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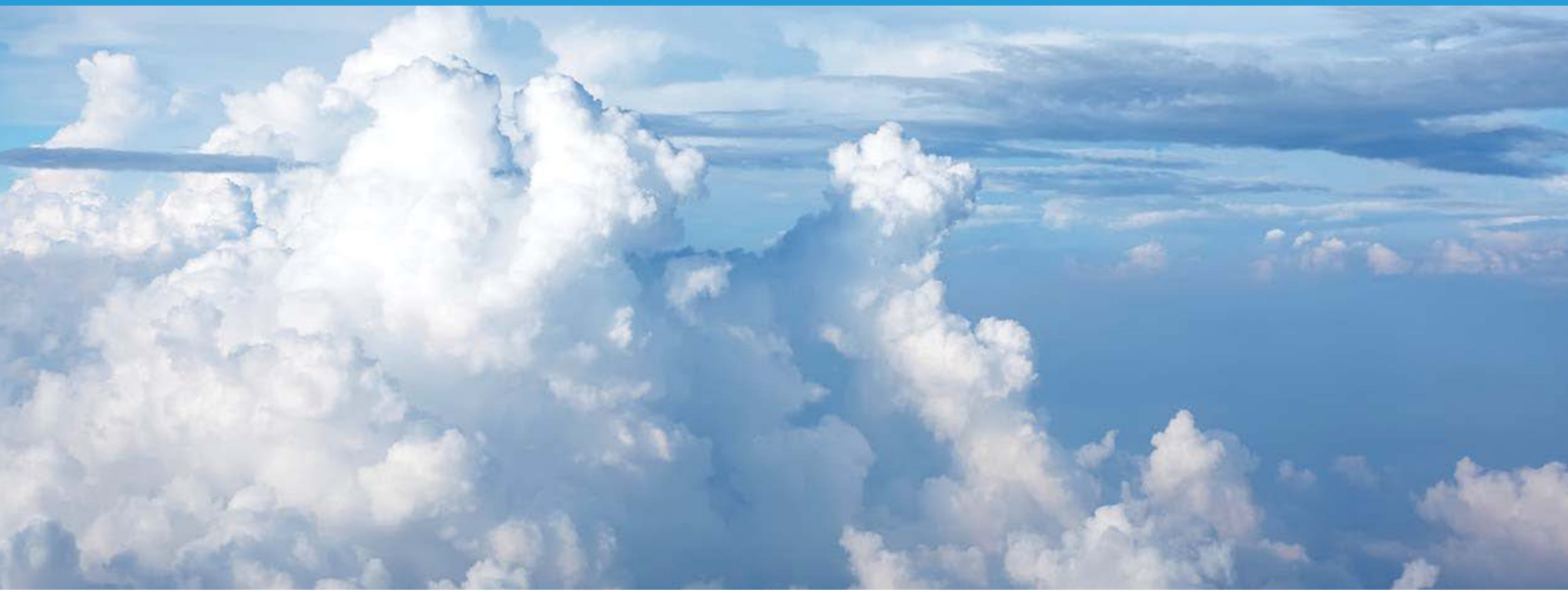
International Standards
and Recommended Practices

Annex 16 to the Convention on International Civil Aviation

Environmental Protection

Volume III — Aeroplane CO_2 Emissions

First Edition, July 2017



The first edition of Annex 16, Volume III, becomes applicable on 1 January 2018.

For information regarding the applicability of the Standards and Recommended Practices, see Foreword.

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS			
No.	Date applicable	Date entered	Entered by

CORRIGENDA			
No.	Date of issue	Date entered	Entered by

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FOREWORD

Historical background

Standards and Recommended Practices for Environmental Protection 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. This Volume III to Annex 16 was developed in the following manner:

At the 36th Session of the ICAO Assembly in 2007, Contracting States adopted Assembly Resolution A36-22, *Consolidated statement of continuing ICAO policies and practices related to environmental protection.* This resolution provided for the establishment of a process which led to the development and recommendation to the Council a Programme of Action on International Aviation and Climate Change and a common strategy to limit or reduce greenhouse gas emissions attributable to international civil aviation.

The development of an aeroplane CO_2 Standard as part of the range of measures for addressing greenhouse gas emissions from international aviation was one of the recommended elements within the ICAO Programme of Action on International Aviation and Climate Change. This was subsequently endorsed by the ICAO High-level Meeting on International Aviation and Climate Change in October 2009.

In line with the ICAO Programme of Action, the Eighth Meeting of the Committee on Aviation Environmental Protection (CAEP/8) in February 2010 agreed to develop International Standards and Recommended Practices for Aeroplane CO_2 Emissions. This was approved by the ICAO Council in May 2010. Subsequently, the 37th Session of the ICAO Assembly in 2010 adopted resolutions A37-18 and A37-19, requesting that the Council develop a global CO_2 Standard for aircraft. The CAEP developed draft International Standards and Recommended Practices for Aeroplane CO_2 Emissions and, after amendment following the usual consultation with the Contracting States of the Organization, Annex 16, Volume III, was adopted by the Council.

Table A shows the origin of amendments to the Annex over time 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 III of Annex 16 contains definitions and symbols. Part II contains Standards and Recommended Practices for certification of aeroplane CO_2 emissions based on the consumption of fuel applicable to the classification of aeroplanes specified in Part II of Volume III of Annex 16, where such aeroplanes are engaged in international air navigation.

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.

e) *Tables and Figures* which add to or illustrate a Standard or Recommended Practice and which are referred to therein, form part of the associated Standard or Recommended Practice and have the same status.

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 six languages — English, Arabic, Chinese, 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.

