



**WORKING PAPER**

**COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)**

**EIGHTH MEETING**

**Montréal, 1 to 12 February 2010**

**Agenda Item 2: Review of technical proposals relating to aircraft engine emissions**

**PROPOSED CHANGES TO ANNEX 16, VOLUME II**

(Presented by Rapporteurs of WG3)

**SUMMARY**

The Working Paper describes proposed changes to ICAO Annex 16, Vol II as the result of the work carried out by the Working Group under the current Work Programme, in fulfilment of remit E.06.

Action by the CAEP is in paragraph 4.

**1. INTRODUCTION**

1.1 The CAEP/8 work programme included task E.06 that requested WG3 to maintain the ICAO Annex 16 Vol II while taking account of updates to SAE-E31 documentation.

1.2 WG3 remitted this to the Certification Task Group (CTG) that agreed to set up an Annex 16 ad-hoc group to take forward this work principally through telecons in between WG3 meetings. The ad-hoc group has held a total of 17 telecons and this paper provides an overview of the main issues that has been considered since CAEP/7.

1.3 Appendix A provides background information to clarify why the changes have been made. Appendix B indicates the specific changes proposed to Annex 16 Vol II, 3<sup>rd</sup> Edition, Amendment 6.

**2. OVERVIEW OF MAIN ISSUES CONSIDERED**

2.1 The following table provides the list of work items that the CTG / Annex 16 ad-hoc group has dealt with.

Item 1.	Clarify certification criteria applicable to modification of currently certified engines - output was proposed ETM text ( <i>see ETM paper CAEP/8-WP/18</i> )
Item 2.	Update ANSI and ARP standards on reflectometers and reflectance measurement
Item 3.	Editorial edits to CAEP 7 amendments and review of Annex 16 structure
Item 4.	Develop dilution correction procedures for smoke number measurements - output was proposed ETM text ( <i>see ETM paper CAEP/8-WP/18</i> )
Item 5.	Harmonise terminology “variation in the procedure” and “equivalent procedure”
Item 6.	Review HC Analyser specifications
Item 7.	Review humidity measurement requirements
Item 8	Exemptions from NO <sub>x</sub> production cut-off
Item 9	Changes related to NO <sub>x</sub> stringency increase

2.2 CTG has completed all items, except 6 and 7, and made proposals for changes to the Annex (Items 3, 5, 8 & 9) or to the associated Environmental Technical Manual (Items 1, 2 & 4).

### 3. DESCRIPTION OF CHANGES

#### 3.1 Work Item 2: Reflectometer standards

3.1.1 CAEP/7 agreed to replace the no longer existing ANSI PH2.17 standard by a reference to the equivalent ISO 5-4 standard. The group was tasked to review whether this change in reference would have any repercussions with respect to the instruments currently in use. The conclusion from a comparative review of several revisions of ANSI standards, ARP 1179 revisions with ISO 5-3, and ISO 5-4, was that all requirements cover basically the same standards and existing manufacturer’s reflectometers conform to ISO 5-4.

3.1.2 There is no need to change or amend current wording in Annex 16. In order to harmonise Annex 16 Vol II with ARP 1179 rev. C on the use of filters, some guidance text for the ETM is proposed.

#### 3.2 Work Item 3: Annex 16 Vol II edits

3.2.1 A few editorial issues, prior to the publication of Amendment 6, were clarified with the ICAO secretariat early in CAEP/8 and are not mentioned further in this paper.

3.2.2 Further edits with regard to typos and moving of paragraphs to more appropriate places were identified and are detailed in the list of changes (Appendix B).

### **3.3 Work Item 5: Harmonisation of terminology**

3.3.1 In linking the Annex 16 Vol II certification requirements with the emissions ETM guidance, CAEP7 requested WG3 to consider harmonisation of the wording “variations in procedures” within Annex 16 Vol II and “equivalent procedures” in the ETM. The initial proposal to simply replace the Annex 16 Vol II text “variations in the procedure” by “equivalent procedure” had raised some concerns on the meaning of the first.

