The Engineering Society
For Advancing Mobility
Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4418
Issued 1995-08

Submitted for recognition as an American National Standard

PROCEDURE FOR SAMPLING AND MEASUREMENT OF ENGINE GENERATED CONTAMINANTS IN BLEED AIR SUPPLIES FROM AIRCRAFT ENGINES UNDER NORMAL OPERATING CONDITIONS

1. SCOPE:

The following individual engine compressor generated contaminants are addressed by this SAE Aerospace Recommended Practice (ARP):

a. Carbon dioxide
b. Hydrogen fluoride
c. Organic material
d. Carbon monoxide
e. Acrolein
f. Respirable particles
g. Oxides of nitrogen
h. Formaldehyde

For reference purposes, information is also given on the current maximum allowable engine bleed air concentration limits for each of these contaminants, as stated in the latest issue of AIR4766.

Recommended techniques for engine sampling and sample transfer are given, together with the specific analytical methodology and acceptable alternate referenced analytical methodology for each of the above contaminants.

Recommendations are also made for an engine test format and for the allowance of ambient air quality on the engine measured contaminant concentration levels.

The previous list of contaminants are considered appropriate for the certification and passenger safety requirements of both civil and military aircraft.

1.1 Purpose:

This document describes the measurement technology required for the quantification of specified aircraft gas turbine engine generated gaseous and particulate contaminants in cabin bleed air supplies, under normal operating conditions.

1.2 Sections:

The procedure is divided into the following sections:

a. Scope
b. References
c. Recommended Specification Limits of Contaminants
d. Methodology
e. Revisions
f. Appendix

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP4418 (DRAFT) Procedure for Sampling and Measurement of Engine Generated Contaminants in Bleed Air Supplies from Aircraft Engines Under Normal Operating Conditions
AIR4766 (DRAFT)

2.1.2 ASTM Publication: Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

1992 Annual Book of ASTM Standards, Volume 11.03, “Atmospheric Analysis; Occupational Health and Safety”

2.1.3 Intersociety Committee Publication: Available from Lewis Publishers, Inc., 121 South Main Street, Chelsea, MI 48118.

Intersociety Committee: AWMA, ACS, AIChE, APWA, ASME, AOAC, HPS, ISA “Methods of Air Sampling and Analysis, Third Edition,” James P. Lodge, Jr., Editor

2.1.4 **JIS** Publication: Available from Japanese Standards Association I-24, **Akasaka** 4, **Minato-ku,** Tokyo 107 Japan.

Japanese **Industrial** Standard

2.1.5 **NIOSH** Publication: Available from National **Institute** of Safety and Health, Division of Physical Sciences and Engineering (R-2), 4676 Columbia Parkway Cincinnati, OH 45226.

NIOSH Manual of Analytical Methods

2.1.6 **OSHA** Publication: Available from

Occupational Safety and Health Administration, **OSHA** Analytical Laboratory, Salt Lake City, Utah.

OSHA Analytical Method Manual

2.2 Definitions and Terminology:

2.2.1 ACCURACY: The closeness with which a measurement approaches the true value as established independently.

2.2.2 AIRCRAFT GAS TURBINE ENGINE: Any gas turbine engine used for aircraft propulsion or aircraft power generation, including those commonly called turbojet, turbofan, **propfan, ducted** propulsion, turboprop, or **turboshaft** type engines.

2.2.3 BIAS: **Identifiable** systematic error in measurement.

2.2.4 CALIBRATION GAS: A mixture of gases of specified and known composition used to determine the response of an instrument to the concentration of gases in the mixture.

2.2.5 CAPTURED OR GRAB SAMPLE: A sample which has been taken into a container, or adsorbed onto a substrate, from the flowing stream, and which will be analyzed subsequently by an off-line measurement technique.

Containers are typically **Tedlar®** plastic bags or internally coated metal cylinders (as recommended by the EPA). Substrates are loaded into glass tubes which are specifically designed to capture certain molecular species.

2.2.6 **CHEMILUMINESCENCE** ANALYZER **(CLA):** An analyzer which quantifies No, concentrations in gaseous samples and standard gas mixtures. It is based on the principle of measuring the amount of light energy produced from the reaction between NO and ozone (O_3). Any NO present is measured directly, and any NO_2 present is first reduced to NO in a converter, and then measured indirectly as part of the total No, value.

2.2.7 CONTINUOUS SAMPLING: The presentation of a flowing sample to the analytical instrument in order to obtain continuous measurement of concentrations of the components of interest.

2.2.8 ENGINE GENERATED CONTAMINANTS: Those substances produced directly by the engine, including those formed by thermal degradation within the engine, and confined to those listed in Section 1.

2.2.9 FLAME IONIZATION DETECTOR (FID): An analyzer which quantifies organic hydrocarbon species concentrations in gaseous samples or standard gas mixtures. It is based on the principle of measuring the large numbers of ions which are produced when hydrocarbon species are burned in a hydrogen in air flame, within the instrument.

2.2.10 GAS CONCENTRATION: The volume fraction of the component of interest in the sample or calibration gas mixture, expressed either as a volume percentage or as parts per million by volume (ppm-v).

