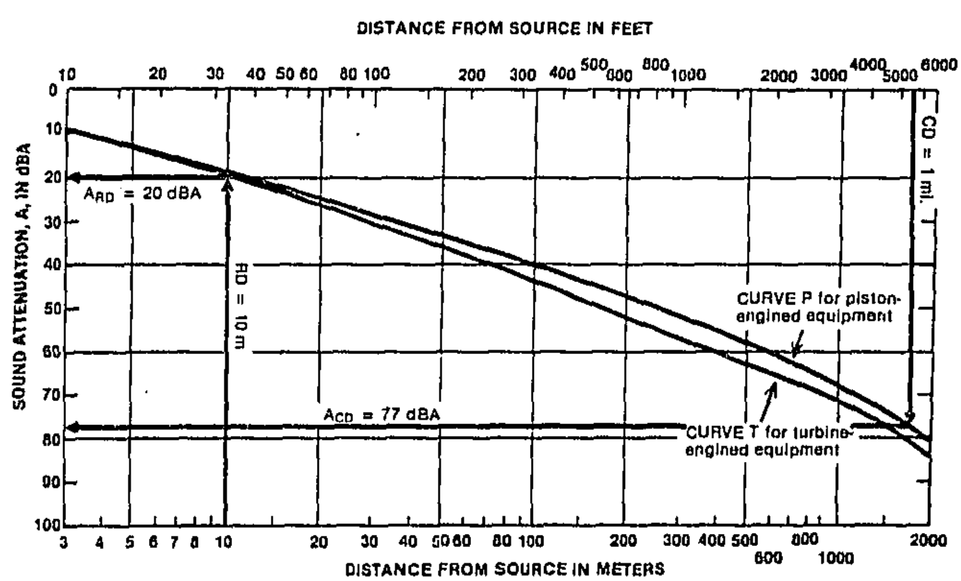


FIGURE E3. EXAMPLE 3

EXAMPLE 4

What is the sound level 300 m to the rear of a Hobart 90 KVA, trailer-mounted, diesel GPU?

Solution:

1. The diesel engine is a piston engine.
2. Since data is available for the Hobart 90G20P, it may be used instead of Figure II-3. From Table II-3, sound levels are available to the rear of the equipment (Angle A = 180° for the trailer-mounted unit), thus, the reference sound level is RL = 84 dBA at RD = 10 m.
3. From Figure II-5, the attenuation, A_{RD}, to reference distance, RD, is A_{RD} = 20 dBA.
4. The receiver distance is CD = 300 m.
5. From Figure II-5 using Curve P for piston-engined equipment, the attenuation, A_{CD}, to the receiver location is A_{CD} = 52 dBA.
6. The noise level at 300 m due to the GPU is

$$CL = RL + A_{RD} - A_{CD}$$

$$CL = 84 + 20 - 52 = 52 \text{ dBA} = CL.$$

ESTIMATION OF NOISE EXPOSURE IN THE COMMUNITY

In the previous section the intensity of the sound from the APU or GPU as it may be experienced in the community was estimated. However, human response to noise is not only a function of the sound amplitude but also its duration and time of day when it is experienced. A measure or descriptor which accounts for all these considerations is used to quantify the noise exposure. The commonly accepted descriptor for noise exposure is the day-night sound level (DNL); it will be used in this guide for the evaluation of APU and GPU noise exposures.

Estimation of Day-Night Sound Levels

Once community sound levels have been determined, such as by the procedure in the previous section, the day-night sound level can be estimated. (Figure II-8 defines this process.) Either actual observations of the operating