Table A. Amendments to Annex 16

Amendment	*Source(s)*	*Subject(s)*	*Adopted* *Effective* *Applicable*
1st Edition	Tenth meeting of the Committee on Aviation Environmental Protection (CAEP/10)	Introduction of Annex 16, Volume III, containing Standards and Recommended Practices relating to the CO_2 emissions certification for subsonic aeroplanes.	3 March 2017 21 July 2017 1 January 2018

INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. 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.

Cockpit crew zone. The part of the cabin that is exclusively designated for flight crew use.

Derived version of a CO_2-certified aeroplane. An aeroplane which incorporates changes in type design that either increase its maximum take-off mass, or that increase its CO_2 emissions evaluation metric value by more than:

a) 1.35 per cent at a maximum take-off mass of 5 700 kg, decreasing linearly to;

b) 0.75 per cent at a maximum take-off mass of 60 000 kg, decreasing linearly to;

c) 0.70 per cent at a maximum take-off mass of 600 000 kg; and

d) a constant 0.70 per cent at maximum take-off masses greater than 600 000 kg.

Note.— 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 aeroplane will be considered to be a new type design rather than a derived version.

Derived version of a non-CO_2-certified aeroplane. An individual aeroplane that conforms to an existing Type Certificate, but which is not certified to Annex 16, Volume III, and to which changes in type design are made prior to the issuance of the aeroplane's first certificate of airworthiness that increase its CO_2 emissions evaluation metric value by more than 1.5 per cent or are considered to be significant CO_2 changes.

Equivalent procedure. A test or analysis procedure which, while differing from the one specified in this volume of Annex 16, in the technical judgement of the certificating authority yields effectively the same CO_2 emissions evaluation metric value as the specified procedure.

Maximum passenger seating capacity. The maximum certificated number of passengers for the aeroplane type design.

Maximum take-off mass. The highest of all take-off masses for the type design configuration.

Optimum conditions. The combinations of altitude and airspeed within the approved operating envelope defined in the aeroplane flight manual that provides the highest specific air range value at each reference aeroplane mass.

Performance model. An analytical tool or method validated from corrected flight test data that can be used to determine the SAR values for calculating the CO_2 emissions evaluation metric value at the reference conditions.

Reference geometric factor. An adjustment factor based on a measurement of aeroplane fuselage size derived from a two-dimensional projection of the fuselage.

Specific air range. The distance an aeroplane travels in the cruise flight phase per unit of fuel consumed.

State of Design. The State having jurisdiction over the organization responsible for the type design.

Subsonic aeroplane. An aeroplane incapable of sustaining level flight at speeds exceeding a Mach number of 1.

Type Certificate. A document issued by a Contracting State to define the design of an aircraft, engine or propeller type and to certify that this design meets the appropriate airworthiness requirements of that State.

Note.— In some Contracting States a document equivalent to a Type Certificate may be issued for an engine or propeller type.

CHAPTER 2. SYMBOLS

Where the following symbols are used in Volume III of this Annex, they have the meanings, and where applicable the units, ascribed to them below:

AVG	Average
CG	Centre of gravity
CO_2	Carbon dioxide
g_0	Standard acceleration due to gravity at sea level and a geodetic latitude of 45.5 degrees, 9.80665 (m/s^2)
Hz	Hertz (cycle per second)
MTOM	Maximum take-off mass (kg)
OML	Outer mould line
RGF	Reference geometric factor
RSS	Root sum of squares
SAR	Specific air range (km/kg)
TAS	True airspeed (km/h)
W_f	Total aeroplane fuel flow (kg/h)
δ	Ratio of atmospheric pressure at a given altitude to the atmospheric pressure at sea level

PART II. CERTIFICATION STANDARD FOR AEROPLANE CO_2 EMISSIONS BASED ON THE CONSUMPTION OF FUEL

CHAPTER 1. ADMINISTRATION

1.1 The provisions of 1.2 to 1.11 shall apply to all aeroplanes included in the classifications defined for CO_2 emissions certification purposes in Chapter 2 of this part where such aeroplanes are engaged in international air navigation.

1.2 CO_2 emissions certification shall be granted or validated by the State of Registry of an aeroplane on the basis of satisfactory evidence that the aeroplane complies with requirements that are at least equal to the applicable Standards specified in this Annex.

1.3 Contracting States shall recognize as valid a CO_2 emissions 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.

1.4 The amendment of this volume of the Annex to be used by a Contracting State shall be that which is applicable on the date of submission to that Contracting State for either a Type Certificate in the case of a new type, approval of a change in type design in the case of a derived version, or under equivalent application procedures prescribed by the certificating authority of that Contracting State.

Note.— As each new edition and amendment of this Annex becomes applicable (according to Table A of the Foreword), it supersedes all previous editions and amendments.

1.5 Unless otherwise specified in this volume of the Annex, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date the application for a Type Certificate was submitted to the State of Design, or the date of submission under an equivalent application procedure prescribed by the certificating authority of the State of Design.

1.6 An application shall be effective for the period specified in the airworthiness regulations appropriate to the aeroplane type, except in special cases where the certificating authority grants an extension. When the period of effectivity is extended, the date to be used in determining the applicability of the Standards in this Annex shall be the date of issue of the Type Certificate, or approval of the change in type design, or the date of issue of approval under an equivalent procedure prescribed by the State of Design, less the period of effectivity.

1.7 For derived versions of non-CO_2-certified aeroplanes and derived versions of CO_2-certified aeroplanes, the applicability provisions concerning the Standards of this Annex refer to the date on which "the application for the certification of the change in type design" was made. The date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date on which the application for the change in type design was submitted to the Contracting State that first certified the change in type design.

1.8 Where the provisions governing the applicability of the Standards of this Annex refer to the date on which the certificate of airworthiness was first issued to an individual aeroplane, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date on which the first certificate of airworthiness was issued by any Contracting State.

1.9 The certificating authority shall publish the certified CO_2 emissions evaluation metric value granted or validated by that authority.