2.2.11 INTERFERENCE: Instrument response to components present in the gas mixture, other than the component that is to be measured.

2.2.12 NOISE: Random variation in instrument output not associated with characteristics of the sample to which the instrument is responding, distinguishable from the instrument drift characteristics.

2.2.13 NONDISPERSIVE INFRARED ANALYZER (NDIR): An analyzer which by absorption of infrared energy, selectively measures specific components.

2.2.14 ORGANIC MATERIAL: The sum total of all organic compounds, above and including molecules with 3 carbon atoms, of all classes and molecular weights, expressed as ppm-v of synthetic lubricating oil equivalent.

2.2.15 OXIDE OF NITROGEN (NOX): The sum of nitric oxide (NO) and nitrogen dioxide (NO_2) in any ratio, and reported as NO_2.

2.2.16 PRECISION: The closeness with which a measurement upon a given variant sample can be reproduced in short term repetitions of the measurement with no intervening instrument adjustment.

2.2.17 REFERENCE METHODS: Those methods which have been identified as being equivalent to those detailed in this document for the quantification of individual pollutant species, and which are recognized as acceptable alternatives for bleed air quality measurements.

2.2.18 RESOLUTION: The lower limit capability of the instrument or analysis technique to differentiate between samples of differing concentrations.

2.2.19 RESPIRABLE PARTICLES: All airborne particles which lie in the respirable size range of 2 µm and smaller (see 4.3.3.5).

2.2.20 RESPONSE: The change in instrument output signal that occurs with change in sample concentration. Also the output signal corresponding to a given sample concentration.

2.2.21 SPAN DRIFT: The time related change in response of the instrument in repetition of a span gas measurement under identical conditions.

2.2.22 SPAN GAS: A calibration gas to be used for routine verification and/or adjustment of instrument or analytical technique response.

2.2.23 SYNTHETIC OIL (LUBRICANT): A mixture of esters of fatty acids with the general empirical formula of $C_xH_yO_z$ and a molecular weight of approximately 600.

2.2.24 TEST SEQUENCE: A series of functionally related tests in which the test operation progresses systematically, without interruption from one test mode to another.

2.2.25 ZERO DRIFT: Time related deviation of instrument output from zero set point when operating on a zero gas.

2.2.26 ZERO GRADE GAS: A gas to be used to establish the zero, or no response adjustment of an instrument, and which is free from the component to be measured by the instrument.

3. RECOMMENDED SPECIFICATION LIMITS OF CONTAMINANTS:

The cabin bleed air quality requirements, as given in AIR4766, Table 1, provides a list of contaminants and their recommended maximum allowable concentration limits in bleed air supplies. The methodology contained within this document is applicable to these contaminants and these limits.

TABLE 1

Engine Generated Contaminant	Maximum Allowable Concentration Above the Ambient Level[4] ppm-v	Maximum Allowable Concentration Above the Ambient Level[4] mg/m^3
Carbon Dioxide	400	720
Carbon Monoxide	5	5.7
Hydrogen Fluoride[1]	1	0.8
Oxides of Nitrogen[2]	1	1.9
Formaldehyde	0.3	0.4
Acrolein	0.05	0.11
Organic Material[3]	0.4	9.8
Respirable Particles	---	0.5

[1] To be included only if fluorinated compounds are known to be present in the engine elastomers, oil, seals, or any other compressor component.

[2] Expressed as NO_2 equivalent.

[3] Expressed as synthetic oil equivalent, assuming a molecular weight of 600.

[4] Concentrations are at 296 K (25 °C) and 101 kPa.

4. METHODOLOGY:

4.1 Test Format:

4.1.1 Engine Test Program: In order to verify that the engine will perform satisfactorily in service, it is important to measure the bleed air quality at as many stabilized conditions as possible over the engine power range. It is recognized that because of high engine running costs it may not be possible to check all conditions, but it is recommended that at least the following stabilized settings be checked for all specification requirements:

a. An idle setting with the high pressure (HP) bleed selected.
b. A condition just before HP to low pressure (LP) bleed switch occurs.
c. A condition just after HP to LP bleed switch occurs.
d. A high power condition, for example altitude cruise, with LP bleed selected.

It is important to ensure that the engine is configured to enable full bleed flow to be taken through the off take pipe work during the test program.

4.1.2 Engine Inlet Measurements: The specification requires that a separate determination for all the contaminants should be carried out on the engine inlet air during the test sequence, to provide information on the magnitude of the ambient contamination levels.

in all cases account should be taken of these measured data in the calculation of the engine generated values.

4.2 General Sampling Requirements:

The sampling methodology which deals with the extraction of samples from the engine and their transport to the measurement instrumentation is described in this section. Analysis techniques for the individual compounds are described in the measurement (see 4.3).

4.2.1 Engine Intake: Samples of engine intake air should be taken via a forward facing probe mounted preferably on the engine debris guard at a location close to the engine centerline.

Inlet air should be drawn through the probe by means of a sample pump located external to the test cell at the extremity of a sample transfer line which is connected to the probe outlet.

The sample transfer line should be constructed of stainless steel or carbon loaded, grounded, PTFE, and preferably heated to a temperature of 323 to 423 K and controlled to a stability of ±25 K. (Heating is only necessary if the possibility exists for the sample to be cooled significantly below ambient temperature en route to the analysis system.)