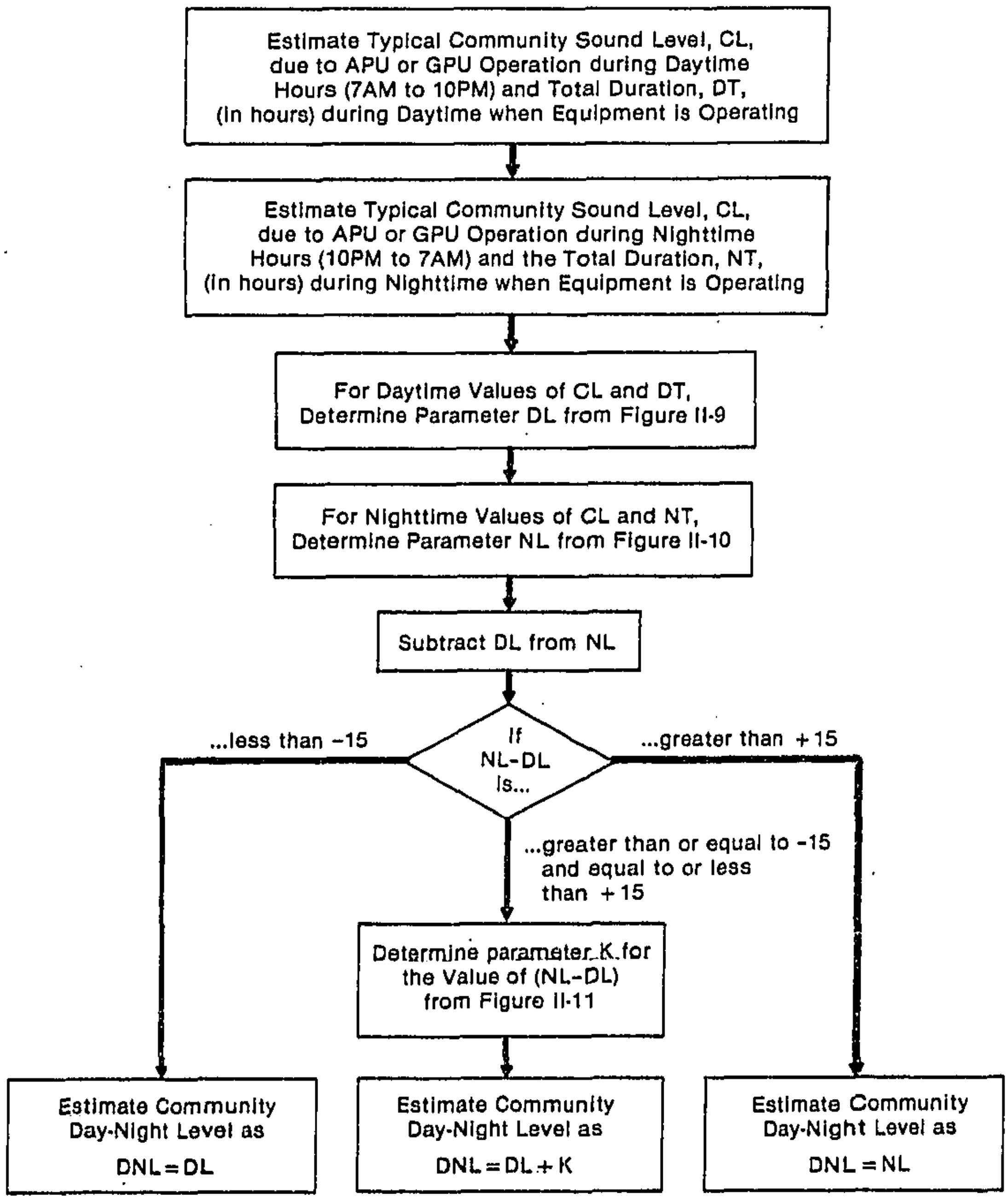


FIGURE II-8. DAY-NIGHT SOUND LEVEL ESTIMATION PROCEDURE

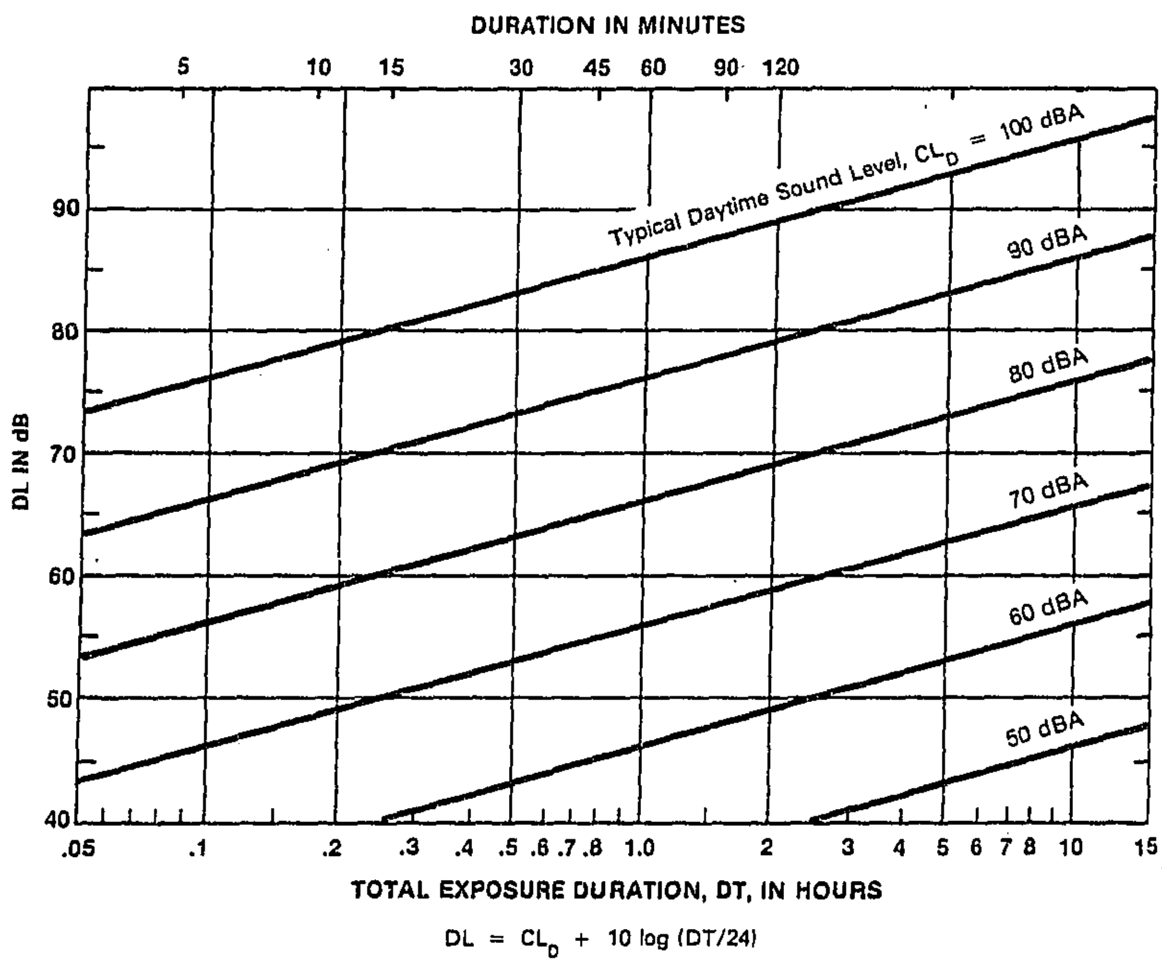


FIGURE II-9. PARAMETER DL ESTIMATION

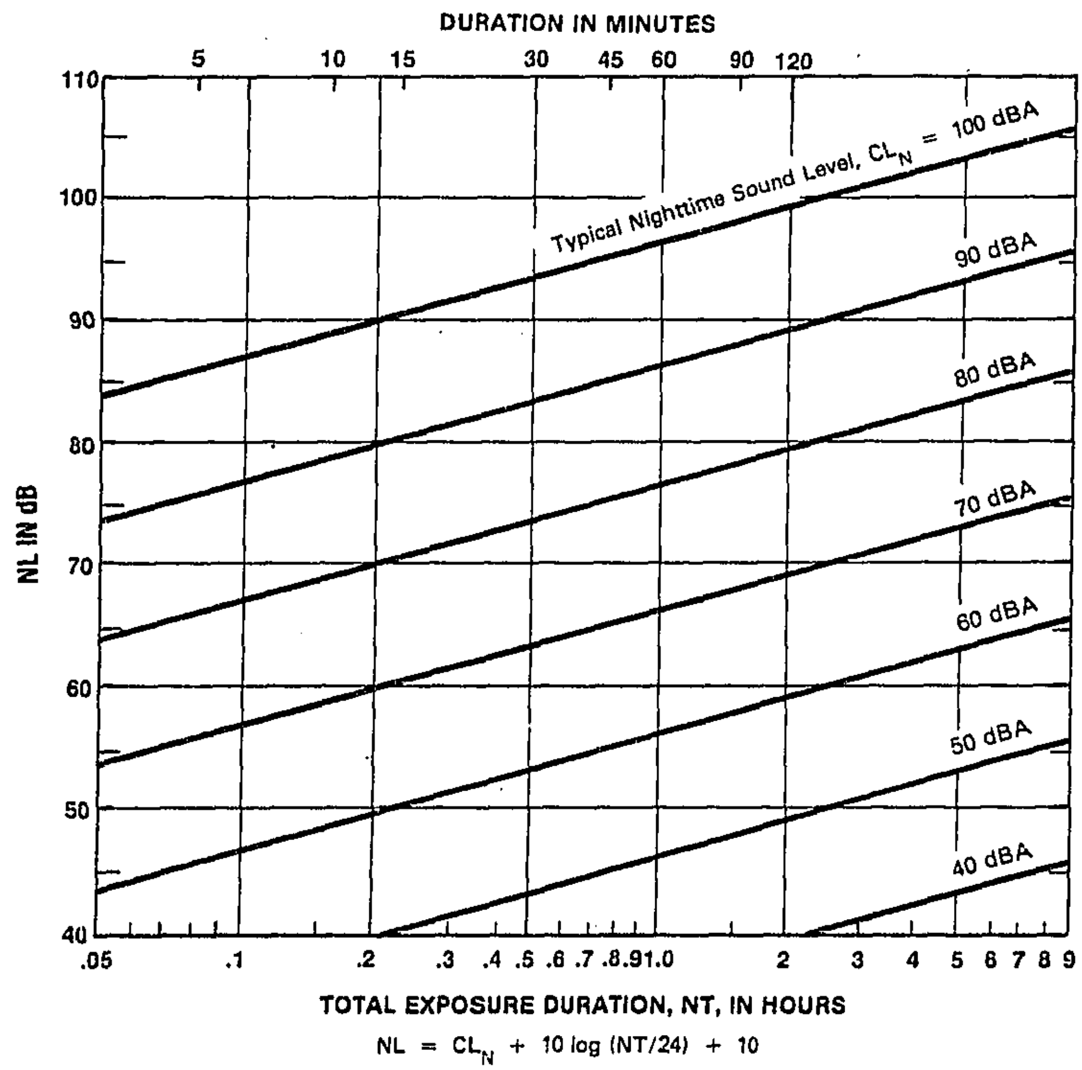


FIGURE II-10. PARAMATER NL ESTIMATION

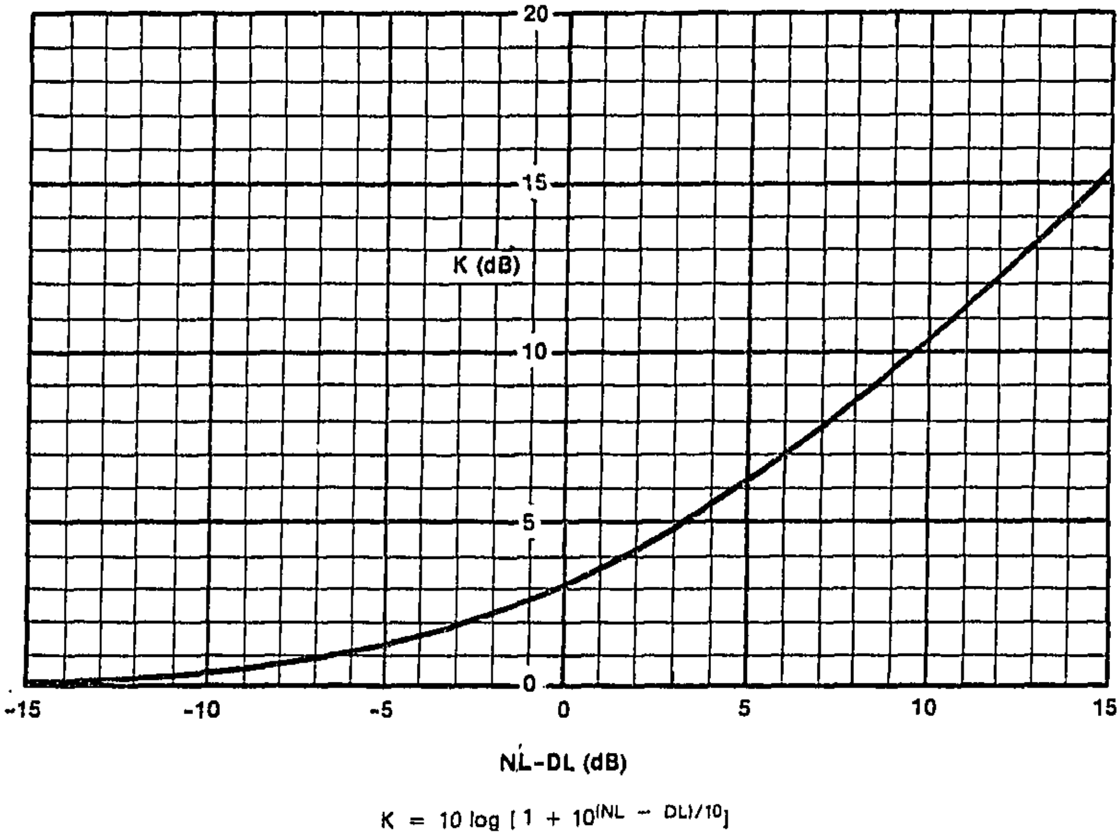


FIGURE II-11. PARAMETER K ESTIMATION

durations of the APU or GPU equipment or estimates may be used. (Table I-1, describing APUs usage patterns and duty cycle durations, may be of guidance for estimations.) Example 5 illustrates the use of Figure II-8.

EXAMPLE 5

A parked aircraft with operating APU results in a community noise level of 60 dBA. If the APU operates from 5 PM to 12 PM, what is the community noise exposure level?

Solution:

1. The typical daytime community sound level, CL, is 60 dBA and the total daytime operating duration is from 5 PM to 10 PM or DT = 5 hours.

2. The typical nighttime community sound level, CL, is 60 dBA and the total nighttime operating duration is from 10 PM to 12 PM or NT = 2 hours.

3. From Figure II-9 for the daytime values of community noise level and operating duration, the parameter, DL = 53 dB. (See Figure E5a.)

4. From Figure II-10 for the nighttime values of community noise level and operating duration, the parameter, NL = 59 dB. (See Figure E5b.)

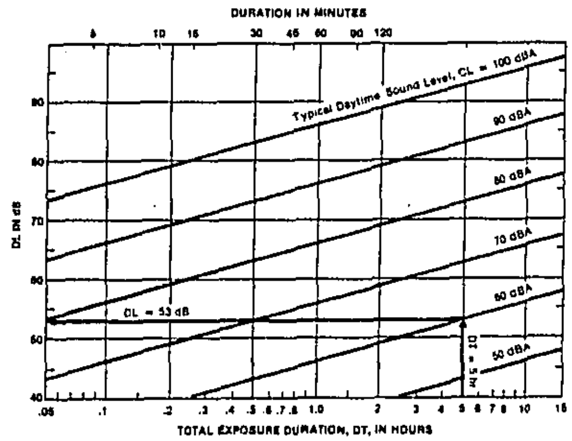
5. Since NL - DL = 6 dB, the parameter, K, must be computed. From Figure II-11 for the value of (NL - DL), parameter K is obtained, K = 7 dB. (See Figure E5c.)

6. The community noise exposure level due to the APU operation (in terms of day-night sound level) is:

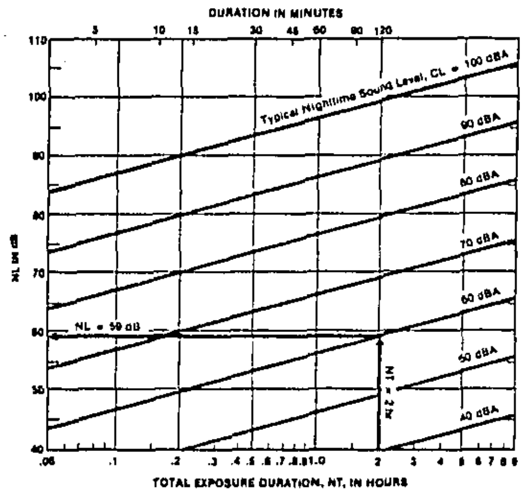
$$DNL = DL + K$$

$$DNL = 53 + 7 = 60 \text{ dB} = DNL.$$

(a)



(b)



(c)

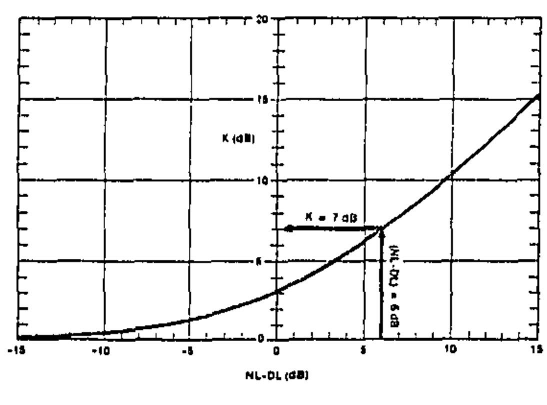


FIGURE E5. EXAMPLE 5

The day-night sound level estimation procedure may be applied to intermittent APU or GPU operation or multiple APU and/or GPU operations as follows:

- For intermittent APU or GPU operation, determine the total APU or GPU operating duration during daytime hours and the total operating duration during nighttime hours and apply the procedure of Figure II-8.
- For multiple APU and/or GPU exposures: estimate the community sound levels for each noise source, in accordance with the previous section; estimate the day-night sound levels for each of these sources per Figure II-8; then compute the total day-night sound level from all sources by the addition of exposure levels procedure, provided for in Appendix E.

EVALUATION OF COMMUNITY NOISE EXPOSURE

APU or GPU community noise exposures are assessed by comparison to established standards or recommended sound levels or by comparison to the noise environment existing in the community in the absence of the APU or GPU noise. The U.S. Department of Housing and Urban Development (HUD) has established environmental criteria and standards for noise abatement and control (24 CFR 51, Subpart B). This regulation establishes criteria for HUD-supported, new residential construction. It defines site acceptability in terms of "acceptable", "normally unacceptable", and "unacceptable" (as described in Table II-5). These acceptability standards may be used as a basis for judging APU or GPU exposures. The U.S. Environmental Protection Agency (EPA) has identified levels "as requisite to protect the public health and welfare with an adequate margin of safety." This level (provided in Table II-5) is based primarily upon activity interference such as the disruption of speech communication and upon the annoyance response to noise.

APU or GPU exposures can also be judged against the existing background noise due to sources other than the APUs or GPUs. This background

TABLE II-5

STANDARDS AND RECOMMENDED LEVELS FOR ASSESSING NOISE EXPOSURES

STANDARD OR RECOMMENDED LEVEL		DAY-NIGHT SOUND LEVEL, DNL (dB)
STANDARD	ASSESSMENT	
HUD 24CFR51 Environmental Criteria and Standards -- Noise Abatement and Control	Unacceptable	Above 75
	Normally Unacceptable	Above 65 but not exceeding 75
	Acceptable	Not exceeding 65
EPA Identified Levels of Environmental Noise*	Requisite to protect the public health and welfare with an adequate margin of safety	Not exceeding 55
Existing background noise	Normally Unacceptable	Above levels per Table II-6

*Reference: Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, U.S. EPA Report No. 550/9-74-004, March 1974.

noise is likely to contain elements of aircraft operational noise, highway traffic noise, local street traffic noise, and/or other definable noises -- such as power transformers. The noise environment around airports may have been quantified previously to meet Federal, state, or local requirements. In such cases, the noise environment would have been quantified in terms of DNL, noise exposure forecast (NEF), or -- in the State of California -- community noise equivalent level (CNEL). The latter descriptors can be related to day-night sound levels as indicated in Table II-6. Highway projects receiving Federal aid are subject to noise analyses under procedures of the Federal Highway Administration. Where these analyses are available, they may be used for comparison to APU or GPU noise. The Federal Highway Administration employs two alternative sound level descriptors:

- The A-weighted sound level not exceeded more than 10% of the time for the highway design hour traffic flow (L_{10})
- The equivalent sound level for the design hour (L_{eq}).

The day-night sound level may be estimated in these descriptors as indicated in Table II-6.

The noise in residential areas is determined primarily by local street traffic in the absence of exposures from aircraft operations, highway traffic, or other definable noise sources. The amplitude of its day-night sound level generally increases with increasing population density. The expected day-night sound level due to local street traffic can be estimated using Figure II-12.

The sound levels from other definable sources, such as, power plants, manufacturing facilities, and construction sites, vary greatly from case to case. For these sources the day-night sound level must be measured or otherwise estimated for the specific situation.

OVERVIEW

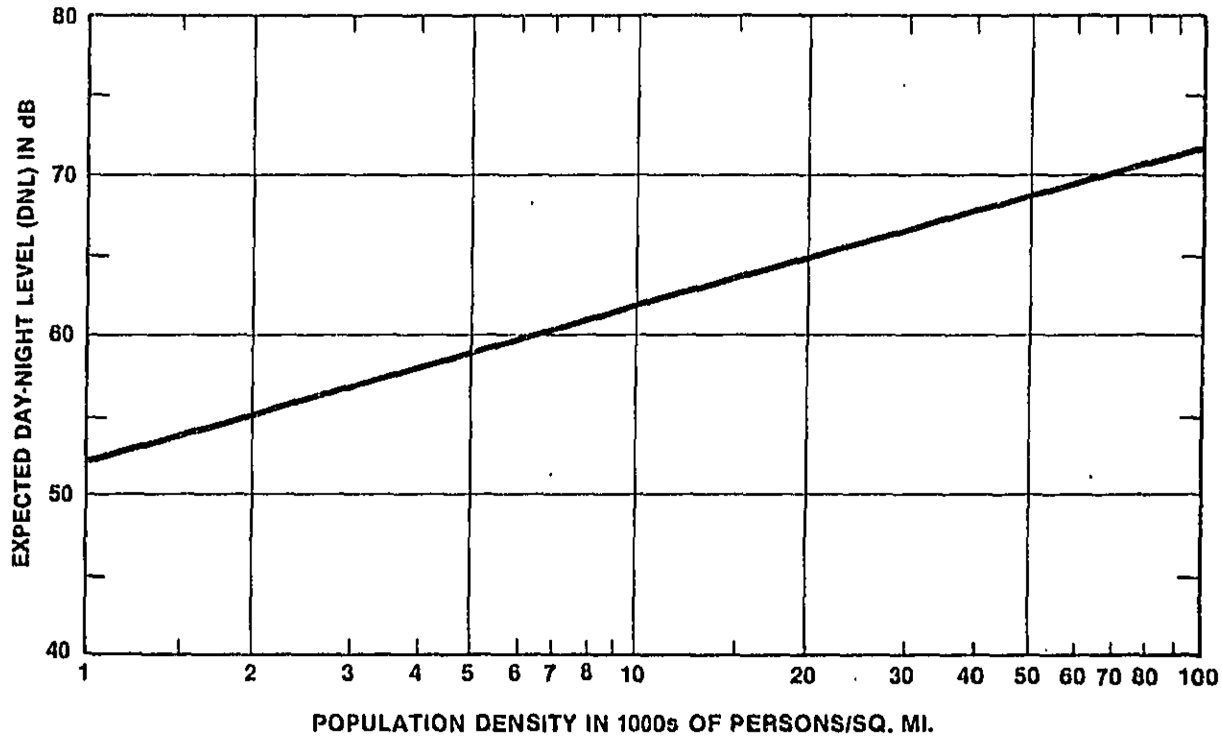
In the preceeding paragraphs a guide has been provided for the evaluation of APU or GPU community noise exposures. The user is cautioned that this procedure is simply a guide and a supplemental tool for evaluating these exposures and should not be used in lieu of actual on-site subjective observation and the exercise of judgment.

TABLE II-6

ESTIMATES OF BACKGROUND NOISE SOURCE DAY-NIGHT SOUND LEVEL, DNL, FROM AVAILABLE DATA

BACKGROUND NOISE SOURCE	ESTIMATE OF DAY-NIGHT LEVEL, DNL, FROM AVAILABLE DATA
Airport/Aircraft Operations	DNL = NEF + 35 DNL = CNEL
Highway Traffic	DNL = L_{10} (design hour) – 3 DNL = L_{eq} (design hour)
Local Street Traffic	DNL = depends upon population density -- see Figure II-12.
Other Defineable Noise Sources	DNL as measured or estimated

NEF = Noise Exposure Forecast
CNEL = Community Noise Equivalent Level
L_{10} (design hour) = A-weighted sound level not exceeded more than 10% of the time for the highway design hour traffic flow
L_{eq} (design hour) = Equivalent Sound Level for the design hour



SOURCE: U.S. Environmental Protection Agency, *Population Distribution Of The United States As A Function Of Outdoor Noise Level*, EPA Report No., 550/9-74-009, June 1974.

FIGURE II-12. OUTDOOR NOISE LEVELS EXPERIENCED IN RESIDENTIAL AREAS (EXCLUDING AIRPORT OPERATIONS AND FREEWAY TRAFFIC NOISE)

Each step in the evaluation process introduces sources of uncertainty:

- The reference sound levels are approximate and not representative of all sources.
- The propagation curves while generally predicting conservative (upper) estimates of community sound levels can be strongly influenced by environmental factors -- including, literally, which way the wind is blowing.
- The day-night sound level estimation procedure provided herein is simplified in some respects.

