If this recommended method for the CO and HC emissions index correction does not provide a satisfactory correlation, an alternative method using parameters derived from component tests may be used.

Any other methods used for making corrections to CO, HC and NO_x emission indices shall have the approval of the certificating authority.

7.2 Control parameter functions (D_p, F_{oo}, π)

7.2.1 Definitions

- D_p The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle.
- *F_{oo}* Rated thrust (see Part I, Chapter 1, Definitions)
- F_n Thrust at LTO operating mode n (kN)
- W_f Fuel mass flow rate of the reference standard engine under ISA sea level conditions (kg/s).
- W_{f_n} Fuel mass flow rate of the reference standard engine under ISA sea level conditions at LTO operating mode *n*.
- π The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating at ISA sea level static conditions.

7.2.2 The emissions indices (EI_n) for each pollutant, corrected to reference atmospheric conditions and, if necessary, to the reference standard engine, (EI_n (corrected)), shall be obtained for each LTO operating mode. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined under reference atmospheric conditions for each gaseous emission:

- a) between EI (corrected) and T_B ; and
- b) between W_f and T_B ; and
- c) between F and T_B ;

Note 1.— These are illustrated, for example, by Figure A3-2 a), b) and c).

Note 2.— The relationships b) and c) may be established directly from engine test data, or may be derived from a validated engine performance model.

7.2.2.1 A reference engine is defined as an engine substantially configured to the production standard of the engine type and with fully representative operating and performance characteristics.

7.2.2.2 The manufacturer shall also supply to the certificating authority all of the necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:

- a) rated thrust (F_{oo}) ; and
- b) engine pressure ratio (π) at maximum rated thrust.

Note.— These are illustrated by Figure A3-2 d).

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Figure A3-2. Calculation procedure



7.2.3 The estimation of EI (corrected) for each gaseous emission at the four LTO operating modes shall comply with the following general procedure:

- a) determine the combustor inlet temperature (T_B) (Figure A3-2 c)) at the values of F_n corresponding to the four LTO operating modes, *n* under reference atmospheric conditions;
- b) from the EI (corrected)/ T_B characteristic (Figure A3-2 a)), determine the EI_n value corresponding to T_B ;
- c) from the W_f/T_B characteristic (Figure A3-2 b)), determine the W_{f_n} value corresponding to T_B;
- d) note the ISA maximum rated thrust and pressure ratio values. These are F_{oo} and π respectively (Figure A3-2 d));
- e) calculate, for each pollutant $D_p = \Sigma (EI_n) (W_{f_n}) (t)$ where:
 - *t* time in LTO mode (minutes)
 - W_{f_n} fuel mass flow rate (kg/min)
 - Σ is the summation for the set of modes comprising the reference LTO cycle.

7.2.4 While the methodology described above is the recommended method, the certificating authority may accept equivalent mathematical procedures which utilize mathematical expressions representing the curves illustrated if the expression have been derived using an accepted curve fitting technique.

7.3 Exceptions to the proposed procedures

In those cases where the configuration of the engine or other extenuating conditions exist which would prohibit the use of this procedure, the certificating authority, after receiving satisfactory technical evidence of equivalent results obtained by an alternative procedure, may approve an alternative procedure.

ATTACHMENT A TO APPENDIX 3. SPECIFICATION FOR HC ANALYSER

Note 1.— As outlined in 5.2 of Appendix 3, the measuring element in this analyser is the flame ionization detector (FID) in which the whole or a representative portion of the sample flow is admitted into a hydrogen-fuelled flame. With suitably positioned electrodes an ionization current can be established which is a function of the mass rate of hydrocarbon entering the flame. It is this current which, referred to an appropriate zero, is amplified and ranged to provide the output response as a measure of the hydrocarbon concentration expressed as ppmC equivalent.

Note 2.— See Attachment D for information on calibration and test gases.

1. GENERAL

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The instrument to be used shall be such as to maintain the temperature of the detector and sample-handling components at a set point not less than 150°C. The leading specification points shall be as follows, the detector response having been optimized and the instrument generally having stabilized:

- a) Total range: 0 to 5 000 ppmC in appropriate ranges.
- b) *Resolution:* better than 0.5 per cent of full scale of range used or 0.5 ppmC, whichever is greater.
- c) *Repeatability:* better than ± 1 per cent of full scale of range used, or ± 0.5 ppmC, whichever is greater.
- d) Stability: better than ± 2 per cent of full scale of range used or ± 1.0 ppmC, whichever is greater, in a period of 1 hour.
- e) Zero drift: less than ± 1 per cent of full scale of range used or ± 0.5 ppmC, whichever is greater, in a period of 1 hour.
- f) Noise: 0.5 Hz and greater, less than ± 1 per cent of full scale of range used or ± 0.5 ppmC, whichever is greater.
- g) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.
- h) *Linearity:* response with propane in air shall be linear for each range within ± 2 per cent of full scale, otherwise calibration corrections shall be used.