1.10 The use of equivalent procedures in lieu of the procedures specified in the appendices of this volume of Annex 16 shall be approved by the certificating authority.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual *(Doc 9501), Volume III —* Procedures for the CO_2 Emissions Certification of Aeroplanes.

1.11 Contracting States shall recognize valid aeroplane exemptions granted by an authority of another Contracting State responsible for production of the aeroplane provided that an acceptable process was used.

Note.— Guidance on acceptable processes and criteria for granting exemptions is provided in the Environmental Technical Manual *(Doc 9501), Volume III —* Procedures for the CO_2 Emissions Certification of Aeroplanes.

CHAPTER 2.

1.— SUBSONIC JET AEROPLANES OVER 5 700 kg

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg

2.1 Applicability

Note.— See also Chapter 1, 1.4, 1.5, 1.6, 1.7, 1.8 and 1.11.

2.1.1 The Standards of this chapter shall, with the exception of amphibious aeroplanes, aeroplanes initially designed or modified and used for specialized operational requirements, aeroplanes designed with zero reference geometric factor (RGF), and those aeroplanes specifically designed or modified and used for fire-fighting purposes, be applicable to:

a) subsonic jet aeroplanes, including their derived versions, of greater than 5 700 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020, except for those aeroplanes of less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less;

b) subsonic jet aeroplanes, including their derived versions, of greater than 5 700 kg and less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less, for which the application for a type certificate was submitted on or after 1 January 2023;

c) all propeller-driven aeroplanes, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;

d) derived versions of non-CO_2-certified subsonic jet aeroplanes of greater than 5 700 kg maximum certificated take-off mass, for which the application for certification of the change in type design was submitted on or after 1 January 2023;

e) derived versions of non-CO_2 certified propeller-driven aeroplanes of greater than 8 618 kg maximum certificated take-off mass, for which the application for certification of the change in type design was submitted on or after 1 January 2023;

f) individual non-CO_2-certified subsonic jet aeroplanes of greater than 5 700 kg maximum certificated take-off mass, for which a certificate of airworthiness was first issued on or after 1 January 2028; and

g) individual non-CO_2-certified propeller-driven aeroplanes of greater than 8 618 kg maximum certificated take-off mass, for which a certificate of airworthiness was first issued on or after 1 January 2028.

Note.— Aeroplanes initially designed or modified and used for specialized operational requirements refer to aeroplane type configurations which, in the view of the certificating authority, have different design characteristics to meet specific operational needs compared to typical civil aeroplane types covered by the scope of this volume of Annex 16, and which may result in a very different CO_2 emissions evaluation metric value.

2.1.2 Notwithstanding 2.1.1, it may be recognized by a Contracting State that aeroplanes on its registry do not require demonstration of compliance with the provisions of the Standards of Annex 16, Volume III, for time-limited engine changes. These changes in type design shall specify that the aeroplane may not be operated for a period of more than 90 days, unless compliance with the provisions of Annex 16, Volume III, is shown for that change in type design. This applies only to changes resulting from a required maintenance action.

2.1.3 The granting of an exemption for an aeroplane against applicability requirements specified in 2.1.1 shall be noted on the aeroplane statement of conformity issued by the certificating authority. Certificating authorities shall take into account the numbers of exempted aeroplanes that will be produced and their impact on the environment. Exemptions shall be reported by aeroplane serial number and made available via an official public register.

Note.— Further guidance on issuing exemptions is provided in the Environmental Technical Manual *(Doc 9501), Volume III* — Procedures for the CO_2 Emissions Certification of Aeroplanes.

2.2 CO_2 emissions evaluation metric

The metric shall be defined in terms of the average of the 1/SAR values for the three reference masses defined in 2.3 and the RGF defined in Appendix 2. The metric value shall be calculated according to the following formula:

$$CO_2 \text{ emissions evaluation metric value} = \frac{\left(1/\text{SAR}\right)_{\text{AVG}}}{\left(\text{RGF}\right)^{0.24}}$$

Note 1.— The metric value is quantified in units of kg/km.

Note 2.— The CO_2 emissions evaluation metric is a specific air range (SAR)-based metric adjusted to take into account fuselage size.

2.3 Reference aeroplane masses

2.3.1 The 1/SAR value shall be established at each of the following three reference aeroplane masses, when tested in accordance with these Standards:

a) high gross mass: 92 per cent maximum take-off mass (MTOM)

b) mid gross mass: simple arithmetic average of high gross mass and low gross mass

c) low gross mass: $(0.45 \times \text{MTOM}) + (0.63 \times (\text{MTOM}^{0.924}))$

Note.— MTOM is expressed in kilograms.

2.3.2 CO_2 emissions certification for MTOM also represents the certification of CO_2 emissions for take-off masses less than MTOM. However, in addition to the mandatory certification of CO_2 metric values for MTOM, applicants may voluntarily apply for the approval of CO_2 metric values for take-off masses less than MTOM.

2.4 Maximum permitted CO_2 emissions evaluation metric value

2.4.1 The CO_2 emissions evaluation metric value shall be determined in accordance with the evaluation methods described in Appendix 1.

