



ICAO

Doc 9501

Environmental Technical Manual

Volume II — Procedures for the Emissions Certification
of Aircraft Engines
Fourth Edition, 2020



Approved by and published under the authority of the Secretary General

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FOREWORD

The revision of the ICAO *Environmental Technical Manual* (Doc 9501), Volume II — *Procedures for the Emissions Certification of Aircraft Engines*, Fourth Edition, includes material that has been approved by the ICAO Committee on Aviation Environmental Protection (CAEP) during its eleventh meeting (CAEP/11) in February 2019. 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 certifying authorities, aircraft engine emissions 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 this edition are consistent with currently accepted techniques and modern instrumentation. In this respect, this edition is compatible with Amendment 10 of Annex 16, Volume II. 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:

The Secretary General
International Civil Aviation Organization
999 Robert-Bourassa Boulevard
Montréal, Quebec H3A 2R2
Canada

11/23/2020 09:00:04 MST

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* (Fifth Edition, July 2020).

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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 exhaustive because this manual will be expanded as new procedures are developed. Also, their presentation does not imply 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; and
- 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, Volume II 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.

...

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

...

EXPLANATORY INFORMATION

The definition in Annex 16, Volume II for Type Certificate is the same as Annex 8 — *Airworthiness of Aircraft*. In the context of Annex 16, Volume II, the Type Certificate refers to the document for approving the appropriate airworthiness and environmental requirements of the engine.

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 foregoing 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 Part III, Appendix 2, 2.1 of the Annex.

CHAPTER 2. SYMBOLS [Reserved]

PART II. VENTED FUEL

CHAPTER 1. ADMINISTRATION

CHAPTER 2. PREVENTION OF INTENTIONAL FUEL VENTING

Aircraft shall be so designed and constructed as to prevent the intentional discharge into the atmosphere of liquid fuel from the fuel nozzle manifolds resulting from the process of engine shutdown following normal flight or ground operations.

EXPLANATORY INFORMATION

1. General

The process of engine shutdown, following normal flight or ground operations, begins with the cut-off of fuel flow from the fuel control unit, and continues until a time when the design features of the engine and/or aircraft stop this flow. The engine and/or aircraft are required to be designed in such a way that this fuel cannot be discharged into the atmosphere.

2. Administration

The fuel venting requirement of Annex 16, Volume II is written as being applicable to aircraft. Part II, Chapter 1, 1.1 further details the applicability to turbine engine powered aircraft. ICAO accepts that demonstrating compliance with the requirement should either be done as part of the certification of the engine and/or the aircraft. Typically, the fuel venting requirement is reviewed by certifying authorities at engine and aircraft level, due to the fact that fuel venting can be influenced by the engine's installation effects.

Certification to the Annex 16, Volume II, Part II, Chapter 2 requirement has been on the basis of the design and construction of the aircraft's engine fuel system in order to prevent the intentional discharge of fuel from the engine's fuel system into the atmosphere, resulting from the process of engine shutdown. This section deals with all aspects of

stopping fuel from the fuel nozzle manifold from leaving the engine/aircraft during, or after, engine shutdown. In the past, engines/aircraft designed with any of the systems stated below to address fuel venting have been considered acceptable and have been approved. None of these systems deliberately cause fuel to be sprayed, vented or dripped outside of the aircraft or engine after the process of engine shutdown is completed. The engine/aircraft systems' design and construction for the prevention of intentional fuel venting is subject to review and approval, or acceptance, by the certifying authority.

3. Engine shutdown process

The process of engine shutdown is described as follows.

The engine shutdown process begins when fuel cut-off is commanded by the pilot. Once fuel flow to the engine is cut off, a process begins leading to engine shutdown. The amount of time for this process to take place is dependent upon the design features of the engine. As a generic description, this process involves the simultaneous movement of the liquid fuel that resides within the engine (whether from pressure and/or gravitational forces), into the combustion chamber, and/or settling in areas of the engine of lower potential energy (e.g. to a drain tank). The process may also include valves closing to prevent fuel flow into the combustor from the fuel manifold system, as well as trying to prevent residual fuel from vaporizing after engine shutdown. Any residual fuel that drains into the combustion chamber during engine shutdown is expected to be combusted, as the chamber remains at a high enough temperature to combust the fuel. Once the combustor temperature has cooled, any remaining uncombusted fuel is expected to be held (fuel delivery system, ecology tank, etc.) and not susceptible to release to the atmosphere after engine shutdown.

TECHNICAL PROCEDURE / EQUIVALENT PROCEDURE

The information contained in this section sets forth acceptable means, but not the only means, by which compliance may be shown with the requirement of ICAO Annex 16, Volume II, Part II, Chapter 2.

