

Doc 9501
AN/929



Environmental Technical Manual

Volume II Procedures for the Emissions Certification of Aircraft Engines

Approved by the Secretary General
and published under his authority

Second Edition — 2014

International Civil Aviation Organization

AVA Documents
Document Sharing Hub

Copyright International Civil Aviation Organization
Not for Resale, 02/26/2015 11:23:18 MST

Doc 9501
AN/929



Environmental Technical Manual

Volume II
Procedures for the Emissions Certification
of Aircraft Engines

Approved by the Secretary General
and published under his authority

Second Edition — 2014

International Civil Aviation Organization

Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 University Street, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

First edition, 2010
Second edition, 2014

Doc 9501, *Environmental Technical Manual*
Volume II, *Procedures for the Emissions Certification of*
Aircraft Engines
Order Number: 9501-2
ISBN 978-92-9249-534-3

© ICAO 2014

All rights reserved. No part of this publication may be reproduced, stored in a
retrieval system or transmitted in any form or by any means, without prior
permission in writing from the International Civil Aviation Organization.

AMENDMENTS

Amendments are announced in the supplements to the *Publications 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

[illegible][illegible]

(iii)



TABLE OF CONTENTS

	<i>Page</i>
Nomenclature.....	(vii)
SECTION 1. INTRODUCTION.....	1-1
1.1 Purpose.....	1-1
1.2 Framework	1-1
1.3 Emissions compliance demonstration plan.....	1-2
1.4 Emissions certification report.....	1-3
Section 2 replicates the structure of Annex 16, Volume II. The text of Annex 16, Volume II, is presented in text boxes followed by the associated guidance material. Where no guidance material is provided, the paragraph is marked as “Reserved”.	
SECTION 2. GUIDANCE MATERIAL	2-1
Part I. DEFINITIONS AND SYMBOLS	2-1
CHAPTER 1. Definitions	2-1
CHAPTER 2. Symbols [Reserved].....	2-1
Part II. VENTED FUEL [Reserved]	2-2
Part III. EMISSIONS CERTIFICATION	2-2
CHAPTER 1. Administration [Reserved].....	2-2
CHAPTER 2. Turbojet and turbofan engines intended for propulsion only at subsonic speeds	2-2
2.1 General	2-2
2.2 Smoke.....	2-11
2.3 Gaseous emissions	2-11
2.4 Information required	2-12
CHAPTER 3. Turbojet and turbofan engines intended for propulsion at supersonic speeds.....	2-12

APPENDICES

APPENDIX 1. Measurement of reference pressure ratio.....	2-13
1. General	2-13
APPENDIX 2. Smoke emission evaluation	2-14
1. Introduction and definitions [Reserved].....	2-14
2. Measurement of smoke emissions.....	2-14
3. Calculation of Smoke Number from measured data.....	2-20
4. Reporting of data to the certificating authority [Reserved]	2-20
APPENDIX 3. Instrumentation and measurement techniques for gaseous emissions	2-20
1. Introduction	2-20
2. Definitions [Reserved]	2-20
3. Data required	2-21
4. General arrangement of the system	2-21
5. Description of component parts	2-22
6. General test procedures	2-25
7. Calculations.....	2-25
Attachment A to Appendix 3. Specification for HC analyser	2-29
Attachment B to Appendix 3. Specification for CO and CO ₂ analysers	2-35
Attachment C to Appendix 3. Specification for NO _x analyser	2-42
Attachment D to Appendix 3. Calibration and test gases	2-46
Attachment E to Appendix 3. The Calculation of the Emissions Parameters — Basis, Measurement Corrections and Alternative Numerical Method	2-48
Attachment F to Appendix 3. Specification for additional data	2-50
APPENDIX 4. Specification for fuel to be used in aircraft turbine engine emission testing	2-51
APPENDIX 5. Instrumentation and measurement techniques for gaseous emissions from afterburning gas turbine engines [Reserved].....	2-52
APPENDIX 6. Compliance procedure for gaseous emissions and smoke	2-52
1. General	2-52

NOMENCLATURE

Definitions and symbols

The definitions and symbols employed in this manual are consistent with those contained in Annex 16 — *Environmental Protection*, Volume II — *Aircraft Engine Emissions* (Third Edition, July 2008).