2.4.2 The CO_2 emissions evaluation metric value shall not exceed the value defined in the following paragraphs:

a) for aeroplanes specified in 2.1.1 a), b) and c) with a maximum take-off mass less than or equal to 60 000 kg:

Maximum permitted value = $10^{(-2.73780 + (0.681310 * \log_{10}(MTOM)) + (-0.0277861 * (\log_{10}(MTOM))^2))}$

b) for aeroplanes specified in 2.1.1 a) and c) with a maximum take-off mass greater than 60 000 kg, and less than or equal to 70 395 kg:

Maximum permitted value = 0.764

c) for aeroplanes specified in 2.1.1 a) and c) with a maximum take-off mass greater than 70 395 kg:

Maximum permitted value = $10^{(-1.412742 + (-0.020517 * \log_{10}(MTOM)) + (0.0593831 * (\log_{10}(MTOM))^2))}$

d) for aeroplanes specified in 2.1.1 d), e), f) and g) with a maximum certificated take-off mass less than or equal to 60 000 kg:

Maximum permitted value = $10^{(-2.57535 + (0.609766 * \log_{10}(MTOM)) + (-0.0191302 * (\log_{10}(MTOM))^2))}$

e) for aeroplanes specified in 2.1.1 d), e), f) and g) with a maximum certificated take-off mass greater than 60 000 kg, and less than or equal to 70 107 kg:

Maximum permitted value = 0.797

f) for aeroplanes specified in 2.1.1 d), e), f) and g) with a maximum take-off mass greater than 70 107 kg:

Maximum permitted value = $10^{(-1.39353 + (-0.020517 * \log_{10}(MTOM)) + (0.0593831 * (\log_{10}(MTOM))^2))}$

2.5 Reference conditions for determining aeroplane specific air range

2.5.1 The reference conditions shall consist of the following conditions within the approved normal operating envelope of the aeroplane:

a) the aeroplane gross masses defined in 2.3;

b) a combination of altitude and airspeed selected by the applicant for each of the specified reference aeroplane gross masses;

Note.— These conditions are generally expected to be the combination of altitude and airspeed that results in the highest SAR value, which is usually at the maximum range cruise Mach number at the optimum altitude. The selection of conditions other than optimum conditions will be to the detriment of the applicant because the SAR value will be adversely affected.

c) steady (unaccelerated), straight and level flight;

d) aeroplane in longitudinal and lateral trim;

e) ICAO standard day atmosphere[1];

f) gravitational acceleration for the aeroplane travelling in the direction of true North in still air at the reference altitude and a geodetic latitude of 45.5 degrees, based on g_0;

g) fuel lower heating value equal to 43.217 MJ/kg (18 580 BTU/lb);

h) a reference aeroplane centre of gravity (CG) position selected by the applicant to be representative of a mid-CG point relevant to design cruise performance at each of the three reference aeroplane masses;

Note.— For an aeroplane equipped with a longitudinal CG control system, the reference CG position may be selected to take advantage of this feature.

i) a wing structural loading condition selected by the applicant for representative operations conducted in accordance with the aeroplane's payload capability and manufacturer standard fuel management practices;

j) applicant selected electrical and mechanical power extraction and bleed flow relevant to design cruise performance and in accordance with manufacturer recommended procedures;

Note.— Power extraction and bleed flow due to the use of optional equipment such as passenger entertainment systems need not be included.

k) engine handling/stability bleeds operating according to the nominal design of the engine performance model for the specified conditions; and

l) engine deterioration level selected by the applicant to be representative of the initial deterioration level (a minimum of 15 take-offs or 50 engine flight hours).

2.5.2 If the test conditions are not the same as the reference conditions, then corrections for the differences between test and reference conditions shall be applied as described in Appendix 1.

2.6 Test procedures

2.6.1 The SAR values that form the basis of the CO_2 emissions evaluation metric value shall be established either directly from flight tests or from a performance model validated by flight tests.

2.6.2 The test aeroplane shall be representative of the configuration for which certification is requested.

1 Doc 7488/3 entitled *Manual of the ICAO Standard Atmosphere (extended to 80 kilometres (262 500 feet))*.

2.6.3 The test and analysis procedures shall be conducted in an approved manner to yield the CO_2 emissions evaluation metric value as described in Appendix 1. These procedures shall address the entire flight test and data analysis process, from pre-flight actions to post-flight data analysis.

Note.— The fuel used for each flight test should meet the specification defined in either ASTM D1655-15[2]*, DEF STAN 91-91 Issue 7, Amendment 3*[3]*, or equivalent.*

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2 ASTM D1655-15 entitled *Standard Specification for Aviation Turbine Fuels*.

3 Defence Standard 91-91, Issue 7, Amendment 3, entitled *Turbine Fuel, Kerosene Type, Jet A-1*.

APPENDIX 1. DETERMINATION OF THE AEROPLANE CO_2 EMISSIONS EVALUATION METRIC VALUE

1.— SUBSONIC JET AEROPLANES OVER 5 700 kg

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg

1. INTRODUCTION

The process for determining the CO_2 emissions evaluation metric value includes:

a) determination of RGF (see Appendix 2);

b) determination of the certification test and measurement conditions and procedures for the determination of SAR (see Section 3), either by direct flight test or by way of a validated performance model, including:

   1) measurement of parameters needed to determine SAR (see Section 4);

   2) correction of measured data to reference conditions for SAR (see Section 5); and

   3) validation of data for calculation of the certified CO_2 emissions evaluation metric value (see Section 6);

c) calculation of the CO_2 emissions evaluation metric value (see Section 7); and

d) reporting of data to the certificating authority (see Section 8).

Note.— The instructions and procedures ensure uniformity of compliance tests, and permit comparison between various types of aeroplanes.

2. METHODS FOR DETERMINING SPECIFIC AIR RANGE

2.1 SAR may be determined by either direct flight test measurement of SAR test points, including any corrections of test data to reference conditions, or by the use of a performance model approved by the certificating authority. A performance model, if used, shall be validated by actual SAR flight test data.

2.2 In either case, the SAR flight test data shall be acquired in accordance with the procedures defined in this Standard and approved by the certificating authority.

2.3 **Recommendation.—** *Validation of the performance model should only need to be shown for the test points and conditions relevant to showing compliance with the Standard. Test and analysis methods, including any algorithms that may be used, should be described in sufficient detail.*

3. SPECIFIC AIR RANGE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

3.1 General

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

Note.— Many applications for certification of a CO_2 emissions metric value involve only minor changes to the aeroplane type design. The resultant changes in the CO_2 emissions metric value can often be established reliably by way of equivalent procedures without the necessity of resorting to a complete test.