Samples for organic material and respirable particle estimations may be taken from this supply, upstream of the pump, in accordance with the procedures given in 4.3.3.4(b) and 4.3.3.5(c).

4.2.2 Engine Bleed Off Takes: The engine bleed air system should be set up to ensure that normal bleed airflows are in operation at each stabilized power setting.

4.2.3 Probe Design and Sample Transfer: All samples of bleed air should be extracted from the engine pipe work via a forward facing metal probe, installed at least 10 pipe diameters downstream of any disturbance such as an elbow, orifice plate or valve, and at least 0.5 diameters upstream from any such disturbance.

The probe may be of single or multihole design and should, in the case of the former, be placed at approximate duct center in a forward facing position. Static wall tapping probes should not be used.

The probe orifice(s) should be sized to provide sufficient sample volume for all the analysis requirements at all engine power settings (typically in the range 1 to 3 mm diameter for single orifice probes).

Care should be taken to ensure that the gas temperature from the probe exit is cooled to below 473 K before it enters the next section of sample transfer line.

Samples should be transferred external to the test bed via heated and controlled, stainless steel or flexible carbon loaded, grounded, PTFE sample lines maintained within the temperature range 323 to 423 K and at a stability of ±25 K. The total length of line from probe outlet to the analyzer/sampling point external to the test cell shall be as short as possible and preferably no greater than 25 m.

Provision should be made to bleed off excess sample gas from this supply, either at the engine or external to the test bed.

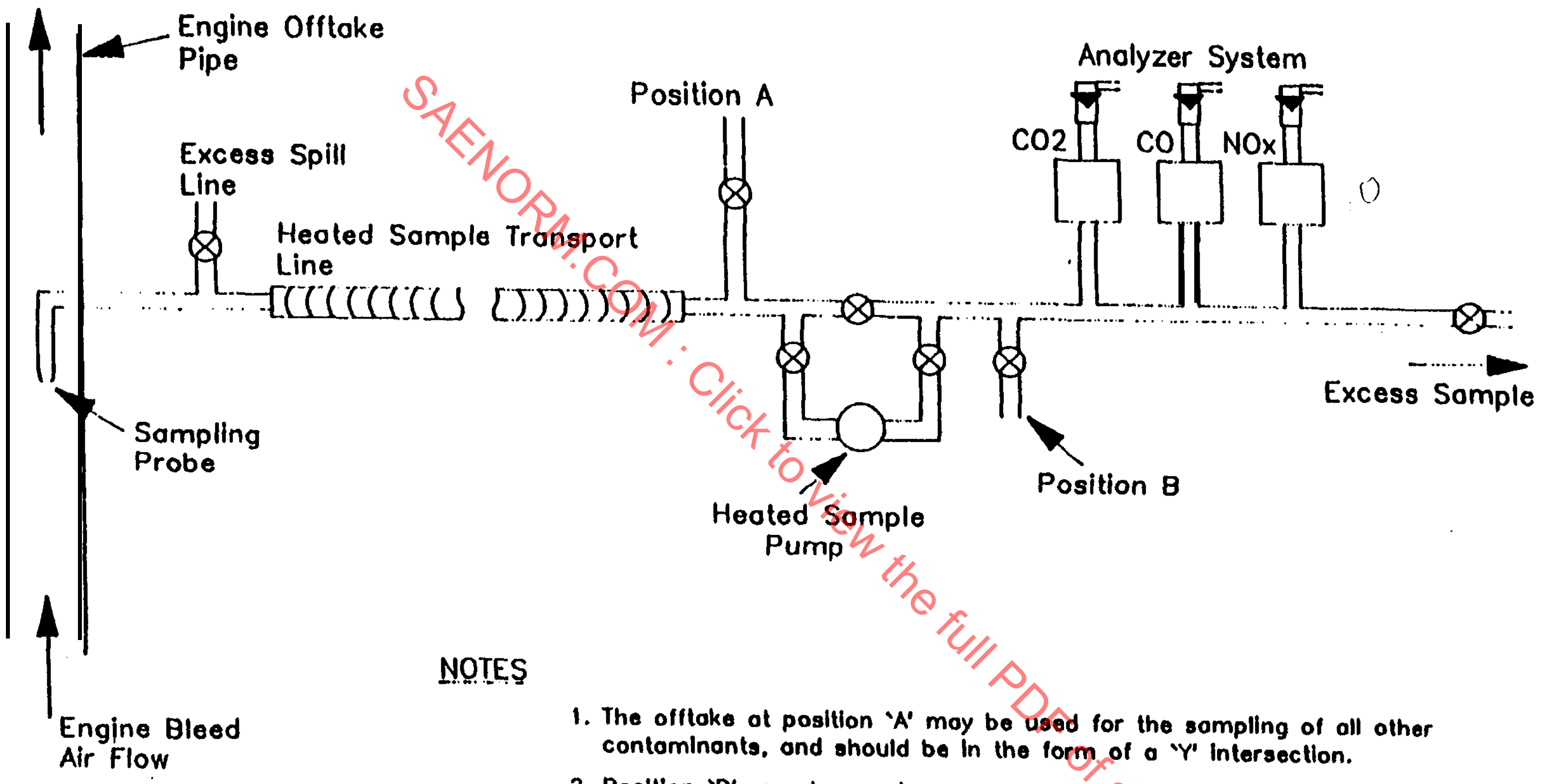
The recommended sampling system is shown diagrammatically in Figure 1.