In assessing the APU or GPU exposures the user must exercise care. In many cases the background noise due to the aircraft flight operations or highway traffic alone will exceed acceptability standards or recommended levels. In other cases -- particularly around airports with night curfews, the nighttime background levels may be extremely low and the APU or GPU noise exposures may be particularly intrusive (although this may not be clearly shown from the day-night sound level). Even when APU or GPU community sound levels do not exceed the sound levels of the background noise sources, they may be quite perceptible and annoying although their absolute sound levels are moderate.

Finally where noise abatement appears indicated, the goals for the abatement controls should be considered in the context of cost and benefits. In some cases, benefits can be obtained with virtually no cost (e.g., aircraft re-orientation) or with significant ancillary benefits (e.g., reduced jet fuel consumption from reduced APU usage); but, in other cases, cost of control may be quite significant.

III. NOISE ABATEMENT OPTIONS

Several airport operators have requested air carriers to quiet APUs and GPUs although their sound levels are generally significantly quieter than those generated by the aircraft during normal operating procedures (including idle, taxi, takeoff, and landing). The trend in the long run will be toward minimizing the use of APUs and mobile GPUs due to their now expensive fuel requirements and due to the installation of fixed, centralized power systems. In the short run, however, airport operators may need to take some noise abatement actions. Actions which can be undertaken which may provide some noise relief are:

- Minimize the load on the APU or GPU
- Re-orient the direction of aircraft or GPU
- Relocate the aircraft or GPU
- Substitute mobile ground equipment for APU usage
- Substitute fixed ground facilities for APUs or GPUs
- Restrict durations or time of day of APU or GPU use
- Maintain GPU to new condition
- Install higher performance GPU exhaust silencers
- Utilize sound barriers.

Each of these abatement options has certain advantages and disadvantages. The load placed upon an APU is largely a function of external conditions (e.g., weather) and is not completely subject to operator discretion, although APU load can be reduced by not operating the ECS or by keeping the cabin doors closed. Re-orienting aircraft can achieve some benefit, but only for certain compass sectors. Boston's Logan Airport requires air carriers operating APUs or GPUs after 11 PM to position "the aircraft so that the APU exhaust or GPU equipment is shielded from the nearest residential area by the fuselage of the aircraft." In practice, it may not be possible to re-orient the aircraft if the aircraft needs to be parked at the specific terminal gate. When aircraft or equipment are parked near airport boundaries and residential areas, repositioning the equipment to some point farther from sensitive receptors will cause greater attenuation of the sound propagating from the noise source to the community.

Ground equipment can substitute for APU functions. Diesel- or gasoline-driven GPUs may be quieter than the turbine-driven APUs. Also, they are more readily muffled since size and weight considerations are of less importance for them than for the aircraft-mounted APUs. Every airline terminal facility has back-up ground support equipment for aircraft with inoperative APUs, but probably no facility relies upon ground power support equipment entirely for its aircraft servicing. The cost of GPUs range from $20,000 for an electric generator to $80,000 for an air start or air conditioning truck.[1] These mobile ground support units require additional labor for both operation and maintenance. Air carriers prefer to minimize the number of ground support vehicles in order to minimize ramp clutter and avoid accidential damage to the aircraft. With GPUs, turnaround times are increased, thereby decreasing aircraft utilization and productivity.

Fixed ground power facilities for either electric and/or pneumatic power can substitute for two of the APUs' functions, but will not perform the engine starting task. Fixed, ground-based, 400 Hz AC electric power has been installed at various airports either by means of an electric generator at each gate location or large, centralized electric motor-generator set which can distribute power to 6-10 aircraft simultaneously (although two generators are generally installed to provide redundancy). The capital cost for installing fixed electric power ranges from about $30,000 to $50,000 per gate -- depending upon the aircraft servicing requirements.[2] Operating costs for electric power average about $1.50 per hour compared to $2.50 to $3.50 per hour for mobile diesel generating units and $24.00 to $135.00 per hour for APUs. Fixed electric power eliminates about one half of the APU fuel costs and air pollutants. Centralized air conditioning (either chilled water or pneumatic) will enable the air carriers to eliminate most of the remaining APU usage normally required. (The Air Transport Association is issuing a design guide on centralized 400 Hz power systems which should be available by Fall, 1980.)

Airport operators can restrict the time or duration of APU use. Informal agreements with their air carriers can be used to restrict APU use during the nighttime hours except for necessary maintenance and to condition the aircraft's cabin temperature in the morning.

Sound barriers are used in some industrial and highway noise control situations. A barrier reduces noise by preventing sound from a noise source from traveling in a straight line to a receiver; therefore, the barrier must visually obscure the noise source from the receiver. Barrier benefits are greatest for noise sources <u>and</u> receivers close to the barrier. For noise sources <u>or</u> receivers at large distances from a barrier, the barrier effect is nil. Sound barrier benefits can be obtained by locating aircraft such that existing airport buildings and structures block visual contact of the APUs or GPUs by the community. Specially constructed sound barriers are rarely practical in airport situations for APU noise abatement because the height of the aircraft APU installation would require prohibitively tall barriers. (The heights of APU installations are provided in Table III-1.) Airport facilities and surrounding structures are subject to certain obstruction height restrictions established by the Federal Aviation Administration for safety purposes. Any

TABLE III-1

APU INSTALLATION DESCRIPTION

AIRCRAFT TYPE	INLET LOCATION	EXHAUST LOCATION	HEIGHT ABOVE GROUND (m)
A 300	Bottom, tail cone	Center, tail cone	7
B 727	Right wheel well	Right wing, top surface	3
B 737	Right, rear fuselage	Center, tail cone	5
B 747	Top, right tail cone	Center, tail cone, exiting upward	8
BAC 1-11	Right, tail cone	Center, tail cone	3
DC-9	Bottom center, fuselage	Top, right engine pylon	3
DC-10	Tail cone	Center, tail cone	6
L1011	Tail cone	Above right horizontal tail	5

noise barrier would need to conform to these regulations. However, GPU noise sources are generally quite low in height and may be effectively reduced by a barrier of moderate height.

The expected sound level reductions and advantages and disadvantages of these options are summarized in Table III-2.

REFERENCES

[1]Kurzak, David and Hubert Wills, "Central Air Start/Conditioning Systems" Airport Operators Council International (AOCI), Record of Proceedings of Technical Committee Meeting, 14-15 October 1979, Honolulu, HI.

[2]Mr. Lombardi of McCormick Morgan Power System Engineers, personal communication with R. A. Samis, 21 Feb. 1980.

TABLE III-2
NOISE ABATEMENT OPTIONS

NOISE ABATEMENT OPTION	SOUND LEVEL REDUCTION *(dBA)	ADVANTAGES	DISADVANTAGES
Reduced APU or GPU Load	0-6	• Incurrs no cost penalty • Results in fuel savings	• Load may be dictated by ambient conditions
Re-orient Aircraft or GPU	0-13 (Reduction equals change in directional sound level, e.g., per Tables II-1 and II-3)	• Incurrs no cost penalty	• Terminal gate may dictate aircraft position
Relocate Equipment	0-10 (Reduction equals attenuation per Figure II-5)	• Incurrs no cost penalty	• Large changes in location required for significant sound level reductions • Terminal gate may dictate aircraft position
Substitute GPU for APU	0-10 (Compare per Chapter II)	• Results in jet fuel saving	• Increased terminal clutter • Additional equipment and labor cost
Substitute fixed, centralized services	5-20	• Results in fuel saving • May be a currently planned airport improvement	• Very expensive to implement • Requires long lead time to implement
Restrict Operating Duration	DNL reduction equals 3 dB per halving of duration	• Incurrs no cost penalty • Results in fuel savings	• Usage dictated by operational requirements • Large changes in duration required for significant DNL reductions
Restrict Nighttime Operations	DNL reduction, 0-10 (night time exposures are considered as 10 dB more intense than identical daytime exposures in computing DNL)	• Incurrs no cost penalty	• Usage dictated by operational requirements • Reduction community adverse response not necessarily proportional to DNL reduction
Improve Equipment Maintenance	0-15	• May improve equipment performance • May be implemented at minimal cost	• Applicable only for defective equipment (probably GPUs only)
Install Higher Performance Equipment Silencing	0-5	• May be implemented at moderate cost	• Applicable only for GPUs
Construct Barriers	0-10		• Barrier must eliminate visual contact of receiver with noise source -- required height may conflict with FAA structural height restrictions • Not appropriate for APU problems • Expensive • Little or no benefit at moderate to large distances
Use Existing Structures as Barriers	0-10	• Incurrs no cost penalty	• Little benefit at large distances • Operational requirements may dictate equipment position

*Estimated range of expected values

APPENDIX A
GLOSSARY

Auxiliary Power Unit (APU). A small, lightweight turbine engine driving a 400 Hz electrical generator providing electrical and pneumatic power. The pneumatic power is obtained by drawing bleed air from the turbine's compressor stages. Either form of power can be delivered independently or interchangeably.

A-weighting. A frequency-dependent weighting or filtering of sound to correspond to the response of the human ear such that sound levels so weighted correlate reasonably well with noise effects such as hearing loss, annoyance, and the interference of speech by noise. Sound levels which have been A-weighted have units of A-weighted decibels (dBA).

Background Noise. Noise from all sources other than that source of immediate interest. For example, if at a given location noise was experienced from aircraft operations, highway traffic, and barking dogs and the sound levels of barking dogs were to be evaluated, the highway traffic and aircraft operation noise would be considered background noise.

Day-Night Sound Level (DNL). A measure of noise exposure in which the time-averaged A-weighted sound levels during daytime hours (7 AM to 10 PM) and during nighttime hours (10 PM to 7 AM) are summed after the nighttime sound levels have been weighted by the addition of 10 dB. Day-night sound levels correlate reasonably well with the annoyance response to environmental noise. For the purpose of this report, it is defined as

$$DNL = 10 \log_{10} \frac{1}{24} \left[DT \times 10^{CL_D/10} + NT \times 10^{(CL_N+10)/10} \right]$$

where CL_D = typical/daytime community noise level

and CL_N = typical/nighttime community noise level.

Decibel (dB). See Level.

Directivity. The variation of sound levels around a source at a fixed distance from the source.

Frequency. The rate at which an oscillation or vibration repeats itself, expressed in cycles (repetitions) per second called hertz (Hz).

Ground Power Unit (GPU). Any of various ground-based, mobile equipment which can be used in lieu of the APU for electrical/pneumatic power generation, engine starting, or air conditioning. GPUs can be either trailer-mounted, truck-mounted, or self-propelled.

Level. A measure defined as the common logarithm of a ratio of a power-related quantity to a reference quantity of the same kind. The units of level are decibels (dB), computed as ten times the common logarithm of the ratio. (The reference quantity should be indicated in presenting level data.)

Noise Abatement. The process of reducing the noise levels or noise exposure levels which a receiver of noise experiences. This reduction may be achieved either by the actual quieting of the source, the blocking of sound traveling from the source to the receiver, the reduction of source operating time, and/or the manipulation of the source to achieve lower sound levels at the receiver (such as by utilizing directivity characteristics of the noise source).

Noise Exposure Level. The measure of noise from a source which considers not only its amplitude (the noise level) but also other factors related to its adverseness, typically the duration of the exposure and its time of day.

Sound Attenuation. The reduction of noise sound levels due to the propagation of sound through the atmosphere as a result of its geometric spreading over progressively larger areas surrounding the source, the absorption of sound by the atmosphere, various atmospheric effects, and interference with ground and other objects.

Sound or Noise Level. Measure of the sound disturbance (i.e., sound pressure) perceived by the human ear. For the presentation of this report, all sound or noise levels are in terms of A-weighted sound level and have a reference sound pressure of 20 micropascal (μPa).

Sound Propagation. The transmission of noise disturbances through the atmosphere. The magnitude of these disturbances is normally diminished with increasing distance due to sound attenuation.

Spectrum (pl., spectra). The range of frequency of airborne sound pressure oscillations sensed by the human ear, approximately 20 to 12,000 Hz.

APPENDIX B

APU AND GPU SOUND LEVELS

APU SOUND LEVELS

Sound levels from APUs were obtained from a variety of sources.[1-4] These data sources presented measured A-weighted sound levels at various distances from the APUs. The available data, as obtained, are summarized in Table B-1. (Some of the sound levels were estimated from sound level contours around the aircraft or interpolations of measurements at angles other than those specified in Table B-1.) To obtain the reference sound levels provided in Table II-1 for the reference distance of 30 m, the available sound levels were normalized for distance using Figure II-5.

GPU SOUND LEVELS

With the exception of the data presented in Table II-3 for the Hobart 90G20P[5], no sound level data were available for commercially available GPUs. To provide reference sound levels for GPUs, sound level data measured by the U.S. Air Force Aerospace Medical Research Laboratory (AMRL), Wright-Patterson Air Force Base were used.[6] These results were derived from data presented in the AMRL-TR-75-50, USAF Bioenvironmental Noise Data Handbook, which were normalized to 10 m radial distance from the source (using a procedure equivalent to the use of Figure II-5) and standard day meterorology (15^{o}C, 0.760 M Hg, and 70% relative humidity). These data are summarized in Table B-2 for GPUs which included turbine and piston-engined drives; electrical and

TABLE B-1

AVAILABLE APU SOUND LEVELS

REFERENCE	AIRCRAFT TYPE	MEASUREMENT DISTANCE		MEASURED APU SOUND LEVELS (dBA) at MEASUREMENT DISTANCE								
					Angle A per Figure II-2							
		(ft)	(m)	Avg.	0^0	45^0	90^0	135^0	180^0	225^0	270^0	315^0
1	A300	98	30.0	80.6	-	-	80	-	81	-	81	-
2	B737	35	10.7	89.8	-	-	91	-	-	-	88	-
3	B727	50	15.2	87.1	84	84	84	91	88	88	88	82
2	B747	100	30.5	86.7	-	-	84	88	84	89	86	-
3	BAC 1-11	50	15.2	89.7	-	85	90	94	89	91	87	82
2	DC-9	30	9.1	93.9	-	-	89	-	98	-	85	-
-	DC-10	-	-	-	-	-	-	-	-	-	-	-
4	L 1011	50	15.2	86.1	87	90	86	84	83	86	85	85

Dash (-) denotes data not available

References:

(1) Airbus Industrie, A300 Aircraft Noise Definition Manual, April 1976.

(2) Odell, A. H., and G. N. Goodman, "APU and Airborne Ground Conditioning Equipment Noise, International Civil Aircraft Organization, Committee on Aircraft Noise, Third Meeting, Working Paper No. 30, March 1973.

(3) Wassenaar, Johan A., "The Self Sufficient Turbine Transport and its Contribution to Airport Noise", International Air Transport Association Meeting, London, May, 1965.

(4) Lockheed California Company, L-1011-1 APU Ramp Noise, Report No. CER 71-109, March 30, 1973.