3.3.2 A review of old (including pre-) CAEP documents was performed to provide a better understanding of the origins of this terminology. While there was no clear definition from the review, the group concluded that the term “variations in procedures” meant, in essence, the same as “equivalent procedures”. Any deviation to the procedures in the Annex 16 Vol II would need to be considered as equivalent in order for the certificating authority to approve the product against the requirements. The group concluded that the term “variations in procedure” is effectively the same as “equivalent procedure” which is defined in the ETM.

### **3.4 Work Item 6: HC analyser specifications**

3.4.1 In reviewing Annex 16, Vol II, Appendix 3, Attachment A, the group found inconsistencies with SAE ARP 1256C on the operating temperatures of the Total Hydrocarbon Analyzer. While Attachment A requires oven housing temperatures between 155 °C and 165°C to a stability of  $\pm 2$  °C, ARP 1256C requires a constant temperature above 160°C should be maintained. As this discrepancy has caused difficulties in past certification projects the group is aiming to, in coordination with SAE E-31, harmonise the requirements.

3.4.2 Experience from past certification projects has confirmed that some manufacturer equipment feature oven temperatures higher than 165°C and that manufacturers have had to declare deviations from Annex 16 Vol II while still being in line with ARP 1256.

3.4.3 SAE E-31 has been contacted and they have initiated work to revisit ARP 1256 and ARP 1179 with the aim to achieve a harmonized approach. This work will continue during CAEP/9 and no Annex 16 revisions are related to this work at this time. For the time being guidance material has been developed for the ETM with respect to the HC analyser.

### **3.5 Work Item 7: Humidity measurements**

3.5.1 This work item had been added to the list at the final Meeting in London. ICCAIA have requested a review of the Annex 16 Vol II humidity measurement requirements which state that they must be within 15m of the intake plane of the engine (Attachment F). This has already caused difficulties in past engine projects and is stricter than that used for performance measurements. Some initial work has been started but not yet finished. It is proposed to carry this work over to the CAEP/9 work programme.

### **3.6 Work Item 8: NOx production cut-off**

3.6.1 In order to implement a potential CAEP/6 NOx production cut-off Annex 16, Vol II, Chapter 2, paragraph 2.3.2 (d) needs to be amended to cover for the ceasing “date of manufacture of the individual production engine” which is subject to CAEP/8 discussions and agreement.

3.6.2 Any exemptions from a potential CAEP/6 NOx production cut off requirement need to be applied uniformly. Specific guidance on the evaluation process and criteria has been developed for the

ETM. In order to link these guiding rules with the Annex a few changes will be necessary. Various amendments are proposed to link the Annex 16 requirements on this issue with the associated guidance in the ETM.

### 3.7 **Work Item 9: CAEP/8 NOx stringency**

3.7.1 Any potential increase in NOx stringency that may be agreed at CAEP/8 will need to be included in Annex 16 Vol II. Paragraph 2.3.2 *Regulatory levels* would be amended by a subparagraph:

a) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December xxxx:

1) *for engines with a pressure ratio of 30 or less:*

i) *for engines with a maximum rated thrust of more than 89.0 kN:*

.....

3.7.2 The structure of this paragraph is dependent on the agreed stringency option, however it would be similar to subparagraph d) containing applicability dates and subsequent formulae.

## 4. **ACTION BY THE CAEP**

4.1 The CAEP is invited to:

a) take note that ICAO Annex 16, Vol II needs to be changed in order to provide an updated and more consistent text reflecting current certification practice; and

b) approve proposed changes to Annex 16, Vol II as presented in Appendix B.

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APPENDIX A

LIST OF PROPOSED CHANGES TO ANNEX 16, VOLUME II

Item Number	Characterisation of change	Affected paragraphs	Remarks
1	<p>Insert the definition of</p> <p><i>Exhaust nozzle</i>. 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</p>	Part I, Chapter 1 Definitions	This definition is moved from Appendix 3, paragraph 2 to Part I, Chapter 1 as it is generally applicable
2	<p>Insert new paragraph</p> <p>1.5 Contracting States shall recognise as valid emissions exemptions against a production cut-off requirement granted by a certificating authority of another Contracting State provided that the exemptions are granted in accordance with the process and criteria defined in the Environmental Technical Manual (ICAO Doc. 9501 Volume II).</p>	Part III, Chapter 1 Administration	This insert is related to exemptions and necessary to provide a link to the ETM which details the process and criteria for such exemptions
3	<p>Insert time criteria for issuing exemptions. Paragraph reads:</p> <p>b) a limited number of engines <b>over a specific period of time</b> beyond the dates of applicability specified in 2.2 and 2.3 for the manufacture</p>	Part III, Chapter 2, paragraph 2.1.1.1 b)	Provide consistency with criteria and process for exemptions as agreed within the ETM

