INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME I
AIRCRAFT NOISE

THIRD EDITION — JULY 1993

This edition incorporates all amendments to Annex 16, adopted by the Council prior to 25 March 1993 and supersedes on 11 November 1993 all previous editions of the Annex.

For information regarding the applicability of the Standards and Recommended Practices, see Foreword and the relevant clauses in each Chapter.

INTERNATIONAL CIVIL AVIATION ORGANIZATION
AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

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FOREWORD

Historical background

Standards and Recommended Practices for Aircraft Noise were first adopted by the Council on 2 April 1971 pursuant to the provisions of Article 37 of the Convention on International Civil Aviation (Chicago, 1944) and designated as Annex 16 to the Convention. The Annex was developed in the following manner:

The Sixteenth Session of the Assembly, Buenos Aires, September 1968, adopted the following Resolution:

A16-3: Aircraft Noise in the Vicinity of Airports

Whereas the problem of aircraft noise is so serious in the vicinity of many of the world’s airports that public reaction is mounting to a degree that gives cause for great concern and requires urgent solution;

Whereas the noise that concerns the public and civil aviation today is being caused by increase in traffic of existing aircraft;

Whereas the introduction of future aircraft types could increase and aggravate this noise unless action is taken to alleviate the situation;

Whereas the Fifth Air Navigation Conference of ICAO held in Montreal in November 1966, with the object of reaching international solutions to the problem through the machinery of ICAO; and

Whereas the Assembly has noted the action being taken by the Council, in consultation with States and the appropriate international organizations, to give effect to the recommendations of the Fifth Air Navigation Conference, as reported to the Assembly by the Secretary General;

THE ASSEMBLY RESOLVES to instruct the Council:

1) to call an international conference within the machinery of ICAO as soon as practicable, bearing in mind the need for adequate preparation, to consider the problem of aircraft noise in the vicinity of airports;

2) to establish international specifications and associated guidance material relating to aircraft noise;

3) to include, in appropriate existing Annexes and other relevant ICAO documents and possibly in a separate

Annex on noise, such material as the description and methods of measurement of aircraft noise and suitable limitations on the noise caused by aircraft that is of concern to communities in the vicinity of airports; and

4) to publish such material on a progressive basis, commencing at the earliest possible time.

In response to Assembly Resolution A16-3, a Special Meeting on Aircraft Noise in the Vicinity of Aerodromes was convened in Montreal (November-December 1969) to examine the following aspects related to the problems of aircraft noise:

a) procedures for describing and measuring aircraft noise;

b) human tolerance to aircraft noise;

c) aircraft noise certification;

d) criteria for establishment of aircraft noise abatement operating procedures;

e) land use control; and

f) ground run-up noise abatement procedures.

Based on the recommendations of the Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, draft International Standards and Recommended Practices for Aircraft Noise were developed and, after amendment following the usual consultation with the Contracting States of the Organization, were adopted by the Council to form the text of this Annex.

With the development of Standards and Recommended Practices dealing with the control of aircraft engine emissions, it was felt that all provisions relating to environmental aspects of aviation should be included in a single document. Accordingly, as part of the Resolution adopting Amendment 5, it was agreed that Annex 16 should be retitled as “Environmental Protection” and Volume I of the Annex should contain the existing provisions (Third Edition) of Annex 16 — Aircraft Noise as amended by Amendment 5 and Volume II should contain the provisions related to aircraft engine emissions.

Table A shows the origin of amendments together with a list of the principal subjects involved and the dates on which
the Annex and the amendments were adopted by the Council, when they became effective and when they became applicable.

Applicability

Part I of Volume I of Annex 16 contains definitions and Part II contains Standards, Recommended Practices and guidelines for noise certification applicable to the classification of aircraft specified in individual Chapters of that Part, where such aircraft are engaged in international air navigation.

Note.— Chapters 2 and 3 exclude jet aeroplanes having short take-off and landing (STOL) capabilities which, pending the development by ICAO of a suitable definition, are described for the purpose of this Annex as those requiring a runway (with no stopway or clearway) of 610 m or less at the maximum certificated mass for airworthiness.

Parts III, IV and V of Volume I of Annex 16 contain Recommended Practices and guidance material for use by States with a view to promoting uniformity in measurement of noise for monitoring purposes, use of an international noise exposure reference unit for land use planning, and establishment of noise abatement operating procedures.

Action by Contracting States

Notification of differences. The attention of Contracting States is drawn to the obligation imposed by Article 38 of the Convention by which Contracting States are required to notify the Organization of any differences between their national regulations and practices and the International Standards contained in this Annex and any amendments thereto. Contracting States are invited to extend such notification to any differences from the Recommended Practices contained in this Annex, and any amendments thereto, when the notification of such differences is important for the safety of air navigation. Further, Contracting States are invited to keep the Organization currently informed of any differences which may subsequently occur, or of the withdrawal of any differences previously notified. A specific request for notification of differences will be sent to Contracting States immediately after the adoption of each amendment to this Annex.

The attention of States is also drawn to the provisions of Annex 15 related to the publication of differences between their national regulations and practices and the related ICAO Standards and Recommended Practices through the Aeronautical Information Service, in addition to the obligation of States under Article 38 of the Convention.

Use of the Annex text in national regulations. The Council, on 13 April 1948, adopted a resolution inviting the attention of Contracting States to the desirability of using in their own national regulations, as far as is practicable, the precise language of those ICAO Standards that are of a regulatory character and also of indicating departures from the Standards, including any additional national regulations that were important for the safety or regularity of international air navigation. Wherever possible, the provisions of this Annex have been written in such a way as to facilitate incorporation, without major textual changes, into national legislation.

Status of Annex components

An Annex is made up of the following component parts, not all of which, however, are necessarily found in every Annex; they have the status indicated:

1.— Material comprising the Annex proper:

a) Standards and Recommended Practices adopted by the Council under the provisions of the Convention. They are defined as follows:

Standard: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as necessary for the safety or regularity of international air navigation and to which Contracting States will conform in accordance with the Convention; in the event of impossibility of compliance, notification to the Council is compulsory under Article 38.

Recommended Practice: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as desirable in the interest of safety, regularity or efficiency of international air navigation, and to which Contracting States will endeavour to conform in accordance with the Convention.

b) Appendices comprising material grouped separately for convenience but forming part of the Standards and Recommended Practices adopted by the Council.

c) Provisions governing the applicability of the Standards and Recommended Practices.

d) Definitions of terms used in the Standards and Recommended Practices which are not self-explanatory in that they do not have accepted dictionary meanings. A definition does not have an independent status but is an essential part of each Standard and Recommended Practice in which the term is used, since a change in the meaning of the term would affect the specification.
2. — Material approved by the Council for publication in association with the Standards and Recommended Practices:

   a) Forewords comprising historical and explanatory material based on the action of the Council and including an explanation of the obligations of States with regard to the application of the Standards and Recommended Practices ensuing from the Convention and the Resolution of Adoption.

   b) Introductions comprising explanatory material introduced at the beginning of parts, chapters or sections of the Annex to assist in the understanding of the application of the text.

   c) Notes included in the text, where appropriate, to give factual information or references bearing on the Standards or Recommended Practices in question, but not constituting part of the Standards or Recommended Practices.

   d) Attachments comprising material supplementary to the Standards and Recommended Practices, or included as a guide to their application.

Selection of language

This Annex has been adopted in four languages — English, French, Russian and Spanish. Each Contracting State is requested to select one of those texts for the purpose of national implementation and for other effects provided for in the Convention, either through direct use or through translation into its own national language, and to notify the Organization accordingly.

Editorial practices

The following practice has been adhered to in order to indicate at a glance the status of each statement: Standards have been printed in light face roman; Recommended Practices have been printed in light face italics, the status being indicated by the prefix Recommendation; Notes have been printed in light italics, the status being indicated by the prefix Note.

It is to be noted that in the English text the following practice has been adhered to when writing the specifications: Standards employ the operative verb “shall” while Recommended Practices employ the operative verb “should”.

The units of measurement used in this document are in accordance with the International System of Units (SI) as specified in Annex 5 to the Convention on International Civil Aviation. Where Annex 5 permits the use of non-SI alternative units these are shown in parentheses following the basic units. Where two sets of units are quoted it must not be assumed that the pairs of values are equal and interchangeable. It may, however, be inferred that an equivalent level of safety is achieved when either set of units is used exclusively.

Any reference to a portion of this document which is identified by a number includes all subdivisions of that portion.

Co-ordination with ISO activity

In the provisions related to certification procedures, extensive use is made of the related specifications developed by the International Organization for Standardization (ISO) and the Commission électrotechnique Internationale (IEC). In most cases these specifications have been incorporated by direct reference. However, in some cases it has been found necessary to modify the specifications to suit ICAO requirements and in such cases the modified material is included in full in this document. The assistance provided by ISO in the development of detailed specifications is recognized.
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<tr>
<td>1</td>
<td>First Meeting of the Committee on Aircraft Noise</td>
<td>Noise certification of light propeller-driven aeroplanes and subsonic jet aeroplanes of 5 700 kg and less maximum certificated take-off weight and guidance on discharge of functions by States in the cases of lease, charter and interchange of aircraft.</td>
<td>6 December 1972</td>
<td>6 April 1973</td>
<td>16 August 1973</td>
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<tr>
<td>2</td>
<td>Third Meeting of the Committee on Aircraft Noise</td>
<td>Noise certification standards for future subsonic jet aeroplanes and propeller-driven aeroplanes, other than STOL aeroplanes, and guidelines for noise certification of future supersonic aeroplanes, propeller-driven STOL aeroplanes and installed APUs and associated aircraft systems when operating on the ground.</td>
<td>21 June 1976</td>
<td>21 October 1976</td>
<td>6 October 1977</td>
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<td>3</td>
<td>Fourth Meeting of the Committee on Aircraft Noise (2nd Edition)</td>
<td>Noise certification standards for subsonic jet aeroplanes, improvements in detailed test procedures to ensure that the same level of technology is applied to all types of aircraft, and editorial changes to simplify the language and eliminate inconsistencies.</td>
<td>11 May 1981</td>
<td>11 September 1981</td>
<td>26 November 1981</td>
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<td>4</td>
<td>Fifth Meeting of the Committee on Aircraft Noise (3rd Edition)</td>
<td>Introduction of a new parameter viz, number of engines in the noise certification standards for subsonic jet aeroplanes, improvements in detailed test procedures to ensure that the same level of technology is applied to all types of aircraft, and editorial changes to simplify the language and eliminate inconsistencies.</td>
<td>6 March 1978</td>
<td>6 July 1978</td>
<td>10 August 1978</td>
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<td>2. Introduction in Volume I of noise certification Standards for helicopters and for future production of existing SST aeroplanes, updating of guidelines for noise certification of installed APU and associated aircraft systems and editorial amendments including changes to units of measurement to bring the Annex in line with Annex 5 provisions.</td>
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<td>2</td>
<td>Seventh Meeting of the Committee on Aircraft Noise</td>
<td>a) Improvements in the noise certification procedures; and b) relaxation of maximum noise limits for helicopters.</td>
<td>6 March 1985</td>
<td>29 July 1985</td>
<td>21 November 1985</td>
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<tr>
<td>3</td>
<td>First meeting of the Committee on Aviation Environmental Protection; study by the Air Navigation Commission following a recommendation of the Obstacle Clearance Panel (Annex 16, Volume I — 2nd Edition)</td>
<td>a) further improvements in the noise certification procedures; b) introduction of a new Chapter 10 for propeller-driven aeroplanes not exceeding 9 000 kg maximum certificated take-off mass; and c) editorial changes in Part V cross-referencing the relevant provisions in the PANS-OPS (Doc 8168).</td>
<td>4 March 1988</td>
<td>31 July 1988</td>
<td>17 November 1988</td>
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### Amendment 4
(3rd Edition)
- **Source(s):** Second Meeting of the Committee on Aviation Environmental Protection; Seventh Meeting of the Committee on Aircraft Noise; and Fifth Meeting of the Operations Panel
- **Subject(s):**
  - a) improvements in the noise certification procedures;
  - b) introduction of a new Chapter 11 for light helicopters;
  - c) expansion of Appendix 2 to include helicopters and replacement of Appendix 4; and
  - d) introduction of guidance on applicability.
- **Adopted:** 24 March 1993
- **Effective:** 26 July 1993
- **Applicable:** 11 November 1993

### Amendment 5
- **Source(s):** Third Meeting of the Committee on Aviation Environmental Protection
- **Subject(s):**
  - a) simplification and clarification of the noise certification schemes in Chapter 3 for propeller-driven aircraft;
  - b) harmonization of the helicopter Standards in Chapters 8 and 11 with national codes; and
  - c) alignment of the take-off mass in Chapter 10 with airworthiness limits.
- **Adopted:** 19 March 1997
- **Effective:** 21 July 1997
- **Applicable:** 6 November 1997

### Amendment 6
- **Source(s):** Fourth Meeting of the Committee on Aviation Environmental Protection
- **Subject(s):**
  - a) introduction of a new definition for human performance in Chapter 1;
  - b) increase in stringency of Chapter 10 noise requirements for light single-engined propeller-driven aeroplanes;
  - c) changes of a detailed technical nature that are intended to improve the consistency of Chapters 3, 8 and 11 as well as Appendices 2 and 4;
  - d) new provisions concerning Human Factors in Part V; and
  - e) changes that have arisen from the ongoing harmonization of the European Joint Aviation Requirements (JARs) and the United States Federal Aviation Regulations (FARs).
- **Adopted:** 26 February 1999
- **Effective:** 19 July 1999
- **Applicable:** 4 November 1999
INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

PART I. DEFINITIONS

Aeroplane. A power-driven heavier-than-air aircraft, deriving its lift in flight chiefly from aerodynamic reactions on surfaces which remain fixed under given conditions of flight.

Aircraft. Any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth’s surface.

Associated aircraft systems. Those aircraft systems drawing electrical/pneumatic power from an auxiliary power unit during ground operations.

Auxiliary power-unit (APU). A self-contained power-unit on an aircraft providing electrical/pneumatic power to aircraft systems during ground operations.

By-pass ratio. The ratio of the air mass flow through the by-pass ducts of a gas turbine engine to the air mass flow through the combustion chambers calculated at maximum thrust when the engine is stationary in an international standard atmosphere at sea level.

Derived version of an aircraft. An aircraft which, from the point of view of airworthiness, is similar to the noise certificated prototype but incorporates changes in type design which may affect its noise characteristics adversely.

Note 1.— Where the certificating authority finds that the proposed change in design, configuration, power or mass is so extensive that a substantially new investigation of compliance with the applicable airworthiness regulations is required, the aircraft should be considered to be a new type design rather than a derived version.

Note 2.— “Adversely” refers to an increase by more than 0.3 dB to any one of the noise certification levels.

External equipment (helicopter). Any instrument, mechanism, part, apparatus, appurtenance, or accessory that is attached to or extends from the helicopter exterior but is not used nor is intended to be used for operating or controlling a helicopter in flight and is not part of an airframe or engine.

Helicopter. A heavier-than-air aircraft supported in flight chiefly by the reactions of the air on one or more power-driven rotors on substantially vertical axes.

Self-sustaining powered sailplane. A powered aeroplane with available engine power which allows it to maintain level flight but not to take off under its own power.

Subsonic aeroplane. An aeroplane incapable of sustaining level flight at speeds exceeding flight Mach number of 1.
PART II. AIRCRAFT NOISE CERTIFICATION

CHAPTER 1. ADMINISTRATION

1.1 The provisions of 1.2 to 1.5 shall apply to all aircraft included in the classifications defined for noise certification purposes in Chapters 2, 3, 4, 5, 6, 8, 10 and 11 of this Part where such aircraft are engaged in international air navigation.

1.2 Noise certification shall be granted or validated by the State of Registry of an aircraft on the basis of satisfactory evidence that the aircraft complies with requirements which are at least equal to the applicable Standards specified in this Annex.

Note.— The documents attesting noise certification may take the form of a separate Noise Certificate or a suitable statement contained in another document approved by the State of Registry and required by that State to be carried in the aircraft.

1.3 The documents attesting noise certification for an aircraft shall provide at least the following information:

a) State of Registry; nationality and registration marks;

b) manufacturer’s serial number;

c) manufacturer’s type and model designation; engine type/model; propeller type/model (if applicable);

d) statement of any additional modifications incorporated for the purpose of compliance with the applicable noise certification Standards;

e) the maximum mass at which compliance with the applicable noise certification Standards has been demonstrated;

f) for aeroplanes for which application for certification of the prototype is submitted on or after 6 October 1977, and for helicopters for which application for certification of the prototype is submitted on or after 1 January 1985:

the average noise level(s) at the reference point(s) for which compliance with the applicable Standard has been demonstrated to the satisfaction of the certifying authority;

g) the chapter of Annex 16, Volume I, according to which the aircraft was certificated.

1.4 The information required under 1.3 b) through g) shall be included in the flight manual.

1.5 Contracting States shall recognize as valid a noise certification granted by another Contracting State provided that the requirements under which such certification was granted are at least equal to the applicable Standards specified in this Annex.

1.6 A Contracting State shall suspend or revoke the noise certification of an aircraft on its Register if the aircraft ceases to comply with the applicable noise Standards. The State of Registry shall not remove the suspension of a noise certification or grant a new noise certification unless the aircraft is found, on reassessment, to comply with the applicable noise Standards.

1.7 Unless otherwise specified in this Volume of the Annex and subject to the provisions in 1.8, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date on which either the application for the certificate of airworthiness for the prototype or, where this procedure is not used, the certificate of airworthiness for the first individual aircraft of the type, exceeds 5 years, the date to be used by the certificating authority in determining the applicability of the appropriate Standards in this Annex shall be the date on which either the application for the certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority.

1.8 When the time interval between the acceptance of the application for and the issue of the certificate of airworthiness for the prototype or, where this procedure is not used, the issue of the certificate of airworthiness for the first individual aircraft of the type, exceeds 5 years, the date to be used by the certificating authority in determining the applicability of the Standards in this Annex shall be 5 years before the date of issue of the certificate of airworthiness for the prototype or, where this procedure is not used, the date of issue of the certificate of airworthiness for the first individual aircraft of the type, except in special cases when the certificating authority accepts an extension of this period beyond 5 years.
CHAPTER 2. SUBSONIC JET AEROPLANES — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED BEFORE 6 OCTOBER 1977

2.1 Applicability

Note.— See also Chapter 1, 1.6.

2.1.1 The Standards of this chapter shall be applicable to all subsonic jet aeroplanes for which either the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority before 6 October 1977, except those aeroplanes:

a) requiring a runway length* of 610 m or less at maximum certificated mass for airworthiness; or

b) powered by engines with a by-pass ratio of 2 or more and for which a certificate of airworthiness for the individual aeroplane was first issued before 1 March 1972; or

c) powered by engines with a by-pass ratio of less than 2, and for which either the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority, before 1 January 1969, and for which a certificate of airworthiness for the individual aeroplane was first issued before 1 January 1976.

2.1.2 The Standards of this chapter shall also be applicable to derived versions of all aeroplanes covered by 2.1.1 above for which the application for certification of a change in type design was accepted, or another equivalent procedure was carried out by the certificating authority on or after 26 November 1981.

2.2 Noise evaluation measure

2.2.1 The noise evaluation measure shall be the effective perceived noise level in EPNdB as described in Appendix 1.

2.3 Noise measurement points

2.3.1 An aeroplane, when tested in accordance with the flight test procedures of 2.6, shall not exceed the noise levels specified in 2.4 at the following points:

a) lateral noise measurement point: the point on a line parallel to and 650 m from the runway centre line, or extended runway centre line, where the noise level is a maximum during take-off;

b) flyover noise measurement point: the point on the extended centre line of the runway and at a distance of 6.5 km from the start of roll;

c) approach noise measurement point: the point on the ground, on the extended centre line of the runway, 120 m (395 ft) vertically below the 3° descent path originating from a point 300 m beyond the threshold. On level ground this corresponds to a position 2 000 m from the threshold.

2.4 Maximum noise levels

2.4.1 The maximum noise levels of those aeroplanes covered by 2.1.1 above, when determined in accordance with the noise evaluation method of Appendix 1, shall not exceed the following:

a) at lateral and approach noise measurement points: 108 EPNdB for aeroplanes with maximum certificated take-off mass of 272 000 kg or over, decreasing linearly with the logarithm of the mass at the rate of 2 EPNdB per halving of the mass down to 102 EPNdB at 34 000 kg, after which the limit remains constant;

b) at flyover noise measurement point: 108 EPNdB for aeroplanes with maximum certificated take-off mass of 272 000 kg or over, decreasing linearly with the logarithm of the mass at the rate of 5 EPNdB per halving of the mass down to 93 EPNdB at 34 000 kg, after which the limit remains constant.

Note.— See Attachment A for equations for the calculation of noise levels as a function of take-off mass.

2.4.2 The maximum noise levels of those aeroplanes covered by 2.1.2 above, when determined in accordance with the noise evaluation method of Appendix 1, shall not exceed the following:

* With no stopway or clearway.
2.4.2.1 At lateral noise measurement point

106 EPNdB for aeroplanes with maximum certificated take-off mass of 400 000 kg or over, decreasing linearly with the logarithm of the mass down to 97 EPNdB at 35 000 kg, after which the limit remains constant.

2.4.2.2 At flyover noise measurement point

a) Aeroplanes with two engines or less

104 EPNdB for aeroplanes with maximum certificated take-off mass of 325 000 kg or over, decreasing linearly with the logarithm of the mass at the rate of 4 EPNdB per halving of mass down to 93 EPNdB, after which the limit remains constant.

b) Aeroplanes with three engines

As a) but with 107 EPNdB for aeroplanes with maximum certificated take-off mass of 325 000 kg or over

or

as defined by 2.4.1 b), whichever is the lower.

c) Aeroplanes with four engines or more

As a) but with 108 EPNdB for aeroplanes with maximum certificated take-off mass of 325 000 kg or over

or

as defined by 2.4.1 b), whichever is the lower.

2.4.2.3 At approach noise measurement point

108 EPNdB for aeroplanes with maximum certificated take-off mass of 280 000 kg or over, decreasing linearly with the logarithm of the mass down to 101 EPNdB at 35 000 kg, after which the limit remains constant.

Note.— See Attachment A for equations for the calculation of noise levels as a function of take-off mass.

2.5 Trade-offs

2.5.1 If the maximum noise levels are exceeded at one or two measurement points:

a) the sum of excesses shall not be greater than 4 EPNdB, except that in respect of four-engined aeroplanes powered by engines with by-pass ratio of 2 or more and for which the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority before 1 December 1969, the sum of any excesses shall not be greater than 5 EPNdB;

b) any excess at any single point shall not be greater than 3 EPNdB; and

c) any excesses shall be offset by corresponding reductions at the other point or points.

2.6 Test procedures

2.6.1 Take-off test procedure

2.6.1.1 Average take-off thrust* shall be used from the start of take-off to the point at which a height of at least 210 m (690 ft) above the runway is reached and the thrust thereafter shall not be reduced below that thrust which will maintain a climb gradient of at least 4 per cent.

2.6.1.2 A speed of at least \( V_2 + 19 \) km/h (\( V_2 + 10 \) kt) shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test.

2.6.1.3 A constant take-off configuration selected by the applicant shall be maintained throughout the take-off noise certification demonstration test except that the landing gear may be retracted.

2.6.2 Approach test procedure

2.6.2.1 The aeroplane shall be stabilized and following a 3° ±0.5° glide path.

2.6.2.2 The approach shall be made at a stabilized airspeed of not less than \( 1.3 V_S + 19 \) km/h (\( 1.3 V_S + 10 \) kt) with thrust stabilized during approach and over the measuring point and continued to a normal touchdown.

2.6.2.3 The configuration of the aeroplane shall be with maximum allowable landing flap setting.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

* Take-off thrust representative of the mean characteristics of the production engine.
CHAPTER 3.  1.— SUBSONIC JET AEROPLANES —
Application for Certificate of Airworthiness
for the Prototype accepted on or after
6 October 1977

2.— PROPELLER-DRIVEN AEROPLANES OVER 5 700 kg —
Application for Certificate of Airworthiness
for the Prototype accepted on or after
1 January 1985 and before 17 November 1988

3.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg —
Application for Certificate of Airworthiness
for the Prototype accepted on or after
17 November 1988

3.1 Applicability

Note 1.— See also Chapter 1, 1.6.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

3.1.1 The Standards of this chapter shall be applicable to:

a) all subsonic jet aeroplanes, including their derived versions, other than aeroplanes which require a runway* length of 610 m or less at maximum certificated mass for airworthiness, in respect of which either the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977;

b) all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum certificated take-off mass (except those described in 6.1.1), for which either the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985 and before 17 November 1988, except where the Standards of Chapter 10 apply;

c) all propeller-driven aeroplanes, including their derived versions, of over 8 618 kg maximum certificated take-off mass, for which either the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988.

3.1.2 Until 19 March 2002, for aeroplanes specified in 3.1.1 b) and c) the requirement for lateral noise in 3.3.1 a) 1) shall alternatively be permitted.

3.2 Noise measurements

3.2.1 Noise evaluation measure

3.2.1.1 The noise evaluation measure shall be the effective perceived noise level in EPNdB as described in Appendix 2.

3.3 Reference noise measurement points

3.3.1 An aeroplane, when tested in accordance with these Standards, shall not exceed the noise levels specified in 3.4 at the following points:

a) lateral full-power reference noise measurement point

1) for jet-powered aeroplanes: the point on a line parallel to and 450 m from the runway centre line, where the noise level is a maximum during take-off;

* With no stopway or clearway.
2) for propeller-driven aeroplanes: the point on the extended centre line of the runway 650 m vertically below the climb-out flight path at full take-off power, as defined in 3.6.2;

Note.— The full-power measurement point under the flight path is an alternative for the lateral measurement point for propeller-driven aeroplanes.

b) flyover reference noise measurement point: the point on the extended centre line of the runway and at a distance of 6.5 km from the start of roll;

c) approach reference noise measurement point: the point on the ground, on the extended centre line of the runway 2 000 m from the threshold. On level ground this corresponds to a position 120 m (394 ft) vertically below the 3° descent path originating from a point 300 m beyond the threshold.

3.3.2 Test noise measurement points

3.3.2.1 If the test noise measurement points are not located at the reference noise measurement points, any corrections for the difference in position shall be made in the same manner as the corrections for the differences between test and reference flight paths.

3.3.2.2 Sufficient lateral test noise measurement points shall be used to demonstrate to the certificating authority that the maximum noise level on the appropriate lateral line has been clearly determined. For jet-powered aeroplanes simultaneous measurements shall be made at one test noise measurement point at a symmetrical position on the other side of the runway. In the case of propeller-driven aeroplanes, because of their inherent asymmetry in lateral noise, simultaneous measurements shall be made at each and every test noise measurement point at a symmetrical position (within ±10 m parallel with the axis of the runway) on the opposite side of the runway.

3.4 Maximum noise levels

3.4.1 The maximum noise levels, when determined in accordance with the noise evaluation method of Appendix 2, shall not exceed the following:

3.4.1.1 At the lateral full-power reference noise measurement point

103 EPNdB for aeroplanes with maximum certificated take-off mass, at which the noise certification is requested, of 400 000 kg and over and decreasing linearly with the logarithm of the mass down to 94 EPNdB at 35 000 kg, after which the limit remains constant.

3.4.1.2 At flyover reference noise measurement point

a) Aeroplanes with two engines or less

101 EPNdB for aeroplanes with maximum certificated take-off mass, at which the noise certification is requested, of 385 000 kg and over and decreasing linearly with the logarithm of the aeroplane mass at the rate of 4 EPNdB per halving of mass down to 89 EPNdB, after which the limit is constant.

b) Aeroplanes with three engines

As a) but with 104 EPNdB for aeroplanes with maximum certificated take-off mass of 385 000 kg and over.

c) Aeroplanes with four engines or more

As a) but with 106 EPNdB for aeroplanes with maximum certificated take-off mass of 385 000 kg and over.

3.4.1.3 At approach reference noise measurement point

105 EPNdB for aeroplanes with maximum certificated take-off mass, at which the noise certification is requested, of 280 000 kg or over, and decreasing linearly with the logarithm of the mass down to 98 EPNdB at 35 000 kg, after which the limit remains constant.

Note.— See Attachment A for equations for the calculation of noise levels as a function of take-off mass.

3.4.2 If a reference ambient air temperature of 15°C is used (see 3.6.1.5. b)), 1 EPNdB shall be added to the measured (and adjusted) noise level obtained at the flyover measurement point before it is compared with the maximum noise level of 3.4.1.2.

3.5 Trade-offs

3.5.1 If the maximum noise levels are exceeded at one or two measurement points:

a) the sum of excesses shall not be greater than 3 EPNdB;

b) any excess at any single point shall not be greater than 2 EPNdB; and

c) any excesses shall be offset by corresponding reductions at the other point or points.
3.6 Noise certification reference procedures

3.6.1 General conditions

3.6.1.1 The reference procedures shall comply with the appropriate airworthiness requirements.

3.6.1.2 The calculations of reference procedures and flight paths shall be approved by the certificating authority.

3.6.1.3 Except in conditions specified in 3.6.1.4, the take-off and approach reference procedures shall be those defined in 3.6.2 and 3.6.3 respectively.

3.6.1.4 When it is shown by the applicant that the design characteristics of the aeroplane would prevent flight being conducted in accordance with 3.6.2 and 3.6.3, the reference procedures shall:

a) depart from the reference procedures defined in 3.6.2 and 3.6.3 only to the extent demanded by those design characteristics which make compliance with the procedures impossible; and

b) be approved by the certificating authority.

3.6.1.5 The reference procedures shall be calculated under the following reference atmospheric conditions:

a) sea level atmospheric pressure of 1 013.25 hPa;

b) ambient air temperature of 25°C, i.e. ISA + 10°C except that, at the discretion of the certificating authority, an alternative reference ambient air temperature of 15°C, i.e. ISA may be used;

c) relative humidity of 70 per cent; and

d) zero wind.

Note.— The reference atmosphere in terms of temperature and relative humidity is homogeneous when used for the calculation of atmospheric absorption coefficients.

3.6.2 Take-off reference procedure

3.6.2.1 Take-off reference flight path shall be calculated as follows:

a) average engine take-off thrust or power shall be used from the start of take-off to the point where at least the following height above runway level is reached:

— aeroplanes with two engines or less — 300 m (984 ft)
— aeroplanes with three engines — 260 m (853 ft)
— aeroplanes with four engines or more — 210 m (689 ft);

b) upon reaching the height specified in a) above, the thrust or power shall not be reduced below that required to maintain:

1) a climb gradient of 4 per cent; and

2) in the case of multi-engined aeroplanes, level flight with one engine inoperative;

whichever thrust or power is greater;

c) for the purpose of determining the lateral full-power noise level, the reference flight path shall be calculated on the basis of using full take-off power throughout without a thrust or power reduction;

d) the speed shall be the all-engines operating take-off climb speed selected by the applicant for use in normal operation, which shall be at least \( V_2 + 19 \text{ km/h} \) (\( V_2 + 10 \text{ kt} \)) but not greater than \( V_2 + 37 \text{ km/h} \) (\( V_2 + 20 \text{ kt} \)) and which shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test;

e) a constant take-off configuration selected by the applicant shall be maintained throughout the take-off reference procedure except that the landing gear may be retracted. Configuration shall be interpreted as meaning the conditions of the systems and centre of gravity position and shall include the position of lift augmentation devices used, whether the APU is operating, and whether air bleeds and power off-takes are operating;

f) the mass of the aeroplane at the brake release shall be the maximum take-off mass at which the noise certification is requested; and

g) the average engine shall be defined by the average of all the certification compliant engines used during the aeroplane flight tests up to and during certification when operated to the limitations and procedures given in the flight manual. This will establish a technical standard including the relationship of thrust/power to control parameters (e.g. \( N_1 \) or EPR). Noise measurements made during certification tests shall be corrected to this standard.

Note.— Take-off thrust/power used shall be the maximum available for normal operations as scheduled in the performance section of the aeroplane flight manual for the reference atmospheric conditions given in 3.6.1.5.
3.6.3 Approach reference procedure

3.6.3.1 The approach reference flight path shall be calculated as follows:

a) the aeroplane shall be stabilized and following a 3° glide path;

b) the approach shall be made at a stabilized airspeed of not less than the minimum value of $V_{REF} + 19$ km/h (minimum $V_{REF} + 10$ kt) with thrust or power stabilized during approach and over the measuring point, and continued to a normal touchdown;

Note.— The minimum value of $V_{REF}$ is defined as $1.3V_S$ or the approximate equivalent of $1.23V_{S1G}$.

c) the constant approach configuration as used in the airworthiness certification tests, but with the landing gear down, shall be maintained throughout the approach reference procedure;

d) the mass of the aeroplane at the touchdown shall be the maximum landing mass permitted in the approach configuration defined in 3.6.3.1 c) at which noise certification is requested; and

e) the most critical (that which produces the highest noise level) configuration with normal deployment of aerodynamic control surfaces including lift and drag producing devices, at the mass at which certification is requested shall be used. This configuration includes all those items listed in 5.2.5 of Appendix 2 that will contribute to the noisiest continuous state at the maximum landing mass in normal operation.

3.7 Test procedures

3.7.1 The test procedures shall be acceptable to the airworthiness and noise certificating authority of the State issuing the certificate.

3.7.2 The test procedures and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure designated as effective perceived noise level, EPNL, in units of EPNdB, as described in Appendix 2.

3.7.3 Acoustic data shall be adjusted by the methods outlined in Appendix 2 to the reference conditions specified in this Chapter. Adjustments for speed and thrust shall be made as described in Section 9 of Appendix 2.

3.7.4 If the mass during the test is different from the mass at which the noise certification is requested, the necessary EPNL adjustment shall not exceed 2 EPNdB for take-offs and 1 EPNdB for approaches. Data approved by the certificating authority shall be used to determine the variation of EPNL with mass for both take-off and approach test conditions. Similarly the necessary EPNL adjustment for variations in approach flight path from the reference flight path shall not exceed 2 EPNdB.

3.7.5 For the approach conditions the test procedures shall be accepted if the aeroplane follows a steady glide path angle of $3° \pm 0.5°$.

3.7.6 If equivalent test procedures different from the reference procedures are used, the test procedures and all methods for adjusting the results to the reference procedures shall be approved by the certificating authority. The amounts of the adjustments shall not exceed 16 EPNdB on take-off and 8 EPNdB on approach, and if the adjustments are more than 8 EPNdB and 4 EPNdB respectively, the resulting numbers shall not be within 2 EPNdB of the limit noise levels specified in 3.4.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

3.7.7 For take-off, lateral, and approach conditions, the variation in instantaneous indicated airspeed of the aeroplane must be maintained within ±3 per cent of the average airspeed between the 10 dB-down points. This shall be determined by reference to the pilot’s airspeed indicator. However, when the instantaneous indicated airspeed varies from the average airspeed over the 10 dB-down points by more than ±5.5 km/h (±3 kt), and this is judged by the certificating authority representative on the flight deck to be due to atmospheric turbulence, then the flight so affected shall be rejected for noise certification purposes.
CHAPTER 4. SUPersonic aeroPLanes

4.1 Supersonic aeroplanes — application for certificate of airworthiness for the prototype accepted before 1 January 1975

4.1.1 The Standards of Chapter 2 of this Part, with the exception of maximum noise levels specified in 2.4, shall be applicable to all supersonic aeroplanes, including their derived versions, in respect of which either the application for the certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority before 1 January 1975 and for which a certificate of airworthiness for the individual aeroplane was first issued after 26 November 1981.

4.1.2 The maximum noise levels of those aeroplanes covered by 4.1.1, when determined in accordance with the noise evaluation method of Appendix 1, shall not exceed the measured noise levels of the first certificated aeroplane of the type.

4.2 Supersonic aeroplanes — application for certificate of airworthiness for the prototype accepted on or after 1 January 1975

Note.— Standards and Recommended Practices for these aeroplanes are not yet developed but the noise levels of Chapter 3 of this Part applicable to subsonic jet aeroplanes may be used as guidelines for aeroplanes for which the application for a certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority on or after 1 January 1975.
CHAPTER 5. PROPELLER-DRIVEN AEROPLANES OVER 5 700 kg — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED BEFORE 1 JANUARY 1985

5.1 Applicability

Note 1.— See also Chapter 1, 1.6.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

5.1.1 The Standards defined hereunder are not applicable to:

a) aeroplanes requiring a runway* length of 610 m or less at maximum certificated mass for airworthiness;

b) aeroplanes specifically designed for fire fighting;

c) aeroplanes specifically designed for agricultural purposes;

d) aeroplanes to which the Standards of Chapter 6 apply; and

e) aeroplanes to which the Standards of Chapter 10 apply.

5.1.2 The Standards of this chapter shall be applicable to all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum certificated take-off mass for which either the application for a certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority on or after 6 October 1977 and before 1 January 1985.

5.1.3 The Standards of Chapter 2, with the exception of Sections 2.1 and 2.4.2, shall be applicable to derived versions and individual aeroplanes of over 5 700 kg maximum certificated take-off mass and to which Standards of Chapter 6 do not apply and are of the type for which application for a certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority before 6 October 1977 and for which a certificate of airworthiness for the individual aeroplane was issued on or after 26 November 1981.

5.1.4 The Standards of Chapter 3, with the exception of Section 3.1 shall be applicable to all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum take-off mass, for which either the application for a certificate of airworthiness for the prototype was accepted, or another equivalent prescribed procedure was carried out by the certificating authority on or after 1 January 1985.

Note.— The Standards in Chapters 2 and 3 although developed previously for subsonic jet aeroplanes are considered suitable for application to other aeroplane types regardless of the type of power installed.

5.2 Noise measurements

5.2.1 Noise evaluation measure

5.2.1.1 The noise evaluation measure shall be the effective perceived noise level in EPNdB as described in Appendix 2.

5.3 Reference noise measurement points

5.3.1 An aeroplane, when tested in accordance with these Standards, shall not exceed the noise levels specified in 5.4 at the following points:

a) lateral reference noise measurement point: the point on a line parallel to and 450 m from the runway centre line or extended runway centre line, where the noise level is a maximum during take-off;

b) flyover reference noise measurement point: the point on the extended centre line of the runway and at a distance of 6.5 km from the start of roll;

c) approach reference noise measurement point: the point on the ground, on the extended centre line of the runway 2 000 m from the threshold. On level ground this corresponds to a position 120 m (395 ft) vertically below the 3° descent path originating from a point 300 m beyond the threshold.

5.3.2 Test noise measurement points

5.3.2.1 If the test noise measurement points are not located at the reference noise measurement points, any corrections for the difference in position shall be made in the same manner as the corrections for the differences between test and reference flight paths.

* With no stopway or clearway.
5.3.2.2 Sufficient lateral test noise measurement points shall be used to demonstrate to the certificating authority that the maximum noise level on the appropriate lateral line has been clearly determined. Simultaneous measurements shall be made at one test noise measurement point at a symmetrical position on the other side of the runway.

5.3.2.3 The applicant shall demonstrate to the certificating authority that during flight test, lateral and flyover noise levels were not separately optimized at the expense of each other.

5.4 Maximum noise levels

5.4.1 The maximum noise levels, when determined in accordance with the noise evaluation method of Appendix 2, shall not exceed the following:

a) at lateral reference noise measurement point:
96 EPNdB constant limit for aeroplanes with maximum take-off mass, at which the noise certification is requested, up to 34,000 kg and increasing linearly with the logarithm of aeroplane mass at the rate of 2 EPNdB per doubling of mass from that point until the limit of 103 EPNdB is reached, after which the limit is constant;

b) at flyover reference noise measurement point:
89 EPNdB constant limit for aeroplanes with maximum take-off mass, at which the noise certification is requested, up to 34,000 kg and increasing linearly with the logarithm of aeroplane mass at the rate of 5 EPNdB per doubling of mass from that point until the limit of 106 EPNdB is reached, after which the limit is constant;

c) at approach reference noise measurement point:
98 EPNdB constant limit for aeroplanes with maximum take-off mass, at which the noise certification is requested, up to 34,000 kg and increasing linearly with the logarithm of aeroplane mass at the rate of 2 EPNdB per doubling of mass from that point until the limit of 105 EPNdB is reached, after which the limit is constant.

Note.—See Attachment A for equations for the calculation of noise levels as a function of take-off mass.

5.5 Trade-offs

5.5.1 If the maximum noise levels are exceeded at one or two measurement points:

a) the sum of excesses shall not be greater than 3 EPNdB;

b) any excess at any single point shall not be greater than 2 EPNdB; and

c) any excesses shall be offset by corresponding reductions at the other point or points.

5.6 Noise certification reference procedures

5.6.1 General conditions

5.6.1.1 The reference procedures shall comply with the appropriate airworthiness requirements.

5.6.1.2 The calculations of reference procedures and flight paths shall be approved by the certificating authority.

5.6.1.3 Except in conditions specified in 5.6.1.4, the take-off and approach reference procedures shall be those defined in 5.6.2 and 5.6.3 respectively.

5.6.1.4 When it is shown by the applicant that the design characteristics of the aeroplane would prevent flight being conducted in accordance with 5.6.2 and 5.6.3, the reference procedures shall:

a) depart from the reference procedures defined in 5.6.2 and 5.6.3 only to the extent demanded by those design characteristics which make compliance with the procedures impossible; and

b) be approved by the certificating authority.

5.6.1.5 The reference procedures shall be calculated under the following reference atmospheric conditions:

a) sea level atmospheric pressure of 1 013.25 hPa;

b) ambient air temperature of 25°C, i.e. ISA + 10°C except that at the discretion of the certificating authority, an alternative reference ambient air temperature of 15°C, i.e. ISA may be used;

c) relative humidity of 70 per cent; and

d) zero wind.

5.6.2 Take-off reference procedure

5.6.2.1 The take-off flight path shall be calculated as follows:

a) average take-off power shall be used from the start of take-off to the point where at least the height above runway level shown below is reached. The take-off power used shall be the maximum available for normal operations as scheduled in the performance section of the aeroplane flight manual for the reference atmospheric conditions given in 5.6.1.5.
— aeroplanes with two engines or less — 300 m (985 ft)
— aeroplanes with three engines — 260 m (855 ft)
— aeroplanes with four engines or more — 210 m (690 ft);

b) upon reaching the height specified in a) above, the power shall not be reduced below that required to maintain:

1) climb gradient of 4 per cent; or
2) in the case of multi-engined aeroplanes, level flight with one engine inoperative;

whichever power is the greater;
c) the speed shall be the all-engines operating take-off climb speed selected by the applicant for use in normal operation, which shall be at least \( V_2 + 19 \text{ km/h} \) (\( V_2 + 10 \text{ kt} \)) and which shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test;
d) a constant take-off configuration selected by the applicant shall be maintained throughout the take-off reference procedure except that the landing gear may be retracted; and
e) the mass of the aeroplane at the brake-release shall be the maximum take-off mass at which the noise certification is requested.

5.6.3 Approach reference procedure

5.6.3.1 The approach reference flight path shall be calculated as follows:

a) the aeroplane shall be stabilized and following a 3° glide path;

b) the approach shall be made at a stabilized airspeed of not less than 1.3 \( V_S + 19 \text{ km/h} \) (1.3 \( V_S + 10 \text{ kt} \)) with power stabilized during approach and over the measuring point, and continued to a normal touchdown;
c) the constant approach configuration used in the airworthiness certification test, but with the landing gear down, shall be maintained throughout the approach reference procedure;
d) the mass of the aeroplane at the touchdown shall be the maximum landing mass permitted in the approach configuration defined in 5.6.3.1 c) at which noise certification is requested; and
e) the most critical (that which produces the highest noise levels) configuration at the mass at which certification is requested, shall be used.

5.7 Test procedures

5.7.1 The test procedures shall be acceptable to the airworthiness and noise certificating authority of the State issuing the certificate.

5.7.2 The test procedures and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure designated as effective perceived noise level, EPNL, in units of EPNdB, as described in Appendix 2.

5.7.3 Acoustic data shall be adjusted by the methods outlined in Appendix 2 to the reference conditions specified in this chapter. Adjustments for speed and thrust shall be made as described in Section 9 of Appendix 2.

5.7.4 If the mass during the test is different from the mass at which the noise certification is requested, the necessary EPNL adjustment shall not exceed 2 EPNdB for take-offs and 1 EPNdB for approaches. Data approved by the certificating authority shall be used to determine the variation of EPNL with mass for both take-off and approach test conditions. Similarly, the necessary EPNL adjustment for variations in approach flight path from the reference flight path shall not exceed 2 EPNdB.

5.7.5 For the approach conditions the test procedures shall be accepted if the aeroplane follows a steady glide path angle of 3° ±0.5°.

5.7.6 If equivalent test procedures different from the reference procedures are used, the test procedures and all methods for adjusting the results to the reference procedures shall be approved by the certificating authority. The amounts of the adjustments shall not exceed 16 EPNdB on take-off and 8 EPNdB on approach, and if the adjustments are more than 8 EPNdB and 4 EPNdB respectively, the resulting numbers shall not be within 2 EPNdB of the limit noise levels specified in 5.4.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).
CHAPTER 6. PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED BEFORE 17 NOVEMBER 1988

6.1 Applicability

Note 1.— See also Chapter 1, 1.6.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

6.1.1 The Standards of this chapter shall be applicable to all propeller-driven aeroplanes, except those aeroplanes specifically designed for aerobatic purposes or agricultural or fire fighting uses, of a maximum certificated take-off mass not exceeding 8 618 kg for which:

a) application for the certificate of airworthiness for the prototype was accepted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1975 and before 17 November 1988, except for derived versions for which an application for a certificate of airworthiness was accepted or another equivalent procedure was carried out by the certificating authority on or after 17 November 1988 in which case the Standards of Chapter 10 apply; or

b) a certificate of airworthiness for the individual aeroplane was first issued on or after 1 January 1980.

6.2 Noise evaluation measure

6.2.1 The noise evaluation measure shall be a weighted over-all sound pressure level as defined in International Electrotechnical Commission (IEC) Publication 179*. The weighting applied to each sinusoidal component of the sound pressure shall be given as a function of frequency by the standard reference curve called “A”.

6.3 Maximum noise levels

6.3.1 For aeroplanes specified in 6.1.1 a) and 6.1.1 b), the maximum noise levels when determined in accordance with the noise evaluation method of Appendix 3 shall not exceed the following:

a 68 dB(A) constant limit up to an aeroplane mass of 600 kg, varying linearly with mass from that point to 1 500 kg, after which the limit is constant at 80 dB(A) up to 8 618 kg.

Note.— Where an aeroplane comes within the provisions of Chapter 10, 10.1.2, the limit of 80 dB(A) applies up to 8 618 kg.

6.4 Noise certification reference procedures

6.4.1 The reference procedure shall be calculated under the following reference atmospheric conditions:

a) sea level atmospheric pressure of 1 013.25 hPa;

b) ambient air temperature of 25°C, i.e. ISA + 10°C.

6.5 Test procedures

6.5.1 Either the test procedures described in 6.5.2 and 6.5.3 or equivalent test procedures approved by the certificating authority shall be used.

6.5.2 Tests to demonstrate compliance with the maximum noise levels of 6.3.1 shall consist of a series of level flights overhead the measuring station at a height of

\[ 300 \pm 10 \text{ m (985 +30 ft)} \]

The aeroplane shall pass over the measuring point within ±10° from the vertical.

6.5.3 Overflight shall be performed at the highest power in the normal operating range**, stabilized airspeed and with the aeroplane in the cruise configuration.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

* As amended. Available from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

** This is normally indicated in the Aeroplane Flight Manual and on the flight instruments.
CHAPTER 7. PROPELLER-DRIVEN STOL AEROPLANES

Note.— Standards and Recommended Practices for this chapter are not yet developed. In the meantime, guidelines provided in Attachment B may be used for noise certification of propeller-driven STOL aeroplanes for which a certificate of airworthiness for the individual aeroplane was first issued on or after 1 January 1976.
CHAPTER 8. HELICOPTERS

8.1 Applicability

Note.— See also Chapter 1, 1.6.

8.1.1 The Standards of this chapter shall be applicable to all helicopters, except those designed exclusively for agricultural, fire fighting or external load carrying purposes, for which:

a) application for the certificate of airworthiness for the prototype was accepted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985; or

b) application for a change of type design, where such change affects any of the helicopter’s noise certification levels adversely, was accepted, or other equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988.

8.1.2 Certification of helicopters which are capable of carrying external loads or external equipment shall be made without such loads or equipment fitted.

Note 1.— Helicopters which comply with the Standards with internal loads may be excepted when carrying external loads or external equipment, if such operations are conducted at a gross mass or with other operating parameters which are in excess of those certificated for airworthiness with internal loads.

Note 2.— The term “adversely” is explained under the definition of “derived version of an aircraft” in Part I.

8.1.3 An applicant under 8.1.1 may alternatively elect to show compliance with Chapter 11 instead of Chapter 8 if the helicopter has a maximum certificated take-off mass of 2 730 kg or less.

8.2 Noise evaluation measure

8.2.1 The noise evaluation measure shall be the effective perceived noise level in EPNdB as described in Appendix 2.

8.3 Reference noise measurement points

8.3.1 A helicopter, when tested in accordance with these Standards, shall not exceed the noise levels specified in 8.4 at the following points:

a) Take-off reference noise measurement points

1) a flight path reference point located on the ground vertically below the flight path defined in the take-off reference procedure (see 8.6.2.1) and 500 m horizontally in the direction of flight from the point at which transition to climbing flight is initiated in the reference procedure (see 8.6.2.1 b));

2) two other points on the ground symmetrically disposed at 150 m on both sides of the flight path defined in the take-off reference procedure and lying on a line through the flight path reference point.

b) Overflight reference noise measurement points

1) A flight path reference point located on the ground 150 m (490 ft) vertically below the flight path defined in the overflight reference procedure (see 8.6.3.1);

2) two other points on the ground symmetrically disposed at 150 m on both sides of the flight path defined in the overflight reference procedure and lying on a line through the flight path reference point.

c) Approach reference noise measurement points

1) a flight path reference point located on the ground 120 m (395 ft) vertically below the flight path defined in the approach reference procedure (see 8.6.4.1). On level ground, this corresponds to a position 1 140 m from the intersection of the 6.0° approach path with the ground plane;

2) two other points on the ground symmetrically disposed at 150 m on both sides of the flight path defined in the approach reference procedure and lying on a line through the flight path reference point.

8.4 Maximum noise levels

8.4.1 For helicopters specified in 8.1.1, the maximum noise levels when determined in accordance with the noise evaluation method of Appendix 2 shall not exceed the following:
8.4.1.1 At the take-off flight path reference point: 109 EPNdB for helicopters with maximum certificated take-off mass at which the noise certification is requested, of 80,000 kg and over and decreasing linearly with the logarithm of the helicopter mass at a rate of 3 EPNdB per halving of mass down to 89 EPNdB after which the limit is constant.

8.4.1.2 At the overflight path reference point: 108 EPNdB for helicopters with maximum certificated take-off mass at which the noise certification is requested, of 80,000 kg and over and decreasing linearly with the logarithm of the helicopter mass at a rate of 3 EPNdB per halving of mass down to 88 EPNdB after which the limit is constant.

8.4.1.3 At the approach flight path reference point: 110 EPNdB for helicopters with maximum certificated take-off mass at which the noise certification is requested, of 80,000 kg and over and decreasing linearly with the logarithm of the helicopter mass at a rate of 3 EPNdB per halving of mass down to 90 EPNdB after which the limit is constant.

Note.— See Attachment A for equations for the calculation of noise levels as a function of take-off mass.

8.5 Trade-offs

8.5.1 If the noise level limits are exceeded at one or two measurement points:

a) the sum of excesses shall not be greater than 4 EPNdB;

b) any excess at any single point shall not be greater than 3 EPNdB; and

c) any excess shall be offset by corresponding reductions at the other point or points.

8.6 Noise certification reference procedures

8.6.1 General conditions

8.6.1.1 The reference procedures shall comply with the appropriate airworthiness requirements.

8.6.1.2 The reference procedures and flight paths shall be approved by the certificating authority.

8.6.1.3 Except in conditions specified in 8.6.1.4, the take-off, overflight and approach reference procedures shall be those defined in 8.6.2, 8.6.3 and 8.6.4 respectively.

8.6.1.4 When it is shown by the applicant that the design characteristics of the helicopter would prevent flight being conducted in accordance with 8.6.2, 8.6.3 or 8.6.4, the reference procedures shall:

a) depart from the reference procedures defined in 8.6.2, 8.6.3 or 8.6.4 only to the extent demanded by those design characteristics which make compliance with the reference procedures impossible; and

b) be approved by the certificating authority.

8.6.1.5 The reference procedures shall be established for the following reference atmospheric conditions:

a) sea level atmospheric pressure of 1,013.25 hPa;

b) ambient air temperature of 25°C, i.e. ISA + 10°C except that, at the discretion of the certificating authority, an alternative reference ambient air temperature of 15°C, i.e. ISA may be used;

c) relative humidity of 70 per cent; and

d) zero wind.

8.6.1.6 In 8.6.2.1 c), 8.6.3.1 c) and 8.6.4.1 c), the maximum normal operating rpm shall be taken as the highest rotor speed for each reference procedure corresponding to the airworthiness limit imposed by the manufacturer and approved by the certificating authority. Where a tolerance on the highest rotor speed is specified, the maximum normal operating rotor speed shall be taken as the highest rotor speed about which that tolerance is given. If the rotor speed is automatically linked with flight condition, the maximum normal operating rotor speed corresponding with that flight condition shall be used during the noise certification procedure. If rotor speed can be changed by pilot action, the highest normal operating rotor speed specified in the flight manual limitation section for power-on conditions shall be used during the noise certification procedure.

8.6.2 Take-off reference procedure

8.6.2.1 The take-off reference flight procedure shall be established as follows:

a) the helicopter shall be stabilized at the maximum take-off power corresponding to minimum installed engine(s) specification power available for the reference ambient conditions or gearbox torque limit, whichever is lower, and along a path starting from a point located 500 m prior to the flight path reference point, at 20 m (65 ft) above the ground;

b) the best rate of climb speed $V_{cl}$ or the lowest approved speed for the climb after take-off, whichever is the greater, shall be maintained throughout the take-off reference procedure;
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8.6.3 Overflight reference procedure

8.6.3.1 The overflight reference procedure shall be established as follows:

a) the helicopter shall be stabilized in level flight overhead the flight path reference point at a height of 150 m (492 ft);

b) a speed of 0.9 \( V_H \) or 0.9 \( V_{NE} \), or 0.45 \( V_H + 120 \) km/h (0.45 \( V_H + 65 \) kt) or 0.45 \( V_{NE} + 120 \) km/h (0.45 \( V_{NE} + 65 \) kt), whichever is the least, shall be maintained throughout the overflight reference procedure;

Note.—For noise certification purposes, \( V_H \) is defined as the airspeed in level flight obtained using the torque corresponding to minimum engine installed, maximum continuous power available for sea level pressure (1 013.25 hPa), 25°C ambient conditions at the relevant maximum certificated mass. \( V_{NE} \) is defined as the not-to-exceed airworthiness airspeed imposed by the manufacturer and approved by the certificating authority.

c) the overflight shall be made with the rotor speed stabilized at the maximum normal operating rpm certificated for level flight;

d) the helicopter shall be in the cruise configuration; and

e) the mass of the helicopter shall be the maximum take-off mass at which noise certification is requested.

8.6.3.2 The value of \( V_H \) and/or \( V_{NE} \) used for noise certification shall be quoted in the approved flight manual.