TABLE B-2

AVAILABLE GPU SOUND LEVELS

GPU DESCRIPTION	MANUFACTURER	OUTPUT RATING	DRIVE ENGINE RATING (HP @ RPM)	DRIVE ENGINE TYPE	DRIVE ENGINE MANUFACTURER, MODEL	MILITARY TYPE DESIGNATION	AVERAGE SOUND LEVEL AT 10 m (dBA)	SOUND LEVEL TEST CONDITION
POWER GENERATORS								
28 V DC generator	ACF-Brill Motors Co.	7.5 KW	30 @ 2400	2-cyl. gasoline engine	Continental Packette, Model PC-30-2	A-1	84.2	1830 RPM; Output: 150 A at 28 V DC with MC-3A load bank
400 Hz AC or 28V DC generator and pneumatic power supply	Libby Welding Co., Inc.	DC:500 A @ 28 V AC:75 KVA, 0.8PF (3 Phase) Air Flow: 120 lb/min	200 @ 42,500 (max)	gas turbine	AiResearch GTC85-397	A/M32 A60	93.5	Turbine speed, 42,500 RPM with air output
Pneumatic Power Supply	AiResearch Manufg. Corp.	Air Flow: 90 lb/min	200 @ 42,500 (max)	gas turbine	AiResearch GTC85-70	MA-1A	103.0	42,500 RPM
Pneumatic Power Supply	Continental Aviation & Eng. Corp.	Air Flow: 90 lb/min	NA @ 35,000	gas turbine	Continental	MA-1A	97.1	35,000 RPM, 100% loaded (40 PSI)
400 Hz AC or 28 V DC Generator	Beech Aircraft Corp.	DC:45 KW AC:15 KW; 0.9PF	180 @ 2400	471 cu. in., 6 cyl., gasoline engine	Continental Motors PE150-2 Packette	C-26	95.8	Gasoline engine at 2500 RPM; 2 DC lines loaded at 400 A
60 Hz AC Generator	NA	10 KW, 0.8 PF	30 @ 1800	Air-cooled, 4-cyl., gasoline engine	Wisconsin Motor Corp. Model MVG4D	EMU-10/MS	72.3	2300 RPM; unloaded
400 Hz AC or 28 V DC Generator	Intl. Fermont Mach. Co. Inc.	DC:60 KW AC:45 KW, 0.75PF	168 @ 2250	471 cu.in., air cooled, 6-cyl. gasoline engine	Continental Motors PE-150-6 Packette	MD-3A	97.3	NA
400 Hz AC Generator	Hobart Model 90G20P	AC: 90 KVA	152 @ 2100	284 cu. in., 4-cyl. water-cooled diesel engine	Detroit Diesel 4-71N	-	96.9	Diesel engine at 2000 RPM; A/M 24T-8A load bank 190A, 240 V AC, 400 Hz 23 KW per AC phase

TABLE B-2 (cont.)

GPU DESCRIPTION	MANUFACTURER	OUTPUT RATING	DRIVE ENGINE RATING (HP @ RPM)	DRIVE ENGINE TYPE	DRIVE ENGINE MANUFACTURER, MODEL	MILITARY TYPE DESIGNATION	AVERAGE SOUND LEVEL AT 10 m (dBA)	SOUND LEVEL TEST CONDITION
AIR CONDITIONERS								
Heating/Air Conditioning Supply	NA	cooling: 84,000 BTU/hr Heating: 23,000 BTU/hr	70 @ 2400	air-cooled gasoline engine	NA	MA-7	73.6	Cooling mode; 1500 RPM; compressor pressure, 120 PSI; suction pressure, 105 PSI
Air Conditioning Supply	NA	100 lb/min 45°F air	110 @ 2400	air-cooled gasoline engine	NA	MA-3	83.3	1750 RPM
COMPRESSORS								
Reciprocating Compressor	Worthington Corp.	15 CFM @ 3500 PSI	23 @ 2200	gasoline engine	NA	MC-1A	76.5	Gasoline engine at 1700 RPM; Low discharge pressure, 600 PSI; high discharge pressure 3500 PSI
Rotary Compressor	Davey Compressor Co.	15 CFM @ 200 PSI	12.9 @ 2700	air-cooled gasoline engine	NA	MC-2A	70.9	Air tank fill cycle
Reciprocating Compressor	Worthington Corp.	15 CFM @ 4000 PSI	25 @ NA	gasoline engine	NA	MC-11	77.9	Air tank fill cycle

NA denotes data not available.

SOURCES: Equipment Descriptions -- MIL-HDBK-300 (USAF).

Sound Level Data -- Coles, J. N.; Aerospace Medical Research Laboratory, Letter to M. Staiano re Ground Support Equipment Noise Data, 24 March 1980

Rau, T; Wright-Patterson AFB Survey, 19 March 1980.

pneumatic power generators, air compressors, and air conditioning supplies. While no pattern appeared for the turbine-engined equipment, the piston-engined equipment sound levels correlated well with drive engine power rating (as shown in Figure B-1) which provided the basis for Figure II-3.

For the purpose of the frequency-dependent sound propagation procedures (presented in Appendix D), the energy-average octave band sound levels were computed from the data in references (5) and (6).* These spectra are presented in Figure B-2.

REFERENCES

1. Airbus Industrie, A300 Aircraft Noise Definition Manual, April 1976.

2. Odell, A. H. and G. N. Goodman, "APU and Airborne Ground Conditioning Equipment Noise", International Civil Aircraft Organization, Committee on Aircraft Noise, Third Meeting, Working Paper No. 30, March 1973.

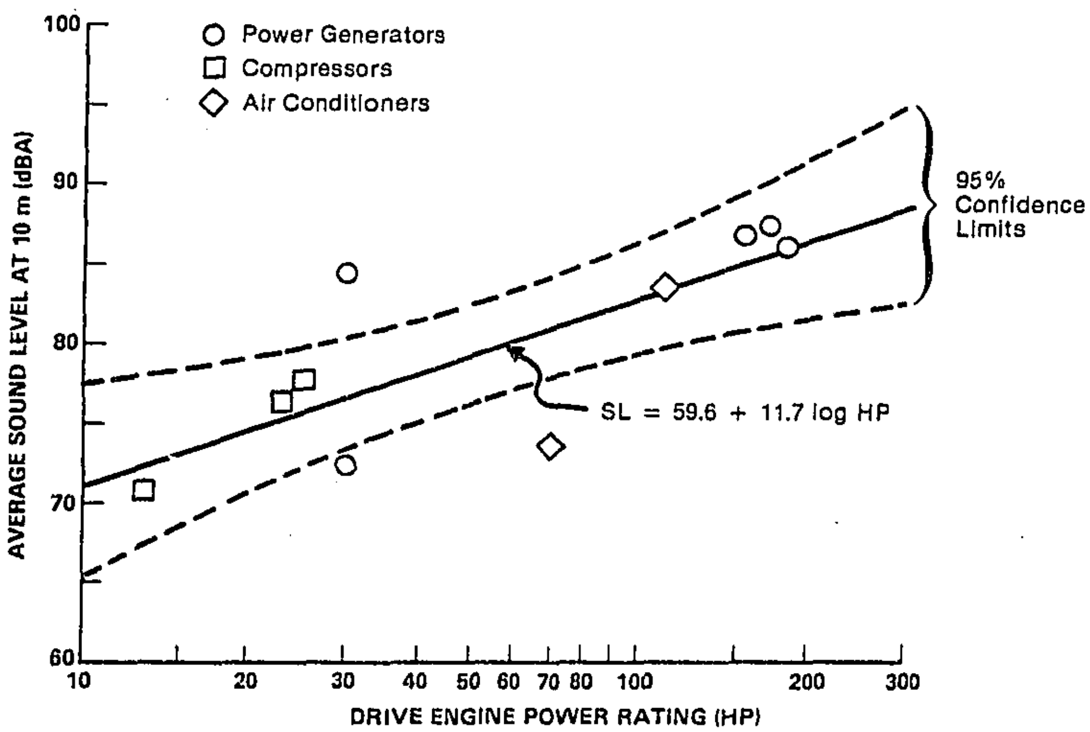
3. Wassenaar, Johan A., "The Self Sufficient Turbine Transport and its Contribution to Airport Noise", International Air Transport Association Meeting, London, May 1965.

4. Lockheed California Company, L-1011-1 APU Ramp Noise, Report No. CER 71-109, March 30, 1973.

5. Rau, T., Wright-Patterson AFB Survey, March 19, 1980.

6. Cole, J. N., Aerospace Medical Research Laboratory, Wright-Patterson AFB, Letter to M. Staiano re Ground Support Equipment Noise Data, March 24, 1980.

* Octave bands are a coarse description of sound amplitude as it varies with frequency. The octave bands increase in size with increasing frequency -- an individual octave band has a frequency width twice that of the adjacent lower band and half that of the adjacent higher band. The band level is the measure of the total sound energy within the band in decibels (dB).



SOURCES: Cole, J.N., Aerospace Medical Research Laboratory Letter, 24 March 1980
Rau, T., Wright-Patterson AFB Survey, 19 March 1980

FIGURE B-1. AVAILABLE PISTON-ENGINED GPU SOUND LEVELS AT 10 m -- EFFECT OF POWER RATING

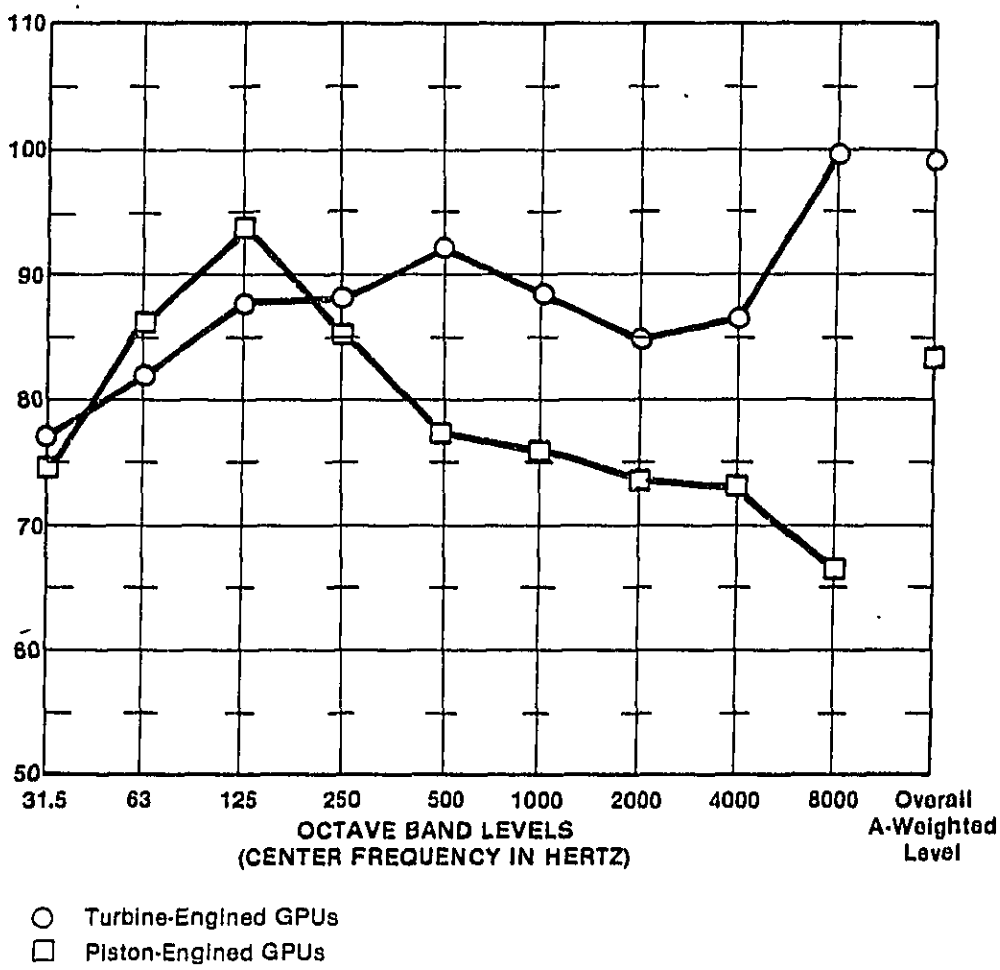


FIGURE B-2. AVAILABLE GPU SOUND LEVELS AT 10 m -- ENERGY-AVERAGE SPECTRA

APPENDIX C

STANDARDS AND GUIDELINES FOR NOISE FROM AUXILIARY POWER UNITS

The Committee on Aircraft Noise (CAN) of the International Civil Aviation Organization (ICAO) has considered the establishment of noise certification of APUs. In a 6 June 1979 meeting, CAN revised existing guidelines for installed auxiliary power units (Attachment E to Annex 16) and adopted the Society of Automotive Engineers (SAE) Aerospace Recommended Practice, ARP 1307, Measurement of Exterior Noise Produced by Aircraft Auxiliary Power Units and Associated Equipment During Ground Operation. A report of that meeting, the revised ICAO Attachment E to Annex 16, and SAE ARP 1307 follow.

Agenda Item 5: Noise certification of installed Auxiliary Power Units (APUs) and associated aircraft systems

5.1 Introduction

It was noted that guidance material on APU noise had been introduced into Annex 16 (Attachment E) on the recommendations of CAN/4. The subject was not included in the agenda of CAN/5, but it was briefly discussed. Joint "focal points" were appointed to examine the subject further in order to develop SARPs using Attachment E to Annex 16 as a basis. The report of the joint "focal points" was discussed by the Committee together with working papers presented by individual members and observers.

5.2 Discussion

5.2.1 The meeting noted the "focal points'" view that three elements of the subject were involved, namely:

a) the status of the provisions;

b) the limiting noise levels;

c) the evaluation method;

and it was agreed to discuss the question under these headings.

5.2.2 Status of the provisions

5.2.2.1 Some members and observers were of the opinion that APU noise was becoming a community noise problem at some airports and had already resulted in the imposition of restrictions on the running of APUs, especially at night. They, therefore, believed that the best way of dealing with this problem would be for ICAO to establish standards which included limiting noise levels.

5.2.2.2 Other members and observers, however, were of the opinion that APU noise was more of an industrial than a community environment problem which affected aerodrome employees rather than the public. As such it could better be resolved directly between operators, manufacturers and airport operators and did not need strong ICAO action. It was, therefore, believed that the present guidance material was appropriate. In support of this a member advised the meeting that in his State Attachment E to Annex 16 was already being used as the basis for negotiating APU noise guarantees between manufacturers and operators.

5.2.2.3 The majority of members agreed that there was no clear indication of a need to change the status of the present provisions and the meeting, therefore, agreed that they should remain as guidance material. One observer expressed disappointment at this result and thought that it would only serve to accelerate the trend towards placing restrictions on the use of APUs at some airports.

