FACTS Detailed Test Plan Task 2.5:
ECS Pack Surface Samples

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Service Contract MOVE/B3/SER/2016-363/SI2.748114: Investigation of the quality level of the air inside the cabin of large transport aeroplanes and its health implication

Executive Summary

FreshAircraft (FACTS) is a research study funded by the Directorate-General for Mobility and Transport (DG-MOVE). Motivation of the project comes from concerns among international governments, pilots, cabin crew and passengers, and other stakeholders of commercial jet aircraft about possible health risks associated with reports of the presence of fumes in the air supplied to aircraft cabins. The over-arching objective of the FACTS project is to ascertain potential safety and/or long-and short-term health risks resulting from the contamination of bleed air in both routine and cabin/cockpit air contamination event, originated in flight conditions. The FACTS project is organised by the following tasks:

- Task 1. Review of the State of the Art and Establishment of the Baseline for the Work
- Task 2. Exposure Monitoring: Identification of the causes of bleed air contamination and assessment of the impact on the quality of cockpit/cabin air
- Task 3a. Toxicological risk assessment
- Task 3b. Health risk assessment
- Task 4. Engineering controls- Risk mitigation strategy
- Task 5. Conclusions and recommendations

This report describes detailed test procedure of the ECS pack surface wipe sampling Task 2.5.

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Abbreviations

ACM	Air Cycle Machine
BACS	Bleed Air Contamination Simulator
EC	Elemental Carbon
ECS	Environmental Control System
FACTS	FreshAircraft Project
IFA	Institute Fur Arbeitsschutz
OC	Organic Carbon
OP	Organophosphate
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PRSOV	Pressure Regulator Shut Of Valve
SVOC	Semi-Volatile Organic Compound
TCP	Tricresyl Phosphate

1 Introduction

1.1 FACTS Project Context

Aircraft bleed air, if contaminated with pyrolized fluid or any other chemical compound present in ambient air, needs to pass long path from aircraft envelope to cabin. Within this path, many ventilation system components are installed, such as pre-cooler, ducts, valves, sensors, ozone convertors, Environmental Control System (ECS) pack components such as heat exchangers, air cycle machine, water extractor, valves, by-pass ducts, etc. Environmental conditions such as air and surface temperature, pressure, velocity or interaction with surfaces change significantly between and within these components and may impact composition of the bleed air chemical compounds. For example, by deposition on and desorption from these surfaces.

What happens to the bleed air quality/contaminants within ECS pack is not well understood nor published in open literature. At the start of the FACTS project, a discussion took place about measurements during revenue flights. In close consultations with the Scientific Committee, EASA, DG-Move, and the consortium it was decided to exclude revenue flights, because of high cost and limited information gaining. It was agreed to carry out a limited witpe sampling campaign for semi-volatile and particle bound compounds in residues form different parts of the ECS pack. The research will provide a unique information on bleed air contamination residuals that is trapped or sedimented within ECS pack surfaces during aircraft operation just before scheduled and unscheduled removal for maintenance. Although it will not be possible to directly link findings from this campaign to bleed air quality, especially due to limited known history of aircraft operation and maintenance, it will provide novel information about what could have been present in the bleed air and what could be possibly later desorbed back to the bleed air and supplied into an aircraft cabin.

Findings from ECS pack surface samples will complement those from other workpackages in FACTS such as from flight tests, BACS tests as well as engine test stand tests.

Results could also provide rationale for potential future large ECS pack surface sampling campaign.

1.2 Objective

Determine presence of bleed air contaminants in ECS packs, by chemical analysis of residuals on internal surfaces of ECS pack parts received at certified maintenance facility for service and cleaning prior the ECS component tear down and cleaning.

Non-objective: Estimation of bleed air quality based on chemical composition of contaminants found on surfaces sampled. Statistical significance of the results, due to limited number of samples. Source of compounds.

2 Method

2.1 ECS Pack Representativeness to Cabin Air Quality Issues

ECS pack objectives for maintenance are a) regular scheduled functional and operational checks on the wing including valves and sensors controls, or scheduled water washing of heat exchangers interiors or b) driven by irregularities identified by operators in environmental parameters such as temperature, pressure, sound, odor etc., which usually lead to mechanical wear. Then, either entire (small aircraft) ECS pack or only a component may be disassembled and sent in to the service center for maintenance. Failures of components are typically caused due to contamination with dirt/sand and carbon, but also due to corrosion and water contamination. The maintenance process is to repair the mechanical defects and clean the unit (internally and externally) and to restore to serviceable specification.