Item Number	Characterisation of change	Affected paragraphs	Remarks
	of the individual engine.		
4	<p>Insert the highlighted text into existing paragraph:</p> <p>2.1.1.2 In such cases, an exemption document shall be issued by the certificating authority, the identification plates on the engines shall be marked “EXEMPT NEW” or “EXEMPT SPARE,” and the grant of exemption shall be noted in the permanent engine record. Exemptions shall be reported by engine serial number and made available via an official public register.</p>	Part III, Chapter 2, paragraph 2.1.1.2	Provide consistency with criteria and process for exemptions as agreed within the ETM
5	<p>Amend the Note below Para 2.1.1.3 with the following sentence:</p> <p><i>Further guidance on issuing exemptions is provided in the Environmental Technical Manual (Doc. No. 9501 Volume II)</i></p>	Para 2.1.1.3	This insert is related to exemptions and necessary to provide a link to the ETM which details the process and criteria for such exemptions
6	<p>A part of the text in the paragraph was deleted to read:</p> <p>The fuel used during tests shall meet the specifications of Appendix 4</p>	Para 2.1.4.4 Fuel specification	Material regarding fuel specification is now dealt within Appendix 4 exclusively
7	<p>Insert the highlighted text into existing paragraph:</p> <p>The Smoke Number at any of the four LTO operating mode thrust settings when measured and computed in accordance with the procedures of Appendix 2, or an equivalent procedure as agreed by the certificating authority, and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level ...</p>	Para 2.2.2 Regulatory SN	This insert is to provide a link to the ETM with respect to any equivalent procedures. This change has been proposed at CAEP/7 but not decided as the ETM was not published at that time.
8	Insert the following Note at the end of this paragraph:	Para 2.2.2	See above

Item Number	Characterisation of change	Affected paragraphs	Remarks
	<i>Note. - Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual - Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines (Doc. No.9501 Volume II).</i>		
9	<p>Insert the highlighted text into existing paragraph:</p> <p>Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 and converted to characteristic levels by the procedures of Appendix 6, <b>or an equivalent procedure as agreed by the certifying authority</b>, shall not exceed the regulatory levels ...</p>	<p>Part III, Chapter 2, Para 2.3.2 Regulatory levels</p>	<p>This insert is to provide a link to the ETM with respect to any equivalent procedures. This change has been proposed at CAEP/7 but not decided as the ETM was not published at that time.</p>
10	<p>Insert the following Note at the end of this paragraph:</p> <p><i>Note. - Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual - Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines (Doc. No.9501 Volume II)</i></p>	<p>Para 2.3.2</p>	<p>See above</p>
11	<p>Amend paragraph 2.3.2 d) to add</p> <p>...and for which the date of manufacture of the individual engine was on or after 31 December xxxx:</p> <p>...</p>	<p>Para 2.3.2 d)</p>	<p>This insert is necessary in case of a CAEP/6 non-production rule for NOx</p>
12	<p>Insert new paragraph 2.3.2 e) as following</p> <p>e) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December xxxx:</p> <p>1) for engines with a pressure ratio of 30 or less:</p>	<p>Para 2.3.2 e)</p>	<p>This insert is necessary in case of a new CAEP/8 NOx Standard</p>