5.2.3 Limiting noise levels

It was proposed that the limiting noise levels contained in the guidance material were not sufficiently stringent and came close to the levels permitted in industrial surroundings in some cases. Other members felt, however, that the limits were already hard to achieve and no change should be made. The Committee agreed that r change was appropriate at present.

5.2.4 Evaluation method

5.2.4.1 The "focal points" had proposed certain detailed changes to the noise evaluation method mainly concerning microphone orientation and the effect of wind on test results. It was also noted, however, that the U.S. Society of Automotive Engineers (SAE) had recently published its document ARP 1307 which contained a comprehensive noise evaluation procedure. It was suggested that this procedure should be used in place of that at present in Annex 16 since it was the result of five years of careful development. Some members were uncertain as to the detailed differences between the SAE procedure and the present Annex 16 material. It was pointed out that the ICAO material had been based in part on an early draft of the SAE procedure and that the differences should not, therefore, be large. It was in general agreed that the SAE procedure should replace the present Annex 16 material.

5.2.4.2 Two detailed differences that were noted concerned the height of the test microphones and their position relative to the aeroplane. It was noted that SAE ARP 1307 called for a microphone height of 1.6 m compared with the Annex 16 height of 1.2 m and there was a proposal to retain the 1.2 m height for compatibility with other parts of the Annex. It was also noted that ARP 1307 called for microphones to be placed in the plane of the fuselage skin whereas Annex 16 currently specifies a position 1 m out from the skin. It was suggested that ARP 1307 should be modified in these instances before incorporation into Annex 16; however, the majority opinion was that it would be unwise to alter the procedure in detail without the full background regarding the derivation of the figures. It was, therefore, agreed to accept ARP 1307 without alteration.

5.3 Recommendation

In light of the foregoing the Committee developed the following recommendation.

RSPP

RECOMMENDATION 5/1 - AMENDMENT OF ANNEX 16 - GUIDANCE MATERIAL RELATING TO THE NOISE CERTIFICATION OF AUXILIARY POWER UNITS

THAT the guidance material in Attachment E to Annex 16 be replaced by the material shown in the appendix to this part of the report.

5.4 Future work

It was agreed that the subject of noise from APUs should now be deleted from the work programme of the Committee. However, it was noted that active investigations were under way in at least one State and although no immediate developments were foreseen, it should be retained. It was, therefore, agreed that the members and observers should maintain a watching brief on the subject and should advise the Secretary if they felt there was a need to pursue the matter more actively in the future.

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APPENDIX TO THE REPORT ON AGENDA ITEM 5

Attachment E to Annex 16

GUIDELINES FOR NOISE CERTIFICATION OF

INSTALLED AUXILIARY POWER UNITS (APU)

AND ASSOCIATED AIRCRAFT SYSTEMS

DURING GROUND OPERATION

(Note: See Chapter 8, Part II of the Annex)

1. Introduction

1.1 The following guidance material has been prepared for the information of States establishing noise certification requirements for installed auxiliary power units (APUs) and associated aircraft systems used during normal ground operation.

1.2 It should apply to installed APUs and associated aircraft systems in all aircraft for which application for a certificate of airworthiness for the prototype, or another equivalent prescribed procedure, is made on or after (date of applicability of the amendment).

1.3 For aircraft of existing type design, for which application for a change of type design involving the basic APU installation, or another equivalent prescribed procedure, is made on or after (date of applicability of the amendment), the noise levels produced by installed APUs and associated aircraft systems should not exceed those existing prior to the change, when determined in accordance with the following guidelines.

2. Noise evaluation procedure

The noise evaluation procedure should be according to the methods of paragraph 4.

3. Maximum noise levels

3.1 The maximum noise levels, when determined in accordance with the noise evaluation procedure specified in 4, should not exceed the following:

a) 85 dB(A) at the points specified in 4.4.2.2 a), b) and c);

b) 90 dB(A) at any point on the perimeter of the rectangle shown in Figure 2.

4 Noise evaluation procedures

4.1 General

4.1.1 Test procedures are described for measuring noise at specific locations (passenger and cargo doors, and servicing positions) and for conducting general noise surveys around aircraft.

4.1.2 Requirements are identified with respect to instrumentation, acoustic and atmospheric environment, data acquisition, reduction and presentation, and such other information as is needed for reporting the results.

4.1.3 Procedures involve recording data on magnetic tape for subsequent processing. The use of tape-recorder/time-integrating analyzer systems avoids the need to average by eye the variations associated with manual readings from sound level meters and octave band analyzers and therefore yields more accurate results.

4.1.4 No provision is made for predicting APU noise from basic engine characteristics, nor for measuring noise of more than one aircraft operating at the same time.

4.2 General test conditions

4.2.1 Meteorological conditions

Wind	Not more than 10 knots (5 m/s).
Temperature	Not less than 2°C (35°F) nor more than 35°C (95°F).
Humidity	Relative humidity not less than 30% nor more than 90%.
Precipitation	None.
Barometric pressure	Not less than 80 kPa (800 mbar) nor more than 110 kPa (1100 mbar).

4.2.2 Test site

The ground between microphone and aircraft should be a smooth, hard surface. No obstructions should be present between aircraft and measurement positions and no reflecting surfaces (except the ground and aircraft) should be near enough to sound paths to significantly influence results. Surface of the ground surrounding the aircraft should be sensibly flat and level at least over an area formed by boundaries parallel to and 60 m (200 ft) beyond the outermost microphone array identified in 4.4.2.2 d).

4.2.3 Ambient noise

Ambient noise of the measurement system and test area (that is, composite of the noise due to environmental background and the electrical noise of the acoustic intrumentation) should be determined.

4.2.4 APU installation

Pertinent APU and associated aircraft systems should be tested for each aircraft model for which acoustic data are required.

4.2.5 Aircraft ground configuration

Aircraft flight control surfaces should be in the "neutral" or "clean" configuration, with gust locks on, or as stated in the aircraft's approved operating manual for aircraft undergoing servicing.

4.3 Instrumentation

4.3.1 Aircraft

Operation data identified in 4.5.3 should be determined from normal aircraft instruments and controls.

4.3.2 Acoustical

4.3.2.1 General

Instrumentation and measurement procedures should be consistent with requirements of latest applicable issues of appropriate standards listed in the references (4.6). All data samples should be at least 2.5 times the data reduction integration period which in no case should be less than 8 seconds. All sound pressure levels should be in decibels to a reference pressure of 20 µpa.

4.3.2.2 Data acquisition systems

Instrumentation systems for recording and analysis of noise, shown in the block diagram of Fig 1, should meet the following specifications:

4.3.2.2.1 Microphone system

a) over a frequency range of at least 45 Hz to 11 200 Hz the system should meet the requirements as outlined under microphone system specifications in the latest issue of reference 6;

b) microphones should be omnidirectional, vented for pressure equalization if of condenser type, and should have known ambient pressure and temperature coefficients. Microphone amplifier specifications should be compatible with those of the microphone and tape recorder;

c) microphone wind screens should be employed when wind speed is in excess of 6 knots (3 m/s). Corrections as a function of frequency should be applied to measured data to account for the presence of microphone wind screens.

4.3.2.2.2 Tape recorder

The tape recorder may be direct record or FM and should have the following characteristics:

Dynamic range 50 dB minimum in 1/1 octave or 1/3 octave bands.

Tape speed accuracy within ± 0.2% of rated speed.

Wow and flutter (peak to peak) less than 0.5% of tape speed.

Maximum third harmonic distortion less than 2%.

4.3.2.3 Calibration

4.3.2.3.1 Microphone

Frequency response calibration should be performed prior to the test series and a subsequent post calibration should be performed within one month of the pre-calibration, with additional calibrations made when shock or damage is suspected. Response calibration should cover the range of at least 45 Hz to 11 200 Hz. Pressure response characteristics of the microphone should be corrected to obtain random incidence calibration.

4.3.2.3.2 Recording System

a) A calibration tape, a recording of broadband noise or a sweep of sinusoidal signals over a minimum frequency range of 45 Hz to 11 200 Hz should be recorded in the field or in the laboratory at the beginning and end of each test. The tape should also include signals at the frequencies employed during sound pressure sensitivity checks as defined below.

b) This calibration signal, an insert voltage, should be applied to the input and should include all signal conditioning preamplifiers, networks and recorder electronics used to record acoustic data. In addition, a "shorted input" (i.e. microphone pressure sensitive element replaced with equivalent electrical impedance) recording of at least 20 sec. should be made as a check on system dynamic range and noise floor.

c) Sound pressure sensitivity calibrations with the arrangement shown in Fig 1 should be made in the field for each microphone prior to beginning and after completion of measurements each day. These calibrations should be made using a calibrator producing a known and constant-amplitude sound pressure level at one or more 1/3 octave band center frequencies, specified in reference 3 or 10 in the frequency range from 45 Hz to 11 200 Hz. A barometric correction should be applied as required. Calibrators employed should be precise at least to within ±0.5 dB and should have a calibration obtained according to reference 4 that is traceable to a recognized standards organization.

d) Each reel of tape should have comparable response and background noise to the calibration tape. A constant amplitude sine wave should be recorded at the start of each reel of tape, for reel-to-reel sound pressure sensitivity comparisons. The frequency of this sine wave should be within the same frequency range as used for sound pressure sensitivity checks. A separate voltage insert device or an acoustic calibrator may be used for this purpose. If an acoustic calibrator is used, it should be carefully "seated" and corrections for ambient pressure should be made so that effects of pressure on calibrator and microphone response are eliminated.

e) Battery-driven tape recorders should be checked at frequent intervals during a test to ensure good battery condition. Tape recorders should not be moved while recording is in progress unless it has been established that such movements will not change tape recorder characteristics.

4.3.2.3.3 Data reduction equipment

Data reduction equipment should be calibrated with electrical signals of known amplitude either at a series of discrete frequencies or with broadband signals covering the frequency range of 45 Hz to 11 200 Hz.

4.3.2.4 Data reduction

4.3.2.4.1 The data reduction system of Fig. 1 should provide 1/3 or 1/1 octave band sound pressure levels. Analyzer filters should comply with requirements of references 8 or 11 (Class II for octave-band filters and Class III for one-third octave-band filters). Analyzer amplitude resolution should be no worse than 0.5 dB; dynamic range should be a minimum of 50 dB between full scale and the root-mean-square (rms) value of the analyzer noise floor in the octave band with the highest noise floor; and amplitude response over the upper 40 dB range should be linear to within ±0.5 dB.

4.3.2.4.2 Mean square sound pressures should be time averaged by integration of the squared output of frequency band filters over an integration interval that should be no less than 8 seconds. All data should be processed within the frequency range from 45 Hz to 11 200 Hz. Data should be corrected for all known or predictable errors, such as deviations of system frequency response from a flat response.

4.3.2.5 Total system

4.3.2.5.1 In addition to specifications for component systems, frequency response of the combined data acquisition and reduction system should be flat within ±3 dB over the frequency range from 45 Hz to 11 200 Hz. Frequency response gradient anywhere within this range should not exceed 5 dB per octave.

4.3.2.5.2 Amplitude resolution should be at least 1.0 dB. Dynamic range should be a minimum of 45 dB between full scale and the rms value of the system noise floor in the frequency band with the highest noise floor. Amplitude response should be linear within ±0.5 dB over the upper 35 dB in each frequency band.

4.3.3 Meteorological

The wind speed should be measured with a device having a range of at least 0 to 15 knots (0 to 8 m/s) with an accuracy of at least ±0.5 knots (±0.3 m/s). Temperature measurements should be made with a device having a range of at least 0° - 40°C (30°- 110°F) with an accuracy at least ±0.2°C (±0.5°F). Relative humidity should be measured with a device having a range of 0 to 100 percent with an accuracy of at least ±3 percentage points. Atmospheric pressure should be measured with a device having a range of at least 80 to 110 kPa (800 to 1 100 mbar) with an accuracy of at least ±0.25 kPa (±2.5 mbar).

4.4 Test procedure

4.4.1 Test conditions

4.4.1.1 Ambient noise measurements should be made in sufficient number to be representative for all acoustic measurement stations, providing correction data to apply to measured APU noise where necessary (see 6.4).

4.4.1.2 The installed APU should meet the noise levels specified in 3.1 at the points specified under typical loads, up to and including those imposed by the electrical power generator and air-conditioning units and any other associated systems at their normal maximum continuous ground operation power requirements.

Note.- A measurement of noise from a particular model of auxiliary power unit installed in a specific aircraft type should not be deemed typical of the same equipment installed in other aircraft types nor of other models of APUs installed in the same aircraft type.

4.4.2 Acoustical measurement locations

4.4.2.1 Except where specified otherwise, noise measurements should be made with microphones at 1.6 m ± 0.025 m (5.25 ft ± 1.0 in) above the ground or surface where passengers or servicing personnel may stand, with the microphone diaphragm parallel to the ground and facing upwards.

4.4.2.2 Locations for measuring noise should be as follows:

a) Cargo door locations: Measurements should be made at each cargo door location, with the door open, while the aircraft is in a typical ground handling configuration. These measurements should be taken at the centre of the opening, in the plane of the fuselage skin.

b) Passenger door locations: Measurements should be made at each passenger entry door, with the door open, on the vertical centerline of the opening, in the plane of the fuselage skin.

c) Servicing locations: Measurements should be made at all servicing positions where persons are normally working during aircraft ground handling operations. These positions to be determined by reference to the approved aircraft operating and service manuals.

d) Survey locations: Appropriate measurement positions should be chosen from a rectilinear grid pattern centered on the test aeroplane as illustrated in Fig 2. The grid pattern should originate 20 m aft of the aircraft and extend at least 20 m forward of the aircraft as well as perpendicular to the aircraft centerline. The length of sides of squares in the grid should be 10 metres. Further subdivision of the grid pattern to accommodate small aeroplanes or to fulfill special requirements may be accomplished by progressively halving dimensions of grid squares as appropriate.

4.4.3 Meteorological Measurement Locations

Meteorological data should be measured at a location at the test site within the microphone array of Fig. 2, but upwind of the aircraft, and at a height of 1.6 m (5.25 ft) above ground level.

4.4.4 Data presentation

4.4.4.1 A-weighted sound levels should be calculated by applying frequency weighting corrections derived from the standards for precision sound level metres (reference 6 or 9) to 1/3 or 1/1 octave-band sound pressure levels. The 1/1 octave-band sound pressure levels may be determined from a summation of mean-square sound pressures in appropriate 1/3 octave bands. Overall sound pressure levels should be determined from a summation of mean-square sound pressures in the twenty-four 1/3 octave, or eight 1/1 octave, frequency bands included in the frequency range from 45 Hz to 11 200 Hz.

4.4.4.2 Overall sound pressure levels, A-weighted sound levels and 1/3 octave band or 1/1 octave band data should be presented to the nearest decibel (dB) in tabular form, with supplementary graphical presentations as appropriate. Sound pressure levels should be corrected, if necessary, for the presence of high ambient noise. No corrections are needed if a sound pressure level is 10 dB or more above ambient noise. For sound pressure levels between 3 and 10 dB above ambient noise, appropriate corrections should be applied, see Table 1. If sound pressure levels are 3 dB or less above the ambient noise, no corrections should be attempted and these data should not be reported.