Bleed air contamination may be more closely related to strategy for maintenance of the entire aircraft, and not a ECS component itself. For example, over servicing an APU with oil could lead to oil contamination of pack, and is not caused by ECS pack component maintenance. Deicing fluid contamination is another example. Less than 10% of ECS packs are received due to odor related complaints. Not necessarily all odor complaints have to be related to pyrolized oil or fluid potentially present in a bleed air. ECS pack received due to recent substantial oil-based contamination is very low.

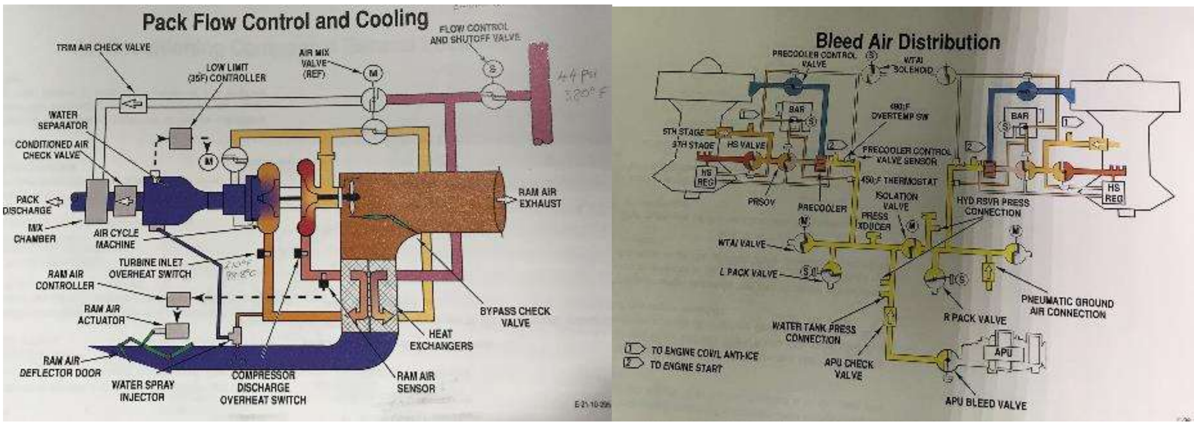
Sampling from a range of ECS pack components as received for maintenance due to various reasons, not necessarily associated with odor in cabin events, will provide baseline for comparison, as well as will show whether oil contamination is common.

Limited information is available about each ECS pack part serviced at Honeywell Bournemouth. Each sample will be accompanied with information such as for example component history (hours and cycles flown), tail number and type of aircraft. Complexity of information provided with the ECS component received for maintenance may vary and will be provided to FACTS program. The last maintenance data will be available if Honeywell carried out the repair. Every ECS component sampled will be accompanied with a photo of the wiped surface before and after the sample.

2.2 ECS Pack Component Selection and Sampling Location

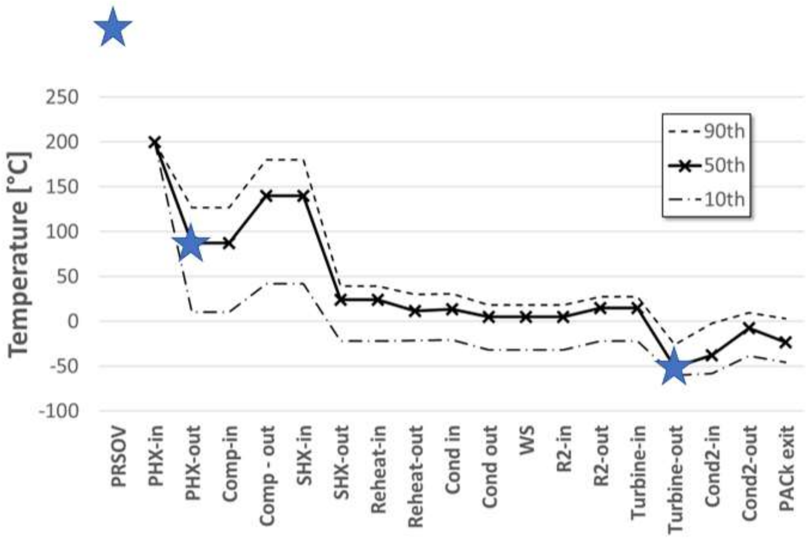
Contaminants in bleed air could be in form of gases, liquid aerosols and particulates. These can deposit on ECS pack surfaces. ECS simplified schematic is depicted in Figure 1~~Figure 1~~ (left). Especially cold surfaces and surfaces with high temperature variations during ECS pack operation are of interest as some bleed air contaminants could be prone to condensation. Notional temperature variations within ECS pack is shown in Figure 2.

