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Short communication

Design of a small personal air monitor and its application in aircraft

*Chris van Netten**

School of Population and Public Health, University of British Columbia, James Mather Building, 5804 Fairview Avenue, Vancouver BC, Canada V6T 1Z3

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ABSTRACT

A small air sampling system using standard air filter sampling technology has been used to monitor the air in aircraft. The device is a small ABS constructed cylinder 5 cm in diameter and 9 cm tall and can be operated by non technical individuals at an instant notice. It is completely self contained with a 4 AAA cell power supply, DC motor, a centrifugal fan, and accommodates standard 37 mm filters and backup pads. The monitor is totally enclosed and pre assembled in the laboratory. A 45° twist of the cap switches on the motor and simultaneously opens up the intake ports and exhaust ports allowing air to pass through the filter. A reverse 45° twist of the cap switches off the motor and closes all intake and exhaust ports, completely enclosing the filter. The whole monitor is returned to the laboratory by standard mail for analysis and reassembly for future use. The sampler has been tested for electromagnetic interference and has been approved for use in aircraft during all phases of flight. A set of samples taken by a BAe-146-300 crew member during two flights in the same aircraft and analyzed by GC-MS, indicated exposure to tricresyl phosphate (TCP) levels ranging from 31 to 83 nanograms/m^3 (detection limit <4.5 nanograms/m^3). The latter elevated level was associated with the use of the auxiliary power unit (APU) in the aircraft. It was concluded that the air sampler was capable of monitoring air concentrations of TCP isomers in aircraft above 4.5 nanogram/m^3.

1. Introduction

Complaints from crew members regarding sporadic fume events in the cabins of BAe-146 aircraft has led to a number of publications (van Netten, 1998, van Netten and Leung, 2000, 2001), and reviews (NRC, 2002, Hocking, 2005), and a special issue in the Journal of Occupational Health and Safety Australia and New Zealand, 2005. Even as recently as October 2007 the British Broadcasting Corporation (BBC), reported (Goldberg, 2007) that these fume events have resulted in some crew members refusing to fly these aircraft maintaining that the poor air quality is a hazard to passengers and crew. These air quality incidents have been traced (van Netten, 1998) to the virtual universal practice of using compressed air from the jet engines to pressurize aircraft cabins and provide heat and air for passengers and crew members. This source of air has been referred to as "bleed air". Bleed air can also come from a small jet engine situated in the tail of the aircraft and referred to as the Auxiliary Power Unit (APU). In time oil seals in jet engines start failing and, if not recognized in time, jet engine lubricating oil can enter the ventilation

* Tel.: +1 604 822 5688; fax: +1 604 822 4114.
E-mail address: cvnetten@interchange.ubc.ca.

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system of the aircraft. Since bleed air exits the compressor stage of the jet engine its temperature can be as high as 500 °C, smoke is generated and jet engine lubricating oil components can enter the cabin exposing passengers and crew.

Laboratory experiments (van Netten and Leung, 2000, 2001) indicate that the constituents of jet engine oils are volatilized and/or aerosolized and can be measured in the air at room temperature. In addition some constituents are pyrolized acting as a source of carbon monoxide (CO). Among the constituents of jet engine oils are various isomers of a high temperature and pressure lubricant, tri-cresyl phosphate (TCP). This compound has 10 different isomers, 6 of which are known neurotoxins (Abou-Donia, 2005) at least one of these, o-TCP, has been identified in jet engine lubricating oils (van Netten and Leung, 2000, 2001). Some of these isomers have been shown to cause a condition referred to as organophosphate induced delayed neuropathy (OPIDN), which has recently been reviewed by Glynn, 1999. For these reasons the use of TCP in these oils has been limited to 3% by weight (Graig and Barth, 1999). Since the majority of chronic health complains from flight crew members often appear to be of neurological nature, followed by respiratory and gastrointestinal symptoms (van Netten, 2001) it was decided to use the presence of TCP as an indicator of jet engine oil exposure. Standard occupational hygiene filter cassette trains along with an appropriate pump are not user friendly and do not lend themselves well for use by non technical individuals, in addition, to have this equipment on continuous standby waiting for such a sporadic oil seal failure to occur, makes it rather unpractical. In order to provide individuals with a sampling system that can be operated by a non technical person, which can be on standby for long periods of time yet requiring only seconds to activate and deactivate without interfering with duties of flight crew members, a small personal air sampler was developed to address this need. Until now no conclusive measurements for oil constituents in aircraft air have been reported in the peer reviewed literature as the aircraft industry has been rather reluctant to allow proper measurements to be taken. Nevertheless some flight crew members adhere to the well established principle in ground based industries, which is that they are entitled to know whether their work environment is safe. They have used the sampler described in this article to monitor aircraft air, as an example a set of results is reported below.