In order to meet the fuel venting requirement, the following means of compliance have been accepted by the certifying authority:

- a) purged forward into the engine combustion chamber as part of the engine shutdown process;
- b) retained within the fuel manifolds or within the engine casings¹; or
- b) recirculated backwards from the fuel manifold.

-
1. It is noted that the practice of retaining fuel from the fuel manifold within the engine casings after shutdown is not considered good practice as any liquid fuel retained in the casing combustion section may be vaporized during shutdown after the flame is extinguished. As such, it may not be considered an acceptable means of compliance in some Member States. Existing Type Certificates which utilize this approach would continue to be considered valid. However, if such an existing/legacy engine model were to be modified in a way that affects the fuel system, a review of the fuel venting requirements may be undertaken as part of the new or amended certification process.

These systems inherently use a means of collecting the fuel, either an airframe or engine mounted tank or a movable piston, to remove and return manifold fuel.

Any of the above specified systems, or any other system which is intended to be applied to demonstrate compliance, has to be agreed with the certificating authority.

Systems which purge fuel forward on engine shutdown

These systems rely on a feature which stores compressed gas, usually air, to purge the fuel manifolds on engine shutdown. One or more valves release the gas into the manifold when the engine fuel flow is cut off, causing the fuel from the manifold to rapidly enter the combustor and burn as the engine shuts down. The temperature during this process is considered to be hot enough to burn the fuel as it enters the combustion chamber. In these systems, some parts may be airframe mounted or the entire system may be considered part of the engine.

Systems which retain fuel within the fuel manifold

Systems which retain fuel within the fuel manifold have multiple valves in the system (sometimes on every fuel injector). These valves prevent the fuel manifolds from draining into the combustor when the engine is shutdown. Consequently, no fuel from the manifolds is released to the atmosphere. In some cases, residual fuel (for example, within the fuel injectors) may settle in the bottom of the fuel manifold due to gravity.

Systems which retain some fuel within engine casings

Some engines do not use valves, so some fuel drains into the engine casings and is retained in the engine. Fuel which is retained inside the engine in this fashion is re-used during the next start. The amount of fuel which can be retained is severely limited. Care should be taken to design engines to prevent residual fuel from becoming exposed to excessive engine temperatures, as it could lead to a release to the atmosphere and hot end deterioration during subsequent starts. Due to this, some (typically smaller) engine models use case drains which collect residual fuel and this fuel is directed back to aircraft mounted tanks. The common feature of all these systems is that the designs are such that no liquid fuel leaves the aircraft.

Systems which purge fuel backwards from the fuel manifolds:

Some systems are designed to cause the fuel from the manifolds to be purged backwards and drain to a separate tank to either be recycled on subsequent engine runs or emptied periodically. Generally, in this arrangement, residual engine air pressure in the combustor, gravity, or a combination of gravity and pressure causes the fuel to be removed from the manifold and fuel injectors (e.g. ecotank). Other systems may use a moving piston to pull fuel out of the manifold and re-use it to refill the manifold on the next start (e.g. ecology valve).

Other/new means of compliance

The above list of fuel venting prevention systems is not exhaustive, and new technologies may yet be developed that meet the intent of the fuel venting requirement. These new technologies should be presented to the certificating authority and should include sufficient substantiation material for evaluation during the design review phase of the certification process to determine compliance with the fuel venting Standard.

PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION

EXPLANATORY INFORMATION

The application for a Type Certificate for engines of a type or model

For any new engine model, the emissions type certification basis and the characteristic emissions levels have to be determined and approved by the certifying authority. For engine models which are introduced with the intention of generating a new Type Certificate, the date of application for the Type Certificate is used for determining the applicable emissions Standard. Similarly, for new models added to an existing Type Certificate, the date of application for the amendment to the Type Certificate is used. This could lead to a more stringent Standard, applicable for engine models which are added to an existing Type Certificate years later. However, it is possible that the existing Standard applied to the models already on the Type Certificate can be retained for the new model, depending on the technical details of design change of this new model. The technical procedure for no emissions / emissions change in the ETM should be applied in agreement with the certifying authority (ETM, Volume II, Section 2, Guidance Material for Part III, Chapter 2, 2.1.1).

EXPLANATORY INFORMATION

Determination of the applicability date for Contracting States other than the State of Design

The State of Design is the State having jurisdiction over the organization responsible for the type design. The National Airworthiness Authority (NAA) of this State is considered to be the primary certifying authority responsible for airworthiness and environmental certification. Certification activities for the same engine in other countries are considered to be validation projects. When they exist, bilateral agreements and working arrangements between the NAA and the validating authority (VA) provide details about the conduct of certification activities.