2. SYNERGISTIC EFFECTS

Note.— In application there are two aspects of performance which can affect the accuracy of measurement:

a) the oxygen effect (whereby differing proportions of oxygen present in the sample give differing indicated hydrocarbon concentration for constant actual HC concentrations); and

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b) the relative hydrocarbon response (whereby there is a different response to the same sample hydrocarbon concentrations expressed as equivalent ppmC, dependent on the class or admixture of classes of hydrocarbon compounds).

The magnitude of the effects noted above shall be determined as follows and limited accordingly.

Oxygen response: measure the response with two blends of propane, at approximately 500 ppmC concentration known to a relative accuracy of ± 1 per cent, as follows:

- a) propane in 10 ± 1 per cent O₂, balance N₂
- b) propane in 21 \pm 1 per cent O₂, balance N₂

If R_1 and R_2 are the respective normalized responses then $(R_1 - R_2)$ shall be less than 3 per cent of R_1 .

Differential hydrocarbon response: measure the response with four blends of different hydrocarbons in air, at concentrations of approximately 500 ppmC, known to a relative accuracy of ± 1 per cent, as follows:

- a) propane in zero air
- b) propylene in zero air
- c) toluene in zero air
- d) n-hexane in zero air.

If R_a , R_b , R_c and R_d are, respectively, the normalized responses (with respect to propane), then $(R_a - R_b)$, $(R_a - R_c)$ and $(R_a - R_d)$ shall each be less than 5 per cent of R_a .

3. OPTIMIZATION OF DETECTOR RESPONSE AND ALIGNMENT

3.1 The manufacturer's instructions for initial setting up procedures and ancillary services and supplies required shall be implemented, and the instrument allowed to stabilize. All setting adjustments shall involve iterative zero checking, and correction as necessary. Using as sample a mixture of approximately 500 ppmC of propane in air, the response characteristics for variations first in fuel flow and then, near an optimum fuel flow, for variations in dilution air flow to select its optimum shall be determined. The oxygen and differential hydrocarbon responses shall then be determined as indicated above.

3.2 The linearity of each analyser range shall be checked by applying propane in air samples at concentrations of approximately 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line (fitted to the points and zero) shall not exceed ± 2 per cent of full scale value. If it does, a calibration curve shall be prepared for operational use.

ATTACHMENT B TO APPENDIX 3. SPECIFICATION FOR CO AND CO₂ ANALYSERS

Note 1.— Paragraph 5.3 of Appendix 3 summarizes the characteristics of the analysis subsystem to be employed for the individual measurements of CO and CO_2 concentrations in the exhaust gas sample. The instruments are based on the principle of non-dispersive absorption of infrared radiation in parallel reference and sample gas cells. The required ranges of sensitivity are obtained by use of stacked sample cells or changes in electronic circuitry or both. Interferences from gases with overlapping absorption bands may be minimized by gas absorption filters and/or optical filters, preferably the latter.

Note 2.— See Attachment D for information on calibration and test gases.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The principal performance specification shall be as follows:

CO Analyser

- a) *Total range:* 0 to 2 500 ppm in appropriate ranges.
- b) *Resolution:* better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.
- c) Repeatability: better than ± 1 per cent of full scale of range used, or ± 2 ppm, whichever is greater.
- d) Stability: better than ± 2 per cent of full scale of range used or ± 2 ppm, whichever is greater, in a period of 1 hour.
- e) Zero drift: less than ± 1 per cent of full scale of range used or ± 2 ppm, whichever is greater, in a period of 1 hour.
- f) Noise: 0.5 Hz and greater, less than ± 1 per cent of full scale of range used or ± 1 ppm, whichever is greater.
- g) Interferences: to be limited with respect to indicated CO concentration as follows:
 - 1) less than 500 ppm/per cent ethylene concentration
 - 2) less than 2 ppm/per cent CO_2 concentration
 - 3) less than 2 ppm/per cent water vapour.*

If the interference limitation(s) for CO₂ and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

Note.— It is recommended, as consistent with good practice, that such correction procedures be adopted in all cases.

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^{*} Need not apply where measurements are on a "dry" basis.

CO₂ Analyser

- a) Total range: 0 to 10 per cent in appropriate ranges.
- b) *Resolution:* better than 0.5 per cent of full scale of range used or 100 ppm, whichever is greater.
- c) Repeatability: better than ± 1 per cent of full scale of range used or ± 100 ppm, whichever is greater.
- d) Stability: better than ± 2 per cent of full scale of range used or ± 100 ppm, whichever is greater, in a period of 1 hour.
- e) Zero drift: less than ± 1 per cent of full scale of range used or ± 100 ppm, whichever is greater, in a period of 1 hour.
- f) Noise: 0.5 Hz and greater, less than ± 1 per cent of full scale of range used or ± 100 ppm, whichever is greater.
- g) The effect of oxygen (O_2) on the CO₂ analyser response shall be checked. For a change from 0 per cent O_2 to 21 per cent O_2 , the response of a given CO₂ concentration shall not change by more than 2 per cent of reading. If this limit cannot be met an appropriate correction factor shall be applied.

Note.— It is recommended, as consistent with good practice, that such correction procedures be adopted in all cases.