2. Methods

2.1. Sampler development

A number of criteria were decided upon that needed to be incorporated into such an air sampling device if it were to be used in aircraft and other air sampling environments. These include the following:

- It should be small and easily carried in a purse, pocket, or briefcase for extended periods of time to be activated during an upset condition or event.
- It should be relatively inexpensive allowing many units to be deployed in the workplace in order for a relatively rare event to be captured.
- It should be self contained with battery power and preassembled with an appropriate filter.
- It should prevent contamination of the filter when not in use or in transport.
- It should be easily transported through standard mail.
- It should pass the criteria for electromagnetic interference allowing it to be used in aircraft during all phases of flight.
- It should not create any problems with airport security requirements that are currently in effect.
- It should be easily activated in seconds and left alone without having to read a long list of directions i.e. it should be intuitive and user friendly.
- It should not interfere with the normal duties of flight crew members.
- When in use it should not interfere with the comfort of, or cause any apprehension in, the passengers.
- It should be capable of accurately and reliably capturing TCP and other oil components in the air of aircraft at levels that are well below those that have been associated with health effects.
- It should be based on standard occupational hygiene methodology using "off the shelf" components such as filters and backup pads and batteries.

After testing of the various components including DC motors, centrifugal fan designs etc., along with various configuration of the housing, and numerous different prototypes, a final configuration was settled upon as described below.

2.2. Sampler deployment

Two samplers were pre assembled with a 37 mm fibreglass filters (Whatman QMA, 1851-037) and porous plastic backup pads (Nuecleopore). Control samples were taken by running the samplers for 60 min at calibrated flow rates (1.54 l/min for sampler A and 1.68 l/min for sampler B), using a model 4146 primary calibrator (TSI incorporated), in a clean laboratory environment. The filters were removed and placed in a 10 ml screw cap vial to be analysed at the same time as the experimental ones. After the controls were taken the samplers were again preassembled with new filters and backup pads and again calibrated for flow rates. Since 4 fresh AAA cells consistently allow the sampler, as configured, to function for almost exactly 55 min at the initial steady flow rate, after which the flow rate drops almost instantly to zero within 15 s. The samplers were not re-calibrated upon receipt if there was no battery power left. The samplers were also calibrated at an air pressure of 564 mm/Hg, i.e. equivalent to 8000 ft altitude and the current level of pressurization of aircraft.

Samplers were mailed to the recipient who resided on another continent.

After exposure in aircraft the samplers were again returned by standard mail to the laboratory where the filters were removed from the sampler, extracted, and analyzed along with the sampler controls, spiked standards on filters, calibration standards as well as laboratory blanks.

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Fig. 1 – VN sampler assembled.

2.3. Filter extraction and analysis

Filters were extracted with 5 ml dichloromethane at ambient temperature and sonicated in a water bath, also at ambient temperature, for 30 min. They were reduced to dryness using a nitrogen stream reconstituted to .5 ml in ethyl acetate and transferred to GC vial, 1 µl was injected into a 30 m Agilent HP-5MS capillary column 250 µm diameter 0.10 µm film situated on a Agilent 6890GC gas chromatograph operating in the splitless mode with a .5 min splitless time, along with an Agilent technologies GMSD 5973, set for specific TCP ion monitoring (SIM) including 368, 165, 107.