8.6.4 Approach reference procedure

8.6.4.1 The approach reference procedure shall be established as follows:

a) the helicopter shall be stabilized and following a 6.0° approach path;

b) the approach shall be made at a stabilized airspeed equal to the best rate of climb speed \( V_y \), or the lowest approved speed for the approach, whichever is the greater, with power stabilized during the approach and over the flight path reference point, and continued to a normal touchdown;

c) the approach shall be made with the rotor speed stabilized at the maximum normal operating rpm certificated for approach;

d) the constant approach configuration used in airworthiness certification tests, with the landing gear extended, shall be maintained throughout the approach reference procedure; and

e) the mass of the helicopter at touchdown shall be the maximum landing mass at which noise certification is requested.

8.7 Test procedures

8.7.1 The test procedures shall be acceptable to the airworthiness and noise certificating authority of the State issuing the certificate.

8.7.2 The test procedures and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure designated as effective perceived noise level, EPNL, in units of EPNdB, as described in Appendix 2.

8.7.3 Test conditions and procedures shall be closely similar to reference conditions and procedures or the acoustic data shall be adjusted, by the methods outlined in Appendix 2, to the reference conditions and procedures specified in this chapter.

8.7.4 Adjustments for differences between test and reference flight procedures shall not exceed:

a) for take-off 4.0 EPNdB, of which the arithmetic sum of \( \Delta_1 \) and the term \(-7.5 \log (Q K/Q_K)\) from \( \Delta_2 \) shall not in total exceed 2.0 EPNdB;

b) for overflight or approach 2.0 EPNdB.

8.7.5 During the test the average rotor rpm shall not vary from the normal maximum operating rpm by more than \( \pm 1.0 \) per cent during the 10 dB-down time period.

8.7.6 The helicopter airspeed shall not vary from the reference airspeed appropriate to the flight demonstration by more than \( \pm 9 \) km/h (5 kt) throughout the 10 dB-down time period.
8.7.7 When the wind speed component in the direction of flight exceeds 9 km/h (5 kt), the number of level overflights made with a head wind component shall be equal to the number of level overflights made with a tail wind component.

8.7.8 The helicopter shall fly within ±10° or ±20 m, whichever is greater, from the vertical above the reference track throughout the 10 dB-down time period (see Figure 8-1).

8.7.9 The helicopter height shall not vary during overflight from the reference height at the overhead point by more than ±9 m (30 ft).

8.7.10 During the approach noise demonstration the helicopter shall be established on a stabilized constant speed approach within the airspace contained between approach angles of 5.5° and 6.5°.

8.7.11 Tests shall be conducted at a helicopter mass not less than 90 per cent of the relevant maximum certificated mass and may be conducted at a mass not exceeding 105 per cent of the relevant maximum certificated mass. For each of the three flight conditions, at least one test must be completed at or above this maximum certificated mass.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).
CHAPTER 9. INSTALLED AUXILIARY POWER UNITS (APU) AND ASSOCIATED AIRCRAFT SYSTEMS DURING GROUND OPERATIONS

Note.— Standards and Recommended Practices for this Chapter are not yet developed. In the meantime, guidelines provided in Attachment C may be used for noise certification of installed auxiliary power units (APU) and associated aircraft systems in:

a) all aircraft for which application for a certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977; and

b) aircraft of existing type design for which application for a change of type design involving the basic APU installation was accepted or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977.
CHAPTER 10. PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE OR DERIVED VERSION ACCEPTED ON OR AFTER 17 NOVEMBER 1988

10.1 Applicability

Note 1.— See also Chapter 1, 1.6.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

10.1.1 The Standards of this chapter shall be applicable to all propeller-driven aeroplanes and their derived versions, with a certificated take-off mass not exceeding 8 618 kg, except those aeroplanes specifically designed for aerobatic purposes and agricultural or fire fighting uses and self-sustaining powered sailplanes.

10.1.2 For an aeroplane for which application for the certificate of airworthiness for the prototype or for all derived versions was accepted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988, except for those aeroplanes specified in 10.1.4, the noise limits of 10.4 a) shall apply.

10.1.3 For aeroplanes specified in 10.1.2 which fail to comply with the Standards of this chapter and where the application for the certificate of airworthiness for the prototype or all derived versions was accepted, or another equivalent prescribed procedure was carried out by the certificating authority, before 17 November 1993, the Standards of Chapter 6 shall apply.

10.1.4 For single-engined aeroplanes, except those aeroplanes specifically designed for aerobatic purposes and agricultural or fire fighting uses, self-sustaining powered sailplanes, float planes and amphibians, for which:

a) the application for the certificate of airworthiness for the prototype or their derived versions was accepted, or another equivalent procedure was carried out by the certificating authority, on or after 4 November 1999, the noise limits of 10.4 b) shall apply;

b) an application for the certificate of airworthiness for the derived version was accepted, or other procedure was carried out, on or after 4 November 1999, but for which the application for the certificate of airworthiness for the prototype, or another equivalent procedure was carried out by the certificating authority, before 4 November 1999, the noise limits of 10.4 b) shall apply;

c) the requirements of b) above apply, but which fail to meet the noise limits of 10.4 b), the noise limits of 10.4 a) shall apply provided that the application for the derived version was made before 4 November 2004.

10.2 Noise evaluation measure

The noise evaluation measure shall be the maximum A-weighted noise level (L_{Amax}) as defined in Appendix 6.

10.3 Reference noise measurement points

10.3.1 An aeroplane, when tested in accordance with these Standards, shall not exceed the noise level specified in 10.4 at the take-off reference noise measurement point.

10.3.2 The take-off reference noise measurement point is the point on the extended centre line of the runway at a distance of 2 500 m from the start of take-off roll.

10.4 Maximum noise levels

The maximum noise levels determined in accordance with the noise evaluation method of Appendix 6 shall not exceed the following:

a) for aeroplanes specified in 10.1.2 and 10.1.4 c), a 76 dB(A) constant limit up to an aeroplane mass of 600 kg varying linearly from that point with the logarithm of aeroplane mass until at 1 400 kg the limit of 88 dB(A) is reached after which the limit is constant up to 8 618 kg; and

b) for aeroplanes specified in 10.1.4 a) and b), a 70 dB(A) constant limit up to an aeroplane mass of 570 kg increasing linearly from that point with the logarithm of aeroplane mass until at 1 500 kg the limit of 85 dB(A) is reached after which the limit is constant up to 8 618 kg.
10.5 Noise certification reference procedures

10.5.1 General conditions

10.5.1.1 The calculations of reference procedures and flight paths shall be approved by the certificating authority.

10.5.1.2 Except in conditions specified in 10.5.1.3, the take-off reference procedure shall be that defined in 10.5.2.

10.5.1.3 When it is shown by the applicant that the design characteristics of the aeroplane would prevent flights being conducted in accordance with 10.5.2, the reference procedures shall:

a) depart from the reference procedures defined only to the extent demanded by those design characteristics which make compliance with the procedures impossible; and

b) be approved by the certificating authority.

10.5.1.4 The reference procedures shall be calculated under the following atmospheric conditions:

a) sea level atmospheric pressure of 1 013.25 hPa;

b) ambient air temperature of 15°C, i.e. ISA;

c) relative humidity of 70 per cent; and

d) zero wind.

10.5.1.5 The acoustic reference atmospheric conditions shall be the same as the reference atmospheric conditions for flight.

10.5.2 Take-off reference procedure

The take-off flight path shall be calculated taking into account the following two phases.

First phase

a) Take-off power shall be used from the brake release point to the point at which the height of 15 m (50 ft) above the runway is reached.

b) A constant take-off configuration selected by the applicant shall be maintained throughout this first phase.

c) The mass of the aeroplane at the brake-release shall be the maximum take-off mass at which the noise certification is requested.

d) The length of this first phase shall correspond to the length given in the airworthiness data for a take-off on a level paved runway.

Second phase

a) The beginning of the second phase corresponds to the end of the first phase.

b) The aeroplane shall be in the climb configuration with landing gear up, if retractable, and flap setting corresponding to normal climb throughout this second phase.

c) The speed shall be the best rate of climb speed $V_y$.

d) Take-off power and, for aeroplanes equipped with variable pitch or constant speed propellers, rpm shall be maintained throughout the second phase. If airworthiness limitations do not permit the application of take-off power and rpm up to the reference point, then take-off power and rpm shall be maintained for as long as is permitted by such limitations and thereafter at maximum continuous power and rpm. Limiting of time for which take-off power and rpm shall be used in order to comply with this chapter shall not be permitted. The reference height shall be calculated assuming climb gradients appropriate to each power setting used.

10.6 Test procedures

10.6.1 The test procedures shall be acceptable to the airworthiness and noise certificating authorities of the State issuing the certificate.

10.6.2 The test procedures and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure in units of $L_{Amax}$ as described in Appendix 6.

10.6.3 Acoustic data shall be adjusted by the methods outlined in Appendix 6 to the reference conditions specified in this chapter.

10.6.4 If equivalent test procedures are used, the test procedures and all methods for correcting the results to the reference conditions shall be approved by the certificating authority.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).
CHAPTER 11. HELICOPTERS NOT EXCEEDING 2 730 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

11.1 Applicability

Note.— See also Chapter 1, 1.6.

11.1.1 The Standards of this chapter shall be applicable to all helicopters having a maximum certificated take-off mass not exceeding 2 730 kg, except those designed exclusively for agricultural, fire fighting or external load carrying purposes, for which:

a) the certificate of airworthiness for the prototype was issued, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 11 November 1993; or

b) the certificate of airworthiness for a change of type design was issued, where such a change may increase the helicopter’s overflight noise level, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 11 November 1993.

11.1.2 Certification of helicopters which are capable of carrying external loads or external equipment shall be made without such loads or equipment fitted.

Note 1.— Helicopters which comply with the Standards with internal loads may be excepted when carrying external loads or external equipment, if such operations are conducted at a gross mass or with other operating parameters which are in excess of those certificated for airworthiness with internal loads.

11.1.3 An applicant under 11.1.1 may alternatively elect to show compliance with Chapter 8 instead of complying with this chapter.

11.2 Noise evaluation measure

The noise evaluation measure shall be the sound exposure level (SEL) as described in Appendix 4.

11.3 Reference noise measurement point

A helicopter, when tested in accordance with these Standards, shall not exceed the noise levels specified in 11.4 at a flight path reference point located on the ground 150 m (492 ft) vertically below the flight path defined in the overflight reference procedure (see 11.5.1.3).

11.4 Maximum noise level

For helicopters specified in 11.1.1, the maximum noise levels when determined in accordance with the noise evaluation method of Appendix 4 shall not exceed 82 decibels SEL for helicopters with maximum certificated take-off mass at which the noise certification is requested, of up to 788 kg and increasing linearly with the logarithm of the helicopter mass at a rate of 3 decibels per doubling of mass thereafter.

11.5 Noise certification reference procedure

11.5.1 General conditions

11.5.1.1 The reference procedure shall comply with the appropriate airworthiness requirements and shall be approved by the certificating authority.

11.5.1.2 Except as otherwise approved, the overflight reference procedure shall be as defined in 11.5.2.

11.5.1.3 When it is shown by the applicant that the design characteristics of the helicopter would prevent flight being conducted in accordance with 11.5.2 the reference procedure shall be permitted to depart from the standard reference procedure, with the approval of the certificating authority, but only to the extent demanded by those design characteristics which make compliance with the reference procedures impossible.

11.5.1.4 The reference procedure shall be established for the following reference atmospheric conditions:

a) sea level atmospheric pressure of 1 013.25 hPa;

b) ambient air temperature of 25°C;

c) relative humidity of 70 per cent; and

d) zero wind.
11.5.1.5 The maximum normal operating rpm shall be taken as the highest rotor speed corresponding to the airworthiness limit imposed by the manufacturer and approved by the certificating authority for overflight. Where a tolerance on the highest rotor speed is specified, the maximum normal operating rotor speed shall be taken as the highest rotor speed about which that tolerance is given. If rotor speed is automatically linked with flight condition, the maximum normal operating rotor speed corresponding with that flight condition shall be used during the noise certification procedure. If rotor speed can be changed by pilot action, the highest normal operating rotor speed specified in the flight manual limitation section for power-on conditions shall be used during the noise certification procedure.

11.5.2 Reference procedure

11.5.2.1 The reference procedure shall be established as follows:

a) the helicopter shall be stabilized in level flight overhead the flight path reference point at a height of 150 m (492 ft) ± 15 m (50 ft);

b) a speed of 0.9 V\textsubscript{H} or 0.9 V\textsubscript{NE} or 0.45 V\textsubscript{H} + 120 km/h (65 kt) or 0.45 V\textsubscript{NE} + 120 km/h (65 kt), whichever is the least, shall be maintained throughout the over-flight procedure. For noise certification purposes, V\textsubscript{H} is defined as the airspeed in level flight obtained using the torque corresponding to minimum engine installed, maximum continuous power available for sea level pressure (1 013.25 hPa), 25°C ambient conditions at the relevant maximum certificated mass. V\textsubscript{NE} is defined as the not-to-exceed airworthiness airspeed imposed by the manufacturer and approved by the certificating authority;

c) the overflight shall be made with the rotor speed stabilized at the maximum normal operating rpm certificated for level flight;

d) the helicopter shall be in the cruise configuration; and

e) the mass of the helicopter shall be the maximum take-off mass at which noise certification is requested.

11.5.2.2 The value of V\textsubscript{H} and/or V\textsubscript{NE} used for noise certification shall be quoted in the approved flight manual.

11.6 Test procedures

11.6.1 The test procedure shall be acceptable to the airworthiness and noise certificating authority of the State issuing the certificate.

11.6.2 The test procedure and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure designated as sound exposure level (SEL) in A-weighted decibels, as described in Appendix 4.

11.6.3 Test conditions and procedures shall be closely similar to reference conditions and procedures or the acoustic data shall be adjusted, by the methods outlined in Appendix 4, to the reference conditions and procedures specified in this chapter.

11.6.4 During the test, flights shall be made in equal numbers with tail and head wind components.

11.6.5 Adjustments for differences between test and reference flight procedures shall not exceed 2.0 dB(A).

11.6.6 During the test, the average rotor rpm shall not vary from the normal maximum operating rpm by more than ±1.0 per cent during the 10 dB-down time period.

11.6.7 The helicopter airspeed shall not vary from the reference airspeed appropriate to the flight demonstration as described in Appendix 4 by more than ±5 km/h (±3 kt) throughout the 10 dB-down time period.

11.6.8 The helicopter shall fly within ±10° from the vertical above the reference track through the reference noise measurement position.

11.6.9 Tests shall be conducted at a helicopter mass not less than 90 per cent of the relevant maximum certificated mass and may be conducted at a mass not exceeding 105 per cent of the relevant maximum certificated mass.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).
PART III.  NOISE MEASUREMENT FOR MONITORING PURPOSES

Note.— The following Recommendation has been developed to assist States which measure noise for monitoring purposes, until such time as agreement on a single method can be reached.

Recommendation.— Where the measurement of aircraft noise is made for monitoring purposes, the method of Appendix 5 should be used.

Note.— These purposes are described as including: monitoring compliance with and checking the effectiveness of such noise abatement requirements as may have been established for aircraft in flight or on the ground. An indication of the degree of correlation between values obtained by the method used for measuring noise for aircraft design purposes and the method(s) used for monitoring purposes would be necessary.
PART IV. ASSESSMENT OF AIRPORT NOISE

Note.— The following Recommendations have been developed for the purpose of promoting international communication between States that have adopted a variety of methods of assessing noise for land-use planning purposes.

1. Recommendation.— Where international comparison of noise assessment around airports is undertaken, the methodology described in Recommended Method for Computing Noise Contours around Airports (Circ. 205) should be used.

2. Recommendation.— Contracting States that have not yet adopted, or are considering changing a national noise assessment methodology, should use the methodology described in Recommended Method for Computing Noise Contours around Airports (Circ. 205).
PART V. CRITERIA FOR THE APPLICATION OF NOISE ABATEMENT OPERATING PROCEDURES

Note.— Provisions in Part II of this Annex are aimed at noise certification which characterizes the maximum noise emitted by the aircraft. However, noise abatement procedures approved by national authorities and included in operations manuals allow a reduction of noise during aircraft operations.

1. Aircraft operating procedures for noise abatement shall not be introduced unless the regulatory authority, based on appropriate studies and consultation, determines that a noise problem exists.

2. Recommendation.— Aircraft operating procedures for noise abatement should be developed in consultation with the operators which use the aerodrome concerned.

3. Recommendation.— The factors to be taken into consideration in the development of appropriate aircraft operating procedures for noise abatement should include the following:

   a) the nature and extent of the noise problem including:
      1) the location of noise sensitive areas; and
      2) critical hours.

   b) the types of aircraft affected, including aircraft mass, aerodrome elevation, temperature considerations;

   c) the types of procedures likely to be most effective;

   d) obstacle clearances (PANS-OPS (Doc 8168), Volumes I and II); and

   e) human performance in the application of the operating procedures.

Note 1.— See Annex 6, Part I, Chapter 4 for aeroplane noise abatement operating procedures.

Note 2.— Guidance material on human performance can be found in Circular 216 (Human Factors Digest No. 1 — Fundamental Human Factors Concepts) and Circular 238 (Human Factors Digest No. 6 — Ergonomics).
APPENDIX 1. EVALUATION METHOD FOR NOISE CERTIFICATION OF SUBSONIC JET AEROPLANES — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED BEFORE 6 OCTOBER 1977

1. INTRODUCTION

Note 1.— This noise evaluation method includes:

a) noise certification test and measurement conditions;

b) measurement of aeroplane noise received on the ground;

c) calculation of effective perceived noise level from measured noise data; and

d) reporting of data to the certificating authority and correcting measured data.

Note 2.— The instructions and procedures given in the method are clearly delineated to ensure uniformity during compliance tests, and to permit comparison between tests of various types of aeroplanes, conducted in various geographical locations. It applies only to aeroplanes within the applicability clauses of Part II, Chapter 2.

Note 3.— A complete list of symbols and units, the mathematical formulation of perceived noisiness, a procedure for determining atmospheric attenuation of sound, and detailed procedures for correcting noise levels from non-reference to reference conditions are included in Sections 6 to 9 of this appendix.

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

2.1.1 This section prescribes the conditions under which noise certification tests shall be conducted and the measurement procedures that shall be used.

Note.— Many applications for a noise certificate involve only minor changes to the aeroplane type design. The resultant changes in noise can often be established reliably without the necessity of resorting to a complete test as outlined in this appendix. For this reason certificating authorities are encouraged to permit the use of appropriate “equivalent procedures”. Also, there are equivalent procedures that may be used in full certification tests, in the interest of reducing costs and providing reliable results. Guidance material on the use of equivalent procedures in the noise certification of subsonic jet aeroplanes is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

2.2 General test conditions

2.2.1 Tests to show compliance with established noise certification levels shall consist of a series of take-offs and landings during which measurements shall be taken at the measuring points specified by the certificating authority. These points are typically:

a) the flyover noise measurement point*;

b) the approach noise measurement point; and

c) the lateral noise measurement point(s)**,

which for noise certification purposes are specified in Part II, Chapter 2.3. To ensure that the maximum subjective noise level along the lateral is obtained, a sufficient number of lateral stations shall be used. To establish whether any asymmetry exists in the noise field at least one measuring station shall be located along the alternative lateral. On each test take-off simultaneous measurements shall be made at the lateral measuring points on both sides of the runway and also at the take-off flyover measuring point.

* Sometimes referred to as the take-off noise measurement point.

** Sometimes referred to as the sideline measurement point(s).
2.2.2 Locations for measuring noise from an aeroplane in flight shall be surrounded by relatively flat terrain having no excessive sound absorption characteristics such as might be caused by thick, matted, or tall grass, shrubs, or wooded areas. No obstructions which significantly influence the sound field from the aeroplane shall exist within a conical space above the measurement position, the cone being defined by an axis normal to the ground and by a half-angle 75° from this axis. If the height of the ground at any measuring point differs from that of the nearest point on the runway by more than 6 m (20 ft), corrections shall be made.

Note.— Those people carrying out the measurements could themselves constitute such obstructions.

2.2.3 The tests shall be carried out under the following atmospheric conditions:

a) no precipitation;

b) relative humidity not higher than 90 per cent or lower than 30 per cent;

c) ambient temperature not above 30°C and not below 2°C at 10 m (33 ft) above ground;

d) average wind, not above 19 km/h (10 kt) and average cross-wind component not above 9 km/h (5 kt) at 10 m (33 ft) above ground. A 30-second averaging period spanning the 10 dB-down time interval is recommended; and

e) no temperature inversion or anomalous wind conditions that would significantly affect the noise level of the aeroplane when the noise is recorded at the measuring points specified by the certificating authority.

2.3 Aeroplane testing procedures

2.3.1 The test procedures shall be acceptable to the airworthiness and noise certificating authorities of the State issuing the certificate.

2.3.2 The aeroplane testing procedures and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure designated as effective perceived noise level, EPNL, in units of EPNdB, as described in Section 4 of this appendix.

2.3.3 The aeroplane height and lateral position relative to the extended centre line of the runway shall be determined by a method independent of normal flight instrumentation such as radar tracking, theodolite triangulation, or photographic scaling techniques to be approved by the certificating authority.

2.3.4 The aeroplane position along the flight path shall be related to the noise recorded at the noise measurement locations by means of synchronizing signals. The position of the aeroplane shall be recorded relative to the runway from a point at least 7.4 km (4 NM) from threshold during the approach and at least 11 km (6 NM) from the start of roll during take-off.

2.3.5 If the take-off test is conducted at a mass different from the maximum take-off mass at which noise certification is requested the necessary EPNL correction shall not exceed 2 EPNdB. If the approach test is conducted at a mass different from the maximum landing mass at which noise certification is requested the EPNL correction shall not exceed 1 EPNdB. Data approved by the certificating authority shall be used to determine the variation of EPNL with mass for both take-off and approach test conditions.

2.4 Measurements

2.4.1 Position and performance data required to make the corrections referred to in Section 5 of this appendix shall be automatically recorded at an approved sampling rate. The position of the aeroplane shall be recorded relative to the runway from a point at least 7.4 km (4 NM) from threshold to touchdown during the approach and at least 11 km (6 NM) from the start of roll during the take-off. Measuring equipment shall be approved by the certificating authority.

2.4.2 Position and performance data shall be corrected by the methods outlined in Section 5 of this appendix to the meteorological reference conditions specified in 5.3.1 a).

2.4.3 Acoustic data shall be corrected by the methods outlined in Section 5 of this appendix to the meteorological reference conditions specified in 5.3.1 a) 1), 2) and 3). Acoustic data corrections shall also be made for variations of the test minimum distance from the reference minimum distance between the aeroplane’s approach path and the approach measuring point, a take-off path vertically above the flyover measuring point and for differences of more than 6 m (20 ft) in elevation of measuring locations relative to the elevation of the nearest point of the runway.

2.4.4 The aerodrome tower or another facility shall be approved for use as the central location at which measurements of atmospheric parameters are representative of those conditions existing over the geographical area in which aeroplane noise measurements are made. However, the surface wind velocity and ambient air temperature shall be measured near the microphone position at the approach, sideline, and take-off measurement locations, and the tests shall not be acceptable unless the conditions conform to Section 2 of this appendix.
3. MEASUREMENT OF AEROPLANE NOISE RECEIVED ON THE GROUND

3.1 General

3.1.1 The measurements shall provide the data for determining one-third octave band noise produced by aeroplanes during flight, at any required observation stations, as a function of time.

3.1.2 Methods for determination of the distance from the observation stations to the aeroplane shall include theodolite triangulation techniques, scaling aeroplane dimensions on photographs made as the aeroplane flies directly over the measurement points, radar altimeters, and radar tracking systems. The method used shall be approved by the certificating authority.

3.1.3 Sound pressure level data for noise evaluation purposes shall be obtained with approved acoustical equipment and measurement practices that conform to the specifications given hereunder (in 3.2 to 3.4).

3.2 Measurement system

3.2.1 The acoustical measurement system shall consist of approved equipment equivalent to the following:

a) a microphone system with frequency response compatible with measurement and analysis system accuracy as stated in 3.3;

b) tripods or similar microphone mountings that minimize interference with the sound being measured;

c) recording and reproducing equipment characteristics, frequency response, and dynamic range compatible with the response and accuracy requirements of 3.3;

d) acoustic calibrators using sine wave or broadband noise of known sound pressure level. If broadband noise is used, the signal shall be described in terms of its average and maximum root-mean-square (rms) value for non-overload signal level;

e) analysis equipment with the response and accuracy requirements of 3.4.

3.3 Sensing, recording and reproducing equipment

3.3.1 The sound produced by the aeroplane shall be recorded in such a way that the complete information, time history included, is retained. A magnetic tape recorder is acceptable.

3.3.2 The characteristics of the system shall comply with the recommendations given in International Electrotechnical Commission (IEC) Publication No. 179* with regard to the sections concerning microphone and amplifier characteristics.

Note.— The text and specifications of IEC Publication No. 179* entitled “Precision Sound Level Meters” are incorporated by reference into this Appendix and are made a part hereof.**

3.3.3 The response of the complete system to a sensibly plane progressive sinusoidal wave of constant amplitude shall lie within the tolerance limits specified in IEC Publication No. 179*, over the frequency range 45 to 11 200 Hz.

3.3.4 If limitations of the dynamic range of the equipment make it necessary, high frequency pre-emphasis shall be added to the recording channel with the converse de-emphasis on playback. The pre-emphasis shall be so applied that the instantaneous recorded sound pressure level between 800 and 11 200 Hz of the maximum measured noise signal does not vary more than 20 dB between the levels of the maximum and minimum one-third octave bands.

3.3.5 The equipment shall be acoustically calibrated using facilities for acoustic free-field calibration and electronically calibrated as stated in 3.4.

3.3.6 A wind screen shall be employed with the microphone during all measurements of aeroplane noise when the wind speed is in excess of 11 km/h (6 kt). Corrections for any insertion loss produced by the wind screen, as a function of frequency, shall be applied to the measured data and the corrections applied shall be reported.

3.4 Analysis equipment

3.4.1 A frequency analysis of the acoustical signal shall be performed in a manner equivalent to using one-third octave filters complying with the recommendations given in International Electrotechnical Commission (IEC) Publication No. 225*.

Note.— The text and specifications of IEC Publication No. 225* entitled “Octave, Half-Octave and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations” are incorporated by reference into this appendix and are made a part hereof.***

* As amended.
** This publication was first issued in 1965 by the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembe, Geneva, Switzerland.
*** This publication was first issued in 1966 by the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembe, Geneva, Switzerland.
3.4.2 A set of 24 consecutive one-third octave filters or its equivalent shall be used. The first filter of the set shall be centred at a geometric mean frequency of 50 Hz and the last shall be centred at a geometric mean frequency of 10 kHz.

3.4.3 The analyser indicating device shall be analog, digital, or a combination of both. The preferred sequence of signal processing shall be:

a) squaring the one-third octave filter outputs;

b) averaging or integrating; and

c) linear to logarithmic conversion.

The indicating device shall have a minimum crest factor capacity of 3 and shall measure, within a tolerance of ±1.0 dB, the true root-mean-square (rms) level of the signal in each of the 24 one-third octave bands. If other than a true rms device is utilized, it shall be calibrated for nonsinusoidal signals and time varying levels. The calibration shall provide means for converting the output levels to true rms values.

3.4.4 The dynamic response of the analyser to input signals of both full-scale and 20 dB less than full-scale amplitude, shall conform to the following two requirements:

a) the maximum output value shall read 4 dB ±1 dB less than the value obtained for a steady state signal of the same frequency and amplitude when a sinusoidal pulse of 0.5 s duration at the centre frequency of each one-third octave band is applied to the input;

b) the maximum output value shall exceed the final steady state value by 0.5 ±0.5 dB when a steady state sinusoidal signal at the geometrical mean frequency of each one-third octave band is suddenly applied to the analyser input and held constant.

3.4.5 A single value of the rms level shall be provided every 0.5 ±0.01 s for each of the 24 one-third octave bands. The levels from all of the 24 one-third octave bands shall be obtained within a 50 ms period. No more than 5 ms of data from any 0.5 s period shall be excluded from the measurement.

3.4.6 The amplitude resolution of the analyser shall be 0.50 dB or less.

3.4.7 Each output level from the analyser shall be accurate within ±1.0 dB with respect to the input signal, after all systematic errors have been eliminated. The total systematic errors for each of the output levels shall not exceed ±3 dB. For contiguous filter systems, the systematic correction between adjacent one-third octave channels shall not exceed 4 dB.

3.4.8 The dynamic range capability of the analyser for display of a single aeroplane noise event shall be at least 45 dB in terms of the difference between full-scale output level and the maximum noise level of the analyser equipment.

3.4.9 The complete electronic system shall be subjected to a frequency and amplitude electrical calibration by the use of sinusoidal or broadband signals at frequencies covering the range of 45 to 11200 Hz, and of known amplitudes covering the range of signal levels furnished by the microphone. If broadband signals are used, they shall be described in terms of their average and maximum rms values for a non-overload signal level.

3.5 Noise measurement procedures

3.5.1 The microphones shall be oriented in a known direction so that the maximum sound received arrives as nearly as reasonable in the direction for which the microphones are calibrated. The microphones shall be placed so that their sensing elements are approximately 1.2 m (4 ft) above ground.

3.5.2 Immediately prior to and after each test, a recorded acoustic calibration of the system shall be made in the field with an acoustic calibrator for the two purposes of checking system sensitivity and providing an acoustic reference level for the analysis of the sound level data.

3.5.3 For the purpose of minimizing equipment or operator error, field calibrations shall be supplemented whenever practicable with the use of an insert voltage device to place a known signal at the input of the microphone, just prior to and after recording aeroplane noise data.

3.5.4 The ambient noise, including both acoustical background and electrical noise of the measurement systems, shall be recorded and determined in the test area with the system gain set at levels which will be used for aeroplane noise measurements. If aeroplane sound pressure levels do not exceed the background sound pressure levels by at least 10 dB in any significant one-third octave band, approved corrections for the contribution of background sound pressure level to the observed sound pressure level shall be applied.

4. CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL FROM MEASURED NOISE DATA

4.1 General

4.1.1 The basic element in the noise certification criteria shall be the noise evaluation measure designated effective perceived noise level, EPNL, in units of EPNdB, which is a single number evaluator of the subjective effects of aeroplane noise on human beings. Simply stated, EPNL
## Table 1-1: Noys as a function of sound pressure level (29<SPL<89)

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Table 1-1 (cont.). Noys as a function of sound pressure level (90<SPL<150)
shall consist of instantaneous perceived noise level, PNL, corrected for spectral irregularities (the correction, called “tone correction factor”, is made for the maximum tone only at each increment of time) and for duration.

4.1.2 Three basic physical properties of sound pressure shall be measured: level, frequency distribution, and time variation. More specifically, the instantaneous sound pressure level in each of 24 one-third octave bands of the noise shall be required for each one-half second increment of time during the aeroplane flyover.

4.1.3 The calculation procedure which utilizes physical measurements of noise to derive the EPNL evaluation measure of subjective response shall consist of the following five steps:

a) the 24 one-third octave bands of sound pressure level are converted to perceived noisiness by means of a noy table*. The noy values are combined and then converted to instantaneous perceived noise levels, PNL(k);

b) a tone correction factor, C(k), is calculated for each spectrum to account for the subjective response to the presence of spectral irregularities;

c) the tone correction factor is added to the perceived noise level to obtain tone corrected perceived noise levels, PNLT(k), at each one-half second increment of time,

\[ \text{PNLT}(k) = \text{PNL}(k) + C(k) \]

The instantaneous values of tone corrected perceived noise level are derived and the maximum value, PNLTM, is determined;

d) a duration correction factor, D, is computed by integration under the curve of tone corrected perceived noise level versus time;

e) effective perceived noise level, EPNL, is determined by the algebraic sum of the maximum tone corrected perceived noise level and the duration correction factor,

\[ \text{EPNL} = \text{PNLTM} + D. \]

* See Table 1-1.

Figure 1-1. Perceived noise level as a function of total perceived noisiness
4.2 Perceived noise level

4.2.1 Instantaneous perceived noise levels, PNL\((k)\), shall be calculated from instantaneous one-third octave band sound pressure levels, SPL\((i,k)\), as follows:

**Step 1.** Convert each one-third octave band SPL\((i,k)\), from 50 to 10 000 Hz, to perceived noisiness, \(n(i,k)\), by reference to Table 1-1, or to the mathematical formulation of the noy table given in Section 7.

**Step 2.** Combine the perceived noisiness values, \(n(i,k)\), found in Step 1 by the following formula:

\[
N(k) = n(k) + 0.15 \sum_{i=1}^{24} n(i,k) \\
= 0.85 n(k) + 0.15 \sum_{i=1}^{24} n(i,k)
\]

where \(n(k)\) is the largest of the 24 values of \(n(i,k)\) and \(N(k)\) is the total perceived noisiness.

**Step 3.** Convert the total perceived noisiness, \(N(k)\), into perceived noise level, PNL\((k)\), by the following formula:

\[
PNL(k) = 40.0 + 10 \frac{10}{\log 2} \log N(k)
\]

which is plotted in Figure 1-1. PNL\((k)\) may also be obtained by choosing \(N(k)\) in the 1 000 Hz column of Table 1-1 and then reading the corresponding value of SPL\((i,k)\) which, at 1 000 Hz, equals PNL\((k)\).

4.3 Correction for spectral irregularities

4.3.1 Noise having pronounced spectral irregularities (for example, the maximum discrete frequency components or tones) shall be adjusted by the correction factor \(C(k)\) calculated as follows:

**Step 1.** Starting with the corrected sound pressure level in the 80 Hz one-third octave band (band number 3), calculate the changes in sound pressure level (or “slopes”) in the remainder of the one-third octave bands as follows:

\[
s(3,k) = \text{no value} \\
\]

\[
s(4,k) = \text{SPL}(4,k) - \text{SPL}(3,k) \\
\]

\[
s(i,k) = \text{SPL}(i,k) - \text{SPL}[(i-1),k] \\
\]

\[
s(24,k) = \text{SPL}(24,k) - \text{SPL}(23,k) \\
\]

**Step 2.** Encircle the value of the slope, \(s(i,k)\), where the absolute value of the change in slope is greater than five; that is, where

\[
|\Delta s\ (i,k)| = |s\ (i,k) - s\ [(i-1),k]| > 5
\]

**Step 3.**

a) If the encircled value of the slope \(s(i,k)\) is positive and algebraically greater than the slope \(s[(i-1),k]\) encircle SPL\((i,k)\).

b) If the encircled value of the slope \(s(i,k)\) is zero or negative and the slope \(s[(i-1),k]\) is positive, encircle SPL\([(i-1),k]\).

c) For all other cases, no sound pressure level value is to be encircled.

**Step 4.** Omit all SPL\((i,k)\) encircled in Step 3 and compute new adjusted sound pressure levels SPL\'\((i,k)\) as follows:

a) For non-encircled sound pressure levels, let the new sound pressure levels equal the original sound pressure levels, SPL\'\((i,k)\) \(\equiv\) SPL\((i,k)\).

**Table 1-2. Tone correction factors**

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Level difference (F), dB</th>
<th>Tone correction (C), dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>(50 &lt; f &lt; 500)</td>
<td>(3^* \leq F &lt; 20) (20 \leq F)</td>
<td>(F/6) (3/6)</td>
</tr>
<tr>
<td>(500 &lt; f &lt; 5000)</td>
<td>(3^* \leq F &lt; 20) (20 \leq F)</td>
<td>(F/3) (6/3)</td>
</tr>
<tr>
<td>(5000 &lt; f &lt; 10000)</td>
<td>(3^* \leq F &lt; 20) (20 \leq F)</td>
<td>(F/6) (3/6)</td>
</tr>
</tbody>
</table>

* See Step 8, 4.3.1.
Step 5. Recompute new slopes \( s'(i,k) \), including one for an imaginary 25th band, as follows:

\[
s'(3,k) ≡ s'(4,k) \]
\[
s'(4,k) = \text{SPL}'(4,k) − \text{SPL}'(3,k)
\]
\[
... \]
\[
s'(24,k) = \text{SPL}'(24,k) − \text{SPL}'(23,k)
\]
\[
s'(25,k) ≡ s'(24,k)
\]

Step 6. For \( i \) from 3 to 23, compute the arithmetic average of the three adjacent slopes as follows:

\[
s(i,k) = \left(\frac{1}{3}\right) \left\{ s'(i,k) + s'[(i+1),k] + s'[(i+2),k] \right\}
\]

Step 7. Compute final one-third octave-band background sound pressure levels, \( \text{SPL}''(i,k) \), by beginning with band number 3 and proceeding to band number 24 as follows:

\[
\text{SPL}''(3,k) = \text{SPL}(3,k)
\]
\[
\text{SPL}''(4,k) = \text{SPL}''(3,k) + s(3,k)
\]
\[
... \]
\[
\text{SPL}''(i,k) = \text{SPL}''[(i–1),k] + s(i–1),k)
\]
\[
... \]
\[
\text{SPL}''(24,k) = \text{SPL}''(23,k) + s(23,k)
\]

Step 8. Calculate the differences, \( F(i,k) \), between the original sound pressure level and the final background sound pressure level as follows:

\[
F(i,k) = \text{SPL}(i,k) − \text{SPL}''(i,k)
\]

and note only values equal to or greater than three.

Step 9. For each of the relevant one-third octave bands (3 to 24), determine tone correction factors from the sound pressure level differences \( F(i,k) \) and Table 1-2.

Step 10. Designate the largest of the tone correction factors, determined in Step 9, as \( C(k) \). An example of the tone correction procedure is given in Table 1-3.

Tone corrected perceived noise levels \( \text{PNLT}(k) \) shall be determined by adding the \( C(k) \) values to corresponding \( \text{PNL}(k) \) values, that is,

\[
\text{PNLT}(k) = \text{PNL}(k) + C(k)
\]

For any \( i \)-th one-third octave band, at any \( k \)-th increment of time, for which the tone correction factor is suspected to result from something other than (or in addition to) an actual tone (or any spectral irregularity other than aeroplane noise), an additional analysis shall be made using a filter with a bandwidth narrower than one-third of an octave. If the narrow band analysis corroborates these suspicions, then a revised value for the background sound pressure level, \( \text{SPL}''(i,k) \), shall be determined from the narrow band analysis and used to compute a revised tone correction factor for that particular one-third octave band.

### 4.4 Maximum tone corrected perceived noise level

4.4.1 The maximum tone corrected perceived noise level, \( \text{PNLT}(k) \), shall be the maximum calculated value of the tone corrected perceived noise level \( \text{PNLT}(k) \). It shall be calculated in accordance with the procedure of 4.3. To obtain a satisfactory noise time history, measurements shall be made at half-second time intervals.

Note.— Figure 1-2 is an example of a flyover noise time history where the maximum value is clearly indicated.

4.4.2 If there are no pronounced irregularities in the spectrum, even when examined by a narrow-band analysis, then the procedure of 4.3 shall be disregarded since \( \text{PNLT}(k) \) would be identically equal to \( \text{PNL}(k) \). For this case, \( \text{PNLT}(k) \) shall be the maximum value of \( \text{PNL}(k) \) and would equal \( \text{PNL}(k) \).

### 4.5 Duration correction

4.5.1 The duration correction factor \( D \) determined by the integration technique shall be defined by the expression:

\[
D = 10 \log \left[ \frac{1}{T} \int_{t(1)}^{t(2)} \text{antilog} \left( \frac{\text{PNLT}}{10} \right) dt \right] - \text{PNLT}
\]

where \( T \) is a normalizing time constant, \( \text{PNLT} \) is the maximum value of \( \text{PNLT} \).
Table 1-3. Example of tone correction calculation for a turbofan engine

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<td>S dB</td>
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Step 1: \(3(i) - 3(i-1)\)
Step 2: \(4(i) - 4(i-1)\)
Step 3: see instructions
Step 4: see instructions
Step 5: \(8(i) - 8(i-1)\)
Step 6: \([7(i) + 7(i+1) + 7(i+2)] + 3\)
Step 7: \(9(i-1) + 8(i-1)\)
Step 8: \(8(i) - 9(i)\)
Step 9: see Table 1-2
4.5.1.1 If PNLT is greater than 100 TPNdB, \( t(1) \) shall be the first point of time after which PNLT becomes greater than PNLT – 10 and \( t(2) \) shall be the point of time after which PNLT remains constantly less than PNLT – 10.

4.5.1.2 If PNLT is less than 100 TPNdB, \( t(1) \) shall be the first point of time after which PNLT becomes greater than 90 TPNdB and \( t(2) \) shall be the point of time after which PNLT remains constantly less than 90 TPNdB.

4.5.1.3 If PNLT is less than 90 TPNdB, the duration correction shall be taken as equal to 0.

4.5.2 Since PNLT is calculated from measured values of SPL, there will, in general, be no obvious equation for PNLT as a function of time. Consequently, the equation shall be rewritten with a summation sign instead of an integral sign as follows:

\[
D = 10 \log \left( \frac{1}{T} \sum_{k=0}^{d/\Delta t} \Delta t \cdot \text{antilog} \left( \frac{\text{PNLT}(k)}{10} \right) \right) - \text{PNLT}
\]

where \( \Delta t \) is the length of the equal increments of time for which PNLT\((k)\) is calculated and \( d \) is the time interval to the nearest 1.0 s during which PNLT\((k)\) remains greater or equal either to PNLT – 10 or to 90 according to the cases specified in 4.5.1.1 to 4.5.1.3 above.

4.5.3 To obtain a satisfactory history of the perceived noise level,

a) half-second time intervals for \( \Delta t \), or

b) a shorter time interval with approved limits and constants shall be used.

4.5.4 The following values for \( T \) and \( \Delta t \) shall be used in calculating \( D \) in the procedure given in 4.5.2:

\[
T = 10 \text{ s, and} \\
\Delta t = 0.5 \text{ s}
\]

Using the above values, the equation for \( D \) becomes

\[
D = 10 \log \left( \sum_{k=0}^{2d} \text{antilog} \left( \frac{\text{PNLT}(k)}{10} \right) \right) - \text{PNLT} - 13
\]

where the integer \( d \) is the duration time defined by the points corresponding to the values PNLT – 10 or 90 as the case may be.

4.5.5 If in the procedures given in 4.5.2, the limits of PNLT – 10 or 90 fall between the calculated PNLT\((k)\) values (the usual case), the PNLT\((k)\) values defining the

---

**Figure 1-2.** Example of perceived noise level corrected for tones as a function of aircraft flyover time
limits of the duration interval shall be chosen from the PNL(\(k\)) values closest to PNLTM – 10 or 90 as the case may be.

### 4.6 Effective perceived noise level

4.6.1 The total subjective effect of an aeroplane flyover, designated "effective perceived noise level", EPNL, shall be equal to the algebraic sum of the maximum value of the tone corrected perceived noise level, PNLTM, and the duration correction, \(D\). That is,

\[
EPNL = PNLTM + D
\]

where PNLTM and \(D\) are calculated in accordance with the procedures given in 4.2, 4.3, 4.4 and 4.5. If the duration correction \(D\) is negative and greater than PNLTM – 90 in absolute values, \(D\) shall be taken as equal to 90 – PNLTM.

### 5. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY AND CORRECTING MEASURED DATA

#### 5.1 General

5.1.1 Data representing physical measurements or corrections to measured data shall be recorded in permanent form and appended to the record except that corrections to measurements for normal equipment response deviations need not be reported. All other corrections shall be approved. Attempts shall be made to keep to a minimum the individual errors inherent in each of the operations employed in obtaining the final data.

#### 5.2 Data reporting

5.2.1 Measured and corrected sound pressure levels shall be presented in one-third octave band levels obtained with equipment conforming to the Standards described in Section 3 of this appendix.

5.2.2 The type of equipment used for measurement and analysis of all acoustic aeroplane performance and meteorological data shall be reported.

5.2.3 The following atmospheric environmental data, measured immediately before, after, or during each test at the observation points prescribed in Section 2 of this appendix shall be reported:

- a) air temperature and relative humidity;
- b) maximum, minimum, and average wind velocities;
- c) atmospheric pressure.

5.2.4 Comments on local topography, ground cover, and events that might interfere with sound recordings shall be reported.

5.2.5 The following aeroplane information shall be reported:

- a) type, model, serial numbers (if any) of aeroplane and engines;
- b) gross dimensions of aeroplane and location of engines;
- c) aeroplane gross mass for each test run;
- d) aeroplane configuration such as flap and landing gear position;
- e) indicated airspeed in kilometres per hour (knots);
- f) engine performance in terms of net thrust, engine pressure ratios, jet exhaust temperatures and fan or compressor shaft rotational speeds as determined from aeroplane instruments and manufacturer’s data;
- g) aeroplane height above ground determined by a method independent of cockpit instrumentation such as radar tracking, theodolite triangulation, or photographic scaling techniques to be approved by the certification authorities.

5.2.6 Aeroplane speed and position and engine performance parameters shall be recorded at an approved sampling rate sufficient to correct to the noise certification reference conditions prescribed in this section and shall be synchronized with the noise measurement.

5.2.6.1 Lateral position relative to the extended centre line of the runway, configuration and gross mass shall be reported.

#### 5.3 Noise certification reference conditions

5.3.1 Aeroplane position and performance data and the noise measurements shall be corrected to the following noise certification reference conditions:

- a) meteorological conditions:

  1) sea level atmospheric pressure of 1 013.25 hPa;
  2) ambient air temperature of 25°C, i.e. ISA + 10°C except that, at the discretion of the certificating authority, an alternative reference ambient air temperature of 15°C, i.e. ISA may be used;
  3) relative humidity of 70 per cent; and
  4) zero wind;
b) aeroplane conditions:

1) maximum take-off mass and landing mass at which noise certification is requested;

2) approach angle of 3°; and

3) aeroplane height of 120 m (395 ft) above the approach noise measuring station.

5.4 Data correction

5.4.1 The noise data shall be corrected to the noise certification reference conditions as stated in 5.3. The measured atmospheric conditions shall be those obtained in accordance with Section 2 of this appendix. Atmospheric attenuation of sound requirements are given in Section 8 of this appendix. If a reference ambient air temperature of 15°C is used (see 5.3.1 a) 2)) a further correction of +1 EPNdB shall be added to the noise levels obtained at the flyover measurement point.

5.4.2 The measured flight path shall be corrected by an amount equal to the difference between the applicant’s predicted flight paths for the test conditions and for the noise certification reference conditions.

Note.— Necessary corrections relating to aeroplane flight path or performance may be derived from approved data other than certification test data.

5.4.2.1 The flight path correction procedure for approach noise shall be made with reference to a fixed aeroplane reference height and the reference approach angle. The effective perceived noise level correction shall be less than 2 EPNdB to allow for:

a) the aeroplane not passing vertically above the measuring point;

b) the difference between the reference height and the height of the aeroplane’s ILS antenna from the approach measuring point; and

c) the difference between the reference and the test approach angles.

5.4.3 Test results on specific measurement shall not be accepted if the difference in EPNL computed from measured data and that corrected to reference conditions exceeds 15 EPNdB.

5.4.4 If aeroplane sound pressure levels do not exceed the ambient sound pressure levels by at least 10 dB in any one-third octave band, approved corrections for the contribution of ambient sound pressure level to the observed sound pressure level shall be applied.

5.5 Validity of results

5.5.1 Three average EPNL values and their 90 per cent confidence limits shall be produced from the test results, each such value being the arithmetical average of the corrected acoustical measurements for all valid test runs at the appropriate measurement point (take-off, approach or sideline). If more than one acoustic measurement system is used at any single measurement location (such as for the symmetrical sideline measuring points), the resulting data for each test run shall be averaged as a single measurement.

5.5.2 The minimum sample size acceptable for each of the three certification measuring points shall be six. The samples shall be large enough to establish statistically for each of the three average noise certification levels a 90 per cent confidence limit not exceeding ±1.5 EPNdB. No test result shall be omitted from the average process unless otherwise specified by the certification authorities.

5.5.3 The average EPNL values and their 90 per cent confidence limits obtained by the foregoing process shall be those by which the noise performance of the aeroplane is assessed against the noise certification criteria, and shall be reported.
6. NOMENCLATURE

6.1 Symbols and units

Note.— The meanings of the various symbols in this appendix are as follows. It is recognized that differences may exist in the units and meanings of similar symbols in Appendix 2.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>antilog</td>
<td>—</td>
<td>Antilogarithm to the base 10.</td>
</tr>
<tr>
<td>C(k)</td>
<td>dB</td>
<td>Tone correction factor. The factor to be added to PNL(k) to account for the presence of spectral irregularities such as tones at the k-th increment of time.</td>
</tr>
<tr>
<td>d</td>
<td>s</td>
<td>Duration time. The length of the significant noise time history being the time interval between the limits of t(1) and t(2) to the nearest second.</td>
</tr>
<tr>
<td>D</td>
<td>dB</td>
<td>Duration correction. The factor to be added to PNLTM to account for the duration of the noise.</td>
</tr>
<tr>
<td>EPNL</td>
<td>EPNdB</td>
<td>Effective perceived noise level. The value of PNL adjusted for both the spectral irregularities and the duration of the noise. (The unit EPNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>f(i)</td>
<td>Hz</td>
<td>Frequency. The geometrical mean frequency for the i-th one-third octave band.</td>
</tr>
<tr>
<td>F(i,k)</td>
<td>dB</td>
<td>Delta-dB. The difference between the original sound pressure level and the final background sound pressure level in the i-th one-third octave band at the k-th interval of time.</td>
</tr>
<tr>
<td>h</td>
<td>dB</td>
<td>dB-down. The level to be subtracted from PNLTM that defines the duration of the noise.</td>
</tr>
<tr>
<td>H</td>
<td>%</td>
<td>Relative humidity. The ambient atmospheric relative humidity.</td>
</tr>
<tr>
<td>i</td>
<td>—</td>
<td>Frequency band index. The numerical indicator that denotes any one of the 24 one-third octave bands with geometrical mean frequencies from 50 to 10 000 Hz.</td>
</tr>
<tr>
<td>k</td>
<td>—</td>
<td>Time increment index. The numerical indicator that denotes the number of equal time increments that have elapsed from a reference zero.</td>
</tr>
<tr>
<td>log</td>
<td>—</td>
<td>Logarithm to the base 10.</td>
</tr>
<tr>
<td>log n(a)</td>
<td>—</td>
<td>Noy discontinuity co-ordinate. The log n value of the intersection point of the straight lines representing the variation of SPL with log n.</td>
</tr>
<tr>
<td>M(b), M(c), etc.</td>
<td>—</td>
<td>Noy inverse slope. The reciprocals of the slopes of straight lines representing the variation of SPL with log n.</td>
</tr>
<tr>
<td>n</td>
<td>noy</td>
<td>Perceived noisiness. The perceived noisiness at any instant of time that occurs in a specified frequency range.</td>
</tr>
<tr>
<td>n(i,k)</td>
<td>noy</td>
<td>Perceived noisiness. The perceived noisiness at the k-th instant of time that occurs in the i-th one-third octave band.</td>
</tr>
<tr>
<td>n(k)</td>
<td>noy</td>
<td>Maximum perceived noisiness. The maximum value of all of the 24 values of n(i) that occurs at the k-th instant of time.</td>
</tr>
<tr>
<td>N(k)</td>
<td>noy</td>
<td>Total perceived noisiness. The total perceived noisiness at the k-th instant of time calculated from the 24-instantaneous values of n(i,k).</td>
</tr>
<tr>
<td>p(b), p(c), etc.</td>
<td>—</td>
<td>Noy slope. The slopes of straight lines representing the variation of SPL with log n.</td>
</tr>
<tr>
<td>PNL</td>
<td>PNdB</td>
<td>Perceived noise level. The perceived noise level at any instant of time. (The unit PNdB is used instead of the unit dB.)</td>
</tr>
</tbody>
</table>
### Appendix 1

#### Annex 16 — Environmental Protection

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNL(k)</td>
<td>PNdB</td>
<td>Perceived noise level. The perceived noise level calculated from the 24 values of SPL(i,k) at the k-th increment of time. (The unit PNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNLm</td>
<td>PNdB</td>
<td>Maximum perceived noise level. The maximum value of PNL(k). (The unit PNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNLt</td>
<td>TPNdB</td>
<td>Tone corrected perceived noise level. The value of PNL adjusted for the spectral irregularities that occur at any instant of time. (The unit TPNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNLtm</td>
<td>TPNdB</td>
<td>Maximum tone corrected perceived noise level. The maximum value of PNLt(k). (The unit TPNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>s(i,k)</td>
<td>dB</td>
<td>Slope of sound pressure level. The change in level between adjacent one-third octave band sound pressure levels at the i-th band for the k-th instant of time.</td>
</tr>
<tr>
<td>Δs(i,k)</td>
<td>dB</td>
<td>Change in slope of sound pressure level.</td>
</tr>
<tr>
<td>s'34(i,k)</td>
<td>dB</td>
<td>Adjusted slope of sound pressure level. The change in level between adjacent adjusted one-third octave band sound pressure levels at the i-th band for the k-th instant of time.</td>
</tr>
<tr>
<td>s(i,k)</td>
<td>dB</td>
<td>Average slope of sound pressure level.</td>
</tr>
<tr>
<td>SPL</td>
<td>dB re 20 µPa</td>
<td>Sound pressure level. The sound pressure level at any instant of time that occurs in a specified frequency range.</td>
</tr>
<tr>
<td>SPL(a)</td>
<td>dB re 20 µPa</td>
<td>Noy discontinuity co-ordinate. The SPL value of the intersection point of the straight lines representing the variation of SPL with log n.</td>
</tr>
<tr>
<td>SPL(b)</td>
<td>dB re 20 µPa</td>
<td>Noy intercept. The intercepts on the SPL-axis of the straight lines representing the variation of SPL with log n.</td>
</tr>
<tr>
<td>SPL(i), SPL(c)</td>
<td>dB re 20 µPa</td>
<td>Sound pressure level. The sound pressure level at the k-th instant of time that occurs in the i-th one-third octave band.</td>
</tr>
<tr>
<td>SPL'(i,k)</td>
<td>dB re 20 µPa</td>
<td>Adjusted sound pressure level. The first approximation to background sound pressure level in the i-th one-third octave band for the k-th instant of time.</td>
</tr>
<tr>
<td>SPL(i)</td>
<td>dB re 20 µPa</td>
<td>Maximum sound pressure level. The sound pressure level that occurs in the i-th one-third octave band of the spectrum for PNLTM.</td>
</tr>
<tr>
<td>SPL(i)c</td>
<td>dB re 20 µPa</td>
<td>Corrected maximum sound pressure level. The sound pressure level that occurs in the i-th one-third octave band of the spectrum for PNLTM corrected for atmospheric sound absorption.</td>
</tr>
<tr>
<td>SPL''(i,k)</td>
<td>dB re 20 µPa</td>
<td>Final background sound pressure level. The second and final approximation to background sound pressure level in the i-th one-third octave band for the k-th instant of time.</td>
</tr>
<tr>
<td>t</td>
<td>s</td>
<td>Elapsed time. The length of time measured from a reference zero.</td>
</tr>
<tr>
<td>t1, t2</td>
<td></td>
<td>Time limit. The beginning and end of the significant noise time history defined by h.</td>
</tr>
<tr>
<td>Δt</td>
<td>s</td>
<td>Time increment. The equal increments of time for which PNL(k) and PNLt(k) are calculated.</td>
</tr>
<tr>
<td>T</td>
<td>s</td>
<td>Normalizing time constant. The length of time used as a reference in the integration method for computing duration corrections, where T = 10 s.</td>
</tr>
<tr>
<td>t°C</td>
<td>°C</td>
<td>Temperature. The ambient atmospheric temperature.</td>
</tr>
<tr>
<td>α(i)</td>
<td>dB/100 m</td>
<td>Test atmospheric absorption. The atmospheric attenuation of sound that occurs in the i-th one-third octave band for the measured atmospheric temperature and relative humidity.</td>
</tr>
</tbody>
</table>
Symbol | Unit | Meaning
--- | --- | ---
\( \alpha(i)_0 \) | dB/100 m | Reference atmospheric absorption. The atmospheric attenuation of sound that occurs in the \( i \)-th one-third octave band for a reference atmospheric temperature and relative humidity.
\( \beta \) | degrees | First constant* climb angle.
\( \gamma \) | degrees | Second constant** climb angle.
\( \delta \) | degrees | Thrust cutback angles. The angles defining the points on the take-off flight path at which thrust reduction is started and ended respectively.
\( \eta \) | degrees | Approach angle.
\( \eta_r \) | degrees | Reference approach angle.
\( \theta \) | degrees | Take-off noise angle. The angle between the flight path and noise path for take-off operations. It is identical for both measured and corrected flight paths.
\( \lambda \) | degrees | Approach noise angle. The angle between the flight path and the noise path for approach operations. It is identical for both measured and corrected flight paths.
\( \Delta_1 \) | EPNdB | PNLT correction. The correction to be added to the EPNL calculated from measured data to account for noise level changes due to differences in atmospheric absorption and noise path length between reference and test conditions.
\( \Delta_2 \) | EPNdB | Noise path duration correction. The correction to be added to the EPNL calculated from measured data to account for noise level changes due to the noise duration because of differences in flyover altitude between reference and test conditions.
\( \Delta_3 \) | EPNdB | Mass correction. The correction to be added to the EPNL calculated from measured data to account for noise level changes due to differences between maximum mass and actual mass of the test aeroplane.
\( \Delta_4 \) | EPNdB | Approach angle correction. The correction to be added to the EPNL calculated from measured data to account for noise level changes due to differences between the reference and the test approach angles.
\( \Delta\ AB \) | metres | Take-off profile changes. The algebraic changes in the basic parameters defining the take-off profile due to differences between reference and test conditions.
\( \Delta\ \beta \) | degrees | 
\( \Delta\ \gamma \) | degrees | 
\( \Delta\ \delta \) | degrees | 
\( \Delta\ \epsilon \) | degrees | 

* Gear up, speed of at least \( V_2 + 19 \) km/h (\( V_2 + 10 \) kt), take-off thrust.
** Gear up, speed of at least \( V_2 + 19 \) km/h (\( V_2 + 10 \) kt), after cut-back.

