6.2 Ambient air conditions

6.2.1 A check shall be made on the ambient concentrations of CO, HC, CO₂ and NOx, with the engine under test running at the test condition. Unusually high concentrations indicate abnormal conditions such as exhaust gas recirculation, fuel spillage or some other source of unwanted emissions in the test area and such situations shall be rectified or avoided as appropriate.

Note.— For guidance, the normal ambient concentration of CO_2 is 0.03 per cent, and ambient concentration levels for CO and HC of 5 ppm and NOx of 0.5 ppm are unlikely to be exceeded under normal conditions.

6.2.2 Extreme climatic conditions, such a those involving precipitation or excessive wind speed shall also be avoided.

6.3 Major instrument calibration

Note.— The general objective of this calibration is to confirm stability and linearity.

6.3.1 The applicant shall satisfy the certificating authority that the calibration of the analytical system is valid at the time of the test.

6.3.2 For the hydrocarbon analyser this calibration shall include checks that the detector oxygen and differential hydrocarbon responses are within the limits specified in Attachment A to this appendix. The efficiency of the NO₂/NO converter shall also be checked and verified to meet the requirements in Attachment C to this appendix.

6.3.3 The procedure for checking the performance of each analyser shall be as follows (using the calibration and test gases as specified in Attachment D to this appendix):

- a) introduce zero gas and adjust instrument zero, recording setting as appropriate;
- b) for each range to be used operationally, introduce calibration gas of (nominally) 90 per cent range full-scale deflection (FSD) concentration; adjust instrument gain accordingly and record its setting;
- c) introduce approximately 30, 60 and 90 per cent range FSD concentrations and record analyser readings;
- d) fit a least squares straight line to the zero, 30, 60 and 90 per cent concentration points. For the CO and/or CO_2 analyser used in its basic form without linearization of output, a least squares curve of appropriate mathematical formulation shall be fitted using additional calibration points if judged necessary. If any point deviates by more than 2 per cent of the full scale value (or ±1 ppm^{*}, whichever is greater) then a calibration curve shall be prepared for operational use.

6.4 Operation

6.4.1 No measurements shall be made until all instruments and sample transfer lines are warmed up and stable and the following checks have been carried out:

a) leakage check: prior to a series of tests the system shall be checked for leakage by isolating the probe and the analysers, connecting and operating a vacuum pump of equivalent performance to that used in the smoke measurement system to verify that the system leakage flow rate is less than 0.4 L/min referred to normal temperature and pressure;

^{*} Except for the CO_2 analyser, for which the value shall be ± 100 ppm.

b) cleanliness check: isolate the gas sampling system from the probe and connect the end of the sampling line to a source of zero gas. Warm the system up to the operational temperature needed to perform hydrocarbon measurements. Operate the sample flow pump and set the flow rate to that used during engine emission testing. Record the hydrocarbon analyser reading. The reading shall not exceed 1 per cent of the engine idle emission level or 1 ppm (both expressed as methane), whichever is the greater.

Note 1.— It is good practice to back-purge the sampling lines during engine running, while the probe is in the engine exhaust but emissions are not being measured, to ensure that no significant contamination occurs.

Note. 2.— It is also good practice to monitor the inlet air quality at the start and end of testing and at least once per hour during a test. If levels are considered significant, then they should be taken into account.

- 6.4.2 The following procedure shall be adopted for operational measurements:
- a) apply appropriate zero gas and make any necessary instrument adjustments;
- apply appropriate calibration gas at a nominal 90 per cent FSD concentration for the ranges to be used, adjust and record gain settings accordingly;
- c) when the engine has been stabilized at the requisite operating conditions and sampling location, continue to run it and observe pollutant concentrations until a stabilized reading is obtained, which shall be recorded. At the same engine operating condition repeat the measurement procedure for each of the remaining sampling locations;
- d) recheck zero and calibration points at the end of the test and also at intervals not greater than 1 hour during tests. If either has changed by more than ±2 per cent of full scale of range, the test shall be repeated after restoration of the instrument to within its specification.

