Cabin Air Quality Incidents Project Report

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NOTICE

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This is the final version of the report initially submitted to FAA in June 2009 in fulfillment of FAA Research Grant No. 200505-G-014, "Cabin Air Quality Incident Monitoring and Reporting," This revised version responds to comments from FAA's internal review of August 2009. The FAA elected to not publish this report as an official Office of Aerospace Medicine technical report because it was submitted after the agency's apparent deadline. Because it accurately reflects the research conducted to fulfill the FAA Research Grant listed above, it is available via www.ohrca.org in the interest of sharing the findings with the aviation health community and other researchers.

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ABBREVIATIONS

As used in this report, the following abbreviations/acronyms have the meanings indicated

ABBREVIATION	MEANING
ASHSD	Air Safety Health and Security Department
ACER	Airliner Cabin Environment Research
ATA	Airline and Air Transport Association
AQ	Air Quality
ABS	Acrylonitrile butadiene styrene
AOEC	Association of Occupational and Environmental Clinics
AFA	Association of Flight Attendants
AFA-CWA	Association of Flight Attendants-Communications Workers of America
APU	Auxiliary power unit
BMI	Body mass index
BLS	Bureau of Labor and Statistics
CO	Carbon monoxide
CDC	Centers for Disease Control and Prevention
COPD	Chronic Obstructive Pulmonary Disorder
CAMI	Civil Aeronautical Medical Institute
CVD	Cardiovascular Disease
ESD	Electrostatic Discharge
ER	Emergency Room
FAA	Federal Aviation Administration
FA	Flight Attendant
GC/MS	Gas chromatography/ mass spectrometry
GED	General Education Diploma
GCAQE	Global Cabin Air Quality Executive
GC	Gas chromatography
HSPH	Harvard School of Public Health
HCP	Health Care Provider
Hz	Hertz
IDL	Instrument detection limit
IBT	International Brotherhood of Teamsters
LOD	Level of detection
MCE	Mixed Cellulose Ester
MDL	Method detection limit
MSD	Musculoskeletal Disorder
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Surveys
NIOSH	National Institute for Occupational Safety and Health
NRC	National Research Council
OHRCA	Occupational Health Research Consortium in Aviation
OSHA	Occupational Safety and Health Administration
PAN	N-phenyl-L-naphthylamine

ABBREVIATION	MEANING
PChe	Plasma butylcholinesterase)
PTSD	Post Traumatic Stress Disorder
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RF	Radio Frequency
SPME	Solid Phase Microextraction
SARS	Sever Acute Respiratory Syndrome
SIM	Single Ion Monitoring
SMR	Standardized Mortality Ratio
SHS	Second hand smoke
SPR	Standardized Prevalence Ratio
TCP	Tricresylphosphates
TSA	Transportation Security Administration
TWU	Transport Workers Union
UBC	University of British Columbia
UK	United Kingdom
UMDNJ	University of Medicine and Dentistry New Jersey
UO	University of Oregon
US	United States
VN	van Netten

EXECUTIVE SUMMARY

The National Research Council (NRC) expert report *The Airliner Cabin Environment and the Health of Passengers and Crew* (2002) recommended the establishment of an air quality and health surveillance program to evaluate "the suggested relationship between health effects or complaints and cabin air quality." Such an analysis would require reliable data on exposure to cabin air contaminants, the toxicology of those contaminants, and the health status of cabin occupants with exposure. This report presents findings from a series of studies to assess the feasibility of collecting in-flight exposure data and health symptom, diagnosis, and treatment data from a cohort of working flight attendants. The initial study design would have linked inflight air sample findings to health questionnaire data obtained from flight attendants on those flights completing pre- and post-flight surveys. A modified design was subsequently implemented when airline permission for flight attendants to conduct these activities could not be obtained.

The scope of the study as implemented included three main components, two related to health outcomes and the third involving exposure assessment:

1. Flight attendant health surveillance: Collection of cross-sectional health data by questionnaire from flight attendants by an initial recruitment through airline lists, and further recruitment at major flight attendant bases. Health survey data was analyzed and compared to referent US populations to identify symptoms and diagnoses of interest.
2. Medical case review and reporting, including a review of the scientific literature on cabin air-related medical problems; collection and review of individual case reports identified through flight attendant and pilot unions, clinics, and other health providers who have treated flight crewmembers following suspected air quality incidents; development and dissemination of medical protocols so that exposed and affected crewmembers could be properly assessed and treated and the database of cases can be expanded through enhanced reporting by health care providers.
3. Exposure monitoring of cabin air quality including a) Refinement and initial production of the van Netten (VN) sampler, a small portable air sampling device that can be carried aboard aircraft to take short-term air samples of particulate and semi-volatile contaminants; and b) deployment of VN samplers by research team members on a variety of aircraft and flights to collect air samples that were subsequently analyzed in the laboratory.