### 6.2 Flight profile identification positions

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Start of take-off roll.</td>
</tr>
<tr>
<td>B</td>
<td>Lift-off.</td>
</tr>
<tr>
<td>C</td>
<td>Start of first constant climb.</td>
</tr>
<tr>
<td>D</td>
<td>Start of thrust reduction.</td>
</tr>
<tr>
<td>E</td>
<td>Start of second constant climb.</td>
</tr>
<tr>
<td>E(_c)</td>
<td>Start of second constant climb on corrected flight path.</td>
</tr>
<tr>
<td>F</td>
<td>End of noise certification take-off flight path.</td>
</tr>
<tr>
<td>F(_c)</td>
<td>End of noise certification corrected take-off flight path.</td>
</tr>
<tr>
<td>G</td>
<td>Start of noise certification approach flight path.</td>
</tr>
<tr>
<td>G(_r)</td>
<td>Start of noise certification approach on reference flight path.</td>
</tr>
<tr>
<td>H</td>
<td>Position on approach path directly above noise measuring station.</td>
</tr>
<tr>
<td>H(_r)</td>
<td>Position on reference approach path directly above noise measuring station.</td>
</tr>
<tr>
<td>I</td>
<td>Start of level-off.</td>
</tr>
<tr>
<td>I(_r)</td>
<td>Start of level-off on reference approach flight path.</td>
</tr>
<tr>
<td>J</td>
<td>Touchdown.</td>
</tr>
</tbody>
</table>
6.3 Flight profile distances

<table>
<thead>
<tr>
<th>Distance</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>metres</td>
<td>Length of take-off roll. The distance along the runway between the start of take-off roll and lift off.</td>
</tr>
<tr>
<td>AK</td>
<td>metres</td>
<td>Take-off measurement distance. The distance from the start of roll to the take-off noise measurement station along the extended centre line of the runway.</td>
</tr>
<tr>
<td>AM</td>
<td>metres</td>
<td>Take-off flight track distance. The distance from the start of roll to the take-off flight track position along the extended centre line of the runway for which the position of the aeroplane need no longer be recorded.</td>
</tr>
<tr>
<td>KQ</td>
<td>metres</td>
<td>Measured take-off noise path. The distance from station K to the measured aeroplane position Q.</td>
</tr>
<tr>
<td>Q</td>
<td>metres</td>
<td>Measured take-off noise path. The distance from station K to the corrected aeroplane position Qc.</td>
</tr>
<tr>
<td>KR</td>
<td>metres</td>
<td>Measured take-off minimum distance. The distance from station K to point R on the measured flight path.</td>
</tr>
</tbody>
</table>

7. MATHEMATICAL FORMULATION OF NOY TABLES

Note 1.— The relationship between sound pressure level and perceived noisiness given in Table 1-1 is illustrated in Figure 1-3. The variation of SPL with log n for a given one-third octave band is expressed by either one or two straight lines depending upon the frequency range. Figure 1-3 a) illustrates the double line case for frequencies below 400 Hz and above 6 300 Hz and Figure 1-3 b) illustrates the single line case for all other frequencies.

The important aspects of the mathematical formulation are:

a) the slopes of the straight lines p(b) and p(c); and

b) the intercepts of the lines on the SPL-axis, SPL(b) and SPL(c); and
c) the coordinates of the discontinuity, SPL(a) and log n(a).

Note 2.— Mathematically the relationship is expressed as follows:

Case 1: Figure 1-3 a): f < 400 Hz

\[
\text{SPL}(a) = \frac{\text{p}(c) \text{SPL}(c) - \text{p}(b) \text{SPL}(b)}{\text{p}(c) - \text{p}(b)}
\]

\[
\log n(a) = \frac{\text{SPL}(c) - \text{SPL}(b)}{\text{p}(b) - \text{p}(c)}
\]

a) SPL < SPL(a)

\[
n = \text{antilog} \left( \frac{\text{SPL} - \text{SPL}(b)}{\text{p}(b)} \right)
\]

b) SPL ≥ SPL(a)

\[
n = \text{antilog} \left( \frac{\text{SPL} - \text{SPL}(c)}{\text{p}(c)} \right)
\]

c) log n < log n(a)

\[
\text{SPL} = \text{p}(b) \log n + \text{SPL}(b)
\]

d) log n ≥ log n(a)

\[
\text{SPL} = \text{p}(c) \log n + \text{SPL}(c)
\]

Case 2: Figure 1-3 b): 400 ≤ f ≤ 6 300 Hz

\[
n = \text{antilog} \left( \frac{\text{SPL} - \text{SPL}(c)}{\text{p}(c)} \right)
\]

\[
\text{SPL} = \text{p}(c) \log n + \text{SPL}(c)
\]

Note 3.— If the reciprocals of the slopes are defined as:

\[
M(b) = \frac{1}{\text{p}(b)}
\]

\[
M(c) = \frac{1}{\text{p}(c)}
\]

the equations in Note 2 can be written,

Case 1: Figure 1-3 a): f < 400 Hz

\[
\text{SPL}(a) = \frac{\text{M}(b) \text{SPL}(b) - \text{M}(c) \text{SPL}(c)}{\text{M}(b) - \text{M}(c)}
\]

\[
\log n(a) = \frac{\text{M}(b) \text{M}(c) \left[ \text{SPL}(c) - \text{SPL}(b) \right]}{\text{M}(c) - \text{M}(b)}
\]

a) SPL < SPL(a)

\[
n = \text{antilog} \left( \frac{\text{M}(b) \left( \text{SPL} - \text{SPL}(b) \right)}{\text{M}(b)} \right)
\]

b) SPL ≥ SPL(a)

\[
n = \text{antilog} \left( \frac{\text{M}(c) \left[ \text{SPL} - \text{SPL}(c) \right]}{\text{M}(c)} \right)
\]

c) log n < log n(a)

\[
\text{SPL} = \frac{\log n + \text{SPL}(b)}{\text{M}(b)}
\]

d) log n ≥ log n(a)

\[
\text{SPL} = \frac{\log n + \text{SPL}(c)}{\text{M}(c)}
\]

Note 4.— Table 1-4 lists the values of the important constants necessary to calculate sound pressure level as a function of perceived noisiness.

8. SOUND ATTENUATION IN AIR

8.1 The atmospheric attenuation of sound shall be determined in accordance with the procedure presented below.

8.2 The relationship between sound attenuation, frequency, temperature and humidity is expressed by the following equations:

\[
\alpha(i) = 10^{[0.05 \log (f_0/1000) + 1.1394 \times 10^{-3} \theta - 1.916944] + \eta(\delta)}
\]

\[
\times 10^{[\log (f_0) + 8.42994 \times 10^{-3} \theta - 2.755624]}
\]

where

\[
\delta = \sqrt{\frac{1}{\int_{f_0}^{1010} 10^ {\log H - 1.328924 + 3.179768 \times 10^{-7} \theta} \times 10^{[\log (f_0) + 8.42994 \times 10^{-3} \theta - 2.755624]}}}
\]

\[
\eta(\delta) \text{ is given by Table 1-5 and } f_0 \text{ by Table 1-6;}
\]

\[
\alpha(i) \text{ being the attenuation coefficient in } \text{dB/100 m;}
\]

\[
\theta \text{ being the temperature in } ^{\circ}\text{C; and}
\]

\[
H \text{ being the relative humidity.}
\]
Figure 1-3. Sound pressure level as a function of perceived noisiness
Table 1-4. Constants for mathematically formulated n oy values

<table>
<thead>
<tr>
<th>Band (i)</th>
<th>f (Hz)</th>
<th>$M (b)$</th>
<th>SPL (b) (dB)</th>
<th>SPL (a) (dB)</th>
<th>$M (c)$</th>
<th>SPL (c) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>0.043478</td>
<td>64</td>
<td>91.0</td>
<td>0.030103</td>
<td>52</td>
</tr>
<tr>
<td>2</td>
<td>63</td>
<td>0.040570</td>
<td>60</td>
<td>85.9</td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
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### Table 1-7

**Table 7. Sound attenuation coefficient in dB/100 m**

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### Table 1-8. Sound attenuation coefficient in dB/100 m

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### Table 1-9. Sound attenuation coefficient in dB/100 m

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Table 1-10. Sound attenuation coefficient in dB/100 m

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Table 1-12. Sound attenuation coefficient in dB/100 m

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Table 1-13. Sound attenuation coefficient in dB/100 m

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### Table 1-15. Sound attenuation coefficient in dB/100 m

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<td>10 000</td>
<td>12.6</td>
<td>15.4</td>
</tr>
<tr>
<td>12 500</td>
<td>14.8</td>
<td>19.4</td>
</tr>
</tbody>
</table>
8.3 The equations given in 8.2 are convenient for calculation by means of a computer. For use in other cases, numerical values determined from the equations are given in Tables 1-7 to 1-16.

### 9. DETAILED CORRECTION PROCEDURES

#### 9.1 Introduction

9.1.1 When the noise certification test conditions are not identical to the noise certification reference conditions, appropriate corrections shall be made to the EPNL calculated from the measured data by the methods of this section.

Note 1.— Differences between reference and test conditions which lead to corrections can result from the following:

a) atmospheric absorption of sound under test conditions different from reference;

b) test flight path at altitude different from reference;

and

c) test mass different from maximum.

Note 2.— Negative correction can arise if the atmospheric absorption of sound under test conditions is less than reference and also if the test flight path is at a lower altitude than reference.

The take-off test flight path can occur at a higher altitude than reference if the meteorological conditions permit superior aeroplane performance ("cold day" effect). Conversely, the "hot day" effect can cause the take-off test flight path to occur at a lower altitude than reference. The approach test flight path can occur at either higher or lower altitudes than reference irrespective of the meteorological conditions.

9.1.2 The measured noise values shall be properly corrected to the reference conditions, either by the correction procedures presented as follows or by an integrated programme which shall be approved as being equivalent.

### Table 1-16. Sound attenuation coefficient in dB/100 m

<table>
<thead>
<tr>
<th>Band centre frequency</th>
<th>Relative humidity = 100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature, °C</td>
</tr>
<tr>
<td>Hz</td>
<td>-10</td>
</tr>
<tr>
<td>50</td>
<td>0.0</td>
</tr>
<tr>
<td>63</td>
<td>0.0</td>
</tr>
<tr>
<td>80</td>
<td>0.0</td>
</tr>
<tr>
<td>100</td>
<td>0.0</td>
</tr>
<tr>
<td>125</td>
<td>0.0</td>
</tr>
<tr>
<td>160</td>
<td>0.1</td>
</tr>
<tr>
<td>200</td>
<td>0.1</td>
</tr>
<tr>
<td>250</td>
<td>0.1</td>
</tr>
<tr>
<td>315</td>
<td>0.1</td>
</tr>
<tr>
<td>400</td>
<td>0.2</td>
</tr>
<tr>
<td>500</td>
<td>0.3</td>
</tr>
<tr>
<td>630</td>
<td>0.4</td>
</tr>
<tr>
<td>800</td>
<td>0.6</td>
</tr>
<tr>
<td>1000</td>
<td>0.8</td>
</tr>
<tr>
<td>1250</td>
<td>1.1</td>
</tr>
<tr>
<td>1600</td>
<td>1.6</td>
</tr>
<tr>
<td>2000</td>
<td>2.2</td>
</tr>
<tr>
<td>2500</td>
<td>3.0</td>
</tr>
<tr>
<td>3150</td>
<td>4.2</td>
</tr>
<tr>
<td>4000</td>
<td>5.9</td>
</tr>
<tr>
<td>5000</td>
<td>6.8</td>
</tr>
<tr>
<td>6300</td>
<td>8.5</td>
</tr>
<tr>
<td>8000</td>
<td>10.7</td>
</tr>
<tr>
<td>10000</td>
<td>13.3</td>
</tr>
<tr>
<td>12500</td>
<td>16.0</td>
</tr>
</tbody>
</table>
Appendix 1

9.1.2.1 Correction procedures shall consist of one or more values added algebraically to the EPNL calculated as if the tests were conducted completely under the noise certification reference conditions.

9.1.2.2 The flight profiles shall be determined for both take-off and approach, and for both reference and test conditions. The test procedures shall require noise and flight path recordings with a synchronized time signal from which the test profile can be delineated, including the aeroplane position for which PNLT is observed at the noise measuring station. For take-off, a flight profile corrected to reference conditions shall be derived from data approved by the certificating authority.

Note.— For approach, the reference profile is defined by the reference conditions in 5.3.1.

9.1.2.3 The differing noise path lengths from the aeroplane to the noise measuring station corresponding to PNLT shall be determined for the test and reference conditions. The SPL values in the spectrum of PNLT shall then be corrected for the effects of:

a) change in atmospheric sound absorption;

b) atmospheric sound absorption on the change in noise path length; and

c) inverse square law on the change in noise path length.

9.1.2.4 The corrected values of SPL shall then be converted to PNLT from which PNLT is subtracted.

Note.— The difference represents the correction to be added algebraically to the EPNL calculated from the measured data.

9.1.3 The minimum distances from both the test and reference profiles to the noise measuring station shall be calculated and used to determine a noise duration correction due to the change in the altitude of aeroplane flyover. The duration correction shall be added algebraically to the EPNL calculated from the measured data.

9.1.4 From manufacturer’s data (approved by the certificating authority) in the form of curves, tables or in some other manner giving the variation of EPNL with take-off mass and also for landing mass, corrections shall be determined to be added to the EPNL calculated from the measured data to account for noise level changes due to differences between maximum take-off mass and landing mass and test aeroplane mass.

9.1.5 From manufacturer’s data (approved by the certificating authority) in the form of curves, tables or in some manner giving the variation of EPNL with approach angle, corrections shall be determined to be added algebraically to the EPNL calculated from measured data to account for noise level changes due to differences between the reference and the test approach angles.

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9.2 Take-off profiles

Note.—

a) Figure 1-4 illustrates a typical take-off profile. The aeroplane begins the take-off roll at point A, lifts off at point B, and initiates the first constant climb at point C at an angle \( \beta \). The noise abatement thrust cutback is started at point D and completed at point E where the second constant climb is defined by the angle \( \gamma \) (usually expressed in terms of the gradient in per cent).

b) The end of the noise certification take-off flight path is represented by aeroplane position F whose vertical projection on the flight track (extended centre line of the runway) is point M. The position of the aeroplane is recorded for a distance AM of at least 11 km (6 NM).

c) Position K is the take-off noise measuring station whose distance AK is the specified take-off measurement distance. Position L is the sideline noise measuring station located on a line parallel to and the specified distance from the runway centre line where the noise level during take-off is greatest.

d) The thrust settings after thrust reduction, if used, under the test conditions are such as would produce at least the minimum certification gradient for the reference conditions of atmosphere and mass.

e) The take-off profile is associated with the following five parameters: \( AB \), the length of take-off roll; \( \beta \), the first constant climb angle; \( \gamma \), the second constant climb angle; and \( \delta \) and \( \epsilon \), the thrust cutback angles. These five parameters are functions of the aeroplane performance, mass and atmospheric conditions (ambient air temperature, pressure, and wind velocity). If the test atmospheric conditions are not equal to the reference atmospheric conditions, the corresponding test and reference profile parameters will be different as shown in Figure 1-5. The profile parameter changes (identified as \( \Delta AB \), \( \Delta \beta \), \( \Delta \gamma \), \( \Delta \delta \) and \( \Delta \epsilon \)) can be derived from the manufacturer’s data (approved by the certificating authority) and are used to define the flight profile corrected to the atmospheric reference conditions, the aeroplane mass being unchanged from that of the test. The relationships between the measured and corrected take-off flight profiles can then be used to determine the corrections which are applied to the EPNL calculated from the measured data.

f) Figure 1-6 illustrates portions of the measured and corrected take-off flight paths including the significant geometrical relationships influencing sound propagation. EF represents the second constant measured flight path
with climb angle $\gamma$, and $E$, $F$, represents the second constant corrected flight path at different altitude and with different climb angle $\gamma + \Delta \gamma$.

g) Position Q represents the aeroplane location on the measured take-off flight path for which $P\text{NL}_{TM}$ is observed at the noise measuring station $K$, and $Q_\text{c}$ is the corresponding position on the corrected flight path. The measured and corrected noise propagation paths are $KQ$ and $KQ_\text{c}$, respectively, which are assumed to form the same angle $\theta$ with their flight paths. This assumption of constant angle $\theta$ is one which may not be valid in all cases. Future refinement should be sought. However, for the present application of this test procedure, any differences are considered small.

h) Position R represents the point on the measured take-off flight path nearest the noise measuring station $K$, and $R_\text{c}$ is the corresponding position on the corrected flight path. The minimum distance to the measured and corrected flight paths are indicated by the lines $KR$ and $KR_\text{c}$, respectively, which are normal to their flight paths.

9.2.1 If two peak values of $P\text{NL}$ are observed during flyover which differ by less than 2 TPNdB that noise level which, when corrected to reference conditions, gives the greater value shall be used in the computation for $E\text{PNL}$ at the reference conditions. In that case the point corresponding to the second peak shall be obtained on the corrected flight path by applying manufacturer’s approved data.

9.3 Approach profiles

Note.—

a) Figure 1-7 illustrates a typical approach profile. The beginning of the noise certification approach profile is represented by aeroplane position $G$ whose vertical projection on the flight track (extended centre line of the runway) is point $P$. The position of the aeroplane is recorded for a distance $OP$ from the runway threshold $O$ of at least 7.4 km (4 NM).

b) The aeroplane approaches at an angle $\eta$, passes vertically over the noise measuring station $N$ at a height of $NH$, begins the level-off at position $I$, and touches down at position $J$.

c) The approach profile is defined by the approach angle $\eta$ and the height $NH$ which are functions of the aeroplane operating conditions controlled by the pilot. If the measured approach profile parameters are different from the corresponding reference approach parameters (Figure 1-8), corrections are applied to the $E\text{PNL}$ calculated from the measured data.

d) Figure 1-9 illustrates portions of the measured and reference approach flight paths including the significant geometrical relationships influencing sound propagation. $GI$ represents the measured approach path with approach angle $\eta_\text{r}$ and $G_\text{r}I_\text{r}$ represents the reference approach flight path at reference altitude and the reference approach angle $\eta_\text{r}$.

e) Position $S$ represents the aeroplane location on the measured approach flight path for which $P\text{NL}_{TM}$ is observed at the noise measuring station $N$, and $S_\text{r}$ is the corresponding position on the reference approach flight path. The measured and corrected noise propagation paths are $NS$ and $NS_\text{r}$, respectively, which form the same angle $\lambda$ with their flight paths.

f) Position $T$ represents the point on the measured approach flight path nearest the noise measuring station $N$, and $T_\text{r}$ is the corresponding point on the reference approach flight path. The minimum distances to the measured and reference flight paths are indicated by the lines $NT$ and $NT_\text{r}$, respectively, which are normal to their flight paths.

9.4 $P\text{NL}$ corrections

9.4.1 Whenever the ambient atmospheric conditions of temperature and relative humidity differ from the reference conditions and/or whenever the measured take-off and approach flight paths differ from the reference flight paths respectively, corrections to the $E\text{PNL}$ values calculated from the measured data shall be applied. These corrections shall be calculated as described below:

9.4.1.1 Take-off

9.4.1.1.1 Referring to a typical take-off flight path shown in Figure 1-6, the spectrum of $P\text{NL}_{TM}$ observed at station $K$, for the aeroplane at position $Q$, shall be decomposed into its individual $S\text{PL}(i)$ values. A set of corrected values shall be computed as follows:

$$S\text{PL}(i)_c = S\text{PL}(i) + 0.01[\alpha(i) - \alpha(i)_0]KQ$$

$$+ 0.01\alpha(i)_0(KQ - KQ_0)$$

$$+ 20 \log \left(\frac{KQ}{KQ_0}\right)$$

— the term $0.01[\alpha(i) - \alpha(i)_0] KQ$ accounts for the effects of the change in atmospheric sound absorption where $\alpha(i)$ and $\alpha(i)_0$ are the sound absorption coefficients for the test and reference conditions respectively for the $i$-th one-third octave band and $KQ$ is the measured take-off noise path;

— the term $0.01\alpha(i)_0(KQ - KQ_0)$ accounts for the effect of atmospheric sound absorption on the change in the noise path length, where $KQ_c$ is the corrected take-off noise path; and

— the term $20 \log \left(\frac{KQ}{KQ_0}\right)$ accounts for the effects of the inverse square law on the change in the noise path length.
Figure 1-4. Measured take-off profile

Figure 1-5. Comparison of measured and corrected take-off profiles
Figure 1-6. Take-off profile characteristics influencing sound level

Figure 1-7. Measured approach profile
Figure 1-8. Comparison of measured and corrected approach profiles

Figure 1-9. Approach profile characteristics influencing sound level
Figure 1-10. Take-off mass correction for EPNL

Figure 1-11. Approach mass correction for EPNL
9.4.1.1.2 The corrected values of SPL(i)_c shall then be converted to PNLT and a correction term calculated as follows:

\[ \Delta_1 = \text{PNLT} - \text{PNLT}_M \]

which represents the correction to be added algebraically to the EPNL calculated from the measured data.

9.4.1.2 Approach

9.4.1.2.1 The same procedure shall be used for the approach flight path except that the values for SPL(i)_c relate to the approach noise paths shown in Figure 1-9 as follows:

\[
\text{SPL}(i)_c = \text{SPL}(i) + 0.01 [\alpha(i) - \alpha(i)_0] \text{NS} + 0.01 \alpha(i)_0 (\text{NS} - \text{NS}_r) + 20 \log (\text{NS}/\text{NS}_r)
\]

where NS and NS_r are the measured and reference approach noise paths, respectively. The remainder of the procedure shall be the same as for the take-off flight path.

9.4.1.3 Lateral

9.4.1.3.1 The same procedure shall be used for the lateral flight path except that the values for SPL(i)_c relate only to the measured lateral noise path as follows:

\[
\text{SPL}(i)_c = \text{SPL}(i) + 0.01 [\alpha(i) - \alpha(i)_0] \text{LX}
\]

where LX shall be the measured lateral noise path from station L (Figure 1-4) to position X of the aeroplane for which PNLT_M is observed at station L. Only the correction term accounting for the effects of change in atmospheric sound absorption shall be considered. The difference between the measured and corrected noise path lengths shall be assumed negligible for the lateral flight path. The remainder of the procedure shall be the same as for the take-off flight path.

9.5 Duration correction

9.5.1 Whenever the measured take-off and approach flight paths differ from the corrected and reference flight paths, respectively, duration corrections to the EPNL values calculated from the measured data shall be applied. These corrections shall be calculated as described below:

9.5.1.1 Take-off

9.5.1.1.1 Referring to the take-off flight path shown in Figure 1-6, a correction term shall be calculated as follows:

\[
\Delta_2 = -7.5 \log (\text{KR}/\text{KR}_c)
\]
which represents the corrections to be added algebraically to the EPNL calculated from the measured data. The lengths $KR$ and $KR_c$ shall be the measured and corrected take-off minimum distances, respectively, from the noise measuring station $K$ to the measured and corrected flight paths. The negative sign shall indicate that, for the particular case of a duration correction, the EPNL calculated from the measured data shall be reduced if the measured flight path is at a greater altitude than the corrected flight path.

9.5.1.2 Approach

9.5.1.2.1 The same procedure shall be used for the approach flight path except that the correction relates to the approach minimum distances shown in Figure 1-9 as follows:

$$\Delta_2 = -7.5 \log (NT/NT_c)$$

where $NT$ is the measured approach minimum distance from the noise measuring station $N$ to the measured flight path.

9.5.1.3 Lateral

9.5.1.3.1 No duration correction shall be computed for the lateral flight path because the differences between the measured and corrected flight paths are assumed negligible.

9.6 Mass correction

9.6.1 Whenever the aeroplane mass, during either the noise certification take-off or approach test, is different from the corresponding maximum take-off or landing mass, a correction shall be applied to the EPNL value calculated from the measured data. The corrections shall be determined from the manufacturer’s data (approved by the certificating authority) in the form of tables or curves such as schematically indicated in Figures 1-10 and 1-11. The manufacturer’s data shall be applicable to the noise certification reference atmospheric conditions.

9.7 Approach angle correction

9.7.1 Whenever the aeroplane approach angle during the noise certification approach test is different from the reference approach angle, a correction shall be applied to the EPNL value calculated from the measured data. The corrections shall be determined from the manufacturer’s data (approved by the certificating authority) in the form of tables or curves such as schematically indicated in Figure 1-12. The manufacturer’s data shall be applicable to the noise certification reference atmospheric conditions and to the test landing mass.
APPENDIX 2. EVALUATION METHOD FOR NOISE CERTIFICATION OF:

1.— SUBSONIC JET AEROPLANES—
Application for Certificate of Airworthiness for the Prototype accepted on or after 6 October 1977

2.— PROPELLER-DRIVEN AEROPLANES OVER 5 700 kg—
Application for Certificate of Airworthiness for the Prototype accepted on or after 1 January 1985 and before 17 November 1988

3.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg—
Application for Certificate of Airworthiness for the Prototype accepted on or after 17 November 1988

4.— HELICOPTERS

Note.— See Chapters 3 and 8, Part II.

1. INTRODUCTION

Note 1.— This noise evaluation method includes:

a) noise certification test and measurement conditions;

b) measurement of aeroplane and helicopter noise received on the ground;

c) calculation of effective perceived noise level from measured noise data; and

d) reporting of data to the certificating authority and correcting measured data.

Note 2.— The instructions and procedures given in the method are clearly delineated to ensure uniformity during compliance tests, and to permit comparison between tests of various types of aircraft conducted in various geographical locations.

Note 3.— A complete list of symbols and units, the mathematical formulation of perceived noisiness, a procedure for determining atmospheric attenuation of sound, and detailed procedures for correcting noise levels from non-reference to reference conditions are included in Sections 6 to 9 of this appendix.

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

2.1.1 This section prescribes the conditions under which noise certification shall be conducted and the measurement procedures that shall be used.

Note.— Many applications for a noise certificate involve only minor changes to the aircraft type design. The resultant changes in noise can often be established reliably without the necessity of resorting to a complete test as outlined in this appendix. For this reason certificating authorities are encouraged to permit the use of appropriate “equivalent procedures”. Also, there are equivalent procedures that may be used in full certification tests, in the interest of reducing costs and providing reliable results. Guidance material on the use of equivalent procedures in the noise certification of
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subsonic jet and propeller-driven aeroplanes and helicopters is provided in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

2.2 Test environment

2.2.1 Locations for measuring noise from an aircraft in flight shall be surrounded by relatively flat terrain having no excessive sound absorption characteristics such as might be caused by thick, matted, or tall grass, shrubs, or wooded areas. No obstructions which significantly influence the sound field from the aircraft shall exist within a conical space above the point on the ground vertically below the microphone, the cone being defined by an axis normal to the ground and by a half-angle 80° from this axis.

Note.— Those people carrying out the measurements could themselves constitute such obstructions.

2.2.2 Except as provided in 2.2.3, the tests shall be carried out under the following atmospheric conditions:

a) no precipitation;

b) ambient air temperature not above 35°C and not below 10°C and relative humidity not above 95 per cent and not below 20 per cent over the whole noise path between a point 10 m (33 ft) above the ground and the aircraft;

Note.— Care should be taken to ensure that the noise measuring, aircraft flight path tracking and meteorological instrumentation are operated within their environmental limitations.

c) relative humidity and ambient temperature over the whole noise path between a point 10 m (33 ft) above the ground and the aircraft such that the sound attenuation in the one-third octave band centred on 8 kHz will not be more than 12 dB/100 m;

d) if the atmospheric absorption coefficients vary over the PNLTM sound propagation path by more than ±0.5 dB/100 m in the 3 150 Hz one-third octave band from the value of the absorption coefficient derived from the meteorological measurement obtained at 10 m above the surface, ‘layered’ sections of the atmosphere must be used to compute equivalent weighted sound attenuations in each one-third octave band, sufficient sections being used to the satisfaction of the certificating authority; where multiple layering is not required, equivalent sound attenuations in each one-third octave band shall be determined by averaging the atmospheric absorption coefficients for each such band at 10 m (33 ft) above ground level and at the flight level of the test aircraft at the time of PNLTM, for each measurement;

e) windspeed not above 22 km/h (12 kt) and cross-wind speed not above 13 km/h (7 kt) at 10 m (33 ft) above ground over the 10 dB-down time interval, except for helicopters, for which the windspeed may not exceed 19 km/h (10 kt) and the cross-wind speed may not exceed 9 km/h (5 kt) at 10 m (33 ft) above ground;

Note 1.— For aeroplanes, these limits are based on the use of an anemometer with a built-in detector time constant of 30 s. For anemometers with shorter detector times the effects of short term gusts during the 10 dB-down period must be considered and in such instances the maximum value of gusts should not exceed 28 km/h (15 kt) and a maximum average wind value of no more than 22 km/h (12 kt). The maximum value of cross-wind gust should not exceed 18 km/h (10 kt) and a maximum average cross-wind of 13 km/h (7 kt).

Note 2.— The cross-wind component is based on the continuous windspeed vector resolution in the cross-wind direction.

f) no anomalous meteorological or wind conditions that would significantly affect the measured noise levels when the noise is recorded at the measuring points specified by the certificating authority; and

g) meteorological measurements must be obtained within 30 minutes of each noise test measurement.

When a multiple layering calculation is required by 2.2.2 (d) the atmosphere between the aircraft and 10 m (33 ft) above the ground shall be divided into layers of equal depth. The depth of the layers shall be determined by the minimum depth of the layer giving a variation of ±0.5 dB/100 m in the atmospheric absorption coefficient of the 3 150 Hz one-third octave band over any part of the noise propagation path with a minimum layer depth of 30 m. The mean of the values of the atmospheric absorption coefficients at the top and bottom of each layer may be used to characterize the absorption properties of each layer.

2.2.3 The requirements of 2.2.2 b), c) and d) shall only be applied at a point 10 m (33 ft) above ground for tests of helicopters.

2.2.4 The aerodrome control tower or another facility shall be approved for use as the central location at which measurements of atmospheric parameters are representative of those conditions existing over the geographical area in which noise measurements are made.

2.3 Flight path measurement

2.3.1 The aircraft height and lateral position relative to the flight track shall be determined by a method independent of normal flight instrumentation such as radar tracking, theodolite triangulation, or photographic scaling techniques to be approved by the certificating authority.
2.3.2 The aircraft position along the flight path shall be related to the noise recorded at the noise measurement locations by means of synchronizing signals over a distance sufficient to assure adequate data during the period that the noise is within 10 dB of the maximum value of PNL T.

2.3.3 Position and performance data required to make the adjustments referred to in Section 8 or 9 of this appendix shall be automatically recorded at an approved sampling rate. Measuring equipment shall be approved by the certificating authority.

3. MEASUREMENT OF AIRCRAFT NOISE RECEIVED ON THE GROUND

3.1 General

Note.— These measurements provided one-third octave band levels of the noise observed at each noise-measuring station, as a function of time, for the calculation of effective perceived noise level as described in Section 4.

3.1.1 The measurement system shall consist of equipment equivalent to the following:

a) a microphone system (see 3.2);

b) a recording and reproducing system (when on-line analysis is not employed) to store the measured noise data for subsequent analysis (see 3.3);

c) an analysis system to provide the output for calculation of EPNL (see 3.4);

d) calibration systems to ensure the continuous accuracy of the above systems (see 3.5).

3.1.2 The equipment used shall be shown by its manufacturers or by its users to meet the specifications of IEC 561* and 651* which form the basis of 3.2, 3.3, and 3.4, or to be of equivalent electro-acoustical performance, and shall be approved by the certificating authority.

3.1.3 The calibration and checking procedures to be used during each certification test series shall be shown to meet the corresponding specifications which are quoted in 3.5, or to be equivalent, and shall be approved by the certificating authority.

3.2 Microphone system

3.2.1 The microphone system shall consist of a microphone, preamplifier and wind screen meeting the specifications in 3.2.2, 3.2.3, 3.2.4, 3.2.5, 3.2.6, 3.2.7 and 3.2.8. Other systems may be approved for equivalency by the certificating authority on the basis of demonstrated equivalent over-all acoustic performance. Where two or more microphone systems of the same type are used, demonstration of at least one system to comply with the specifications in full will be sufficient to show type compliance.

Note.— This does not preclude the need to calibrate each system as defined in 3.5.

3.2.2 The microphone shall be of the pressure-sensitive type designed for nearly uniform grazing incidence response.

3.2.3 The microphone shall be mounted with the centre of the sensing element 1.2 m (4 ft) above the local ground surface and shall be oriented for grazing incidence, i.e. with the sensing element substantially in the plane defined by the nominal flight path of the aeroplane or helicopter and the measuring station as shown in Figure 2-1. The microphone mounting arrangement shall minimize the interference of the supports with the sound to be measured.

3.2.4 After an adequate “warm up” period, at least as long as that specified by the equipment manufacturer, the system output for constant acoustical input shall change by not more than 0.3 dB within any one hour nor by more than 0.4 dB within 5 hours.

3.2.5 A reference direction of incidence shall be specified for which the frequency response characteristics given in 3.2.6 apply. The change in sensitivity of the microphone system within angles of ±30° measured from the reference direction (see Figure 2-1) shall not exceed the following values:

<table>
<thead>
<tr>
<th>Change in sensitivity (dB)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45 to 1 120</td>
</tr>
<tr>
<td>1.5</td>
<td>1 120 to 2 240</td>
</tr>
<tr>
<td>2.5</td>
<td>2 240 to 4 500</td>
</tr>
<tr>
<td>4</td>
<td>4 500 to 7 100</td>
</tr>
<tr>
<td>5</td>
<td>7 100 to 11 200</td>
</tr>
</tbody>
</table>

3.2.6 The free-field frequency response of the microphone system at the reference incidence direction shall lie within an envelope having the following values:

<table>
<thead>
<tr>
<th>Tolerance (dB)</th>
<th>Frequency Range (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>±1</td>
<td>45 to 4 500</td>
</tr>
<tr>
<td>±1.5</td>
<td>4 500 to 5 600</td>
</tr>
<tr>
<td>+1.5, –2</td>
<td>5 600 to 7 100</td>
</tr>
<tr>
<td>+1.5, –3</td>
<td>7 100 to 9 000</td>
</tr>
<tr>
<td>+2, –4</td>
<td>9 000 to 11 200</td>
</tr>
</tbody>
</table>

* Available from the Bureau central de la Commission électro-technique internationale, 1 rue de Varembé, Geneva, Switzerland.
3.2.7 With the wind screen in place, the variation in sensitivity in the plane of the diaphragm of the microphone system shall not exceed 1.0 dB over the frequency range 45 to 11 200 Hz.

3.2.8 Specifications concerning sensitivity to environmental factors such as temperature, relative humidity, and vibration shall be in accordance with the requirements of IEC Publication 651.

3.2.9 Each microphone system shall be calibrated as described in 3.5, and the correction for the frequency response of the microphone system shall be reported and applied in the determination of the noise level.

3.3 Recording and reproducing system

3.3.1 A recording system (such as a magnetic tape recorder) shall be used to store data for subsequent analysis, if required. The record/replay system (including tape) shall be shown to meet the specifications in 3.3.2, 3.3.3, 3.3.4 and 3.3.5 at the tape speeds used for the tests.

Figure 2-1. Reference direction of incidence and incidence angle definition for grazing incidence microphones
Appendix 2

3.3.2 At standard recording level (i.e. 10 dB below the 3 per cent harmonic distortion level for direct recording, or ±40 per cent deviation for FM recording), in any selected one-third octave frequency band between 180 and 11 200 Hz, the corrected frequency response shall be flat within ±0.25 dB, and in any band between 45 and 180 Hz shall be flat within ±0.75 dB.

3.3.3 The amplitude fluctuations of a 1 kHz sinusoidal signal recorded at the standard recording level shall be within ±0.5 dB throughout any reel of the type of magnetic tape utilized. Measurements to verify this shall be made using a device with averaging properties equal to those used in the measuring chain (see 3.4).

3.3.4 The performance of the system shall be such that the background noise in any one-third octave band is at least 35 dB below the standard recording level (see 3.3.2).

Note.— With sharply falling spectra appropriate pre-emphasis and de-emphasis networks may need to be included in the system.

3.3.5 Attenuators included in the measuring chain to permit range changing shall operate in intervals of equal integral decibel steps, and the error between any two settings required for operating the equipment during noise certification measurements or for associated calibrations shall not exceed 0.2 dB.

3.3.6 The recording and reproducing system shall be calibrated as described in 3.5.

3.4 Analysis system

3.4.1 The output of the analysis system shall consist of one-third octave band sound levels as a function of time, obtained by processing the (recorded) noise measurements through:

a) a set of 24 one-third octave filters (or their equivalent) having geometric centre frequencies 50 Hz to 10 kHz;

b) an analyser with appropriate response and averaging properties, in which (in principle) the output from any one-third octave band is squared, averaged, converted to logarithmic form and digitized.

3.4.2 The one-third octave band filters shall satisfy the requirements of IEC Publication 225* and additionally have less than 0.5 dB ripple.

The correction for effective bandwidth relative to the response at the frequency of the acoustic calibrator used (see 3.5.5) shall be determined for the appropriate one-third octave band filter, by measuring the filter response to sinusoidal signals at a minimum of 20 frequencies equally spaced between the two adjacent preferred one-third octave frequencies or by using equivalent procedures approved by the certificating authority.

3.4.3 The detector or detectors shall operate over a minimum dynamic range of 60 dB and shall perform as true mean square devices for sinusoidal tone bursts having crest factors of up to 3 over the dynamic range extending from 0 to 30 dB below full scale reading within an accuracy of ±0.5 dB; the accuracy shall be within ±1 dB between 30 and 40 dB below full scale reading, and within ±2.5 dB over the remaining 20 dB of range.

Compliance with this requirement shall be determined by the method described in Appendix B of IEC Publication 179A**, with the signals applied directly to the input of each detector in turn.

3.4.4 The averaging properties of the integrator shall be tested as follows. White noise shall be passed through a one-third octave band filter with centre frequency 200 Hz and statistical bandwidth 46 ±1 Hz, and the output shall be fed in turn to each detector/integrator. The standard deviation of the measured levels shall be determined from a large number of samples of the filtered white noise taken at intervals of not less than 5 s. The value of the standard deviation shall be within the interval 0.48 ±0.06 dB for a probability limit of 95 per cent.

3.4.5 For each detector/integrator, the response to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave band centre frequency shall be measured at sampling instants 0.5, 1, 1.5 and 2 s after the onset and 0.5 and 1 s after interruption. The rising response at 0.5 s shall be –4 ±1 dB, at 1 s –1.75 ±0.75 dB, at 1.5 s –1 ±0.5 dB and at 2 s –0.6 ±0.5 dB relative to the steady-state level. The falling response shall be such that the sum of the decibel readings (below initial steady-state level) and the corresponding rising response reading is 6.5 ±1 dB, at both 0.5 and 1 s and on subsequent records the sum of the onset plus decay must be greater than 7.5 dB. This equals to an exponential averaging process (SLOW response) with a normal 1 s time constant (i.e. 2 s averaging time).

Note 1.— For analysers with linear detection an approximation of this response would be given by:

\[ \text{SPL}(i,k) = 10 \log \left[ 0.13 \left( 10^{0.1L(i-3)} \right) + 0.21 \left( 10^{0.1L(i-2)} \right) + 0.27 \left( 10^{0.1L(i-1)} \right) + 0.39 \left( 10^{0.1L(i)} \right) \right] \]

* As amended. The publication was first issued in 1966 by the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

** As amended. This publication was first issued in 1973 as a supplement to IEC publication 179.
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Where the weighting coefficients for simulation of slow response are:

- Current: \( L(i,k) \) \( \frac{1}{2} \) s record: 39 per cent
- Previous: \( L(i,k-1) \) \( \frac{1}{2} \) s record: 27 per cent
- Second: \( L(i,k-2) \) \( \frac{1}{2} \) s record: 21 per cent
- Third: \( L(i,k-3) \) \( \frac{1}{2} \) s record: 13 per cent

and where:

\[ L(i,k), L(i,k-1), L(i,k-2) \text{ and } L(i,k-3) \text{ are the as-measured } \frac{1}{2} \text{ s values from the analyser. These are not the weighted values of } \text{SPL}(i,k), \text{SPL}(i,k-1), \text{SPL}(i,k-2) \text{ as defined in Section 7.} \]

It should be noted that when this approximation is used the calibration signal should be established without this weighting.

Note 2.— Some analysers have been shown to have signal sampling rates that are insufficiently accurate to detect signals with crest factor ratios greater than three (common to helicopter noise) and are therefore not considered suitable for helicopter certification. Use of analysis systems with high signal sampling rates (greater than 60 kHz) or those with analog detectors prior to digitization at the output of each one-third octave filter is encouraged.

3.4.6 Analysers using true integration cannot meet 3.4.4 and 3.4.5 directly because the over-all averaging time, \( T_a \) is greater than the sampling interval, \( T_S \) (see 3.4.7). Compliance with these clauses shall then be demonstrated in terms of the output of the data processor. Furthermore, in cases where readout and integrator resetting of the total system (including the data processor) require a deadtime during acquisition, the percentage loss of the total data shall not exceed 1 per cent. When an analyser with true integration is used, this response can be obtained at times greater than 2.5 s from start-up, using a continuous exponential averaging process with the following equation:

\[ \text{SPL}(i,k) = 10 \log \left[ \left(1-1/R\right)10^{0.1 \text{ SPL}(i,k-1)} + \left(1/R\right)10^{0.1 \text{ SPL}(i,k)} \right] \]

where \( \text{SPL}(i,k) \) is the sound pressure level at the \( k \)-th instant of time that occurs in the \( i \)-th one-third octave and where \( R = 2.5 \) for linear 0.5 s data records.

3.4.7 The sampling interval \( T_S \) between successive data readouts shall not exceed 500 ms and its precise value shall be known to within ±1 per cent. The instant in time by which a readout is characterized shall be 0.75 s earlier than the actual readout time for \( T_a = 2 \) s.

Note.— The definition of this instant in time is required to correlate the recorded noise with the position of the aircraft when that noise was emitted and takes into account the averaging period of the SLOW response.

3.4.8 In order to achieve adequate over-all precision, the resolution of the digitizing system output shall be equal to, or better than 0.25 dB.

3.5 Calibration and checking of system

3.5.1 Calibration and checking of the complete measurement and analysis system used during the noise certification tests shall be carried out to the satisfaction of the certificating authority at appropriate times during the tests and before or after them, by the methods quoted in 3.5.2, 3.5.3, 3.5.4, 3.5.5 and 3.5.6.

3.5.2 When on account of the use of a microphone system of known frequency response (see 3.2.5) the over-all system is calibrated for frequency response using an insert voltage technique, the frequency response of the electrical system shall be determined, during each test series, at a level within 10 dB of the full-scale reading used during the tests, utilizing pink or pseudorandom noise. The output of the noise generator shall have been checked by an approved standards laboratory within 6 months of the test series; and tolerable changes in the relative output at each one-third octave band shall be not more than 0.2 dB. Sufficient determinations shall be made to ensure that the over-all calibration of the system is known for each test.

Where a magnetic tape recorder forms part of the measuring chain, each reel of magnetic tape shall carry 30 s of this electrical calibration signal at its beginning and end for this purpose. In addition, data obtained from tape-recorded signals shall be accepted as reliable only if the level difference in the 10 kHz one-third octave band filtered levels of the two signals is not more than 0.75 dB.

3.5.3 The response of each detector/integrator shall be determined in accordance with 3.4.5.

3.5.4 The performance of switched attenuators in the equipment used during noise certification measurements and calibration shall be checked for each test series, using the most accurate part of the readout device to ensure that the maximum error does not exceed the resolution.

3.5.5 The response of the over-all electro-acoustical system shall be determined using an acoustic calibrator generating a known sound pressure level at a known frequency. The output of the acoustic calibrator shall have been checked by a standardizing laboratory within 6 months of the test series; tolerable changes in output shall be not more than 0.2 dB. A pistonphone operating at a nominal 124 dB (re 20 µPa) and 250 Hz is generally used for this purpose. Sufficient determinations shall be made during the day’s work to ensure that the response of the equipment is known for each test.
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The equipment shall be considered satisfactory if the variation over the period immediately prior to and immediately following each test series within a given day is not greater than 0.5 dB.

The insertion loss of the wind screen shall also have been checked over the useful frequency range by a standardizing laboratory within 6 months of the test series; tolerable changes in insertion loss shall be not more than 0.4 dB.

The insertion loss of the wind screen over the frequency range 40 Hz to 12.5 kHz shall also have been determined to the satisfaction of the certificating authority.

Note.— The insertion loss of a new wind screen may be taken from manufacturer's data.

3.5.6 The ambient noise, including both acoustical background and electrical noise of the measurement system, shall be recorded at the measurement points with the system gain set at the levels used for the aircraft noise measurements, at appropriate times during each test day. The recorded aircraft noise data shall be accepted only if the ambient noise levels when analysed in the same way and quoted in PNL (see 4.1.3 a)) are at least 20 dB below the maximum PNL of the aircraft.

Aircraft sound pressure levels within the 10 dB-down points (see 4.5.1) shall exceed the mean ambient noise levels determined above by at least 3 dB in each one-third octave band or be adjusted using the method described in Appendix 3 of the *Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft* (Doc 9501).

Where more than seven consecutive one-third octaves are within 3 dB of the ambient noise levels a time frequency extrapolation of the noise data shall be performed using a procedure such as described in the above-mentioned ICAO Environmental Technical Manual or by other such equivalent procedure approved by the certificating authority.

4. CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL FROM MEASURED NOISE DATA

4.1 General

4.1.1 The basic element in the noise certification criteria shall be the noise evaluation measure designated effective perceived noise level, EPNL, in units of EPNdB, which is a single number evaluator of the subjective effects of aircraft noise on human beings. Simply stated, EPNL shall consist of instantaneous perceived noise level, PNL, corrected for spectral irregularities (the correction, called “tone correction factor”, is made for the maximum tone only at each increment of time) and for duration.

4.1.2 Three basic physical properties of sound pressure shall be measured level, frequency distribution, and time variation. More specifically, the instantaneous sound pressure level in each of 24 one-third octave bands of the noise shall be required for each 500 ms increment of time during the aircraft noise measurement.

4.1.3 The calculation procedure which utilizes physical measurements of noise to derive the EPNL evaluation measure of subjective response shall consist of the following five steps:

a) the 24 one-third octave bands of sound pressure level are converted to perceived noisiness by the methods of Section 4.7. The noy values are combined and then converted to instantaneous perceived noise levels, PNL(k);

b) a tone correction factor, \( C(k) \) is calculated for each spectrum to account for the subjective response to the presence of spectral irregularities;

c) the tone correction factor is added to the perceived noise level to obtain tone corrected perceived noise levels, PNLT(k), at each one-half second increment of time:

\[
PNLT(k) = PNL(k) + C(k)
\]

The instantaneous values of tone corrected perceived noise level are derived and the maximum value, PNLTM, is determined;

d) a duration correction factor, \( D \), is computed by integration under the curve of tone corrected perceived noise level versus time;

e) effective perceived noise level, EPNL, is determined by the algebraic sum of the maximum tone corrected perceived noise level and the duration correction factor:

\[
EPNL = PNLTM + D
\]

4.2 Perceived noise level

4.2.1 Instantaneous perceived noise levels, PNL(k), shall be calculated from instantaneous one-third octave band sound pressure levels, SPL(i,k) as follows:

*Step 1.* Convert each one-third octave band SPL(i,k), from 50 to 10 000 Hz, to perceived noisiness \( n(i,k) \), by reference to the Table of Perceived Noisiness in Appendix 4 of the *Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft* (Doc 9501), or to the mathematical formulation of the noy table given in Section 4.7.
Step 2. Combine the perceived noisiness values, \( n(i,k) \), found in step 1 by the following formula:

\[
N(k) = n(k) + 0.15 \left[ \sum_{i=1}^{24} n(i,k) \right] - n(k)
\]

or

\[
N(k) = 0.85 n(k) + 0.15 \sum_{i=1}^{24} n(i,k)
\]

where \( n(k) \) is the largest of the 24 values of \( n(i,k) \) and \( N(k) \) is the total perceived noisiness.

Step 3. Convert the total perceived noisiness, \( N(k) \), into perceived noise level, \( \text{PNL}(k) \), by the following formula:

\[
\text{PNL}(k) = 40.0 + \frac{10}{\log 2} \log N(k)
\]

Note.— \( \text{PNL}(k) \) is plotted in Figure 4-1 of Appendix 4 of Doc 9501.

4.3 Correction for spectral irregularities

4.3.1 Noise having pronounced spectral irregularities (for example, the maximum discrete frequency components or tones) shall be adjusted by the correction factor \( C(k) \) calculated as follows:

Step 1. Except for helicopters which start at 50 Hz (band number 1), start with the corrected sound pressure level in the 80 Hz one-third octave band (band number 3), calculate the changes in sound pressure level (or “slopes”) in the remainder of the one-third octave bands as follows:

\[
s(3,k) = \text{no value}
\]

\[
s(4,k) = \text{SPL}(4,k) - \text{SPL}(3,k)
\]

•

\[
s(i,k) = \text{SPL}(i,k) - \text{SPL}(i-1,k)
\]

•

\[
s(24,k) = \text{SPL}(24,k) - \text{SPL}(23,k)
\]

Step 2. Encircle the value of the slope, \( s(i,k) \), where the absolute value of the change in slope is greater than five; that is, where:

\[
| \Delta s(i,k) | = | s(i,k) - s(i-1,k) | > 5
\]

Step 3.

a) If the encircled value of the slope \( s(i,k) \), is positive and algebraically greater than the slope \( s(i-1,k) \) encircle \( \text{SPL}(i,k) \).

b) If the encircled value of the slope \( s(i,k) \) is zero or negative and the slope \( s(i-1,k) \) is positive, encircle \( \text{SPL}(i-1,k) \).

c) For all other cases, no sound pressure level value is to be encircled.

Step 4. Compute new adjusted sound pressure levels \( \text{SPL}'(i,k) \) as follows:

a) For non-encircled sound pressure levels, let the new sound pressure levels equal the original sound pressure levels, \( \text{SPL}'(i,k) = \text{SPL}(i,k) \).

b) For encircled sound pressure levels in bands 1 to 23 inclusive, let the new sound pressure level equal the arithmetic average of the preceding and following sound pressure levels:

\[
\text{SPL}'(i,k) = \frac{1}{2} \left[ \text{SPL}(i-1,k) + \text{SPL}(i+1,k) \right]
\]

c) If the sound pressure level in the highest frequency band \((i = 24)\) is encircled, let the new sound pressure level in that band equal:

\[
\text{SPL}'(24,k) = \text{SPL}(23,k) + s(23,k)
\]

Step 5. Recompute new slope \( s'(i,k) \), including one for an imaginary 25-th band, as follows:

\[
s'(3,k) = s'(4,k)
\]

\[
s'(4,k) = \text{SPL}'(4,k) - \text{SPL}'(3,k)
\]

•

\[
s'(i,k) = \text{SPL}'(i,k) - \text{SPL}'(i-1,k)
\]

•

\[
s'(24,k) = \text{SPL}'(24,k) - \text{SPL}'(23,k)
\]

Step 6. For \( i \) from 3 to 23 (or 1 to 23 for helicopters) compute the arithmetic average of the three adjacent slopes as follows:

\[
\tilde{s}(i,k) = \frac{1}{3} [s'(i,k) + s'(i+1,k) + s'(i+2,k)]
\]

Step 7. Compute final one-third octave-band sound pressure levels, \( \text{SPL}''(i,k) \), by beginning with band number 3 (or band number 1 for helicopters) and proceeding to band number 24 as follows:

\[
\text{SPL}''(3,k) = \text{SPL}(3,k)
\]

\[
\text{SPL}''(4,k) = \text{SPL}''(3,k) + \tilde{s}(3,k)
\]

•

\[
\text{SPL}''(i,k) = \text{SPL}''(i-1,k) + \tilde{s}(i-1,k)
\]

•

\[
\text{SPL}''(24,k) = \text{SPL}''(23,k) + \tilde{s}(23,k)
\]
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Step 8. Calculate the differences, \( F(i,k) \) between the original sound pressure level and the final background sound pressure level as follows:

\[
F(i,k) = SPL(i,k) - SPL''(i,k)
\]

and note only values equal to or greater than one and a half.

Step 9. For each of the relevant one-third octave bands (3 to 24), determine tone correction factors from the sound pressure level differences \( F(i,k) \) and Table 2-1.

Step 10. Designate the largest of the tone correction factors, determined in Step 9, as \( C(k) \). An example of the tone correction procedure is given in Table 4-2 of Appendix 4 of Doc 9501.

Tone corrected perceived noise levels \( PNLT(k) \) shall be determined by adding the \( C(k) \) values to corresponding \( PNL(k) \) values, that is:

\[
PNLT(k) = PNL(k) + C(k)
\]

For any \( i \)-th one-third octave band, at any \( k \)-th increment of time, for which the tone correction factor is suspected to result from something other than (or in addition to) an actual tone (or any spectral irregularity other than aircraft noise), an additional analysis shall be made using a filter with a bandwidth narrower than one-third of an octave. If the narrow band analysis corroborates these suspicions, then a revised value for the background sound pressure level SPL''(i,k) shall be determined from the narrow band analysis and used to compute a revised tone correction factor for that particular one-third octave band.