3.2 Flight test procedure

3.2.1 Pre-flight

The pre-flight procedure shall be approved by the certificating authority and shall include the following elements:

a) ***Aeroplane conformity***. The test aeroplane shall be confirmed to be in conformance with the type design configuration for which certification is sought.

b) ***Aeroplane weighing***. The test aeroplane shall be weighed. Any change in mass after the weighing and prior to the test flight shall be accounted for.

c) ***Fuel lower heating value***. A sample of fuel shall be taken for each flight test to determine its lower heating value. Fuel sample test results shall be used for the correction of measured data to reference conditions. The determination of lower heating value and the correction to reference conditions shall be subject to the approval of the certificating authority.

   1) **Recommendation.—** *The fuel lower heating value should be determined in accordance with methods which are at least as stringent as those defined in ASTM specification D4809-13*[1].

   2) **Recommendation.—** *The fuel sample should be representative of the fuel used for each flight test and should not be subject to errors or variations due to fuel being uplifted from multiple sources, fuel tank selection or fuel layering in a tank.*

d) ***Fuel specific gravity and viscosity***. A sample of fuel shall be taken for each flight test to determine its specific gravity and viscosity when volumetric fuel flow meters are used.

   Note.— When using volumetric fuel flow meters, the fuel viscosity is used to determine the volumetric fuel flow from the parameters measured by a volumetric fuel flow meter. The fuel specific gravity (or density) is used to convert the volumetric fuel flow to a mass fuel flow.

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[1] ASTM D4809-13 entitled *Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)*.

1) **Recommendation.—** *The fuel specific gravity should be determined in accordance with methods which are at least as stringent as those defined in ASTM specification D4052-11*[2].

2) **Recommendation.—** *The fuel kinematic viscosity should be determined in accordance with methods which are at least as stringent as those defined in ASTM specification D445-15*[3].

3.2.2 Flight test method

3.2.2.1 The flight tests shall be performed in accordance with the following flight test method and the stability conditions described in 3.2.3.

3.2.2.2 Test points shall be separated by a minimum duration of two minutes, or separated by an exceedance of one or more of the stability criteria limits described in 3.2.3.1.

3.2.2.3 **Recommendation.—** *During the test conditions flown to determine SAR, the following criteria should be adhered to:*

a) the aeroplane is flown at constant pressure altitude and constant heading along isobars to the extent that is practicable;

b) the engine thrust/power setting is stable for unaccelerated level flight;

c) the aeroplane is flown as close as practicable to the reference conditions to minimize the magnitude of any corrections;

d) there are no changes in trim or engine power/thrust settings, engine stability and handling bleeds, and electrical and mechanical power extraction (including bleed flow). Any changes in the use of aeroplane systems that may affect the SAR measurement should be avoided; and

e) movement of on-board personnel is kept to a minimum.

3.2.3 Test condition stability

3.2.3.1 For a SAR measurement to be valid, the following parameters shall be maintained within the indicated tolerances for a minimum duration of 1 minute during which the SAR data is acquired:

a) Mach number within ±0.005;

b) ambient temperature within ±1°C;

c) heading within ±3 degrees;

d) track within ±3 degrees;

e) drift angle less than 3 degrees;

f) ground speed within ±3.7 km/h (±2 kt);

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2 ASTM D4052-11 entitled *Standard Test Method for Density and Relative Density of Liquids by Digital Density Meter*.
3 ASTM D445-15 entitled *Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)*.

g) difference in ground speed at the beginning of the test condition from the ground speed at the end of the test condition within ±2.8 km/h/min (±1.5 kt/min); and

h) pressure altitude within ±23 m (±75 ft).

3.2.3.2 Alternatives to the stable test condition criteria listed above may be used provided that stability can be sufficiently demonstrated to the certificating authority.

3.2.3.3 Test points that do not meet the stable test criteria defined in 3.2.3.1 should normally be discarded. However, test points that do not meet the stability criteria listed in 3.2.3.1 may be acceptable subject to the approval of the certificating authority, and would be considered as an equivalent procedure.

3.2.4 Verification of aeroplane mass at test conditions

3.2.4.1 The procedure for determining the mass of the aeroplane at each test condition shall be subject to the approval of the certificating authority.

3.2.4.2 **Recommendation.—** *The mass of the aeroplane during a flight test should be determined by subtracting the fuel used (i.e. integrated fuel flow) from the mass of the aeroplane at the start of the test flight. The accuracy of the determination of the fuel used should be verified by weighing the test aeroplane on calibrated scales either before and after the SAR test flight, or before and after another test flight with a cruise segment provided that flight occurs within one week or 50 flight hours (at the option of the applicant) of the SAR test flight and with the same, unaltered fuel flow meters.*

4. MEASUREMENT OF AEROPLANE SPECIFIC AIR RANGE

4.1 Measurement system

4.1.1 The following parameters shall be recorded at a minimum sampling rate of 1 Hz:

a) airspeed;

b) ground speed;

c) true airspeed;

d) fuel flow;

e) engine power setting parameter (e.g. fan speed, engine pressure ratio, torque, shaft horse power);

f) pressure altitude;

g) temperature;

h) heading;

i) track; and

j) fuel used (for the determination of gross mass and CG position).

4.1.2 The following parameters shall be recorded at a suitable sampling rate:

a) latitude;

b) engine bleed positions and power off-takes; and

c) power extraction (electrical and mechanical load).

4.1.3 The value of each parameter used for the determination of SAR, except for ground speed, shall be the simple arithmetic average of the measured values for that parameter obtained throughout the stable test condition (see 3.2.3.1).

Note.— The rate of change of ground speed during the test condition is to be used to evaluate and correct any acceleration or deceleration that might occur during the test condition.