As required in Annex 16, Volume II, for determining the certification basis for emissions certification of an engine, Contracting States shall use the date of application for a Type Certificate for engines of a type or model which was established by the NAA of the State of Design (either a new Type Certificate or an amendment to an existing Type Certificate). The VA shall use this date when determining the certification basis for validation of this particular engine.

Example: A manufacturer, for which the State of Design is the United States and for which the engine was already certified by the Federal Aviation Administration (FAA), applies for engine type validation in Europe with the European Aviation Safety Agency (EASA) as the VA. The EASA engine emissions Type Certificate basis for the engine validation is based on the date when the engine manufacturer applied for the Type Certificate with the FAA. The certification basis (established by the VA), using their own regulatory standards, is set at the equivalent level as the State of Design's certification basis for this particular engine. This is independent of the Standards that would currently apply for new engine type applications. A more current Standard would only be applied voluntarily, or if it was required as a production Standard according to this Annex.

EXPLANATORY INFORMATION

Period of effectivity of the type certification application

If an application for an engine Type Certificate (either a new Type Certificate or an amendment to an existing one) is required to be extended, then an agreement of what the extension period will be is required. This agreement is made between the engine manufacturer and certifying authority. In practice, the agreement between the engine manufacturer and certifying authority is based on the time period needed for the applicant to provide the complete evidence for compliance to all the relevant airworthiness and environmental Standards. Thus, the new deadline for the Type Certificate date shifts forward by a certain period from the original Type Certificate issuance date. The certification basis is re-established based on this newly forecasted date: newly forecasted date less the effectivity period provides a new date for the certification basis. It is important to note that in the sentence *“When this the period of effectivity is exceeded, 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 the type design, or the date of issue of approval under an equivalent procedure prescribed by the State of Design, less the period of effectivity.”*, “the date of issue of the Type Certificate or...” should be interpreted to be “the deadline of the issue of the Type Certificate or...”

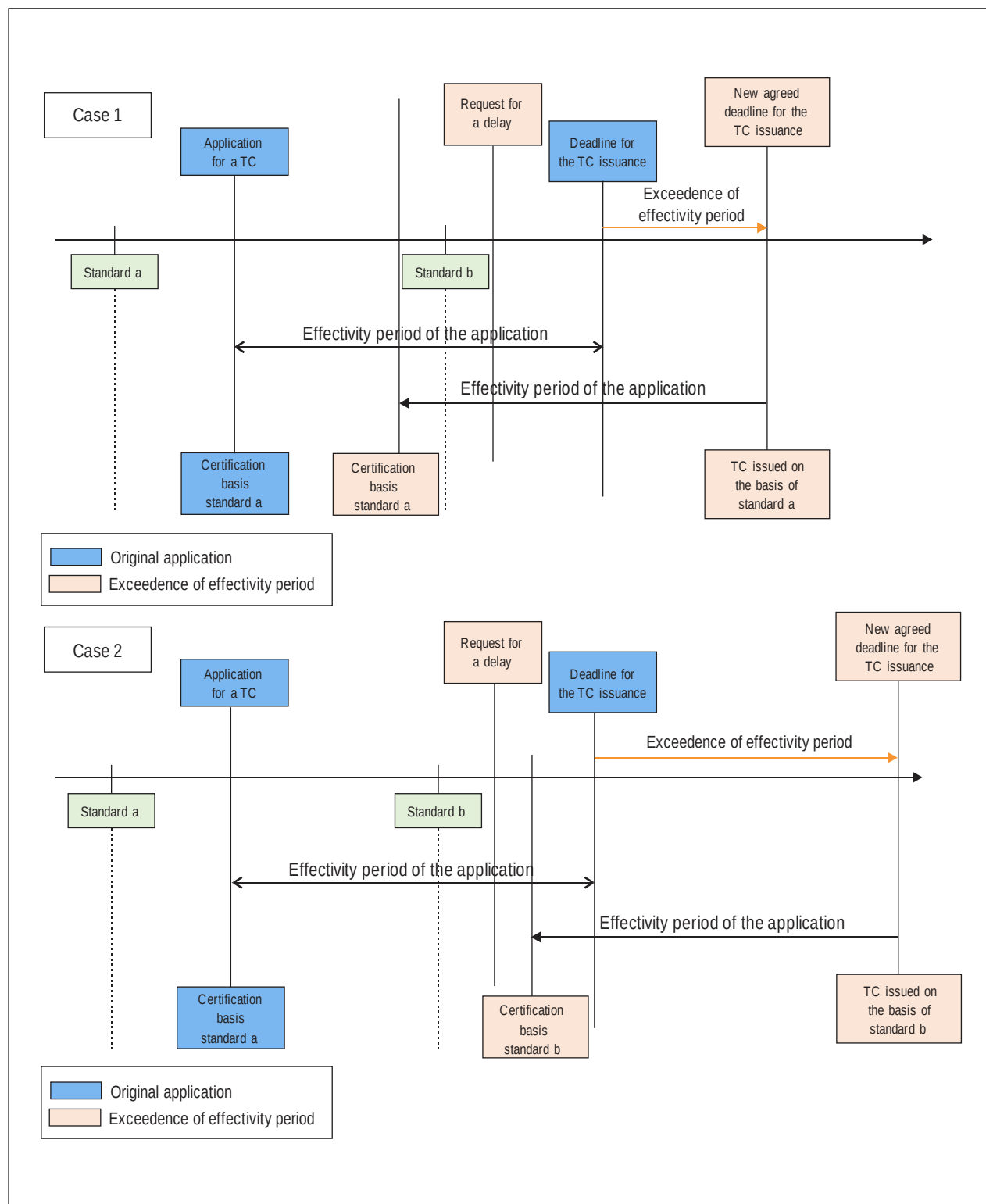
Note that the effectivity period on an application has a fixed duration established by the certifying authorities.

