



ICAO

Doc 9501

Environmental Technical Manual

Volume III — Procedures for the CO₂ Emissions Certification of Aeroplanes
First Edition, 2018



Approved by and published under the authority of the Secretary General

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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

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FOREWORD

The *Environmental Technical Manual* (Doc 9501), Volume III — *Procedures for the CO₂ Emissions Certification of Aeroplanes*, First Edition, includes material that has been approved by the ICAO Committee on Aviation Environmental Protection (CAEP) during their tenth meeting (CAEP/10) in February 2016. This manual is to be periodically revised under the supervision of the CAEP Steering Group and is intended to make the most recent information available to certificating authorities, aeroplane certification applicants and other interested parties in a timely manner, aiming at achieving the highest degree of harmonization possible. The technical procedures and equivalent procedures described in the manual are consistent with currently accepted techniques and modern instrumentation. This edition and subsequent revisions that may be approved by the CAEP Steering Group will be posted on the ICAO website (<http://www.icao.int/>) under “publications” until the latest approved revision is submitted to CAEP for formal endorsement and subsequent publication by ICAO.

Comments on this manual, particularly with respect to its application and usefulness, would be appreciated from all States. These comments will be taken into account in the preparation of subsequent editions. Comments concerning this manual should be addressed to:

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ACRONYMS AND ABBREVIATIONS

A	Area (m ²)
CAEP	Committee on Aviation Environmental Protection
CD	Drag coefficient
CFD	Computational fluid dynamics
CG	Centre of gravity
CI	Confidence interval
CL	Lift coefficient
CO ₂	Carbon dioxide
g	Gravitational acceleration (m/s ²)
h	Altitude (m)
LHV	Lower heating value (MJ/kg)
M	Mach number
MAC	Mean aerodynamic chord (cm)
MTOM	Maximum take-off mass (kg)
Re	Radius of the Earth (m)
RE	Reynolds number
RGF	Reference geometric factor
SAR	Specific air range (km/kg)
SFC	Specific fuel consumption
STC	Supplemental type certificate
T	Temperature (K)
TAS	True airspeed (km/h)
TC	Type certificate
TOM	Take-off mass (kg)
V	Speed (m/s)
Wf	Total aeroplane fuel flow (kg/h)
W	Weight (N)
WV	Weight variant
δ	Ratio of atmospheric pressure at a given altitude to the atmospheric pressure at sea level
Φ	Latitude degrees
ρ	Density (kg/m ³)
σ	Ground track angle degrees

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Chapter 1

INTRODUCTION

1.1 PURPOSE

The aim of this manual is to promote uniformity in the implementation of the technical procedures of Annex 16 — *Environmental Protection*, Volume III — *Aeroplane CO₂ Emissions* by providing: 1) guidance to certifying authorities, applicants and other interested parties regarding the intended meaning of the Standards in the current edition of the Annex; 2) guidance on specific methods that are deemed acceptable in demonstrating compliance with those Standards; and 3) equivalent procedures resulting in effectively the same CO₂ emissions evaluation metric that may be used in lieu of the procedures specified in the appendices of Annex 16, Volume III.

1.2 DOCUMENT STRUCTURE

1.2.1 Chapter 1 provides general information regarding the use of this manual. Chapter 2 provides general guidelines on the interpretation of Annex 16, Volume III. Chapter 3 brings technical guidelines for the certification of aeroplanes against Annex 16, Volume III, including equivalent procedures.

1.2.2 Guidance is provided in the form of explanatory information, acceptable methods for showing compliance, and equivalent procedures.

1.3 EQUIVALENT PROCEDURES

1.3.1 The procedures described in the Annex, as supplemented by the means of compliance information provided in this manual, shall be used unless an equivalent procedure is approved by the certifying authority. Equivalent procedures should not be considered as limited only to those described herein, as this manual will be expanded as new equivalent procedures are developed. Also, their presentation does not imply limitation of their application or commitment by certifying authorities to their further use.