Section 1

INTRODUCTION

1.1 PURPOSE

1.1.1 The aim of this manual is to promote uniformity in the implementation of ICAO Annex 16 — *Environmental Protection*, Volume II — *Aircraft Engine Emissions*, by providing guidance to certifying authorities and applicants regarding the intended meaning of the current Annex 16, Volume II, emissions Standards and the specific procedures that are deemed acceptable for demonstrating compliance with those Standards.

1.1.2 Annex 16, Volume II, procedures must be used unless an equivalent procedure is approved by the certifying authority. This manual provides guidance in the wider application of equivalent procedures that have been accepted as a technical means for demonstrating compliance with the emissions certification requirements of Annex 16, Volume II. Such equivalent procedures are referred to in the chapters of Annex 16, Volume II, but are not dealt with in the same detail as in the Appendices to the Annex, which describe the emissions evaluation methods for compliance with the relevant chapters.

1.1.3 Procedures presented in this manual should not be considered as exhaustive because this manual will be expanded as new procedures are developed. Also, their presentation does not infer limitation of their application or commitment by certifying authorities to their further use.

1.2 FRAMEWORK

1.2.1 Section 1 of this manual provides general information and Section 2 provides guidance material concerning the application of the emissions Standards of Annex 16, Volume II. Section 2 replicates the structure of Annex 16, Volume II. For ease of reference the requirements of Annex 16, Volume II, are presented in text boxes, followed by the associated guidance material. Where no guidance material has been provided, the relevant paragraph of Annex 16 has been “Reserved” for future use. The aim of this presentation is to minimize repetition of the Annex 16 text in order to simplify the content of the manual, lower maintenance costs, and reduce the danger of inconsistencies between the Annex and the manual in subsequent revisions.

1.2.2 The guidance material consists of three types of information (explanatory information, equivalent procedure and technical procedure) as follows:

Explanatory information

- a) explains the language of the Annex 16 emissions Standards;
- b) states current policies of regulatory authorities regarding compliance with Annex 16 emissions Standards;
- c) provides information on critical issues for approval of applicants’ compliance methodology proposals.

Equivalent procedure

- a) An equivalent procedure is a test or analysis procedure which, while differing from the one specified in Annex 16, Volume II, in the technical judgement of the certificating authority, yields effectively the same emissions levels as the specified procedure.
- b) The use of equivalent procedures may be requested by applicants for many reasons, including:
 - 1) to make use of previously acquired certification test data for the engine type; and
 - 2) to minimize the costs of demonstrating compliance with the requirements of Annex 16, Volume II, by keeping engine test time, test bed usage, and equipment and personnel costs to a minimum.

Technical procedure

A technical procedure is a test or analysis procedure not defined in detail in the Annex 16 emissions Standards but which certificating authorities have approved as being acceptable for compliance with the general provisions specified in the emissions Standards.

1.3 EMISSIONS COMPLIANCE DEMONSTRATION PLAN

1.3.1 Prior to undertaking an emissions certification demonstration, the applicant is normally required to submit to the certificating authority an emissions compliance demonstration plan containing the method by which the applicant proposes to show compliance with the emissions requirements. Approval of the compliance demonstration plan and the proposed use of any equivalent procedure remain with the certificating authority. The determination of equivalency for any procedure or group of procedures must be based on consideration of all pertinent facts relating to the application.

1.3.2 Emissions compliance demonstration plans should include the following types of information:

- a) *Introduction:* a description of the engine emissions certification basis, i.e. the applicable amendment and chapter of Annex 16, Volume II;
- b) *Engine description:* type, model number and specific details of the basic configuration to be certified;
- c) *Engine emissions certification methodology:* test concepts, equivalent procedures and technical procedures;
- d) *Test description:* test methods to comply with the emissions Standards;
- e) *Measurement system:* a description of measurement and sampling system components and procedures, including calibration procedures, that are intended to be used to demonstrate compliance with the emissions Standards; and
- f) *Data evaluation procedures:* emissions evaluation and adjustment procedures (including equivalent and technical procedures such as those provided in this manual) to be used in compliance with the provisions of Annex 16, Volume II, appropriate to the engine type being certificated.

1.4 EMISSIONS CERTIFICATION REPORT

1.4.1 Following completion of an emissions certification demonstration test, an applicant is normally required to submit an emissions certification report providing a complete description of the test process and the test results with respect to compliance with the provisions of Annex 16, Volume II.

