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(R) Measurement of Exterior Noise Produced by Aircraft Auxiliary Power Units (APUs) and Associated Aircraft Systems During Ground Operation

RATIONALE

This document has been updated and expanded to reflect current instrumentation and test practices for measurement and analysis of noise from APUs and associated equipment.

INTRODUCTION

Many commercial, business 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 (ECS), electrical generators, blowers, fuel pumps, hydraulic pumps and cooling fans has created a need for a common basis whereby noise information can be communicated among airport authorities, airline operators, and aircraft equipment manufacturers. Identification of all contributing noise sources is required to properly interpret the measured data. Standard procedures for noise measurement, analysis and reporting will help fulfill this need.

1. SCOPE

Test procedures are described for measuring noise at specific receiver locations (passenger and cargo doors, and servicing positions) and for conducting general noise surveys around aircraft. Procedures are also described for measuring noise level and directivity at noise source locations to facilitate the understanding and interpretation of the data.

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.

This document makes no provision for predicting APU or component noise from basic engine characteristics or design parameters, 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. ICAO Annex 16 Volume I Attachment C provides guidance on recommended maximum noise levels.

1.1 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.

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http://www.sae.org/technical/standards/ARP1307B

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 ANSI Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ANSI S1.1-1994 American National Standard Acoustical Terminology

ANSI S1.4-1983 American National Standard Specification for Sound Level Meters

ANSI S1.6-1984 American National Standard Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements

ANSI S1.8-1989 American National Standard Reference Quantities for Acoustical Levels

ANSI S1.11-2004 American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters

ANSI S1.13-2005 American National Standard Measurement of Sound Pressure Levels in Air

ANSI S1.15-2005 Measurement Microphones - Part 2: Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique

ANSI S1.40-2006 Specifications and Verification Procedures for Sound Calibrators

2.2 ICAO Documents

Available from International Civil Aviation Organization, Document Sales Unit, 999 University Street, Montréal, Quebec H3C 5H7, Canada, Tel.: +1 514-954-8022, http://icaodsu.openface.ca/mainpage.ch2.

ICAO Annex 16 Attachment C of Annex 16 to the Convention on International Civil Aviation, Environmental Protection, Volume I Aircraft Noise, as amended.

2.3 IEC Documents

Available from International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +44-22-919-02-11, www.iec.ch.

IEC 60942:2003 Electroacoustics - Sound Calibrators

IEC 61094-2:2009 Electroacoustics - Measurement Microphones - Part 2: Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique

IEC 61260:1995 Electroacoustics - Octave-Band and Fractional-Octave-Band Filters

IEC 61265:1995 Electroacoustics - Instruments for measurement of aircraft noise - Performance requirements for systems to measure one-third-octave band sound pressure levels in noise certification of transport-category aeroplanes, IEC 61265: (1995-04) and Corrigendum (1995-06)

IEC 61672-1:2002 Electroacoustics - Sound Level Meters Part 1: Specifications

2.4 ISO Documents

Available from International Standards Organization, ISO Central Secretariat, 1, ch. De la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

ISO 266-1997 ISO International Standard for Acoustics - Preferred Frequencies for Measurements

ISO 1683-2008 ISO International Standard for Acoustics - Preferred Reference Quantities for Acoustic Levels

ISO R31/VII-1978 ISO Recommendations for Quantities and Units of Acoustics

3. GENERAL CONDITIONS:

3.1 Meteorological Conditions

Wind	Not more than 5 m/s (10 knots).
Temperature	Not less than 2 °C (35 °F) nor more than 35 °C (95 °F) .
Humidity	Relative humidity not less than 20% nor more than 95%.
Precipitation	None
Barometric Pressure	Not less than 80 kPa (800 mbar) nor more than 110 kPa (1100 mbar).

Care should be exercised to ensure that wind effects do not adversely affect any measurements. For example, ambient temperature measurements could be affected if hot exhaust gases are blown into the meteorological measurement area, and the directivity and symmetry of exhaust noise can be distorted by crosswinds.

