

AEROSPACE INFORMATION REPORT

AIR6418™

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Transient Measurement Method Development for
Aircraft Propulsion Engine and Auxiliary Power Unit
Generated Contaminants in Bleed Air

RATIONALE

For engineering design and development, there is a need for methodologies to conduct real-time and transient measurements of aircraft propulsion engine and auxiliary power unit (APU) generated contaminants in compressor bleed air. Current ARP4418 methodologies are primarily for standard filtration and off-line steady state measurement techniques. Such steady state, long-time measurements do not have the capability to give real-time results or capture short-term events, since they average out peak levels. This SAE Aerospace Information Report (AIR) explores proposals for conducting transient real-time semi-quantitative measurements of engine compressor bleed air contamination on test stands.

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1. SCOPE

This SAE Aerospace Information Report (AIR) outlines transient measurement methods to determine engine-generated levels of relevant compressor bleed air contaminant marker compounds on a ground level test cell for aircraft propulsion engine or auxiliary power unit (APU) to be fitted on civil and military aircraft. This AIR focuses on lubrication oils that might enter the bleed air through leaking engine seals or other sources. Also considered are ingested engine combustion products, which must be differentiated from oil. The intent of this AIR is to identify key species that are markers typical of contaminants, not to characterize all possible contaminants. Real-time (transient) measurement methods to approximately quantify those markers are also discussed. Real-time methods developed for transient measurement could also be applied for real-time measurements in steady state operations in ground level test beds. Discussions of test setup and test procedures, techniques for sampling ambient air and compressor bleed air, and one or more specific analytical methodologies for each of the identified bleed air contaminant marker compounds are included. This AIR will not recommend levels of acceptability.

1.1 Introduction

This AIR explores several developmental measurement procedures that would enable the user to determine in real time whether there are low levels of engine generated substances present in the bleed air during engine operation, including transient operating conditions. Environmental engine inlet conditions must be considered. Other measurement methodologies may exist that are not identified in this AIR.

Transient measurements discussed here are not intended as accurate gas or particle measurement techniques. They are intended to identify and approximately quantify engine generated contamination under simulated operating conditions.

Each engine model has its own design features and characteristics. Setting threshold levels for one model may not be applicable to other models. This AIR will not recommend levels of acceptability. It will discuss how to make measurements to determine if there are variations in contaminant concentrations that could be attributed to engineering design features.

The user will need to review and interpret the data to determine the measured concentrations which indicate greater than expected transient bleed air contamination. This document focuses on specific markers, test conditions, sample setup, and instrument LOQ and range. The instrument measurement range may need to be at least an order of magnitude greater than the concentrations measured during steady state conditions to avoid over-ranging during transients.

A strong approach is where the user simultaneously measures gas phase and particle phase markers, which could include carbon dioxide (CO₂), formaldehyde or acetaldehyde, and ultrafine particles (UFP) using absolute and differential measurement techniques to evaluate ambient inlet conditions and differential conditions between the engine inlet and the engine compressor bleed air exit. The absolute and differential measurements may help to inform the user whether the source of contamination in the compressor bleed air is from the ambient air or is engine generated. Future work discussed in Section 6 identifies additional research that is needed for use of marker compounds.

The presence of elevated levels of carbon dioxide and aldehydes along with UFP is an indicator of ingestion of combustion exhaust or recirculation, or external ground sources. In rare cases, internal exhaust products could be present. This is discussed at greater length in sections three and four.

However, depending on the environmental conditions of the engine test location, ambient air as a source of contamination may be negligible and therefore just gas phase marker (aldehydes) and particle marker measurements at engine compressor bleed air exit would be acceptable. Formaldehyde and acetaldehyde are gas phase indicators of turbine oil decomposition or exhaust ingestion. Depending on the mechanism for oil contamination generation, measurements of only particles may be acceptable.

Combining measurements of different contaminant markers should enable the user of this document to assess the source of contamination and identify whether the source is engine ingested or engine generated.

A single event of engine generated contamination might be of short duration and require an appropriate high frequency analyzer sample rate and data recording speed to identify the event. Also, data smoothing and reduction of peak concentrations due to mixing and diffusion in the sample line must be considered when designing a sampling system and interpreting data.

This AIR contains theoretical information and discussions that still require scientific evaluation.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document 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 document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6241	Procedure for the Continuous Sampling and Measurement of Non-Volatile Particle Emissions from Aircraft Turbine Engines
AIR7521	Measurement Data and Reference Values for Compounds Potentially Found in Aircraft Engine Bleed Air
ARP4418	Procedure for Sampling and Measurement of Aircraft Propulsion Engine and APU Generated Contaminants in Bleed Air
ARP6320	Procedure for the Continuous Sampling and Measurement of Non-Volatile Particulate Matter Emissions from Aircraft Turbine Engines

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2.2 Definitions

AEROSOL: A system of particles suspended in a gas.