Item Number	Characterisation of change	Affected paragraphs	Remarks
	<p>i) for engines with a maximum rated thrust of more than 89.0 kN:</p> <p>...</p>		
13	Replace the words “Variations in the procedure” by the words “Any equivalent procedures to those”	Appendix 2, Para 1.1	This change is to provide consistency between ETM and Annex 16 language
14	<p>A part of the text in the paragraph was deleted to read:</p> <p>The fuel shall meet the specifications of Appendix 4.</p>	Appendix 2, Para 2.4	Material regarding fuel specification is now dealt within Appendix 4 exclusively
15	Replace the words “metre” by “meter”	Appendix 2, Para 2.5.3	Type error
16	Replace “pascal” by “Pascal” and “kelvin” by “Kelvin”	Appendix 2, Para 3.	Capital letter
17	Replace the words “Variations in the procedure” by the words “Any equivalent procedures to those”	Appendix 3, Para 1	This change is to provide consistency between ETM and Annex 16 language
18	Delete “Exhaust nozzle” definition	Appendix 3, Para 2	Definition is moved to Part I, Chapter 1
19	<p>Change “n” from subscript to normal script</p> <p>Thrust at LTO operating mode, <math>n</math>, (kN)</p>	Appendix 3, Para 7.2.1	Formatting error

<b>Item Number</b>	<b>Characterisation of change</b>	<b>Affected paragraphs</b>	<b>Remarks</b>
20	Insert the following text after the headline:  The fuel shall meet the specifications of this Appendix 4, unless a deviation and any necessary corrections have been agreed by the certificating authority. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.	Appendix 4	This is text that was agreed at CAEP/7 but was forgotten to be included in Amendment 6.

**APPENDIX B**  
**PROPOSED AMENDMENTS TO THE**  
**INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES**  
**ENVIRONMENTAL PROTECTION**  
**ANNEX 16**  
**TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION**  
**VOLUME II**  
**AIRCRAFT ENGINE EMISSIONS**

**1. INTRODUCTION**

1.1 The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

- |   |                                   |
|---|-----------------------------------|
| 1. <del>Text to be deleted is shown with a line through it.</del>   | text to be deleted                |
| 2. <b>New text to be inserted is highlighted with grey shading.</b>   | new text to be inserted           |
| 3. <del>Text to be deleted is shown with a line through it</del> followed by the replacement text which is highlighted with grey shading. | new text to replace existing text |

**TEXT OF PROPOSED AMENDMENTS TO THE  
INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES  
ENVIRONMENTAL PROTECTION  
ANNEX 16  
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION  
VOLUME II  
AIRCRAFT ENGINE EMISSIONS**

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**PART I. DEFINITIONS AND SYMBOLS**

**CHAPTER 1. DEFINITIONS**

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Note.— Attention is drawn to the difference between the definition of a derived version of an aeroplane in Volume I of Annex 16 and the definition of a derivative version in this Volume.

*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.

*Oxides of nitrogen.* The sum of the amounts of the nitric oxide and nitrogen dioxide contained in a gas sample calculated as if the nitric oxide were in the form of nitrogen dioxide.

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**PART 111. EMISSIONS CERTIFICATION**

**CHAPTER 1. ADMINISTRATION**

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1.4 Contracting States shall recognize as valid emissions certification granted by the certifying authority of another Contracting State provided that the requirements under which such certification was granted are not less stringent than the provisions of Volume II of this Annex.

1.5 Contracting States shall recognise as valid emissions exemptions against a production cut-off requirement granted by a certifying authority of another Contracting State provided that the

exemptions are granted in accordance with the process and criteria defined in the Environmental Technical Manual (ICAO Doc. 9501 Volume II).

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## CHAPTER 2. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

### 2.1 General

#### 2.1.1 Applicability

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 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 certifying authority, the identification plates on the engines shall be marked “EXEMPT NEW” or “EXEMPT SPARE,” and the grant of exemption shall be noted in the permanent engine record. Exemptions shall be reported by engine serial number and made available via an official public register.

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.

*Note.— In considering exemptions, certifying authorities should take into account the probable numbers of such engines that will be produced and their impact on the environment. When such an exemption is granted, the certifying authority should consider imposing a time limit on the production of such engines for installation on new aircraft or on existing aircraft as spares.. Further guidance on issuing exemptions is provided in the Environmental Technical Manual (Doc. No. 9501 Volume II)*

...