Note.— Other methods of rejecting spurious tone corrections such as those described in Appendix 2 of the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501) may be used.

4.3.2 This procedure will underestimate EPNL if an important tone is of a frequency such that it is recorded in two adjacent one-third octave bands. It shall be demonstrated to the satisfaction of the certificating authority:

either that this has not occurred,

or that if it has occurred that the tone correction has been adjusted to the value it would have had if the tone had been recorded fully in a single one-third octave band.

4.4 Maximum tone corrected perceived noise level

4.4.1 The maximum tone corrected perceived noise level, \( PNLTM \), shall be the maximum calculated value of the tone corrected perceived noise level \( PNLT(k) \). It shall be calculated in accordance with the procedure of 4.3. To obtain a satisfactory noise time history, measurements shall be made at 500 ms time intervals.

Note 1.— Figure 2-2 is an example of a flyover noise time history where the maximum value is clearly indicated.

Note 2.— In the absence of a tone correction factor, \( PNLTM \) would equal \( PNLM \).

4.4.2 After the value of \( PNLTM \) is obtained, the frequency band for the largest tone correction factor is identified for the two preceding and two succeeding 500 ms data samples. The following test shall be applied to these four samples to identify the possibility of tone suppression by one-third octave band sharing of that tone. The frequency band of the maximum tone correction factor for the four samples is tested for a shift to lower frequencies (limited to three consecutive one-third octave bands) from the first to the fourth data sample. If the value of the tone correction factor \( C(k) \) for \( PNLTM \) is less than the average value of \( C(k) \) for the five consecutive time intervals the average value of \( C(k) \) shall be used to compute a new value for \( PNLTM \).

4.5 Duration correction

4.5.1 The duration correction factor \( D \) determined by the integration technique shall be defined by the expression:

\[
D = 10 \log \left[ \frac{1}{T} \int_{t_1}^{t_2} \sin^{-1} \left( \frac{PNLT}{10} \right) \, dt \right] - PNLTM
\]

where \( T \) is a normalizing time constant, \( PNLTM \) is the maximum value of \( PNLT \), \( t_1 \) is the first point of time after which \( PNLT \) becomes greater than \( PNLTM - 10 \) and \( t_2 \) is the point of time after which \( PNLT \) remains constantly less than \( PNLTM - 10 \).

4.5.2 Since \( PNLT \) is calculated from measured values of SPL, there will, in general, be no obvious equation for \( PNLT \) as a function of time. Consequently, the equation shall be rewritten with a summation sign instead of an integral sign as follows:

\[
D = 10 \log \left[ \frac{1}{T} \sum_{k=0}^{d/\Delta t} \Delta t \cdot \sin^{-1} \left( \frac{PNLT(k)}{10} \right) \right] - PNLTM
\]

where \( \Delta t \) is the length of the equal increments of time for which \( PNLT(k) \) is calculated and \( d \) is the time interval to the nearest 1.0 s during which \( PNLT(k) \) remains greater or equal to \( PNLTM - 10 \).
4.5.3 To obtain a satisfactory history of the perceived noise level,

a) half-second time intervals for \( \Delta t \), or

b) a shorter time interval with approved limits and constants,

shall be used.

4.5.4 The following values for \( T \) and \( \Delta t \) shall be used in calculating \( D \) in the procedure given in 4.5.2:

\[ T = 10 \text{ s}, \text{ and} \]
\[ \Delta t = 0.5 \text{ s} \]

Using the above values, the equation for \( D \) becomes

\[
D = 10 \log \left[ \sum_{k=0}^{2d} \text{antilog} \frac{\text{PNLT}(k)}{10} \right] - \text{PNLT} - 13
\]

where the integer \( d \) is the duration time defined by the points corresponding to the values PNLT – 10.

4.5.5 If in the procedures given in 4.5.2, the limits of PNLT – 10 fall between the calculated PNLT\((k)\) values (the usual case), the PNLT\((k)\) values defining the limits of the duration interval shall be chosen from the PNLT\((k)\) values closest to PNLT – 10. For those cases with more than one peak value of PNLT\((k)\), the applicable limits must be chosen to yield the largest possible value for the duration time.

### Table 2-1. Tone correction factors

<table>
<thead>
<tr>
<th>Frequency ( f ), Hz</th>
<th>Level difference ( F ), dB</th>
<th>Tone correction ( C ), dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 50 \leq f &lt; 500 )</td>
<td>( 1\frac{1}{2}^* \leq F &lt; 3 )</td>
<td>( F/3 ) – ( \frac{1}{2} )</td>
</tr>
<tr>
<td></td>
<td>( 3 \leq F &lt; 20 )</td>
<td>( F/6 )</td>
</tr>
<tr>
<td></td>
<td>( 20 \leq F )</td>
<td>( \frac{3}{2} )</td>
</tr>
<tr>
<td>( 500 \leq f \leq 5000 )</td>
<td>( 1\frac{1}{2}^* \leq F &lt; 3 )</td>
<td>( 2F/3 ) – 1</td>
</tr>
<tr>
<td></td>
<td>( 3 \leq F &lt; 20 )</td>
<td>( F/3 )</td>
</tr>
<tr>
<td></td>
<td>( 20 \leq F )</td>
<td>( 3\frac{3}{2} )</td>
</tr>
<tr>
<td>( 5000 \leq f \leq 10000 )</td>
<td>( 1\frac{1}{2}^* \leq F &lt; 3 )</td>
<td>( F/3 ) – ( \frac{1}{2} )</td>
</tr>
<tr>
<td></td>
<td>( 3 \leq F &lt; 20 )</td>
<td>( F/6 )</td>
</tr>
<tr>
<td></td>
<td>( 20 \leq F )</td>
<td>( 3\frac{3}{2} )</td>
</tr>
</tbody>
</table>

* See Step 8, 4.3.1.
Figure 2-2. Example of perceived noise level corrected for tones as a function of aeroplane flyover time

Figure 2-3. Perceived noisiness as a function of sound pressure level
4.6 Effective perceived noise level

4.6.1 The total subjective effect of an aircraft noise event, designated effective perceived noise level, EPNL, shall be equal to the algebraic sum of the maximum value of the tone corrected perceived noise level, PNLTM, and the duration correction \( D \). That is:

\[
EPNL = PNLTM + D
\]

where PNLTM and \( D \) are calculated in accordance with the procedures given in 4.2, 4.3, 4.4 and 4.5.

4.7 Mathematical formulation of noy tables

4.7.1 The relationship between sound pressure level (SPL) and the logarithm of perceived noisiness is illustrated in Table 2-2 and Figure 2-3.

4.7.2 The important aspects of the mathematical formulation are:

a) the slopes \((M(b), M(c), M(d)\) and \( M(e) \)) of the straight lines;

b) the intercepts \((\text{SPL}(b)\) and \( \text{SPL}(c) \)) of the lines on the SPL axis; and

c) the coordinates of the discontinuities, \( \text{SPL}(a) \) and \( \log n(a) \); \( \text{SPL}(d) \) and \( \log n = -1.0 \); and \( \text{SPL}(e) \) and \( \log n = \log (0.3) \).

4.7.3 The equations are as follows:

a) \( \text{SPL} > \text{SPL}(a) \)
\[ n = \text{antilog} \{ M(c) \left[ \text{SPL} - \text{SPL}(c) \right] \} \]

b) \( \text{SPL}(b) \leq \text{SPL} < \text{SPL}(a) \)
\[ n = \text{antilog} \{ M(b) \left[ \text{SPL} - \text{SPL}(b) \right] \} \]

c) \( \text{SPL}(e) \leq \text{SPL} < \text{SPL}(b) \)
\[ n = 0.3 \text{antilog}_{10} \{ M(e) \left[ \text{SPL} - \text{SPL}(e) \right] \} \]

d) \( \text{SPL}(d) \leq \text{SPL} < \text{SPL}(e) \)
\[ n = 0.1 \text{antilog} \{ M(d) \left[ \text{SPL} - \text{SPL}(d) \right] \} \]

4.7.4 Table 2-2 lists the values of the constants necessary to calculate perceived noisiness as a function of sound pressure level.

5. REPORTING OF DATA TO THE CERTIFYING AUTHORITY

5.1 General

5.1.1 Data representing physical measurements or corrections to measured data shall be recorded in permanent form and appended to the record.

5.1.2 All corrections shall be approved by certifying authority. In particular the corrections to measurements for equipment response deviations shall be reported.

5.1.3 Estimates of the individual errors inherent in each of the operations employed in obtaining the final data shall be reported, if required.

5.2 Data reporting

5.2.1 Measured and corrected sound pressure levels shall be presented in one-third octave band levels obtained with equipment conforming to the Standards described in Section 3 of this appendix.

5.2.2 The type of equipment used for measurement and analysis of all acoustic performance and meteorological data shall be reported.

5.2.3 The following atmospheric environmental data, measured immediately before, after, or during each test at the observation points prescribed in Section 2 of this appendix shall be reported:

a) air temperature and relative humidity;

b) maximum, minimum and average wind velocities; and

c) atmospheric pressure.

5.2.4 Comments on local topography, ground cover, and events that might interfere with sound recordings shall be reported.

5.2.5 The following information shall be reported:

a) type, model and serial numbers (if any) of aircraft, engines, propellers, or rotors (as applicable);

b) gross dimensions of aircraft and location of engines and rotors (if applicable);

c) aircraft gross mass for each test run and centre of gravity range for each series of test runs;

d) aircraft configuration such as flap, airbrakes and landing gear positions and propeller pitch angles (if applicable);

e) whether auxiliary power units (APU), when fitted, are operating;

f) conditions of pneumatic engine bleeds and engine power take-offs;

g) indicated airspeed in kilometres per hour (knots);
### Table 2-2. Constants for mathematically formulated noy values

<table>
<thead>
<tr>
<th>BAND ( i )</th>
<th>( f ) HZ</th>
<th>SPL ( (a) )</th>
<th>SPL ( (b) )</th>
<th>SPL ( (c) )</th>
<th>SPL ( (d) )</th>
<th>SPL ( (e) )</th>
<th>( M(b) )</th>
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<th>( M(e) )</th>
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<tr>
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<td>0.029960</td>
<td>0.079520</td>
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</tr>
<tr>
<td>24</td>
<td>10000</td>
<td>50.7</td>
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<td>29</td>
<td></td>
<td></td>
<td>0.059640</td>
<td>0.043573</td>
</tr>
</tbody>
</table>
h) 1) for jet aeroplanes: engine performance in terms of net thrust, engine pressure ratios, jet exhaust temperatures and fan or compressor shaft rotational speeds as determined from aeroplane instruments and manufacturer’s data;

2) for propeller-driven aeroplanes: engine performance in terms of brake horsepower and residual thrust or equivalent shaft horsepower or engine torque and propeller rotational speed as determined from aeroplane instruments and manufacturer’s data;

3) for helicopters: engine performance and rotor speed in rpm during each demonstration;

i) aircraft flight path and ground speed during each demonstration; and

j) any modifications or non-standard equipment likely to affect the noise characteristics of the aircraft.

5.3 Reporting of noise certification reference conditions

5.3.1 Aircraft position and performance data and the noise measurements shall be corrected to the noise certification reference conditions as specified in the relevant chapter of Part II, and these conditions, including reference parameters, procedures and configurations shall be reported.

5.4 Validity of results

5.4.1 Three average reference EPNL values and their 90 per cent confidence limits shall be produced from the test results and reported, each such value being the arithmetical average of the adjusted acoustical measurements for all valid test runs at the appropriate measurement point (take-off, approach, or lateral or overflight, in the case of helicopters). If more than one acoustic measurement system is used at any single measurement location, the resulting data for each test run shall be averaged as a single measurement. For helicopters, the three microphone test results for each flight should be averaged as a single measurement. The calculation shall be performed by:

a) computing the arithmetic average for each flight phase using the values from each reference microphone point;

b) computing the over-all arithmetic average for each appropriate reference condition (take-off, overflight, or approach) using the values in a) and the related 90 per cent confidence limits.

5.4.2 The minimum sample size acceptable for each of the three certification measuring points for aeroplanes and for each set of three microphones for helicopters is six. The samples shall be large enough to establish statistically for each of the three average noise certification levels a 90 per cent confidence limit not exceeding ±1.5 EPNdB. No test result shall be omitted from the averaging process unless otherwise specified by the certificating authority.

Note.— Methods for calculating the 90 per cent confidence interval are given in Appendix 1 of the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

5.4.3 The average EPNL figures obtained by the foregoing process shall be those by which the noise performance of the aircraft is assessed against the noise certification criteria.

6. NOMENCLATURE: SYMBOLS AND UNITS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>antilog</td>
<td>—</td>
<td>Antilogarithm to the base 10.</td>
</tr>
<tr>
<td>C(k)</td>
<td>dB</td>
<td>Tone correction factor. The factor to be added to PNL(k) to account for the presence of spectral irregularities such as tones at the k-th increment of time.</td>
</tr>
<tr>
<td>d</td>
<td>s</td>
<td>Duration time. The length of the significant noise time history being the time interval between the limits of t(1) and t(2) to the nearest second.</td>
</tr>
<tr>
<td>D</td>
<td>dB</td>
<td>Duration correction. The factor to be added to PNLT to account for the duration of the noise.</td>
</tr>
<tr>
<td>EPNL</td>
<td>EPNdB</td>
<td>Effective perceived noise level. The value of PNL adjusted for both the spectral irregularities and the duration of the noise. (The unit EPNdB is used instead of the unit dB.)</td>
</tr>
</tbody>
</table>
Appendix 2

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(i)$</td>
<td>Hz</td>
<td>Frequency. The geometrical mean frequency for the $i$-th one-third octave band.</td>
</tr>
<tr>
<td>$F(i,k)$</td>
<td>dB</td>
<td>Delta-dB. The difference between the original sound pressure level and the final background sound pressure level in the $i$-th one-third octave band at the $k$-th interval of time.</td>
</tr>
<tr>
<td>$h$</td>
<td>dB</td>
<td>dB-down. The level to be subtracted from PNLTM that defines the duration of the noise.</td>
</tr>
<tr>
<td>$H$</td>
<td>%</td>
<td>Relative humidity. The ambient atmospheric relative humidity.</td>
</tr>
<tr>
<td>$i$</td>
<td>—</td>
<td>Frequency band index. The numerical indicator that denotes any one of the 24 one-third octave bands with geometrical mean frequencies from 50 to 10 000 Hz.</td>
</tr>
<tr>
<td>$k$</td>
<td>—</td>
<td>Time increment index. The numerical indicator that denotes the number of equal time increments that have elapsed from a reference zero.</td>
</tr>
<tr>
<td>$\log$</td>
<td>—</td>
<td>Logarithm to the base 10.</td>
</tr>
<tr>
<td>$\log n(a)$</td>
<td>—</td>
<td>Noy discontinuity co-ordinate. The log $n$ value of the intersection point of the straight lines representing the variation of SPL with log $n$.</td>
</tr>
<tr>
<td>$M(b), M(c), \text{etc.}$</td>
<td>—</td>
<td>Noy inverse slope. The reciprocals of the slopes of straight lines representing the variation of SPL with log $n$.</td>
</tr>
<tr>
<td>$n$</td>
<td>noy</td>
<td>Perceived noisiness. The perceived noisiness at any instant of time that occurs in a specified frequency range.</td>
</tr>
<tr>
<td>$n(i,k)$</td>
<td>noy</td>
<td>Perceived noisiness. The perceived noisiness at the $k$-th instant of time that occurs in the $i$-th one-third octave band.</td>
</tr>
<tr>
<td>$n(k)$</td>
<td>noy</td>
<td>Maximum perceived noisiness. The maximum value of all of the 24 values of $n(i)$ that occurs at the $k$-th instant of time.</td>
</tr>
<tr>
<td>$N(k)$</td>
<td>noy</td>
<td>Total perceived noisiness. The total perceived noisiness at the $k$-th instant of time calculated from the 24-instantaneous values of $n(i,k)$.</td>
</tr>
<tr>
<td>$p(b), p(c), \text{etc.}$</td>
<td>—</td>
<td>Noy slope. The slopes of straight lines representing the variation of SPL with log $n$.</td>
</tr>
<tr>
<td>PNL</td>
<td>PNdB</td>
<td>Perceived noise level. The perceived noise level at any instant of time. (The unit PNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNL($k$)</td>
<td>PNdB</td>
<td>Perceived noise level. The perceived noise level calculated from the 24 values of SPL$(i,k)$ at the $k$-th increment of time. (The unit PNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNLm</td>
<td>PNdB</td>
<td>Maximum perceived noise level. The maximum value of PNL($k$). (The unit PNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNLt</td>
<td>TPNdB</td>
<td>Tone corrected perceived noise level. The value of PNL adjusted for the spectral irregularities that occur at any instant of time. (The unit TPNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNL($t$)</td>
<td>TPNdB</td>
<td>Tone corrected perceived noise level. The value of PNL($t$) adjusted for the spectral irregularities that occur at the $k$-th increment of time. (The unit TPNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNLtm</td>
<td>TPNdB</td>
<td>Maximum tone corrected perceived noise level. The maximum value of PNL($t$). (The unit TPNdB is used instead of the unit dB.)</td>
</tr>
<tr>
<td>PNL$_r$</td>
<td>TPNdB</td>
<td>Tone corrected perceived noise level adjusted for reference conditions.</td>
</tr>
<tr>
<td>$s(i,k)$</td>
<td>dB</td>
<td>Slope of sound pressure level. The change in level between adjacent one-third octave band sound pressure levels at the $i$-th band for the $k$-th instant of time.</td>
</tr>
<tr>
<td>Symbol</td>
<td>Unit</td>
<td>Meaning</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>$\Delta s(i,k)$</td>
<td>dB</td>
<td>Change in slope of sound pressure level. The change in level between adjacent adjusted one-third octave band sound pressure levels at the $i$-th band for the $k$-th instant of time.</td>
</tr>
<tr>
<td>$s'(i,k)$</td>
<td>dB</td>
<td>Adjusted slope of sound pressure level. The change in level between adjacent adjusted one-third octave band sound pressure levels at the $i$-th band for the $k$-th instant of time.</td>
</tr>
<tr>
<td>$\bar{z}(i,k)$</td>
<td>dB</td>
<td>Average slope of sound pressure level.</td>
</tr>
<tr>
<td>SPL</td>
<td>dB re 20 µPa</td>
<td>Sound pressure level. The sound pressure level at any instant of time that occurs in a specified frequency range.</td>
</tr>
<tr>
<td>SPL($a$)</td>
<td>dB re 20 µPa</td>
<td>Noy discontinuity co-ordinate. The SPL value of the intersection point of the straight lines representing the variation of SPL with log $n$.</td>
</tr>
<tr>
<td>SPL($b$)</td>
<td>dB re 20 µPa</td>
<td>Noy intercept. The intercepts on the SPL-axis of the straight lines representing the variation of SPL with log $n$.</td>
</tr>
<tr>
<td>SPL($c$)</td>
<td>dB re 20 µPa</td>
<td>Sound pressure level. The sound pressure level at the $k$-th instant of time that occurs in the $i$-th one-third octave band.</td>
</tr>
<tr>
<td>SPL('($i,k$)</td>
<td>dB re 20 µPa</td>
<td>Adjusted sound pressure level. The first approximation to background sound pressure level in the $i$-th one-third octave band for the $k$-th instant of time.</td>
</tr>
<tr>
<td>SPL($i$)</td>
<td>dB re 20 µPa</td>
<td>Maximum sound pressure level. The sound pressure level that occurs in the $i$-th one-third octave band of the spectrum for PNLT.</td>
</tr>
<tr>
<td>SPL($i_r$)</td>
<td>dB re 20 µPa</td>
<td>Corrected maximum sound pressure level. The sound pressure level that occurs in the $i$-th one-third octave band of the spectrum for PNLT corrected for atmospheric sound absorption.</td>
</tr>
<tr>
<td>SPL(″($i,k$)</td>
<td>dB re 20 µPa</td>
<td>Final background sound pressure level. The second and final approximation to background sound pressure level in the $i$-th one-third octave band for the $k$-th instant of time.</td>
</tr>
<tr>
<td>$t$</td>
<td>s</td>
<td>Elapsed time. The length of time measured from a reference zero.</td>
</tr>
<tr>
<td>$t_1$, $t_2$</td>
<td>s</td>
<td>Time limit. The beginning and end, respectively, of the significant noise time history defined by $h$.</td>
</tr>
<tr>
<td>$\Delta t$</td>
<td>s</td>
<td>Time increment. The equal increments of time for which PNLT($k$) and PNL($k$) are calculated.</td>
</tr>
<tr>
<td>$T$</td>
<td>s</td>
<td>Normalizing time constant. The length of time used as a reference in the integration method for computing duration corrections, where $T = 10$ s.</td>
</tr>
<tr>
<td>$t$ (°C)</td>
<td>°C</td>
<td>Temperature. The ambient atmospheric temperature.</td>
</tr>
<tr>
<td>$\alpha(i)$</td>
<td>dB/100 m</td>
<td>Test atmospheric absorption. The atmospheric attenuation of sound that occurs in the $i$-th one-third octave band for the measured atmospheric temperature and relative humidity.</td>
</tr>
<tr>
<td>$\alpha(i)_0$</td>
<td>dB/100 m</td>
<td>Reference atmospheric absorption. The atmospheric attenuation of sound that occurs in the $i$-th one-third octave band for a reference atmospheric temperature and relative humidity.</td>
</tr>
<tr>
<td>$A_1$</td>
<td>degrees</td>
<td>First constant* climb angle.</td>
</tr>
<tr>
<td>$A_2$</td>
<td>degrees</td>
<td>Second constant** climb angle.</td>
</tr>
<tr>
<td>$\delta$</td>
<td>degrees</td>
<td>Thrust cutback angles. The angles defining the points on the take-off flight path at which thrust reduction is started and ended respectively.</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>degrees</td>
<td>Approach angle.</td>
</tr>
</tbody>
</table>

* Gear up, speed of at least $V_2 + 19$ km/h ($V_2 + 10$ kt), take-off thrust.
** Gear up, speed of at least $V_2 + 19$ km/h ($V_2 + 10$ kt), after cut-back.
Symbol | Unit | Meaning
--- | --- | ---
η | degrees | Reference approach angle.
θ | degrees | Noise angle (relative to flight path). The angle between the flight path and noise path. It is identical for both measured and corrected flight paths.
ψ | degrees | Noise angle (relative to ground). The angle between the noise paths and the grounds. It is identified for both measured and corrected flight paths.
µ | degrees | Engine noise emission parameter. (See 9.3.4.)
Δ₁ | EPNdB | PNLT correction. The correction to be added to the EPNL calculated from measured data to account for noise level changes due to differences in atmospheric absorption and noise path length between reference and test conditions.
Δ₂ | EPNdB | Adjustment to duration correction. The adjustment to be made to the EPNL calculated from measured data to account for noise level changes due to the noise duration between reference and test conditions.
Δ₃ | EPNdB | Source noise adjustment. The adjustment to be made to the EPNL calculated from measured data to account for noise level changes due to differences between reference and test engine regime.

7. SOUND ATTENUATION IN AIR

7.1 The atmospheric attenuation of sound shall be determined in accordance with the procedure presented below.

7.2 The relationship between sound attenuation, frequency, temperature and humidity is expressed by the following equations:

\[ \alpha(i) = 10^{[2.05 \log (f_o/1000) + 1.1394 \times 10^{-3} \theta - 1.916984]} \]

\[ + \eta(\delta) \times 10^{[\log (f_o) + 8.42994 \times 10^{-3} \theta - 2.755624]} \]

\[ \delta = \frac{1010}{f_o} 10^{[\log H - 1.328924 + 3.179768 \times 10^{-2} \theta - 1.328924]} \]

\[ \times 10^{-2.173716 \times 10^{-2} \theta^2 + 1.7496 \times 10^{-6} \theta^3} \]

where:

\( \eta(\delta) \) is given by Table 2-3 and \( f_o \) by Table 2-4;

\( \alpha(i) \) being the attenuation coefficient in dB/100 m;

\( \theta \) being the temperature in °C; and

\( H \) being the relative humidity expressed as a percentage.

7.3 The equations given in 7.2 are convenient for calculation by means of a computer.

8. ADJUSTMENT OF HELICOPTER FLIGHT TEST RESULTS

8.1 General

8.1.1 Adjustments shall be made to the measured noise data by the methods of this section. Compliance with the test conditions of Chapter 8, 8.7.5 is necessary for the test to be acceptable. Adjustments shall be made for differences between test and reference flight procedures and shall account for differences in the following:

a) helicopter flight path and velocity relative to the flight path reference point;

b) sound attenuation in air;

c) in the overflight case, parameters affecting the noise generating mechanisms such as those described in 8.5.

8.1.2 Adjustments to the measured noise data shall be made using the methods prescribed in 8.3 and 8.4, for differences in the following:

a) attenuation of the noise along its path as affected by “inverse square” and atmospheric attenuation;

b) duration of the noise as affected by distance and speed of aircraft relative to the flight path reference point;
### Table 2.3 Values of $\eta(\delta)$

<table>
<thead>
<tr>
<th>$\delta$</th>
<th>$\eta(\delta)$</th>
<th>$\delta$</th>
<th>$\eta(\delta)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.000</td>
<td>2.50</td>
<td>0.450</td>
</tr>
<tr>
<td>0.25</td>
<td>0.315</td>
<td>2.80</td>
<td>0.400</td>
</tr>
<tr>
<td>0.50</td>
<td>0.700</td>
<td>3.00</td>
<td>0.370</td>
</tr>
<tr>
<td>0.60</td>
<td>0.840</td>
<td>3.30</td>
<td>0.330</td>
</tr>
<tr>
<td>0.70</td>
<td>0.930</td>
<td>3.60</td>
<td>0.300</td>
</tr>
<tr>
<td>0.80</td>
<td>0.975</td>
<td>4.15</td>
<td>0.260</td>
</tr>
<tr>
<td>0.90</td>
<td>0.996</td>
<td>4.45</td>
<td>0.245</td>
</tr>
<tr>
<td>1.00</td>
<td>1.000</td>
<td>4.80</td>
<td>0.230</td>
</tr>
<tr>
<td>1.10</td>
<td>0.970</td>
<td>5.25</td>
<td>0.220</td>
</tr>
<tr>
<td>1.20</td>
<td>0.900</td>
<td>5.70</td>
<td>0.210</td>
</tr>
<tr>
<td>1.30</td>
<td>0.840</td>
<td>6.05</td>
<td>0.205</td>
</tr>
<tr>
<td>1.50</td>
<td>0.750</td>
<td>6.50</td>
<td>0.200</td>
</tr>
<tr>
<td>1.70</td>
<td>0.670</td>
<td>7.00</td>
<td>0.200</td>
</tr>
<tr>
<td>2.00</td>
<td>0.570</td>
<td>10.00</td>
<td>0.200</td>
</tr>
<tr>
<td>2.30</td>
<td>0.495</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A term of quadratic interpolation shall be used where necessary.

### Table 2.4 Value of $f_o$

<table>
<thead>
<tr>
<th>Centre frequency of the 1/3 octave band (Hz)</th>
<th>$f_o$ (Hz)</th>
<th>Centre frequency of the 1/3 octave band (Hz)</th>
<th>$f_o$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>63</td>
<td>63</td>
<td>1 000</td>
<td>1 000</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>1 250</td>
<td>1 250</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>1 600</td>
<td>1 600</td>
</tr>
<tr>
<td>125</td>
<td>125</td>
<td>2 000</td>
<td>2 000</td>
</tr>
<tr>
<td>160</td>
<td>160</td>
<td>2 500</td>
<td>2 500</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
<td>3 150</td>
<td>3 150</td>
</tr>
<tr>
<td>250</td>
<td>250</td>
<td>4 000</td>
<td>4 000</td>
</tr>
<tr>
<td>315</td>
<td>315</td>
<td>5 000</td>
<td>4 500</td>
</tr>
<tr>
<td>400</td>
<td>400</td>
<td>6 300</td>
<td>5 600</td>
</tr>
<tr>
<td>500</td>
<td>500</td>
<td>8 000</td>
<td>7 100</td>
</tr>
<tr>
<td>630</td>
<td>630</td>
<td>10 000</td>
<td>9 000</td>
</tr>
</tbody>
</table>
c) the adjustment procedure described in this section shall apply to the lateral microphones in the take-off, overflight and approach cases. Although the noise emission is strongly dependent on the directivity pattern, variable from one helicopter type to another, the propagation angle $\psi$, defined in Appendix 2, 9.3.2, Figure 2-11, shall be the same for the test and reference flight paths. The elevation angle $\psi$ shall not be constrained as in the third note of Appendix 2, 9.3.2, but must be determined and reported. The certification authority shall specify the acceptable limitations on $\psi$. Corrections to data obtained when these limits are exceeded shall be applied using procedures approved by the certificating authority. In the particular case of lateral noise measurement, sound propagation is affected not only by “inverse square” and atmospheric attenuation, but also by ground absorption and reflection effects which depend mainly on the angle $\psi$.

Note 1.— Chapter 8, 8.7.5 in Part II of this volume places limits on the maximum adjustments that may be made between test and reference flight procedures and conditions.

Note 2.— Adjustments of noise levels for test to reference conditions may be made, subject to agreement by the certificating authority, by the methods of this section. The corrections are derived from sets of curves linking the instant at which the PNLTM is emitted for each reference procedure with appropriate parameters. The sensitivity curves provide noise level variations as a function of the parameter for which a correction is necessary.

8.2 Flight profiles

Note.— Flight profiles for the test conditions are described by their geometry relative to the ground, together with the associated helicopter speed.

8.2.1 Take-off profile

Note 1.— Figure 2-4 illustrates typical test and reference profiles.

a) During actual testing the helicopter is initially stabilized in level flight at the best rate of climb speed, $V_y$, at a point $A$ and continues to a point $B$ where take-off power is applied and a steady climb is initiated. A steady climb shall be maintained throughout the 10 dB-down period and beyond to the end of the certification flight path (point $F$).

b) Position $K_1$ is the take-off flight path reference point and $NK_1$ is the distance from the initiation of the steady climb to the take-off flight path reference point. Positions $K_1'$ and $K_1''$ are associated noise measurement points located on a line at right angles to and at the specified distance from the take-off flight track TM.

c) The distance TM is the distance over which the helicopter position is measured and synchronized with the noise measurements (see 2.3.2 of this appendix).

Note 2.— The position of point B may vary within the limits allowed by the certificating authority.

8.2.2 Overflight profile

Note.— Figure 2-5 illustrates a typical overflight profile.

a) The helicopter is stabilized in level flight at point D and flies through point W, overhead the flight path reference point, to point E, the end of the noise certification overflight flight path.

b) Position $K_2$ is the overflight flight path reference point and $K_2W$ is the height of the helicopter overhead the overflight flight path reference point. Positions $K_2'$ and $K_2''$ are associated noise measurement points located on a line at right angles to and at the specified distance from the overflight flight track RS.

c) The distance RS is the distance over which the helicopter position is measured and synchronized with the noise measurements (see 2.3.2 of this appendix).

8.2.3 Approach profile

Note.— Figure 2-6 illustrates a typical approach profile.

a) The helicopter is initially stabilized at the specified approach path angle at point G and continues through point H, point I and then to touchdown.

b) Position $K_3$ is the approach flight path reference point and $K_3H$ is the height of the helicopter overhead the approach flight path reference point. Positions $K_3'$ and $K_3''$ are associated noise measurement locations on a line at right angles to and at the specified distance from the approach flight path track PU.

c) The distance PU is the distance over which the helicopter position is measured and synchronized with the noise measurements (see 2.3.2 of this appendix).
Figure 2-4. Typical test and reference profiles

Figure 2-5. Typical overflight profile
Figure 2-6. Typical approach profile

Figure 2-7. Profile characteristics influencing sound level
8.3 Adjustments of PNL and PNLT

Note.— The portions of the test flight path and reference flight path which are significant for the EPNL calculation are illustrated in Figure 2-7 for take-off, overflight and approach measurements.

a) XY represents the useful portion of the measured flight path and XrYr, that of the corresponding reference flight path.

b) Q represents the helicopter position on the measured flight path at which the noise was emitted and observed as PNLT at the noise measuring point K. Qr is the corresponding position on the reference flight path and Kr is the reference noise measuring point. QK and QrKr are respectively the measured and reference noise propagation paths, Q, being located on the assumption that QK and QrKr form the same angle I with their respective flight paths.

8.3.1 The one-third octave band levels SPL(i) comprising PNL (the PNL at the moment of PNLT observed at K) shall be adjusted to reference levels SPL(i)r as follows:

\[
\text{SPL}(i)_r = \text{SPL}(i) + 0.01 [\alpha(i) - \alpha(i)_o] \text{ QK} + 0.01 \alpha(i)_o (\text{QK} - \text{QrKr}) + 20 \log (\text{QK}/\text{QrKr})
\]

In this expression:

— the term 0.01 \([\alpha(i) - \alpha(i)_o]\) QK accounts for the effect of the change in sound attenuation coefficient and \(\alpha(i)\) and \(\alpha(i)_o\) are the coefficients for the test and reference atmospheric conditions respectively, obtained from Section 7 of this Appendix;

— the term 0.01 \(\alpha(i)_o (\text{QK} - \text{QrKr})\) accounts for the effect of the change in the noise path length on the sound attenuation;

— the term 20 log (QK/QrKr) accounts for the effect of the change in the noise path length due to the “inverse square” law;

— QK and QrKr are measured in metres and \(\alpha(i)\) and \(\alpha(i)_o\) are in dB/100 m.

Note.— When SPL(i) is zero (for example as a result of applying background noise corrections) SPL(i)r must also be kept equal to zero in the adjustment process.

8.3.2 The corrected values SPL(i)r shall be converted to PNLT, and a correction term calculated as follows:

\[
\Delta_1 = \text{PNLT}_r - \text{PNLT}\]

8.3.3 \(\Delta_1\) shall be added algebraically to the EPNL calculated from the measured data.

8.3.4 If, during a test flight, several peak values of PNLT are observed which are within 2 dB of PNLT, the procedure defined in 8.3.1, 8.3.2 and 8.3.3 shall be applied at each peak and the adjustment term so calculated shall be added to each peak to give corresponding adjusted peak values of PNLT. If these peak values exceed that at the moment of PNL, the maximum value of such excess shall be added as a further adjustment to the EPNL calculated from the measured data.

8.4 Adjustments of duration correction

8.4.1 Whenever the measured flight paths and/or the ground velocities in the test conditions differ from the reference flight paths and/or the ground velocities in the reference conditions, duration adjustments shall be applied to the EPNL values calculated from the measured data. The adjustments shall be calculated as described below.

8.4.2 Referring to the flight path shown in Figure 2-7, the adjustment term shall be calculated as follows:

\[
\Delta_2 = -7.5 \log (\text{QK}/\text{QrKr}) + 10 \log (V/V_r)
\]

which represents the adjustment to be added algebraically to the EPNL calculated from the measured data.

8.5 Correction of noise at source

For overflight, if any combination of the following three factors:

a) airspeed deviations from reference;

b) rotor speed deviations from reference;

c) temperature deviations from reference;

results in an agreed noise correlating parameter whose value deviates from the reference value of this parameter, then source noise adjustments shall be determined from manufacturer’s data approved by the certificating authority. This correction should normally be made using a sensitivity curve of PNLT versus advancing blade tip Mach number; however, the correction may be made using an alternative parameter, or parameters, approved by the certificating authority.

Note 1.— If it is not possible to attain the reference value of advancing blade tip Mach number or the agreed reference noise correlating parameter then an extrapolation of the sensitivity curve is permitted providing that the data cover a range of values of the noise correlating parameter agreed by
Appendix 2

8.6 Flight path identification positions and parameters

8.6.1 General

<table>
<thead>
<tr>
<th>Position/parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Noise measurement point</td>
</tr>
<tr>
<td>K&lt;sub&gt;r&lt;/sub&gt;</td>
<td>Reference measurement point</td>
</tr>
<tr>
<td>Q</td>
<td>Position on measured flight path corresponding to apparent PNLTM at position K (see 8.3.2)</td>
</tr>
<tr>
<td>Q&lt;sub&gt;r&lt;/sub&gt;</td>
<td>Position on corrected flight path corresponding to PNLTM at position K&lt;sub&gt;r&lt;/sub&gt; (see 8.3.2)</td>
</tr>
<tr>
<td>V</td>
<td>Helicopter test ground speed</td>
</tr>
<tr>
<td>V&lt;sub&gt;r&lt;/sub&gt;</td>
<td>Helicopter reference ground speed</td>
</tr>
<tr>
<td>V&lt;sub&gt;H&lt;/sub&gt;</td>
<td>Maximum speed in level flight at power not exceeding maximum continuous power</td>
</tr>
<tr>
<td>V&lt;sub&gt;NE&lt;/sub&gt;</td>
<td>Never exceed speed</td>
</tr>
<tr>
<td>V&lt;sub&gt;y&lt;/sub&gt;</td>
<td>Speed for best rate of climb</td>
</tr>
</tbody>
</table>

8.6.2 Take-off (see Figure 2-4)

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Start of noise certification take-off flight path</td>
</tr>
<tr>
<td>B</td>
<td>Start of transition to climb</td>
</tr>
<tr>
<td>F</td>
<td>End of noise certification take-off flight path</td>
</tr>
<tr>
<td>K&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Take-off flight path reference point</td>
</tr>
<tr>
<td>K&lt;sub&gt;1&lt;/sub&gt;’, K&lt;sub&gt;1&lt;/sub&gt;”</td>
<td>Associated noise measurement points (of 3-microphone array)</td>
</tr>
<tr>
<td>M</td>
<td>End of noise certification take-off flight track</td>
</tr>
<tr>
<td>N</td>
<td>Point on ground vertically below start of transition to climb</td>
</tr>
<tr>
<td>T</td>
<td>Start of noise certification take-off flight track, point on ground vertically below A</td>
</tr>
</tbody>
</table>

8.6.3 Overflight (see Figure 2-5)

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Start of noise certification overflight flight path</td>
</tr>
<tr>
<td>E</td>
<td>End of noise certification overflight flight path</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Overflight flight path reference point</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;’, K&lt;sub&gt;2&lt;/sub&gt;”</td>
<td>Associated noise measurement points (of 3-microphone array)</td>
</tr>
<tr>
<td>R</td>
<td>Start of noise certification overflight flight track</td>
</tr>
<tr>
<td>S</td>
<td>End of noise certification overflight flight track</td>
</tr>
</tbody>
</table>

8.6.4 Approach (see Figure 2-6)

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Start of noise certification approach flight path</td>
</tr>
<tr>
<td>H</td>
<td>Position on approach path vertically above approach flight path reference point</td>
</tr>
<tr>
<td>I</td>
<td>End of noise certification approach flight path</td>
</tr>
<tr>
<td>J</td>
<td>Touchdown</td>
</tr>
<tr>
<td>K&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Approach flight path reference point</td>
</tr>
<tr>
<td>K&lt;sub&gt;3&lt;/sub&gt;’, K&lt;sub&gt;3&lt;/sub&gt;”</td>
<td>Associated noise measurement points (of 3-microphone array)</td>
</tr>
<tr>
<td>O</td>
<td>Intersection of the approach path with the ground plane</td>
</tr>
<tr>
<td>P</td>
<td>Start of noise certification approach flight track</td>
</tr>
<tr>
<td>U</td>
<td>Point on ground vertically below start of flare</td>
</tr>
</tbody>
</table>

8.7 Flight path distance

<table>
<thead>
<tr>
<th>Distance</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>NK&lt;sub&gt;1&lt;/sub&gt;</td>
<td>metres</td>
<td>Take-off measurement distance. The distance from start of transition to climb to the take-off flight path reference point.</td>
</tr>
<tr>
<td>TM</td>
<td>metres</td>
<td>Take-off flight track distance. The distance over which the position of the helicopter is to be recorded.</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;W</td>
<td>metres (feet)</td>
<td>Helicopter overflight height. The height of the helicopter above the overflight flight reference point.</td>
</tr>
<tr>
<td>RS</td>
<td>metres</td>
<td>Overflight flight track distance. The distance over which the position of the helicopter is to be recorded.</td>
</tr>
<tr>
<td>K&lt;sub&gt;3&lt;/sub&gt;H</td>
<td>metres (feet)</td>
<td>Helicopter approach height. The height of the helicopter above the approach flight reference point.</td>
</tr>
</tbody>
</table>
9. ADJUSTMENT OF AEROPLANE FLIGHT TEST RESULTS

9.1 When certification test conditions are not identical to reference conditions, appropriate adjustments shall be made to the measured noise data by the methods of this Section.

Note.— Differences between test and reference conditions result in differences in the following:

— aeroplane flight path and velocity relative to measurement point
— sound attenuation in air
— parameters affecting engine-noise generating mechanisms.

9.1.1 Adjustments to the measured noise values shall be made by one of the methods described in 9.3 and 9.4 for differences in the following:

— attenuation of the noise along its path as affected by “inverse square” and atmospheric attenuation
— duration of the noise as affected by distance and speed of aeroplane relative to measuring point
— source noise emitted by engine as affected by the relevant parameters
— aeroplane/engine source noise as affected by large differences between test and reference airspeeds. In addition to the effect on duration, the effects of airspeed on component noise sources can also become significant and must be considered; for conventional aeroplane configurations, when differences between test and reference airspeeds exceed 28 km/h (15 kt) true airspeed, test data and/or analysis approved by the certificating authority shall be used to quantify effects of airspeed adjustment on resulting certification noise levels.

9.1.2 The “integrated” method described in 9.4 shall be used on flyover or approach under the following conditions:

a) when the amount of the adjustments (using the “simplified” method) is greater than 8 dB on flyover, or 4 dB on approach; or

b) when the resulting final EPNL value on flyover or approach (using the “simplified” method) is within 1 dB of the limited noise levels as prescribed in 3.4 of Chapter 5.

Note.— See also Part II, Chapter 3, 3.7.6.

9.2 Flight profiles

Note.— Flight profiles for both test and reference conditions are described by their geometry relative to the ground, together with the associated aircraft speed relative to the ground, and the associated engine control parameter(s) used for determining the noise emission of the aeroplane.

9.2.1 Take-off profile

Note.— Figure 2-8 illustrates a typical take-off profile.

a) The aeroplane begins the take-off roll at point A, lifts off at point B and begins its first climb at constant angle at point C. Where thrust or power (as appropriate) cut-back is used, it is started at point D and completed at point E. From here the aeroplane begins a second climb at constant angle up to point F, the end of the noise certification take-off flight path.

b) Position \( K_1 \) is the take-off noise measuring station and \( AK_1 \) is the distance from start of roll to the flyover measuring point. Position \( K_2 \) is the lateral noise measuring station located on a line parallel to and the specified distance from the runway centre line where the noise level during take-off is greatest.

c) The distance \( AF \) is the distance over which the aeroplane position is measured and synchronized with the noise measurements (see 2.3.2 of this appendix).

9.2.2 Approach profile

Note.— Figure 2-9 illustrates a typical approach profile.

a) The aeroplane begins its noise certification approach flight path at point G and touches down on the runway at point J, and at a distance OJ from the threshold.

b) Position \( K_3 \) is the approach noise measuring station and \( AK_3 \) is the distance from start of roll to the flyover measuring point. Position \( K_2 \) is the lateral noise measuring station located on a line parallel to and the specified distance from the runway centre line where the noise level during take-off is greatest.

c) The distance \( GI \) is the distance over which the aeroplane position is measured and synchronized with the noise measurements (see 2.3.2 of this appendix).

The aeroplane reference point during approach measurements shall be the ILS antenna.
Figure 2-8. Typical take-off profile

Figure 2-9. Typical approach profile
Figure 2-10. Profile characteristics influencing sound level

Figure 2-11. Lateral measurement — determination of reference station
9.3 “Simplified” method of adjustment

9.3.1 General

Note.— The “simplified” adjustment method consists of applying adjustments to the EPNL calculated from the measured data for the differences between measured and reference conditions at the moment of PNLTM.

9.3.2 Adjustments to PNL and PNLT

Note 1.— The portions of the test flight path and the reference flight path which are significant for the EPNL calculation are illustrated in Figure 2-10 for the flyover and approach noise measurements.

a) XY represents the useful portion of the measured flight path, and XrYr that of the corresponding reference flight path.

b) Q represents the aeroplane position on the measured flight path at which the noise was emitted and observed as PNLTM at the noise measuring station K. Qr is the corresponding position on the reference flight path and Kr, the reference measuring station. QK and QrKr are respectively the measured and reference noise propagation paths, Qr being found from the assumption that QK and QrKr form the same angle θ with their respective flight paths.

Note 2.— The portions of test flight path and reference flight path which are significant for the EPNL calculation are illustrated in Figure 2-11 a) and b) for the lateral noise measurements.

a) XY represents the useful portion of the measured flight path (Figure 2-11 a)), and XrYr that of the corresponding reference flight path (Figure 2-11 b)).

b) Q represents the aeroplane position on the measured flight path at which the noise was emitted and observed as PNLT at the noise measuring station K. Qr is the corresponding position on the reference flight path and Kr, the reference measuring station. QK and QrKr are respectively the measured and reference noise propagation paths. In this case Kr is only specified as being on a particular lateral line; K1 and Qr are therefore found from the assumptions that QK and QrKr:

1) form the same angle θ with their respective flight paths, and

2) form the same angle ψ with the ground.

Note 3.— In the particular case of lateral noise measurement, sound propagation is affected not only by “inverse square” and atmospheric attenuation, but also by ground absorption and reflection effects which depend mainly on the angle ψ.

9.3.2.1 The one-third octave band levels SPL(i) comprising PNL (the PNL at the moment of PNLT at K) shall be adjusted to reference levels SPL(i)r as follows:

\[
SPL(i)_r = SPL(i) + 0.01 [\alpha(i) - \alpha(i)_0] QK + 0.01 \alpha(i)_0 (QK - QrKr) + 20 \log (QK/QrKr)
\]

In this expression,

— the term 0.01 [\alpha(i) - \alpha(i)_0] QK accounts for the effect of the change in sound attenuation coefficient, and \(\alpha(i)_0\) are the coefficients for the test and reference atmospheric conditions respectively, obtained from Section 7;

— the term 0.01 \(\alpha(i)_0 (QK - QrKr)\) accounts for the effect of the change in the noise path length on the sound attenuation;

— the term 20 log (QK/QrKr) accounts for the effect of the change in the noise path length due to the “inverse square” law;

— QK and QrKr are measured in metres and \(\alpha(i)\) and \(\alpha(i)_0\) are in dB/100 m.

Note.— When SPL(i) is zero (for example as a result of applying background noise corrections) SPL(i)r must also be kept equal to zero in the adjustment process.

9.3.2.2 The corrected values SPL(i)_r shall be converted to PNLT_r, and a correction term calculated as follows:

\[
\Delta_1 = PNLT_r - PNLT
\]

9.3.2.1.2 \(\Delta_1\) shall be added algebraically to the EPNL calculated from the measured data.

9.3.2.2 If, during a test flight, several peak values of PNLT are observed which are within 2 dB of PNLTM, the procedure defined in 9.3.2.1 shall be applied at each peak and the adjustment term calculated as in 9.3.2.1 shall be added to each peak to give corresponding adjusted peak values of PNLT. If these peak values exceed that at the moment of PNLTM, the maximum value of such exceedance shall be added as a further adjustment to the EPNL calculated from the measured data.

9.3.3 Adjustments to duration correction

9.3.3.1 Whenever the measured flight paths and/or the ground velocities in the test conditions differ from the...
reference flight paths and/or the ground velocities in the reference conditions, duration adjustments shall be applied to the EPNL values calculated from the measured data. The adjustments shall be calculated as described below.

9.3.3.2 Referring to the flight path shown in Figure 2-10 the adjustment term shall be calculated as follows:

\[
\Delta_2 = -7.5 \log(Q_K/Q_r) + 10 \log(V/V_r)
\]

which represents the adjustment to be added algebraically to the EPNL calculated from the measured data.

9.3.4 Source noise adjustments

9.3.4.1 The source noise adjustment shall be applied to take account of differences between the parameters affecting engine noise measured in the certification flight tests and those calculated or specified in the reference conditions. The adjustment shall be determined from manufacturers’ data approved by the certificating authority.

Note.— Typical data are illustrated in Figure 2-12 which shows a curve of EPNL versus the engine control parameter \( \mu \), the EPNL data being corrected to all the other relevant reference conditions (aeroplane mass, speed and altitude, air temperature) and for the difference in noise between the installed engine and the flight manual standard of engine at each value of \( \mu \). Data of this type are required around the values of \( \mu \) used for lateral, flyover and approach noise measurements.

9.3.4.2 The adjustment term \( \Delta_3 \) shall be obtained by subtracting the EPNL value corresponding to the parameter \( \mu \) from the EPNL value corresponding to the parameter \( \mu_r \) and shall be added algebraically to the EPNL value calculated from the measured data.

Note.— See Figure 2-12 in which \( \mu, \mu_r \) is the value of the engine control parameter in the flight test conditions, \( \mu_r \) is the corresponding value in the reference conditions.

9.3.5 Symmetry adjustments

9.3.5.1 For the lateral noise, a symmetry adjustment shall be made (see Chapter 3, 3.3.2.2) as follows:

— if the symmetrical measurement point is opposite the point where the highest noise level is obtained on the main lateral measurement line, the certification noise level shall be the (arithmetical) mean of the noise levels measured at these two points (see Figure 2-13 a));

— if not, it shall be assumed that the variation of noise with the altitude of the aeroplane is the same on both sides (i.e. there is a constant difference between the lines of noise versus altitude on the two sides (see Figure 2-13 b)). The certification noise level shall then be the maximum value of the mean between these lines. 

9.4 “Integrated” method of adjustment

9.4.1 General

Note.— The “integrated” adjustment method consists of recomputing under reference conditions points on the PNLT time history corresponding to measured points obtained during the tests, and computing EPNL directly for the new time history obtained in this way. The main principles are described below.

9.4.2 PNLT computations

Note 1.— The portions of the test flight path and the reference profile which are significant for the EPNL computation are illustrated in Figure 2-14 for the flyover, full-power and approach noise measurements.

a) XY represents the useful portion of the measured flight path and \( X_rY_r \) that of the corresponding reference flight path;

b) The points \( Q_0, Q_1, Q_n \) represent aeroplane positions on the measured flight path at time \( t_0, t_1, t_n \) respectively. Consider the point \( Q_1 \) at which the noise was emitted and observed as one-third octave values SPL\((i)_1 \) at the noise measuring station \( K \) at time \( t_1 \). The point \( Q_1 \) represents the corresponding position on the reference flight path for noise observed as SPL\((i)_{1r} \) at the reference measuring station \( K_r \) at time \( t_{1r} \). If \( Q_nK_0 \) and \( Q_nK_r \) are respectively the measured and reference noise propagation paths which in each case form the angle \( \theta_n \) with their respective flight paths, \( Q_0, Q_0r \) are similarly the points on the reference flight path corresponding to \( Q_0, Q_n \) on the measured flight path. \( Q_0, Q_0r \) are chosen so that between \( Q_0, Q_n \) all values of PNLT\(_r\) (computed and described below) within 10 dB of the peak value are included.

Note 2.— The portions of the test flight path and the reference profile which are significant for the EPNL computation are illustrated in Figure 2-15 a) and b) for the lateral noise measurements.

a) XY represents the useful portion of the measured flight path and \( X_rY_r \) that of the corresponding reference flight path;
Figure 2-12. Noise thrust correction

Figure 2-13. Symmetry correction

Figure 2-14. Correspondence between measured and reference flight paths for application of correction integrated methods
Figure 2-15 a). Measured flight path

Figure 2-15 b). Reference flight path
Appendix 2

b) The points Q_n, Q_1, Q_r represent aeroplane positions on the measured flight path at time t_0, t_1, and t_r respectively. Consider the point Q_1 at which the noise was emitted and observed as one-third octave values SPL(\theta_1) at the noise measuring station K at time t_1. The point Q_{1r} represents the corresponding position on the reference flight path for noise observed as SPL(\theta_{1r}) at the measuring station K_r at time t_{1r}. Q_0 and Q_{1r} are respectively the measured and reference noise propagation paths. Q_n and Q_{nr} are similarly the points on the reference flight path corresponding to Q_0 and Q_n on the measured flight path. Q_0 and Q_n are chosen so that between Q_0 Q_n and all values of PNLT (computed and described below) within 10 dB of the peak value are included. In this case K_r is only specified as being on a particular lateral line. The position of K_r and Q_{1r} are found from the assumptions that:

1) Q_1K and Q_{1r}K_r form the same angle \theta_1 with their respective flight paths for all times t_1; and

2) the differences between the angles \psi_1 and \psi_{1r} are minimized over the relevant part of the time history by a method approved by the certificating authorities.

Note 3.— In the particular case of lateral noise measurement, sound propagation is affected not only by “inverse square” and atmospheric attenuation, but also by ground absorption and reflection effects which depend mainly on the angle \psi. For geometrical reasons it is generally not possible to choose K_r so that condition 1) above is fulfilled while at the same time \psi_1 and \psi_{1r} are kept equal at all times t_1.

Note 4.— The time t_{1r} is later (for Q_{1r}K_r > Q_1K) than t_1 by two separate amounts:

1) the time taken for the aeroplane to travel the distance Q_{1r}Q_0 at a speed V, less the time taken for it to travel Q_1Q_0 at V;

2) the time taken for sound to travel the distance Q_{1r}K_r – Q_1K.

Note 5.— Where thrust or power cut-back is used there will be test and reference flight paths at full thrust or power and at cut-back thrust or power. Where the transient region between these affects the final result an interpolation must be made between them by an approved method such as that given in Section 2.2.1 of the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

9.4.2.1 The measured values of SPL(\theta_1) etc. shall be adjusted to the reference values SPL(\theta_{1r}) etc. for the differences between measured and reference noise path lengths and between measured and reference atmospheric conditions, by the methods of 9.3.2.1 of this appendix. Corresponding values of PNLT_{1r} shall be computed.

9.4.2.2 For each value of PNLT_{1r} a pure sound correction C_1 shall be determined by analysing the reference values SPL(\theta), etc. by the methods of 4.3 of this appendix, and added to PNLT to give PNLT_{1r}.

9.4.3 Duration correction

9.4.3.1 The values of PNLT_{1r} corresponding to those of PNLT at each one-half second interval shall be plotted against time (PNLT_{1r} at time t_{1r} etc.). The duration correction shall then be determined by the method of 4.5.1 of this appendix, to give EPNL_{1r}.