Inlet Temperature of the column was 250 °C changing at a rate of 10 degrees/minute to a final temperature of 325. Carrier gas was helium at a pressure of 2.57 psi and at a flow of 1.3 l/min.

TCP Standards were obtained from Fluka Chemicals.

3. Results

The final configuration of the sampler that incorporated most, if not all of the requirements above, is shown in Figs. 1 and 2. It has been awarded US and European patents (US patent #8,945,127 B2, European patent # 01973929.1) and has patents pending in other countries. It houses standard 37 mm filters, a 4.5 V DC motor that can also operate at 3 V, and 6 V, using 4 AAA cells. The whole assembly is 9 cm tall and 5 cm in diameter and is injection moulded using ABS plastic.

The main principle of operation is identified in Fig. 2 showing 4 intake ports in the outer cap which can be aligned with similar ports on a disc (not shown) located on the inside of the outer cap. This disc engages with the main body by means of two slots that mate with the two prongs. Similarly there are 8 exhaust ports on the cap that can be aligned with the ones located on the main body. When the cap and the main body are assembled, the inner disc will compress the O ring onto the filter and backup pad making a tight seal into the filter housing. This slight compression is maintained by means of the captive button that fits snugly into the slot after applying slight pressure onto the cap which allows the captive button to click into position. Once assembled, a 45° twist of the outer cap aligns the intake ports and the exhaust ports and also simultaneously activates a switch to the motor allowing air to pass through the filter. A reverse twist of the cap switches the motor off and disaligns the various ports, enclosing the filter, ensuring protection during transport from and to the laboratory. Depending on the filter and backup pads used, and using for instance the ones identified above and a fresh set of batteries, airflows rates ranging from .7–.8 l/min for 6 h with minimal noise (54 dBA at 2 ft) when configured for operation at 3 V are obtained. At 6 V using similar filter and pads flow rates between 1.5 and 1.7 l/min are obtained lasting for exactly 55 min. At this flow the operation of the sampler is

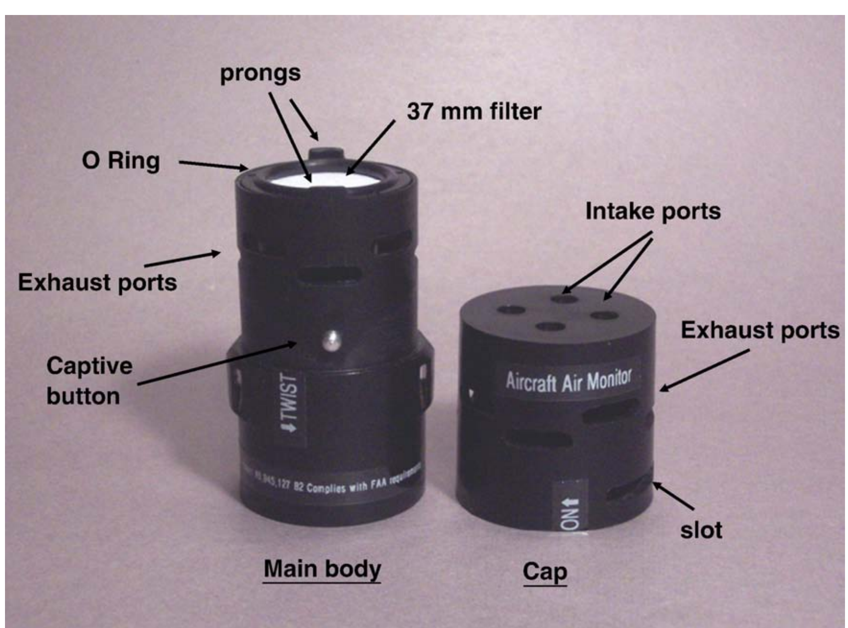

Fig. 2 – VN sampler with cap removed showing details and filter housing.