1.3.2 The use of equivalent procedures may be requested by applicants for many reasons, including:

- a) to make use of previously acquired or existing data for the aeroplane; and
- b) to minimize the costs of demonstrating compliance with the requirements of Annex 16, Volume III, by keeping aeroplane test time and equipment and personnel costs to a minimum.

1.4 EXPLANATORY INFORMATION

Explanatory information has the following purpose:

- a) to explain the intent of the Annex 16 Volume III Standards;
- b) to state current policies of certificating authorities regarding compliance with the Annex; and
- c) to provide information on critical issues concerning approval of applicants' compliance methodology proposals.

1.5 CONVERSION OF UNITS

Conversions of some non-critical numerical values between U.S. Customary (English) and SI units are shown in the context of acceptable approximations.

1.6 REFERENCES

1.6.1 Unless otherwise specified, references throughout this document to “the Annex” relate to Annex 16 — *Environmental Protection*, Volume III — *Aeroplane CO₂ Emissions*, First Edition.

1.6.2 References to sections of this manual are defined only by the section number to which they refer. References to documents other than the Annex are numbered sequentially (e.g., Reference 1, Reference 2, etc.). A list of these documents is provided in Appendix 1 of this manual, and a bibliography can be found in Appendix 2.

1.6.2

Chapter 2

GENERAL GUIDELINES

2.1 APPLICABILITY OF ANNEX 16, VOLUME III

2.1.1 The *Convention on International Civil Aviation*, Article 3, specifically states that it is not applicable to state aircraft and provides some examples (see below), but this can also include specific flights carrying official government representatives:

- “a) This Convention shall be applicable only to civil aircraft, and shall not be applicable to state aircraft.
- b) Aircraft used in military, customs and police services shall be deemed to be state aircraft.”

2.1.2 In addition, Annex 16, Vol. III, Part II, Chapter 2, 2.1 excepts amphibious aeroplanes, aeroplanes initially designed or modified for specialized operational requirements and used as such, aeroplanes designed with zero reference geometric factor (RGF), and those aeroplanes specifically designed or modified and used for fire-fighting purposes. These are typically special categories of aeroplanes which are limited in numbers and have specific technical characteristics resulting in very different CO₂ metric values compared to all other aeroplane types in the proposed applicability scope.

2.1.3 Examples of specialized operational requirements include:

- a) aeroplanes that are initially certified as civil aeroplanes during the production process but immediately converted to military aeroplanes;
- b) a required capacity to carry cargo that is not possible by using less specialized aeroplanes;
- c) a required capacity for very short or vertical take-offs and landings;
- d) a required capacity to conduct scientific, research or humanitarian missions exclusive of commercial service; or
- e) similar factors.

2.1.4 Type design configurations which shall be certified

2.1.4.1 Annex 16, Volume III, Part I, Chapter 1, defines maximum take-off mass (MTOM) as “the highest of all take-off masses for the type design configuration”. Part II, Chapter 2, 2.3, defines the three reference masses at which the 1/SAR value shall be established, and these masses are calculated based on the MTOM.

2.1.4.2 Applicants may develop multiple take-off mass (TOM) variants of a specific type design configuration (i.e. combination of airframe/engine) for operational purposes. As stated above, only the highest MTOM of a specific airframe/engine combination is required to be certified against Annex 16, Volume III. As stated in Annex 16, Volume III, Part II, Chapter 2, 2.3.2, certification at MTOM also certifies all TOM variants. These TOM variants would have the same CO₂ emissions evaluation metric value as MTOM.

2.1.4.3 Annex 16, Volume III, Part II, Chapter 2, 2.3.2, also states that “applicants may voluntarily apply for the approval of CO₂ metric values for take-off masses less than MTOM.” The purpose of this statement is to allow the applicant to apply for approval of a separate CO₂ emissions evaluation metric value for a TOM lower than MTOM. In that case, the reference aeroplane masses and the maximum permitted CO₂ emissions evaluation metric value would be based on the TOM instead of MTOM. The CO₂ emissions evaluation metric value for this TOM could then also be used for any TOM variant of even lower mass. Applicants can apply for approval for separate CO₂ emissions evaluation metric values for as many or as few TOM variants as they desire.