4.2.4 Sample Line Cleanliness: It is recommended that a dedicated bleed air sampling line system should be set aside for bleed air test requirements. If it is necessary to use normal engine exhaust emissions testing sampling lines, their cleanliness must be assured as described below.

Prior to each engine test, sample transfer lines should be checked to ensure that they are clean and when operating at their normal temperature are not responsible for significantly increasing the level of organic material in the incoming sample.

A check on cleanliness may be carried out by connecting the sampling line to a “zero air” supply, heating the line to its normal operating temperature, flowing zero air through the line at a velocity similar to that of the sample during an engine test, and checking, by means of the FID or the total capture technique, the organic material content of the outflowing gas.

The sample line should be regarded as being “clean,” when the organic material content of the outflowing zero gas is at or below 10% of the specification maximum value; i.e., 0.04 parts per million by volume.



NOTES

1. The offtake at position 'A' may be used for the sampling of all other contaminants, and should be in the form of a 'Y' intersection.
2. Position 'B' may be used as a span gas entry point and/or for an entry for 'Grab Bag' samples
3. Flow control valves are designated: ⊗

FIGURE 1 - Schematic Layout for C Flow Analysis System

4.3 Contamination Analysis Techniques:

4.3.1 General Information: A number of options exist for the analysis of the majority of the listed bleed air contaminants, and this document provides the detailed methodology for one preferred analysis technique for each contaminant and references other acceptable published methods. The detailed methodology for individual contaminants given here has been shown to be capable of meeting the requirements of the referenced specification and it is recommended that any other technique used for engine testing must have a demonstrable capability of meeting or improving on the criteria set for each of the preferred methods.

The analytical techniques fall into two separate categories; i.e., continuous flow and **extractive** sample analysis techniques, and these are dealt with separately in the following text.

4.3.2 Continuous Flow Sample Analysis Techniques:

4.3.2.1 Carbon Dioxide, Carbon Monoxide, and Oxides of Nitrogen:

a. Analytical Methods: Carbon dioxide and carbon monoxide levels in the sample may be determined by **nondispersive** infrared **(NDIR)** techniques to the requirements as given in the latest issue of **ARP1256.**

Oxides of nitrogen levels in the sample may be determined by **chemiluminescence** analysis **(CLA)** techniques to the requirements as given in the latest issue of **ARP1256.**

b. Equipment Calibration: The **NDIR** and **CLA** analyzers may be calibrated over the following ranges (see Table **2)**, using appropriate gas standard mixtures and to the given resolution, to the general requirements as given in the latest issue of **ARP1256.**

TABLE 2

Contaminant	Typical Analyzer Range	Resolution	Typical Standard Gas Mixture
Carbon Dioxide	**0 to 1000 ppm**	±**1%** full scale	1000 **ppm** CO_2 in air
Carbon Monoxide	0 to 50 **ppm**	±**1%** full scale	50 **ppm** CO in air
Oxides of Nitrogen	0 to **10 ppm**	±**1%** full scale	10 **ppm** NO in N_2

c. **Interference** Effects: At the normal ambient levels of these bleed air contaminants, no one species should significantly interfere with the determination of any other species assuming the instrument meets the requirements of the latest issue of **ARP1256.**

4.3.2.1 (Continued):

d. Sampling Technique: Samples shall be transferred from the engine bleed sampling probe off take to the analyzers via electrically heated, flexible PTFE or stainless steel lines which conform to the general requirements as given in the latest issue of ARP1256.

A general schematic layout for the overall sample transfer system is given in Figure 1.

The sample flow rate and the line length shall be such that the measured or calculated sample transport time from probe to instruments is less than 10 s, and if necessary, a pump may be used to reduce the sample transfer time. If this pump is located upstream of the analyzers it must be heated to the same temperature as the transfer line.

4.3.3 Extractive Sample Analysis Techniques:

4.3.3.1 Hydrogen Fluoride:

a. Analytical Method: Quantification of the hydrogen fluoride content in bleed air supplies may be made by an anionic determination of fluoride ions in aqueous solution by means of an ion exchange chromatograph incorporating a conductivity detector.

b. Sampling Technique: A standard volume of bleed air from the engine supply (typically 50 L at 298 K and 101 kPa) is passed through two bubblers in series, both containing a specified volume of deionized water. The sample flow rate through the bubblers must be such that the collection efficiency of any HF in the gaseous sample is greater than 90% overall (typically 10 L/min). If this cannot be achieved by two bubblers, more should be employed.

On completion of the sampling at any one engine condition, the bubbler solutions are amalgamated and made up to their original volume with deionized water (this is only necessary if evaporative losses of more than 10% have occurred during the sampling process).