Note that the period of effectivity of the type certification application shall not be confused with the effective date that is part of the ICAO process to amend Annex 16, Volume II (date by which the States must inform of their disagreement with the proposed amendment).

The examples below clarify two cases:

Case 1: An extension of the effectivity period not requiring compliance with a new Standard.

Case 2: An extension of the effectivity period requiring compliance with a new Standard.



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 version² 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. Changes to a certificated engine which are considered to be major from an airworthiness perspective require an amendment or supplement to the Type Certificate. However, these same modifications may have no or very little effect on the emissions characteristics of that engine. If Annex 16, Volume II 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 requirements at any time.

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.

2. *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.



- 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.³ 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:⁴

NOx	±3 grams/kN;
HC	±1 gram/kN;
CO	±5 grams/kN; and
Smoke	±2 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. The method used to determine new characteristic levels will depend on the scope of design change and should be discussed in the manufacturer’s certification plan and approved by the certification authority. The appropriate approach could include a combination of analysis based on test, component test or a new emissions certification test. For example:

- a) Use of calculated emissions values as in Appendix 3, 7.1.3.2, from a previous emissions certification test may be appropriate for a cycle change where combustor inlet conditions are within the range of conditions tested previously.
- b) Use of simple, well documented design correlations may be appropriate for small design changes.

-
- 3. Good engineering judgement means judgement that is consistent with generally accepted scientific and engineering principles and all available relevant information.
 - 4. 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.

- c) Use of more complex analysis methods, such as computational fluid dynamics, may be appropriate if the manufacturer can show that the accuracy of the methods have been validated and approved by the certifying authority and are sufficient for the design change being considered.
- d) A combination of validated analyses supported by combustor rig testing may be acceptable in cases where analysis alone is not sufficient.
- e) A new emissions certification test is required if the accuracy of other analytical and test methods is insufficient.

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 engine⁵ 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); and
- 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 applicable emissions Standards when:

- a) the engine requires a new Type Certificate;
- 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);

5. 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.

- f) there are significant future environmental impacts;⁶ or
- g) an applicant/engine manufacturer elects to comply with a new and/or later Standard of Annex 16, Volume II, as agreed with the certifying authority, provided that the new/later Standard has become applicable (“applicable date” in the foreword of the Annex) and the certifying authority has implemented the new Standard. Certification test data that was approved by the CA to show compliance with an earlier Standard may be used to demonstrate compliance with a new/later Standard, provided that the test engine build Standard and technical details of measurement, sampling and correction have not changed with the revision of the Standard. The formal process of application and approval remains unchanged.

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, d)) and thrust to an accuracy of ± 1 per cent at take-off power and ± 5 per cent at the minimum thrust (f) 1)). It may be that no effect on emissions beyond those prescribed in 1 c) above 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 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.

6. 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.

Boundary conditions

Similar limitations to those for key design characteristics can be applied to those 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 the certificating authority or the competent authority having jurisdiction over the organization responsible for production of the engine grants 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;
- b) a limited number of engines over a specific period of time 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 certificating authority or the competent authority having jurisdiction over the organization responsible for production of the engines, the identification plates on the engines shall be marked “EXEMPT” and the grant of exemption shall be noted in the permanent engine record. The certificating authority or the competent authority having jurisdiction over the organization responsible for production of the engines shall take into account the numbers of exempted engines that will be produced and their impact on the environment. Exemptions shall be reported by engine serial number and made available via an official public register.