4.1.4 The resolution of the individual measurement devices shall be sufficient to determine that the stability of the parameters defined in 3.2.3.1 is maintained.

4.1.5 The overall SAR measurement system is considered to be the combination of instruments and devices, including any associated procedures, used to acquire the following parameters necessary for the determination of SAR:

a) fuel flow;

b) Mach number;

c) altitude;

d) aeroplane mass;

e) ground speed;

f) outside air temperature;

g) fuel lower heating value; and

h) CG.

4.1.6 The accuracy of the individual elements that comprise the overall SAR measurement system is defined in terms of its effect upon SAR. The cumulative error associated with the overall SAR measurement system is defined as the root sum of squares (RSS) of the individual accuracies.

Note.— Parameter accuracy need only be examined within the range of the parameter needed for showing compliance with the CO_2 emissions Standard.

4.1.7 If the absolute value of the cumulative error of the overall SAR measurement system is greater than 1.5 per cent, a penalty equal to the amount that the RSS value exceeds 1.5 per cent shall be applied to the SAR value corrected to reference conditions (see Section 5). If the absolute value of the cumulative error of the overall SAR measurement system is less than or equal to 1.5 per cent, no penalty shall be applied.

5. CALCULATION OF REFERENCE SPECIFIC AIR RANGE FROM MEASURED DATA

5.1 Calculation of SAR

SAR is calculated from the following equation:

$$SAR = TAS/W_f$$

where:

TAS is the true airspeed; and

W_f is total aeroplane fuel flow.

5.2 Corrections from test to reference conditions

5.2.1 Corrections shall be applied to the measured SAR values to correct to the reference conditions specified in 2.5 of Part II, Chapter 2. Corrections shall be applied for each of the following measured parameters that are not at the reference conditions:

Acceleration/deceleration (energy). Drag determination is based on an assumption of steady, unaccelerated flight. Acceleration or deceleration occurring during a test condition affects the assessed drag level. The reference condition is steady, unaccelerated flight.

Aeroelastics. Wing aeroelasticity may cause a variation in drag as a function of aeroplane wing mass distribution. Aeroplane wing mass distribution will be affected by the fuel load distribution in the wings and the presence of any external stores.

Altitude. The altitude at which the aeroplane is flown affects the fuel flow.

Apparent gravity. Acceleration, caused by the local effect of gravity, and inertia, affect the test weight of the aeroplane. The apparent gravity at the test conditions varies with latitude, altitude, ground speed, and direction of motion relative to the Earth's axis. The reference gravitational acceleration is the gravitational acceleration for the aeroplane travelling in the direction of true North in still air at the reference altitude, a geodetic latitude of 45.5 degrees, and based on g_0.

CG position. The position of the aeroplane CG affects the drag due to longitudinal trim.

Electrical and mechanical power extraction and bleed flow. Electrical and mechanical power extraction, and bleed flow affect the fuel flow.

Engine deterioration level. When first used, engines undergo a rapid, initial deterioration in fuel efficiency. Thereafter, the rate of deterioration significantly decreases. Engines with less deterioration than the reference engine deterioration level may be used, subject to the approval of the certificating authority. In such a case, the fuel flow shall be corrected to the reference engine deterioration level using an approved method. Engines with more deterioration than the reference engine deterioration level may be used. In this case, a correction to the reference condition shall not be permitted.

Fuel lower heating value. The fuel lower heating value defines the energy content of the fuel. The lower heating value directly affects the fuel flow at a given test condition.

Mass/δ. The lift coefficient of the aeroplane is a function of mass/δ and Mach number, where δ is the ratio of the atmospheric pressure at a given altitude to the atmospheric pressure at sea level. The lift coefficient for the test condition affects the drag of the aeroplane. The reference mass/δ is derived from the combination of the reference mass, reference altitude and atmospheric pressures determined from the ICAO standard atmosphere.

Reynolds number. The Reynolds number affects aeroplane drag. For a given test condition the Reynolds number is a function of the density and viscosity of air at the test altitude and temperature. The reference Reynolds number is derived from the density and viscosity of air from the ICAO standard atmosphere at the reference altitude and temperature.

Temperature. The ambient temperature affects the fuel flow. The reference temperature is the standard day temperature from the ICAO standard atmosphere at the reference altitude.

Note.— Post-flight data analysis includes the correction of measured data for data acquisition hardware response characteristics (e.g. system latency, lag, offset, buffering, etc.).

5.2.2 Correction methods are subject to the approval of the certificating authority. If the applicant considers that a particular correction is unnecessary, then acceptable justification shall be provided to the certificating authority.

5.3 Calculation of specific air range

The SAR values for each of the three reference masses defined in 2.3 of Part II, Chapter 2, shall be calculated either directly from the measurements taken at each valid test point adjusted to reference conditions, or indirectly from a performance model that has been validated by the test points. The final SAR value for each reference mass shall be the simple arithmetic average of all valid test points at the appropriate gross mass, or derived from a validated performance model. No data acquired from a valid test point shall be omitted unless agreed by the certificating authority.

Note.— Extrapolations consistent with accepted airworthiness practices to masses other than those tested may be allowable using a validated performance model. The performance model should be based on data covering an adequate range of lift coefficient, Mach number, and thrust specific fuel consumption such that there is no extrapolation of these parameters.

6. VALIDITY OF RESULTS

6.1 The 90 per cent confidence interval shall be calculated for each of the SAR values at the three reference masses.

6.2 If clustered data is acquired independently for each of the three gross mass reference points, the minimum sample size acceptable for each of the three gross mass SAR values shall be six.

6.3 Alternatively, SAR data may be collected over a range of masses. In this case, the minimum sample size shall be 12 and the 90 per cent confidence interval shall be calculated for the mean regression line through the data.