2.1.4.4 Example of type design configurations to be certified

2.1.4.4.1 Assuming an applicant applies for the approval of the following type design configurations:

- a) two fuselage lengths: Model A and Model B;
- b) two engine options: Engine X and Engine Y;
- c) two weight variants (WV) for each fuselage length: WV01 and WV02 for Model A and WV11 and WV12 for Model B.

The possible combinations are summarized in Table 2-1.

Table 2-1. Type design configuration combinations

Model A	Engine X	WV01
		WV02
	Engine Y	WV01
		WV02
Model B	Engine X	WV11
		WV12
	Engine Y	WV11
		WV12

2.1.4.4.2 The type design configurations that shall be certified against Annex 16, Volume III, are the ones that have the highest MTOM. Each combination of fuselage length and engine option is a separate type design configuration. Assuming WV01 and WV11 have higher MTOMs than WV02 and WV12, the following combinations shall be certified:

- a) Model A — Engine X – WV01;
- b) Model A — Engine Y – WV01;

- c) Model B — Engine X – WV11;
- d) Model B — Engine Y – WV11.

2.1.4.4.3 The combinations with WV02 and WV12 would be assigned the same CO₂ emissions evaluation metric value as the combinations with WV01 and WV11, respectively. At the applicant's option, the combinations with WV02 and/or WV12 could also be certified to obtain a different CO₂ emissions evaluation metric value for those combinations.

2.1.5 Appropriate margin to regulatory level

2.1.5.1 If an applicant chooses to voluntarily certify a lower TOM variant, as discussed in 2.1.4, it should be kept in mind that an underlying principle in applying the CO₂ standard is that the highest weight variant (MTOM) has the lowest margin to the regulatory limit level. The 1/SAR value used in the CO₂ metric system is calculated as an average of three reference masses (high, medium and low).

2.1.5.2 In establishing the reference conditions for specific air range (SAR) determination, it is expected that the highest SAR value will be sought at the maximum range cruise condition at the optimum altitude (Annex 16, Volume III, Chapter 2, 2.5). It is noted that a greater non-linearity in the 1/SAR versus mass relationship could be introduced by a constraint unrelated to the aerodynamic and propulsive efficiency of the aeroplane (e.g. an altitude pressurization limitation). In this instance, particular care should be taken to ensure that the principle of the highest weight variant having the lowest margin to the regulatory limit level continues to hold.

2.2 CHANGES TO CO₂-APPROVED AEROPLANE TYPE DESIGNS

2.2.1 Annex 16, Volume III, Part I, Chapter 1, includes the following definition:

“Derived version of a CO₂-certified aeroplane. An aeroplane which incorporates changes in type design that either increase its maximum take-off mass, or that increase its CO₂ 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.”

2.2.2 Consequently, any change to a CO₂-certified aeroplane type design that increases its MTOM shall be considered a derived version, and the applicant shall demonstrate compliance with Annex 16, Volume III. In addition, any change to a CO₂-certified aeroplane type design that increases its certified CO₂ emissions evaluation metric value by more than the above-mentioned thresholds shall be considered a derived version, and the applicant shall demonstrate compliance with Annex 16, Volume III.

2.2.3 Changes to a CO₂-certified aeroplane type design that do not increase its MTOM or its CO₂ emissions evaluation metric by more than the above-mentioned thresholds are considered no-CO₂ changes, and the CO₂ emissions evaluation metric value of the changed type design configuration shall be considered the same as the parent type design. This definition of the no-CO₂ change thresholds is also referred to as the “no-CO₂-change criterion”.

2.2.4 The evaluation of certain changes can be done by simpler equivalent procedures, as detailed in 3.4.2 and 3.4.3.

2.2.5 Visualization of the no-CO₂-change criterion thresholds is provided in Figure 2-1. The trend line equations may be used to evaluate what the no-CO₂ change threshold is for any MTOM.