Health survey: Focus groups with flight attendant union safety representatives from five airlines provided initial data for survey construction. In addition items and scales were selected from other validated health surveys. Questions covered work history and working conditions, health (symptoms, diagnoses, treatment), and demographic information. Addresses were chosen randomly from union-provided lists of flight attendants at the three largest domiciles (hubs) of one airline and the two largest of the second airline. Fifty percent of the hub populations were selected. Subjects were contacted in two ways: survey packets were mailed to all selected addresses, and 48% of subjects contacted by mail completed surveys. Additional subjects were recruited onsite at the five hub airports through personal contact. An online version of the survey was available to subjects from one of the airlines. In all 4011 flight attendants completed surveys, 37% of the entire population domiciled at those hubs. The most common health conditions resulting in health provider visits fell in the categories respiratory, musculoskeletal, fatigue, and neurological/ psychological.

For comparison to the general population, data were used from the National Health and Nutrition Examination Surveys (NHANES) for the survey years 2005-2006 and 2007-2008. Standardized prevalence ratios (SPR) on similar questions were used with an NHANES respondent sample demographically similar to the flight attendant survey population. Significantly elevated SPRs among flight attendants were found for chronic bronchitis (male SPR 3.5, female 2.75), cardiac disease (female SPR 3.5), diagnosed sleep disorders (male 3.7, female 5.6), fatigue (female 1.8, male 2.2), and depression (female 2.2, male 5.6).

Flight attendants in this study also reported work-related injuries in the past year at much higher frequency than official U.S. government data. Nearly half of the flight attendants reported one or more work-related injuries, while 29% reported

more than one. This compares with 4.2% for all industries and 10.2% for all transportation in 2007 BLS statistics. Besides descriptive statistics the data were also analyzed for associations using a deletion-substitution algorithm, and these results are presented. The study design used does not permit association between health outcomes and particular occupational exposures, including cabin air contamination, but the results provide a health profile of a larger cohort of flight attendants on more dimensions of health than any previous literature identified.

Medical case review: A series of 11 cases were reviewed and symptoms and examination findings summarized. Based on these cases and the literature review a case definition for acute health outcomes related to bleed-air exposure was developed and is presented. A draft medical protocol for assessment and treatment of patients involved in a suspected incident was distributed for review by occupational and aviation medical specialists. Following revisions the final protocol was widely distributed through practitioner networks, at aviation health and safety conferences, through union networks, and through the project website. The aim is both to improve recognition, evaluation, and treatment and to promote reporting of suspected contaminated-air incidents and sequelae so the problem can be better understood.

Exposure data study: Tri-cresyl phosphate (TCP), an anti-wear additive to engine oil, was selected as the primary air contaminant of interest based on concerns for its toxicity and reports of presence in bleed air under certain circumstances, e.g. "smoke in the cabin" incidents. The sampling instrument tested and deployed was the van Netten (VN) sampler, a small portable device to sample semi-volatile and particulate contaminants. Testing against standard occupational hygiene air sampling equipment showed the VN device capable of capable of capturing TCP at a level of 0.04 ng per filter. The device yields semi-quantitative results based on approximate flow-rate data due to motor and battery life variability. Filter analysis used GC/MS in a method developed and validated in two laboratories. Samplers were deployed on 80 commercial flights by researchers, and the sampler proved convenient and unobtrusive for periods of approximately 1.5 to 5 hours at flow rates in the range of 0.4-0.9 liters per minute. Interlaboratory findings on 18 sets of duplicate samples showed reasonable comparability with some disparities potentially related to numerous samples at or near the method detection limits. TCP isomers were detected in about 18% of onboard samples versus none in pre-flight controls, and peak patterns of TCP isomers in in-flight samples corresponded closely to those from tested oil samples from manufacturers.

The initial study design of equipping on-duty flight attendants with samplers to deploy during flights could not be tested because airlines would not permit their participation. The samplers were not disruptive to flights when activated by researchers.

The report concludes with a series of findings and recommendations including:

1. **Reporting of air contamination events and work-related injuries/illnesses**: The FAA, airlines, and flight crew unions should come together with independent experts in occupational injury and illness surveillance to design a proactive surveillance system for reporting air contamination events and work-related injuries and illnesses.

2. **Exposure monitoring:** The exposure monitoring aims of the current research were not fully realized due to funding limitations and the failure of the airlines to allow the original protocol of flight attendants taking air samples to go forward. However, this research did establish that the VN sampler is capable of replicating accepted industrial hygiene sampling methods for tri-cresyl phosphates, presented no problems at TSA checkpoints, and was not disruptive in flight. Follow-up should address the following:

   a. Exposure to low-level TCPs was detected under apparently normal operating conditions, where some oil leakage may occur. Further air sampling should be conducted to verify these findings. It should be considered that pilots may be in the best position to carry out such sampling and to be able to record other conditions during the sampling, including the status of the environmental control systems. This will require FAA and airline involvement in designing the sampling protocols and insuring that they are carried out as designed.
   b. Commercial airplanes as working environments pose some unique challenges to exposure monitoring for employee (and

passenger) protection using traditional occupational hygiene methods and instruments. The difficulty of monitoring many different aircraft for largely unpredictable exposures to bleed air contaminants could be addressed by the development and deployment of biomarker tests, including exposure to specific air contaminants (e.g., TCPs) Since data collection in this study took place, potential blood markers for TCPs have shown promise and should be further explored (Marsillach et al 2013).

c. The research succeeded in collecting some exposure data and considerable health survey data, but without airline cooperation to allow employee participation it was not possible to link these two types of data. A true exposure health outcomes study will require airline participation and facilitation.