3.2 Test Site

The ground between microphones and aircraft should be a smooth, hard surface. No obstructions should be present between the aircraft and the measurement positions and no reflecting surfaces (except the ground and aircraft) should be near enough to sound paths to significantly influence the results. The 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 feet) beyond, if possible, the outermost microphone array identified in item 4 of 5.2. In the case of prototype testing, it may be difficult to meet this flatness requirement due to restrictions of the test site. In such cases, a less restrictive requirement may be acceptable provided care is taken to minimize the potential for reflected noise to contaminate the measurements.

3.3 Ambient Noise

Ambient noise of the measurement system and test area (that is, composite of the noise due to the electrical noise of acoustic instrumentation and the environmental background) should be determined. Sources of ambient noise should be identified and minimized. It is desirable that the overall ambient noise levels be at least 10 dB below the expected aircraft ramp noise levels at all microphone locations. This goal should encourage exploration and resoution of any ambient noise issues. Special attention should be paid to controlling noise from support equipment such as ground carts, generators, fuel delivery systems, lighting systems, and so forth.

3.4 APU and Related Systems Installation

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

3.5 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. Propulsion engines should be restrained from windmilling during ramp noise testing. APU and ECS ram inlet doors should be in the correct positions for ground operation.

Ramp noise tests should be conducted with all passenger, baggage, and service doors open, in order to expedite testing. Any deviations to this configuration should be reported. This configuration is generally representative of the typical servicing configuration. However, this does not necessarily imply that the loudest conditions will be measured, since some open doors might block sound from propagating to some of the receiver locations.

4. INSTRUMENTATION

4.1 Aircraft

Operational data identified in 6.4 should be determined from normal aircraft instruments and controls.

4.2 Acoustical

4.2.1 General

Instrumentation and measurement procedures should be consistent with the requirements of the latest applicable issues of the appropriate standards listed in the references (Section 2). All sound pressure levels should be quoted in decibels using a reference pressure of 20 µPa.

4.2.2 Data Acquisition Systems

Instrumentation systems for recording and analysis of noise, shown in the block diagram of Figure 1, should meet the following specifications (additional guidance on suitable data acquisition systems can be found in ISO 61265):

4.2.2.1 Microphone System

Over a frequency range of at least 45 to 22 400 Hz the system should meet the requirements as outlined in the latest issue of ANSI S1.4 or IEC 61672.

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 data recording system.

Microphone wind screens should be employed when wind speed is in excess of 3 m/s (6 knots). Corrections as a function of frequency should be applied to measured data to account for the presence of microphone wind screens. Corrections should be applied up to a one-third-octave-band frequency of 10 kHz, above which corrections are not recommended. For low noise test articles (e.g., a cooling fan) a lower wind limit may be desirable to ensure that low frequency wind noise does not contaminate the measurement. For ground microphones, it may be desirable to install hemispherical windscreens (e.g., a windscreen cut in half) to minimize the impact of wind noise.

4.2.2.2 Data Recorder

The digital data recording system shall incorporate an anti-aliasing filter prior to the analog-to-digital conversion with a cut-off frequency that is less than 0.5 times the sampling frequency. The numerical representation of the data should be sufficient to provide a dynamic range of at least 50 dB.

4.2.3 Calibration

4.2.3.1 Microphone

Frequency response calibration should be performed prior to the test series, with additional calibrations made when shock or damage is suspected. The response calibration should cover the range of at least 45 to 11 200 Hz. Pressure response characteristics of the microphones at aircraft servicing and perimeter locations should be corrected to obtain random incidence calibration. For microphones used in source noise measurements, the random incidence correction is optional.

4.2.3.2 Recording System

Sound pressure sensitivity calibrations with the arrangement shown in Figure 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 of the 1/3 octave-band center frequencies specified in ANSI S1.6 or ISO-266 in the frequency range from 45 to 22 400 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 ANSI S1.40 or IEC 60942 that is traceable to the National Institute of Standards and Technology, or to a recognized international equivalent.

4.2.3.3 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 to 22 400 Hz.