9.4.4 Source noise adjustment

9.4.4.1 Finally, a source noise adjustment \Delta_3 shall be determined by the methods by 9.3.4 of this appendix.

9.5 Flight path identification positions

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Start of take-off roll.</td>
</tr>
<tr>
<td>B</td>
<td>Lift-off.</td>
</tr>
<tr>
<td>C</td>
<td>Start of first constant climb.</td>
</tr>
<tr>
<td>D</td>
<td>Start of thrust reduction.</td>
</tr>
<tr>
<td>E</td>
<td>Start of second constant climb.</td>
</tr>
<tr>
<td>F</td>
<td>End of noise certification take-off flight path.</td>
</tr>
<tr>
<td>G</td>
<td>Start of noise certification approach flight path.</td>
</tr>
<tr>
<td>H</td>
<td>Position on approach path directly above noise measuring station.</td>
</tr>
<tr>
<td>I</td>
<td>Start of level-off.</td>
</tr>
<tr>
<td>J</td>
<td>Touchdown.</td>
</tr>
<tr>
<td>K</td>
<td>Noise measurement point.</td>
</tr>
<tr>
<td>K_r</td>
<td>Reference measurement point.</td>
</tr>
<tr>
<td>K_1</td>
<td>Flyover noise measurement point.</td>
</tr>
<tr>
<td>K_2</td>
<td>Lateral noise measurement point.</td>
</tr>
<tr>
<td>K_3</td>
<td>Approach noise measurement point.</td>
</tr>
<tr>
<td>M</td>
<td>End of noise certification take-off flight track.</td>
</tr>
<tr>
<td>O</td>
<td>Threshold of approach end of runway.</td>
</tr>
<tr>
<td>P</td>
<td>Start of noise certification approach flight track.</td>
</tr>
<tr>
<td>Q</td>
<td>Position on measured take-off flight path corresponding to apparent PNLT at station K. See 9.3.2.</td>
</tr>
<tr>
<td>Q_r</td>
<td>Position on corrected take-off flight path corresponding to PNLT at station K. See 9.3.2.</td>
</tr>
<tr>
<td>V</td>
<td>Aeroplane test speed.</td>
</tr>
<tr>
<td>V_r</td>
<td>Aeroplane reference speed.</td>
</tr>
</tbody>
</table>
### 9.6 Flight path distances

<table>
<thead>
<tr>
<th>Distance</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>metres</td>
<td><em>Length of take-off roll.</em> The distance along the runway between the start of take-off roll and lift off.</td>
</tr>
<tr>
<td>AK</td>
<td>metres</td>
<td><em>Take-off measurement distance.</em> The distance from the start of roll to the take-off noise measurement station along the extended centre line of the runway.</td>
</tr>
<tr>
<td>AM</td>
<td>metres</td>
<td><em>Take-off flight track distance.</em> The distance from the start of roll to the take-off flight track position along the extended centre line of the runway for which the position of the aeroplane need no longer be recorded.</td>
</tr>
<tr>
<td>QK</td>
<td>metres</td>
<td><em>Measured noise path.</em> The distance from the measured aeroplane position Q to station K.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance</th>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qₜ,Kₜ</td>
<td>metres</td>
<td>Reference noise path. The distance from the reference aeroplane position Qₜ to station Kₜ.</td>
</tr>
<tr>
<td>K₃H</td>
<td>metres</td>
<td>(feet) <em>Aeroplane approach height.</em> The height of the aeroplane above the approach measuring station.</td>
</tr>
<tr>
<td>OK₃</td>
<td>metres</td>
<td>Approach measurement distance. The distance from the runway threshold to the approach measurement station along the extended centre line of the runway.</td>
</tr>
<tr>
<td>OP</td>
<td>metres</td>
<td>Approach flight track distance. The distance from the runway threshold to the approach flight track position along the extended centre line of the runway for which the position of the aeroplane need no longer be recorded.</td>
</tr>
</tbody>
</table>
APPENDIX 3. NOISE EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED BEFORE 17 NOVEMBER 1988

Note.— See Part II, Chapter 6.

1. INTRODUCTION

Note 1.— This noise evaluation method includes:

a) noise certification test and measurement conditions;
b) measurement of aeroplane noise received on the ground; and
c) reporting of data to the certificating authority and correction of measured data.

Note 2.— The instructions and procedures given in the method are clearly delineated to ensure uniformity during compliance tests, and to permit comparison between tests of various types of aeroplanes, conducted in various geographical locations. The method applies only to aeroplanes within the applicability clauses of Part II, Chapter 6.

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

This section prescribes the conditions under which noise certification tests shall be conducted and the measurement procedures that shall be used to measure the noise made by the aeroplane for which the test is conducted.

2.2 General test conditions

2.2.1 Locations for measuring noise from an aeroplane in flight shall be surrounded by relatively flat terrain having no excessive sound absorption characteristics such as might be caused by thick, matted, or tall grass, shrubs, or wooded areas. No obstructions which significantly influence the sound field from the aeroplane shall exist within a conical space above the measurement position, the cone being defined by an axis normal to the ground and by a half-angle 75° from this axis.

2.2.2 The tests shall be carried out under the following atmospheric conditions:

   a) no precipitation;
   b) relative humidity not higher than 95 per cent and not lower than 20 per cent and ambient temperature not above 35°C and not below 2°C at 1.2 m (4 ft) above ground except that on a diagram of temperature plotted against relative humidity combinations of temperature and relative humidity which fall below a straight line between 2°C and 60 per cent and 35°C and 20 per cent shall be avoided;
   c) reported wind not above 19 km/h (10 kt) at 1.2 m (4 ft) above ground and cross-wind component not above 9 km/h (5 kt) at 1.2 m (4 ft) above ground. Flights shall be made in equal numbers with tail and head wind components; and
   d) no temperature inversions or anomalous wind conditions that would significantly affect the noise level of the aeroplane when the noise is recorded at the measuring points specified by the certificating authority.

2.3 Aeroplane testing procedures

2.3.1 The test procedures and noise measurement procedure shall be acceptable to the airworthiness and noise certificating authorities of the State issuing the certification.

2.3.2 The aeroplane height and lateral position relative to the microphone shall be determined by a method independent of normal flight instrumentation such as radar tracking, theodolite triangulation, photographic scaling techniques or other methods to be approved by the certificating authority.

3. MEASUREMENT OF AEROPLANE NOISE RECEIVED ON THE GROUND

3.1 General

3.1.1 All measuring equipment shall be approved by the certificating authority.
3.1.2 Sound pressure level data for noise evaluation purposes shall be obtained with acoustical equipment and measurement practices that conform to the specifications given hereunder in 3.2.

3.2 Measurement system

3.2.1 The acoustical measurement system shall consist of approved equipment equivalent to the following:

a) a microphone system with frequency response compatible with measurement and analysis system accuracy as stated in 3.3;

b) tripods or similar microphone mountings that minimize interference with the sound being measured;

c) recording and reproducing equipment characteristics, frequency response, and dynamic range compatible with the response and accuracy requirements of 3.3; and

d) acoustic calibrators using sine wave or broadband noise of known sound pressure level. If broadband noise is used, the signal shall be described in terms of its average and maximum root-mean-square (rms) value for non-overload signal level.

3.3 Sensing, recording and reproducing equipment

3.3.1 When so specified by the certificating authority, the sound produced by the aeroplane shall be recorded in such a way that the complete information, including time history, is retained. A magnetic tape recorder is acceptable.

3.3.2 The characteristics of the complete system shall comply with the recommendations given in International Electrotechnical Commission (IEC) Publication No. 179* with regard to the sections concerning microphone, amplifier and indicating instrument characteristics. The text and specifications of IEC Publication No. 179* entitled “Precision Sound Level Meters” are incorporated by reference into this section and are made a part hereof.

Note.—When a tape recorder is used it forms part of the complete system complying with IEC Recommendation 561.*

3.3.3 The response of the complete system to a sensibly plane progressive sinusoidal wave of constant amplitude shall lie within the tolerance limits specified in Table IV and Table V for Type I instruments in IEC Publication No. 179,* for weighting curve “A” over the frequency range 45 to 11 200 Hz.

3.3.4 The recorded noise signal shall be read through an “A” filter as defined in IEC Publication No. 179,* and with dynamic characteristics designated “slow”.

3.3.5 The equipment shall be acoustically calibrated using facilities for acoustic free field calibration. The over-all sensitivity of the measuring system shall be checked before and after the measurement of the noise level for a sequence of aeroplane operations, using an acoustic calibrator generating a known sound pressure level at a known frequency.

Note.—A pistonphone operating at a nominal 124 dB and 250 Hz is generally used for this purpose.

3.3.6 A wind screen shall be employed with the microphone during all measurements of aeroplane noise when the wind speed is in excess of 11 km/h (6 kt). Its characteristics shall be such that when it is used, the complete system including the wind screen will meet the specifications above. Its insertion loss at the frequency of the acoustic calibrator shall also be known and included in the provision of an acoustic reference level for the analysis of the measurements.

3.4 Noise measurement procedures

3.4.1 The microphones shall be oriented in a known direction so that the maximum sound received arrives as nearly as possible in the direction for which the microphones are calibrated. The microphones shall be placed so that their sensing elements are approximately 1.2 m (4 ft) above ground.

3.4.2 Immediately prior to and after each test, a recorded acoustic calibration of the system shall be made in the field with an acoustic calibrator for the two purposes of checking system sensitivity and providing an acoustic reference level for the analysis of the sound level data.

3.4.3 The ambient noise, including both acoustical background and electrical noise of the measurement systems, shall be recorded and determined in the test area with the system gain set at levels which will be used for aeroplane noise measurements. If aeroplane sound pressure levels do not exceed the background sound pressure levels by at least 10 dB(A), approved corrections for the contribution of background sound pressure level to the observed sound pressure level shall be applied.

* As amended. Available from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.
4. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY AND CORRECTION OF MEASURED DATA

4.1 Data reporting

4.1.1 Measured and corrected sound pressure levels obtained with equipment conforming to the specifications described in Section 3 of this appendix shall be reported.

4.1.2 The type of equipment used for measurement and analysis of all acoustic aeroplane performance and meteorological data shall be reported.

4.1.3 The following atmospheric environmental data, measured immediately before, after, or during each test at the observation points prescribed in Section 2 of this appendix shall be reported:
   a) air temperature and relative humidity; and
   b) maximum, minimum and average wind velocities.

4.1.4 Comments on local topography, ground cover, and events that might interfere with sound recordings shall be reported.

4.1.5 The following aeroplane information shall be reported:
   a) type, model and serial numbers of aeroplane, engine(s) and propeller(s);
   b) any modifications or non-standard equipment likely to affect the noise characteristics of the aeroplane;
   c) maximum certificated take-off mass;
   d) for each overflight, airspeed and air temperature at the flyover altitude determined by properly calibrated instruments;
   e) for each overflight, engine performance as manifold pressure or power, propeller speed in revolutions per minute and other relevant parameters determined by properly calibrated instruments;
   f) aeroplane height above ground (see 2.3.2);
   g) corresponding manufacturer’s data for the reference conditions relevant to d) and e) above.

4.2 Data correction

4.2.1 Correction of noise at source

4.2.1.1 When so specified by the certificating authority, corrections for differences between engine power achieved during the tests and the power that would be achieved at settings corresponding to the highest power in the normal operating range by an average engine of the type under reference conditions, shall be applied using approved methods.

4.2.1.2 At a propeller helical tip Mach number at or below 0.70 no correction is required if the test helical tip Mach number is within 0.014 of the reference helical tip Mach number. At a propeller helical tip Mach number above 0.70 and at or below 0.80 no correction is required if the test helical tip Mach number is within 0.007 of the reference helical tip Mach number. Above a helical tip Mach number of 0.80 no correction is required if the helical tip Mach number is within 0.005 of the reference helical tip Mach number. If the test power at any helical tip Mach number is within 10 per cent of the reference power, no correction for source noise variation with power is required. No corrections are to be made for power changes for fixed pitch propeller-driven aeroplanes. If test propeller helical tip Mach number and power variations from reference conditions are outside these constraints, corrections based on data developed using the actual test aeroplane or a similar configured aeroplane with the same engine and propeller operating as the aeroplane being certificated shall be used as described in Section 4.1 of the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

4.2.2 Correction of noise received on the ground

4.2.2.1 The noise measurements made at heights different from 300 m (985 ft) shall be adjusted to 300 m (985 ft) by the inverse square law.

4.2.3 Performance correction

Note.— The performance correction is intended to credit higher performance aeroplanes based on their ability to climb at a steeper angle and to fly the traffic pattern at a lower power setting. Also, this correction penalizes aeroplanes with limited performance capability which results in lower rates of climb and higher power settings in the traffic pattern.

4.2.3.1 A performance correction determined for sea level, 15°C conditions and limited to a maximum of 5 dB(A) shall be applied using the method described in 4.2.3.2 and added algebraically to the measured value.

4.2.3.2 The performance correction shall be calculated by using the following formula:

$$\Delta dB = 49.6 - 20 \log_{10} \left(3 \cdot 500 - D_{15} \frac{R/C}{V_y} \right) + 15$$

where $$D_{15} = \text{Take-off distance to 15 m at maximum certificated take-off mass and maximum take-off power (paved runway)}$$
R/C = Best rate of climb at maximum certificated take-off mass and maximum take-off power

V_y = Climb speed corresponding to R/C at maximum take-off power and expressed in the same units.

Note.— When take-off distance is not certificated, the figure of 610 m for single-engined aeroplanes and 825 m for multi-engined aeroplanes is used.

4.3 Validity of results

4.3.1 The measuring point shall be overflown at least four times. The test results shall produce an average dB(A) value and its 90 per cent confidence limits, the noise level being the arithmetic average of the corrected acoustical measurements for all valid test runs over the measuring point.

4.3.2 The samples shall be large enough to establish statistically a 90 per cent confidence limit not exceeding ±1.5 dB(A). No test result shall be omitted from the averaging process, unless otherwise specified by the certificating authority.

Note.— Methods for calculating the 90 per cent confidence interval are given in Appendix I of the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).
APPENDIX 4. EVALUATION METHOD FOR NOISE CERTIFICATION OF HELICOPTERS NOT EXCEEDING 2 730 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

Note.— See Part II, Chapter 11.

1. INTRODUCTION

Note 1.— This noise evaluation method includes:

a) noise certification test and measurement conditions;

b) definition of sound exposure level using measured noise data;

c) measurement of helicopter noise received on the ground;

d) adjustment of flight test results; and

e) reporting of data to the certificating authority.

Note 2.— The instructions and procedures given in the method are intended to ensure uniformity during compliance tests of various types of helicopters conducted in various geographical locations. The method applies only to helicopters meeting the applicability clauses of Part II, Chapter 11, of this volume of the Annex.

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

This section prescribes the conditions under which noise certification shall be conducted and the meteorological and flight path measurement procedures that shall be used.

2.2 Test environment

2.2.1 The location for measuring noise from the helicopter in flight shall be surrounded by relatively flat terrain having no excessive ground absorption characteristics such as might be caused by thick, matted or tall grass, shrubs or wooded areas. No obstructions which significantly influence the sound field from the helicopter shall exist within a conical space above the test noise measurement position, the cone being defined by an axis normal to the ground and by a half-angle of 80° from this axis.

Note.— Those people carrying out the measurements could themselves constitute such obstructions.

2.2.2 The tests shall be carried out under the following atmospheric conditions:

a) no precipitation;

b) relative humidity not higher than 95 per cent or lower than 20 per cent and ambient temperature not above 35°C and not below 2°C at a height between 1.2 m and 10 m above ground (if the measurement site is within 2 000 m of aerodrome weather measuring equipment, the aerodrome reported temperature, relative humidity and wind speed may be used). Combinations of temperature and humidity which lead to an absorption coefficient in the 8 KHz one-third octave band of greater than 10 dB/100 m shall be avoided. Absorption coefficients as a function of temperature and relative humidity are given in Section 7 of Appendix 2 or SAE ARP 866 A;

c) reported wind speed not above 19 km/h (10 kt) and the wind speed component at right angles to the direction of flight not above 9 km/h (5 kt) at a height between 1.2 m and 10 m above ground; and

d) no other anomalous meteorological conditions that would significantly affect the noise level when recorded at the measuring points specified by the certificating authority.

2.3 Flight path measurement

2.3.1 The helicopter position relative to the flight path reference point shall be determined by a method independent of normal flight instrumentation, such as radar tracking.
theodolite triangulation or photographic scaling techniques, approved by the certificating authority.

2.3.2 The helicopter noise shall be measured over a distance sufficient to ensure adequate data during the period that the noise is within 10 dB(A) of the maximum value of dB(A).

2.3.3 Position and performance data required to make the adjustments referred to in Section 5 of this appendix shall be recorded at an approved sampling rate. Measuring equipment shall be approved by the certificating authority.

2.4 Flight test conditions

2.4.1 The helicopter flyover noise test shall be conducted at the airspeed referred to in 11.5.2 with such airspeed adjusted as necessary to produce the same advancing blade tip Mach number as associated with the reference conditions.

2.4.2 Advancing blade tip Mach number (Mat) is defined as the ratio of the arithmetic sum of blade tip rotational speed (Vt) and the helicopter true airspeed (Vr) divided by the speed of sound (c) at 25°C such that:

\[
Mat = \frac{(Vt + Vr)}{c}
\]

3. NOISE UNIT DEFINITION

3.1 The value of sound exposure level \(L_{AE}\) is defined as the level, in decibels, of the time integral of squared A-weighted sound pressure \(P_A\) over a given time period or event, with reference to the square of the standard reference sound pressure \(P_0\) or 20 micropascals and a reference duration of one second.

3.2 This unit is defined by the expression:

\[
L_{AE} = 10 \log \left( \frac{1}{T_0} \int_{t_1}^{t_2} \left( \frac{P_A(t)}{P_0} \right)^2 \, dt \right)
\]

where \(T_0\) is the reference integration time of one second and \((t_2 - t_1)\) is the integration time interval.

3.3 The above integral can also be expressed as:

\[
L_{AE} = 10 \log \left( \frac{1}{T_0} \int_{t_1}^{t_2} 10 \log \left( \frac{L_A(t)}{10} \right) \, dt \right)
\]

where \(L_A(t)\) is the time varying A-weighted sound level.

3.4 The integration time \((t_2 - t_1)\) in practice shall not be less than the time interval during which \(L_A(t)\) first rises to within 10 dB(A) of its maximum value \(L_{AMAX}\) and last falls below 10 dB(A) of its maximum value.

3.5 The SEL may be approximated by the following expression:

\[
L_{AE} = L_{AMAX} + \Delta A
\]

where \(\Delta A\) is the duration allowance given by

\[
\Delta A = 10 \log_{10} \tau
\]

where \(\tau = (t_2 - t_1)/2\).

\(L_{AMAX}\) is defined as the maximum level, in decibels, of the A-weighted sound pressure (slow response) with reference to the square of the standard reference sound pressure \(P_0\).

4. MEASUREMENT OF HELICOPTER NOISE RECEIVED ON THE GROUND

4.1 General

4.1.1 All measuring equipment shall be approved by the certificating authority.

4.1.2 Sound pressure level data for noise evaluation purposes shall be obtained with acoustical equipment and measurement practices that conform to the specifications given in 4.2.

4.2 Measurement system

The acoustical measurement system shall consist of approved equipment equivalent to the following:

a) a microphone system with frequency response compatible with measurement and analysis system accuracy as stated in 4.3;

b) tripods or similar microphone mountings that minimize interference with the sound being measured;

c) recording and reproducing equipment characteristics, frequency response, and dynamic range compatible with the response and accuracy requirements of 4.3; and

d) acoustic calibrators using sine wave or broadband noise of known sound pressure level. If broadband noise is used, the signal shall be described in terms of its average and maximum root-mean-square (rms) value for non-overload signal level.
4.3 Sensing, recording and reproducing equipment

4.3.1 With the approval of the certificating authority the sound level produced by the helicopter may be stored on a magnetic tape recorder for later evaluation. Alternatively, the A-weighted sound level time history may be written onto a graphic level recorder set at “slow” response from which the SEL value may be determined or the SEL may be directly determined from an integrating sound level meter complying with the Standards of the International Electrotechnical Commission (IEC) Publication No. 804* for a Type I instrument set at “slow” response.

4.3.2 The characteristics of the complete system shall comply with the recommendations given in International Electrotechnical Commission (IEC) Publication No. 651* with regard to the sections concerning microphone, amplifier and indicating instrument characteristics. The text and specifications of IEC Publication No. 651, entitled “Sound Level Meters”, are incorporated by reference into this section and are made a part hereof.

4.3.3 If a tape recording is used, the tape recorder shall comply with the IEC Recommendation 561*.

4.3.4 The response of the complete system to a sensibly plane progressive sinusoidal wave of constant amplitude shall lie within the tolerance limits specified in Table IV and Table V for Type I instruments in IEC Publication No. 651, for weighting curve A over the frequency range 45 to 11 500 Hz.

4.3.5 The over-all sensitivity of the measuring system shall be checked before tests start and at intervals during testing using an acoustic calibrator generating a known sound pressure level at a known frequency. The output of the acoustic calibrator shall have been checked by a standardizing laboratory within 6 months of the test series; tolerable changes in output shall be not more than 0.2 dB. The equipment shall be considered satisfactory if the variation over the period immediately prior to and immediately following each test series within a given test day is not greater than 0.5 dB.

Note.— A pistonphone operating at a nominal 124 dB and 250 Hz is generally used for this purpose.

4.3.6 A wind screen should be employed with the microphone during all measurements of helicopter noise. Its characteristics should be such that when it is used, the complete system including the wind screen will meet the specifications. Its insertion loss at the frequencies of the pistonphone should also be known and included in the acoustic reference level for analysis of the measurements.

4.4 Noise measurement procedures

4.4.1 The microphone shall be of the pressure-sensitive type designed for nearly uniform grazing incidence response.

4.4.2 The microphone shall be mounted with the centre of the sensing element 1.2 m above the local ground surface and shall be oriented for grazing incidence, i.e. with the sensing element substantially in the plane defined by the nominal flight path of the helicopter and the measuring station. The microphone mounting arrangement shall minimize the interference of the supports with the sound to be measured.

4.4.3 If the noise signal is tape-recorded, the frequency response of the electrical system shall be determined, during each test series, at a level within 10 dB of the full-scale reading used during the tests, utilizing random or pseudo-random pink noise. The output of the noise generator shall have been checked by an approved standards laboratory within six months of the test series, and tolerable changes in the relative output at each one-third octave band shall be not more than 0.2 dB. Sufficient determinations shall be made to ensure that the over-all calibration of the system is known for each test.

4.4.4 Where a magnetic tape recorder forms part of the measuring chain, each reel of magnetic tape shall carry 30 s of this electrical calibration signal at its beginning and end for this purpose. In addition, data obtained from tape-recorded signals shall be accepted as reliable only if the level difference in the 10 kHz one-third octave band filtered levels of the two signals is not more than 0.75 dB.

4.4.5 The ambient noise, including both acoustical background and electrical noise of the measurement systems, shall be determined in the test area with the system gain set at levels which will be used for helicopter noise measurements. If helicopter sound pressure levels do not exceed the background sound pressure levels by at least 15 dB(A), flyovers at an approved lower height may be used and the results adjusted to the reference measurement point by an approved method.

5. ADJUSTMENT TO TEST RESULTS

5.1 When certification test conditions differ from the reference conditions appropriate adjustments shall be made to the measured noise data by the methods of this section.

5.2 Corrections and adjustments

5.2.1 The adjustments may be limited to the effects of differences in spherical spreading between the helicopter test flight path and the reference flight path (and between reference and adjusted reference airspeed). No adjustment for the differences in atmospheric attenuation between the test and reference meteorological conditions and between the helicopter test and reference ground speeds need be applied.

* Available from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.
5.2.2 The adjustments for spherical spreading may be approximated from:

\[ \Delta_1 = 12.5 \log_{10} \left( \frac{H}{150} \right) \text{ dB} \]

where \( H \) is the height, in metres, of the test helicopter when directly over the noise measurement point.

5.2.3 The adjustment for the difference between reference airspeed and adjusted reference airspeed is calculated from:

\[ \Delta_2 = 10 \log_{10} \left( \frac{V_{ar}}{V_r} \right) \text{ dB} \]

where \( \Delta_2 \) is the quantity in decibels that must be algebraically added to the measured SEL noise level to correct for the influence of the adjustment of the reference airspeed on the duration of the measured flyover event as perceived at the noise measurement station. \( V_r \) is the reference airspeed as prescribed under 11.5.2 and \( V_{ar} \) is the adjusted reference airspeed as prescribed in 2.4.1 of this appendix.

6. REPORTING OF DATA TO THE CERTIFYING AUTHORITY AND VALIDITY OF RESULTS

6.1 Data reporting

6.1.1 Measured and corrected sound pressure levels obtained with equipment conforming to the specifications described in Section 4 of this appendix shall be reported.

6.1.2 The type of equipment used for measurement and analysis of all acoustic helicopter performance and meteorological data shall be reported.

6.1.3 The following atmospheric environmental data, measured immediately before, after, or during each test at the observation point prescribed in Section 2 of this appendix shall be reported:

- air temperature and relative humidity;
- wind speeds and wind directions; and
- atmospheric pressure.

6.1.4 Comments on local topography, ground cover and events that might interfere with sound recording shall be reported.

6.1.5 The following helicopter information shall be reported:

- type, model and serial numbers of helicopter, engine(s) and rotor(s);
- any modifications or nonstandard equipment likely to affect the noise characteristics of the helicopter;
- maximum certificated take-off and landing mass;
- indicated airspeed in kilometres per hour (knots) and rotor speed in rpm during each demonstration;
- engine performance parameters during each demonstration; and
- helicopter height above the ground during each demonstration.

6.2 Reporting of noise certification reference conditions

Helicopter position and performance data and noise measurements shall be corrected to the noise certification reference conditions specified in Part II, Chapter 11, 11.5 of this volume. These conditions, including reference parameters, procedures and configurations shall be reported.

6.3 Validity of results

6.3.1 The measuring point shall be overflown at least six times. The test results shall produce an average SEL and its 90 per cent confidence limits, the noise level being the arithmetic average of the corrected acoustical measurements for all valid test runs over the measuring point for the reference procedure.

6.3.2 The sample shall be large enough to establish statistically a 90 per cent confidence limit not exceeding ±1.5 dB(A). No test results shall be omitted from the averaging process unless approved by the certificating authority.

Note.—Methods for calculating the 90 per cent confidence interval are given in Appendix 1 of the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).
APPENDIX 5. MONITORING AIRCRAFT NOISE ON AND IN THE VICINITY OF AERODROMES

Note.— See Part III.

1. INTRODUCTION

Note 1.— The introduction of jet aircraft operations, as well as the general increase in air traffic, has resulted in international concern over aircraft noise. To facilitate international collaboration on the solution of aircraft noise problems, it is desirable to recommend a procedure for monitoring aircraft noise on and in the vicinity of aerodromes.

Note 2.— In this appendix monitoring is understood to be the routine measurement of noise levels created by aircraft in the operation of an aerodrome. Monitoring usually involves a large number of measurements per day, from which an immediate indication of the noise level may be required.

Note 3.— This appendix specifies the measuring equipment to be used in order to measure noise levels created by aircraft in the operation of an aerodrome. The noise levels measured according to this appendix are approximations to perceived noise levels PNL, in PNdB, as calculated by the method described in Appendix 1, 4.2.

1.1 Monitoring aircraft noise should be carried out either with mobile equipment, often using only a sound level meter, or with permanently installed equipment incorporating one or more microphones with amplifiers located at different positions in the field with a data transmission system linking the microphones to a central recording installation. This appendix describes primarily the latter method, but specifications given in this appendix should also be followed, to the extent the specifications are relevant, when using mobile equipment.

2. DEFINITION

Monitoring of aircraft is defined as the routine measurement of noise levels created by aircraft on and in the vicinity of aerodromes for the purpose of monitoring compliance with and checking the effectiveness of noise abatement requirements.

3. MEASUREMENT EQUIPMENT

3.1 The measurement equipment should consist of either portable recording apparatus capable of direct reading, or apparatus located at one or more fixed positions in the field linked through a radio transmission — or cable system (e.g. telephone line, etc.) to a centrally located recording device.

3.2 The characteristics of the field equipment, including the transmission system, should comply with IEC Publication 179*, “Precision Sound Level Meters”, except that frequency weighting equal to the inverse of the 40 noy contour (see Figure 5-1) should apply. An approximation, to the nearest decibel, of the inverse of the 40 noy contour relative to the value at 1 000 Hz, is given in Table 5-1. The relative frequency response of the weighting element of the equipment should be maintained within a tolerance of ±0.5 dB. When such a weighting network is incorporated in a direct reading instrument, the relation between the acoustical input to the microphone and the meter reading should follow the inverse of the 40 noy contour with the same tolerances as those specified for weighting curve C in IEC Publication 179*. Measurements obtained by means of the instrumentation described above provide, after adding 7 dB, values which are approximations to the perceived noise levels in PNdB.

3.3 An alternative method of determining approximations to the perceived noise levels can be obtained from measuring the noise using a sound-level meter incorporating the A-weighting network** and adding a correction K normally between 9 and 14 dB dependent on the frequency spectrum of the noise. The value of K and the method used by the measuring authorities for determination of that value should be specified when reporting results.

3.4 The field installation of microphones for aircraft noise monitoring purposes should provide for suitable protection of the microphones from rain, snow and other adverse weather conditions. Adequate correction for any insertion loss, as a function of frequency and weather conditions, produced by wind screens or other protective enclosures should be applied to the measured data.

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* This publication was first issued in 1965 by the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembe, Geneva, Switzerland.

** The A-weighting network is described in IEC Publication 179.
Figure 5-1. Contours of perceived noisiness
1.1 Where a record of the noise as a function of time is required this can be obtained by recording the noise signal on a magnetic tape, a graphic level recorder or other suitable equipment.

3.5 The recording and indicating equipment should comply with IEC Publication 179* regarding the dynamic characteristics of the indicating instrument designated as “slow”.

Note.— If the anticipated duration of the noise signal is less than 5 s, the dynamic characteristics designated as “fast” may be used.

For the purpose of this note, the duration is described as the length of the significant time history during which the recorded signal, passed through a weighting network having an amplitude characteristic equal to the inverse 40 noy contour, remains within 10 dB of its maximum value.

3.6 The microphone system should have been originally calibrated at a laboratory equipped for free-field calibration and its calibration should be rechecked at least every six months.

3.7 The complete measurement system prior to field installation and at periodic intervals thereafter should be calibrated in a laboratory to ensure that the frequency response and dynamic range requirements of the system comply with the specifications described in this document.

Note.— Direct reading measuring systems that yield approximate values of perceived noise levels other than those defined above are not meant to be excluded from use in monitoring.

### 4. FIELD EQUIPMENT INSTALLATION

4.1 Microphones used for monitoring noise levels from aircraft operations should be installed at appropriate locations with the axis of maximum sensitivity of each microphone oriented in a direction such that the highest sensitivity to sound waves is achieved. The microphone position should be selected so that no obstruction which influences the sound field produced by an aircraft exists above a horizontal plane passing through the active centre of the microphone.

Note 1.— Monitoring microphones may need to be placed in locations having substantial background noise levels caused by motor vehicle traffic, children playing, etc. In these instances it is often expedient to locate the microphone on a roof-top, telephone pole or other structure rising above the ground. Consequently, it is necessary to determine the background noise level and to carry out a field check, at one or more frequencies, of the overall sensitivity of the measuring system after or before the measurement of the noise level for a sequence of aircraft operations.

Note 2.— If, due to the microphone being placed in a structure above the ground, it is impracticable for operating personnel to calibrate it directly because of its inaccessibility, it can be useful to provide a calibrated sound source at the microphone location. This sound source can be a small loudspeaker, an electrostatic actuator, or similar device.

4.2 Monitoring concerns the noise produced by a single aircraft flight, by a series of flights or by a specified type of aircraft, or by a large number of operations of different aircraft. Such noise levels vary, for a specific monitoring location, with variations in flight procedures or meteorological conditions. In interpretation of the results of a monitoring procedure, consideration should therefore be given to the statistical distribution of the measured noise levels. In describing the results of a monitoring procedure an appropriate description of the distribution of the observed noise levels should be provided.

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* This publication was first issued in 1965 by the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.
APPENDIX 6. NOISE EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR CERTIFICATE OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED ON OR AFTER 17 NOVEMBER 1988

Note.— See Part II, Chapter 10.

1. INTRODUCTION

Note 1.— This noise evaluation method includes:

a) noise certification test and measurement conditions;

b) noise unit;

c) measurement of aeroplane noise received on the ground;

d) adjustments to test data; and

e) reporting of data to the certificating authority and validity of results.

Note 2.— The instructions and procedures given in the method are clearly delineated to ensure uniformity during compliance tests and to permit comparison between tests of various types of aeroplanes, conducted in various geographical locations. The method applies only to aeroplanes within the applicability clauses of Part II, Chapter 10.

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

This section prescribes the conditions under which noise certification tests shall be conducted and the measurement procedures that shall be used to measure the noise made by the aeroplane for which the test is conducted.

2.2 General test conditions

2.2.1 Locations for measuring noise from an aeroplane in flight shall be surrounded by relatively flat terrain having no excessive sound absorption characteristics such as might be caused by thick, matted, or tall grass, shrubs, or wooded areas. No obstructions which significantly influence the sound field from the aeroplane shall exist within a conical space above the measurement position, the cone being defined by an axis normal to the ground and by a half-angle 75° from this axis.

2.2.2 The tests shall be carried out under the following atmospheric conditions:

a) no precipitation;

b) relative humidity not higher than 95 per cent and not lower than 20 per cent and ambient temperature not above 35°C and not below 2°C;

c) reported wind not above 19 km/h (10 kt) and cross wind not above 9 km/h (5 kt), using a 30 s average;

d) no other anomalous meteorological conditions that would significantly affect the noise level of the aeroplane when the noise is recorded at the measuring points specified by the certificating authority; and

e) the meteorological measurements must be made between 1.2 m and 10 m above ground level. If the measurement site is within 2 000 m of an airport meteorological station, measurements from this station may be used.

2.3 Aeroplane testing procedures

2.3.1 The test procedures and noise measurement procedure shall be acceptable to the airworthiness and noise certificating authorities of the State issuing the certification.

2.3.2 The flight test programme shall be initiated at the maximum take-off mass for the aeroplane, and the mass shall be adjusted to maximum take-off mass after each hour of flight time.

2.3.3 The flight test shall be conducted at $V_y \pm 9$ km/h (5 kt) indicated airspeed.
2.3.4 The aeroplane position relative to the flight path reference point shall be determined by a method independent of normal flight instrumentation, such as radar tracking, theodolite triangulation or photographic scaling techniques, approved by the certificating authorities.

2.3.5 The aeroplane height when directly over the microphone shall be measured by an approved technique. The aeroplane shall pass over the microphone within ±10° from the vertical and within ±20 per cent of the reference height (see Figure 6-1).

2.3.6 Aeroplane speed, position and performance data required to make the adjustments referred to in Section 5 of this appendix shall be recorded when the aeroplane is directly over the measurement site. Measuring equipment shall be approved by the certificating authority.

2.3.7 An independent device accurate to within ±1 per cent shall be used for the measurement of propeller rotational speed to avoid orientation and installation errors when the test aeroplane is equipped with mechanical tachometers.

3. NOISE UNIT DEFINITION

The $L_{A_{max}}$ is defined as the maximum level, in decibels, of the A-weighted sound pressure (slow response) with reference to the square of the standard reference sound pressure ($P_0$) of 20 micropascals ($\mu$Pa).

4. MEASUREMENT OF AEROPLANE NOISE RECEIVED ON THE GROUND

4.1 General

4.1.1 All measuring equipment shall be approved by the certificating authority.

4.1.2 Sound pressure level data for noise evaluation purposes shall be obtained with acoustical equipment and measurement practices that conform to the specifications given hereunder in 4.2.

4.2 Measurement system

The acoustical measurement system shall consist of approved equipment equivalent to the following:

a) a microphone system with frequency response compatible with measurement and analysis system accuracy as stated in 4.3;

b) tripods or similar microphone mountings that minimize interference with the sound being measured;

![Figure 6-1. Typical test and reference profiles](image-url)
c) recording and reproducing equipment characteristics, frequency response, and dynamic range compatible with the response and accuracy requirements of 4.3; and

d) acoustic calibrators using sine wave or broadband noise of known sound pressure level. If broadband noise is used, the signal shall be described in terms of its average and maximum root-mean-square (rms) value for non-overload signal level.

4.3 Sensing, recording and reproducing equipment

4.3.1 The sound level produced by the aeroplane shall be recorded. A magnetic tape recorder, graphic level recorder or sound level meter is acceptable at the option of the certificating authority.

4.3.2 The characteristics of the complete system shall comply with the recommendations given in International Electrotechnical Commission (IEC) Publication No. 651* with regard to the sections concerning microphone, amplifier and indicating instrument characteristics. The text and specifications of IEC Publication No. 651 entitled “Sound Level Meters” are incorporated by reference into this section and are made a part hereof.

Note.— If a tape recording is required by the certificating authority, the tape recorder shall comply with IEC Recommendation 561.

4.3.3 The response of the complete system to a sensibly plane progressive sinusoidal wave of constant amplitude shall lie within the tolerance limits specified in Table IV and Table V for Type I instruments in IEC Publication No. 651, for weighting curve “A” over the frequency range 45 to 11 500 Hz.

4.3.4 The noise signal shall be passed through an “A” filter as defined in IEC Publication No. 651.

4.3.5 The over-all sensitivity of the measuring system shall be checked before tests start and at intervals during testing using an acoustic calibrator generating a known sound pressure level at a known frequency.

Note.— A pistonphone operating at a nominal 124 dB and 250 Hz is generally used for this purpose.

4.3.6 When a tape recording is used, the maximum A-weighted noise level $L_{A\text{max}}$ may be determined using a graphic level recorder or digital equivalent.

Note.— The maximum noise level $L_{A\text{max}}$ could also be determined using an approved sound level meter.

4.4 Noise measurement procedures

4.4.1 The microphone shall be a 12.7 mm diameter pressure type, with its protective grid, mounted in an inverted position such that the microphone diaphragm is 7 mm above and parallel to a circular metal plate. This white-painted metal plate shall be 40 cm in diameter and at least 2.5 mm thick, and shall be placed horizontally and flush with the surrounding ground surface with no cavities below the plate. The microphone shall be located three-quarters of the distance from the centre to the edge along a radius normal to the line of flight of the test aeroplane.

4.4.2 If the noise signal is tape-recorded, the frequency response of the electrical system shall be determined, during each test series, at a level within 10 dB of the full-scale reading used during the tests, utilizing random or pseudorandom pink noise. The output of the noise generator shall have been checked by an approved Standards laboratory within six months of the test series, and tolerable changes in the relative output at each one-third octave band shall be not more than 0.2 dB. Sufficient determinations shall be made to ensure that the over-all calibration of the system is known for each test.

4.4.3 Where a magnetic tape recorder forms part of the measuring chain, each reel of magnetic tape shall carry 30 s of this electrical calibration signal at its beginning and end for this purpose. In addition, data obtained from tape-recorded signals shall be accepted as reliable only if the level difference in the 10 kHz one-third octave band filtered levels of the two signals is not more than 0.75 dB.

4.4.4 The ambient noise, including both acoustical background and electrical noise of the measurement systems, shall be determined in the test area with the system gain set at levels which will be used for aeroplane noise measurements. If aeroplane peak sound pressure levels do not exceed the background sound pressure levels by at least 10 dB(A), a take-off measurement point nearer to the start of roll shall be used and the results adjusted to the reference measurement point by an approved method.

5. ADJUSTMENT TO TEST RESULTS

5.1 When certification test conditions differ from the reference conditions appropriate adjustments shall be made to the measured noise data by the methods of this section.

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* Available from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.
5.2 Corrections and adjustments

5.2.1 The adjustments take account of the effects of:

a) differences in atmospheric absorption between meteorological test conditions and reference conditions;

b) differences in the noise path length between the actual aeroplane flight path and the reference flight path;

c) the change in the helical tip Mach number between test and reference conditions; and

d) the change in engine power between test and reference conditions.

5.2.2 The noise level under reference conditions \( (L_{A\text{max}})_{\text{REF}} \) is obtained by adding increments for each of the above effects to the test day noise level \( (L_{A\text{max}})_{\text{TEST}} \).

\[
(L_{A\text{max}})_{\text{REF}} = (L_{A\text{max}})_{\text{TEST}} + \Delta(M) + \Delta_1 + \Delta_2 + \Delta_3
\]

where

\( \Delta(M) \) is the adjustment for the change in atmospheric absorption between test and reference conditions;

\( \Delta_1 \) is the adjustment for noise path lengths;

\( \Delta_2 \) is the adjustment for helical tip Mach number; and

\( \Delta_3 \) is the adjustment for engine power.

a) When the test conditions are within those specified in Figure 6-2, no adjustments for differences in atmospheric absorption need be applied, i.e. \( \Delta(M) = 0 \). If conditions are outside those specified in Figure 6-2 then adjustments must be applied by an approved procedure or by adding an increment \( \Delta(M) \) to the test day noise levels where,

\[
\Delta(M) = 0.01 (H_T \alpha - 0.2 H_R)
\]

and where \( H_T \) is the height in metres of the test aeroplane when directly over the noise measurement point, \( H_R \) is the reference height of the aeroplane above the noise measurement point, and \( \alpha \) is the rate of absorption at 500 Hz specified in Tables 1-5 to 1-16 of Appendix 1.

b) Measured noise levels should be adjusted to the height of the aeroplane over the noise measuring point on a reference day by algebraically adding an increment equal to \( \Delta_1 \). When test day conditions are within those specified in Figure 6-2:

\[
\Delta_1 = 22 \log \left( \frac{H_T}{H_R} \right)
\]

When test day conditions are outside those specified in Figure 6-2:

\[
\Delta_1 = 20 \log \left( \frac{H_T}{H_R} \right)
\]

where \( H_T \) is the height of the aeroplane when directly over the noise measurement point and \( H_R \) is the
c) No adjustments for helical tip Mach number variations need be made if the propeller helical tip Mach number is:

1) at or below 0.70 and the test helical tip Mach number is within 0.014 of the reference helical tip Mach number;

2) above 0.70 and at or below 0.80 and the test helical tip Mach number is within 0.007 of the reference helical tip Mach number;

3) above 0.80 and the test helical tip Mach number is within 0.005 of the reference helical tip Mach number. For mechanical tachometers, if the helical tip Mach number is above 0.8 and the test helical tip Mach number is within 0.008 of the reference helical tip Mach number.

Outside these limits measured noise levels shall be adjusted for helical tip Mach number by an increment equal to:

\[ \Delta_2 = K_2 \log \left( \frac{M_R}{M_T} \right) \]

which shall be added algebraically to the measured noise level, where \( M_T \) and \( M_R \) are the test and reference helical tip Mach numbers respectively. The value of \( K_2 \) shall be determined from approved data from the test aeroplane. In the absence of flight test data and at the discretion of the certificating authority a value of \( K_2 = 150 \) may be used for \( M_T \) less than \( M_R \); however, for \( M_T \) greater than or equal to \( M_R \) no correction is applied.

Note.— The reference helical tip Mach number \( M_R \) is the one corresponding to the reference conditions above the measurement point:

\[ \frac{D \pi N}{10} \frac{c}{\sqrt{V_T^2 + \frac{12}{10}}} \]

where \( D \) is the propeller diameter in metres

\( V_T \) is the true airspeed of the aeroplane in reference conditions in metres per second

\( N \) is the propeller speed in reference conditions in rpm. If \( N \) is not available, its value can be taken as the average of the propeller speeds over nominally identical power conditions during the flight tests.

d) Measured sound levels shall be adjusted for engine power by algebraically adding an increment equal to:

\[ \Delta_3 = K_3 \log \left( \frac{P_R}{P_T} \right) \]

where \( P_T \) and \( P_R \) are the test and reference engine powers respectively obtained from the manifold pressure/torque gauges and engine rpm. The value of \( K_3 \) shall be determined from approved data from the test aeroplane. In the absence of flight test data and at the discretion of the certificating authority a value of \( K_3 = 17 \) may be used. The reference power \( P_R \) shall be that obtained at the reference height pressure and temperature assuming an ISA temperature lapse rate with height.

6. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY AND VALIDITY OF RESULTS

6.1 Data reporting

6.1.1 Measured and corrected sound pressure levels obtained with equipment conforming to the specifications described in Section 4 of this appendix shall be reported.

6.1.2 The type of equipment used for measurement and analysis of all acoustic aeroplane performance and meteorological data shall be reported.

6.1.3 The following atmospheric environmental data, measured immediately before, after, or during each test at the observation points prescribed in Section 2 of this appendix shall be reported:

a) air temperature and relative humidity;

b) wind speeds and wind directions; and

c) atmospheric pressure.

6.1.4 Comments on local topography, ground cover and events that might interfere with sound recordings shall be reported.

6.1.5 The following aeroplane information shall be reported:

a) type, model and serial numbers of aeroplane, engine(s) and propeller(s);

b) any modifications or nonstandard equipment likely to affect the noise characteristics of the aeroplane;
c) maximum certificated take-off mass;
d) for each overflight, airspeed and air temperature at the flyover altitude determined by properly calibrated instruments;
e) for each overflight, engine performance as manifold pressure or power, propeller speed in revolutions per minute and other relevant parameters determined by properly calibrated instruments;
f) aeroplane height above the measurement point; and
g) corresponding manufacturer’s data for the reference conditions relevant to d), e) and f) above.

6.2 Validity of results

6.2.1 The measuring point shall be overflown at least six times. The test results shall produce an average noise level ($L_{A\text{max}}$) value and its 90 per cent confidence limits, the noise level being the arithmetic average of the corrected acoustical measurements for all valid test runs over the measuring point.

6.2.2 The samples shall be large enough to establish statistically a 90 per cent confidence limit not exceeding ±1.5 dB(A). No test results shall be omitted from the averaging process, unless otherwise specified by the certificating authority.
ATTACHMENTS TO ANNEX 16, VOLUME I

ATTACHMENT A. EQUATIONS FOR THE CALCULATION OF NOISE LEVELS AS A FUNCTION OF TAKE-OFF MASS

Note.— See Part II, 2.4.1, 2.4.2, 3.4.1, 5.4.1, 6.3.1, 8.4.1, 10.4 and 11.4.

1. CONDITIONS DESCRIBED IN CHAPTER 2, 2.4.1

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<th>Approach noise level (EPNdB)</th>
<th>91.83 + 6.64 log M</th>
<th>Flyover noise level (EPNdB)</th>
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<td>4 engines or more</td>
<td>93</td>
<td>74.62 + 13.29 log M</td>
<td>108</td>
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3. CONDITIONS DESCRIBED IN CHAPTER 3, 3.4.1

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<th>Lateral full-power noise level (EPNdB)</th>
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<th>Approach noise level (EPNdB)</th>
<th>86.03 + 7.75 log M</th>
<th>Flyover noise levels (EPNdB)</th>
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<td>All aeroplanes</td>
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4. CONDITIONS DESCRIBED IN CHAPTER 5, 5.4.1

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5. CONDITIONS DESCRIBED IN CHAPTER 6, 6.3.1

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6. CONDITIONS DESCRIBED IN CHAPTER 8, 8.4.1

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<td>Approach noise level (EPNdB)</td>
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7. CONDITIONS DESCRIBED IN CHAPTER 10, 10.4 a) and 10.4 b)

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10.4 b):

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8. CONDITIONS DESCRIBED IN CHAPTER 11, 11.4

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ATTACHMENT B. GUIDELINES FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN STOL AEROPLANES

Note.— See Part II, Chapter 7.

Note 1.— For the purpose of these guidelines, STOL aeroplanes are those which, when operating in the short take-off and landing mode, consistent with the relevant airworthiness requirements, require a runway length (with no stopway or clearway) of not more than 610 m at maximum certificated mass for airworthiness.

Note 2.— These guidelines are not applicable to aircraft with vertical take-off and landing capabilities.

1. APPLICABILITY

The following guidelines should be applied to all propeller-driven aeroplanes of over 5 700 kg maximum certificated take-off mass intended for operation in the short take-off and landing (STOL) mode, requiring a runway length, compatible with the relevant take-off and landing distance requirements, of less than 610 m at maximum certificated mass for airworthiness, and for which a certificate of airworthiness for the individual aeroplane was first issued on or after 1 January 1976.

2. NOISE EVALUATION MEASURE

The noise evaluation measure should be the effective perceived noise level in EPNdB as described in Appendix 2 to this volume of the Annex.

3. NOISE MEASUREMENT REFERENCE POINTS

The aeroplane, when tested in accordance with the flight test procedure of Section 6, should not exceed the noise levels specified in Section 4 at the following reference points:

a) lateral noise reference point: the point on a line parallel to, and 300 m from the runway centre line, or extended runway centre line, where the noise level is a maximum during take-off or landing, with the aeroplane operating in the STOL mode;

b) flyover noise reference point: the point on the extended centre line of the runway 1 500 m from the start of the take-off roll; and

c) approach noise reference point: the point on the extended centre line of the runway 900 m from the runway threshold.

4. MAXIMUM NOISE LEVELS

The maximum noise level at any of the reference points, when determined in accordance with the noise evaluation method of Appendix 2, should not exceed 96 EPNdB in the case of aeroplanes with maximum certificated mass of 17 000 kg or less, this limit increasing linearly with the logarithm of mass at a rate of 2 EPNdB per doubling of mass in the case of aeroplanes having maximum certificated mass in excess of 17 000 kg.

5. TRADE-OFFS

If the maximum noise levels are exceeded at one or two measurement points:

a) the sum of any excesses should not be greater than 4 EPNdB;

b) any excess at any single point should not be greater than 3 EPNdB; and

c) any excesses should be offset by a corresponding reduction at the other point or points.

6. TEST PROCEDURES

6.1 The take-off reference procedure should be as follows:

* With no stopway or clearway.
a) the aeroplane should be at the maximum take-off mass for which noise certification is requested;

b) the propeller and/or engine speed (rpm) and engine power setting scheduled for STOL take-off should be used; and

c) throughout the take-off noise certification demonstration test, the airspeed, climb gradient, aeroplane attitude and aeroplane configuration should be those specified in the flight manual for take-off in the STOL mode.

6.2 The approach reference procedure should be as follows:

a) the aeroplane should be at the maximum landing mass for which the noise certification is requested;

b) throughout the approach noise certification demonstration test, the propeller and/or engine speed (rpm), engine power setting, airspeed, descent gradient, aeroplane attitude and aeroplane configuration should be those specified in the flight manual for STOL landing; and

c) the use of reverse thrust after landing should be the maximum specified in the flight manual.

7. ADDITIONAL NOISE DATA

Where so specified by the certificating authority, data permitting measured noise levels to be evaluated in terms of the A-weighted over-all sound pressure level (dB(A)) should be provided.
ATTACHMENT C. GUIDELINES FOR NOISE CERTIFICATION OF INSTALLED AUXILIARY POWER UNITS (APU) AND ASSOCIATED AIRCRAFT SYSTEMS DURING GROUND OPERATION

Note.—See Part II, Chapter 9.

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 (APU) and associated aircraft systems used during normal ground operation.

1.2 It should apply to installed APU 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 26 November 1981.

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 26 November 1981, the noise levels produced by installed APU 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 specified in Section 4.

3. MAXIMUM NOISE LEVELS

The maximum noise levels, when determined in accordance with the noise evaluation procedure specified in Section 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 C-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 analyser systems avoids the need to average by eye the variations associated with manual readings from sound level meters and octave band analysers 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 19 km/h (10 kt).

Temperature: not less than 2°C nor more than 35°C.

Humidity: relative humidity not less than 30 per cent nor more than 90 per cent.

Precipitation: none.

Barometric pressure: not less than 800 hPa nor more than 1 100 hPa.
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 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 instrumentation) 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 (see 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 s. 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 Figure C-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 10 (see 4.6).

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 11 km/h (6 kt). 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 of 50 dB minimum in the octave or one-third octave bands;
tape speed accuracy within ±0.2 per cent of rated speed;
wow and flutter (peak to peak) less than 0.5 per cent of tape speed;
maximum third harmonic distortion less than 2 per cent.

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.
Figure C-1. Noise measurement systems

Figure C-2. Rectangle of noise survey measurement positions
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 s should be made as a check on system dynamic range and noise floor.

c) Sound pressure sensitivity calibrations with the arrangements shown in Figure C-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 one-third octave band centre frequencies, specified in reference 11 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 references 6 to 9 (see 4.6).

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 Figure C-1 should provide one-third or one octave band sound pressure levels. Analyser filters should comply with requirements of reference 12 (Class II for octave band filters and Class III for one-third octave-band filters). Analyser 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 analyser 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 s. 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 28 km/h (0-15 kt) with an accuracy of at least ±2 km/h (±1 kt). Temperature measurements should be made with a device having a range of at least 0°C to 40°C with an accuracy of at least ±0.5°C. Relative humidity should be measured with a device having a range of 0 to 100 per cent with an accuracy of at least ±5 percentage points. Atmospheric pressure should be measured with a device having a range of at least 800 to 1 100 hPa with an accuracy of at least ±3 hPa.

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 4.4.4).

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 electric 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 APU 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 centre line 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 along the sides of a rectangle centred on the test aircraft as illustrated in Figure C-2. The distance between measurement positions should not be greater than 10 m for large aircraft. This distance may be reduced to accommodate small aeroplanes or to fulfil special requirements.

4.4.3 Meteorological measurement locations

Meteorological data should be measured at a location at the test site within the microphone array of Figure C-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 meters (reference 10) to one-third or one octave band sound pressure levels. The one octave band sound pressure levels may be determined from a summation of mean-square sound pressures in appropriate one-third octave bands. Over-all sound pressure levels should be determined from a summation of mean-square sound pressures in the 24 one-third octave, or 8 one octave, frequency bands included in the frequency range from 45 Hz to 11 200 Hz.

4.4.4.2 Over-all sound pressure levels, A-weighted sound levels and one-third or one 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, measured values should be corrected for ambient noise by logarithmic subtraction of levels. If sound pressure levels do not exceed ambient noise by as much as 3 dB, the measured values may be adjusted by means of a method agreed to by the certificating authority.

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, km/h (kt) and direction, degrees, relative to aircraft centre line (forward 0°).

b) Ambient temperature °C.

c) Relative humidity, per cent.

d) Barometric pressure, hPa.

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 percentage of normal rated.

c) APU normal rated shaft speed, rpm.

d) APU shaft load (kW), horse-power and/or electric power output, kVA.

e) Pneumatic load, kg/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.

g) Operating mode of environmental control system, cooling or heating.

h) Air conditioning distribution system supply duct temperature, °C.

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 specified in 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 standard for instruments and measurement procedures


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

IEC publications may be obtained from:

Bureau central de la Commission électrotechnique 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.
ATTACHMENT D. GUIDELINES FOR EVALUATING AN ALTERNATIVE METHOD OF MEASURING HELICOPTER NOISE DURING APPROACH

Note.—The approach reference procedure of 8.6.4.1 specifies a single approach path angle. This can coincide with the impulsive noise regime for some helicopters and not for others. In order that alternative methods of establishing compliance may be evaluated, States are encouraged to undertake additional measurements as described below.

1. INTRODUCTION

The following guidance material has been prepared for the use of States when obtaining additional information on which a future revision of the approach test procedures of Chapter 8 may be based.

2. APPROACH NOISE EVALUATION PROCEDURE

When conducting such tests the provisions of Chapter 8 shall be observed except as follows.

2.1 Approach reference noise measurement points

A flight path reference point located on the ground 120 m (395 ft) vertically below the flight paths defined in the approach reference procedure. On level ground this corresponds to the following positions:

- 2 290 m from the intersection of the 3° approach path with the ground plane
- 1 140 m from the intersection of the 6° approach path with the ground plane
- 760 m from the intersection of the 9° approach path with the ground plane.

2.2 Maximum noise levels

At the approach flight path reference point: the noise level to be calculated by taking the arithmetical average of the corrected levels for 3°, 6°, and 9° approaches.

2.3 Approach reference procedure

The approach reference procedure shall be established as follows:

- a) the helicopter shall be stabilized and following approach paths of 3°, 6°, and 9°;
- b) the approach shall be made at a stabilized airspeed equal to the best rate of climb speed \( V_Y \), or the lowest approved speed for the approach, whichever is the greater, with power stabilized during the approach and over the flight path reference point, and continued to a normal touchdown;
- c) the approach shall be made with the rotor speed stabilized at the maximum normal operating rpm certificated for approach;
- d) the constant approach configuration used in airworthiness certification tests, with the landing gear extended, shall be maintained throughout the approach reference procedure; and
- e) the mass of the helicopter at touchdown shall be the maximum landing mass at which noise certification is requested.
ATTACHMENT E. APPLICABILITY OF ICAO ANNEX 16
NOISE CERTIFICATION STANDARDS FOR
PROPELLER-DRIVEN AEROPLANES*

Note.—Attachment E is currently under review to determine what changes are required as a result of Amendments 5 and 6 to the Annex.