It is recommended that the temperature of the sampled gas into the bubblers be kept at or below 338 K, to minimize evaporative losses during sampling.

c. Equipment Calibration: The ion exchange chromatograph is calibrated over a range of concentrations from 0 to 1 part per million by volume of hydrogen fluoride equivalent in the gaseous engine sample, and the overall method must have a resolution capability of 0.1 ppm or better.

The ion chromatograph must be set up to ensure that adequate separation of the following anionic species (chloride, bromide, iodide, fluoride, phosphate, nitrate, and nitrite) can be achieved, and that the system parameters (flow rate, temperature, etc.) are controlled such that sample repeatability is better than ±0.1 ppm equivalent in the gaseous sample.

4.3.3.1 (Continued):

The equipment shall be calibrated by means of repeat injections of appropriate standards of high purity sodium fluoride in deionized aqueous solution.

Ideally a series of these standards should be used to calibrate the above operational range, but in practice, since the detector is linear, a single standard corresponding to the maximum value of 1 ppm is adequate (provided that the standard and engine sample are measured on the same instrumental range). A blank determination should also be carried out on the deionized water used to make up the standard solutions and in the sample bubblers.

d. Sample Analysis: When the required sample volume has been passed through the bubblers, the aqueous solutions are mixed and made up to their original volume with deionized water (this is only necessary if evaporative losses, as mentioned in 4.3.3.1 (b), of more than 10% have occurred during the sampling process).

Appropriate repeat volumes of aqueous sample are extracted from the bulk solution and injected into the chromatograph after calibration. The concentration of HF in the engine sample is derived from the instrument calibration curve and the finally reported value should take into account the magnitude of the measured solution blank (as mentioned in 4.3.3.1 (c)).

e. Reference or Acceptable Alternative Methods: See Appendix A.

4.3.3.2 **Acrolein:**

a. Analytical Method: Quantification of the acrolein content in bleed air supplies may be made by a spectrofluorimetric determination of the 7-hydroxyquinoline produced from the reaction between acrolein and m-aminophenol under controlled conditions.

b. Sampling Technique: A standard volume of bleed air from the engine supply (typically 40 L) is passed through two bubblers in series, as previously described in 4.3.3.1 (b) for HF, except that deionized water is replaced by stock solution (b).

c. Equipment Calibration: The spectrofluorimeter is calibrated over a range of concentrations from 0 to 0.05 parts per million by volume of acrolein equivalent in the gaseous sample, and the overall method must have a resolution capability of 0.01 ppm or better.

The spectrofluorimeter is set up at an excitation wavelength of 346 nm and an optimized emission wavelength in the range 400 to 600 nm.

The instrument emission slit width and sample cell size must also be optimized and controlled.

4.3.3.2 (Continued):

Separate stock solutions of the following chemicals are prepared:

(a) **Acrolein** in Deionized Water: At a concentration level suitable for the production of a series of standard solutions covering the range from 0 to 0.1 **ppm-v.**

(b) m-Aminophenol/Hydroxylamine Hydrochloride in Hydrochloric Acid: Approximately 2.86 **gms m-Aminophenol** and 3.43 **gms hydroxylamine** hydrochloride in 85 **mL** concentration. Hydrochloric acid made up to **1 L** with deionized water.

Specified volumes of these two solutions are combined, heated in a steam bath, cooled in ice, and equilibrated to room temperature for specified time periods, after which their fluorescence is measured by the **spectrofluorimeter** and a calibration graph is produced.

Sufficient volume of each standard should be made up to enable repeat calibrations to be carried out if necessary, and a reagent blank should be used to set up the instrument zero.

Care should be taken at all stages throughout this **determination** to ensure that solution temperatures and color development times are accurately monitored as these are critical to the success of the method.

d. Sample Analysis: A specified volume of sample (typically 15 **mL)** is extracted from the combined bubble sample volume and chemically analyzed by the same technique as described in 4.3.3.2(c) for the standard acrolein solutions (a). The acrolein concentration of this sample is derived from the calibration curve, and the finally reported value should take into account the measured solution blank, as mentioned in 4.3.3.2(c).

e. Reference or Acceptable **Alternative** Methods: See Appendix A.

4.3.3.3 Formaldehyde:

a. Analytical Method: The formaldehyde content in bleed air supplies may be determined **spectrophotometrically** as a function of the color density of a solution produced by a two stage reaction between the **aldehydes** and **3-methyl-2-benzo-thiazolinone hydrazone** hydrochloride **(MBTH)** initially, and an oxidation reaction of this complex and more **MBTH** by a mixture of ferric chloride and **sulfamic** acid.

b. Sampling Technique: A standard volume (typically 30 **L** at 298 **K** and **101 kPa)** of bleed air from the engine supply is passed through two bubblers in series (at a flow rate of typically 10 **L/min)** as for **HF,** except that the deionized water is replaced by **MBTH** stock solution (a).

4.3.3.3 (Continued):

c. Equipment Calibration: The spectrophotometer is calibrated over a range of concentrations from 0 to 0.5 parts per million by volume of formaldehyde equivalent in the gaseous sample, and the overall method must have a resolution capability of 0.05 parts per million or better.

The spectrophotometer is set up at an optimized wavelength in the range 625 to 630 nm, with a red photocell and controlled sample cell size.