Recommendation.— *When such an exemption is granted, the certificating authority or the competent authority having jurisdiction over the organization responsible for production of the engines should consider imposing a time limit on the production of such engines.*

The below “Technical Procedure” on exemptions is valid for both Part III, Chapter 2, section 2.1.1 and Part III, Chapter 4, section 4.1.1. For that reason, it is not specifically duplicated for Part III, Chapter 4, section 4.1.1 in this ETM.

TECHNICAL PROCEDURE

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 production cut-off Standards.

1. Introduction

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

- a) the “date of manufacture of the first individual production model” which refers to the engine type certification;

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

1.2 The reference in 1.1 c) is used in the application of aircraft engine production cut-off Standards which specify a date after which all in-production engine models must meet a certain emissions 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 (e.g. parts).

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.

2. Exemption process

2.1 Application

The applicant should submit to the competent authority⁷ 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 number, Type Certificate date, emissions Type Certificate 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; and
 - 4) designation of whether the proposed exempted engines are “spare engines” or “new engines” (see 2.2 a)) and to whom the engines will be originally delivered (including aircraft type and serial number, if applicable).
- 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:

7. The certifying authority or the competent authority responsible for the production organization of the engine.

- 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 emissions that will be emitted as a result of the exemption, including items such as:
 - the amount that the engine model exceeds the Standards, taking into account any other engine models in the engine family covered by the same Type Certificate and their relation to the Standards;
 - the amount of emissions that would be emitted by an alternative engine for the same application;
 - the impact of changes to reduce emissions 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

- 1) "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 2.1 c). For spare engines, the evaluation of the exemption application would be conducted for record keeping and reporting purposes, but it would not be done for approval of an exemption.
- 2) "New engines" are defined as complete new engine units which are to be installed on new aircraft. They can be exempted from an emissions production cut-off requirement only if they already meet the previous Standard as applicable (e.g. exemption from a CAEP/6 NO_x production cut-off is possible only if an engine type already meets the CAEP/4 NO_x Standard). Also, in order to gain approval for this type of

exemption, applicants must clearly demonstrate that they meet the criteria for an exemption by including items described in 2.1 a), b) and c). The competent authority may require additional information regarding the appropriateness of the potential exemption.

b) Number of engine exemptions

1) “spare engines”

Unlimited number engine exemptions should be granted for spare engines having emissions equivalent to or better than the engines they replace.

2) “new engines”

Exemptions should be based on the total number of engines and the time period for delivery of these engines, which would be agreed at the time the application is approved and based on the considerations explained in 2.1 c). The number of engines exempted would normally not exceed 75 per engine Type Certificate, and the duration would not exceed four years from the effective date of the production cut-off. Exemptions would apply only to non-compliant engine models on an engine Type Certificate. In general, it would be expected that the requested number of engines exempted per engine Type Certificate would be fairly low. However, it is also understood that there may be unique cases in which unforeseen circumstances would result in a need for the number of engines exempted to be well above the limit of 75, up to an absolute maximum of 200. In addition, when the number of engines exempted exceeds what might be considered the tail end of production for an engine type which is going out of production (e.g. more than 30), the manufacturer should endeavour to develop a fix for the exempted engine to bring it into compliance according to a schedule agreed to with the competent authority.

Exemptions for new engines should be processed and approved by the competent authorities for both the manufacture of the exempted engines and the initial operator of the aircraft to which they are to be fitted. Given the international nature of aviation, civil aviation authorities of Member States should attempt to collaborate and consult on the details of exemptions. In the case where engine type certification is done through a reciprocity agreement between Member States, the States involved should coordinate the processing of exemptions and concur before approval is granted.

In cases where an engine is not compliant with the Standard at the date of applicability but where the ultimate goal is compliance with the Standard, the competent authority may consider time-limited exemptions. Time-limited exemptions would define a time period or final date by which the exempted engine would be brought into compliance. The time-limited exemption may also limit the number of engines produced during that timeframe. The competent authority would put a process into place to monitor the technical work progress within the allotted time, consider the consequences of not being able to bring the engine model into compliance, and follow the registration and communication procedures (section 3), as applicable. The consequences of not being able to bring the engine into compliance would be assessed on a case-by-case basis.