#### 2.1.4.4 Fuel specifications

The fuel used during tests shall meet the specifications of Appendix 4, ~~unless a deviation and any necessary corrections have been agreed by the certifying authority.~~ Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

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## 2.2 Smoke

### 2.2.1 Applicability

The provisions of 2.2.2 shall apply to engines whose date of manufacture is on or after 1 January 1983.

### 2.2.2 Regulatory Smoke Number

The Smoke Number at any of the four LTO operating mode thrust settings when measured and computed in accordance with the procedures of Appendix 2, or an equivalent procedure as agreed by the certifying authority, and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level determined from the following formula:

$$\text{Regulatory Smoke Number} = 83.6 (F_{oo})^{-0.274}$$

or a value of 50, whichever is lower

*Note. - Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual - Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines (Doc. No.9501 Volume II).*

## 2.3 Gaseous emissions

### 2.3.1 Applicability

The provisions of 2.3.2 shall apply to engines whose rated thrust is greater than 26.7 kN and whose date of manufacture is on or after 1 January 1986 and as further specified for oxides of nitrogen.

### 2.3.2 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 and converted to characteristic levels by the procedures of Appendix 6, or an equivalent procedure as agreed by the certifying authority, shall not exceed the regulatory levels determined from the following formulas:

...

d) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 2007 and for which the date of manufacture of the individual engine was on or after 31 December xxxx :

...

e) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December xxxx:

1) for engines with a pressure ratio of 30 or less:

i) for engines with a maximum rated thrust of more than 89.0 kN:

.....

Note. - Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual - Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines (*Doc. No.9501 Volume II*).

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## APPENDIX 2. SMOKE EMISSION EVALUATION

### 1. INTRODUCTION AND DEFINITIONS

Note.— The procedures specified here are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system.

1.1 Any equivalent procedures to those Variations in the procedure contained in this Appendix shall only be allowed after prior application to and approval by the certifying authority.

1.2 Where the following expressions and symbols are used in this Appendix, they have the meanings ascribed to them below:

...

### 2. MEASUREMENT OF SMOKE EMISSIONS

#### 2.4 Fuel specifications

The fuel shall meet the specifications of Appendix 4. ~~Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.~~

...

#### 2.5.3 Smoke measurement

...

h) the chosen sample sizes shall be such as to be within the range of 12 kg to 21 kg of exhaust gas per square ~~metre~~ meter of filter, and shall include samples which are either at the value of 16.2 kg of exhaust gas per square ~~metre~~ meter of filter or lie above and below that value. The number of samples at each engine operating condition shall not be less than 3 and e) to g) shall be repeated as necessary.

...

### 3. CALCULATION OF SMOKE NUMBER FROM MEASURED DATA

...

The masses of the various samples shall be calculated by

$$W = 0.348 PV/T \times 10^{-2}(\text{kg})$$

where P and T are, respectively, the sample pressure in ~~paseals~~ Pascal and the temperature in ~~kelvin~~ Kelvin, measured immediately upstream of the volume meter. V is the measured sample volume in cubic ~~metres~~ meters.

...

### APPENDIX 3. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS

#### 1. INTRODUCTION

Note.— The procedures specified in this appendix are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system. The procedures do not apply to engines employing afterburning. The methods proposed are representative of the best readily available and most established practice.

~~Variations in the procedure~~ Any equivalent procedures to those contained in this appendix shall only be allowed after prior application to and approval by the certificating authority.

#### 2. DEFINITIONS

...

Concentration. The volume fraction of the component of interest in the gas mixture — expressed as volume percentage or as parts per million.

~~Exhaust nozzle. In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.~~

Flame ionization detector. A hydrogen-air diffusion flame detector that produces a signal nominally proportional to the mass-flow rate of hydrocarbons entering the flame per unit of time — generally assumed responsive to the number of carbon atoms entering the flame.

...

**APPENDIX 4. SPECIFICATION FOR FUEL TO BE USED IN  
AIRCRAFT TURBINE ENGINE EMISSION TESTING**

The fuel shall meet the specifications of this Appendix 4, unless a deviation and any necessary corrections have been agreed by the certificating authority. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

...

— END —