Separate stock solutions of the following chemicals are prepared:

(a) MBTH: Approximately 0.5 gm/L in deionized water.

(b) Ferric Chloride/Sulfamic Acid: Approximately 10 and 16 gm/L respectively in deionized water.

(c) Formaldehyde in Deionized Water: At a concentration level suitable for the production of a series of standard solutions covering the range 0 to 0.5 ppm-v.

Increments of solution (c) are transferred to standard volumetric flasks to which are added a standard volume of solution (a) (typically 20 mL).

This solution is allowed to stand for at least 1 h, after which time a standard volume of solution (b) is added (typically 2 mL).

After a further controlled period of standing (typically 6 min ± 1 min) the solution is made up to the mark with deionized water and left to stand for a further controlled period (typically 12 min ± 3 min).

The color intensity of each standard is then measured on the spectrophotometer, together with that of a reagent blank that has been prepared in the same way, and a calibration curve is produced.

d. Sample Analysis: Aliquots of each of the sample solutions obtained by the technique described in 4.3.3.3(b) are treated similarly to the formaldehyde calibration solutions. The total aldehyde concentrations are derived from the instrument calibration curve, and the finally reported values should take into account the magnitude of the measured solution blank (as mentioned in 4.3.3.3(c)).

It is recommended that the equipment calibration and sample analysis procedures should be carried out simultaneously and time periods of longer than 1 h between calibration and sample analysis should be avoided.

e. Reference or Acceptable Alternative Methods: See Appendix A.

4.3.3.4 Organic Material:

a. Analytical Method: The recommended method involves a total adsorption technique which is followed by thermal desorption and catalytic oxidation of the organic material, at high temperature, to carbon dioxide. The carbon dioxide content of the sample is quantified by NDIR analysis and the final results are expressed in terms of a volume concentration of synthetic oil equivalent in the original bleed air sample volume.

b. Sampling Technique: Samples for analysis are taken from the engine bleed off take heated transfer line supply (see 4.2) by passing a standard volume of gas (typically 5 L), at a controlled flow rate, in the range of 0.5 to 1.5 L/min, and controlled temperature, through specially prepared, previously sealed glass absorption tubes containing high purity, gas chromatographic grade, 60 to 120 mesh silica gel. On completion of the sampling, the tubes are immediately resealed and transferred to the laboratory for subsequent analysis, which under normal circumstances must be carried out within 8 h of test completion.

c. Equipment Calibration: The analysis system should be set up as shown diagrammatically in Figure 2.

Zero or artificial air should be supplied from a cylinder and the flow controlled by the gas cylinder regulator.

Trace quantities of CO_2 and hydrocarbons should be removed if necessary from the carrier gas flow by chemical techniques and the standard four way valve for CO_2 mixture injection may be manually or pneumatically operated.

The sample tube is normally made from heat resistant 12.5 mm diameter glass and contains typically a 30 to 50 mm plug of 60 to 120 mesh silica gel. This tube is surrounded by a small low temperature heater which operates at a controlled temperature of 673 K ± 25 K and the high temperature furnace is of typical commercial design with an operational range of up to 1200 K. Inside the furnace tube is a further ceramic tube, packed with a metal or metal oxide catalyst for oxidation of the organic material which is controlled at a temperature of 973 K ± 25 K by the furnace.

Water removal downstream of the furnace is achieved by chemical desiccation and the NDIR CO_2 analyzer should satisfy all the operational criteria as outlined in the latest issue of ARP1256. The choice of chart recorder and integrator systems is optional, and a logger/PC combination would be equally acceptable.

The analyzer should be calibrated before use over its operational linearized range using the appropriate zero and calibration gas standards (typically zero grade air and 1000 parts per million of CO_2 in balance air).