1.4.2 Emissions certification reports should include the following types of information:

- a) *Basis for test approval:* the approved emissions certification compliance plan for the engine type and model being certificated;
- b) *Description of tests:* actual configurations tested and non-conforming items (with justification that they are not significant to emissions or, if significant, can be dealt with by an approved method), test methodology (including equivalent procedures and technical procedures), tests conducted, test data validity, and data analysis and adjustment procedures used;
- c) *Test results:* data to demonstrate compliance with the provisions of Annex 16, Volume II, regarding maximum emissions levels for the engine type being certificated; and
- d) *References.*

Section 2

GUIDANCE MATERIAL

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

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.

EQUIVALENT PROCEDURE

Defining the exhaust nozzle in this manner, where the fan and core nozzles are not coplanar, is problematic. With imperfect knowledge of the fan flow characteristics when discharged upstream of the core exit nozzle, the effective nozzle size may be ambiguous. This affects the extreme downstream location of the sampling probe or rake and causes problems in terms of a detailed traverse of the total exhaust nozzle. In order to obtain equivalent, but more accurate, gaseous emissions measurements and representative samples, it is considered best practice to arrange the engine configuration in such a way as to separate the fan and core flows, without affecting the engine performance, and sample just the core flow. The above is equally applicable to both gaseous and smoke emissions measurements; however for smoke, the dilution and mixing of bypass air also need to be taken into account and this is covered under Appendix 2, 2.1.

CHAPTER 2. SYMBOLS

[Reserved]

PART II. VENTED FUEL

[Reserved]

PART III. EMISSIONS CERTIFICATION**CHAPTER 1. ADMINISTRATION**

[Reserved]

**CHAPTER 2. TURBOJET AND TURBOFAN ENGINES
INTENDED FOR PROPULSION ONLY
AT SUBSONIC SPEEDS****2.1 GENERAL****2.1.1 Applicability****EXPLANATORY INFORMATION**

Part I of Annex 16, Volume II, defines a derivative version¹ in terms of emissions certification, but this definition is referred to in the Annex only in the context of granting exemptions and does not specify how the rule should be applied to modifications of already certificated engine types. Many changes to a certificated engine, which are considered to be major from an airworthiness perspective, require an amendment or supplement to the type certificate (TC). However, these same modifications may have no or very little effect on the emissions characteristics of that engine. If Annex 16 is interpreted literally, these small effects would require a full investigation of compliance with the emissions certification requirements. This may not be necessary in many cases. The following guidelines have been developed to help determine whether a modification can be classified as a “no emissions change” or if it would affect the emissions levels to such an extent that the engine type would need to be re-certificated to Annex 16, Volume II, requirements. Of course manufacturers may elect to re-certify to the latest Annex 16 requirements at any time.

1. *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 certifying authority, have not changed.

TECHNICAL PROCEDURE

1. No emissions change

The principle of a “no emissions change” is that an engine would not need to be re-certified to the emissions requirements if the manufacturer can demonstrate that the modification(s) would result in a small cumulative change to the current certified engine emissions levels. Cumulative change could be as a result of more than one change at a given time or multiple changes from more than one derivative version of the same engine being developed. The determination of a “no emissions change” is limited to the following conditions:

- a) If all of the characteristic levels prior to any modification are greater than or equal to 95 per cent of the existing ICAO Standard, the manufacturer must provide new engine emissions test data to demonstrate that the resulting characteristic levels after the cumulative changes since original emissions testing will not exceed the existing ICAO exhaust emissions Standard.
- b) If all of the characteristic levels are less than 95 per cent of the existing ICAO exhaust emissions Standard, then new or related emissions test data and good engineering judgement based on substantive analysis may be an acceptable means to demonstrate that the resulting emissions levels after the cumulative changes since original emissions testing will not exceed the existing ICAO exhaust emissions Standard.² Analyses should consider areas such as cycle changes, combustor and fuel nozzle design, or large changes in combustor inlet velocity profile or turbine cooling flows as discussed in paragraph 5 below.
- c) Any new emissions test data and/or engineering/technical analysis under 1 a) and b) must demonstrate that the cumulative changes in absolute emissions levels, as compared to those of the original certification, are within:³

$\text{NO}_x \pm 3 \text{ g/kN}$
 $\text{HC} \pm 1 \text{ g/kN}$
 $\text{CO} \pm 5 \text{ g/kN}$
 $\text{Smoke} \pm 2 \text{ SN}.$

With respect to the tracking of cumulative changes, an applicant should maintain formal documentation of the technical basis for all approved “no emissions changes” for an engine model. The tracking list will be reproduced in each emissions certification dossier demonstration.