Table 1

Corrections for Ambient Sound Pressure Levels

Difference (in Decibels) Between Sound Pressure Level Measured with Sound Source Operating and Ambient Sound Pressure Level Alone	Correction (in Decibels) to be Subtracted from Sound Pressure Level Measured with Sound Source Operating to Obtain Sound Pressure Level due to Sound Source Alone
4	2.2
5	1.7
6	1.3
7	1.0
8	0.8
9	0.6
10	0.4
11	0.3
12	0.3
13	0.2
14	0.2
15	0.1

Note: For the survey and field methods, corrections of less than 0.5 dB are seldom necessary.

4.4.4.3 Acoustical data need not be normalized for atmospheric absorption losses. Test results should be reported under the actual test-day meteorological conditions.

4.5 Data reporting

4.5.1 Identification information:

a) test location, date and time of test;

b) manufacturer and model of the APU and pertinent associated equipment;

c) aircraft type, manufacturer, model and air registry number;

d) plan and elevation views, as appropriate, of the aircraft outline showing location of the APU (including inlet and exhaust ports), all associated equipment, and all acoustical measurement stations.

4.5.2 Test site description

a) type and location of ground surfaces;

b) location and extent of any above-ground-level reflective surfaces, such as buildings or other aircraft, that might have been present in spite of the precautions noted in 4.2.2;

4.5.3 Meteorological data (for each test condition):

a) wind speed, knots (or m/s) and direction, degrees, relative to aircraft centerline (forward -0°);

b) ambient temperature °C (°F);

c) relative humidity, percent;

d) barometric pressure, kPa (mbar).

4.5.4 Operational data (for each test condition):

a) number of air conditioning packs operated and their locations;

b) APU shaft speed(s), rpm or percent of normal rated;

c) APU normal rated shaft speed, rpm;

d) APU shaft load, horsepower, (W) and/or electrical power output, kVA;

e) pneumatic load, kg/min (lb/min) delivered by APU to all pneumatically operated aircraft systems during the test (calculated as required);

f) temperature of APU exhaust gas at location specified in aircraft's approved operations manual, °C (°F);

g) operating mode of environmental control system, cooling or heating;

h) air conditioning distribution system supply duct temperature, °C (°F);

i) events occurring during the test which may have influenced the measurements.

4.5.5 Instrumentation

a) a brief description (including manufacturer and type or model numbers) of the acoustical and meteorological measuring instruments;

b) a brief description (including manufacturer and type or model numbers) of the data acquisition and data processing systems.

4.5.6 Acoustical data

a) ambient noise;

b) acoustical data per 4.4.4 with a description of corresponding microphone locations;

c) list of standards used and description and reason for any deviations.

4.6 References

Related standards for instruments and measurement procedures

*1. American National Standard Acoustical Terminology, American National Standards Institute, ANSI S1.1-1960.

*2. American National Standard Preferred Reference Quantities for Acoustical Levels, American National Standards Institute, ANSI S1.8-1969.

*3. American National Standard Methods for Measurement of Sound Pressure Levels, American National Standards Institute, ANSI S1.13-1971

*4. American National Standard Specifications for Laboratory Standard Microphones, American National Standards Institute, ANSI S1.12-1967.

*5. American National Standard Method for the Calibration of Microphones, American National Standards Institute, ANSI S1.10-1966.

* These references will be replaced by equivalent international specifications, where possible

6. IEC Recommendations for Sound Level Meters, International Electrotechnical Commission, IEC 651 (1979).

7. ISO Recommendations for Preferred Frequencies for Acoustical Measurements, International Organization for Standardization, ISO/R266-1962(E).

8. IEC Recommendations for Octave, Half-Octave and Third Octave-Band Filters Intended for the Analysis of Sounds and Vibrations, International Electrotechnical Commission, IEC 225 (1966).

Note: The texts and specifications of these publications, as amended, are incorporated by reference into this Attachment.

American National Standards Institue specifications may be obtained from:

1430 Broadway
New York
New York 10018
UNITED STATES

IEC publications may be obtained from:

Bureau Central de la Commission Electrotechnique Internationale
1, Rue de Varembé
Geneva, Switzerland

ISO publications may be obtained from:

International Organization for Standardization
1 Rue de Varembé
Geneva, Switzerland

or from state ISO member bodies.

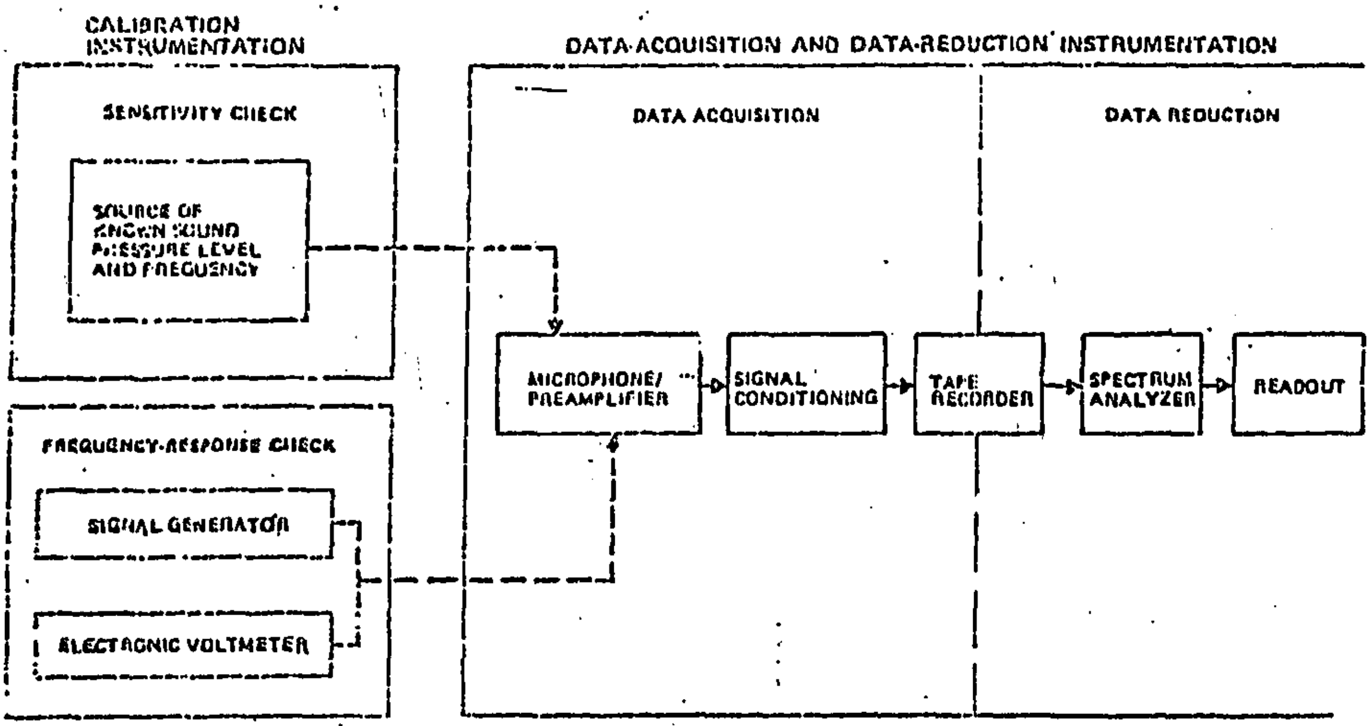

FIGURE 7. NOISE MEASUREMENT SYSTEMS

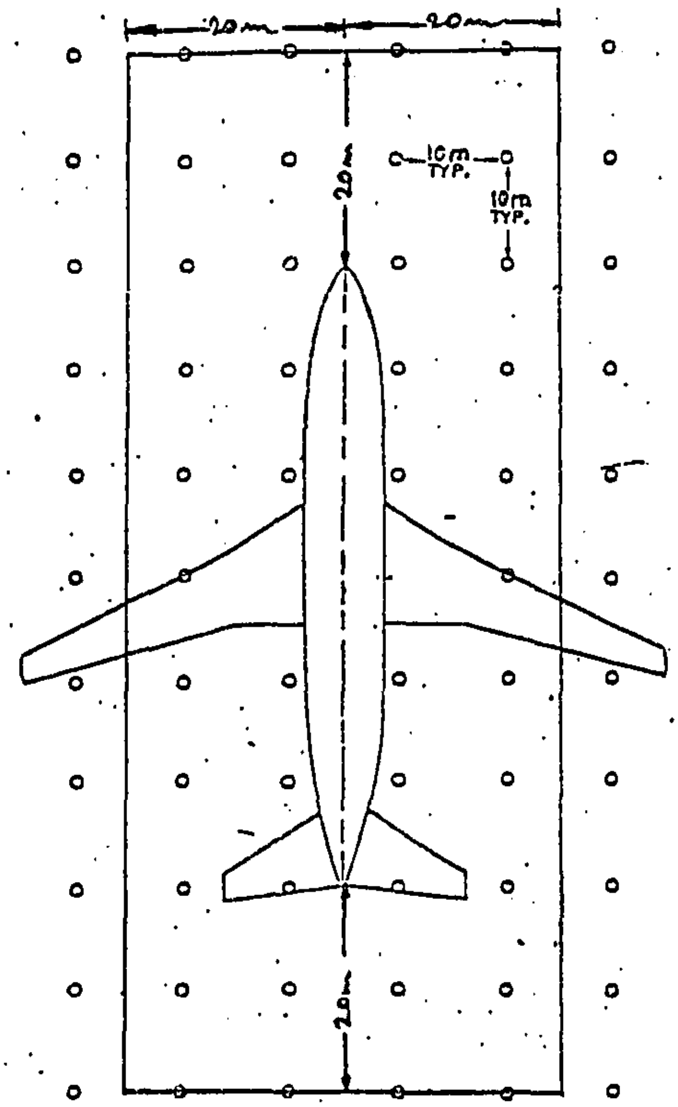

FIGURE 2 GRID PATTERN FOR SELECTING NOISE SURVEY MEASUREMENT POSITIONS

APPENDIX

AEROSPACE RECOMMENDED PRACTICE

ARP 1307

Society of Automotive Engineers, Inc.
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Revised

MEASUREMENT OF EXTERIOR NOISE PRODUCED BY AIRCRAFT AUXILIARY POWER UNITS (APUs) AND ASSOCIATED EQUIPMENT DURING GROUND OPERATION

1. INTRODUCTION

Many commercial and military transport aircraft are equipped with one or more on-board auxiliary power units (APUs) to provide self-contained power for operating essential aircraft systems during typical servicing of aircraft and during passenger boarding operations. Increased awareness of noise produced during these operations of APUs and associated ground operated equipment such as environmental control systems, electrical generators, blowers and cooling fans has created a need for a common basis whereby noise information can be communicated among airport authorities, airline operators, aircraft and equipment manufacturers. Standard procedures for noise measurement, analysis and reporting will help fulfill this need.

2. PURPOSE

This Aerospace Recommended Practice (ARP) describes standard conditions and procedures for measuring, analyzing and reporting noise, resulting from operation of on-board APUs and associated equipment of aircraft undergoing servicing.

3. SCOPE

Test procedures are described for measuring noise at specific locations (passenger and cargo doors, and servicing positions) and for conducting general noise surveys around aircraft.

Requirements are identified with respect to instrumentation; acoustic and atmospheric environment; data acquisition, reduction and presentation, and such other information as is needed for reporting the results.

Recommended procedures involve recording data on magnetic tape for subsequent processing. The use of tape-recorder/time-integrating analyzer systems avoids the need to average by eye the variations associated with manual readings from sound level meters and octave band analyzers and therefore yields more accurate results.

This document makes no provision for predicting APU noise from basic engine characteristics, nor for measuring noise of more than one aircraft operating at the same time.

No attempt is made to suggest acceptable levels of noise or suitable subjective criteria for judging acceptability.

4. GENERAL TEST CONDITIONS

4.1 Meteorological Conditions:

Wind	Not more than 10 knots (5 m/s).
Temperature	Not less than 35°F (2°C) nor more than 95°F (35°C).
Humidity	Relative humidity not less than 30% nor more than 90%.
Precipitation	None.
Barometric Pressure	Not less than 800 mbar (80 kPa) nor more than 1100 mbar (110 kPa).

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4.2 Test Site: The ground between microphones and aircraft should be a smooth, hard surface. No obstructions should be present between aircraft and measurement positions and no reflecting surfaces (except the ground and aircraft) should be near enough to sound paths to significantly influence results. Surface of the ground surrounding the aircraft should be sensibly flat and level at least over an area formed by boundaries parallel to and 200 ft (60 m) beyond the outermost microphone array identified in item 4 of 6.2.

4.3 Ambient Noise: Ambient noise of the measurement system and test area (that is, composite of the noise due to environmental background and the electrical noise of the acoustic intrumentation) should be determined.

4.4 APU Installation: Pertinent APU and associated aircraft systems should be tested for each aircraft model for which acoustic data are required.

4.5 Aircraft Ground Configuration: Aircraft flight control surfaces should be in the "neutral" or "clean" configuration, with gust locks on, or as stated in the aircraft's approved operating manual for aircraft undergoing servicing.

5. INSTRUMENTATION

5.1 Aircraft: Operation data identified in 7.4 should be determined from normal aircraft instruments and controls.

5.2 Acoustical:

5.2.1 General: Instrumentation and measurement procedures should be consistent with requirements of latest applicable issues of appropriate standards listed in the references (Section 8.). All data samples should be at least 2.5 times the data reduction integration period which in no case should be less than 8 seconds. All sound pressure levels should be in decibels to a reference pressure of 20 μpa.

5.2.2 Data Acquisition Systems: Instrumentation systems for recording and analysis of noise, shown in the block diagram of Fig. 1, should meet the following specifications:

5.2.2.1 Microphone System: Over a frequency range of at least 45 Hz to 11,200 Hz the system should meet the requirements as outlined under microphone system specifications in the latest issue of reference 9.

Microphones should be omnidirectional, vented for pressure equalization if of condenser type, and should have known ambient pressure and temperature coefficients. Microphone amplifier specifications should be compatible with those of the microphone and tape recorder.

Microphone wind screens should be employed when wind speed is in excess of 6 knots (3 m/s). Corrections as a function of frequency should be applied to measured data to account for the presence of microphone wind screens.

5.2.2.2 Tape Recorder: The tape recorder may be direct record or FM and should have the following characteristics:

Dynamic range 50 dB minimum in 1/1 octave or 1/3 octave bands.
Tape speed accuracy within ± 0.2% of rated speed.
Wow and flutter (peak to peak) less than 0.5% of tape speed.
Maximum third harmonic distortion less than 2%.