BLEED: Compressor bleed air from an aircraft gas turbine propulsion or auxiliary power unit engine.

MARKER: A bleed air contaminant that can be measured to identify the presence of an upstream source of contamination.

PARTICLE: Liquid or solid constituent of aerosol.

PLUG FLOW: A constant velocity across a pipe.

T_{10-90%}: Response time for instrument output signal to change from 10 to 90% of final output change after a step change at the instrument inlet.

ULTRA-FINE PARTICLES: No formal standard definition exists. For the purpose of this document, UFP diameter is defined as less than 0.5 μm or 500 nm. UFP may be described elsewhere as particles less than 100 nm in diameter.

2.3 Acronyms

AMS	Aerosol mass spectrometer
APU	Auxiliary power unit
CPC	Condensation particle counter
cPTFE	Carbon loaded polytetrafluoroethylene
CRDS	Cavity ring down spectrometer
DC	Diffusion charging
ECS	Environmental control system
EI	Electrical impactor
EM	Electrical mobility
FID	Flame ionization detector
FP	Fine particles
HP	High pressure
LOD	Limit of detection
LOQ	Limit of quantitation
LP	Low pressure
MDL	Minimum detection limit
MES	Main engine start
NDIR	Non-dispersive infrared
nvPM	Non-volatile particulate matter
PM	Particulate matter
PRSOV	Pressure regulation shutoff valve
SIFT-MS	Selected-ion flow-tube mass spectrometer
SMPS	Scanning mobility particle sizer
TILDAS	Tunable infrared laser direct absorption spectroscopy
TOF-PTRMS	Time of flight proton transfer reaction mass spectrometer
UDL	Upper detection limit
UFP	Ultra fine particles

2.4 Units

bara	Absolute pressure in bar
barg	Gauge pressure in bar
g/h	Grams per hour
L/min	Liters per minute
μm	Micron
nm	Nanometer
ppmV	Parts per million (1e-6) on a volume basis
pptV	Parts per trillion (1e-12) on a volume basis
ppbV	Parts per billion (1e-9) on a volume basis
psi	Absolute pressure in pounds per square inch

3. GASEOUS MARKER MEASUREMENTS

3.1 Measurement of Gaseous Ambient and Engine Marker Compounds

3.1.1 Formaldehyde and Acetaldehyde

Formaldehyde and acetaldehyde are created at easily measurable levels in turbine exhaust and in turbine oil decomposition. Formaldehyde and acetaldehyde concentrations typically rise and fall together. Therefore, only one aldehyde (formaldehyde or acetaldehyde) needs to be measured. Typical ambient background concentrations are low, below 350 ppbV.

In areas where ozone may typically be elevated (exceeding 20 ppbV), ozone measurements are also recommended. Ground level ozone concentration measurements at Charleston Airport were approximately 40 ppbV (Licht et al., 2021). Due to the potential for reactions of ozone with other ingested compounds to produce aldehydes, it may be beneficial to measure ambient ozone (for example, using an ultraviolet (UV) or solid-state ozone sensor) to distinguish or identify potential error sources that produce formaldehyde readings.

Several real-time formaldehyde and acetaldehyde measurement methods are presented in [Table 1](#):

- Tunable infrared laser direct absorption spectrometry (TILDAS) is usually free of measurement interference from other molecular species. TILDAS operates at reduced pressure, reducing water interference, and enabling specific detection by targeting laser frequency to a unique finger-print for a target molecule (Winkowski and Stacewicz, 2020; McManus et al., 2015). TILDAS relies on the selection of a laser operating at the wavelength of one of the peaks in the fingerprint of a compound. Other interferences must be identified and addressed if present at the selected wavelength.
- Cavity ring down spectroscopy (CRDS) measures the decay of laser intensity in an optical cavity. The specificity of the measurement is based on the vibrational motion at frequencies specific for a molecular type in the IR region. Concentration of a molecule will determine decay rate of the IR light pulse (Wheeler et al., 1998).
- Selected ion flow tube mass spectrometry (SIFT-MS) uses reaction ions to interact with sample molecules in a gas mixture, which is analyzed by a downstream mass spectrometer to provide real-time quantification of complex gas mixtures (Smith and Spanel, 2015).
- Time-of-flight proton-transfer-reaction mass-spectrometers (TOF-PTR-MS) uses a soft ionization technique to ionize chemicals prior to analysis. Fragmentation still occurs in the drift tube for many compounds, so the analyzer must be calibrated for the environment being tested.