If a modification is classified as a “no emissions change”, the characteristic levels for the derivative version will be considered the same as the parent engine.

2. Changes requiring new emissions levels

A change, or cumulative set of changes, to the type design, which is not considered a “no emissions change” and thus affects the characteristic levels would require new characteristic levels to be determined during the certification programme. This would normally be done through a new emissions certification test.

-
2. Good engineering judgement means judgement that is consistent with generally accepted scientific and engineering principles and all available relevant information.
 3. Absolute emissions level refers to the average of the measured emissions levels corrected to reference conditions. This does not include application of the Appendix 6 statistical factors used to determine characteristic levels.

3. Existing emissions certification basis retained

If a modified engine remains on the existing type certificate, it may retain the existing certification basis of the parent engine⁴ if the modification(s):

- a) meets the demonstration criteria of 1 a) or b);
- b) results in a decrease in the absolute emissions levels;
- c) results in an increase in the absolute emissions levels below those prescribed in 1 c);
- d) is necessary for improved safety and continued airworthiness (e.g. Airworthiness Directives).

4. Latest emissions Standards applied

An engine type should demonstrate compliance with the latest emissions Standards when:

- a) the engine requires a new TC;
- b) the engine modification(s) involves significant technical modifications and where, in the judgement of the certifying authority, the engine would not meet the definition of a derivative engine as defined in Annex 16, Volume II;
- c) the engine modification(s) does not meet the demonstration criteria of 1 a) or b);
- d) the engine modification(s) results in an increase in any of the absolute emissions levels below those prescribed in 1 c) but which results in an exceedance of the existing ICAO Standard;
- e) the engine modification(s) results in an increase in any of the absolute emissions levels in excess of those prescribed in 1 c); or
- f) there are significant future environmental impacts.⁵

5. Engineering analysis examples

The basic premise in assessing the emissions effects of design changes from an engineering analysis perspective is that emissions are mainly affected by cycle changes, combustor and fuel nozzle design, or large changes in combustor inlet velocity profile or turbine cooling flows. A number of examples are provided below for illustration.

Cycle change

Annex 16, Volume II, requires the measurement of fuel mass flow by direct measurement only to an accuracy of ± 2 per cent (Attachment F to Appendix 3, paragraph d)) and thrust to an accuracy of ± 1 per cent at take-off power and ± 5 per

4. In terms of emissions certification, the parent engine must have demonstrated emissions compliance and is itself not considered to be a derivative of an even earlier Standard.
5. The application of an old engine type to a new aircraft design could mean a lifetime of 30 years or more and thereby have a more serious impact on the environment than if the engine was produced for spare only.

cent at the minimum thrust. It may be that no effect on emissions beyond those prescribed in paragraph 1 c) would be expected unless changes in air fuel ratio result in a specific fuel consumption change of more than 1 per cent.

Regarding combustor inlet temperature (T3), the Annex also states that the combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas. Following a comparison of T3 detailed traverses versus typical certification test measurements, it was concluded that measurements are within $\pm 6^{\circ}\text{F}$ (approximately 3.5°C) of theoretical calculations. It may be that no effect on emissions beyond those prescribed in paragraph 1 c) would be expected if the cycle T3 change is within $\pm 6^{\circ}\text{F}$.

Combustor and fuel nozzle

Combustor and fuel nozzle changes include some key design characteristics that can significantly affect emissions (e.g. swirl cup flow, primary hole flow, front-end cooling flow, injector atomization). Changes within or outside of production tolerances or part-to-part variation may indicate when a change would be important for emissions or else considered to be not measurable. No effect on emissions beyond those prescribed in 1 c) would be expected if the changes are within current part-to-part variation or prescribed production tolerances.