4.2.4 Data Reduction

The data reduction system of Figure 1 should provide 1/3 octave-band or 1/1 octave-band sound pressure levels. Analyzer filters should comply with the requirements of reference ANSI S1.11 or IEC 61260 (-filters should be at least 3rd order). 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. The 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 30 seconds. All data should be processed within the frequency range from 45 to 22 400 Hz. Data should be corrected for all known or predictable errors, such as deviations of system frequency response from a flat response.

4.2.5 Total System

In addition to specifications for component systems, the frequency response of the combined data acquisition and reduction system should be flat within ±3 dB over the frequency range from 45 to 22 400 Hz, on a 1/3 octave-band basis. Frequency response gradient anywhere within this range should not exceed 5 dB per octave.

Amplitude resolution should be better than 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 to within ±0.5 dB over the upper 35 dB range in each frequency band.

4.3 Meteorological

The wind speed should be measured with a device having a range of at least 0 to 10 m/s (0 to 20 knots) with an accuracy of at least ±0.6 m/s (±1.2 knots). The wind direction should be measured with a device having a range of 0 to 360 degrees with an accuracy of at least ±5.0 degrees. Temperature measurements should be made with a device having a range of at least 0 to 40 °C (32 to 104 °F) with an accuracy of at least ±0.5 °C (±1.0 °F). Relative humidity should be measured with a device having a range of 0 to 100% with an accuracy of at least ±3 percentage points. Atmospheric pressure should be measured with a device having a range at least 80 to 110 kPa (800 to 1100 mbar) with an accuracy of at least ±0.5 kPa (±5.0 mbar).

5. TEST PROCEDURE

5.1 Test Conditions

Ambient noise measurements should be made in a sufficient number of locations to be representative for all acoustic measurement stations, providing correction data to apply to measured aircraft system noise where necessary (see 5.4).

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. A steady state operation of the APU and associated equipment should be achieved during the noise recording period to ensure that the source noise levels remain stable.

5.2 Acoustical Measurement Locations

Except where specified otherwise, noise measurements should be made with microphones at 1.6 m ± 0.025 m (5.25 feet ± 1.0 inch) 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:

5.2.1 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.

5.2.2 Passenger and Service Personnel Door Locations

Measurements should be made at each passenger or service personnel entry door, with the door open, on the vertical centerline of the opening, in the plane of the fuselage skin, at a height of 1.6 m (5.25 feet) above the door threshold or stairway.

5.2.3 Servicing Locations

Measurements should be made at all servicing positions where persons are normally working during aircraft ground handling operations (e.g., fueling, lavatory servicing, water servicing). These positions should be determined by reference to the approved aircraft operating and servicing manuals. Where applicable, the microphone position should be defined by locating the center of the panel (e.g., fuel servicing panel) and moving a distance 30 cm (1 feet) normal to the panel.

5.2.4 Perimeter Locations

Appropriate measurement positions should be chosen along a 20 m (65 feet 7 inches) perimeter centered on the test airplane as illustrated in Figure 2. The perimeter should extend 20 m forward of the aircraft nose and 20 m aft of the end of the aircraft fuselage, and extend 20 m perpendicular to the aircraft centerline. Microphones should be placed along the perimeter at a height of 1.6 m (5.25 feet), and at spacing of no more than 10 m (32 feet 9 inches) in order to capture the maximum noise level along the perimeter. In cases where the general location of maximum noise level is known in advance, it may not be necessary to place microphones around the entire perimeter. Instead the location of maximum noise level may be found by manually traversing a marked perimeter while monitoring the measured noise levels. Care must be taken to find the location of maximum noise level for all normal operating modes of the APU and associated equipment as it may not be the same for all modes.

5.2.5 Contour Measurements [Optional]

In some cases it may be of interest to obtain more information on how noise levels vary with position around the aircraft. A rectilinear grid of measurement points can be used for such studies as illustrated in Figure 3. The length of the sides of squares in the grid should be 10 m (32 feet 9 inches). Further subdivision of the grid pattern to accommodate small airplanes may be accomplished by progressively halving the dimensions of the grid squares as appropriate. The grid pattern will allow the generation of equal sound pressure level contours.