2.3 Review

The competent authority should review, in a timely manner, the application using the information provided in 2.1 and against the definitions/criteria in 2.2. The analysis and conclusions from the review should be communicated to the applicant in a formal response. If the application is approved, the response should clearly state the scope of the exemptions which have been granted. If the application is rejected, then the response should include a detailed justification.

3. Registration and communication

Oversight of the granted exemptions should include the following elements:

- a) The competent authority should publish details of the exempted engines in an official public register, including engine model, maximum number of permitted exemptions and use of the engine.
- b) The applicant should have a quality control process for maintaining oversight of and managing the production of engines which have been granted exemptions against an emissions production cut-off Standard.
- c) Exempted engine identification plates should be marked “EXEMPT”.
- d) An exemption should be recorded in the engine release to service document which states conformity with the Type Certificate (e.g. European Aviation Safety Agency (EASA) Form 1, United States Federal Aviation Administration (FAA) Form 8130-3), Transport Canada Civil Aviation (TCCA) Authorized Release Certificate. Proposed standard text: “engine exempted from [*reference to the type of emission*] emissions production cut-off requirement”.
- e) The applicant should provide to the competent authority, on a regular basis and appropriate to the limitation of the approval, details on the actual exempted engines which have been produced (e.g. model, serial number, use of engine, aircraft type and serial number on which “new engines” are installed).

2.1.1.3 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines and which are designed as an integrated propulsive power plant and certified with a rated thrust.

EXPLANATORY INFORMATION

Paragraph 2.1.1.3 anticipates the introduction of future engine technologies. The emissions Standards in Chapter 2 would also be applicable to future engine types not categorized as turbojet or turbofan but intended for use in international air transport services. Turbofan and turbojet engines are considered to be integrated propulsive powerplants, as all components which are required to produce thrust are included in the engine and are part of the package certified. However, other types such as turboprop or turboshaft engines are certified without including the complete train of components which produce thrust and are commonly found on aircraft which are not used in a manner consistent with the turbofan LTO cycle. Since the current regulations are based on rated thrust, they would be applicable only to future engine types which are certified to produce thrust.

2.1.2 Emissions involved
[Reserved]

2.1.3 Units of measurement

EXPLANATORY INFORMATION

Smoke level is determined indirectly by means of the loss of reflectance of a filter used to trap smoke particles from a prescribed mass of exhaust per unit area of filter. The result is a dimensionless Smoke Number “SN” which acts as a surrogate for, or indicator of, plume opacity. These smoke sampling and measurement procedures, standardized in Annex 16, Volume II, Appendix 2, are derived from SAE Aerospace Recommended Practice (ARP) 1179 — *Aircraft Gas Turbine Engine Exhaust Smoke Measurement*.

The smoke measurement Standard was developed for engines that generated smoke at considerably higher levels than are seen today. This affects the relative accuracy of the method. The measurement is considered (by the E-31 Committee of SAE International that developed the method) to be no more accurate than ± 3 SN. At smoke levels of SN 50 to 60 this represents an accuracy of 5 per cent to 6 per cent. At regulatory standards of 30 and below, relative accuracy becomes 10 per cent to 20 per cent, or more.

2.1.4 Reference conditions

2.1.4.1 Atmospheric conditions

EXPLANATORY INFORMATION

The reference atmospheric conditions to which the gaseous emissions (HC, CO and NO_x) are to be corrected are the reference day conditions, as follows: temperature = 15°C, humidity = 0.00634 kg H₂O/kg of dry air, pressure = 101.325 kPa.

There are two terms used for humidity in Annex 16; mass of water vapour per mass of dry air (known as the “mixing ratio” or “mass ratio”) and moles of water vapour per moles of dry air (known as the “mole ratio” or “volume ratio”).

Note that the mass of dry air is used instead of the total air plus water vapour because it is conservative (values do not change) for a change of temperature.

For gas emissions calculation, the humidity term is the mole ratio to be consistent with the other molar terms when solving the gas calculation matrix. To perform the NO_x reference humidity correction, humidity conversion is required from the mole ratio into the mass ratio.

Conversion between mass ratios and mole (or volume) ratios can be performed with the following equations:

$$[\text{mass ratio}] \frac{\text{kg of water vapour}}{\text{kg of dry air}} = 0.622 \times [\text{mole ratio}] \frac{\text{moles of water vapour}}{\text{moles of dry air}}$$

$$[\text{mass ratio}] \frac{\text{kg of water vapour}}{\text{kg of dry air}} = 0.622 \times [\text{volume ratio}] \frac{\text{volume of water vapour}}{\text{volume of dry air}}$$

2.1.4.2 *Thrust settings*
[Reserved]

2.1.4.3 *Reference emissions landing and take-off (LTO) cycle*

EXPLANATORY INFORMATION

The exhaust emissions test is designed to measure hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen concentrations during a simulated aircraft landing and take-off cycle (LTO). The LTO cycle is based on times in mode data during high activity periods at major airports for four modes of engine operation: taxi/idle, take-off, climb-out and approach. The mass emissions for these modes are combined to yield the reported emissions certification levels.