Boundary conditions

Similar limitations to that for key design characteristics can be applied to that resulting from changes in boundary conditions. For example, if turbine cooling changes by 2 per cent, one could look at the resulting change in combustor flow distribution, and if the change is of the same order as typical part-to-part variation, it may be acceptable to conclude that no effect on emissions beyond that prescribed in 1 c) would be expected.

2.1.1.1 The provisions of this chapter shall apply to all turbojet and turbofan engines, as further specified in 2.2 and 2.3, intended for propulsion only at subsonic speeds, except when certifying authorities make exemptions for:

- a) 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; and
- b) a limited number of engines beyond the dates of applicability specified in 2.2 and 2.3 for the manufacture of the individual engine.

2.1.1.2 In such cases, an exemption document shall be issued by the certifying authority, the identification plates on the engines shall be marked "EXEMPT," and the grant of exemption shall be noted in the permanent engine record. ...

TECHNICAL PROCEDURE

1. Introduction

1.1 The current edition of Annex 16, Volume II, contains two different references to applicability dates:

- a) the “date of manufacture for the first individual production model” which refers to the engine type certification; and
- b) the “date of manufacture for the individual engine” which refers to the production date of a specific engine serial number.

1.2 The second reference is used in the application of global engine NO_x production cut-off Standards which specify a date after which all in-production engine models must meet a certain NO_x emissions Standard. For example, all engines manufactured after 31 December 1999 must be compliant with the CAEP/2 NO_x Standard. It should be noted that these requirements are applicable to complete new “engine units” released into service as spares or for new aircraft installations, as discussed below, and not engine components required for maintenance aspects, overhaul, parts, etc.

1.3 It is recognized that there may be circumstances where it is justified to permit manufacturers to continue to produce new non-compliant engine units after a production cut-off date. These take the form of exemptions from the relevant Annex 16, Volume II, provisions.

1.4 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 an NO_x production cut-off Standard.

2. Exemption process

2.1 Application

The applicant should submit to the competent authority⁶ a formal application letter for the manufacture of the exempted engines, signed by an appropriate manager, and copied 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
 - name, address and contact details of the applicant.
- b) Scope of application for exemptions
 - 1) engine type (model designation, type certificate (TC) number, TC date, emissions TC basis, ICAO engine emissions databank unique identification (UID) number);
 - 2) number of engine exemptions requested;
 - 3) duration (end date) of continued production of exempted engines;
 - 4) designation of whether the proposed exempted engines are “spares” or “new”⁷ and to whom the engines will be originally delivered.

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

7. In the case that engines are “new” (installed on new aircraft) and would thus result in a larger negative environmental impact compared to “spare” engines, more justification may be required.

- 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 with a production cut-off;
 - 2) economic impacts on the manufacturer, operator(s) and the aviation industry at large;
 - 3) environmental effects. This should consider the amount of additional NO_x that will be emitted as a result of the exemption, including items such as:
 - the amount that the engine model exceeds the Standard, taking into account any other engine models in the engine family covered by the same type certificate and their relation to the Standard;
 - the amount of NO_x that would be emitted by an alternative engine for the same application;
 - the impact of changes to reduce NO_x on other environmental factors, including community noise and CO₂ emissions;
 - 4) the impact of unforeseen circumstances and hardship due to business circumstances beyond the manufacturer's control (e.g. employee strike, supplier disruption or calamitous event);
 - 5) projected future production volumes and plans for producing a compliant version of the engine model for which exemptions are sought;
 - 6) equity issues in administering the production cut-off among economically competing parties (e.g. provide the rationale for granting an exemption when another manufacturer has a compliant engine and does not need an exemption, taking into account the implications for operator fleet composition, commonality and related issues in the absence of the engine for which exemptions are sought); and
 - 7) any other relevant factors.

2.2 Evaluation

The evaluation of an exemption application should be based on the justification provided and the following definitions and criteria:

a) Use of engines

“Spare engines” are defined as complete new engine units which are to be installed on in-service aircraft for maintenance and replacement. It can be presumed that applications associated with engines for this purpose would be granted as long as the emissions are equal to or better than the engines they are replacing. The application should also include the other items described in 2.1 a) and b), but it would not need to include the items specified in paragraph 2.1 c). For spare engines, the evaluation of the exemption application would be conducted for recordkeeping and reporting purposes, but it would not be done for approval of an exemption.