5.2.3 Calibration:

5.2.3.1 Microphone: Frequency response calibration should be performed prior to the test series and a subsequent post calibration should be performed within one month of the pre-calibration, with additional calibrations made when shock or damage is suspected. Response calibration should cover the range of at least 45 Hz to 11,200 Hz. Pressure response characteristics of the microphone should be corrected to obtain random incidence calibration.

5.2.3.2 Recording System: A calibration tape, a recording of broadband noise or a sweep of sinusoidal signals over a minimum frequency range of 45 Hz to 11,200 Hz should be recorded in the field or in the laboratory at the beginning and end of each test. The tape should also include signals at the frequencies employed during sound pressure sensitivity checks as defined in the following paragraph:

This calibration signal, an insert voltage, should be applied to the input and should include all signal conditioning preamplifiers, networks and recorder electronicsused to record acoustic data. In addition, a "shorted input" (i.e, microphone pressure sensitive element replaced with equivalent electrical impedance) recording of at least 20 sec. should be made as a check on system dynamic range and noise floor.

Sound pressure sensitivity calibrations with the arrangement shown in Fig. 1 should be made in the field for each microphone prior to beginning and after completion of measurements each day. These calibrations should be made using a calibrator producing a known and constant-amplitude sound pressure level at one or more 1/3 octave band center frequencies, specified in reference 3 or 10 in the frequency range from 45 Hz to 11,200 Hz. A barometric correction should be applied as required. Calibrators employed should be precise at least to within ± 0.5 dB and should have a calibration obtained according to reference 5 that is traceable to the United States National Bureau of Standards, or to a recognized international equivalent.

Each reel of tape should have comparable response and background noise as the calibration tape. A constant amplitude sine wave should be recorded at the start of each reel of tape, for reel-to-reel sound pressure sensitivity comparisons. The frequency of this sine wave should be within the same frequency range as used for sound pressure sensitivity checks. A separate voltage insert device or an acoustic calibrator may be used for this purpose. If an acoustic calibrator is used, it should be carefully "seated" and corrections for ambient pressure should be made so that effects of pressure on calibrator and microphone response are eliminated.

Battery-driven tape recorders should be checked at frequent intervals during a test to ensure good battery condition. Tape recorders should not be moved while recording is in progress unless it has been established that such movements will not change tape recorder characteristics.

5.2.3.3 Data Reduction Equipment: Data reduction equipment should be calibrated with electrical signals of known amplitude either at a series of discreet frequencies or with broadband signals covering the frequency range of 45 Hz to 11,200 Hz.

5.2.4 Data Reduction: The data reduction system of Fig. 1 should provide 1/3 or 1/1 octave band sound pressure levels. Analyzer filters should comply with requirements of references 3 or 11 (Class II for octave-band filters and Class III for one-third octave-band filters). Analyzer amplitude resolution should be no worse than 0.5 dB; dynamic range should be a minimum of 50 dB between full scale and the root-mean-square (rms) value of the analyzer noise floor in the octave band with the highest noise floor; and amplitude response over the upper 40 dB range should be linear to within ± 0.5 dB.

Mean square sound pressures should be time averaged by integration of the squared output of frequency band filters over an integration interval that should be no less than 8 seconds. All data should be processed within the frequency range from 45 Hz to 11,200 Hz. Data should be corrected for all known or predictable errors, such as deviations of system frequency response from a flat response.

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5.2.5 Total System: In addition to specifications for component systems, frequency response of the combined data acquisition and reduction system should be flat within ±3 dB over the frequency range from 45 Hz to 11,200 Hz. Frequency response gradient anywhere within this range should not exceed 5 dB per octave.

Amplitude resolution should be at least 1.0 dB. Dynamic range should be a minimum of 45 dB between full scale and the rms value of the system noise floor in the frequency band with the highest noise floor. Amplitude response should be linear within ±0.5 dB over the upper 35 dB in each frequency band.

5.3 Meterological: The wind speed should be measured with a device having a range of at least 0 to 15 knots (0 to 8 m/s) with an accuracy of at least ±0.5 knots (±0.3 m/s). Temperature measurements should be made with a device having a range of at least 30° - 110°F (0° - 40°C) with an accuracy at least ±0.5°F (±0.2°C). Relative humidity should be measured with a device having a range of 0 to 100 percent with an accuracy of at least ±3 percentage points. Atmospheric pressure should be measured with a device having a range of at least 800 to 1100 mbar (80 to 110 kPa) with an accuracy of at least ±2.5 mbar (±0.25 kPa).

6. TEST PROCEDURE

6.1 Test Conditions: Ambient noise measurements should be made in sufficient number to be representative for all acoustic measurement stations, providing correction data to apply to measured APU noise where necessary (see 6.4).

Acoustic test measurements should be made with the installed APU and associated equipment operating under load conditions appropriate to the normal modes of operations required for aircraft ground handling.

6.2 Acoustical Measurement Locations: Except where specified otherwise, noise measurements should be made with microphones at 5.25 ft ± 1.0 in. (1.6 m ± 0.025 m) above the ground or surface where passengers or servicing personnel may stand, with the microphone diaphragm parallel to the ground and facing upwards.

Locations for measuring noise should be as follows:

6.2.1 Cargo Door Locations: Measurements should be made at each cargo door location, with the door open, while the aircraft is in a typical ground handling configuration. These measurements should be taken at the center of the opening, in the plane of the fuselage skin.

6.2.2 Passenger Door Locations: Measurements should be made at each passenger entry door, with the door open, on the vertical centerline of the opening, in the plane of the fuselage skin.

6.2.3 Servicing Locations: Measurements should be made at all servicing positions where persons are normally working during aircraft ground handling operations. These positions to be determined by reference to the approved aircraft operating and service manuals.

6.2.4 Survey Locations: Appropriate measurement positions should be chosen from a rectilinear grid pattern centered on the test airplane as illustrated in Fig. 2. The grid pattern should originate 20 m aft of the aircraft and extend at least 20 m forward of the aircraft as well as perpendicular to the aircraft centerline. The length of sides of squares in the grid should be 10 metres. Further subdivision of the grid pattern to accommodate small airplanes or to fulfill special requirements may be accomplished by progressively halving dimensions of grid squares as appropriate.

6.3 Meteorological Measurement Locations: Meteorological data should be measured at a location at the test site within the microphone array of Fig. 2, but upwind of the aircraft, and at a height of 5.25 ft (1.6 m) above ground level.

6.4 Data Presentation: A-weighted sound levels should be calculated by applying frequency weighting corrections derived from the standards for precision sound level meters (reference 8 or 9) to 1/3 or 1/1 octave-band sound pressure levels. The 1/1 octave-band sound pressure levels may be determined from a summation of mean-square sound pressures in appropriate 1/3 octave bands. Overall sound pressure levels should be determined from a summation of mean-square sound pressures in the twenty-four 1/3 octave, or eight 1/1 octave, frequency bands included in the frequency range from 45 Hz to 11,200 Hz.

Overall sound pressure levels, A-weighted sound levels and 1/3 octave band or 1/1 octave band data should be presented to the nearest decibel (dB) in tabular form, with supplementary graphical presentations as appropriate. Sound pressure levels should be corrected, if necessary, for the presence of high ambient noise. No corrections are needed if a sound pressure level is 10 dB or more above ambient noise. For sound pressure levels between 3 and 10 dB above ambient noise, appropriate corrections should be applied, see Table 4 of reference 4. If sound pressure levels are 3 dB or less above the ambient noise, no corrections should be attempted and these data should not be reported.

Acoustical data need not be normalized for atmospheric absorption losses. Test results should be reported under the actual test-day meteorological conditions.

7. DATA REPORTING

7.1 Identification Information:

7.1.1 Test location, date and time of test.

7.1.2 Manufacturer and model of the APU and pertinent associated equipment.

7.1.3 Aircraft type, manufacturer, model and air registry number

7.1.4 Plan and elevation views, as appropriate, of the aircraft outline showing location of the APU (including inlet & exhaust ports), all associated equipment, and all acoustical measurement stations.

7.2 Test Site Description:

7.2.1 Type and location of ground surfaces.

7.2.2 Location and extent of any above-ground-level reflective surfaces, such as buildings or other aircraft, that might have been present in spite of the precautions noted in 4.2.

7.3 Meteorological Data: For each test condition:

7.3.1 Wind speed, knots or (m/s) and direction, degrees, relative to aircraft centerline (forward = 0°)

7.3.2 Ambient temperature, °F (°C).

7.3.3 Relative humidity, percent.

7.3.4 Barometric pressure, mbar (kPa)

7.4 Operational Data: For each test condition:

7.4.1 Number of air conditioning packs operated and their locations.

7.4.2 APU shaft speed(s), rpm or percent of normal rated.

7.4.3 APU normal rated shaft speed, rpm.

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7.4.4 APU shaft load, horsepower, (W), and/or electrical power output, kVA.

7.4.5 Pneumatic load, lb/min (kg/min) delivered by APU to all pneumatically operated aircraft systems during the test (calculated as required).

7.4.6 Temperature of APU exhaust gas at location specified in aircraft's approved operations manual, °F, (°C).

7.4.7 Operating mode of environmental control system, cooling or heating.

7.4.8 Air conditioning distribution system supply duct temperature, °F, (°C).

7.4.9 Events occuring during the test which may have influenced the measurements.

7.5 Instrumentation:

7.5.1 A complete description (including manufacturer and type or model numbers) of the acoustical and meteorological measuring instruments.

7.5.2 A complete description (including manufacturer and type or model numbers) of the data acquisition and data processing systems.

7.6 Acoustical Data:

7.6.1 Ambient noise.

7.6.2 Acoustical data per 6.4 with a description of corresponding microphone locations.

7.6.3 List of standards used and description and reason for any deviations.

PREPARED BY

SAE COMMITTEE A-21, AIRCRAFT NOISE MEASUREMENT

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8. REFERENCES

RELATED STANDARDS FOR INSTRUMENTS AND MEASUREMENT PROCEDURES

1. American National Standard Acoustical Terminology, American National Standards Institute, ANSI S1.1-1960.

2. American National Standard Preferred Reference Quantities for Acoustical Levels, American National Standards Institute, ANSI S1.8-1969.

3. American National Standard Preferred Frequencies and Band Numbers for Acoustical Measurements, American National Standards Institute, ANSI S1.6-1967.

4. American National Standard Methods for Measurement of Sound Pressure Levels, American National Standards Institute, ANSI S1.13-1971.

5. American National Standard Specifications for Laboratory Standard Microphones, American National Standards Institute, ANSI S1.12-1967.

6. American National Standard Specification for Sound Level Meters, American National Standards Institute, ANSI S1.4-1971.

7. American National Standard Method for the Calibration of Microphones, American National Standards Institute, ANSI S1.10-1966.

8. American National Standard Specification for Octave, Half-Octave and Third-Octave-Band Filter Sets, American National Standards Institute, ANSI S1.11-1966.

9. IEC Recommendations for Precision Sound Level Meters, International Electrotechnical Commission, IEC 179 (1965).

10. ISO Recommendations for Preferred Frequencies for Acoustical Measurements, International Organization for Standardization, ISO/R266-1962(E).

11. IEC Recommendations for Octave, Half-Octave and Third Octave-Band Filters Intended for the Analysis of Sounds and Vibrations, International Electrotechnical Commission, IEC 225 (1966).