2.1.4.4 *Fuel specifications*

EXPLANATORY INFORMATION

Aircraft gas turbine engines use a variety of fuels. The specific fuel type and composition can, and often do, have a significant effect on engine emissions. Hence, these are important factors when comparing emissions levels from one engine with those from another. It is particularly important in evaluating engine emissions levels relative to a regulation that was based, in part, on an assumed fuel specification. The ICAO fuel specification defined in Appendix 4 is typical, but tighter, than the general Jet A aviation fuel specification. The requirement for emissions certification testing with a fuel that meets a particular specification provides a fixed point of reference for the engine. It provides for some degree of control over the effect of fuel composition on smoke formation and emission. It also helps in the assessment of the effects of changing technology.

2.1.5 Test conditions
[Reserved]

2.2 Smoke

2.2.1 Applicability
[Reserved]

2.2.2 Regulatory Smoke Number
[Reserved]

2.3 Gaseous emissions

2.3.1 Applicability
[Reserved]

2.3.2 Regulatory levels



EXPLANATORY INFORMATION

Paragraphs 2.3.2 a) through e) use the “date of manufacture of the first individual production model” as the applicability date of the Standard. This language was introduced in the second edition of Annex 16, Volume II when a new oxides of nitrogen (NO_x) Standard, applicable to new engine types, was adopted (previous Standards applied to all engines produced after a given date, rather than just new engine types). Because the concept of engine type certification did not exist in the ICAO regulations at that time (the engine being part of the aircraft), it was not possible to relate the NO_x Standards applicability dates for new engine types to the engine type certification process. Since the publication of the first new engine type Standards in the second edition of Annex 16, Volume II, and because the date of manufacture of the first individual production engine is not known at the beginning of the certification process, certifying authorities have used the date of issue of the engine Type Certificate as a surrogate for the date of manufacture of the first individual production model. While using the date of Type Certificate issuance as a surrogate has been helpful, this date is also unknown at the beginning of the certification process and needs to be estimated.

On 10 November 2016, Amendment 105-A to Annex 8 formally introduced the concept of a Type Certificate for engines into the ICAO regulations. This change permitted the introduction of a new applicability date for new engines of a type or model, based on the date of application for the Type Certificate. This new applicability date is included in 2.3.2 f) with the same regulatory levels as in 2.3.2 e). According to 2.3.2 f), “*for engines of a type or model for which an application for a Type Certificate was submitted on or after 1 January 2023*”, certifying authorities will no longer use the date of issue of the engine Type Certificate as a surrogate. For such engines, the Standard applicability date is based on the date of application for a Type Certificate, and no longer on the “date of manufacture of the first individual production model”. To ensure there are no gaps in coverage for engines types or models in development, new text is added to 2.3.2 e) to cover those engines which have not yet reached the point of the manufacture of the first production model but an application for a Type Certificate has been submitted before the effective date of 2.3.2 f).

2.4 Information Required

2.4.1 General information
[Reserved]

2.4.2 Test information
[Reserved]

2.4.3 Derived information

EXPLANATORY INFORMATION

The “maximum Smoke Number” is formally defined as the greatest value of SN measured at any of the four thrust levels defined in 2.1.4.2. However, if a higher Smoke Number is measured at any other test condition between 7 per cent and 100 per cent of rated thrust during emissions certification tests, it is recommended that the higher value be reported as the “maximum Smoke Number”.

CHAPTER 3. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION AT SUPERSONIC SPEEDS

EXPLANATORY INFORMATION

As part of the CAEP/7 work programme, CAEP Working Group 3 (WG3) reviewed the historical background on the development of the emissions Standards for turbojet and turbofan engines intended for propulsion at supersonic speeds and discussed general technology aspects of supersonic engines in comparison to those for subsonic applications. The output of this work was reported in the *Report of the Seventh Meeting of the Committee on Aviation Environmental Protection* (Doc 9886), February 2007.