7. CALCULATIONS

7.1 Gaseous emissions

7.1.1 General

The analytical measurements made shall be the concentrations of the various classes of pollutant, at the relevant afterburning mode(s) of the engine, at the various locations in the sampling plane. In addition to the recording of these basic parameters, other parameters shall be computed and reported, as follows.

7.1.2 Analysis and validation of measurements

a) At each engine setting, the concentrations measured at different probe sampling positions must be averaged as follows:

$$C_{i moy} = \sum_{j=1}^{n} C_{i j}$$

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where

- $\sum_{j=1}^{n}$
- Summation of the total number *n* of sampling positions used.
- C_{ij} Concentration of species *i* measured at the *j*th sampling position.

 $C_{i moy}$ average or mean concentration of species *i*.

All dry concentration measurements shall be converted into real wet concentrations. (See Attachment E to this appendix).

b) The quality of the measurements for each pollutant will be determined through a comparison with measurements of CO₂ using the correlation coefficient:

$$r_{i} = \frac{n \sum_{j=1}^{n} C_{ij} CO_{2j} - \sum_{j=1}^{n} C_{ij} \sum_{j=1}^{n} CO_{2j}}{\sqrt{\left(\left\{n \sum_{j=1}^{n} (CO_{2j})^{2} - \left(\sum_{j=1}^{n} CO_{2j}\right)^{2}\right\} \left\{n \sum_{j=1}^{n} C_{ij}^{2} - \left(\sum_{j=1}^{n} C_{ij}^{2}\right)^{2}\right\}\right)}}$$

Values of r_i which are near to 1 indicate that measurements taken over the entire sampling period are sufficiently stable and that the curves are Gaussian. In the event that r_i is less than 0.95, measurements must be repeated in a sampling plane located at a more remote distance from the aircraft engine. The measurement process, per se, is then followed by the same calculations and the same demonstration as previously.

7.1.3 Basic parameters

For the measurements at each engine operating mode the average concentration for each gaseous species is estimated as shown in 7.1.2, any necessary corrections for dry sample measurement and/or interferences having been made as indicated in Attachment E to this appendix. These average concentrations are used to compute the following basic parameters:

$$\begin{aligned} \operatorname{EI}_{p} (\operatorname{emission index}_{\text{for component } p)} &= \frac{\operatorname{mass of } p \text{ produced in } g}{\operatorname{mass of fuel used in } kg} \\ \operatorname{EI}(\operatorname{CO}) &= \left(\frac{[\operatorname{CO}]}{[\operatorname{CO}_{2}] + [\operatorname{CO}] + [\operatorname{HC}]}\right) \left(\frac{10^{3} M_{\operatorname{CO}}}{M_{\operatorname{C}} + (n/m)M_{\operatorname{H}}}\right) (1 + T(\operatorname{P}_{0}/m)) \\ \operatorname{EI}(\operatorname{HC}) &= \left(\frac{[\operatorname{HC}]}{[\operatorname{CO}_{2}] + [\operatorname{CO}] + [\operatorname{HC}]}\right) \left(\frac{10^{3} M_{\operatorname{HC}}}{M_{\operatorname{C}} + (n/m)M_{\operatorname{H}}}\right) (1 + T(\operatorname{P}_{0}/m)) \\ \operatorname{EI}(\operatorname{HO}_{x})_{(\operatorname{as } \operatorname{NO}_{2})} &= \left(\frac{[\operatorname{NO}_{x}]}{[\operatorname{CO}_{2}] + [\operatorname{CO}] + [\operatorname{HC}]}\right) \left(\frac{10^{3} M_{\operatorname{NO}_{2}}}{M_{\operatorname{C}} + (n/m)M_{\operatorname{H}}}\right) (1 + T(\operatorname{P}_{0}/m)) \\ \operatorname{Air/fuel ratio} &= (\operatorname{P}_{0}/m) \left(\frac{M_{\operatorname{AIR}}}{M_{\operatorname{C}} + (n/m)M_{\operatorname{H}}}\right) \end{aligned}$$