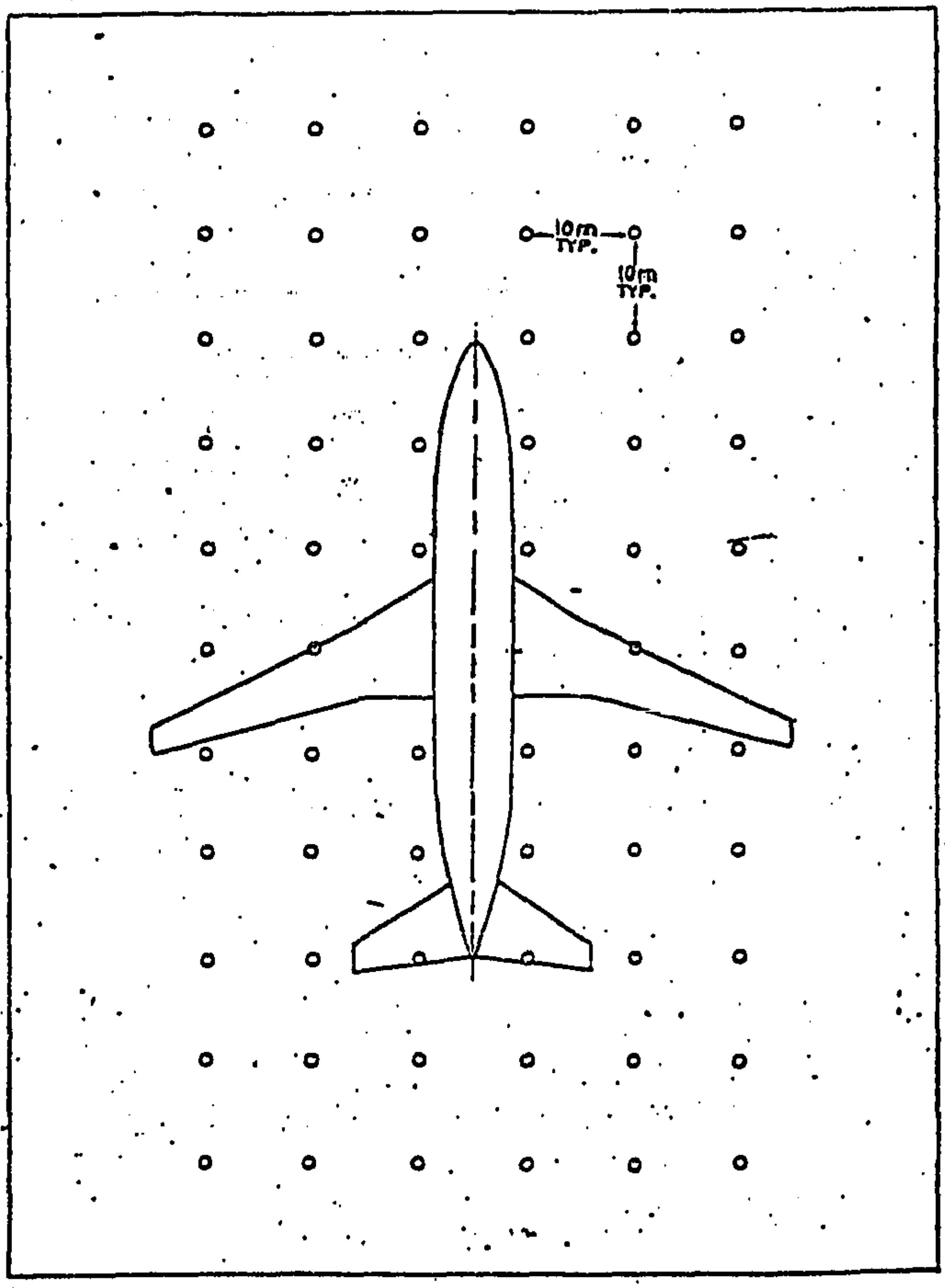

FIGURE 2 GRID PATTERN FOR SELECTING NOISE SURVEY MEASUREMENT POSITIONS

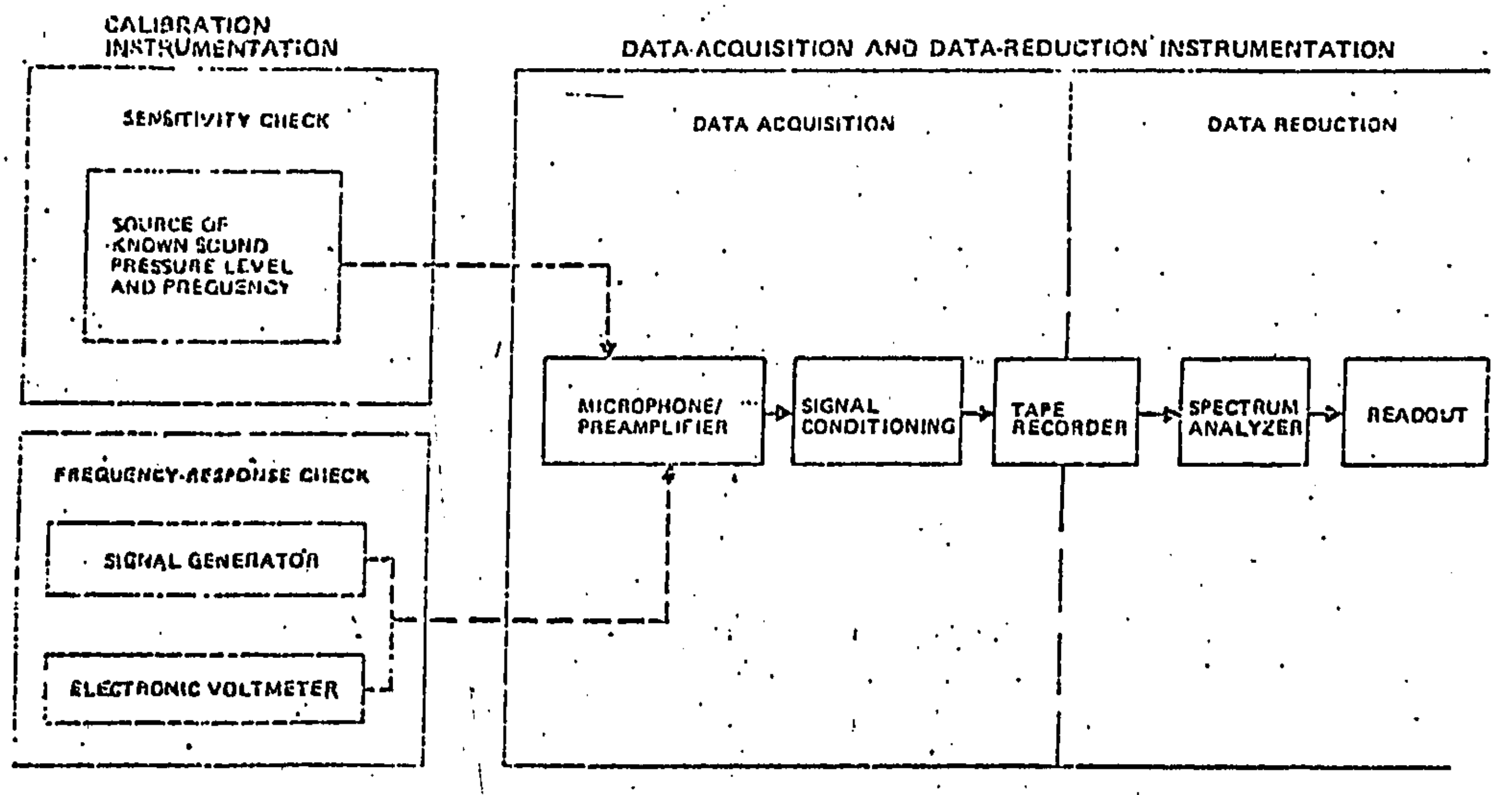

FIGURE 1. NOISE MEASUREMENT SYSTEMS

- END -

APPENDIX D
SOUND PROPAGATION

As the sound from a noise source propagates through the atmosphere, its amplitude is normally diminished by sound attenuation caused by:

- Geometric spreading
- Atmospheric absorption
- Excess attenuation.

Geometric dispersion is the divergence of sound from a source. Beyond a distance from the source approximately equal to twice the largest dimension of the source, the sound level is inversely proportional to the square of the distance from the source. This means that the sound level decreases at 6 dB for every doubling of distance due to geometric spreading alone. This effect does not depend upon frequency.

Sound propagation is a vibration of air molecules which travels through the atmosphere. As the air molecules vibrate, they experience tiny amounts of damping losses which over long distances result in significant attenuation of the sound pressure excitation. This effect is called atmospheric absorption. The magnitude of the sound absorption losses depends primarily on the frequency of the sound and the temperature and relative humidity of the atmosphere through which it is traveling.

Excess attenuation depends on frequency and propagation distance. It accounts for the attenuation of sound in excess of that attenuation caused by air absorption and simple geometric spreading. This attenuation is caused by ground cover (such as grass or trees), sound scattering by air turbulence, sound refraction by temperature and wind velocity gradients, and other factors.

PROCEDURE FOR THE ESTIMATION OF SOUND PROPAGATION FROM A SOURCE

Several similar -- but slightly different -- procedures exist for the prediction of sound levels distant from a source. For the purpose of this guide, a procedure was selected which was relatively simple, was based on airport situations, and results in conservative (i.e., high) estimates of the predicted sound levels.[1] Fundamental to this procedure is the use of a sound level relatively near the noise source (the reference level) as a basis for predicting the more distant sound levels through the estimation of sound propagation losses. The frequency dependency of sound attenuation was addressed by the characterization of two source types, turbine-engined equipment (including both APUs and GPUs) and piston-engined equipment (including GPUs only), and the determination of typical octave band frequency spectra for the sources, as discussed in Appendix B.

The effect of geometric spreading depends only upon the ratio of the distance to the point of interest to the reference distance and does not depended upon frequency. In this guide it was taken to result in sound level decreases at the rate of 6 dB per doubling of distance.

The magnitude of the sound absorption was quantified based upon the Society of Automotive Engineers (SAE) Aerospace Recommended Practice ARP 866a, Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for standard atmospheric conditions (15°C, 0.760 m Hg, and 70% relative humidity). Atmospheric absorption for ambient conditions other than the standard conditions will be greater. Thus, this procedure results in lower estimates of the atmospheric attenuation and, consequently, upper bound estimates of the community sound levels.

The excess attenuation values are derived from the results of experimental studies on noise propagating along the earth's surface of typical airport/airbase situations. These data apply for sound propagating downwind or on still days. Since the excess attenuation of sound propagating upwind is generally greater than that for downwind, this guide will again provide somewhat over-estimates of the noise levels for upwind conditions.

These effects discussed above were applied to the A-weighted values of the spectra provided in Figure B-2 to generate the sound attenuation curves provided in Figure II-5.

REFERENCE

[1]Cole, J. N.; USAF Bioenvironmental Noise Data Handbook -- Volume I, Organization Content, and Application; Aerospace Medical Research Laboratory Report AMRL-TR-75-50, Volume I; June 1975.

APPENDIX E

ADDITION OF EXPOSURES FROM SEVERAL NOISE SOURCES

Since noise exposures are defined in terms of levels, they must be added by means of a special procedure which accommodates the logarithmic definition of level. This procedure is defined by Figure E-1; an illustration of its use is provided in an example.

Example

Three pieces of equipment individually resulting in estimated day-night sound levels of 44 dB, 50 dB, and 51 dB are being operated. What is their total day-night sound level?

Solution:

1. Of the first two levels, the smaller level is SL = 44 dB and the larger level is LL = 50 dB.
2. The difference of the larger less the smaller level is (LL - SL) = 6 dB.
3. From Figure E-2 for the value of (LL-SL), parameter D is found to be about D = 1 dB.
4. The sum of the first two levels is then

   TL = LL + D

   TL = 50 + 1 = 51 dB = TL.

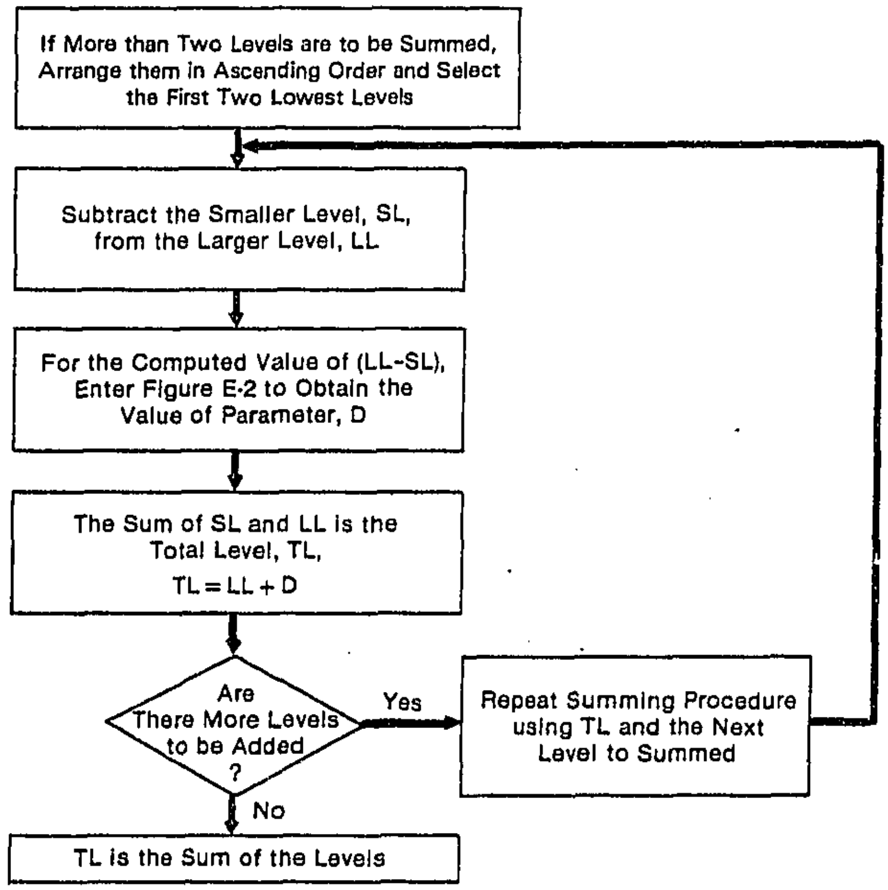

FIGURE E-1. PROCEDURE FOR ADDITION OF SEVERAL NOISE EXPOSURES.

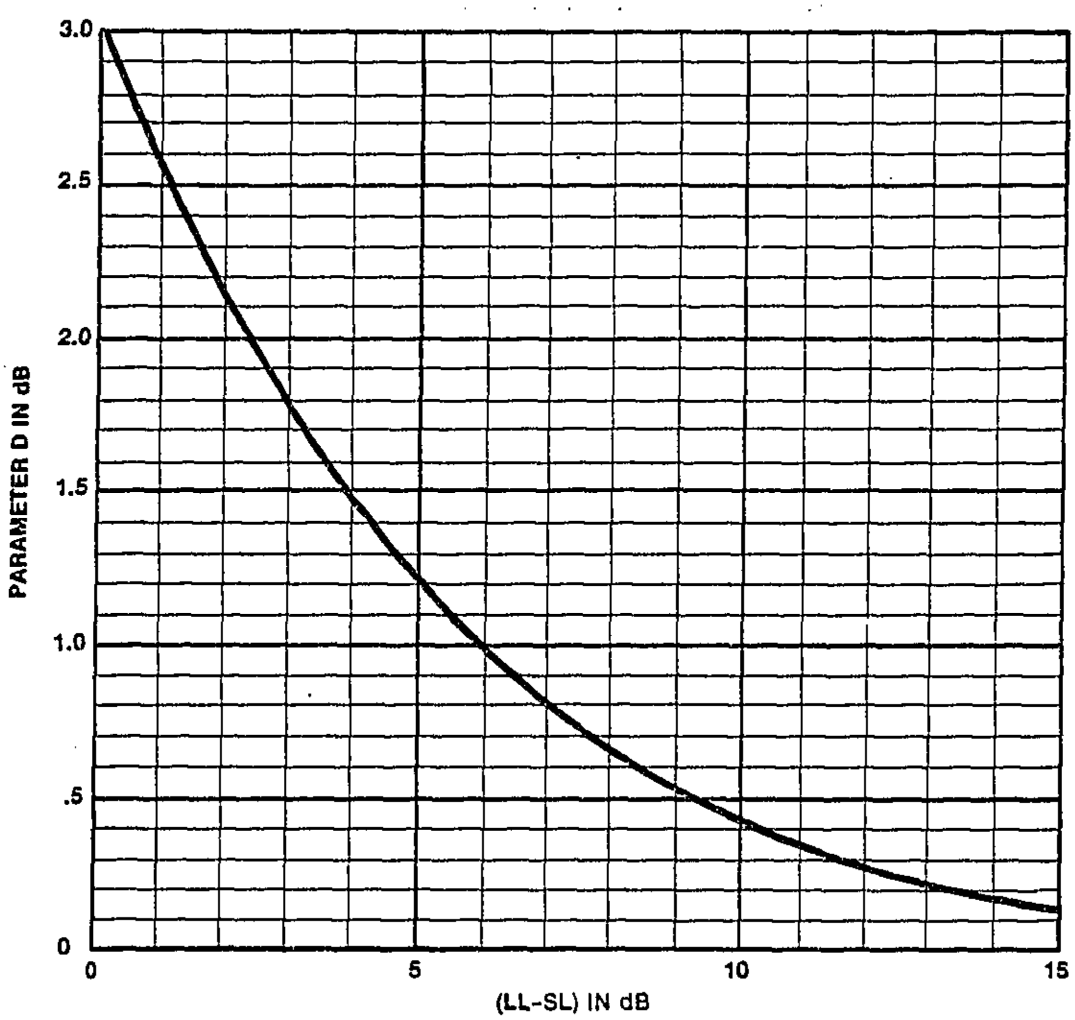

FIGURE E-2. PARAMETER D ESTIMATION

Example (cont.)

5. Since another level is to be summed, the process is repeated with the just-computed value of the TL and the next level.

6. Since both levels are equal, TL = LL = SL = 51 dB and (LL - SC) = 0 dB.

7. From Figure E-2 for the value of (LL - SC), parameter D is found to be D = 3 dB.

8. The new sum is then

   $TL = LL + D$

   $TL = 51 + 3 = 54\text{ dB} = TL.$

9. Since 51 dB was the last source level to be added, the sum of the three day-night sound levels is TL = 54 dB.