6.4 If the 90 per cent confidence interval of the SAR value at any of the three reference aeroplane masses exceeds ±1.5 per cent, the SAR value at that reference mass may be used, subject to the approval of the certificating authority, if a penalty is applied to it. The penalty shall be equal to the amount that the 90 per cent confidence interval exceeds ±1.5 per cent. If the 90 per cent confidence interval of the SAR value is less than or equal to ±1.5 per cent, no penalty need be applied.

Note.— Methods for calculating the 90 per cent confidence interval are given in the Environmental Technical Manual *(Doc 9501), Volume III —* Procedures for the CO_2 Emissions Certification of Aeroplanes.

7. CALCULATION OF THE CO_2 EMISSIONS EVALUATION METRIC VALUE

The CO_2 emissions evaluation metric value shall be calculated according to the formula defined in 2.2 of Part II, Chapter 2.

8. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY

Note.— The information required is divided into: 1) general information to identify the aeroplane characteristics and the method of data analysis; 2) list of reference conditions used; 3) data obtained from the aeroplane test(s); 4) calculations and corrections of SAR test data to reference conditions; and 5) results derived from the test data.

8.1 General information

The following information shall be provided for each aeroplane type and model for which CO_2 certification is sought:

a) designation of the aeroplane type and model;

b) general characteristics of the aeroplane, including CG range, number and type designation of engines and, if fitted, propellers;

c) MTOM;

d) relevant dimensions needed for calculation of RGF; and

e) serial number(s) of the aeroplane(s) tested for CO_2 certification purposes and, in addition, any modifications or non-standard equipment likely to affect the CO_2 characteristics of the aeroplane.

8.2 Reference conditions

The reference conditions used for the determination of SAR (see Part II, Chapter 2, 2.5) shall be provided.

8.3 Test data

The following measured test data, including any corrections for instrumentation characteristics, shall be provided for each of the test measurement points:

a) airspeed, ground speed and true airspeed;

b) fuel flow;

c) pressure altitude;

d) static air temperature;

e) aeroplane gross mass and CG for each test point;

f) levels of electrical and mechanical power extraction and bleed flow;

g) engine performance:

   1) for jet aeroplanes, engine power setting; and

   2) for propeller-driven aeroplanes, shaft horsepower or engine torque and propeller rotational speed;

h) fuel lower heating value;

i) fuel specific gravity and kinematic viscosity if volumetric fuel flow meters are used (see 3.2.1 d));

j) the cumulative error (RSS) of the overall measurement system (see 4.1.6);

k) heading, track and latitude;

l) stability criteria (see 3.2.3.1); and

m) description of the instruments and devices used to acquire the parameters necessary for the determination of SAR, and their individual accuracies in terms of their effect on SAR (see 4.1.5 and 4.1.6).

8.4 Calculations and corrections of SAR test data to reference conditions

The measured SAR values, corrections to the reference conditions and corrected SAR values shall be provided for each of the test measurement points.

8.5 Derived data

The following derived information shall be provided for each aeroplane tested for certification purposes:

a) SAR (km/kg) for each reference aeroplane mass and the associated 90 per cent confidence interval;

b) average of the inverse of the three reference mass SAR values;

c) RGF; and

d) CO_2 emissions evaluation metric value.

APPENDIX 2. REFERENCE GEOMETRIC FACTOR

1. RGF is a non-dimensional parameter used to adjust $(1/SAR)_{AVG}$. RGF is based on a measure of fuselage size normalized with respect to 1 m^2, and is derived as follows:

a) for aeroplanes with a single deck determine the area of a surface (expressed in m^2) bounded by the maximum width of the fuselage outer mould line (OML) projected to a flat plane parallel with the main deck floor; and

b) for aeroplanes with an upper deck determine the sum of the area of a surface (expressed in m^2) bounded by the maximum width of the fuselage OML projected to a flat plane parallel with the main deck floor, and the area of a surface bounded by the maximum width of the fuselage OML at or above the upper deck floor projected to a flat plane parallel with the upper deck floor is determined; and

c) determine the non-dimensional RGF by dividing the areas defined in 1 a) or 1 b) by 1 m^2.

2. RGF includes all pressurized space on the main or upper deck including aisles, assist spaces, passage ways, stairwells and areas that can accept cargo and auxiliary fuel containers. It does not include permanent integrated fuel tanks within the cabin or any unpressurized fairings, nor crew rest/work areas or cargo areas that are not on the main or upper deck (e.g. 'loft' or under floor areas). RGF does not include the cockpit crew zone.

3. The aft boundary to be used for calculating RGF is the aft pressure bulkhead. The forward boundary is the forward pressure bulkhead except for the cockpit crew zone.

4. Areas that are accessible to both crew and passengers are excluded from the definition of the cockpit crew zone. For aeroplanes with a cockpit door, the aft boundary of the cockpit crew zone is the plane of the cockpit door. For aeroplanes having optional interior configurations that include different locations of the cockpit door, or no cockpit door, the boundary shall be determined by the configuration that provides the smallest cockpit crew zone. For aeroplanes certified for single-pilot operation, the cockpit crew zone shall extend half the width of the cockpit.