CO and CO₂ Analysers

- a) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.
- b) Sample temperature: the normal mode of operation is for analysis of the sample in its (untreated) "wet" condition. This requires that the sample cell and all other components in contact with the sample in this subsystem be maintained at a temperature of not less than 50°C, with a stability of $\pm 2^{\circ}$ C. The option to measure CO and CO₂ on a dry basis (with suitable water traps) is allowed, in which case unheated analysers are permissible and the interference limits for H₂O vapour removed, and subsequent correction for inlet water vapour and water of combustion is required.
- c) *Calibration curves:*
 - Analysers with a linear signal output characteristic shall be checked on all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line, fitted to the points and the zero reading, shall not exceed ±2 per cent of the full scale value. If it does then a calibration curve shall be prepared for operational use.
 - 2) Analysers with a non-linear signal output characteristic, and those that do not meet the requirements of linearity given above, shall have calibration curves prepared for all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. Additional mixes shall be used, if necessary, to define the curve shape properly.

ATTACHMENT C TO APPENDIX 3. SPECIFICATION FOR NO_x ANALYSER

Note.— See Attachment D for information on calibration and test gases.

1. As indicated in 5.4 of Appendix 3, the measurement of the oxides of nitrogen concentration shall be by the chemiluminescent technique in which radiation emitted by the reaction of NO and O_3 is measured. This method is not sensitive to NO₂ and therefore the sample shall be passed through a converter in which NO₂ is converted to NO before the measurement of total NO_x is made. Both the original NO and the total NO_x concentrations shall be recorded. Thus by difference, a measure of the NO₂ concentration shall be obtained.

2. The instrument to be used shall be complete with all necessary flow control components, such as regulators, valves, flowmeters, etc. Materials in contact with the sample gas shall be restricted to those which are resistant to attack by oxides of nitrogen, such as stainless steel, glass, etc. The temperature of the sample shall everywhere be maintained at values, consistent with the local pressures, which avoid condensation of water.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

3. The principal performance specification, determined for the instrument operated in an ambient temperature stable to within 2°C, shall be as follows:

- a) Total range: 0 to 2 500 ppm in appropriate ranges.
- b) *Resolution:* better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.
- c) *Repeatability:* better than ± 1 per cent of full scale of range used, or ± 1 ppm, whichever is greater.
- d) Stability: better than ± 2 per cent of full scale of range used or ± 1 ppm, whichever is greater, in a period of 1 hour.
- e) Zero drift: less than ± 1 per cent of full scale of range used or ± 1 ppm, whichever is greater, in a period of 1 hour.
- f) *Noise:* 0.5 Hz and greater, less than ± 1.0 per cent of full scale of range used or ± 1 ppm, whichever is greater, in a period of 2 hours.
- g) Interference: suppression for samples containing CO₂ and water vapour, shall be limited as follows:
 - 1) less than 0.05 per cent reading/per cent CO_2 concentration;
 - 2) less than 0.1 per cent reading/per cent water vapour concentration.

If the interference limitation(s) for CO₂ and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

Note.— It is recommended, as consistent with good practice, that such correction procedures be adopted in all cases.

h) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system to the achievement of 90 per cent of the final reading.

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- i) *Linearity:* better than ± 2 per cent of full scale of range used or ± 2 ppm, whichever is greater.
- j) *Converter:* this shall be designed and operated in such a matter as to reduce NO₂ present in the sample to NO. The converter shall not affect the NO originally in the sample.

The converter efficiency shall not be less than 90 per cent.

This efficiency value shall be used to correct the measured sample NO₂ value (i.e. $[NO_x]_c - [NO]$) to that which would have been obtained if the efficiency had not been 100 per cent.

ATTACHMENT D TO APPENDIX 3. CALIBRATION AND TEST GASES

Analy	ser Gas	Accuracy*	
НС	propane in zero air	±2 per cent or ±0.05 ppm**	
CO	$_2$ CO ₂ in zero air	± 2 per cent or ± 100 ppm**	
CC	CO in zero air	± 2 per cent or ± 2 ppm**	
NO_x NO_x in zero nitrogen		± 2 per cent or ± 1 ppm**	
Taken over the 95 per cent confidence interval.* Whichever is greater.			

Table of calibration gases

The above gases are required to carry out the routine calibration of analysers during normal operational use.

Analyser	Gas	Accuracy*	
НС	propane in 10 ±1 per cent O ₂ balance zero nitrogen	±1 per cent	
НС	propane in 21 ±1 per cent O ₂ balance zero nitrogen	±1 per cent	
НС	propylene in zero air	±1 per cent	
НС	toluene in zero air	± 1 per cent	
HC	n-hexane in zero air	± 1 per cent	
НС	propane in zero air	± 1 per cent	
CO ₂	CO_2 in zero air	±1 per cent	
CO_2	CO ₂ in zero nitrogen	±1 per cent	
СО	CO in zero air	±1 per cent	
NO_x	NO in zero nitrogen	±1 per cent	
⁵ Taken over the 95 per cent confidence interval.			

Table of test gases

The above gases are required to carry out the tests of Attachments A, B and C.

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