* These Standards do not apply to aeroplanes specifically designed for aerobatic purposes or agricultural or fire fighting uses or to self-sustaining powered sailplanes.
SUPPLEMENT TO

ANNEX 16 — ENVIRONMENTAL PROTECTION

VOLUME I —

AIRCRAFT NOISE

(Third Edition)

1. The attached Supplement supersedes all previous Supplements to Annex 16, Volume I and includes differences notified by Contracting States up to 4 January 1999 with respect to all amendments up to and including Amendment 5.

2. This Supplement should be inserted at the end of Annex 16, Volume I (Third Edition). Additional differences received from Contracting States will be issued at intervals as amendments to this Supplement.
SUPPLEMENT TO ANNEX 16 — THIRD EDITION

ENVIRONMENTAL PROTECTION

Volume I — Aircraft Noise

Differences between the national regulations and practices of Contracting States and the corresponding International Standards and Recommended Practices contained in Annex 16, Volume I as notified to ICAO in accordance with Article 38 of the Convention on International Civil Aviation and the Council’s resolution of 21 November 1950.
# RECORD OF AMENDMENTS

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# AMENDMENTS TO ANNEX 16, VOLUME I ADOPTED OR APPROVED BY THE COUNCIL SUBSEQUENT TO THE THIRD EDITION ISSUED JULY 1993

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1. **Contracting States which have notified ICAO of differences**

The Contracting States listed below have notified ICAO of differences which exist between their national regulations and practices and the International Standards of Annex 16, Volume I (Third Edition), up to and including Amendment 5, or have commented on implementation.

The page numbers shown for each State and the dates of publication of those pages correspond to the actual pages in this Supplement.

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- Antigua and Barbuda
- Armenia
- Australia
- Austria
- Azerbaijan
- Bahamas
- Bangladesh
- Belarus
- Belgium
- Belize
- Benin
- Bhutan
- Bolivia
- Bosnia and Herzegovina
- Botswana
- Brazil
- Brunei Darussalam
- Bulgaria
- Burkina Faso
- Burundi
- Cambodia
- Cape Verde
- Central African Republic

4/1/99
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General

The applicable noise emission Standards of Annex 16, Chapters 2, 3, 5, 6, 8 and 10 apply:

1) in respect of issuance of new or amended type approvals (type certifications) for aeroplanes after 31 December 1985 and in respect of application for new or amended type approvals for helicopters after 31 December 1988; or

2) for aircraft that were first registered on the Canadian Register, for aeroplanes after 31 December 1985 and for helicopters after 31 December 1988 and are type designs that had previously been noise tested and found in compliance.

PART II

Chapter 3

3.1.1 c) Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

Chapter 4

Not adopted.

Chapter 6

6.1.1 Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

6.3.1 Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

Chapter 7

Not adopted.

Chapter 9

Not adopted.

Chapter 10

10.1.1 Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

10.4 Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

Appendix 2

Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

Appendix 3

Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).

Appendix 6

Maximum certificated take-off mass for propeller-driven aeroplanes is reduced from 9 000 kg to 8 618 kg (19 000 lb).
General

In addition to the following differences, minor deviations may be introduced into the German Regulations. However, these deviations will be less significant than those listed below.

PART II

Chapter 1

1.3 The document contains additional information such as muffler type, noise requirements, 90 per cent confidence level(s), noise limit(s).

1.7 The applicability of noise standards is determined by the date of application for registration.

Chapter 6

6.1.1 Applicable also to powered sailplanes.

6.3.1 The maximum noise level when determined in accordance with the noise evaluation method of Appendix 3 shall not exceed the following:

- a 64 dB(A) constant limit up to an aeroplane mass of 600 kg, varying linearly with mass from that point to 1 500 kg, after which the limit is constant at 76 dB(A) up to 9 000 kg.

6.5.3 “Highest power in the normal operating range” has been replaced by “maximum continuous power”.

Chapter 10

10.1.1 Applicable also to powered sailplanes.

10.4 The maximum noise level determined in accordance with the noise evaluation method of Appendix 6 shall not exceed the following:

- a 68 dB(A) constant limit up to an aeroplane mass of 500 kg, varying linearly with mass from that point to 1 500 kg, after which the limit is constant at 85 dB(A) up to 9 000 kg.

10.5.2 If the reference height of the aeroplane over the microphone exceeds 450 m, the distance between the reference noise measurement point and the start of take-off roll has to be reduced.

Appendix 3

4.2.1.1 “Highest power in the normal operating range” has been replaced by “maximum continuous power”. See also 6.5.3.

4.3.1 The measuring point shall be overflown at least six times.
PART II

Chapter 2  Under the laws and regulations of Japan, noise certification is required for all aeroplanes equipped with turbo-jet engines, including those aeroplanes which are exempted by 2.1.1 a), b) and c). The operation of turbo-jet aeroplanes which do not meet the Standards of Chapter 3 is restricted under the conditions specified in Assembly Resolution A28-3 “Possible operating restrictions on subsonic jet aircraft which exceed the noise levels in Volume I, Chapter 3 of Annex 16”.

_Secretariat Note._—Assembly Resolution A28-3 was consolidated into Resolution A31-11 which has now been superseded by Resolution A32-8.

Chapter 3  For propeller-driven aeroplanes, including their derived versions, for which the Standards of Chapter 3 are applicable, the requirement for lateral noise in 3.3.1 a) 1) shall be alternatively permitted, if either the application for a Certificate of Airworthiness for the prototype is accepted or another equivalent prescribed procedure is carried out by the certificating authority before 19 March 2002.

Chapter 4  Since the laws and regulations of Japan do not differentiate between supersonic aeroplanes and subsonic aeroplanes, the noise Standards of Annex 16 that are applicable to subsonic jet aeroplanes are also applicable to supersonic aeroplanes.
General  Currently the Netherlands requirements refer to the third edition of Annex 16, Volume I. At a date yet to be determined, all sections of Annex 16, Volume I covered by JAR 36 will be implemented by an appropriate reference in our national legislation to JAR 36, and the remaining sections will be incorporated by reference to Annex 16, Volume I, Amendment 5.

PART II

Chapter 1  A noise certificate is not routinely issued.
PART II

Chapter 3  No person shall operate a subsonic turbo-jet aircraft of more than 34,044 kg maximum certificated take-off weight to or from any aerodrome within New Zealand after 31 March 2002 unless that aircraft has been:

a) certificated under Civil Aviation Rules, Part 36 to Stage 3 noise levels prescribed in that Part; or

b) certificated by another State to the equivalent specification for Stage 3 noise levels that is acceptable to the Director of Civil Aviation.

Civil Aviation Rules, Part 36, Aircraft Noise Certification, is under development.
PART II

Chapter 6

Instead of an 8 618 kg value for maximum take-off mass, the analogous Russian standards (Aviation Regulations, Part 36) use a value of 8 600 kg. Furthermore, the Chapter 6 requirements together with the Chapter 10 requirements are applied to aeroplanes for which the application for a certificate of airworthiness of a prototype or derivative was adopted after 17 November 1988.

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Note

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Chapter 10

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10.4

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Appendix 2

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Appendix 3

Instead of an 8 618 kg value for maximum take-off mass, the analogous Russian standards (Aviation Regulations, Part 36) use a value of 8 600 kg.
PART II

Chapter 8

8.4.1.1 The maximum permitted noise levels are 3 dB below the limits determined in accordance with 8.4.1.1.

8.4.1.2 The maximum permitted noise levels are 3 dB below the limits determined in accordance with 8.4.1.2.

8.4.1.3 The maximum permitted noise levels are 3 dB below the limits determined in accordance with 8.4.1.3.

Chapter 10

10.4 A 68 dB(A) constant limit up to an aeroplane mass of 500 kg, varying linearly with mass from that point up to 1 500 kg, after which the limit is constant at 85 dB(A).

10.5.2 The reference height of the aeroplane over the microphone shall be determined according to the procedures of this chapter except that it shall not exceed 450 m.
PART II

Chapter 3

3.1.2 A difference to be registered for paragraph 3.1.2 to read:

“For aeroplanes specified in 3.1.1 b) and c) the requirement for lateral noise in 3.3.1 a) shall alternatively be permitted.”
General
In addition to the differences detailed below, minor deviations may be identified with respect to incorporated references, nomenclature and tolerances. These minor deviations are considered to be acceptable in the context of approved equivalent procedures and are less significant than the tabled differences.

PART II

Chapter 1

1.7 Each person who applies for a type certificate for an aeroplane covered by Part 36, irrespective of the date of application for the type certificate, must show compliance with 14 CFR Part 36.

Chapter 2

2.1.1 For type design change applications made after 14 August 1989, if an aeroplane is a Stage 3 aeroplane prior to a change in type design, it must remain a Stage 3 aeroplane after the change in type design regardless of whether Stage 3 compliance was required before the change in type design.

2.3.1 a) Sideline noise is measured along a line 450 m from and parallel to the extended runway centre line for two- and three-engined aircraft; for four-engined aircraft, the sideline distance is 0.35 NM.

2.4.2 Noise level limits for Stage 2 derivative aircraft depend upon whether the engine by-pass ratio is less than two. If it is, the Stage 2 limits apply. Otherwise, the limits are the Stage 3 limits plus 3 dB or the Stage 2 value, whichever is lower.

2.4.2.2 b) Take-off noise limits for three-engined, Stage 2 derivative aeroplanes with a by-pass ratio equal to or greater than 2 are 107 EPNdB for maximum weights of 385 000 kg (850 000 lb) or more, reduced by 4 dB per halving of the weight down to 92 EPNdB for maximum weights of 28 700 kg (63 177 lb) or less. Aircraft with a by-pass ratio less than 2 only need meet the Stage 2 limits.

2.5.1 Trade-off sum of excesses not greater than 3 EPNdB and no excess greater than 2 EPNdB.

2.6.1.1 For aeroplanes that do not have turbo-jet engines with a by-pass ratio of 2 or more, the following apply:
   a) four-engined aeroplanes — 214 m (700 ft);
   b) all other aeroplanes — 305 m (1 000 ft).

For all aeroplanes that have turbo-jet engines with a by-pass ratio of two or more, the following apply:
   a) four-engined aeroplanes — 210 m (689 ft);
   b) three-engined aeroplanes — 260 m (853 ft);
   c) aeroplanes with fewer than three engines — 305 m (1 000 ft).

The power may not be reduced below that which will provide level flight for an engine inoperative or that will maintain a climb gradient of at least 4 per cent, whichever is greater.

Chapter 3

3.1.1 For type design change applications made after 14 August 1989, if an aeroplane is a Stage 3 aeroplane prior to a change in type design, it must remain a Stage 3 aeroplane after the change in type design regardless of whether Stage 3 compliance was required before the change in type design.
3.3.1 a), 2) No equivalent provision in 14 CFR Part 36.

3.3.2.2 A minimum of two microphones symmetrically positioned about the test flight track must be used to define the maximum sideline noise. This maximum noise may be assumed to occur where the aircraft reaches 305 m (1 000 ft). 14 CFR Part 36 does not require symmetrical measurements to be made at each and every point for propeller-driven aeroplane sideline noise determination.

3.6.2.1 c) Under 14 CFR Part 36, during each test take-off, simultaneous measurements should be made at the sideline noise measuring stations on each side of the runway and also at the take-off noise measuring station. If test site conditions make it impractical to simultaneously measure take-off and sideline noise, and if each of the other sideline measurement requirements is met, independent measurements may be made of the sideline noise under simulated flight path techniques. If the reference flight path includes a power cutback before the maximum sideline noise level is developed, the reduced sideline noise level, which is the maximum value developed by the simulated flight path technique, must be the certificated sideline noise value.

d) 14 CFR Part 36 specifies the day speeds and the acoustic reference speed to be the minimum approved value of $V_2 + 10$ kt or the all-engines operating speed at 35 ft (for turbine-engine powered aeroplanes) or 50 ft (for reciprocating engine powered aeroplanes), whichever speed is greater as determined under the regulations constituting the type certification basis of the aeroplane. Tests must be conducted at the test day speeds ± 3 kt.

3.7.4 If a take-off test series is conducted at weights other than the maximum take-off weight for which noise certification is requested:

a) at least one take-off test must be at or above that maximum weight;
b) each take-off test weight must be within +5 or −10 per cent of the maximum weight.

If an approach test series is conducted at weights other than the maximum landing weight for which certification is requested:

a) at least one approach test must be conducted at or above that maximum weight;
b) each test weight must exceed 90 per cent of the maximum landing weight.

Total EPNL adjustment for variations in approach flight path from the reference flight path and for any difference between test engine thrust or power and reference engine thrust or power must not exceed 2 EPNdB.

Chapter 5

5.1.1 Applies to all large transport category aircraft (as it does to all subsonic turbo-jet aircraft regardless of category). Commuter category aircraft, propeller-driven aeroplanes below 8 640 kg (19 000 lb) are subject to FAR Part 36, Appendix F or to Appendix G, depending upon the date of completion of the noise certification tests.

Chapter 6

6.1.1 Applies to new, all propeller-driven aeroplane types below 19 000 lb (8 640 kg) in the normal, commuter, utility, acrobatic, transport or restricted categories for which the noise certification tests are completed before 22 December 1988.
Chapter 8

General

FAR 36.1(g) defines Stage 1 and Stage 2 noise levels and Stage 1 and Stage 2 helicopters. These definitions parallel those used in FAR Part 36 for turbo-jets and are used primarily to simplify the acoustical change provisions in 36.11.

FAR 36.805(c) provides for certain derived versions of helicopters for which there are no civil prototypes to be certificated above the noise level limits.

8.1.1 a) Applicable to new helicopter types for which application for an original type certificate was made on or after 6 March 1988.

b) Applicable only to “acoustical changes” for which application for an amended or supplemental type certificate was made on or after 6 March 1988.

8.4 14 CFR Part 36, Appendix H specifies a slightly different rate of allowable maximum noise levels as a function of helicopter mass. The difference can lead to a difference in the calculated maximum noise limits of 0.1 EPNdB under certain round-off conditions.

8.6.3.1 b) Does not include the $V_{NE}$ speeds.

8.7 14 CFR Part 36, Appendix H does not permit certain negative corrections. Annex 16 has no equivalent provision.

8.7.4 EPNL correction must be less than 2.0 EPNdB for any combination of lateral deviation, height, approach angle and, in the case of flyover, thrust or power.

Corrections to the measured data are required if the tests were conducted below the reference weight.

Corrections to the measured data are required if the tests were conducted at other than reference engine power.

8.7.5 The rotor speed must be maintained within one per cent of the normal operating RPM during the take-off procedure.

8.7.8 The helicopter shall fly within $\pm 10^\circ$ from the zenith for approach and take-off, but within $\pm 5^\circ$ from the zenith for horizontal flyover.

Chapter 10

General

Exception from acoustical change rule given for aircraft with flight time prior to 1 January 1955 and land configured aircraft reconfigured with floats or skis.

10.1.1 Applies to new, amended or supplemental type certificates for propeller-driven aeroplanes not exceeding 8 640 kg (19 000 lb) for which noise certification tests have not been completed before 22 December 1988.

10.4 The maximum noise level is a constant 73 dBA up to 600 kg (1 320 lb). Above that weight, the limit increases at the rate of 1 dBA/75 kg (1 dBA/165 lb) up to 85 dBA at 1 500 kg (3 300 lb) after which it is constant up to and including 8 640 kg (19 000 lb).
10.5.2 Second phase, paragraph d). For variable pitched propellers the definition of engine power is different in the second segment of the reference path. Maximum continuous installed power instead of maximum power is used.

Chapter 11

11.1 FAR Appendix J was effective 11 September 1992 and applies to those helicopters for which application for a type certificate was made on or after 6 March 1986.

11.4 14 CFR Part 36, Appendix J specifies a slightly different rate of allowable maximum noise levels as a function of helicopter mass. The difference can lead to a difference in the calculated maximum noise limits of 0.1 EPNdB under certain round-off conditions.

11.6 14 CFR Part 36, Appendix J prescribes a ±15 m limitation on the allowed vertical deviation around the reference flight path. Annex 16 has no equivalent provision.

PART V

General No comparable provision exists in United States Federal Regulations. Any local airport proprietor may propose noise abatement operating procedures to the FAA which reviews them for safety and appropriateness.

Appendix 1

General Sections 3, 8 and 9 of Appendix 1 which contain the technical specifications for equipment, measurement and analysis and data correction for Chapter 2 aircraft and their derivatives differ in many important aspects from the corresponding requirements in Appendix 2 which has been updated several times. Part 36 updates have generally paralleled those of Appendix 2 of Annex 16. These updated requirements are applicable in the United States to both Stage 2 and Stage 3 aircraft and their derivatives.

2.2.1 A minimum of two microphones symmetrically positioned about the test flight track must be used to define the maximum sideline noise. This maximum noise may be assumed to occur where the aircraft reaches 305 m (1 000 ft), except for four-engine, Stage 2 aircraft for which 439 m (1 440 ft) may be used.

2.2.2 No obstructions in the cone defined by the axis normal to the ground and the half-angle $\frac{80}{45}$ from the axis.

2.2.3 c) Relative humidity and ambient temperature over the sound path between the aircraft and 10 m above the ground at the noise measuring site is such that the sound attenuation in the 8 kHz one-third octave band is not greater than 12 dB/100 m and the relative humidity is between 20 and 95 per cent. However, if the dew point and dry bulb temperature used for obtaining relative humidity are measured with a device which is accurate to within one-half a degree Celsius, the sound attenuation rate shall not exceed 14 dB/100 m in the 8 kHz one-third octave band.

d) Test site average wind not above 12 kt and average cross-wind component not above 7 kt.

2.3.4 The aircraft position along the flight path is related to the recorded noise 10 dB downpoints.

2.3.5 At least one take-off test must be a maximum take-off weight and the test weight must be within +5 or −10 per cent of maximum certificated take-off weight.
Appendix 2

2.2.1 A minimum of two symmetrically placed microphones must be used to define the maximum sideline noise at the point where the aircraft reaches 305 m.

2.2.2 When a multiple layering calculation is required, the atmosphere between the aeroplane and the ground shall be divided into layers. These layers are not required to be of equal depth and the maximum layer depth must be 100 m.

b) 14 CFR Part 36 specifies that the lower limit of the temperature test window is 36 degrees Fahrenheit (2.2 degrees Celsius). Annex 16 provides 10 degrees Celsius as the lower limit for the temperature test window. 14 CFR Part 36 does not specify that the airport facility used to obtain meteorological condition measurements be within 2 000 m of the measurement site.

c) Part 36 imposes a limit of 14 dB/100 m in the 8 kHz one-third octave band when the temperature and dew point are measured with a device which is accurate to within one-half a degree Celsius.

2.2.3 14 CFR Part 36 requires that the limitations on the temperature and relative humidity test window must apply over the whole noise propagation path between a point 10 m above the ground and the helicopter. Annex 16 specifies that the limitations on the temperature and relative humidity test window apply only at a point 10 m above the ground. 14 CFR Part 36 requires that corrections for sound attenuation must be based on the average of temperature and relative humidity readings at 10 m above the ground and the helicopter. Annex 16 implies that the corrections for sound absorption are based on the temperature and relative humidity measured at 10 m only.

3.2.6 No equivalent requirement.

3.4.5 For each detector/integrator the response to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave band centre frequency must be measured at sampling times 0.5, 1.0, 1.5 and 2.0 seconds after the onset or interruption. The rising responses must be the following amounts before the steady-state level:

- 0.5 seconds: 4.0 ± 1.0 dB
- 1.0 seconds: 1.75 ± 0.75 dB
- 1.5 seconds: 1.0 ± 0.5 dB
- 2.0 seconds: 0.6 ± 0.5 dB

Note 1 No equivalent provision in 14 CFR Part 36.

3.5.2 No equivalent requirement.

5.4 14 CFR Part 36 requires that the difference between airspeed and ground speed shall not exceed 10 kt between the 10 dB down time period.

8.4.2 14 CFR Part 36 specifies a value of −10 in the adjustment for duration correction. Annex 16 specifies a value of −7.5.

9.1.2 If the correction factor exceeds 8 dB on take-off or 4 dB on approach, or the correction results in a final EPNL value which is within 1.0 dB of the noise level limits, the “integrated” method must be used. Note that there is no stated requirement for the use of the “integrated” procedure on sideline and the 1.0 dB test is not tied to the amount of the adjustment on take-off.
Appendix 6

4.4.1 The microphone performance, not its dimensions, is specified. The microphone must be mounted 1.2 m (4 ft) above ground level. A windscreen must be employed when the wind speed is in excess of 9 km/h (5 kt).

5.2.2 a) Reference conditions are different. Noise data outside the applicable range must be corrected to 77 degrees Fahrenheit and 70 per cent humidity.

c) No equivalent provision in 14 CFR Part 36. Fixed pitched propeller-driven aeroplanes have a special provision. If the propeller is fixed pitched and the test power is not within 5 per cent of reference power, a helical tip Mach number correction is required.
This edition incorporates all amendments to Annex 16, adopted by the Council prior to 25 March 1993 and supersedes on 11 November 1993 all previous editions of the Annex.

For information regarding the applicability of the Standards and Recommended Practices, see Foreword and the relevant clauses in each Chapter.
AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

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FOREWORD

Historical background

In 1972 the United Nations Conference on the Human Environment was held in Stockholm. The position of ICAO at this Conference was developed in Assembly Resolution A18-11 which contained the following clause among others:

“2. in fulfilling this role ICAO is conscious of the adverse environmental impact that may be related to aircraft activity and its responsibility and that of its member States to achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the human environment;”

The 18th Assembly also adopted Resolution A18-12 relating to the environment which states:

“THE ASSEMBLY:

1. REQUESTS the Council, with the assistance and co-operation of other bodies of the Organization and other international organizations to continue with vigour the work related to the development of Standards, Recommended Practices and Procedures and/or guidance material dealing with the quality of the human environment;”

This resolution was followed up by the establishment of an ICAO Action Programme Regarding the Environment. As part of this Action Programme a Study Group was established to assist the Secretariat in certain tasks related to aircraft engine emissions. As a result of the work of this Study Group, an ICAO Circular entitled Control of Aircraft Engine Emissions (Circular 134) was published in 1977. This Circular contained guidance material in the form of a certification procedure for the control of vented fuel, smoke and certain gaseous emissions for new turbo-jet and turbofan engines intended for propulsion at subsonic speeds.

It was agreed by the Council that the subject of aircraft engine emissions was not one that was solely confined to objective technical issues but was one that needed consideration by experts in many fields and included the direct views of Member States. A Council committee, known as the Committee on Aircraft Engine Emissions (CAEE) was therefore established in 1977 to pursue a number of aspects of the subject.

At the second meeting of the Committee on Aircraft Engine Emissions, held in May 1980, proposals were made for material to be included in an ICAO Annex. After amendment following the usual consultation with Member States of the Organization, the proposed material was adopted by the Council to form the text of this document. The Council agreed that it was desirable to include all provisions relating to environmental aspects of aviation in one Annex. It therefore renamed Annex 16 as “Environmental Protection”, making the existing text of the Annex into “Volume I — Aircraft Noise”, the material contained in this document becoming “Volume II — Aircraft Engine Emissions”.

Applicability

Part I of Volume II of Annex 16 contains definitions and symbols and Part II contains Standards relating to vented fuel. Part III contains Standards relating to emissions certification applicable to the classes of aircraft engines specified in the individual chapters of the Part, where such engines are fitted to aircraft engaged in international civil aviation.

Action by Contracting States

Notification of differences. The attention of Contracting States is drawn to the obligation imposed by Article 38 of the Convention by which Contracting States are required to notify the Organization of any differences between their national regulations and practices and the International Standards contained in this Annex and any amendments thereto. Contracting States are invited to extend such notification to any differences from the Recommended Practices contained in this Annex, and any amendments thereto, when the notification of such differences is important for the safety of air navigation. Further, Contracting States are invited to keep the Organization currently informed of any differences which may subsequently occur, or of the withdrawal of any differences previously notified. A specific request for notification of differences will be sent to Contracting States immediately after the adoption of each amendment to this Annex.

The attention of States is also drawn to the provisions of Annex 15 related to the publication of differences between their national regulations and practices and the related ICAO Standards and Recommended Practices through the Aeronautical Information Service, in addition to the obligation of States under Article 38 of the Convention.

Use of the Annex text in national regulations. The Council, on 13 April 1948, adopted a resolution inviting the attention
of Contracting States to the desirability of using in their own national regulations, as far as is practicable, the precise language of those ICAO Standards that are of a regulatory character and also of indicating departures from the Standards, including any additional national regulations that were important for the safety or regularity of international air navigation. Wherever possible, the provisions of this Annex have been written in such a way as to facilitate incorporation, without major textual changes, into national legislation.

**Status of Annex components**

An Annex is made up of the following component parts, not all of which, however, are necessarily found in every Annex; they have the status indicated.

1. — Material comprising the Annex proper:

   a) **Standards** and **Recommended Practices** adopted by the Council under the provisions of the Convention. They are defined as follows:

   **Standard:** Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as necessary for the safety or regularity of international air navigation and to which Contracting States will conform in accordance with the Convention; in the event of impossibility of compliance, notification to the Council is compulsory under Article 38.

   **Recommended Practice:** Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as desirable in the interest of safety, regularity or efficiency of international air navigation, and to which Contracting States will endeavour to conform in accordance with the Convention.

   b) **Appendices** comprising material grouped separately for convenience but forming part of the Standards and Recommended Practices adopted by the Council.

   c) **Provisions** governing the applicability of the Standards and Recommended Practices.

   d) **Definitions** of terms used in the Standards and Recommended Practices which are not self-explanatory in that they do not have accepted dictionary meanings. A definition does not have an independent status but is an essential part of each Standard and Recommended Practice in which the term is used, since a change in the meaning of the term would affect the specification.

2. — Material approved by the Council for publication in association with the Standards and Recommended Practices:

   a) **Forewords** comprising historical and explanatory material based on the action of the Council and including an explanation of the obligations of States with regard to the application of the Standards and Recommended Practices ensuing from the Convention and the Resolution of Adoption.

   b) **Introductions** comprising explanatory material introduced at the beginning of parts, chapters or sections of the Annex to assist in the understanding of the application of the text.

   c) **Notes** included in the text, where appropriate, to give factual information or references bearing on the Standards or Recommended Practices in question, but not constituting part of the Standards or Recommended Practices.

   d) **Attachments** comprising material supplementary to the Standards and Recommended Practices, or included as a guide to their application.

**Selection of language**

This Annex has been adopted in four languages — English, French, Russian and Spanish. Each Contracting State is requested to select one of those texts for the purpose of national implementation and for other effects provided for in the Convention, either through direct use or through translation into its own national language, and to notify the Organization accordingly.

**Editorial practices**

The following practice has been adhered to in order to indicate at a glance the status of each statement: **Standards** have been printed in light face roman; **Recommended Practices** have been printed in light face italics, the status being indicated by the prefix **Recommendation**; **Notes** have been printed in light face italics, the status being indicated by the prefix **Note**.

It is to be noted that in the English text the following practice has been adhered to when writing the specifications: Standards employ the operative verb “shall” while Recommended Practices employ the operative verb “should”.

In accordance with Annex 5, the International System of Units (SI) is used throughout this document.

Any reference to a portion of this document which is identified by a number includes all subdivisions of that portion.
## Table A. Amendments to Annex 16

<table>
<thead>
<tr>
<th>Amendment</th>
<th>Source(s)</th>
<th>Subject(s)</th>
<th>Adopted</th>
<th>Effective</th>
<th>Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First Meeting of the Committee on Aircraft Noise</td>
<td>Noise certification of light propeller-driven aeroplanes and subsonic jet aeroplanes of 5 700 kg and less maximum certificated take-off weight and guidance on discharge of functions by States in the cases of lease, charter and interchange of aircraft.</td>
<td></td>
<td>6 December 1972</td>
<td>6 April 1973</td>
</tr>
<tr>
<td>2</td>
<td>Third Meeting of the Committee on Aircraft Noise</td>
<td>Noise certification standards for future subsonic jet aeroplanes and propeller-driven aeroplanes, other than STOL aeroplanes, and guidelines for noise certification of future supersonic aeroplanes, propeller-driven STOL aeroplanes and installed APU and associated aircraft systems when operating on the ground.</td>
<td></td>
<td>21 June 1976</td>
<td>21 October 1976</td>
</tr>
<tr>
<td>(2nd Edition)</td>
<td>Fourth Meeting of the Committee on Aircraft Noise</td>
<td>Noise certification standards for subsonic jet aeroplanes, improvements in detailed test procedures to ensure that the same level of technology is applied to all types of aircraft, and editorial changes to simplify the language and eliminate inconsistencies.</td>
<td></td>
<td>6 October 1977</td>
<td></td>
</tr>
<tr>
<td>(3rd Edition)</td>
<td>Fifth Meeting of the Committee on Aircraft Noise</td>
<td>Introduction of a new parameter, viz. number of engines in the noise certification standards for subsonic jet aeroplanes, and improvements in test fuel specifications, Appendix 4.</td>
<td></td>
<td>6 March 1978</td>
<td>6 July 1978</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Introduction in Volume I of noise certification Standards for helicopters and for future production of existing SST aeroplanes, updating of guidelines for noise certification of installed APU and associated aircraft systems and editorial amendments including changes to units of measurement to bring the Annex in line with Annex 5 provisions.</td>
<td></td>
<td>26 November 1981</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>First Meeting of the Committee on Aviation Environmental Protection</td>
<td>Changes in test fuel specifications, Appendix 4.</td>
<td></td>
<td>18 February 1982</td>
<td>4 March 1988</td>
</tr>
<tr>
<td>(2nd Edition)</td>
<td>Second Meeting of the Committee on Aviation Environmental Protection</td>
<td>a) increased stringency of NOx emissions limits; b) improvements in the smoke and gaseous emissions certification procedure.</td>
<td></td>
<td>24 March 1993</td>
<td>26 July 1993</td>
</tr>
<tr>
<td>3</td>
<td>Third Meeting of the Committee on Aviation Environmental Protection</td>
<td>Amendment of the criteria on calibration and test gases in Appendices 3 and 5.</td>
<td></td>
<td>11 November 1993</td>
<td>20 March 1997</td>
</tr>
</tbody>
</table>

<p>| (vii) | | | | | |</p>
<table>
<thead>
<tr>
<th>Amendment</th>
<th>Source(s)</th>
<th>Subject(s)</th>
<th>Adopted</th>
<th>Effective</th>
<th>Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Fourth Meeting of the Committee on Aviation Environmental Protection</td>
<td>Increased stringency of NO(_x) emissions limits.</td>
<td>26 February 1999</td>
<td>19 July 1999</td>
<td>4 November 1999</td>
</tr>
</tbody>
</table>
PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

Where the following expressions are used in Volume II of this Annex, they have the meanings ascribed to them below:

**Afterburning.** A mode of engine operation wherein a combustion system fed (in whole or part) by vitiated air is used.

**Approach phase.** The operating phase defined by the time during which the engine is operated in the approach operating mode.

**Climb phase.** The operating phase defined by the time during which the engine is operated in the climb operating mode.

**Date of manufacture.** The date of issue of the document attesting that the individual aircraft or engine as appropriate conforms to the requirements of the type or the date of an analogous document.

**Derivative version.** An aircraft gas turbine engine of the same generic family as an originally type-certificated engine and having features which retain the basic core engine and combustor design of the original model and for which other factors, as judged by the certificating authority, have not changed.

*Note.— Attention is drawn to the difference between the definition of “derived version of aircraft” in Volume I of Annex 16 and the definition of “derivative version” in this Volume.*

**Rated output.** For engine emissions purposes, the maximum power/thrust available for take-off under normal operating conditions at ISA sea level static conditions without the use of water injection as approved by the certificating authority. Thrust is expressed in kilonewtons.

**Reference pressure ratio.** The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating in ISA sea level static conditions.

*Note.— Methods of measuring reference pressure ratio are given in Appendix 1.*

**Smoke.** The carbonaceous materials in exhaust emissions which obscure the transmission of light.

**Smoke Number.** The dimensionless term quantifying smoke emissions (see 3 of Appendix 2).

**Take-off phase.** The operating phase defined by the time during which the engine is operated at the rated output.

**Taxi/ground idle.** The operating phases involving taxi and idle between the initial starting of the propulsion engine(s) and the initiation of the take-off roll and between the time of runway turn-off and final shutdown of all propulsion engine(s).

**Unburned hydrocarbons.** The total of hydrocarbon compounds of all classes and molecular weights contained in a gas sample, calculated as if they were in the form of methane.
CHAPTER 2. SYMBOLS

Where the following symbols are used in Volume II of this Annex, they have the meanings ascribed to them below:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>$D_p$</td>
<td>The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle</td>
</tr>
<tr>
<td>$F_n$</td>
<td>Thrust in International Standard Atmosphere (ISA), sea level conditions, for the given operating mode</td>
</tr>
<tr>
<td>$F_{oo}$</td>
<td>Rated output (see definition)</td>
</tr>
<tr>
<td>$F^*_{oo}$</td>
<td>Rated output with afterburning applied</td>
</tr>
<tr>
<td>HC</td>
<td>Unburned hydrocarbons (see definition)</td>
</tr>
<tr>
<td>NO</td>
<td>Nitric oxide</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>Nitrogen dioxide</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>Oxides of nitrogen (see definition)</td>
</tr>
<tr>
<td>SN</td>
<td>Smoke Number (see definition)</td>
</tr>
<tr>
<td>$\pi_{oo}$</td>
<td>Reference pressure ratio (see definition)</td>
</tr>
</tbody>
</table>
PART II. VENTED FUEL

CHAPTER 1. ADMINISTRATION

1.1 The provision of this Part shall apply to all turbine engine powered aircraft intended for operation in international air navigation manufactured after 18 February 1982.

1.2 Certification related to the prevention of intentional fuel venting shall be granted by the certificating authority on the basis of satisfactory evidence that either the aircraft or the aircraft engines comply with requirements of Chapter 2.

Note.— The document attesting certification relating to fuel venting may take the form of a separate fuel venting certificate or a suitable statement contained in another document approved by the certificating authority.

1.3 Contracting States shall recognize as valid a certification relating to fuel venting granted by the certificating authority of another Contracting State provided the requirements under which such certification was granted are not less stringent than the provision of Volume II of this Annex.
CHAPTER 2. PREVENTION OF INTENTIONAL FUEL VENTING

Aircraft shall be so designed and constructed as to prevent the intentional discharge into the atmosphere of liquid fuel from the fuel nozzle manifolds resulting from the process of engine shutdown following normal flight or ground operations.
PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION

1.1 The provision of 1.2 to 1.4 shall apply to all engines included in the classifications defined for emission certification purposes in Chapters 2 and 3 where such engines are fitted to aircraft engaged in international air navigation.

1.2 Emissions certification shall be granted by the certificating authority on the basis of satisfactory evidence that the engine complies with requirements which are at least equal to the stringency of the provisions of Volume II of this Annex. Compliance with the emissions levels of Chapters 2 and 3 shall be demonstrated using the procedure described in Appendix 6.

*Note.*—The document attesting emissions certification may take the form of a separate emissions certificate or a suitable statement contained in another document approved by the certificating authority.

1.3 The document attesting emissions certification for each individual engine shall include at least the following information which is applicable to the engine type:

- a) name of certificating authority;
- b) manufacturer’s type and model designation;
- c) statement of any additional modifications incorporated for the purpose of compliance with the applicable emissions certification requirements;
- d) rated output;
- e) reference pressure ratio;
- f) a statement indicating compliance with Smoke Number requirements;
- g) a statement indicating compliance with gaseous pollutant requirements.

1.4 Contracting States shall recognize as valid emissions certification granted by the certificating authority of another Contracting State provided that the requirements under which such certification was granted are not less stringent than the provisions of Volume II of this Annex.
CHAPTER 2. TURBO-JET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

2.1 General

2.1.1 Applicability

The provisions of this chapter shall apply to all turbo-jet and turbofan engines, as further specified in 2.2 and 2.3, intended for propulsion only at subsonic speeds, except when certificating authorities make exemptions for specific engine types and derivative versions of such engines for which the type certificate of the first basic type was issued or other equivalent prescribed procedure was carried out before 1 January 1965. In such cases an exemption document shall be issued by the certificating authority. The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbo-jet and turbofan engines.

Note.—In considering exemptions, certificating authorities should take into account the probable numbers of such engines that will be produced and their impact on the environment. When such an exemption is granted, the certificating authority should consider imposing a time limit on the future production of such engines for installation on new aircraft, although production of such engines as spares should be permitted indefinitely.

2.1.2 Emissions involved

The following emissions shall be controlled for certification of aircraft engines:

Smoke
Gaseous emissions
  Unburned hydrocarbons (HC);
  Carbon monoxide (CO); and
  Oxides of nitrogen (NO\textsubscript{x}).

2.1.3 Units of measurement

2.1.3.1 The smoke emission shall be measured and reported in terms of Smoke Number (SN).

2.1.3.2 The mass (D\textsubscript{g}) of the gaseous pollutant HC, CO, or NO\textsubscript{x} emitted during the reference emissions landing and take-off (LTO) cycle, defined in 2.1.4.2 and 2.1.4.3, shall be measured and reported in grams.

2.1.4 Reference conditions

2.1.4.1 Atmospheric conditions

The reference atmospheric conditions shall be ISA at sea level except that the reference absolute humidity shall be 0.00629 kg water/kg dry air.

2.1.4.2 Thrust settings

The engine shall be tested at sufficient power settings to define the gaseous and smoke emissions of the engine so that mass emission rates and Smoke Numbers corrected to the reference ambient conditions can be determined at the following specific percentages of rated output as agreed by the certificating authority:

<table>
<thead>
<tr>
<th>Operating mode</th>
<th>Thrust setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>100 per cent F\textsubscript{oo}</td>
</tr>
<tr>
<td>Climb</td>
<td>85 per cent F\textsubscript{oo}</td>
</tr>
<tr>
<td>Approach</td>
<td>30 per cent F\textsubscript{oo}</td>
</tr>
<tr>
<td>Taxi/ground idle</td>
<td>7 per cent F\textsubscript{oo}</td>
</tr>
</tbody>
</table>

2.1.4.3 Reference emissions landing and take-off (LTO) cycle

The reference emissions LTO cycle for the calculation and reporting of gaseous emissions shall be represented by the following time in each operating mode.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time in operating mode, minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>0.7</td>
</tr>
<tr>
<td>Climb</td>
<td>2.2</td>
</tr>
<tr>
<td>Approach</td>
<td>4.0</td>
</tr>
<tr>
<td>Taxi/ground idle</td>
<td>26.0</td>
</tr>
</tbody>
</table>

2.1.4.4 Fuel specifications

The fuel used during tests shall meet the specifications of Appendix 4. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.
2.1.5 Test conditions

2.1.5.1 The tests shall be made with the engine on its test bed.

2.1.5.2 The engine shall be representative of the certificated configuration (see Appendix 6); off-take bleeds and accessory loads other than those necessary for the engine’s basic operation shall not be simulated.

2.1.6 When test conditions differ from the reference conditions in 2.1.4 the test results shall be corrected to the reference conditions by the methods given in Appendix 3.

2.2 Smoke

2.2.1 Applicability

The provisions of 2.2.2 shall apply to engines whose date of manufacture is on or after 1 January 1983.

2.2.2 Regulatory Smoke Number

The Smoke Number at any thrust setting when measured and computed in accordance with the procedures of Appendix 2 and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level determined from the following formula:

Regulatory Smoke Number = 83.6 $(F_{oo})^{-0.274}$

or a value of 50, whichever is lower

2.3 Gaseous emissions

2.3.1 Applicability

The provisions of 2.3.2 shall apply to engines whose rated output is greater than 26.7 kN and whose date of manufacture is on or after 1 January 1986 and as further specified for oxides of nitrogen.

2.3.2 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 and converted to characteristic levels by the procedures of Appendix 6 shall not exceed the regulatory levels determined from the following formulas:

Hydrocarbons (HC): $D_p/F_{oo} = 19.6$

Carbon monoxide (CO): $D_p/F_{oo} = 118$

Oxides of nitrogen (NOx):

a) for engines of a type or model for which the date of manufacture of the first individual production model was on or before 31 December 1995 and for which the date of manufacture of the individual engine was on or before 31 December 1999.

$D_p/F_{oo} = 40 + 2π_{oo}$

b) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 1995 or for which the date of manufacture of the individual engine was after 31 December 1999.

$D_p/F_{oo} = 32 + 1.6π_{oo}$

c) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 2003:

1) for engines with a pressure ratio of 30 or less:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$D_p/F_{oo} = 19 + 1.6π_{oo}$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$D_p/F_{oo} = 37.572 + 1.6π_{oo} - 0.2087F_{oo}$

2) for engines with a pressure ratio of more than 30 but less than 62.5:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$D_p/F_{oo} = 7 + 2.0π_{oo}$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$D_p/F_{oo} = 42.71 + 1.4286π_{oo} - 0.4013F_{oo} + 0.00642π_{oo} \times F_{oo}$

3) for engines with a pressure ratio of 62.5 or more:

$D_p/F_{oo} = 32 + 1.6π_{oo}$
Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.

2.4 Information required

Note.— The information required is divided into three groups: 1) general information to identify the engine characteristics, the fuel used and the method of data analysis; 2) the data obtained from the engine test(s); and 3) the results derived from the test data.

2.4.1 General information

The following information shall be provided for each engine type for which emissions certification is sought:

a) engine identification;

b) rated output (in kilonewtons);

c) reference pressure ratio;

d) fuel specification reference;

e) fuel hydrogen/carbon ratio;

f) the methods of data acquisition;

g) the method of making corrections for ambient conditions; and

g) the method of data analysis.

2.4.2 Test information

The following information shall be provided for each engine tested for certification purposes at each of the thrust settings specified in 2.1.4.2. The information shall be provided after correction to the reference ambient conditions where applicable:

a) fuel flow (kilograms/second);

b) emission index (grams/kilogram) for each gaseous pollutant; and

c) measured Smoke Number.

2.4.3 Derived information

2.4.3.1 The following derived information shall be provided for each engine tested for certification purposes:

a) emission rate, i.e. emission index × fuel flow, (grams/second) for each gaseous pollutant;

b) total gross emission of each gaseous pollutant measured over the LTO cycle (grams);

c) values of $D_p/F_{oo}$ for each gaseous pollutant (grams/kilonewton); and

d) maximum Smoke Number.

2.4.3.2 The characteristic Smoke Number and gaseous pollutant emission levels shall be provided for each engine type for which emissions certification is sought.

Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.
CHAPTER 3. TURBO-JET AND TURBOFAN ENGINES INTENDED FOR PROPULSION AT SUPersonic SPEEDS

3.1 General

3.1.1 Applicability

The provisions of this chapter shall apply to all turbo-jet and turbofan engines intended for propulsion at supersonic speeds whose date of manufacture is on or after 18 February 1982.

3.1.2 Emissions involved

The following emissions shall be controlled for certification of aircraft engines:

Smoke
Gaseous emissions
- Unburned hydrocarbons (HC);
- Carbon monoxide (CO);
- Oxides of nitrogen (NO\textsubscript{x}).

3.1.3 Units of measurement

3.1.3.1 The smoke emission shall be measured and reported in terms of Smoke Number (SN).

3.1.3.2 The mass ($D_p$) of the gaseous pollutants HC, CO, or NO\textsubscript{x} emitted during the reference emissions landing and take-off (LTO) cycle, defined in 3.1.5.2 and 3.1.5.3 shall be measured and reported in grams.

3.1.4 Nomenclature

Throughout this chapter, where the expression $F^{*}\textsubscript{\infty}$ is used, it shall be replaced by $F\textsubscript{\infty}$ for engines which do not employ afterburning. For taxi/ground idle thrust setting, $F\textsubscript{\infty}$ shall be used in all cases.

3.1.5 Reference conditions

3.1.5.1 Atmospheric conditions

The reference atmospheric conditions shall be ISA at sea level except that the reference absolute humidity shall be 0.00629 kg water/kg dry air.

3.1.5.2 Thrust settings

The engine shall be tested at sufficient power settings to define the gaseous and smoke emissions of the engine so that mass emission rates and Smoke Numbers corrected to the reference ambient conditions can be determined at the following specific percentages of rated output as agreed by the certificating authority.

<table>
<thead>
<tr>
<th>Operating mode</th>
<th>Thrust setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>100 per cent $F^{*}\textsubscript{\infty}$</td>
</tr>
<tr>
<td>Climb</td>
<td>65 per cent $F^{*}\textsubscript{\infty}$</td>
</tr>
<tr>
<td>Descent</td>
<td>15 per cent $F^{*}\textsubscript{\infty}$</td>
</tr>
<tr>
<td>Approach</td>
<td>34 per cent $F^{*}\textsubscript{\infty}$</td>
</tr>
<tr>
<td>Taxi/ground idle</td>
<td>5.8 per cent $F\textsubscript{\infty}$</td>
</tr>
</tbody>
</table>

3.1.5.3 Reference emissions landing and take-off (LTO) cycle

The reference emissions LTO cycle for the calculation and reporting of gaseous emissions shall be represented by the following time in each operating mode.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time in operating mode, minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>1.2</td>
</tr>
<tr>
<td>Climb</td>
<td>2.0</td>
</tr>
<tr>
<td>Descent</td>
<td>1.2</td>
</tr>
<tr>
<td>Approach</td>
<td>2.3</td>
</tr>
<tr>
<td>Taxi/ground idle</td>
<td>26.0</td>
</tr>
</tbody>
</table>

3.1.5.4 Fuel specifications

The fuel used during tests shall meet the specifications of Appendix 4. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

3.1.6 Test conditions

3.1.6.1 The tests shall be made with the engine on its test bed.
3.1.6.2 The engine shall be representative of the certificated configuration (see Appendix 6); off-take bleeds and accessory loads other than those necessary for the engine’s basic operation shall not be simulated.

3.1.6.3 Measurements made for determination of emission levels at the thrusts specified in 3.1.5.2 shall be made with the afterburner operating at the level normally used, as applicable.

3.1.7 When test conditions differ from the reference conditions in 3.1.5, the test results shall be corrected to the reference conditions by the methods given in Appendix 5.

3.2 Smoke

3.2.1 Regulatory Smoke Number

The Smoke Number at any thrust setting when measured and computed in accordance with the procedures of Appendix 2 and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the regulatory level determined from the following formula:

\[
\text{Regulatory Smoke Number} = 83.6 \left( F^{*}_{\infty} \right)^{-0.274}
\]

or a value of 50, whichever is lower

Note.— Certificating authorities may alternatively accept values determined using afterburning provided that the validity of these data is adequately demonstrated.

3.3 Gaseous emissions

3.3.1 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 or Appendix 5, as applicable, and converted to characteristic levels by the procedures of Appendix 6 shall not exceed the regulatory levels determined from the following formulas:

- Hydrocarbons (HC): \( D_p / F^{*}_{\infty} = 140(0.92)^{p_{\infty}} \)
- Carbon monoxide (CO): \( D_p / F^{*}_{\infty} = 4 \times 550(p_{\infty})^{-1.03} \)
- Oxides of nitrogen (NO\(_x\)): \( D_p / F^{*}_{\infty} = 36 + 2.42p_{\infty} \)

Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.

3.4 Information required

Note.— The information required is divided into three groups: 1) general information to identify the engine characteristics, the fuel used and the method of data analysis; 2) the data obtained from the engine test(s); and 3) the results derived from the test data.

3.4.1 The following information shall be provided for each engine type for which emissions certification is sought:

a) engine identification;

b) rated output (in kilonewtons);

c) rated output with afterburning applied, if applicable (in kilonewtons);

d) reference pressure ratio;

e) fuel specification reference;

f) fuel hydrogen/carbon ratio;

g) the methods of data acquisition;

h) the method of making corrections for ambient conditions; and

i) the method of data analysis.

3.4.2 Test information

The following information shall be provided for each engine tested for certification purposes at each of the thrust settings specified in 3.1.5.2. The information shall be provided after correction to the reference ambient conditions where applicable:

a) fuel flow (kilograms/second);

b) emission index (grams/kilogram) for each gaseous pollutant;

c) percentage of thrust contributed by afterburning; and

d) measured Smoke Number.

3.4.3 Derived information

3.4.3.1 The following derived information shall be provided for each engine tested for certification purposes:
a) emission rate, i.e. emission index × fuel flow, (grams/second), for each gaseous pollutant;

b) total gross emission of each gaseous pollutant measured over the LTO cycle (grams);

c) values of $D_p / F_{\infty}^*$ for each gaseous pollutant (grams/kilonewton); and

d) maximum Smoke Number.

3.4.3.2 The characteristic Smoke Number and gaseous pollutant emission levels shall be provided for each engine type for which emissions certification is sought.

Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.
APPENDIX 1. MEASUREMENT OF REFERENCE PRESSURE RATIO

1. GENERAL

1.1 Pressure ratio shall be established using a representative engine.

1.2 Reference pressure ratio shall be derived by correlating measured pressure ratio with engine thrust corrected to standard day ambient pressure and entering this correlation at the standard day rated take-off thrust.

2. MEASUREMENT

2.1 Total pressure shall be measured at the last compressor discharge plane and the first compressor front face by positioning at least four probes so as to divide the air flow area into four equal sectors and taking a mean of the four values obtained.

Note.— Compressor discharge total pressure may be obtained from total or static pressure measured at a position as close as possible to the compressor discharge plane. However, the certificating authority may approve alternative means of estimating the compressor discharge total pressure if the engine is so designed that the provision of the probes referred to above is impractical for the emissions test.

2.2 Necessary correlation factors shall be determined during type certification testing using a minimum of one engine and any associated engine component tests and analysis.

2.3 Procedures shall be acceptable to the certificating authority.
APPENDIX 2. SMOKE EMISSION EVALUATION

1. INTRODUCTION AND DEFINITIONS

Note.— The procedures specified here are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system.

1.1 Variations in the procedure contained in this Appendix shall only be allowed after prior application to and approval by the certificating authority.

1.2 Where the following expressions and symbols are used in this Appendix, they have the meanings ascribed to them below:

Sampling reference size. The sample mass, 16.2 kg/m² of stained filter area, which if passed through the filter material results in a change of reflectance which gives a value of the SN parameter.

Sampling size. A chosen exhaust sample, the magnitude of whose mass (expressed in kilograms per square metre of stained filter surface area) lies in the range prescribed in 2.5.3 h) of this Appendix which, when passed through the filter material, causes a change in reflectance yielding a value for the SN' parameter.

Sampling volume. The chosen sample volume (expressed in cubic metres) whose equivalent mass, calculated as indicated in 3 of this Appendix, conforms to the above definition of sampling size.

SN. Smoke Number; Dimensionless term quantifying smoke emission level based upon the staining of a filter by the reference mass of exhaust gas sample, and rated on a scale of 0 to 100 (see 3 of this Appendix).

SN'. Smoke Number obtained from an individual smoke sample, not necessarily of the reference size, as defined in 3 of this Appendix.

W. Mass of individual exhaust gas smoke sample, in kilograms, calculated from the measurements of sample volume, pressure and temperature (see 3 of this Appendix).

b) The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.

c) The number of sampling orifices shall not be less than 12.

d) The sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameters of the exit plane.

e) The applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed power setting.

2. MEASUREMENT OF SMOKE EMISSIONS

2.1 Sampling probe for smoke emissions

a) The probe shall be made of stainless steel. If a mixing probe is used, all sampling orifices shall be of equal diameter.
around the volume meter may be installed to facilitate meter reading. The major elements of the system shall meet the following requirements:

a) sample size measurement: a wet or dry positive displacement volume meter shall be used to measure sample volume to an accuracy of ±2 per cent. The pressure and temperature at entry to this meter shall also be measured to accuracies of 0.2 per cent and ±2°C respectively;

b) sample flow rate measurement: the sample flow rate shall be maintained at a value of 14 ±0.5 L/min and the flowmeter for this purpose shall be able to make this measurement with an accuracy of ±5 per cent;

c) filter and holder: the filter holder shall be constructed in corrosion-resistant material and shall have the flow channel configuration shown in Figure 2-1. The filter material shall be Whatman type No. 4, or any equivalent approved by the certificating authority;

d) valves: four valve elements shall be provided as indicated in Figure 2-1:

1) valve A shall be a quick-acting, full-flow, flow diverter enabling the incoming sample to be directed through the measuring filter or around the bypass circuits or shut off;

Note.—Valve A may, if necessary, consist of two valves interlocked to give the requisite function.

2) valves B and C shall be throttling valves used to establish the system flow rate;

---

Figure 2-1. Smoke analysis system
3) valve D shall be a shut-off valve to enable the filter holder to be isolated;

all valves shall be made of corrosion-resistant material;

e) vacuum pump: this pump shall have a no-flow vacuum capability of \(-75\) kPa with respect to atmospheric pressure; its full-flow rate shall not be less than \(28\) L/min at normal temperature and pressure;

f) temperature control: the incoming sample line through to the filter holder shall be maintained at a temperature between \(60^\circ\)C and \(175^\circ\)C with a stability of \(\pm 15^\circ\)C;

Note.— The objective is to prevent water condensation prior to reaching the filter holder and within it.

g) If it is desired to draw a higher sample flow rate through the probe than through the filter holder, an optional flow splitter may be located between the probe and valve A (Figure 2-1), to dump excess flow. The dump line shall be as close as possible to probe off-take and shall not affect the ability of the sampling system to maintain the required 80 per cent pressure drop across the probe assembly. The dump flow may also be sent to the \(\text{CO}_2\) analyser or complete emissions analysis system.

h) If a flow splitter is used, a test shall be conducted to demonstrate that the flow splitter does not change the smoke level passing to the filter holder. This may be accomplished by reversing the outlet lines from the flow splitter and showing that, within the accuracy of the method, the smoke level does not change.

i) leak performance: the sub-system shall meet the requirements of the following test:

1) clamp clean filter material into holder,

2) shut off valve A, fully open valves B, C and D.

3) run vacuum pump for one minute to reach equilibrium conditions;

4) continue to pump and measure the volume flow through the meter over a period of five minutes. This volume shall not exceed \(5\) L (referred to normal temperature and pressure) and the system shall not be used until this standard has been achieved.

j) reflectometer: the measurements of the reflectance of the filter material shall be by an instrument conforming to the American National Standards Institute (ANSI) Standard No. PH2.17/1977 for diffuser reflectance density. The diameter of the reflectometer light beam on the filter paper shall not exceed \(D/2\) nor be less than \(D/10\) where \(D\) is the diameter of filter stained spot as defined in Figure 2-1.

2.4 Fuel specifications

The fuel shall meet the specifications of Appendix 4. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

2.5 Smoke measurement procedures

2.5.1 Engine operation

2.5.1.1 The engine shall be operated on a static test facility which is suitable and properly equipped for high accuracy performance testing.

2.5.1.2 The tests shall be made at the power settings approved by the certificating authority. The engine shall be stabilized at each setting.