Figure 1 ECS schematic example



Air is bled from low (intermediate) or high pressure bleed port at various temperatures and pressures. This is the highest air temperature in the bleed air system. Still within engine, air is cooled down in precooler by air by-passing the engine core. Precoolers are designed to cool air to approx. 200°C. Then, air is drawn to primary heat exchanger (PHX) where it is cooled by ram air down to 90 °C (range from 10 to 130 °C depending on operational conditions). PHX and compressor inlet share the same temperature and sampling could be performed based on convenience of sampling area. In compressor stage of air cycle machine, air temperature is increased on average by 50 °C. In secondary heat exchanger, the air is cooled down by ram air to about 20 °C (range from -20 to 40 °C). The lowest temperature in the ECS pack would be found in ACM's turbine outlet. Stars in the Figure 2 indicate components selected and available for the sampling campaign at Bournemouth facility. Temperature variation in Figure 2 would be different for various ECS packs, but notionally would follow very similar pattern.

Figure 2 Air temperature variations in ECS pack. 10th, 50th and 90th data points represent percentiles across wide range of simulated operational conditions. Stars show selected components for wipe sampling.



Honeywell maintenance facility in Bournemouth service ECS pack components from wide range of large commercial aircraft, but also individual components from bleed air distribution system (Figure 1-right) and full ECS packs from business jets. Exact type of aircraft and reason for maintenance will depend on samples of convenience and will be recorded. Following components from ECS pack and bleed air system were selected for sampling:

- Pressure regulating shut of valve, located between bleed port and a precooler. The component is from B737, and several are available per week.
- Primary heat exchanger outlet from business jet ECS pack. The component is from Units available of Dassault -7X. About 1 ECS pack per month. About 1/10th is in service due to odor.
- Air cycle machine (ACM) turbine outlet. The ACMs are available from wide range of aircraft such as A320, A330, A340 and Boeing B737, B757 or B767. Several ACMs are available per week.

No heat exchangers from large commercial aircraft are currently being serviced at Bournemouth. However, should it be available during the sampling campaign, they will be sampled as well. Heat exchangers from large aircraft are serviced in France. About 2 HX are received per month with some indication of "smell in cabin".

Figure 3 ACM parts (left and middle) and Pressure regulating shut off valve (right) serviced at Honeywell, Bournemouth

Location of sampling area will be finalized during the pre-test phase, based on convenience and observations. Size of sampled area will be measured and photo recorded. As some ECS parts might exhibit high gradients of contamination, larger area (up to 10 x 10 cm) will be sampled (e.g. PRSOV). Other parts, for example ACM, will likely come from various aircraft platforms and shape and size will be different. Again, as large area as possible will be sampled and recorded.

2.3 Sampling Procedure and Method

Sampling campaign will be structured into pretest phase and main test. In the pretest phase, samples will be taken from all selected ECS pack parts and bleed air valve (Table 1) in Bournemouth, UK. Wet and dry wipe sampling method will be investigated for analysis of bleed air contaminants deposited on surfaces plus one sample for OC/EC. Depending on the results of the pre-test, main test will either continue in the same scope as pre-test or will be narrowed down to less methods and/or less number of ECS parts (Table 2). In addition, we will sample from large HX anytime they are received for maintenance in Bournemouth. However, likelihood is low. In addition, if not received in Bournemouth, a couple of samples could be pursued from France maintenance facility for large HXs only, with indicated “smell in cabin” reason for maintenance.

Table 1 Pre-test summary

		Dry wipe					Wet wipe					Quartz wipe	
ECS pack	PHX outlet	1x					1x					1x	
ACM	turbine outlet	1x					1x					1x	
PRSV	cylindrical duct area	1x					1x					1x	
Analysis		OPs	PAHs	PCB	dioxines	fatty acids	OPs	PAHs	PCB	dioxines	fatty acids	Organic carbon	Elemental carbon
Blank sample		1x					1x					1x	
Number of wipe samples		4					4					4	
Total number of wipe samples		**16**											

Table 2 Main-test summary example

		Dry wipe					Wet wipe					Quartz wipe	
ECS pack	PHX outlet	12x					---					12x	
ACM	turbine outlet	---					---					---	
PRSV	cylindrical duct area	12x					---					12x	
Analysis (tbd)		OPs	PAHs	PCB	dioxines	fatty acids	OPs	PAHs	PCB	dioxines	fatty acids	Organic carbon	Elemental carbon
Blank		---					---					---	
Number of wipe samples		24					---					24	
Total number of wipe samples		**48**											