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rather noisy (66 dBA at 2 ft) and would likely not be acceptable in a quiet environment or with individuals in close proximity. At 4.5 V, using only 3 AAA cells, the sampler runs for about 90 min at a flow rate of 1.2 l/min at an intermediate noise level (62 dBA at 2 ft).

The sampler has been tested for electromagnetic interference by CKC laboratories Inc. and has been shown to comply with FAA regulations for use in aircraft during all phases of flight. (CKC report, 2005). The sampler has been taken through airport security and other checks hundreds of times without any questions.

The samplers that were mailed to another continent for deployment were returned 6 weeks later, at which time they were analysed for TCP content.

Laboratory analysis for total TCP levels indicated, using ground level calibrated flow rates, 92 nanograms/m^3 in flight A and 31 nanograms/m^3 for flight B (Detection limit 4.5 nanograms/m^3). However, since the samplers were 15% less efficient at and equivalent altitude of 8000 ft, the corresponding values of 108, and 36, nanograms/m^3 respectively, were obtained. The latter figures reflect the actual on board exposure more correctly. All controls and blanks were less than the detection limit. Recovery from TCP spiked filters ranged between 87 and 91%.

Sampler A was deployed during level flight 1 h prior to landing and also included descend, and landing. Sampler B was deployed at takeoff and sampled air for 55 min running out of power 8 min prior to landing.

Both flights were on the same aircraft, a BAe 164-300, but days apart.

In addition flight A used the APU during flight prior to landing. In this flight one of the crew members complained of a mild headache that persisted for 5 days, another noticed a light smell/odour. The APU was not used in flight B and no complains from those present were reported.

4. Discussion and conclusions

The use of the sampler, currently referred to as the "VN-Sampler" along with the results obtained, indicate that the sampler has incorporated most, if not all the criteria that were set out initially. For the current set of data, the time delay of 6 weeks between mailing of the samplers and their return, indicates that this configuration is ideal as a standby item in aircraft capable of monitoring the air with a detection limit of 4.5 nanograms/m^3.

Craig and Barth, 1999 have reviewed the inhalation exposure levels including the TWA as set by AGCIH for TOCP exposure which are 0.1 mg/m^3 for pure TOCP and 5 mg/m^3 as a 3% component in oil mist. Solbu et al. (2007) measured TCP concentrations in a mechanical workshop specializing in bench testing aircraft components. They found TCP levels in the air ranging from 0.024 to .28 mg/m^3.

Even if the proper altitude correction were to be applied to the current TWA (ACGIH, 2008), the exposure levels of 108 and 36 nanograms/m^3 reported here at altitude, are well below these values by several orders of magnitude. It should not be forgotten that these results likely reflect background levels and not upset conditions such as fume events in the cabin.

Further investigation into the status of this particular aircraft indicates that the APU was subsequently diagnosed with a failing oil seal, hence the elevated levels of TCP in flight A compared to flight B. Whether this observation is a real reflection of the mechanical status of the APU or just a fluctuation in background TCP levels remains to be verified with additional measurements. Nevertheless it is interesting to note that these results appear to correlate well with the minor complains from those present, the level of exposure, and the mechanical status of the APU in the aircraft.

Although the TCP levels reported here are well below the current TWA, it should be noted that the presence of TCP components in the air is also an indicator of exposure to other compounds present in jet engine oils. In addition other agents present in aircraft air might exhibit a synergistic effect with TCP exposure such as, for instance, pyrethrins (van Netten, 2002), the use of which is required by certain countries prior to landing. It should be noted that the current standards for TCP exposure do not necessarily apply to heated engine oils with temperatures that result in pyrolysis of oil components as indicated by the release of CO (van Netten and Leung, 2000, 2001). Additional exposure measurements during flights along with a record of symptoms experienced by those present would be necessary to identify an acceptable, no complaint level of exposure.

This data also appears to indicate that elevated levels of TCP in the aircraft might have potential as an inexpensive early warning system of jet engine oil seal failure, which appears to be a general problem in the aircraft industry (Lufthansa, 2006).

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