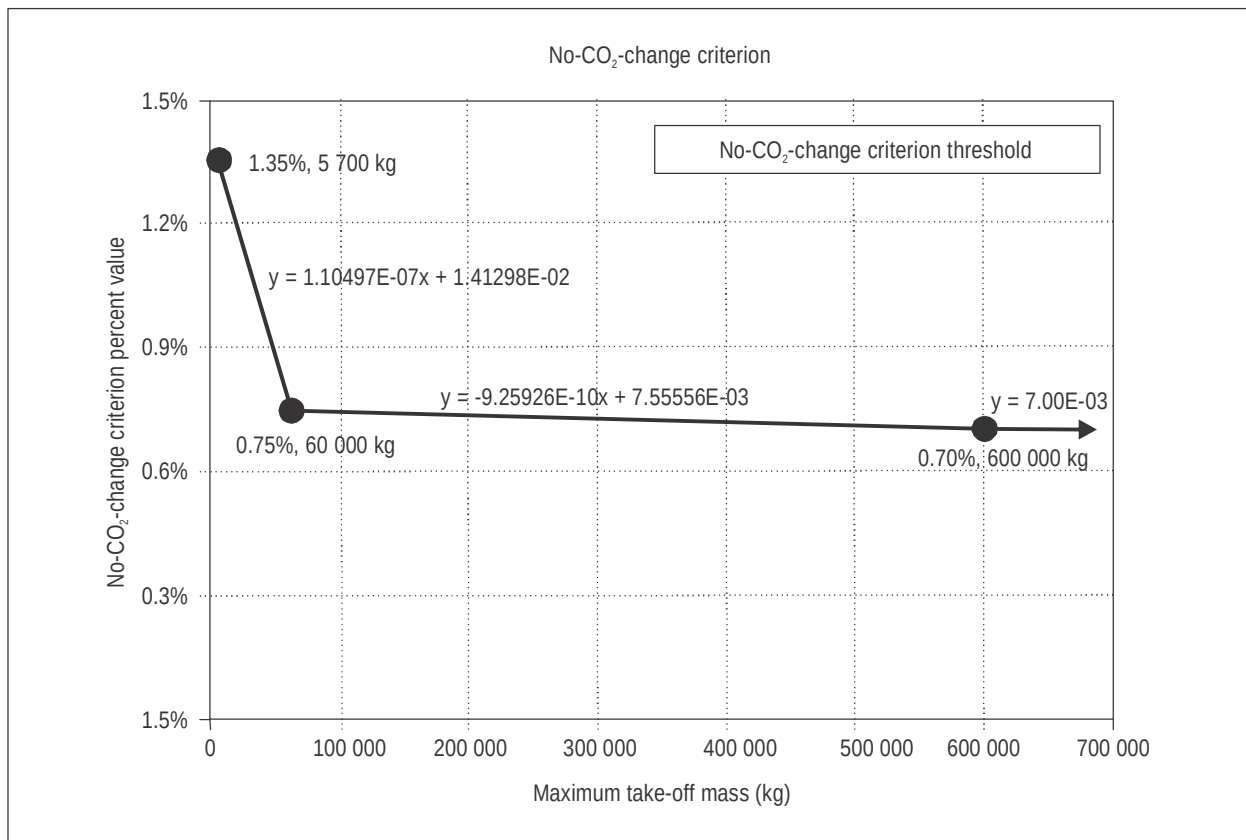


Figure 2-1. Visualization of the no-CO₂-change criterion

2.3 CO₂ EMISSIONS EVALUATION METRIC COMPLIANCE DEMONSTRATION PLANS

Prior to undertaking a CO₂ certification demonstration, the applicant should submit to the certifying authority a CO₂ compliance demonstration plan. This plan contains a complete description of the methodology and procedures by which an applicant proposes to demonstrate compliance with the CO₂ certification Standards specified in Annex 16, Volume III. Approval of the plan and the proposed use of any equivalent procedures or technical procedures not included in the Annex remains with the certifying authority. CO₂ compliance demonstration plans should include the following information:

- a) *Introduction.* A description of the aeroplane CO₂ certification basis.
- b) *Aeroplane description.* Type, model number and the specific configuration to be certificated.