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where

$$P_0 / m = \frac{2Z - (n/m)}{4(1 + h_{vol} - [TZ / 2])}$$

and

$$Z = \frac{2 - [\text{CO}] - ([2/x] - [y/2x])[\text{HC}] + [\text{NO}_2]}{[\text{CO}_2] + [\text{CO}] + [\text{HC}]}$$

$M_{ m AIR}$	molecular mass of dry air = 28.966 g or, where appropriate, = $(32 R + 28.156 4 S + 44.011 T)$ g
$M_{ m HC}$	molecular mass of exhaust hydrocarbons, taken as $CH_4 = 16.043$ g
$M_{\rm CO}$	molecular mass of $CO = 28.011$ g
$M_{\rm NO_2}$	molecular mass of $NO_2 = 46.088 \text{ g}$
M _C	atomic mass of carbon = 12.011 g
$M_{ m H}$	atomic mass of hydrogen = 1.008 g
R	concentration of O_2 in dry air, by volume = 0.209 5 normally
S	concentration of N_2 + rare gases in dry air, by volume = 0.709 2 normally
Т	concentration of CO_2 in dry air, by volume = 0.000 3 normally
[HC]	mean concentration of exhaust hydrocarbons vol/vol, wet, expressed as carbon
[CO]	mean concentration of CO vol/vol, wet
[CO ₂]	mean concentration of CO ₂ vol/vol, wet
[NOx]	mean concentration of NOx vol/vol, wet = $[NO + NO_2]$
[NO]	mean concentration of NO in exhaust sample, vol/vol, wet
[NO ₂]	mean concentration of NO ₂ in exhaust sample, vol/vol, wet
	$=\frac{([NO_x]_c - [NO]]}{\eta}$
[NOx] _c	mean concentration of NO in exhaust sample after passing through the NO ₂ /NO converter, vol/vol, wet
η	efficiency of NO ₂ /NO converter
h_{vol}	humidity of ambient air, vol water/vol dry air
т	number of C atoms in characteristic fuel molecule

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n	number of H atoms in characteristic fuel molecule
x	number of C atoms in characteristic exhaust hydrocarbon molecule

y number of H atoms in characteristic exhaust hydrocarbon molecule

The value of n/m, the ratio of the atomic hydrogen to atomic carbon of fuel used, is evaluated by fuel type analysis. The ambient air humidity, h, shall be measured at each set condition. In the absence of contrary evidence as to the characterization (x, y) of the exhaust hydrocarbons, the values x = 1, y = 4 are to be used. If dry or semi-dry CO and CO₂ measurements are to be used then these shall first be converted to the equivalent wet concentrations as shown in Attachment E to this appendix, which also contains interference correction formulas for use as required.

Note.— The procedure given in 7.1.4 and 7.2 is only applicable to tests made when afterburning is not used. For tests when afterburning is used, a similar procedure could be used after approval by the certificating authority.

7.1.4 Correction of emission indices to reference conditions

Corrections shall be made to the measured engine emission indices for all pollutants in all relevant engine operating modes to account for deviations from the reference conditions (ISA at sea level) of the actual test inlet air conditions of temperature and pressure. The reference value for humidity shall be 0.00634 kg water/kg dry air.