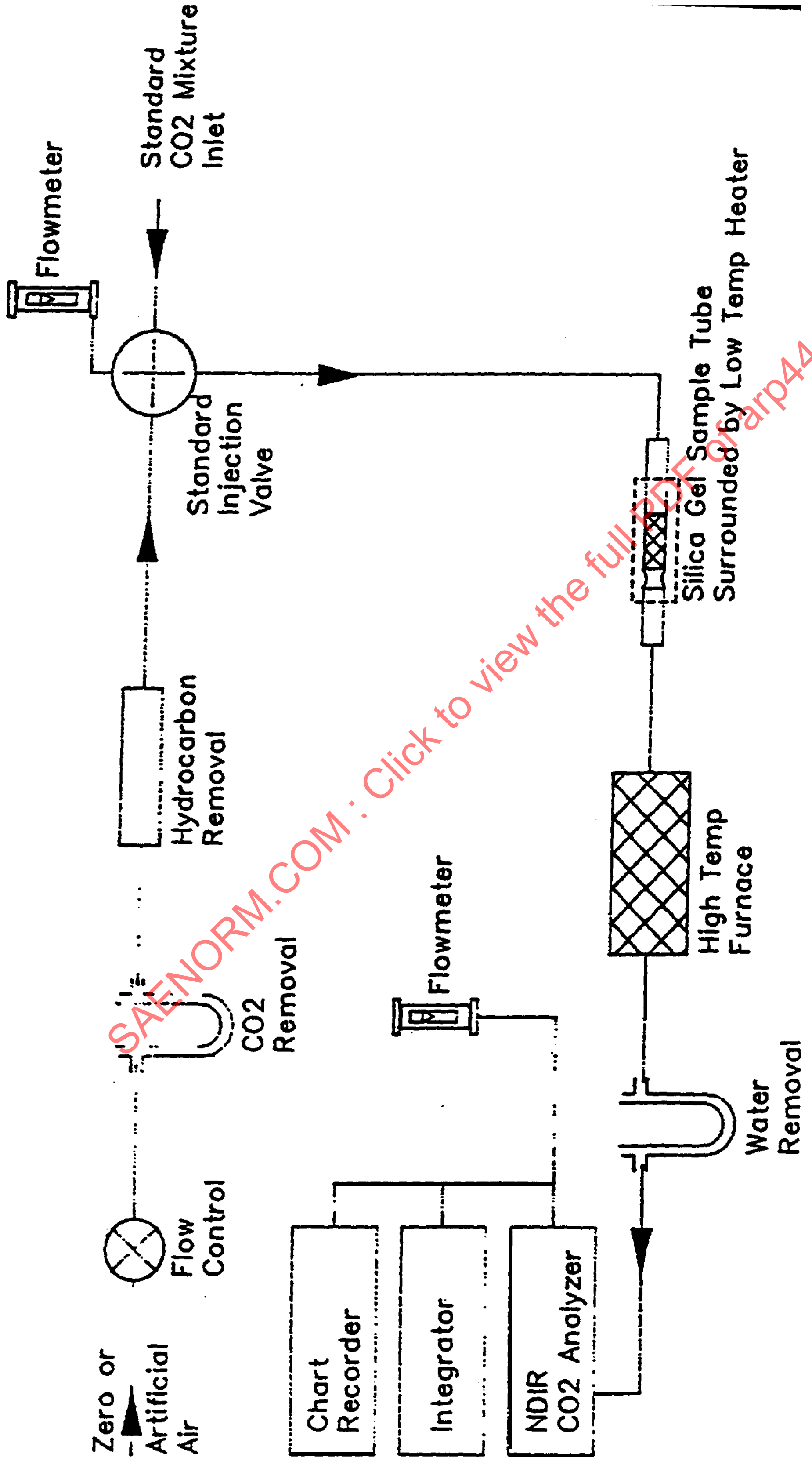


FIGURE 2 - Cabin Bleed Air Organic Material Analysis System Layout

4.3.3.4 (Continued):

Zero grade air is passed through the analysis system at a controlled flow rate (typically 20 L/h) and the tube heater and oxidation furnace switched on and allowed to reach their operating temperatures.

All instruments and heaters in the system should be allowed to warm up for at least 1 h before use, and zero grade air should be flowing through the system for this period.

After warm up, the system is calibrated by means of injecting repeat standard volumes of the CO_2 calibrated gas standard (typically 1000 ppm-v), via the injector valve and sample loop system, into the zero grade air stream and measuring the resultant integrator count. The sample loop is refilled in between each injection by purging it for typically about 15 s with the gas standard at a flow rate of typically 0.1 L/min.

The volume of the sample loop in combination with the CO_2 concentration in the gas standard should correspond approximately to that signal which would be produced from the controlled engine sample volume contaminated with organic material at or about the specification maximum value.

The introduction of standard gas by this means should be repeated until the integrator counts are consistent to within ±1% of the mean.

d. Sample Analysis: Remove the blank silica gel tube from the system when calibration has been completed and remove the end caps from the first sample tube to be analyzed.

Insert the silica gel sample tube into the analysis system as indicated in Figure 2 and place the low temperature heater over the tube downstream of the silica gel plug. Connect the zero air supply to the tube and note, but ignore, the first peak produced on the chart recorder, which corresponds to the CO_2 adsorbed onto the silica gel during sampling.

Once the atmospheric CO_2 has been driven off, the low temperature heater may be moved over the silica gel plug to desorb all the adsorbed organic material into the high temperature total oxidation furnace.

Integrate the area of the CO_2 peak(s) produced and calculate the concentration of organic material in the original sample by reference to the system calibration data.

Repeat this technique for all the samples to be analyzed.

4.3.3.4 (Continued):

e. Calculation Procedure: The following calculation derives the relationship between the measured CO_2 concentration from the sample analysis in ppm-v and the organic material concentration as ppm-v in the original sample of bleed air (expressed as synthetic lubricant equivalent).