2.5.2 Leakage and cleanliness checks

No measurements shall be made until all sample transfer lines and valves are warmed up and stable. Prior to a series of tests the system shall be checked for leakage and cleanliness as follows:

a) leakage check: isolate probe and close off end of sample line, perform leakage test as specified in 2.3 g) with the exceptions that valve A is opened and set to “bypass”, valve D is closed and that the leakage limit is \(2\) L. Restore probe and line interconnection;

b) cleanliness check:

1) open valves B, C and D;

2) run vacuum pump and alternately set valve A to “bypass” and “sample” to purge the entire system with clean air for five minutes;

3) set valve A to “bypass”;

4) close valve D and clamp clean filter material into holder. Open valve D;

5) set valve A to “sample” and reset back to “bypass” after 50 kg of air per square metre of filter has passed through the filter material;

6) measure resultant filter spot \(SN'\) as described in paragraph 3 of this Appendix.
7) if this SN' exceeds 3, the system shall be cleaned (or otherwise rectified) until a value lower than 3 is obtained.

The system shall not be used until the requirements of these leakage and cleanliness checks have been met.

2.5.3 Smoke measurement

Smoke measurement shall be made independently of other measurements unless the smoke values so measured are significantly below the limiting values, or unless it can be demonstrated that the smoke values from simultaneous smoke and gaseous emissions measurements are valid, in which case smoke measurements may be made simultaneously with gaseous emissions measurements. In all cases the bend radius requirements for sampling lines detailed in 2.2.2 shall be strictly observed. The smoke analysis sub-system shall be set up and conform to the specifications of 2.3. Referring to Figure 2-1, the following shall be the major operations in acquiring the stained filter specimens:

a) during engine operation with the probe in position, valve A shall not be placed in the no-flow condition, otherwise particulate buildup in the lines might be encouraged;

b) set valve A to “bypass”, close valve D and clamp clean filter into holder. Continue to draw exhaust sample in the bypass setting for at least five minutes while the engine is at or near to the requisite operating mode, valve C being set to give a flow rate of 14 ±0.5 L/min;

c) open valve D and set valve A to “sample”, use valve B to set flow rate again to value set in b);

d) set valve A to “bypass” and close valve D, clamp clean filter material into the holder;

e) when the engine is stabilized on condition, allow one minute of sample flow with settings as at d);

f) open valve D, set valve A to “sample”, reset flow rate if necessary, and allow chosen sample volume (see h)) to pass, before setting valve A back to “bypass” and close valve D;

g) set aside stained filter for analysis, clamp clean filter into holder;

h) the chosen sample sizes shall be such as to be within the range of 12 kg to 21 kg of exhaust gas per square metre of filter, and shall include samples which are either at the value of 16.2 kg of exhaust gas per square metre of filter or lie above and below that value. The number of samples at each engine operating condition shall not be less than 3 and c) to g) shall be repeated as necessary.

3. CALCULATION OF SMOKE NUMBER FROM MEASURED DATA

The stained filter specimens obtained as outlined in 2.5.3 shall be analysed using a reflectometer as specified in 2.3. The backing material used shall be black with an absolute reflectance of less than 3 per cent. The absolute reflectance reading $R_S$ of each stained filter shall be used to calculate the reduction in reflectance by

$$ SN' = 100 (1 - \frac{R_S}{R_W}) $$

where $R_W$ is the absolute reflectance of clean filter material.

The masses of the various samples shall be calculated by

$$ W = 0.348 \times P \times T \times 10^{-2} (kg) $$

where $P$ and $T$ are, respectively, the sample pressure in pascals and the temperature in kelvin, measured immediately upstream of the volume meter. $V$ is the measured sample volume in cubic metres.

For each engine condition in the case that the sample sizes range above and below the reference value, the various values of SN' and $W$ shall be plotted as $SN'$ versus log $W/A$, where $A$ is the filter stain area (m$^2$). Using a least squares straight line fit, the value of SN' for $W/A = 16.2$ kg/m$^2$ shall be estimated and reported as the Smoke Number (SN) for that engine mode. Where sampling at the reference size value only is employed, the reported SN shall be the arithmetic average of the various individual values of SN'.

4. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY

The measured data shall be reported to the certificating authority. In addition the following data shall be reported for each test:

a) sample temperature;

b) sample pressure;

c) actual sample volume at sampling conditions;

d) actual sample flow rate at sampling conditions; and

e) leak and cleanliness checks substantiation (see 2.5.2).
APPENDIX 3. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS

1. INTRODUCTION

Note.— The procedures specified in this appendix are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system. The procedures do not apply to engines employing afterburning. The methods proposed are representative of the best readily available and most established practice.

Variations in the procedure contained in this appendix shall only be allowed after prior application to and approval by the certificating authority.

2. DEFINITIONS

Where the following expressions are used in this appendix, they have the meanings ascribed to them below:

**Accuracy.** The closeness with which a measurement approaches the true value established independently.

**Air/fuel ratio.** The mass rate of airflow through the hot section of the engine divided by the mass rate of fuel flow to the engine.

**Calibration gas.** A high accuracy reference gas to be used for alignment, adjustment and periodic checks of instruments.

**Concentration.** The volume fraction of the component of interest in the gas mixture — expressed as volume percentage or as parts per million.

**Exhaust nozzle.** In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.

**Flame ionization detector.** A hydrogen-air diffusion flame detector that produces a signal nominally proportional to the mass-flow rate of hydrocarbons entering the flame per unit of time — generally assumed responsive to the number of carbon atoms entering the flame.

**Interference.** Instrument response due to presence of components other than the gas (or vapour) that is to be measured.

**Noise.** Random variation in instrument output not associated with characteristics of the sample to which the instrument is responding, and distinguishable from its drift characteristics.

**Non-dispersive infra-red analyser.** An instrument that by absorption of infra-red energy selectively measures specific components.

**Parts per million (ppm).** The unit volume concentration of a gas per million unit volume of the gas mixture of which it is a part.

**Parts per million carbon (ppmC).** The mole fraction of hydrocarbon multiplied by $10^6$ measured on a methane-equivalence basis. Thus, 1 ppm of methane is indicated as 1 ppmC. To convert ppm concentration of any hydrocarbon to an equivalent ppmC value, multiply ppm concentration by the number of carbon atoms per molecule of the gas. For example, 1 ppm propane translates as 3 ppmC hydrocarbon; 1 ppm hexane as 6 ppmC hydrocarbon.

**Reference gas.** A mixture of gases of specified and known composition used as the basis for interpreting instrument response in terms of the concentration of the gas to which the instrument is responding.

**Repeatability.** The closeness with which a measurement upon a given, invariant sample can be reproduced in short-term repetitions of the measurement with no intervening instrument adjustment.

**Resolution.** The smallest change in a measurement which can be detected.

**Response.** The change in instrument output signal that occurs with change in sample concentration. Also the output signal corresponding to a given sample concentration.

**Stability.** The closeness with which repeated measurements upon a given invariant sample can be maintained over a given period of time.

**Zero drift.** Time-related deviation of instrument output from zero set point when it is operating on gas free of the component to be measured.

**Zero gas.** A gas to be used in establishing the zero, or no-response, adjustment of an instrument.
Figure 3-1. Sampling and analysis system, schematic
3. DATA REQUIRED

3.1 Gaseous emissions

Concentrations of the following emissions shall be determined:

a) Hydrocarbons (HC): a combined estimate of all hydrocarbon compounds present in the exhaust gas.

b) Carbon monoxide (CO).

c) Carbon dioxide (CO$_2$).

Note.— CO$_2$ is not considered a pollutant but its concentration is required for calculation and check purposes.

d) Oxides of nitrogen (NO$_x$): an estimate of the sum of the two oxides, nitric oxide (NO) and nitrogen dioxide (NO$_2$).

e) Nitric oxide (NO).

3.2 Other information

In order to normalize the emissions measurement data and to quantify the engine test characteristics, the following additional information shall be provided:

— inlet temperature;
— inlet humidity;
— atmospheric pressure;
— hydrogen/carbon ratio of fuel;
— other required engine parameters (for example, thrust, rotor speeds, turbine temperatures and gas-generator air flow).

This data shall be obtained either by direct measurement or by calculation, as presented in Attachment F to this appendix.

4. GENERAL ARRANGEMENT

OF THE SYSTEM

No desiccants, dryers, water traps or related equipment shall be used to treat the exhaust sample flowing to the oxides of nitrogen and the hydrocarbon analysis instrumentation. Requirements for the various component sub-systems are given in 5, but the following list gives some qualifications and variations:

a) it is assumed that each of the various individual sub-systems includes the necessary flow control, conditioning and measurement facilities;

b) the necessity for a dump and/or a hot-sample pump will depend on ability to meet the sample transfer time and analysis sub-system sample flow rate requirements. This in turn depends on the exhaust sample driving pressure and line losses. It is considered that these pumps usually will be necessary at certain engine running conditions; and
c) the position of the hot pump, relative to the gas analysis sub-systems, may be varied as required. (For example, some HC analysers contain hot pumps and so may be judged capable of being used upstream of the system hot pump.)

5. DESCRIPTION OF COMPONENT PARTS

Note.— A general description and specification of the principal elements in the engine exhaust emissions measurement system follows. Greater detail, where necessary, will be found in Attachments A, B and C to this appendix.

5.1 Sampling system

5.1.1 Sampling probe

a) The probe shall be made of stainless steel. If a mixing probe is used, all sampling orifices shall be of equal diameter;
b) the probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices;
c) the number of sampling orifices shall not be less than 12;
d) the sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameter of the exit plane; and
e) the applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed power setting.

5.1.2 Sampling lines

The sample shall be transferred from the probe to the analysers via a line of 4.0 to 8.5 mm inside diameter, taking
the shortest route practicable and using a flow rate such that the transport time is less than 10 seconds. The line shall be maintained at a temperature of 160°C ±15°C (with a stability of ±10°C), except for a) the distance required to cool the gas from the engine exhaust temperature down to the line control temperature, and b) the branch which supplies samples to the CO, CO₂, and NOₓ analysers. This branch line shall be maintained at a temperature of 65°C ± 15°C (with a stability of ±10°C). When sampling to measure HC, CO, CO₂ and NOₓ components the line shall be constructed in stainless steel or carbon-loaded grounded PTFE.

5.2 HC analyser

The measurement of total hydrocarbon sample content shall be made by an analyser using the heated flame ionization detector (FID), between the electrodes of which passes an ionization current proportional to the mass rate of hydrocarbon entering a hydrogen flame. The analyser shall be deemed to include components arranged to control temperature and flow rates of sample, sample bypass, fuel and diluent gases, and to enable effective span and zero calibration checks.

Note.— An over-all specification is given in Attachment A to this appendix.

5.3 CO and CO₂ analysers

Non-dispersive infra-red analysers shall be used for the measurements of these components, and shall be of the design which utilizes differential energy absorption in parallel reference and sample gas cells, the cell or group of cells for each of these gas constituents being sensitized appropriately. This analysis sub-system shall include all necessary functions for the control and handling of sample, zero and span gas flows. Temperature control shall be that appropriate to whichever basis of measurement, wet or dry, is chosen.

Note.— An over-all specification is given in Attachment B to this appendix.

5.4 NOₓ analyser

The measurement of NO concentration shall be by the chemiluminescent method in which the measure of the radiation intensity emitted during the reaction of the NO in the sample with added O₃ is the measure of the NO concentration. The NO₂ component shall be converted to NO in a converter of the requisite efficiency prior to measurement. The resultant NOₓ measurement system shall include all necessary flow, temperature and other controls and provide for routine zero and span calibration as well as for converter efficiency checks.

Note.— An over-all specification is given in Attachment C to this appendix.

6. GENERAL TEST PROCEDURES

6.1 Engine operation

6.1.1 The engine shall be operated on a static test facility which is suitable and properly equipped for high accuracy performance testing.

6.1.2 The emissions tests shall be made at the power settings prescribed by the certificating authority. The engine shall be stabilized at each setting.

6.2 Major instrument calibration

Note.— The general objective of this calibration is to confirm stability and linearity.

6.2.1 The applicant shall satisfy the certificating authority that the calibration of the analytical system is valid at the time of the test.

6.2.2 For the hydrocarbon analyser this calibration shall include checks that the detector oxygen and differential hydrocarbon responses are within the limits specified, as laid down in Attachment A to this appendix. The efficiency of the NO₂/NO converter shall also be checked and verified to meet the requirements in Attachment C to this appendix.

6.2.3 The procedure for checking the performance of each analyser shall be as follows (using the calibration and test gases as specified in Attachment D to this appendix):

a) introduce zero gas and adjust instrument zero, recording setting as appropriate;

b) for each range to be used operationally, introduce calibration gas of (nominally) 90 per cent range full-scale deflection (FSD) concentration; adjust instrument gain accordingly and record its setting;

c) introduce approximately 30 per cent, 60 per cent, and 90 per cent range FSD concentration and record analyser readings;

d) fit a least squares straight line to the zero, 30 per cent, 60 per cent and 90 per cent concentration points. For the CO and/or CO₂ analyser used in their basic form without linearization of output, a least squares
curve of appropriate mathematical formulation shall be fitted using additional calibration points if judged necessary. If any point deviates by more than 2 per cent of the full scale value (or ±1 ppm*, whichever is greater) then a calibration curve shall be prepared for operational use.

6.3 Operation

6.3.1 No measurements shall be made until all instruments and sample transfer lines are warmed up and stable and the following checks have been carried out:

a) leakage check: prior to a series of tests the system shall be checked for leakage by isolating the probe and the analysers, connecting and operating a vacuum pump of equivalent performance to that used in the smoke measurement system to verify that the system leakage flow rate is less than 0.4 L/min referred to normal temperature and pressure;

b) cleanliness check: isolate the gas sampling system from the probe and connect the end of the sampling line to a source of zero gas. Warm the system up to the operational temperature needed to perform hydrocarbon measurements. Operate the sample flow pump and set the flow rate to that used during engine emission testing. Record the hydrocarbon analyser reading. The reading shall not exceed 1 per cent of the engine idle emission level or 1 ppm (both expressed as methane), whichever is the greater.

Note 1.— It is good practice to back-purge the sampling lines during engine running, while the probe is in the engine exhaust but emissions are not being measured, to ensure that no significant contamination occurs.

Note 2.— It is also good practice to monitor the inlet air quality at the start and end of testing and at least once per hour during a test. If levels are considered significant, then they should be taken into account.

6.3.2 The following procedure shall be adopted for operational measurements:

a) apply appropriate zero gas and make any necessary instrument adjustments;

b) apply appropriate calibration gas at a nominal 90 per cent FSD concentration for the ranges to be used, adjust and record gain settings accordingly;

c) when the engine has been stabilized at the requisite operating mode, continue to run it and observe pollutant concentrations until a stabilized reading is obtained, which shall be recorded;

d) recheck zero and calibration points at the end of the test and also at intervals not greater than 1 hour during tests. If either has changed by more than ±2 per cent of range FSD, the test shall be repeated after restoration of the instrument to within its specification.

6.4 Carbon balance check

Each test shall include a check that the air/fuel ratio as estimated from the integrated sample total carbon concentration exclusive of smoke, agrees with the estimate based on engine air/fuel ratio within ±15 per cent for the taxi/ground idle mode, and within 10 per cent for all other modes (see 7.1.2).

7. CALCULATIONS

7.1 Gaseous emissions

7.1.1 General

The analytical measurements made shall be the concentrations of the various classes of pollutant, as detected at their respective analysers for the several engine operation modes, and these values shall be reported. In addition, other parameters shall be computed and reported, as follows**.

7.1.2 Basic parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>( \text{El}<em>{\text{CO}} = \left( \frac{[\text{CO}]}{[\text{CO}<em>2] + [\text{CO}] + [\text{HC}]} \right) \left( \frac{10^3 M</em>{\text{CO}}}{M</em>{\text{C}} + (n/\text{m}) M_{\text{H}}} \right) (1 + T(P/m)) )</td>
</tr>
<tr>
<td>HC</td>
<td>( \text{El}<em>{\text{HC}} = \left( \frac{[\text{HC}]}{[\text{CO}<em>2] + [\text{CO}] + [\text{HC}]} \right) \left( \frac{10^3 M</em>{\text{HC}}}{M</em>{\text{C}} + (n/\text{m}) M_{\text{H}}} \right) (1 + T(P/m)) )</td>
</tr>
<tr>
<td>NOₓ</td>
<td>( \text{El}_{\text{NO}_x} = \left( \frac{[\text{NO}<em>x]}{[\text{CO}<em>2] + [\text{CO}] + [\text{HC}]} \right) \left( \frac{10^3 M</em>{\text{NO}<em>x}}{M</em>{\text{C}} + (n/\text{m}) M</em>{\text{H}}} \right) (1 + T(P/m)) )</td>
</tr>
</tbody>
</table>

Air/fuel ratio = \( \left( \frac{P/m}{M_{\text{AIR}}}{M_{\text{C}} + (n/\text{m}) M_{\text{H}}} \right) \)

* Except for the CO₂ analyser, for which the value shall be ±100 ppm.
** A more comprehensive and precise alternative methodology which is acceptable is presented in Attachment E to this appendix.
Appendix 3

where

\[ P_{im} = \frac{2Z - (n/m)}{4(1 + h - \left|\frac{T}{2}\right|)} \]

and

\[ Z = \frac{2 - [CO] - (|2x| - |y|/2x) \cdot [HC] + [NO_2]}{[CO_2] + [CO] + [HC]} \]

\[ M_{AIR} \quad \text{molecular mass of dry air} = 28.966 \text{ g} \]

or, where appropriate,

\[ = (32 R + 28.156 4 S + 44.011 T)g \]

\[ M_{HC} \quad \text{molecular mass of exhaust hydrocarbons, taken as CH}_4 = 16.043 \text{ g} \]

\[ M_{CO} \quad \text{molecular mass of CO} = 28.011 \text{ g} \]

\[ M_{NO_2} \quad \text{molecular mass of NO}_2 = 46.008 \text{ g} \]

\[ M_C \quad \text{atomic mass of carbon} = 12.011 \text{ g} \]

\[ M_H \quad \text{atomic mass of hydrogen} = 1.008 \text{ g} \]

\[ R \quad \text{concentration of O}_2 \text{ in dry air, by volume} = 0.209 5 \text{ normally} \]

\[ S \quad \text{concentration of N}_2 + \text{ rare gases in dry air, by volume} = 0.709 2 \text{ normally} \]

\[ T \quad \text{concentration of CO}_2 \text{ in dry air, by volume} = 0.000 3 \text{ normally} \]

\[ [HC] \quad \text{mean concentration of exhaust hydrocarbons vol/vol, expressed as carbon} \]

\[ [CO] \quad \text{mean concentration of CO vol/vol, wet} \]

\[ [CO_2] \quad \text{mean concentration of CO}_2 \text{ vol/vol, wet} \]

\[ [NO_x] \quad \text{mean concentration of NO}_x \text{ vol/vol, wet} = [NO + NO_2] \]

\[ [NO] \quad \text{mean concentration of NO in exhaust sample, vol/vol, wet} \]

\[ [NO_2] \quad \text{mean concentration of NO}_2 \text{ in exhaust sample, vol/vol, wet} \]

\[ = \frac{([NO_2] - [NO])}{\eta} \]

\[ [NO]_c \quad \text{mean concentration of NO in exhaust sample after passing through the NO}_2/\text{NO converter, vol/vol, wet} \]

\[ \eta \quad \text{efficiency of NO}_2/\text{NO converter} \]

Annex 16 — Environmental Protection

\[ h \quad \text{humidity of ambient air, vol water/vol dry air} \]

\[ m \quad \text{number of C atoms in characteristic fuel molecule} \]

\[ n \quad \text{number of H atoms in characteristic fuel molecule} \]

\[ x \quad \text{number of C atoms in characteristic exhaust hydrocarbon molecule} \]

\[ y \quad \text{number of H atoms in characteristic exhaust hydrocarbon molecule} \]

The value of \( n/m \), the ratio of the atomic hydrogen to atomic carbon of the fuel used, is evaluated by fuel type analysis. The ambient air humidity, \( h \), shall be measured at each set condition. In the absence of contrary evidence as to the characterization (\( x,y \)) of the exhaust hydrocarbons, the values \( x = 1, y = 4 \) are to be used. If dry or semi-dry CO and CO\(_2\) measurements are to be used then these shall first be converted to the equivalent wet concentration as shown in Attachment E to this appendix, which also contains interference correction formulas for use as required.

7.1.3 Correction of emission indices to reference conditions

Corrections shall be made to the measured engine emission indices for all pollutants in all relevant engine operating modes to account for deviations from the reference conditions (ISA at sea level) of the actual test inlet air conditions of temperature and pressure. The reference value for humidity shall be 0.00629 kg water/kg dry air.

Thus, \( EI_{corrected} = K \times EI_{measured} \),

where the generalized expression for \( K \) is:

\[ K = (P_{Bref}/P_B)^a \times (FAR_{ref}/FAR_B)^b \times \exp \left( |T_{Bref} - T_B| /c \right) \times \exp \left( d|h - 0.006 29|\right) \]

\[ P_B \quad \text{Combustor inlet pressure, measured} \]

\[ T_B \quad \text{Combustor inlet temperature, measured} \]

\[ FAR_B \quad \text{Fuel/air ratio in the combustor} \]

\[ h \quad \text{Ambient air humidity} \]

\[ P_{ref} \quad \text{ISA sea level pressure} \]

\[ T_{ref} \quad \text{ISA sea level temperature} \]

\[ P_{Bref} \quad \text{Pressure at the combustor inlet of the engine tested (or the reference engine if the data is} \]
corrected to a reference engine) associated with $T_B$ under ISA sea level conditions.

$T_{B_{\text{ref}}}$ Temperature at the combustor inlet under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine). This temperature is the temperature associated with each thrust level specified for each mode.

$\text{FA}_R_{\text{ref}}$ Fuel/air ratio in the combustor under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine).

$a,b,c,d$ Specific constants which may vary for each pollutant and each engine type.

The combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas.

7.1.4 Using the recommended curve fitting technique to relate emission indices to combustor inlet temperature effectively eliminates the $\exp((T_{\text{B_{\text{ref}}} - T_B}/c)$ term from the generalized equation and for most cases the $(\text{FA}_R_{\text{ref}}/\text{FA}_R)$ term may be considered unity. For the emissions indices of CO and HC many testing facilities have determined that the humidity term is sufficiently close to unity to be eliminated from the expression and that the exponent of the $(P_{B_{\text{ref}}}/P_B)$ term is close to unity.

Thus,

$$\text{EI(CO) corrected} = \text{EI derived from} \left(\frac{P_B}{P_{B_{\text{ref}}}}\right) \cdot \text{EI(CO)} \text{ v. } T_B \text{ curve}$$

$$\text{EI(HC) corrected} = \text{EI derived from} \left(\frac{P_B}{P_{B_{\text{ref}}}}\right) \cdot \text{EI(HC)} \text{ v. } T_B \text{ curve}$$

$$\text{EI(NO}_x\text{) corrected} = \text{EI derived from} \left(\frac{P_{B_{\text{ref}}}}{P_B}\right)^{0.5} \exp\left(19 | h - 0.006 29 | \right) \text{ v. } T_B \text{ curve}$$

If this recommended method for the CO and HC emissions index correction does not provide a satisfactory correlation, an alternative method using parameters derived from component tests may be used.

Any other methods used for making corrections to CO, HC and NO$_x$ emission indices shall have the approval of the certificating authority.

7.2 Control parameter functions $(D_p, F_{\text{oo}}, \pi)$

7.2.1 Definitions

$D_p$ The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle.

$F_{\text{oo}}$ The maximum thrust available for take-off under normal operating conditions at ISA sea level static conditions, without the use of water injection, as approved by the applicable certificating authority.

$\pi$ The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating at ISA sea level static conditions.

7.2.2 The emission indices (EI) for each pollutant, corrected for pressure and humidity (as appropriate) to the reference ambient atmospheric conditions as indicated in 7.1.4 and if necessary to the reference engine, shall be obtained for the required LTO engine operating mode settings ($n$) of idle, approach, climb-out and take-off, at each of the equivalent corrected thrust conditions. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined for each pollutant:

a) between EI and $T_B$; and

b) between $W_f$ (engine fuel mass flow rate) and $T_B$; and

c) between $F_{n}$ (corrected to ISA sea level conditions) and $T_B$ (corrected to ISA sea level conditions);

Note.— These are illustrated, for example, by Figure 3-2 a), b) and c).

When the engine being tested is not a “reference” engine, the data may be corrected to “reference” engine conditions using the relationships b) and c) obtained from a reference engine. A reference engine is defined as an engine substantially configured to the description of the engine to be certificated and accepted by the certificating authority to be representative of the engine type for which certification is sought.

The manufacturer shall also supply to the certificating authority all of the necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:

d) maximum rated thrust ($F_{\text{oo}}$); and

e) engine pressure ratio ($\pi$) at maximum rated thrust.

Note.— These are illustrated by Figure 3-2 d).

7.2.3 The estimation of EI for each pollutant at each of the required engine mode settings, corrected to the reference ambient conditions, shall comply with the following general procedure:

a) at each mode ISA thrust condition $F_{n_r}$, determine the equivalent combustor inlet temperature ($T_B$) (Figure 3-2 c));
Figure 3-2. Calculation procedure

EI = EMISSION INDEX
TB = COMBUSTOR INLET TEMPERATURE
WF = ENGINE FUEL MASS FLOW RATE
F = ENGINE THRUST
π = ENGINE PRESSURE RATIO
b) from the EI/T_B characteristic (Figure 3-2 a)), determine the EI_n value corresponding to T_B;

c) from the W_f/T_B characteristic (Figure 3-2 b)), determine the W_f/n value corresponding to T_B;

d) note the ISA maximum rated thrust and pressure ratio values. These are F_{oo} and \( \pi \) respectively (Figure 3-2 d));

e) calculate, for each pollutant \( D_p = \Sigma (E_{I_n}) (W_{f_n}) (t) \)

where:

\( t \) time in LTO mode (minutes)

\( W_{f_n} \) fuel mass flow rate (kg/min)

\( \Sigma \) is the summation for the set of modes comprising the reference LTO cycle.

7.2.4 While the methodology described above is the recommended method, the certificating authority may accept equivalent mathematical procedures which utilize mathematical expressions representing the curves illustrated if the expression have been derived using an accepted curve fitting technique.

7.3 Exceptions to the proposed procedures

In those cases where the configuration of the engine or other extenuating conditions exist which would prohibit the use of this procedure, the certificating authority, after receiving satisfactory technical evidence of equivalent results obtained by an alternative procedure, may approve an alternative procedure.
ATTACHMENT A TO APPENDIX 3. SPECIFICATION FOR HC ANALYSER

Note 1.— As outlined in 5.2 of Appendix 3, the measuring element in this analyser is the flame ionization detector (FID) in which the whole or a representative portion of the sample flow is admitted into a hydrogen-fuelled flame. With suitably positioned electrodes an ionization current can be established which is a function of the mass rate of hydrocarbon entering the flame. It is this current which, referred to an appropriate zero, is amplified and ranged to provide the output response as a measure of the hydrocarbon concentration expressed as ppmC equivalent.

Note 2.— See Attachment D for information on calibration and test gases.

1. GENERAL

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The instrument to be used shall be such as to maintain the temperature of the detector and sample-handling components at a set point temperature within the range 155°C to 165°C to a stability of ±2°C. The leading specification points shall be as follows, the detector response having been optimized and the instrument generally having stabilized:

a) **Total range:** 0 to 5 000 ppmC in appropriate ranges.

b) **Resolution:** better than 0.5 per cent of full scale of range used or 0.5 ppmC, whichever is greater.

c) **Repeatability:** better than ±1 per cent of full scale of range used, or ±0.5 ppmC, whichever is greater.

d) **Stability:** better than ±2 per cent of full scale of range used or ±1.0 ppmC, whichever is greater, in a period of 1 hour.

e) **Zero drift:** less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater, in a period of 1 hour.

f) **Noise:** 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater.

g) **Response time:** shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.

h) **Linearity:** response with propane in air shall be linear for each range within ±2 per cent of full scale, otherwise calibration corrections shall be used.

2. SYNERGISTIC EFFECTS

Note.— In application there are two aspects of performance which can affect the accuracy of measurement:

a) the oxygen effect (whereby differing proportions of oxygen present in the sample give differing indicated hydrocarbon concentration for constant actual HC concentrations); and

b) the relative hydrocarbon response (whereby there is a different response to the same sample hydrocarbon concentrations expressed as equivalent ppmC, dependent on the class or admixture of classes of hydrocarbon compounds).

The magnitude of the effects noted above shall be determined as follows and limited accordingly.

**Oxygen response:** measure the response with two blends of propane, at approximately 500 ppmC concentration known to a relative accuracy of ±1 per cent, as follows:

1) propane in 10 ± 1 per cent O₂, balance N₂
2) propane in 21 ± 1 per cent O₂, balance N₂

If R₁ and R₂ are the respective normalized responses then (R₁ – R₂) shall be less than 3 per cent of R₁.

**Differential hydrocarbon response:** measure the response with four blends of different hydrocarbons in air, at concentrations of approximately 500 ppmC, known to a relative accuracy of ±1 per cent, as follows:

a) propane in zero air
b) propylene in zero air
c) toluene in zero air
d) n-hexane in zero air.
If \( R_a, R_b, R_c \) and \( R_d \) are, respectively, the normalized responses (with respect to propane), then \((R_a - R_b), (R_a - R_c)\) and \((R_a - R_d)\) shall each be less than 5 per cent of \( R_a \).

### 3. OPTIMIZATION OF DETECTOR RESPONSE AND ALIGNMENT

3.1 The manufacturer’s instructions for initial setting up procedures and ancillary services and supplies required shall be implemented, and the instrument allowed to stabilize. All setting adjustments shall involve iterative zero checking, and correction as necessary. Using as sample a mixture of approximately 500 ppmC of propane in air, the response characteristics for variations first in fuel flow and then, near an optimum fuel flow, for variations in dilution air flow to select its optimum shall be determined. The oxygen and differential hydrocarbon responses shall then be determined as indicated above.

3.2 The linearity of each analyser range shall be checked by applying propane in air samples at concentrations of approximately 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line (fitted to the points and zero) shall not exceed \( \pm 2 \) per cent of full scale value. If it does, a calibration curve shall be prepared for operational use.

### ATTACHMENT B TO APPENDIX 3. SPECIFICATION FOR CO AND CO\(_2\) ANALYSERS

Note 1.– Paragraph 5.3 of Appendix 3 summarizes the characteristics of the analysis sub-system to be employed for the individual measurements of CO and CO\(_2\) concentrations in the exhaust gas sample. The instruments are based on the principle of non-dispersive absorption of infra-red radiation in parallel reference and sample gas cells. The required ranges of sensitivity are obtained by use of stacked sample cells or changes in electronic circuitry or both. Interferences from gases with overlapping absorption bands may be minimized by gas absorption filters and/or optical filters, preferably the latter.

Note 2.— See Attachment D for information on calibration and test gases.

**Precautions:** The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The principal performance specification shall be as follows:

**CO Analyser**

a) **Total range:** 0 to 2 500 ppm in appropriate ranges.
b) **Resolution:** better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.
c) **Repeatability:** better than \( \pm 1 \) per cent of full scale of range used, or \( \pm 2 \) ppm, whichever is greater.
d) **Stability:** better than \( \pm 2 \) per cent of full scale of range used or \( \pm 2 \) ppm, whichever is greater, in a period of 1 hour.
e) **Zero drift:** less than \( \pm 1 \) per cent of full scale of range used or \( \pm 2 \) ppm, whichever is greater, in a period of 1 hour.
f) **Noise:** 0.5 Hz and greater, less than \( \pm 1 \) per cent of full scale of range used or \( \pm 1 \) ppm, whichever is greater.
g) **Interferences:** to be limited with respect to indicated CO concentration as follows:

1) less than 500 ppm/per cent ethylene concentration
2) less than 2 ppm/per cent CO\(_2\) concentration
3) less than 2 ppm/per cent water vapour.*

If the interference limitation(s) for CO\(_2\) and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

* Need not apply where measurements are on a “dry” basis.

**CO\(_2\) Analyser**

a) **Total range:** 0 to 10 per cent in appropriate ranges.
b) **Resolution:** better than 0.5 per cent of full scale of range used or 100 ppm, whichever is greater.
c) **Repeatability:** better than \( \pm 1 \) per cent of full scale of range used or \( \pm 100 \) ppm, whichever is greater.
Appendix 3

d) Stability: better than ±2 per cent of full scale of range used or ±100 ppm, whichever is greater, in a period of 1 hour.

e) Zero drift: less than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater, in a period of 1 hour.

f) Noise: 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater.

g) The effect of oxygen (O₂) on the CO₂ analyser response shall be checked. For a change from 0 per cent O₂ to 21 per cent O₂, the response of a given CO₂ concentration shall not change by more than 2 per cent of reading. If this limit cannot be met an appropriate correction factor shall be applied.

Note.— It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

CO and CO₂ Analysers

a) Response time: shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.

b) Sample temperature: the normal mode of operation is for analysis of the sample in its (untreated) “wet” condition. This requires that the sample cell and all other components in contact with the sample in this sub-system be maintained at a temperature of not less than 50°C, with a stability of ±2°C. The option to measure CO and CO₂ on a dry basis (with suitable water traps) is allowed, in which case unheated analysers are permissible and the interference limits for H₂O vapour removed, and subsequent correction for inlet water vapour and water of combustion is required.

c) Calibration curves:

i) Analysers with a linear signal output characteristic shall be checked on all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line, fitted to the points and the zero reading, shall not exceed ±2 per cent of the full scale value. If it does then a calibration curve shall be prepared for operational use.

ii) Analysers with a non-linear signal output characteristic, and those that do not meet the requirements of linearity given above, shall have calibration curves prepared for all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. Additional mixes shall be used, if necessary, to define the curve shape properly.

ATTACHMENT C TO APPENDIX 3. SPECIFICATION FOR NOₓ ANALYSER

Note.— See Attachment D for information on calibration and test gases.

1. As indicated in 5.4 of Appendix 3, the measurement of the oxides of nitrogen concentration shall be by the chemiluminescent technique in which radiation emitted by the reaction of NO and O₃ is measured. This method is not sensitive to NO₂ and therefore the sample shall be passed through a converter in which NO₂ is converted to NO before the measurement of total NOₓ is made. Both the original NO and the total NOₓ concentrations shall be recorded. Thus by difference, a measure of the NO₂ concentration shall be obtained.

2. The instrument to be used shall be complete with all necessary flow control components, such as regulators, valves, flowmeters, etc. Materials in contact with the sample gas shall be restricted to those which are resistant to attack by oxides of nitrogen, such as stainless steel, glass, etc. The temperature of the sample shall everywhere be maintained at values, consistent with the local pressures, which avoid condensation of water.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

3. The principal performance specification, determined for the instrument operated in an ambient temperature stable to within 2°C, shall be as follows:

a) Total range: 0 to 2 500 ppm in appropriate ranges.

b) Resolution: better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.

c) Repeatability: better than ±1 per cent of full scale of range used, or ±1 ppm, whichever is greater.
d) **Stability:** better than ±2 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 1 hour.

e) **Zero drift:** less than ±1 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 1 hour.

f) **Noise:** 0.5 Hz and greater, less than ±1.0 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 2 hours.

g) **Interference:** suppression for samples containing CO\(_2\) and water vapour, shall be limited as follows:

- less than 0.05 per cent reading/per cent CO\(_2\) concentration;
- less than 0.1 per cent reading/per cent water vapour concentration.

If the interference limitation(s) for CO\(_2\) and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

Note.— It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

h) **Response time:** shall not exceed 10 seconds from inlet of the sample to the analysis system to the achievement of 90 per cent of the final reading.

i) **Linearity:** better than ±2 per cent of full scale of range used or ±2 ppm, whichever is greater.

j) **Converter:** this shall be designed and operated in such a matter as to reduce NO\(_2\) present in the sample to NO. The converter shall not affect the NO originally in the sample.

The converter efficiency shall not be less than 90 per cent.

This efficiency value shall be used to correct the measured sample NO\(_2\) value (i.e. \([\text{NO}_2]_c – [\text{NO}]\)) to that which would have been obtained if the efficiency had not been 100 per cent.

### ATTACHMENT D TO APPENDIX 3. CALIBRATION AND TEST GASES

#### Table of calibration gases

<table>
<thead>
<tr>
<th><strong>Analysers</strong></th>
<th><strong>Gas</strong></th>
<th><strong>Accuracy</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>propane in zero air</td>
<td>±2 per cent or ±0.05 ppm**</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>CO(_2) in zero air</td>
<td>±2 per cent or ±100 ppm**</td>
</tr>
<tr>
<td>CO</td>
<td>CO in zero air</td>
<td>±2 per cent or ±2 ppm**</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>NO(_x) in zero nitrogen</td>
<td>±2 per cent or ±1 ppm**</td>
</tr>
</tbody>
</table>

* Taken over the 95 per cent confidence interval.
** Whichever is greater.

The above gases are required to carry out the routine calibration of analysers during normal operational use.
Appendix 3

Table of test gases

<table>
<thead>
<tr>
<th>Analyser</th>
<th>Gas</th>
<th>Accuracy*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>propane in 10 ±1 per cent O₂</td>
<td>±1 per cent</td>
</tr>
<tr>
<td></td>
<td>balance zero nitrogen</td>
<td></td>
</tr>
<tr>
<td>HC</td>
<td>propane in 21 ±1 per cent O₂</td>
<td>±1 per cent</td>
</tr>
<tr>
<td></td>
<td>balance zero nitrogen</td>
<td></td>
</tr>
<tr>
<td>HC</td>
<td>propylene in zero air</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>HC</td>
<td>toluene in zero air</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>HC</td>
<td>n-hexane in zero air</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>HC</td>
<td>propane in zero air</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>CO₂</td>
<td>CO₂ in zero air</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>CO₂</td>
<td>CO₂ in zero nitrogen</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>CO</td>
<td>CO in zero air</td>
<td>±1 per cent</td>
</tr>
<tr>
<td>NOₓ</td>
<td>NO in zero nitrogen</td>
<td>±1 per cent</td>
</tr>
</tbody>
</table>

* Taken over the 95 per cent confidence interval.

The above gases are required to carry out the tests of Attachments A, B and C.

Carbon monoxide and carbon dioxide calibration gases may be blended singly or as dual component mixtures. Three component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

Zero gas as specified for the CO₂ and HC analysers shall be zero air (which includes “artificial” air with 20 to 22 per cent O₂ blended with N₂). For the NOₓ analyser zero nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following concentrations:

- 1 ppm C
- 1 ppm CO
- 100 ppm CO₂
- 1 ppm NOₓ

The applicant shall ensure that commercial gases supplied to him do in fact meet this specification, or are so specified by the vendor.
1. SYMBOLS

AFR  air/fuel ratio, the ratio of the mass flow rate of dry air to that of the fuel

EI  emission index; \(10^3 \times \) mass flow rate of gaseous emission product in exhaust per unit mass flow rate of fuel

\( K \)  ratio of concentration measured wet to that measured dry (after cold trap)

\( L, L' \)  analyser interference coefficient for interference by CO₂

\( M, M' \)  analyser interference coefficient for interference by H₂O

\( M_{AIR} \)  molecular mass of dry air = 28.966 g or, where appropriate, \(= \left(32 R + 28.156 S + 44.011 T\right)\) g

\( M_{CO} \)  molecular mass of CO = 28.011 g

\( M_{HC} \)  molecular mass of exhaust hydrocarbon, taken as \(CH_4 = 16.043\) g

\( M_{NO_2} \)  molecular mass of NO₂ = 46.008 g

\( M_C \)  atomic mass of carbon = 12.011 g

\( M_H \)  atomic mass of hydrogen = 1.008 g

\( P_1 \)  number of moles of CO₂ in the exhaust sample per mole of fuel

\( P_2 \)  number of moles of N₂ in the exhaust sample per mole of fuel

\( P_3 \)  number of moles of O₃ in the exhaust sample per mole of fuel

\( P_4 \)  number of moles of H₂O in the exhaust sample per mole of fuel

\( P_5 \)  number of moles of CO in the exhaust sample per mole of fuel

\( P_6 \)  number of moles of \(C_xH_y\) in the exhaust sample per mole of fuel

\( P_7 \)  number of moles of NO₂ in the exhaust sample per mole of fuel

\( P_8 \)  number of moles of NO in the exhaust sample per mole of fuel

\( P_T = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 \)

\( R \)  concentration of O₂ in dry air, by volume = 0.2095 normally

\( S \)  concentration of N₂ + rare gases in dry air, by volume = 0.7902 normally

\( T \)  concentration of CO₂ in dry air, by volume = 0.0003 normally

\( P_0 \)  number of moles of air per mole of fuel in initial air/fuel mixture

\( Z \)  symbol used and defined in 3.4

\([\text{CO}_2]\)  mean concentration of CO₂ in exhaust sample, vol/vol

\([\text{CO}]\)  mean concentration of CO in exhaust sample, vol/vol

\([\text{HC}]\)  mean concentration of HC in exhaust sample, vol C/vol

\([\text{NO}]\)  mean concentration of NO in exhaust sample, vol/vol

\([\text{NO}_2]\)  mean concentration of NO₂ in exhaust sample, vol/vol

\([\text{NO}_x]\)  mean concentration of NO and NO₂ in exhaust sample, vol/vol

\([\text{NO}_x]_c\)  mean concentration of NO in exhaust sample, after passing through the NO₂/NO converter, vol/vol

\([\text{NO}_2]\)  mean concentration of NO₂ in exhaust sample, vol/vol

\([\text{NO}]\)  mean concentration of NO in exhaust sample, vol/vol

\([\text{NO}_x]\)  mean concentration of NO and NO₂ in exhaust sample, vol/vol

\([\text{NO}_x]_c\)  mean concentration of NO in exhaust sample, after passing through the NO₂/NO converter, vol/vol

\([\text{NO}_2]\)  mean = \(\frac{([\text{NO}_x]_c - [\text{NO}])}{\eta}\)

\([\text{NO}_2]\)  mean concentration in exhaust sample after cold trap, vol/vol

\([\text{NO}_2]\)  mean concentration measurement indicated before instrument correction applied, vol/vol
2. BASIS OF CALCULATION OF EI AND AFR PARAMETERS

2.1 It is assumed that the balance between the original fuel and air mixture and the resultant state of the exhaust emissions as sampled can be represented by the following equation:

\[ C_nH_n + P_0[R(O_2) + S(N_2) + T(CO_2) + h(H_2O)] = P_1(CO_2) + P_2(N_2) + P_3(O_2) + P_4(H_2O) + P_5(CO) + P_6(C\_CH) + P_7(NO_2) + P_8(NO) \]

from which the required parameters can, by definition, be expressed as

\[ EI(\text{CO}) = P_5 \left( \frac{10^3 M_{\text{CO}}}{mM_{\text{C}} + nM_{\text{H}}} \right) \]

\[ EI(\text{HC}) = xP_6 \left( \frac{10^3 M_{\text{HC}}}{mM_{\text{C}} + nM_{\text{H}}} \right) \text{ expressed as methane equivalent} \]

\[ EI(\text{NO}_x) = (P_7 + P_8) \left( \frac{10^3 M_{\text{NO}_2}}{mM_{\text{C}} + nM_{\text{H}}} \right) \text{ expressed as NO}_2 \text{ equivalent} \]

\[ AFR = P_0 \left( \frac{M_{\text{AIR}}}{mM_{\text{C}} + nM_{\text{H}}} \right) \]

2.2 Values for fuel hydrocarbon composition \((m, n)\) are assigned by fuel specification or analysis. If only the ratio \(n/m\) is so determined, the value \(m = 12\) may be assigned. The mole fractions of the dry air constituents \((R, S, T)\) are normally taken to be the recommended standard values but alternative values may be assigned, subject to the restriction \(R + S + T = 1\) and the approval of the certificating authority.

2.3 The ambient air humidity, \(h\), is as measured at each test condition. It is recommended that, in the absence of contrary evidence as to the characterization \((x, y)\) of the exhaust hydrocarbon, values of \(x = 1\) and \(y = 4\) are assigned.

2.4 Determination of the remaining unknowns requires the solution of the following set of linear simultaneous equations, where (1) to (4) derive from the fundamental atomic conservation relationships and (5) to (9) represent the gaseous product concentration relationships.

\[ m + TP_0 = P_1 + P_5 + xP_6 \]  \hspace{1cm} (1)

\[ n + 2hP_0 = 2P_4 + yP_6 \]  \hspace{1cm} (2)

\[ (2R + 2T + h)P_0 = 2P_1 + 2P_3 + P_4 + P_5 + 2P_7 + P_8 \]  \hspace{1cm} (3)

\[ 2SP_0 = 2P_2 + P_7 + P_8 \]  \hspace{1cm} (4)

\[ [\text{CO}] \ P_T = P_1 \]  \hspace{1cm} (5)

\[ [\text{CO}] \ P_T = P_5 \]  \hspace{1cm} (6)

\[ [\text{HC}] \ P_T = xP_6 \]  \hspace{1cm} (7)

\[ [\text{NO}_x] \ cP_T = \eta P_7 + P_8 \]  \hspace{1cm} (8)

\[ [\text{NO}] \ P_T = P_8 \]  \hspace{1cm} (9)

\[ P_1 = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 \]  \hspace{1cm} (10)

The above set of conditional equations is for the case where all measured concentrations are true ones, that is, not subject to interference effects or to the need to correct for sample drying. In practice, interference effects are usually present to a significant degree in the CO, and NO measurements, and the option to measure CO2 and CO on a dry or partially dry basis is often used. The necessary modifications to the relevant equations are described in 2.5 and 2.6.

2.5 The interference effects are mainly caused by the presence of CO2 and H2O in the sample which can affect the CO and the NOx analysers in basically different ways. The CO analyser is prone to a zero-shifting effect and the NOx analyser to a sensitivity change, represented thus:

\[ [\text{CO}] = [\text{CO}]_m + L[\text{CO}_2] + M[\text{H}_2\text{O}] \]

and \([\text{NO}_x]_c = [\text{NO}_x]_{cm} (1 + L'[\text{CO}_2] + M'[\text{H}_2\text{O}])\)
which transform into the following alternative equations to (6), (8) and (9), when interference effects require to be corrected,

\[ [\text{CO}]_{m} P_{T} + LP_{1} + MP_{A} = P_{5} \]  \hspace{1cm} (6A)

\[ [\text{NO}_{x}]_{cm} (P_{T} + L'P_{1} + M'P_{A}) = \eta P_{7} + P_{8} \]  \hspace{1cm} (8A)

\[ [\text{NO}]_{m} (P_{T} + L'P_{1} + M'P_{A}) = P_{8} \]  \hspace{1cm} (9A)

2.6 The option to measure \( \text{CO}_{2} \) and \( \text{CO} \) concentrations on a dry or partially dry sample basis, that is, with a sample humidity reduced to \( h_{d} \), requires the use of modified conditional equations as follows:

\[ [\text{CO}_{2}]_{d} (P_{T} - P_{d}) (1 + h_{d}) = P_{1} \]  \hspace{1cm} (5A)

and

\[ [\text{CO}]_{d} (P_{T} - P_{d}) (1 + h_{d}) = P_{5} \]

However, the \( \text{CO} \) analyser may also be subject to interference effects as described in 2.5 above and so the complete alternative \( \text{CO} \) measurement concentration equation becomes

\[ [\text{CO}]_{imd} (P_{T} - P_{d}) (1 + h_{d}) + LP_{1} + Mh_{d} (P_{T} - P_{d}) = P_{5} \]  \hspace{1cm} (6B)

3. ANALYTICAL FORMULATIONS

3.1 General

Equations (1) to (10) can be reduced to yield the analytical formulations for the EI and AFR parameters, as given in 7.1 to this appendix. This reduction is a process of progressive elimination of the roots \( P_{0}, P_{1} \) through \( P_{S}, P_{F} \), making the assumptions that all concentration measurements are of the “wet” sample and do not require interference corrections or the like. In practice the option is often chosen to make the \( \text{CO}_{2} \) and \( \text{CO} \) concentration measurements on a “dry” or “semi-dry” basis; also it is often found necessary to make interference corrections. Formulations for use in these various circumstances are given in 3.2, 3.3 and 3.4 below.

3.2 Equation for conversion of dry concentration measurements to wet basis

Concentration wet = \( K \times \) concentration dry; that is,

\[ [ ] = K [ ]_{d} \]

3.3 Interference corrections

The measurements of \( \text{CO} \) and/or \( \text{NO}_{2} \) and \( \text{NO} \) may require corrections for interference by the sample \( \text{CO}_{2} \) and water concentrations before use in the above analytical equations. Such corrections can normally be expressed in the following general ways:

\[ [\text{CO}] = [\text{CO}]_{m} + L[\text{CO}_{2}] + M[\text{H}_{2}\text{O}] \]

\[ [\text{CO}]_{d} = [\text{CO}]_{md} + L[\text{CO}_{2}]_{d} + M \left( \frac{h_{d}}{1 + h_{d}} \right) \]

\[ [\text{NO}] = [\text{NO}]_{m} (1 + L'[\text{CO}_{2}] + M'[\text{H}_{2}\text{O}]) \]

\[ \eta[\text{NO}_{2}] = ([\text{NO}_{x}]_{cm} - [\text{NO}]_{m} (1 + L'[\text{CO}_{2}] + M'[\text{H}_{2}\text{O}])) \]

3.4 Equation for estimation of sample water content

Water concentration in sample

\[ [\text{H}_{2}\text{O}] = \frac{([n/2m] + h[P_{0}/m]) ([\text{CO}_{2}] + [\text{CO}] + [\text{HC}])}{1 + T[P_{0}/m]} - (y[2x])/[\text{HC}] \]

where

\[ P_{0}/m = \frac{2Z - (n/m)}{4(1 + h - Z/2)} \]

and

\[ Z = \frac{2 - [\text{CO}] - ([2x] - [y/2x])/[\text{HC}] + [\text{NO}_{2}]}{[\text{CO}_{2}] + [\text{CO}] + [\text{HC}]} \]

It should be noted that this estimate is a function of the various analyses concentration readings, which may them-
selves require water interference correction. For better accuracy an iterative procedure is required in these cases with successive recalculation of the water concentration until the requisite stability is obtained. The use of the alternative, numerical solution methodology (4) avoids this difficulty.

4. ALTERNATIVE METHODOLOGY — NUMERICAL SOLUTION

4.1 As an alternative to the analytical procedures summarized in 3 above, it is possible to obtain readily the emissions indices, fuel/air ratio, corrected wet concentrations, etc., by a numerical solution of equations (1) to (10) for each set of measurements, using a digital computer.

4.2 In the equation set (1) to (10) the actual concentration measurements are substituted using whichever of the alternative equations (5A), (6A), etc. applies for the particular measuring system, to take account of interference corrections and/or dried sample measurements.

4.3 Suitable simple two-dimensional array equation-solving computer programmes are widely available and their use for this purpose is convenient and flexible, allowing ready incorporation and identification of any sample drying options and interference or other corrections.

ATTACHMENT F TO APPENDIX 3. SPECIFICATIONS FOR ADDITIONAL DATA

As required in 3.2 of Appendix 3, in addition to the measured sample constituent concentrations, the following data shall also be provided:

a) inlet temperature: measured as the total temperature at a point within one diameter of the engine intake plane to an accuracy of ±0.5°C;

b) inlet humidity (kg water/kg dry air): measured at a point within 15 m of the intake plane ahead of the engine to an accuracy of ±5 per cent of reading;

c) atmospheric pressure: measured within 1 km of the engine test location and corrected as necessary to the test stand altitude to an accuracy of ±100 Pa;

d) fuel mass flow: by direct measurement to an accuracy of ±2 per cent;

e) fuel H/C ratio: defined as \( \frac{n}{m} \), where \( C_nH_m \) is the equivalent hydrocarbon representation of the fuel used in the test and evaluated by reference to the engine fuel type analysis;

f) engine parameters:

1) thrust: by direct measurement to an accuracy of ±1 per cent at take-off power and ±5 per cent at the minimum thrust used in the certification test, with linear variation between these points;

2) rotation speed(s): by direct measurement to an accuracy of at least ±0.5 per cent;

3) gas generator airflow: determined to an accuracy of ±2 per cent by reference to engine performance calibration.

The parameters a), b), d) and f) shall be determined at each engine emissions test setting, while c) shall be determined at intervals of not less than 1 hour over a period encompassing that of the emissions tests.
### APPENDIX 4. SPECIFICATION FOR FUEL TO BE USED IN AIRCRAFT TURBINE ENGINE EMISSION TESTING

<table>
<thead>
<tr>
<th>Property</th>
<th>Allowable range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density kg/m³ at 15°C</td>
<td>780 – 820</td>
</tr>
<tr>
<td>Distillation temperature, °C</td>
<td></td>
</tr>
<tr>
<td>10% boiling point</td>
<td>155 – 201</td>
</tr>
<tr>
<td>Final boiling point</td>
<td>235 – 285</td>
</tr>
<tr>
<td>Net heat of combustion, MJ/kg</td>
<td>42.86 – 43.50</td>
</tr>
<tr>
<td>Aromatics, volume %</td>
<td>15 – 23</td>
</tr>
<tr>
<td>Naphthalenes, volume %</td>
<td>1.0 – 3.5</td>
</tr>
<tr>
<td>Smoke point, mm</td>
<td>20 – 28</td>
</tr>
<tr>
<td>Hydrogen, mass %</td>
<td>13.4 – 14.1</td>
</tr>
<tr>
<td>Sulphur, mass %</td>
<td>less than 0.3%</td>
</tr>
<tr>
<td>Kinematic viscosity at –20°C, mm²/s</td>
<td>2.5 – 6.5</td>
</tr>
</tbody>
</table>
APPENDIX 5. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS FROM AFTERBURNING GAS TURBINE ENGINES

1. INTRODUCTION

Note.— The procedures specified in this appendix are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system. These procedures only apply when afterburning is employed. The methods proposed are representative of the best readily available and most established modern practice. The need to correct for ambient conditions is recognized and a method will be specified when one becomes available. Meanwhile any correction methods used when afterburning is employed should be approved by the certificating authority.

Variations in the procedure contained in this appendix shall only be allowed after prior application to and approval by the certificating authority.

2. DEFINITIONS

Where the following expressions are used without further explanation in this appendix, they have the meanings ascribed to them below:

Accuracy. The closeness with which a measurement approaches the true value established independently.

Calibration gas. A high accuracy reference gas to be used for alignment, adjustment and periodic checks of instruments.

Concentration. The volume fraction of the component of interest in the gas mixture — expressed as volume percentage or as parts per million.

Flame ionization detector. A hydrogen-air diffusion flame detector that produces a signal nominally proportional to the mass-flow rate of hydrocarbons entering the flame per unit of time — generally assumed responsive to the number of carbon atoms entering the flame.

Interference. Instrument response due to presence of components other than the gas (or vapour) that is to be measured.

Noise. Random variation in instrument output not associated with characteristics of the sample to which the instrument is responding, and distinguishable from its drift characteristics.

Non-dispersive infra-red analyser. An instrument that by absorption of infra-red energy selectively measures specific components.

Parts per million (ppm). The unit volume concentration of a gas per million unit volume of the gas mixture of which it is a part.

Parts per million carbon (ppmC). The mole fraction of hydrocarbon multiplied by 10^6 measured on a methane-equivalence basis. Thus, 1 ppm of methane is indicated as 1 ppmC. To convert ppm concentration of any hydrocarbon to an equivalent ppmC value, multiply ppm concentration by the number of carbon atoms per molecule of the gas. For example, 1 ppm propane translates as 3 ppmC hydrocarbon; 1 ppm hexane as 6 ppmC hydrocarbon.

Plume. Total external engine exhaust flow, including any ambient air with which the exhaust mixes.

Reference gas. A mixture of gases of specified and known composition used as the basis for interpreting instrument response in terms of the concentration of the gas to which the instrument is responding.

Repeatability. The closeness with which a measurement upon a given, invariant sample can be reproduced in short-term repetitions of the measurement with no intervening instrument adjustment.