5. Figures A2-1 and A2-2 provide a notional view of the RGF boundary conditions.

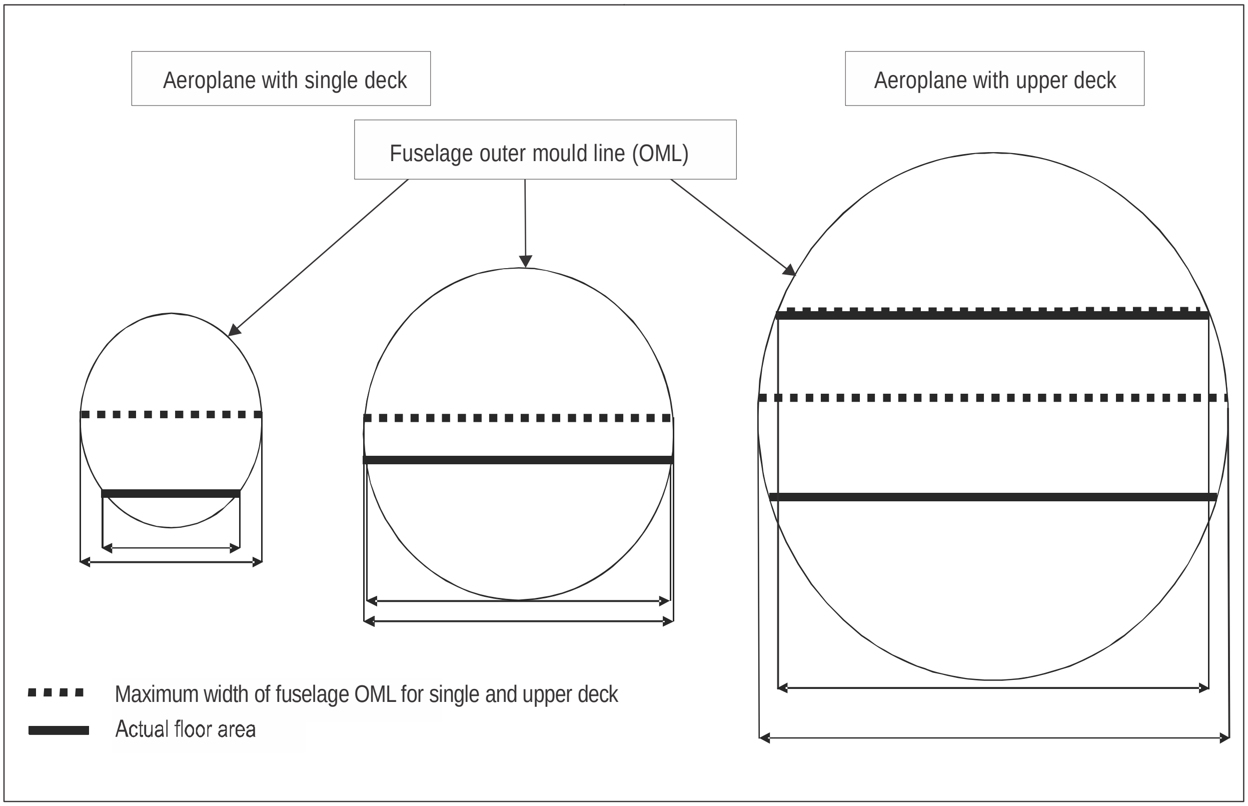

Figure A2-1. Cross-sectional view

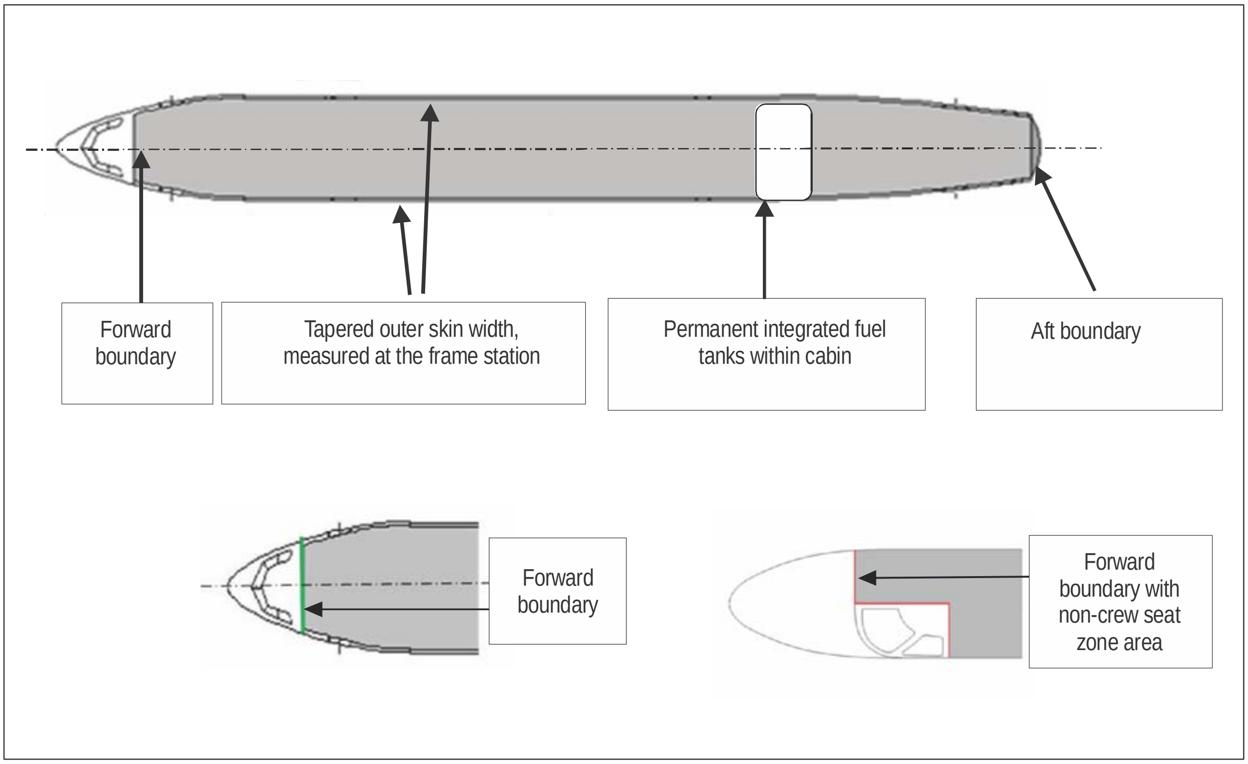

Figure A2-2. Longitudinal view

— END —

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