The molar mass of a typical 5 **cSt** oil is approximately 600 and its composition by mass percentage is as follows:

(a) Carbon - 72%
(b) Hydrogen - 9%
(c) Oxygen - 19%

If the assumed concentration of organic material in the bleed air sample is O_m **ppm-w,** this is equivalent to:

$$\frac{O_m \times 72 \times 44}{100 \times 12} \text{ ppm} - \text{w of } CO_2$$

or

$$\frac{O_m \times 72 \times 44 \times 1.1845}{100 \times 12 \times 1.811} \text{ ppm} - \text{v of CO,}$$

where:

ppm-w = Parts per million by weight
ppm-v = Parts per million by volume
Molar mass of CO_2 = 44
Molar mass of Carbon = 12

Density of air at 298 K = 1.1645

Density of CO_2 at 298 K = 1.811

$$\therefore 1.727 \times O_m = CO_2 \text{ ppm-v}$$

$$\& \ \frac{CO_2 \text{ ppm} - \text{v}}{1.727} = O_m \text{ ppm} - \text{w}$$

4.3.3.4 (Continued):

Convert O_m from **ppm-w** to ppm-v (0,) by:

$$O_v = \frac{O_m \times 29}{600} \text{ or } \frac{CO, \text{ ppm} - v \times 29}{600 \times 1727}$$

where:

Molar mass of air = 29
Molar mass of oil = 600

$$\therefore O_v = CO_2 \text{ ppm-v x } 2.8 \text{ x } 10^{-2} \qquad \textbf{(Eq.1)}$$

The conversion of the integrator count into CO_2 ppm-v is achieved by:

$$CO_2 \text{ ppm} - v = \frac{A_1 \times a \times b}{A_2 \times V} \qquad \textbf{(Eq.2)}$$

where:

A_1 = **Integrated** area of the sample
A_2 = **Integrated** area of the standard
a = Concentration of CO_2 in the standard as ppm-v
b = Volume of standard injected (liters)
V = Volume of sample (liters)

Combining Equations **1** and 2 provides the final concentration of organic material in the sampled bleed air expressed as parts per million by volume of synthetic oil equivalent as shown in Equation 3:

$$O_v = \frac{2.8 \times 10^{-2} \times A_1 \times a \times b}{A_2 \times V} \qquad \textbf{(Eq.3)}$$

NOTES:

(a) The silica gel sample tube should not be connected into the system in such a manner which permits zero air to pass through the tube before it is connected to the rest of the system, otherwise lighter fractions of the organic material contamination may be **desorbed** prematurely from the gel bed.

(b) The two desiccants recommended for use are general purpose grade calcium chloride granules, and self-indicating calcium sulfate granules. Both desiccants should be changed immediately if any discoloration of the calcium sulfate occurs.

4.3.3.4 (Continued):

(c) It is important to ensure that the **NDIR** analyzer output and integrator response are synchronized. This may be achieved by zeroing the **NDIR** analyzer and adjusting the integrator until it is just on the point of counting when this occurs. The chart recorder should be set up to confirm this visually both at the original zero point and when the analysis has been completed, when counting should stop.

Check the synchronization of the integrator, **NDIR** analyzer, and chart recorder between each sample and adjust as appropriate.

(d) A **NDIR** analyzer not incorporating a linearized output should not be used for this measurement due to the difficulties which occur with both the calibration and sample analysis procedures.

f. Reference or Acceptable Alternative Methods: See Appendix A.

4.3.3.5 **Respirable** Particles: Engine generated particles are generally accepted to comprise of general nuisance particles that are only considered hazardous to human health if their particle size range falls within the so called alveolar or respirable fraction.

Sampling and analysis of the alveolar fraction of engine generated particulate material presents a number of practical difficulties in an engine test cell environment. The larger particles within this fraction will not be quantitatively transported through the long sample transfer lines required to transfer the sample from the engine to the particle measurement equipment.

In practice, a similar situation will exist on the aircraft in relation to the quantitative transfer of engine generated particulate into the cabin via the air conditioning pack. The larger particles within the alveolar range will suffer similar losses for similar reasons.

Thus, the pragmatic approach to this dilemma within **SAE** has been to define respirable particles (for the purpose of this document) as those with an aerodynamic diameter of 2 pm or less. The assumption is then made that this size fraction of the particulate material will be transported with close to 100% efficiency from the engine to the measurement equipment location.

The following methodology reflects this approach.

a. Analytical Method: Concentrations of respirable particles in bleed **airstreams** are determined by passing a known volume of air through a filter of predetermined weight. By reweighing the filter after this operation, the quantity of material is determined by difference. Care must be taken to ensure that the filter weighing techniques take account of ambient humidity and temperature effects in accordance with standard laboratory practice.

4.3.3.5 (Continued):

a. Apparatus:

(a) Filters with a capture efficiency of 99.9% for particles above 0.3 urn.

(b) A balance capable of weighing to an accuracy equivalent to a particulate concentration of 0.05 mg/m^{-3} in the sampled volume.

Figure 3 shows a typical layout for sampling **respirable** particles.

c. Sampling Technique: Prior to the commencement of sampling, a **preweighed,** conditioned filter is placed in the fitter holder. Sampled air from the engine bleed air supply is transported, via the heated line system, to the filter and a sample of typically 2 to 3 m^3 in volume is passed through the filter.

At the end of the sampling period the pump, if required, is switched off and the filter is removed, reconditioned, and reweighed to determine the mass of the captured particulate.

d. Calculation of Results: The weight gain of the filter **(mg)** is divided by the volume sample to give the average concentration in milligrams per cubic meter.

The volume sampled is corrected to 298 **K** and 101 **kPa.**

e. Reference or Acceptable Alternative Techniques: Any technique which can be demonstrated to effectively capture those particles in the air stream which lie within the required size range and which provides a mass measurement of the captured particles which is traceable to **international** standards.