Resolution. The smallest change in a measurement which can be detected.

Response. The change in instrument output signal that occurs with change in sample concentration. Also the output signal corresponding to a given sample concentration.

Stability. The closeness with which repeated measurements upon a given invariant sample can be maintained over a given period of time.

Zero drift. Time-related deviation of instrument output from zero set point when it is operating on gas free of the component to be measured.

Zero gas. A gas to be used in establishing the zero, or no response, adjustment of an instrument.
Figure 5-1. Exhaust gas sampling system, schematic
Figure 5-2. Sample transfer and analysis system, schematic
3. DATA REQUIRED

3.1 Gaseous emissions

Concentrations of the following emissions shall be determined:

a) Hydrocarbons (HC): a combined estimate of all hydrocarbon compounds present in the exhaust gas.

b) Carbon monoxide (CO).

c) Carbon dioxide (CO₂).

Note.— CO₂ is not considered a pollutant but its concentration is required for calculation and check purposes.

d) Oxides of nitrogen (NOₓ): an estimate of the sum of the two oxides, nitric oxide (NO) and nitrogen dioxide (NO₂).

e) Nitric oxide (NO).

3.2 Other information

In order to normalize the emissions measurement data and to quantify the engine test characteristics, other information in addition to the requirements of Chapter 3, 3.4 shall be provided as follows:

— inlet temperature;
— inlet humidity;
— atmospheric pressure;
— wind vectors relative to engine exhaust axis;
— hydrogen/carbon ratio of fuel;
— engine installation details;
— other required engine parameters (for example, thrust, rotor speeds, turbine temperatures);
— pollutant concentration data and statistical validation parameters.

This data shall be obtained either by direct measurement or by calculation, as presented in Attachment F to this appendix.

4. GENERAL ARRANGEMENT OF THE SYSTEM

Owing to the reactive nature of the exhaust plume from engines using afterburning, it is necessary to ensure that the measured emissions do in fact correspond to those actually emitted into the surrounding atmosphere. This is achieved by sampling the plume sufficiently far downstream from the engine that the exhaust gases have cooled to a temperature where reactions have ceased. No desiccants, dryers, water traps or related equipment shall be used to treat the exhaust sample flowing to the oxides of nitrogen and the hydrocarbon analysis instrumentation. Requirements for the various component sub-systems are given in 5, but the following list gives some qualifications and variations:

a) it is assumed that each of the various individual sub-systems includes the necessary flow control, conditioning and measurement facilities;

b) the necessity for a dump and/or a hot-sample pump will depend on the ability to meet the sample transfer time and analysis sub-system sample flow rate requirements. This in turn depends on the exhaust sample-driving pressure and line losses. It is considered that these pumps usually will be necessary at certain engine running conditions; and

c) the position of the hot pump, relative to the gas analysis sub-systems, may be varied as required. (For example, some HC analysers contain hot pumps and so may be judged capable of being used upstream of the system hot pump.)

Note.— Figures 5-1 and 5-2 are schematic drawings of the exhaust gas sampling and analytical system and typify the basic requirements for emissions testing.

5. DESCRIPTION OF COMPONENT PARTS

Note.— A general description and specification of the principal elements in the engine exhaust emissions measurement system follows. Greater detail, where necessary, will be found in Attachments A, B and C to this appendix.

5.1 Sampling system

5.1.1 Sampling probe

a) The probe shall be constructed so that individual samples can be withdrawn at various locations across a diameter of the plume. Mixed samples shall not be permitted.

b) The material with which the sample is in contact shall be stainless steel and its temperature shall be maintained at a value not less than 60°C.

c) The sampling plane shall be perpendicular to the projected engine nozzle centre line, and shall be situated as close as possible to a position 18 nozzle diameters from the nozzle exit plane, consistent with 7.1.2, but in no case greater than 25 nozzle diameters. The nozzle exit diameter shall be for the maximum engine power condition. Between and including exit and sampling planes there shall be an unobstructed region of at least 4 nozzle exit diameters in radial distance about the project engine nozzle centre line.
d) The minimum number of sampling points shall be equal to 11. The measurement plane, located at a distance $X$ from the engine shall be divided into three sections demarcated by circles centred around the exhaust stream axis with radii

\[ R_1 = 0.05X \]
\[ R_2 = 0.09X \]

and a minimum of 3 samples shall be taken from each section. The difference between the number of samples in each section must be less than 3. The sample taken at the most remote distance from the axis shall be from a point located at a radius of between 0.11X and 0.16X.

5.1.2 Sampling lines

The sample shall be transferred from the probe to the analysers via a line of 4.0 to 8.5 mm inside diameter, taking the shortest route practicable and using a flow rate such that the transport time is less than 10 seconds. The line shall be maintained at a temperature of 160°C ±15°C (with a stability of ±10°C). When sampling to measure HC, CO, CO$_2$ and NO$_x$ components, the line shall be constructed in stainless steel or carbon-loaded grounded PTFE.

5.2 HC analyser

The measurement of total hydrocarbon sample content shall be made by an analyser using the heated flame ionization detector (FID), between the electrodes of which passes an ionization current proportional to the mass rate of hydrocarbon entering a hydrogen flame. The analyser shall be deemed to include components arranged to control temperature and flow rates of sample, sample bypass, fuel and diluent gases, and to enable effective span and zero calibration checks.

Note.— An over-all specification is given in Attachment A to this appendix.

5.3 CO and CO$_2$ analysers

Non-dispersive infra-red analysers shall be used for the measurement of these components, and shall be of the design which utilizes differential energy absorption in parallel reference and sample gas cells, the cell or group of cells for each of these gas constituents being sensitized appropriately. This analysis sub-system shall include all necessary functions for the control and handling of sample, zero and span gas flows. Temperature control shall be that appropriate to whichever basis of measurement, wet or dry, is chosen.

Note.— An over-all specification is given in Attachment B to this appendix.

5.4 NO$_x$ analyser

The measurement of NO concentration shall be by the chemiluminescent method in which the measure of the radiation intensity emitted during the reaction of the NO in the sample with added O$_3$ is the measure of the NO concentration. The NO$_2$ component shall be converted to NO in a converter of the requisite efficiency prior to measurement. The resultant NO$_x$ measurement system shall include all necessary flow, temperature and other controls and provide for routine zero and span calibration as well as for converter efficiency checks.

Note.— An over-all specification is given in Attachment C to this appendix.

6. GENERAL TEST PROCEDURES

6.1 Engine operation

The engine shall be operated on an open air static test facility which is suitable and properly equipped for high accuracy performance testing, and which conforms to the requirements for sampling probe installation as specified in 5.1. The emissions tests shall be made at the power settings prescribed by the certificating authority. The engine shall be stabilized at each setting.

6.2 Ambient air conditions

6.2.1 A check shall be made on the ambient concentrations of CO, HC, CO$_2$ and NO$_x$, with the engine under test running at the test condition. Unusually high concentrations indicate abnormal conditions such as exhaust gas recirculation, fuel spillage or some other source of unwanted emissions in the test area and such situations shall be rectified or avoided as appropriate.

Note.— For guidance, the normal ambient concentration of CO$_2$ is 0.03 per cent, and ambient concentration levels for CO and HC of 5 ppm and NO$_x$ of 0.5 ppm are unlikely to be exceeded under normal conditions.

6.2.2 Extreme climatic conditions, such as those involving precipitation or excessive wind speed shall also be avoided.

6.3 Major instrument calibration

Note.— The general objective of this calibration is to confirm stability and linearity.

6.3.1 The applicant shall satisfy the certificating authority that the calibration of the analytical system is valid at the time of the test.
6.3.2 For the hydrocarbon analyser this calibration shall include checks that the detector oxygen and differential hydrocarbon responses are within the limits specified in Attachment A to this appendix. The efficiency of the NO₂/NO converter shall also be checked and verified to meet the requirements in Attachment C to this appendix.

6.3.3 The procedure for checking the performance of each analyser shall be as follows (using the calibration and test gases as specified in Attachment D to this appendix):

a) introduce zero gas and adjust instrument zero, recording setting as appropriate;

b) for each range to be used operationally, introduce calibration gas of (nominally) 90 per cent range full-scale deflection (FSD) concentration; adjust instrument gain accordingly and record its setting;

c) introduce approximately 30 per cent, 60 per cent, and 90 per cent range FSD concentrations and record analyser readings;

d) fit a least squares straight line to the zero, 30 per cent, 60 per cent and 90 per cent concentration points. For the CO and/or CO₂ analyser used in its basic form without linearization of output, a least squares curve of appropriate mathematical formulation shall be fitted using additional calibration points if judged necessary. If any point deviates by more than 2 per cent of the full scale value (or ±1 ppm*, whichever is greater) then a calibration curve shall be prepared for operational use.

6.4 Operation

6.4.1 No measurements shall be made until all instruments and sample transfer lines are warmed up and stable and the following checks have been carried out:

a) leakage check: prior to a series of tests the system shall be checked for leakage by isolating the probe and the analysers, connecting and operating a vacuum pump of equivalent performance to that used in the smoke measurement system to verify that the system leakage flow rate is less than 0.4 L/min referred to normal temperature and pressure;

b) cleanliness check: isolate the gas sampling system from the probe and connect the end of the sampling line to a source of zero gas. Warm the system up to the operational temperature needed to perform hydrocarbon measurements. Operate the sample flow pump and set the flow rate to that used during engine emission testing. Record the hydrocarbon analyser reading. The reading shall not exceed 1 per cent of the engine idle emission level or 1 ppm (both expressed as methane), whichever is the greater.

Note 1.— It is good practice to back-purge the sampling lines during engine running, while the probe is in the engine exhaust but emissions are not being measured, to ensure that no significant contamination occurs.

Note 2.— It is also good practice to monitor the inlet air quality at the start and end of testing and at least once per hour during a test. If levels are considered significant, then they should be taken into account.

6.4.2 The following procedure shall be adopted for operational measurements:

a) apply appropriate zero gas and make any necessary instrument adjustments;

b) apply appropriate calibration gas at a nominal 90 per cent FSD concentration for the ranges to be used, adjust and record gain settings accordingly;

c) when the engine has been stabilized at the requisite operating conditions and sampling location, continue to run it and observe pollutant concentrations until a stabilized reading is obtained, which shall be recorded. At the same engine operating condition repeat the measurement procedure for each of the remaining sampling locations;

d) recheck zero and calibration points at the end of the test and also at intervals not greater than 1 hour during tests. If either has changed by more than ±2 per cent of full scale of range, the test shall be repeated after restoration of the instrument to within its specification.

7. CALCULATIONS

7.1 Gaseous emissions

7.1.1 General

The analytical measurements made shall be the concentrations of the various classes of pollutant, at the relevant afterburning mode(s) of the engine, at the various locations in the sampling plane. In addition to the recording of these basic parameters, other parameters shall be computed and reported, as follows.

* Except for the CO₂ analyser, for which the value shall be ±100 ppm.
7.1.2 Analysis and validation of measurements

a) At each engine setting, the concentrations measured at different probe sampling positions must be averaged as follows:

\[ C_{i\ moy} = \sum_{j=1}^{n} C_{i\ j} \]

where

\[ \sum_{j=1}^{n} \] Summation of the total number \( n \) of sampling positions used.
\( C_{i\ j} \) Concentration of species \( i \) measured at the \( j \)th sampling position.
\( C_{i\ moy} \) average or mean concentration of species \( i \).

All dry concentration measurements shall be converted into real wet concentrations. (See Attachment E to this appendix).

b) The quality of the measurements for each pollutant will be determined through a comparison with measurements of CO\(_2\) using the correlation coefficient:

\[ r_i = \sqrt{\left( \frac{n}{n-1} \sum_{j=1}^{n} (C_{i\ CO_2 j} - \overline{C_{i\ CO_2}})^2 / \left( \sum_{j=1}^{n} C_{i\ CO_2 j}^2 - \left( \frac{1}{n} \sum_{j=1}^{n} C_{i\ CO_2 j} \right)^2 \right) \right)} \]

Values of \( r_i \) which are near to 1 indicate that measurements taken over the entire sampling period are sufficiently stable and that the curves are gaussian. In the event that \( r_i \) is less than 0.95, measurements must be repeated in a sampling plane located at a more remote distance from the aircraft engine. The measurement process, per se, is then followed by the same calculations and the same demonstration as previously.

7.1.3 Basic parameters

For the measurements at each engine operating mode the average concentration for each gaseous species is estimated as shown in 7.1.2, any necessary corrections for dry sample measurement and/or interferences having been made as indicated in Attachment E to this appendix. These average concentrations are used to compute the following basic parameters:

\[ EI_p (\text{emission index for component } p) = \frac{\text{mass of } p \text{ produced in g}}{\text{mass of fuel used in kg}} \]

\[ EI(CO) = \left( \frac{[CO]}{[CO_2] + [CO] + [HC]} \right) \left( \frac{10^3 M_{CO}}{M_{C} + (n/m)M_H} \right) \left( 1 + T/P_{d/m} \right) \]

\[ EI(HC) = \left( \frac{[HC]}{[CO_2] + [CO] + [HC]} \right) \left( \frac{10^3 M_{HC}}{M_{C} + (n/m)M_H} \right) \left( 1 + T/P_{d/m} \right) \]

\[ EI(NO_x) = \left( \frac{[NO_x]}{[CO_2] + [CO] + [HC]} \right) \left( \frac{10^7 M_{NO_x}}{M_{C} + (n/m)M_H} \right) \left( 1 + T/P_{d/m} \right) \]

Air/fuel ratio = \( P_{d/m} \left( \frac{M_{AIR}}{M_{C} + (n/m)M_H} \right) \)

where

\[ P_{d/m} = \frac{2Z - (n/m)}{4(1 + h - |T|Z^2)} \]

and

\[ Z = \frac{2 - [CO] - (2Z|a| - |y|/|x|)}{[CO_2] + [CO] + [HC]} [HC] + [NO_x] \]

\( M_{AIR} \) molecular mass of dry air = 28.966 g
\( M_{HC} \) molecular mass of exhaust hydrocarbons, taken as \( CH_4 \) = 16.043 g
\( M_{CO} \) molecular mass of CO = 28.011 g
\( M_{NO_2} \) molecular mass of NO\(_2\) = 46.088 g
\( M_C \) atomic mass of carbon = 12.011 g
\( M_H \) atomic mass of hydrogen = 1.008 g
\( R \) concentration of O\(_2\) in dry air, by volume = 0.2095 normally
\( S \) concentration of N\(_2\) + rare gases in dry air, by volume = 0.7092 normally
\( T \) concentration of CO\(_2\) in dry air, by volume = 0.003 normally
\( [HC] \) mean concentration of exhaust hydrocarbons vol/vol, wet, expressed as carbon
\( [CO] \) mean concentration of CO vol/vol, wet
\( [CO_2] \) mean concentration of CO\(_2\) vol/vol, wet
\( [NO_x] \) mean concentration of NO\(_x\) vol/vol, wet = \([NO + NO_2]\)
\( [NO] \) mean concentration of NO in exhaust sample, vol/vol, wet
Appendix 5

\[ [\text{NO}_2] \text{ mean concentration of NO}_2 \text{ in exhaust sample, vol/vol, wet} \]
\[ = \frac{([\text{NO}_2]_c - [\text{NO}])}{\eta} \]

\[ [\text{NO}_x]_c \text{ mean concentration of NO in exhaust sample after passing through the NO}_2/\text{NO converter, vol/vol, wet} \]

\[ \eta \text{ efficiency of NO}_2/\text{NO converter} \]
\[ h \text{ humidity of ambient air, vol water/vol dry air} \]

\[ m \text{ number of C atoms in characteristic fuel molecule} \]
\[ n \text{ number of H atoms in characteristic fuel molecule} \]
\[ x \text{ number of C atoms in characteristic exhaust hydrocarbon molecule} \]
\[ y \text{ number of H atoms in characteristic exhaust hydrocarbon molecule} \]

The value of \( n/m \), the ratio of the atomic hydrogen to atomic carbon of fuel used, is evaluated by fuel type analysis. The ambient air humidity, \( h \), shall be measured at each set condition. In the absence of contrary evidence as to the characterization \((x,y)\) of the exhaust hydrocarbons, the values \( x=1, y=4 \) are to be used. If dry or semi-dry CO and CO\(_2\) measurements are to be used then these shall first be converted to the equivalent wet concentrations as shown in Attachment E to this appendix, which also contains interference correction formulas for use as required.

Note.— The procedure given in 7.1.4 and 7.2 is only applicable to tests made when afterburning is not used. For tests when afterburning is used, a similar procedure could be used after approval by the certificating authority.

7.1.4 Correction of emission indices to reference conditions

Corrections shall be made to the measured engine emission indices for all pollutants in all relevant engine operating modes to account for deviations from the reference conditions (ISA at sea level) of the actual test inlet air conditions of temperature and pressure. The reference value for humidity shall be 0.00629 kg water/kg dry air.

Thus, EI corrected = \( K \times \) EI measured,

where the generalized expression for \( K \) is:

\[ K = \left( \frac{P_{\text{ref}}}{P_B} \right)^a \times \left( \frac{\text{FAR}_{\text{ref}}}{\text{FAR}_B} \right)^b \times \exp \left( \frac{T_{\text{ref}}}{T_B} \right)^c \times \exp \left( d|h - 0.00629| \right) \]

\( P_B \) Combustor inlet pressure, measured
\( T_B \) Combustor inlet temperature, measured
\( \text{FAR}_B \) Fuel/air ratio in the combustor
\( h \) Ambient air humidity
\( P_{\text{ref}} \) ISA sea level pressure
\( T_{\text{ref}} \) ISA sea level temperature
\( \text{FAR}_{\text{ref}} \) Fuel/air ratio in the combustor under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine).
\( T_{\text{Bref}} \) Temperature at the combustor inlet under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine).

\( a,b,c,d \) Specific constants which may vary for each pollutant and each engine type.

The combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas.

7.1.5 Using the recommended curve fitting technique to relate emission indices to combustor inlet temperature effectively eliminates the \( \exp \left( \frac{T_{\text{Bref}} - T_B}{c} \right) \) term from the generalized equation and for most cases the \( \left( \frac{\text{FAR}_{\text{ref}}}{\text{FAR}_B} \right) \) term may be considered unity. For the emissions indices of CO and HC many testing facilities have determined that the humidity term is sufficiently close to unity to be eliminated from the expression and that the exponent of the \( \left( \frac{P_{\text{ref}}}{P_B} \right) \) term is close to unity.

Thus,

\[ \text{EI(CO) corrected} = \text{EI derived from} \left( \frac{P_B}{P_{\text{Bref}}} \right) \times \text{EI(CO) v. } T_B \text{ curve} \]
\[ \text{EI(HC) corrected} = \text{EI derived from} \left( \frac{P_B}{P_{\text{Bref}}} \right) \times \text{EI(HC) v. } T_B \text{ curve} \]
EI(NO\textsubscript{x}) corrected = EI derived from
\[ EI(NO\textsubscript{x}) (P_{\text{ref}} / P_B)^{0.5} \exp(19 \cdot h - 0.00629) \] v. \( T_B \) curve

If this recommended method for the CO and HC emissions index correction does not provide a satisfactory correlation, an alternative method using parameters derived from component tests may be used.

Any other methods used for making corrections to CO, HC and NO\textsubscript{x} emissions indices shall have the approval of the certificating authority.

### 7.2 Control parameter functions

\( (D_p, F_{oo}, \pi) \)

#### 7.2.1 Definitions

- **\( D_p \)**: The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle.
- **\( F_{oo} \)**: The maximum thrust available for take-off under normal operating conditions at ISA sea level static conditions, without the use of water injection, as approved by the applicable certificating authority.
- **\( \pi \)**: The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating at ISA sea level static conditions.

#### 7.2.2 The emission indices (EI) for each pollutant, corrected for pressure and humidity (as appropriate) to the reference ambient atmospheric conditions as indicated in 7.1.4 and if necessary to the reference engine, shall be obtained for the required LTO engine operating mode settings \((n)\) of idle, approach, climb-out and take-off, at each of the equivalent corrected thrust conditions. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined for each pollutant:

a) between EI and \( T_B \); and
b) between \( W_f \) (engine fuel mass flow rate) and \( T_B \); and
c) between \( F_n \) (corrected to ISA sea level conditions) and \( T_B \) (corrected to ISA sea level conditions);

**Note.**— These are illustrated, for example, by Figure 5-3 a), b) and c).

When the engine being tested is not a “reference” engine, the data may be corrected to “reference” engine conditions using the relationships b) and c) obtained from a reference engine. A reference engine is defined as an engine substantially configured to the description of the engine to be certified and accepted by the certificating authority to be representative of the engine type for which certification is sought.

The manufacturer shall also supply to the certificating authority all of the necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:

- d) maximum rated thrust \( (F_{oo}) \); and
- e) engine pressure ratio \( (\pi) \) at maximum rated thrust.

**Note.**— These are illustrated by Figure 5-3 d).

#### 7.2.3 The estimation of EI for each pollutant at each of the required engine mode settings, corrected to the reference ambient conditions, shall comply with the following general procedure:

a) at each mode ISA thrust condition \( F_n \), determine the equivalent combustor inlet temperature \( (T_B) \) (Figure 5-3 c));

b) from the EI/\( T_B \) characteristic (Figure 5-3 a)), determine the EI\textsubscript{n} value corresponding to \( T_B \);

c) from the \( W_f /T_B \) characteristics (Figure 5-3 b)), determine the \( W_{fn} \) value corresponding to \( T_B \);

d) note the ISA maximum rated thrust and pressure ratio values. These are \( F_{oo} \) and \( \pi \) respectively (Figure 5-3 d));

e) calculate, for each pollutant \( D_p = \sum (E_{in}) (W_{fn}) \) (t) where:

\[ t \] time in LTO mode (minutes)

\[ W_{fn} \] fuel mass flow rate (kg/min)

\[ \Sigma \] is the summation for the set of modes comprising the reference LTO cycle.

#### 7.2.4 While the methodology described above is the recommended method, the certificating authority may accept equivalent mathematical procedures which utilize mathematical expressions representing the curves illustrated if the expressions have been derived using an accepted curve fitting technique.

### 7.3 Exceptions to the proposed procedures

In those cases where the configuration of the engine or other extenuating conditions exist which would prohibit the use of this procedure, the certificating authority, after receiving satisfactory technical evidence of equivalent results obtained by an alternative procedure, may approve an alternative procedure.
Figure 5-3. Calculation procedure

**Legend:**

- **EI** = EMISSION INDEX
- **TB** = COMBUSTOR INLET TEMPERATURE
- **WF** = ENGINE FUEL MASS FLOW RATE
- **F** = ENGINE THRUST
- **π** = ENGINE PRESSURE RATIO

**Axes:**

- (EI) vs. TB
- (WF) vs. TB
- (F) vs. TB (ISA SEA LEVEL)
- (Fπ) vs. π (ISA SEA LEVEL)
ATTACHMENT A TO APPENDIX 5. SPECIFICATION FOR HC ANALYSER

Note 1.— As outlined in 5.2 of Appendix 5, the measuring element in this analyser is the flame ionization detector (FID) in which the whole or a representative portion of the sample flow is admitted into a hydrogen-fuelled flame. With suitably positioned electrodes an ionization current can be established which is a function of the mass rate of hydrocarbon entering the flame. It is this current which, referred to an appropriate zero, is amplified and ranged to provide the output response as a measure of the hydrocarbon concentration expressed as ppmC equivalent.

Note 2.— See Attachment D for information on calibration and test gases.

1. GENERAL

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The instrument to be used shall be such as to maintain the temperature of the detector and sample-handling components at a set point temperature within the range 155°C to 165°C to a stability of ±2°C. The leading specification points shall be as follows, the detector response having been optimized and the instrument generally having stabilized:

a) Total range: 0 to 500 ppmC in appropriate ranges.
b) Resolution: better than 0.5 per cent of full scale of range used or 0.5 ppmC, whichever is greater.
c) Repeatability: better than ±1 per cent of full scale of range used, or ±0.5 ppmC, whichever is greater.
d) Stability: better than ±2 per cent of full scale of range used or ±1 ppmC, whichever is greater, in a period of 1 hour.
e) Zero drift: less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater, in a period of 1 hour.
f) Noise: 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater.
g) Response time: shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.
h) Linearity: response with propane in air shall be linear for each range within ±2 per cent of full scale, otherwise calibration corrections shall be used.

2. SYNERGISTIC EFFECTS

Note.— In application there are two aspects of performance which can affect the accuracy of measurement:

a) the oxygen effect (whereby differing proportions of oxygen present in the sample give differing indicated hydrocarbon concentration for constant actual HC concentrations); and

b) the relative hydrocarbon response (whereby there is a different response to the same sample hydrocarbon concentrations expressed as equivalent ppmC, dependent on the class or admixture of classes of hydrocarbon compounds).

The magnitude of the effects noted above shall be determined as follows and limited accordingly.

Oxygen response: measure the response with two blends of propane, at approximately 500 ppmC concentration known to a relative accuracy of ±1 per cent, as follows:

1) propane in 10 ± 1 per cent O_2, balance N_2
2) propane in 21 ± 1 per cent O_2, balance N_2

If R_1 and R_2 are the respective normalized responses then (R_1 – R_2) shall be less than 3 per cent of R_1.

Differential hydrocarbon response: measure the response with four blends of different hydrocarbons in air, at concentrations of approximately 500 ppmC, known to a relative accuracy of ±1 per cent, as follows:

a) propane in zero air
b) propylene in zero air
c) toluene in zero air
d) n-hexane in zero air.
If \( R_a, R_b, R_c \) and \( R_d \) are, respectively, the normalized responses (with respect to propane), then \((R_a - R_b), (R_a - R_c)\) and \((R_a - R_d)\) shall each be less than 5 per cent of \( R_a \).

### 3. OPTIMIZATION OF DETECTOR RESPONSE AND ALIGNMENT

3.1 The manufacturer’s instructions for initial setting up procedures and ancillary services and supplies required shall be implemented, and the instrument allowed to stabilize. All setting adjustments shall involve iterative zero checking, and correction as necessary. Using as sample a mixture of approximately 500 ppmC of propane in air, the response characteristics for variations first in fuel flow and then, near an optimum fuel flow, for variations in dilution air flow to select its optimum shall be determined. The oxygen and differential hydrocarbon responses shall then be determined as indicated above.

3.2 The linearity of each analyser range shall be checked by applying propane in air samples at concentrations of approximately 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line (fitted to the points and zero) shall not exceed ±2 per cent of full scale value. If it does, a calibration curve shall be prepared for operational use.

### ATTACHMENT B TO APPENDIX 5. SPECIFICATION FOR CO AND CO\(_2\) ANALYSERS

**Note 1.**— Paragraph 5.3 of Appendix 5 summarizes the characteristics of the analysis sub-system to be employed for the individual measurements of CO and CO\(_2\) concentrations in the exhaust gas sample. The instruments are based on the principle of non-dispersive absorption of infra-red radiation in parallel reference and sample gas cells. The required ranges of sensitivity are obtained by use of stacked sample cells or changes in electronic circuitry or both. Interferences from gases with overlapping absorption bands may be minimized by gas absorption filters and/or optical filters, preferably the latter.

**Note 2.**— See Attachment D for information on calibration and test gases.

**Precautions:** The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The principal performance specification shall be as follows:

**CO Analyser**

a) **Total range:** 0 to 2 500 ppm in appropriate ranges.

b) **Resolution:** better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.

c) **Repeatability:** better than ±1 per cent of full scale of range used, or ±2 ppm, whichever is greater.

d) **Stability:** better than ±2 per cent of full scale of range used or ±2 ppm, whichever is greater, in a period of 1 hour.

e) **Zero drift:** less than ±1 per cent of full scale of range used or ±2 ppm, whichever is greater, in a period of 1 hour.

f) **Noise:** 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±1 ppm, whichever is greater.

g) **Interferences:** to be limited with respect to indicated CO concentration as follows:

1) less than 500 ppm/per cent ethylene concentration

2) less than 2 ppm/per cent CO\(_2\) concentration

3) less than 2 ppm/per cent water vapour.*

If the interference limitation(s) for CO\(_2\) and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

**Note.—** It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

**CO\(_2\) Analyser**

a) **Total range:** 0 to 10 per cent in appropriate ranges.

---

* Need not apply where measurements are on a “dry” basis.
b) **Resolution:** better than 0.5 per cent of full scale of range used or 100 ppm, whichever is greater.

c) **Repeatability:** better than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater.

d) **Stability:** better than ±2 per cent of full scale of range used or ±100 ppm, whichever is greater, in a period of 1 hour.

e) **Zero drift:** less than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater, in a period of 1 hour.

f) **Noise:** 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater.

g) The effect of oxygen (O_2) on the CO_2 analyser response shall be checked. For a change from 0 per cent O_2 to 21 per cent O_2 the response of a given CO_2 concentration shall not change by more than 2 per cent of reading. If this limit cannot be met an appropriate correction factor shall be applied.

Note.— It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

**CO and CO_2 Analysers**

a) **Response time:** shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.

b) **Sample temperature:** the normal mode of operation is for analysis of the sample in its (untreated) “wet” condition. This requires that the sample cell and all other components in contact with the sample in this sub-system be maintained at a temperature of not less than 50°C, with a stability of ±2°C. The option to measure CO and CO_2 on a dry basis (with suitable water traps) is allowed, in which case unheated analysers are permissible and the interference limits for H_2O vapour removed, and subsequent correction for inlet water vapour and water of combustion is required.

c) **Calibration curves:**

i) Analysers with a linear signal output characteristic shall be checked on all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line, fitted to the points and the zero reading, shall not exceed ±2 per cent of the full scale value. If it does then a calibration curve shall be prepared for operational use.

ii) Analysers with a non-linear signal output characteristic, and those that do not meet the requirements of linearity given above, shall have calibration curves prepared for all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. Additional mixes shall be used, if necessary, to define the curve shape properly.

**ATTACHMENT C TO APPENDIX 5. SPECIFICATION FOR NO_x ANALYSER**

Note.— See Attachment D for information on calibration and test gases.

1. As indicated in 5.4 of Appendix 5, the measurement of the oxides of nitrogen concentration shall be by the chemiluminescent technique in which radiation emitted by the reaction of NO and O_3 is measured. This method is not sensitive to NO_2 and therefore the sample shall be passed through a converter in which NO_2 is converted to NO before the measurement of total NO_x is made. Both the original NO and the total NO_x concentrations shall be recorded. Thus by difference, a measure of the NO_2 concentration shall be obtained.

2. The instrument to be used shall be complete with all necessary flow control components, such as regulators, valves, flowmeters, etc. Materials in contact with the sample gas shall be restricted to those which are resistant to attack by oxides of nitrogen, such as stainless steel, glass, etc. The temperature of the sample shall everywhere be maintained at values, consistent with the local pressures, which avoid condensation of water.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when
3. The principal performance specification, determined for the instrument operated in an ambient temperature stable to within 2°C, shall be as follows:

a) **Total range:** 0 to 2500 ppm in appropriate ranges.

b) **Resolution:** better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.

c) **Repeatability:** better than ±1 per cent of full scale of range used, or ±1 ppm, whichever is greater.

d) **Stability:** better than ±2 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 1 hour.

e) **Zero drift:** less than ±1 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 1 hour.

f) **Noise:** 0.5 Hz and greater, less than ±1.0 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 2 hours.

g) **Interference:** suppression for samples containing CO_2 and water vapour, shall be limited as follows:

h) **Linearity:** better than ±2 per cent of full scale of range used or ±2 ppm, whichever is greater.

i) **Converter:** this shall be designed and operated in such a manner as to reduce NO_2 present in the sample to NO. The converter shall not affect the NO originally in the sample.

The converter efficiency shall not be less than 90 per cent.

This efficiency value shall be used to correct the measured sample NO_2 value (i.e. \([NO\_x]_c – [NO]\)) to that which would have been obtained if the efficiency had not been 100 per cent.

### ATTACHMENT D TO APPENDIX 5. CALIBRATION AND TEST GASES

**Table of calibration gases**

<table>
<thead>
<tr>
<th>Analyser</th>
<th>Gas</th>
<th>Accuracy*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>propane in zero air</td>
<td>±2 per cent or ±0.05 ppm**</td>
</tr>
<tr>
<td>CO_2</td>
<td>CO_2 in zero air</td>
<td>±2 per cent or ±100 ppm**</td>
</tr>
<tr>
<td>CO</td>
<td>CO in zero air</td>
<td>±2 per cent or ±2 ppm**</td>
</tr>
<tr>
<td>NO_2</td>
<td>NO_2 in zero nitrogen</td>
<td>±2 per cent or ±1 ppm**</td>
</tr>
</tbody>
</table>

* Taken over the 95 per cent confidence interval.
** Whichever is greater.

The above gases are required to carry out the routine calibration of analysers during normal operational use.
Table of test gases

<table>
<thead>
<tr>
<th>Analyser</th>
<th>Gas</th>
<th>Accuracy*</th>
</tr>
</thead>
</table>
| HC       | propane in 10 ±1 per cent O₂  
balance zero nitrogen | ±1 per cent |
| HC       | propane in 21 ±1 per cent O₂  
balance zero nitrogen | ±1 per cent |
| HC       | propylene in zero air    | ±1 per cent |
| HC       | toluene in zero air      | ±1 per cent |
| HC       | n-hexane in zero air     | ±1 per cent |
| HC       | propane in zero air      | ±1 per cent |
| CO₂      | CO₂ in zero air          | ±1 per cent |
| CO₂      | CO₂ in zero nitrogen     | ±1 per cent |
| CO       | CO in zero air           | ±1 per cent |
| NOₓ      | NO in zero nitrogen      | ±1 per cent |

* Taken over the 95 per cent confidence interval.

The above gases are required to carry out the tests of Attachments A, B and C.

Carbon monoxide and carbon dioxide calibration gases may be blended singly or as dual component mixtures. Three component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

Zero gas as specified for the CO, CO₂ and HC analysers shall be zero air (which includes “artificial” air with 20 to 22 per cent O₂ blended with N₂). For the NOₓ analyser zero nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following concentrations:

- 1 ppm C
- 1 ppm CO
- 100 ppm CO₂
- 1 ppm NOₓ

The applicant shall ensure that commercial gases supplied to him do in fact meet this specification, or are so specified by the vendor.
1. SYMBOLS

AFR  air/fuel ratio; the ratio of the mass flow rate of dry air to that of the fuel

EI  emission index; \(10^3 \times \) mass flow rate of gaseous emission product in exhaust per unit mass flow rate of fuel

\( K \)  ratio of concentration measured wet to that measured dry (after cold trap)

\( L, L' \)  analyser interference coefficient for interference by CO₂

\( M, M' \)  analyser interference coefficient for interference by H₂O

\( M_{\text{AIR}} \)  molecular mass of dry air = 28.966 g or, where appropriate, = \((32 \ R + 28.156 \ S + 44.011 \ T) \) g

\( M_{\text{CO}} \)  molecular mass of CO = 28.011 g

\( M_{\text{HC}} \)  molecular mass of exhaust hydrocarbon, taken as CH₄ = 16.043 g

\( M_{\text{NO}_2} \)  molecular mass of NO₂ = 46.008 g

\( M_{C} \)  atomic mass of carbon = 12.011 g

\( M_{H} \)  atomic mass of hydrogen = 1.008 g

\( P_1 \)  number of moles of CO₂ in the exhaust sample per mole of fuel

\( P_2 \)  number of moles of N₂ in the exhaust sample per mole of fuel

\( P_3 \)  number of moles of O₂ in the exhaust sample per mole of fuel

\( P_4 \)  number of moles of H₂O in the exhaust sample per mole of fuel

\( P_5 \)  number of moles of CO in the exhaust sample per mole of fuel

\( P_6 \)  number of moles of CₓHᵧ in the exhaust sample per mole of fuel

\( P_7 \)  number of moles of NO₂ in the exhaust sample per mole of fuel

\( P_8 \)  number of moles of NO in the exhaust sample per mole of fuel

\( P_T \)  \( P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 \)

\( R \)  concentration of O₂ in dry air, by volume = 0.2095 normally

\( S \)  concentration of N₂ + rare gases in dry air, by volume = 0.7902 normally

\( T \)  concentration of CO₂ in dry air, by volume = 0.0003 normally

\( P_0 \)  number of moles of air per mole of fuel in initial air/fuel mixture

\( Z \)  symbol used and defined in 3.4

\([\text{CO}_2]\)  mean concentration of CO₂ in exhaust sample, vol/vol

\([\text{CO}]\)  mean concentration of CO in exhaust sample, vol/vol

\([\text{HC}]\)  mean concentration of HC in exhaust sample, vol/vol

\([\text{NO}]\)  mean concentration of NO in exhaust sample, vol/vol

\([\text{NO}_2]\)  mean concentration of NO₂ in exhaust sample, vol/vol

\([\text{NO}_x]\)  mean concentration of NO and NO₂ in exhaust sample, vol/vol

\([\text{NO}_x]_c\)  mean concentration of NO in exhaust sample, after passing through the NO₂/NO converter, vol/vol

\([\text{NO}_2]\)  mean concentration of NO₂ in exhaust sample after cold trap, vol/vol

\([\text{NO}_2]\_d\)  mean concentration in exhaust sample after cold trap, vol/vol

\([\text{NO}_2]\_m\)  mean concentration measurement indicated before instrument correction applied, vol/vol

\( h \)  humidity of ambient air, vol water/vol dry air

\( h_d \)  humidity of exhaust sample leaving “drier” or “cold trap”, vol water/vol dry sample
2. BASIS OF CALCULATION OF EI AND AFR PARAMETERS

2.1 It is assumed that the balance between the original fuel and air mixture and the resultant state of the exhaust emissions as sampled can be represented by the following equation:

\[ \text{C}_m\text{H}_n + P_0[\text{O}_2] + S(\text{N}_2) + T(\text{CO}_2) + h(\text{H}_2\text{O})] \]

\[ = P_1(\text{CO}) + P_2(\text{N}_2) + P_3(\text{O}_2) + P_4(\text{H}_2\text{O}) \]

\[ + P_5(\text{CO}) + P_6(\text{C}_x\text{H}_y) + P_7(\text{NO}_2) + P_8(\text{NO}) \]

from which the required parameters can, by definition, be expressed as:

\[ \text{EI}(\text{CO}) = P_5 \left( \frac{10^3 M_{\text{CO}}}{mM_C + nM_H} \right) \]

\[ \text{EI}(\text{HC}) = xP_6 \left( \frac{10^3 M_{\text{HC}}}{mM_C + nM_H} \right) \text{ expressed as methane equivalent} \]

\[ \text{EI}(\text{NO}_2) = (P_7 + P_8) \left( \frac{10^3 M_{\text{NO}_2}}{mM_C + nM_H} \right) \text{ expressed as NO}_2 \text{ equivalent} \]

\[ \text{AFR} = P_0 \left( \frac{M_{\text{AIR}}}{mM_C + nM_H} \right) \]

2.2 Values for fuel hydrocarbon composition \((m, n)\) are assigned by fuel specification or analysis. If only the ratio \(n/m\) is so determined, the value \(m = 12\) may be assigned. The mole fractions of the dry air constituents \(R, S, T\) are normally taken to be the recommended standard values but alternative values may be assigned, subject to the restriction \(R + S + T = 1\) and the approval of the certificating authority.

2.3 The ambient air humidity, \(h\), is as measured at each test condition. It is recommended that, in the absence of contrary evidence as to the characterization \((x, y)\) of the exhaust hydrocarbon, values of \(x = 1\) and \(y = 4\) are assigned.

2.4 Determination of the remaining unknowns requires the solution of the following set of linear simultaneous equations, where (1) to (4) derive from the fundamental atomic conservation relationships and (5) to (9) represent the gaseous product concentration relationships.

\[ m + TP_0 = P_1 + P_5 + xP_6 \]  \(\ldots (1)\)

\[ n + 2hP_0 = 2P_4 + yP_6 \]  \(\ldots (2)\)

\[ (2R + 2T + h)P_0 \]

\[ = 2P_1 + 2P_3 + P_4 + P_5 + 2P_7 + P_8 \]  \(\ldots (3)\)

\[ 2SP_0 = 2P_2 + P_7 + P_8 \]  \(\ldots (4)\)

\[ [\text{CO}_2] P_T = P_1 \]  \(\ldots (5)\)

\[ [\text{CO}] P_T = P_3 \]  \(\ldots (6)\)

\[ [\text{HC}] P_T = xP_6 \]  \(\ldots (7)\)

\[ [\text{NO}_x] cP_T = \eta P_7 + P_8 \]  \(\ldots (8)\)

\[ [\text{NO}] P_T = P_8 \]  \(\ldots (9)\)

\[ P_T = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 \]  \(\ldots (10)\)

The above set of conditional equations is for the case where all measured concentrations are true ones, that is, not subject to interference effects or to the need to correct for sample drying. In practice, interference effects are usually present to a significant degree in the CO, NO\(_x\) and NO measurements, and the option to measure CO\(_2\) and CO on a dry or partially dry basis is often used. The necessary modifications to the relevant equations are described in 2.5 and 2.6.

2.5 The interference effects are mainly caused by the presence of CO\(_2\) and H\(_2\)O in the sample which can affect the basis is often used. The necessary modifications to the relevant analyser is prone to a zero-shifting effect and the NO\(_x\) analyser to a sensitivity change, represented thus:

\[ [\text{CO}] = [\text{CP}]_m + L[\text{CO}_2] + M[\text{H}_2\text{O}] \]

and

\[ [\text{NO}_x]_c = [\text{NO}_x]_c(1 + L[\text{CO}_2] + M'[\text{H}_2\text{O}]) \]
which transform into the following alternative equations to
(6), (8) and (9), when interference effects require to be
corrected,

\[
[\text{CO}]_{md} P_T + LP_1 + M'P_4 = P_5 \quad \ldots \quad (6A)
\]

\[
[\text{NO}_x]_{cm} (P_T + L'P_1 + M'P_4) = \eta P_7 + P_8 \quad \ldots \quad (8A)
\]

\[
[\text{NO}]_m (P_T + L'P_1 + M'P_4) = P_8 \quad \ldots \quad (9A)
\]

2.6 The option to measure CO2 and CO concentrations on
a dry or partially dry sample basis, that is, with a sample
humidity reduced to \( h_d \), requires the use of modified
conditional equations as follows:

\[
[\text{CO}_2]_{d} (P_T - P_4) (1 + h_d) = P_1 \quad \ldots \quad (5A)
\]

and

\[
[\text{CO}]_{d} (P_T - P_4) (1 + h_d) = P_5
\]

However, the CO analyser may also be subject to
interference effects as described in 2.5 above and so the
complete alternative CO measurement concentration equation
becomes

\[
[\text{CO}]_{md} (P_T - P_4) (1 + h_d)
\]

\[+ LP_1 + Mh_d (P_T - P_4) = P_5 \quad \ldots \quad (6B)
\]

3. ANALYTICAL FORMULATIONS

3.1 General

Equations (1) to (10) can be reduced to yield the analytical
formulations for the EI and AFR parameters, as given in 7.1 to
this appendix. This reduction is a process of progressive
elimination of the roots \( P_0, P_1 \) through \( P_8, P_T \), making the
assumptions that all concentration measurements are of the
"wet" sample and do not require interference corrections or the
like. In practice the option is often chosen to make the CO2
and CO concentration measurements on a "dry" or "semi-dry"
basis; also it is often found necessary to make interference
corrections. Formulations for use in these various
circumstances are given in 3.2, 3.3 and 3.4 below.

3.2 Equation for conversion of
dry concentration measurements
to wet basis

Concentration wet = \( K \times \) concentration dry; that is,

\[
[ \_ ] = K [ \_ ]_{d}
\]

The following expression for \( K \) applies when CO and CO2
are determined on a "dry" basis:

\[
K = \frac{4 + (n/m) T + (|n/m| T - 2h) ([NO_2] - (2[HC]/|x|))}{(2 + h) \left( 2 + (n/m) (1 + h_d) \left( [CO_2]_d + [CO]_d \right) \right)}
\]

\[+ (2 + h) \left( |x|/\eta - |n/m| \right) [HC] \right) \right) (1 + h_d)
\]

\[\left( |n/m| T - 2h \right) (1 - |x|/2) [CO]_d)
\]

3.3 Interference corrections

The measurements of CO and/or NO2 and NO may require
corrections for interference by the sample CO2 and water
concentrations before use in the above analytical equations.
Such corrections can normally be expressed in the following
general ways:

\[
[\text{CO}] = [\text{CO}]_m + L[\text{CO}_2] + M[H_2O]
\]

\[
[\text{CO}]_d = [\text{CO}]_{md} + L[\text{CO}_2]_d + M \left( \frac{h_d}{1 + h_d} \right)
\]

\[
[\text{NO}] = [\text{NO}]_m (1 + L'[\text{CO}_2] + M'[\text{H}_2O])
\]

\[\eta[\text{NO}_2] = ([\text{NO}_x]_{cm} - [\text{NO}]_m) (1 + L'[\text{CO}_2] + M'[\text{H}_2O])
\]

3.4 Equation for estimation of
sample water content

Water concentration in sample

\[
[H_2O] = \frac{\left( |n/2m| + h[P_0/m] \right) (\left[ \text{CO}_2 \right] + [\text{CO}] + [\text{HC}] \right)}{1 + T(P_0/m)} - (y/2x) \ [HC]
\]

where

\[
P_0/m = \frac{2Z - (n/m)}{4(1 + h - (2Z/2))}
\]

and

\[
Z = \frac{2 - \left[ \text{CO} \right] - \left( (2|x| - |y/2x|) [HC] + [\text{NO}_2] \right)}{\left[ \text{CO}_2 \right] + [\text{CO}] + [\text{HC}]}
\]

It should be noted that this estimate is a function of the
various analyses concentration readings, which may them-
selves require water interference correction. For better accuracy an iterative procedure is required in these cases with successive recalculation of the water concentration until the requisite stability is obtained. The use of the alternative, numerical solution methodology (4) avoids this difficulty.

4. ALTERNATIVE METHODOLOGY — NUMERICAL SOLUTION

4.1 As an alternative to the analytical procedures summarized in 3 above, it is possible to obtain readily the emissions indices, fuel/air ratio, corrected wet concentrations, etc., by a numerical solution of equations (1) to (10) for each set of measurements, using a digital computer.

4.2 In the equation set (1) to (10) the actual concentration measurements are substituted using whichever of the alternative equations (5A), (6A), etc. applies for the particular measuring system, to take account of interference corrections and/or dried sample measurements.

4.3 Suitable simple two-dimensional array equation-solving computer programmes are widely available and their use for this purpose is convenient and flexible, allowing ready incorporation and identification of any sample drying options and interference or other corrections.

ATTACHMENT F TO APPENDIX 5. SPECIFICATIONS FOR ADDITIONAL DATA

As required in 3.2 of Appendix 5, in addition to the measured sample constituent concentrations, the following data shall also be provided:

a) inlet temperature: measured as the total temperature at a point within one diameter of the engine intake plane to an accuracy of ±0.5°C;

b) inlet humidity (kg water/kg dry air): measured at a point within 15 m of the intake plane ahead of the engine to an accuracy of ±5 per cent of reading;

c) atmospheric pressure: measured within 1 km of the engine test location and corrected as necessary to the test stand altitude to an accuracy of ±100 Pa;

d) fuel mass flow: by direct measurement to an accuracy of ±2 per cent;

e) fuel H/C ratio: defined as \( \frac{n}{m} \), where \( C_mH_n \) is the equivalent hydrocarbon representation of the fuel used in the test and evaluated by reference to the engine fuel type analysis;

f) engine parameters:

1) thrust: by direct measurement to an accuracy of ±1 per cent at take-off power and ±5 per cent at the minimum thrust used in the certification test, with linear variation between these points;

2) rotation speed(s): by direct measurement to an accuracy of at least ±0.5 per cent;

3) gas generator airflow: determined to an accuracy of ±2 per cent by reference to engine performance calibration.

The parameters a), b), d) and f) shall be determined at each engine emissions test setting, while c) shall be determined at intervals of not less than 1 hour over a period encompassing that of the emissions tests.
APPENDIX 6. COMPLIANCE PROCEDURE FOR GASEOUS EMISSIONS AND SMOKE

1. GENERAL

The following general principles shall be followed for compliance with the regulatory levels set forth in Volume II, Part III, 2.2, 2.3, 3.2 and 3.3 of this Annex:

a) the manufacturer shall be allowed to select for certification testing any number of engines, including a single engine if so desired;

b) all the results obtained during the certification tests shall be taken into account by the certification authority;

c) a total of at least 3 engine tests shall be conducted, so that if a single engine is presented for certification it must be tested at least 3 times;

d) if a given engine is tested several times, the arithmetic mean value of the tests shall be considered to be the mean value for that engine. The certification result \( \bar{X} \) is then the mean of the values \( X_i \) obtained for each engine tested;

e) the manufacturer shall provide to the certificating authority, the information specified in Volume II, Part III, 2.4 or 3.4 of this Annex as appropriate;

f) the engines submitted for testing shall have emissions features representative of the engine type for which certification is sought. However, at least one of the engines shall be substantially configured to the production standard of the engine type and have fully representative operating and performance characteristics. One of these engines shall be declared to be the reference standard engine. The methods for correcting to this reference standard engine from any other engines tested shall have the approval of the national certificating authority. The methods for correcting test results for ambient effects shall be those outlined in 7 of Appendix 3 or 7 of Appendix 5, as applicable.

2. COMPLIANCE PROCEDURES

The certificating authority shall award a certificate of compliance if the mean of the values measured and corrected (to the reference standard engine and reference ambient conditions) for all the engines tested, when converted to a characteristic level using the appropriate factor which is determined by the number of engines tested \( i \) as shown in the table below, does not exceed the regulatory level.

Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions divided by the coefficient corresponding to the number of engines tested, as shown in the table below.

<table>
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<tr>
<th>Number of engines tested ( i )</th>
<th>( \text{CO} )</th>
<th>( \text{HC} )</th>
<th>( \text{NOx} )</th>
<th>( \text{SN} )</th>
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<td>0.6493</td>
<td>0.8627</td>
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<td>0.9467</td>
<td>0.8990</td>
<td>0.9605</td>
<td>0.9358</td>
</tr>
<tr>
<td>7</td>
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<td>0.9065</td>
<td>0.9634</td>
<td>0.9405</td>
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<tr>
<td>8</td>
<td>0.9538</td>
<td>0.9126</td>
<td>0.9658</td>
<td>0.9444</td>
</tr>
<tr>
<td>9</td>
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<td>0.9677</td>
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<td>10</td>
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<td>more than 10</td>
<td>( \frac{1 - 0.13059}{\sqrt{i}} )</td>
<td>( \frac{1 - 0.24724}{\sqrt{i}} )</td>
<td>( \frac{1 - 0.09678}{\sqrt{i}} )</td>
<td>( \frac{1 - 0.15736}{\sqrt{i}} )</td>
</tr>
</tbody>
</table>

3. PROCEDURE IN THE CASE OF FAILURE

Note.— When a certification test fails, it does not necessarily mean that the engine type does not comply with the requirements, but it may mean that the confidence given to the certificating authority in compliance is not sufficiently high, i.e. less than 90 per cent. Consequently, the manufacturer should be allowed to present additional evidence of engine type compliance.

3.1 If an engine type fails a certification test, the certificating authority shall permit the manufacturer, if he so wishes, to conduct additional tests on the certification engines. If the total results available still show that the engine type fails the certification requirements, the manufacturer shall be allowed to test as many additional engines as desired. The resulting test results shall then be considered with all previous data.
3.2 If the result is still failure, the manufacturer shall be allowed to select one or more engines for modification. The results of the tests already made on the selected engine(s) while unmodified shall be inspected, and further testing shall be done so that at least three tests are available. The mean of these tests shall be determined for each engine and described as the “unmodified mean”.

3.3 The engine(s) may then be modified, and at least three tests shall be conducted on the modified engine(s), the mean of which shall be described as the “modified mean” in each case. This “modified mean” shall be compared to the “unmodified mean” to give a proportional improvement which shall then be applied to the previous certification test result to determine if compliance has been achieved. It shall be determined before testing of any modified engine is begun that the modification(s) comply with the appropriate airworthiness requirements.

3.4 This procedure shall be repeated until compliance has been demonstrated or the engine type application is withdrawn.
SUPPLEMENT TO

ANNEX 16 — ENVIRONMENTAL PROTECTION

VOLUME II —
AIRCRAFT ENGINE EMISSIONS

(Second Edition)

1. The attached Supplement supersedes all previous Supplements to Annex 16, Volume II and includes differences notified by Contracting States up to 31 December 1994.

2. This Supplement should be inserted at the end of Annex 16, Volume II, Second Edition. Additional differences received from Contracting States will be issued at intervals as amendments to this Supplement.
SUPPLEMENT TO ANNEX 16 —
ENVIRONMENTAL PROTECTION

Volume II — Aircraft Engine Emissions

Second Edition

Differences between the national regulations and practices of Contracting States and the corresponding International Standards and Recommended Practices contained in Annex 16, Volume II as notified to ICAO in accordance with Article 38 of the Convention on International Civil Aviation and the Council’s resolution of 21 November 1950.

DECEMBER 1994

INTERNATIONAL CIVIL AVIATION ORGANIZATION
RECORD OF AMENDMENTS TO SUPPLEMENT

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AMENDMENTS TO ANNEX 16, VOLUME II ADOPTED OR APPROVED BY THE COUNCIL SUBSEQUENT TO THE SECOND EDITION ISSUED JULY 1993

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1. Contracting States which have notified ICAO of differences

The Contracting States listed below have notified ICAO of differences which exist between their national regulations and practices and the International Standards of Annex 16, Volume II, Second Edition, or have commented on implementation.

The page numbers shown for each State and the dates of publication of those pages correspond to the actual pages in this Supplement.

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4. Paragraphs with respect to which differences have been notified

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**Chapter 2**

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**Chapter 3**

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Chapter 2

General The new engines certificated in France meet the emission conditions specified by Chapters 2 and 3 of Annex 16, Volume II. To date, France still does not issue an emission certificate and does not make an explicit reference to these technical specifications in its regulations.

Chapter 3

General The new engines certificated in France meet the emission conditions specified by Chapters 2 and 3 of Annex 16, Volume II. To date, France still does not issue an emission certificate and does not make an explicit reference to these technical specifications in its regulations.
**General**

Engine emission standards are not applicable. The Ministry of the Environment is responsible for setting emission standards. Discussions between the Ministry of Transport and the Ministry of the Environment on rulemaking have commenced.
General

New Zealand does not certificate aircraft with respect to the prevention of intentional fuel venting. New Zealand does not itself carry out aircraft engine emission certification.
General

No regulations for aircraft engine emissions exist currently in the State of Qatar and no specific date can be given at present regarding incorporation of the ICAO provisions in the national regulations.
General

Work is presently under way in the Russian Federation on the preparation of new national standards (aviation regulations) for local aircraft noise which take into account the provisions of Annex 16, Volume II, including Amendment 2. It is intended to put these regulations into effect within the next six months, after which the Russian Federation will submit the required notification of differences.
General Standards for control of aircraft engine emissions have not yet been established for the Kingdom of Saudi Arabia.
General

While we do not disapprove of any of the amendments, we are not in a position to make a statement that differences will or will not exist on a certain date between the Vanuatu regulations and the Provisions of Annex 16, Volume I.

The Vanuatu Civil Aviation Directorate has been restructured and it is planned that as a result of this restructuring the necessary expertise will be available in approximately 12 months to commence a rewrite of the Vanuatu Civil Aviation Regulations. The rewrite will attempt to harmonize our regulations for the application of ICAO Standards with other States in the region.

As each part of our regulations is rewritten, we will advise you of any difference that may exist between our national rules and ICAO Standards.