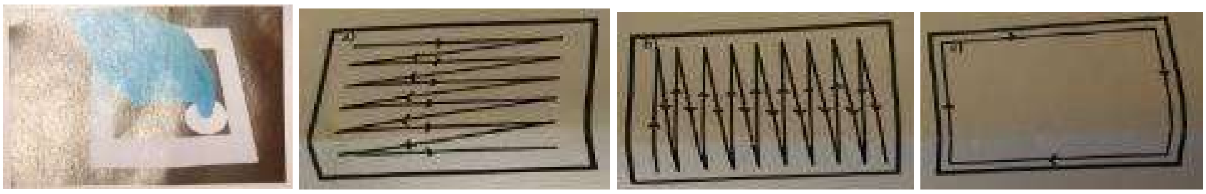
The samples for total organic carbon and total elemental carbon will be collected on quartz fiber material. Alternatively, based on experience on site, gentle rub of soot will be collected and analysed for composition (EDX).

Samples for VOCs will be taken based on procedure of Institut Für Arbeitsschutz (IFA) and their sampling kits. Two methods will be applied, dry sampling (original IFA method) and a limited number of wet samples. The hypothesis is that dry and wet samples will be qualitatively same or very similar, but wet sample would be quantitatively larger. Results will reveal what chemical contaminants might have been present in the bleed air.

Dry sampling method is expected to capture just a top layer of surface contaminants, i.e. from the last contamination events only. This method was used in FACTS flight campaign for sampling from bleed air ducts surface. Detailed IFA procedure will be provided to engineers in Bournemouth. Simplified procedure is as follows:

- Designate area to sample from, measure area, try to keep ideally 5x5 [cm]
- Use sterile wipe as provided by IFA
- Wipe designated surface as shown on Figure 4
- Pack and seal the wipe to the dedicated container and prepare for shipment to laboratory.

Figure 4 IFA wipe sampling method excerpt



Wet sampling method is expected to capture deeper layers of surface contaminants, i.e. old surface contamination deposits. Method is as follows:

- Use sterile tissue/wipe as provided by IFA
- Moist the tissue with acetone
- Wipe the same designated surface where dry sample was performed as shown in Figure 4
- Pack and seal the wipe to the dedicated container and prepare for shipment to laboratory.

A few samples will be taken in parallel and shipped to IFA laboratories for OPs analysis and quality control.

2.4 Laboratory Analyses

Quartz, wet and dry tissues from the wipe samplings will be shipped to TNO Laboratories in the Netherlands. Contaminants will be analyzed for presence and signs of oil and oil degradation products such as:

- organophosphates (OPs)
- polycyclic aromatic hydrocarbons (PAH)
- polychlorinated biphenyls (7 indicator-PCBs). On high concentration samples, analysis for PCB like dioxins will be done
- synthetic fatty acids
- OC/EC

Tissues will be extracted with ASE 350 (Dionex) with dichloromethane/hexane as extraction solvent. Before extraction internal standard Triphenyl Phosphate-d15 and Triethyl Phosphate-d15, 16 deuterated PAHs and ^{13}C labelled indicator PCBs will be added to the tissues.

After clean up and concentration, the extracts will be split into an extract for OPs and an extract for PAH/PCB analyses including identification of synthetic fatty acids.

After extraction, the OPC sample extract is concentrated and analysed by GC/MS. The method is based on the work of Solbu (2007). PAH’s will be analysed by GC-MS isotope dilution according to ISO 12884 and PCB’s will be analysed based on isotope dilution and GC-MS according to EN 1948:4-2010.

3 Timeline

Updated detailed test plan for Scientific Committee review	July 7, 2019
Approval of Scientific Committee	2-4 weeks
Pre-Test campaign	August, 2019
Pre-Test campaign results review and main test approval	September, 2019
Main Test campaign execution	October-November, 2019
Visit of Scientific Committee on site to witness the sampling	TBD
Results and analyses	December-January, 2020
Test report ready for internal review	February, 2020
Submission to Scientific committee for review & approval	March, 2020

4 References

ISO 12884:2000. Ambient air – Determination of total (gas and particle-phase) polycyclic aromatic hydrocarbons – Collection on sorbent-backed filters with gas chromatographic/mass spectrometric analyses.

EN 1948:4-2010. Stationary source emissions - Determination of the mass concentration of PCDDs/PCDFs and dioxin-like PCBs - Part 4: Sampling and analysis of dioxin-like PCBs

Solbu K. et al. 2007. Determination of airborne trialkyl and triaryl organophosphates originating from hydraulic fluids by gas chromatography-mass spectrometry. Development of methodology for combined aerosol and vapor sampling. Journal of Chromatography A, 1161: 275-283.