5.2.6 Source Locations [Optional]

The locations of all noise sources that contribute to measured levels at the receiver locations listed in 5.2.1 through 5.2.5 shall be identified and recorded. Examples of such sources include hydraulic pumps, cooling fans, cabin air vents, APU, ECS packs and pack bay vents, etc. The emitted noise level of each source shall be measured at a distance of 1 m (39 inches) from the source along the path(s) between the source and the affected receiver(s). The source measurement location may be adjusted based on the following considerations: the size of the noise source (e.g., small sources may be measured closer than large sources considering nearfield effects), the position of the noise source on the aircraft (e.g., its height above the ground may prevent close measurement), and the noise level of the source relative to other sources (e.g., if two sources have similar levels at the 1 m distance, a shorter distance or temporary local shielding of one source may be required). The locations of the source and the source measurement microphone shall be recorded.

5.3 Meteorological Measurement Locations

Meteorological data should be measured at a location at the test site within an 80 m wide rectangle centered on the aircraft, or within 10 m (32.8 feet) outside of the array defined in 5.2.4, upwind of the aircraft, and at a height of 1.6 m (5.25 feet) above ground level.

5.4 Data Presentation

A-weighted sound levels should be calculated by applying frequency weighting corrections derived from the standards for precision sound level meters (ANSI S1.4 or ISO 61672) to 1/3 octave-band 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 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 supplemental graphical presentations as appropriate. Each measured 1/3 or 1/1 octave-band sound pressure level that is 3 to 10 dB above its corresponding ambient noise level should be corrected for ambient noise contamination by subtracting the mean-square sound pressure of the ambient noise from the corresponding measured mean-square sound pressure of the combination of ambient noise and APU noise (plus any other aircraft source noise). The data should be flagged to note that a correction for ambient noise has been applied. No correction is needed if the measured 1/1 or 1/3 octave-band sound pressure level is at least 10 dB above its corresponding ambient noise level. If the measured sound pressure level is less than 3 dB above its corresponding ambient noise level, no correction should be attempted. These data should be appropriately flagged as being contaminated by ambient noise and thus representing an upper bound to the measured noise level.

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

6. DATA REPORTING

6.1 Identification Information

6.1.1 Test location, date and time of test.

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

6.1.3 Aircraft type, manufacturer, model and serial number.

6.1.4 Plan and elevation views of the aircraft outline and test photos, as appropriate, showing location of the APU (including inlet and exhaust ports), all associated equipment, meteorological instrumentation, and all acoustical measurement stations.

6.2 Test Site Description

6.2.1 Type of ground surfaces.

6.2.2 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 3.2.

6.3 Meteorological Data

For each test condition:

6.3.1 Wind speed, m/s (knots) and direction, degrees, relative to aircraft centerline (forward = 0 degrees).

6.3.2 Ambient temperature, °C (°F).

6.3.3 Relative humidity, percent.

6.3.4 Barometric pressure, kPa (mbar).

6.4 Operational Data

For each test condition:

6.4.1 Name and location of all contributing noise sources (e.g., number of air conditioning packs operating and their locations).

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

6.4.3 APU normal rated shaft speed, rpm.

6.4.4 APU shaft load, horsepower (W), and/or electrical power output, KVA.

6.4.5 Pneumatic load kg/s (lb/m) delivered by APU to all pneumatically operated aircraft systems during the test (or calculated as required).

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

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

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

6.4.9 Events occurring during the test which may have influenced measurements.

6.5 Instrumentation

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

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

6.6 Acoustical Data

6.6.1 Ambient noise.

6.6.2 Acoustical data per 5.4 with a description of corresponding microphone locations.

6.6.3 List of standards used for the processing of the 1/3 or 1/1 octave-band acoustical data. Description and reason for any deviations. If narrowband data is reported, details of the processing methodology (amplitude scaling, bandwidth, windowing, number of averages, etc.) should also be provided.

7. NOTES

7.1 A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.