Note.— The certifying authority should require that the applicant demonstrate and document the conformity of the test aeroplane, particularly with regard to those parts which might affect its CO₂ emissions evaluation metric.

- c) *Aeroplane CO₂ certification methodology.* Means of compliance, equivalent procedures from this manual, and technical procedures from Annex 16, Volume III.

- d) *Plans for tests.* The plans for test should include:

- 1) *Test description.* Test methods to comply with the test environment and flight path conditions of the Annex, as appropriate.

Note.— Plans for tests shall either be integrated into the basic CO₂ compliance demonstration plan or submitted separately and referenced in the basic plan.

- e) *Deliverables.* List the documents that should show compliance with Annex 16, Volume III (test and analysis reports, including RGF determination).

2.4 ENGINE INTERMIX

2.4.1 Applicants will typically demonstrate compliance with the Standards in Annex 16, Volume III, Chapter 2, for an aeroplane type configuration where all engines are of the same design. However, an applicant may wish to demonstrate compliance of an aeroplane type configuration where not all the engines are of the same design. Such a configuration is commonly referred to as an “engine intermix” configuration.

2.4.2 In such a case, the applicant may, subject to the approval of the certifying authority, demonstrate compliance in one of three ways:

- a) in accordance with the test procedures defined in Annex 16, Volume III, Chapter 2, 2.6, and for which the test aeroplane shall be representative of the intermix configuration for which certification is requested; or
- b) in cases where the CO₂ metric value has been established for aeroplanes on which each of the intermix engine models has been exclusively installed, compliance can be demonstrated on the basis of either:
 - 1) the average of the CO₂ emissions evaluation metrics for aeroplanes on which each of the intermix engine models has been exclusively installed; or
 - 2) the highest CO₂ emissions evaluation metric for aeroplanes on which each of the intermix engine models has been exclusively installed.

Note.— Annex 16, Volume III, Chapter 2, 2.1.2, states that in the case of time-limited engine changes, Contracting States may not require a demonstration of compliance with the Standards of Annex 16, Volume III.

2.5 EXEMPTIONS

2.5.1 Introduction

2.5.1.1 The current edition of Annex 16, Volume III, contains applicability requirements in Part II, Chapter 2, 2.1.

2.5.1.2 It is recognized that there may be circumstances where it is justified for certifying authorities to exempt new aeroplane units from the applicability requirements in Annex 16, Volume III, Part II, Chapter 2, 2.1.1.

2.5.1.3 In order to promote a harmonized global approach to the granting, implementing and monitoring of these exemptions, this section provides guidelines on the process and criteria for issuing exemptions from the CO₂ Standard.

2.5.2 Exemption process

2.5.2.1 Application

In order for the competent authority to review an application, the applicant should submit to the competent authority¹ a formal application letter for the manufacture of the exempted aeroplanes, with a copy to all other relevant organizations and involved competent authorities. The letter should include the following information in order for the competent authority to be in a position to review the application:

a) *Administration*

- 1) name, address and contact details of the applicant.

b) *Scope of application for exemptions*

- 1) aeroplane type (e.g. model designation, type certificate (TC) number and TC date);
- 2) number of aeroplane exemptions requested;
- 3) anticipated duration (end date) of continued production of exempted aeroplanes;
- 4) designation of to whom the aeroplanes will be originally delivered.

c) *Justification for the exemptions.* In applying for an exemption, an applicant should, to the extent possible, address the following factors (with quantification) in order to support the merits of the exemption request:

- 1) technical issues from an environmental and airworthiness perspective which may have delayed compliance;
- 2) economic impacts on the manufacturer, operator(s) and the aviation industry at large;
- 3) environmental effects. This should consider the amount of additional CO₂ that will be emitted as a result of the exemption, including items such as the amount by which the aeroplane model

1. In most cases this will be the certifying authority, although it may vary depending on the processes of individual Member States.