Thus, EI corrected = $K \times EI$ measured,

where the generalized expression for K is:

 $K = (P_{Bref}/P_B)^a \times (FAR_{ref}/FAR_B)^b \times \exp\left([T_{Bref} - T_B]/c\right) \times \exp\left(d[h_{vol} - 0.00634]\right)$

- P_B Combustor inlet pressure, measured
- T_B Combustor inlet temperature, measured
- *FAR*_B Fuel/air ratio in the combustor
- h_{vol} Ambient air humidity, vol water/vol dry air
- $P_{\rm ref}$ ISA sea level pressure
- $T_{\rm ref}$ ISA sea level temperature
- P_{Bref} Pressure at the combustor inlet of the engine tested (or the reference engine if the data is corrected to a reference engine) associated with T_B under ISA sea level conditions.
- T_{Bref} Temperature at the combustor inlet under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine). This temperature is the temperature associated with each thrust level specified for each mode.
- FAR_{ref} Fuel/air ratio in the combustor under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine).
- *a,b,c,d* Specific constants which may vary for each pollutant and each engine type.

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The combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas.

7.1.5 Using the recommended curve fitting technique to relate emission indices to combustor inlet temperature effectively eliminates the exp ($[T_{Bref} - T_B]/c$) term from the generalized equation and for most cases the (FAR_{ref}/FAR_B) term may be considered unity. For the emissions indices of CO and HC many testing facilities have determined that the humidity term is sufficiently close to unity to be eliminated from the expression and that the exponent of the (P_{Bref}/P_B) term is close to unity.

Thus,

EI(CO) corrected = EI derived from $(P_B/P_{Bref}) \cdot EI(CO)$ v. T_B curve

EI(HC) corrected = EI derived from $(P_B / P_{Bref}) \cdot EI(HC)$ v. T_B curve

EI(NOx) corrected = EI derived from EI(NOx) $(P_{Bref}/P_B)^{0.5 exp} (19[h_{vol} - 0.00634])$ v. T_B curve

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 NOx emissions 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} The maximum thrust available for take-off under normal operating conditions at ISA sea level static conditions, without the use of water injection, as approved by the applicable certificating authority.
- 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 emission indices (EI) for each pollutant, corrected for pressure and humidity (as appropriate) to the reference ambient atmospheric conditions as indicated in 7.1.4 and if necessary to the reference engine, shall be obtained for the required LTO engine operating mode settings (n) of idle, approach, climb-out and take-off, at each of the equivalent corrected thrust conditions. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined for each pollutant:

- a) between EI and T_B ; and
- b) between W_f (engine fuel mass flow rate) and T_B ; and
- c) between F_n (corrected to ISA sea level conditions) and T_B (corrected to ISA sea level conditions);

Note.— These are illustrated, for example, by Figure A5-3 a), b) and c).

When the engine being tested is not a "reference" engine, the data may be corrected to "reference" engine conditions using the relationships b) and c) obtained from a reference engine. A reference engine is defined as an engine substantially configured

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to the description of the engine to be certificated and accepted by the certificating authority to be representative of the engine type for which certification is sought.

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:

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

Note.— These are illustrated by Figure A5-3 d).

7.2.3 The estimation of EI for each pollutant at each of the required engine mode settings, corrected to the reference ambient conditions, shall comply with the following general procedure:

- a) at each mode ISA thrust condition F_n , determine the equivalent combustor inlet temperature (T_B) (Figure A5-3 c));
- b) from the EI/ T_B characteristic (Figure A5-3 a)), determine the EI_n value corresponding to T_B ;
- c) from the W_f/T_B characteristics (Figure A5-3 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 A5-3 d));
- e) calculate, for each pollutant $Dp = \Sigma (\text{EI}_n) (W_{f_n}) (t)$ 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 expressions 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.



Figure A5-3. Calculation procedure

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ATTACHMENT A TO APPENDIX 5. SPECIFICATION FOR HC ANALYSER

Note 1.— As outlined in 5.2 of Appendix 5, 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 temperature within the range 155°C to 165°C to a stability of $\pm 2^{\circ}$ 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 500 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 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:

- 1) propane in 10 ± 1 per cent O₂, balance N₂
- 2) 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.