While further work, taking into account aircraft and engine development, was considered to be necessary to give clear recommendations on future changes to Chapter 3, the following preliminary observations and conclusions were agreed:

- a) The current supersonic Standard seems to be outdated.
- b) The Standard should not be applied to new engine projects.
- c) Part III, Chapter 3, of Annex 16, Volume II needs to be revised.
- d) The timescale for updating should take into account the technological development of any new supersonic transport (SST) engine project and be in line with the work to be undertaken on development of revised noise Standards.
- e) Any alleviation compared to the current subsonic Standard would require detailed technical investigation.
- f) In order for these conclusions to become recommendations, work needs to be completed on whether the current subsonic LTO regulatory approach can be applied to supersonic.
- g) Effects of cruise emissions from a potential fleet of supersonic business jets require more scientific understanding.

WG3 continues to monitor developments within the aviation industry and scientific community on this issue. WG3 has also agreed not to update Chapter 3 until a new SST engine project reaches a sufficiently mature level such that it can inform discussions on potential future revisions.

EXPLANATORY INFORMATION

Based on work in ICAO, it is recognized that additional supersonic engine emissions data would be helpful to inform potential updates to the supersonic engine emissions Standards in Annex 16, Volume II, Part III, Chapter 3. It is highlighted that engine manufacturers may voluntarily measure and report engine emissions according to the Chapters 2 and 4 subsonic LTO cycle. The engine manufacturer is encouraged to offer the broader set of emissions data spanning Chapters 2, 3 and 4 to support discussions in ICAO/CAEP for the purpose of updating the supersonic engine emissions Standards in Annex 16, Volume II, Part III, Chapter 3.

CHAPTER 4. PARTICULATE MATTER EMISSIONS

4.1 General

4.1.1 Applicability

The “Technical Procedure” on exemptions for Part III, Chapter 4, 4.1.1 can be found under Part III, Chapter 2, section 2.1.1 in this ETM.

4.1.2 Emissions involved [Reserved]

4.1.3 Units of measurement [Reserved]

4.1.4 Reference conditions

4.1.4.1 *Atmospheric conditions* [Reserved]

4.1.4.2 *Reference emissions landing and take-off (LTO) cycle* [Reserved]

4.1.4.3 *Fuel specifications* [Reserved]

4.1.5 Test conditions [Reserved]

4.2 Non-volatile particulate matter emissions

4.2.1 Applicability

4.2.1.1 [Reserved]

4.2.1.2 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines and which are designed as an integrated propulsive powerplant and certified with a rated thrust.

EXPLANATORY INFORMATION

Paragraph 4.2.1.2 anticipates the introduction of future engine technologies. The emissions Standards in Chapter 4 would also be applicable to future engine types not categorized as turbojet or turbofan but intended for use in

international air transport services. Turbofan and turbojet engines are considered to be integrated propulsive power plants, as all components which are required to produce thrust are included in the engine and are part of the package certified. However, other types such as turboprop or turboshaft engines are certified without including the complete train of components which produce thrust and are commonly found on aircraft which are not used in a manner consistent with the turbofan LTO cycle. Since the current regulations are based on rated thrust, they would be applicable only to future engine types which are certified to produce thrust.

4.2.2 Regulatory levels

4.2.2.1 *Maximum nvPM mass concentration*

EXPLANATORY INFORMATION

The characteristic level for the maximum nvPM mass concentration should be reported in micrograms/m³ with no decimals.

EXPLANATORY INFORMATION

Since there is a correlation between nvPM mass concentration and Smoke Number, the regulatory level in 4.2.2.1 was derived from the Smoke Number regulatory level.

nvPM mass measurements have proven that maximum nvPM mass concentration is correlated to Smoke Number (SN). Based on the correlation developed using simultaneous measurements of nvPM mass concentration and SN, the maximum mass concentration value must be below the 4.2.2.1 regulatory level for visibility purposes. The SN measured used the fuel, as specified in Appendix 4, with a hydrogen content of 13.4 to 14.3 per cent preserved the visibility criterion without any fuel composition correction to a reference hydrogen content.

TECHNICAL PROCEDURE

In order to determine the maximum nvPM concentration, it is recommended that one of the following averaging approaches be used:

- 1) Average the individual data points at each T3 to develop one dataset for each engine tested. Then average the engine datasets at each T3, whereupon a curve fit should be developed to find the overall average maximum concentration. T3 values within +/- 6 degrees F are considered common.
- 2) Develop a single, separate curve fit of nvPM concentration vs T3 for each engine tested using all datasets from that engine. For each engine tested, find the maximum from the curve fit. Average the maximum values from all engines tested to find the overall average maximum concentration.
- 3) Develop curve fits of nvPM concentration vs T3 for each individual dataset and find the maxima for each curve fit. Average the maxima values for each engine tested, and then average all engine values to find the overall average maximum concentration.

Variants of these approaches that yield equivalent results could be deemed acceptable subject to the approval of the certifying authority.