3. **Engineering controls:** While further research to characterize air contaminant exposure should go forward, funding should also support research into engineering, design, and administrative controls for reducing risk of exposure to engine oil contaminants in the cabin and cockpit including:

- Alternative oils with reduced toxicity anti-wear additives;
- Improved engine seal designs to minimize leakage;
- Filtration systems between the bleed air intake and cabin air supply system;
- Improved maintenance practices and more frequent inspections of aging parts;
- On-board sensor systems to ensure that engineering and administrative controls are having their intended effects; and
- Mandatory education and training for flight and cabin crew to ensure that workers can adequately recognize and respond to the presence of air supply system-sourced smoke/fumes, in order to mitigate/prevent exposure.

4. **Other flight attendant health issues:** The health survey data suggest a range of symptoms, outcomes, and possibly related exposures worthy of further investigation. Since these studies were conducted FAA and OSHA have been negotiating policies for further application of OSHA standards to cabin crew in flight, pursuant to the FAA Modernization and Reform Act of 2012 (HR 658 2012). As of this writing (Jan. 2014), OSHA has partial jurisdiction over occupational safety and health of flight attendants, including hearing conservation, blood-borne pathogen protections, hazard communication, employee access to exposure records, injury/illness recordkeeping and reporting, and whistleblower protections (78 Federal Register 2013). Some of the health concerns listed below may be more effectively addressed as a result of this development.

a. Fatigue and sleep problems: These are recognized by FAA as highly prevalent conditions among flight attendants. The current study offers further evidence that fatigue and sleeping problems are widely experienced among flight attendants.

b. Noise exposure and hearing conservation: Noise induced hearing loss has been not been monitored in flight crew even though previous studies of flight attendants, including the current study, suggest an unusually high prevalence of hearing loss in this group.

c. Neurological problems: The prevalence of neurological symptoms (e.g., severe headaches, dizziness, numbness/ tingling in extremities, memory loss) that were described as serious enough to seek medical treatment, is cause for concern.

d. Musculoskeletal disorders: The reported incidence of musculoskeletal injuries and the percentage of FAs reporting treatment for low back pain in our sample suggest a focus on MSD prevention would have benefit for both flight attendants and airlines. Numerous ergonomic risk factors are present in flight attendant tasks, including pushing and pulling carts, handling baggage, and prolonged sitting and standing.

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CABIN AIR QUALITY INCIDENTS PROJECT REPORT

I. INTRODUCTION AND BACKGROUND

The National Research Council (NRC) in 2002 published *The Airliner Cabin Environment and the Health of Passengers and Crew*, the report of an expert panel convened to assess the state of knowledge regarding aircraft cabin air quality and health. This report recommended the establishment by Federal Aviation Administration (FAA) of "an air-quality and health-surveillance program" and detailed a set of objectives and approaches for this program (NRC 2002). In making this recommendation the committee stated that

> [T]he health and air quality components should be coordinated so that the data are collected in a manner that allows analysis of the suggested relationship between health effects or complaints and cabin air quality (NRC 2002, p.10).

This basic principle of occupational health surveillance, linking exposure data and health data, forms the foundation of the research reported herein. For a variety of reasons this principle was not always successfully followed, but the methods, results, and interpretations offered are intended to advance understanding of flight crew exposures and health and point to future research directions.

Several components of the air quality research recommended by the NRC report were legislatively operationalized in Section 815 of Vision 100, the FAA reauthorization act of 2003. The FAA elected to establish a center of excellence for cabin air quality research to address some of these research questions, and the Airliner Cabin Environment Research (ACER) group led by Auburn University was named as that center in 2005. However, a portion of the funds allocated for Section 815 items was awarded to the Occupational Health Research Consortium in Aviation (OHRCA), led by the University of Oregon, to conduct research on air quality incidents and health effects on airline crewmembers. In this report air quality incidents are defined as the potential entry of heated engine oil and hydraulic fluid components and their byproducts into the cabin in bleed air through the environmental control system. FAA coordinated an arrangement for a joint effort on air quality incident research between the OHRCA team and an ACER subgroup led by the Harvard School of Public Health (HSPH).

The research plan designed by OHRCA and ACER was initially premised on the aforementioned occupational health surveillance model. The NRC report identified numerous inadequacies with current databases and reporting systems for health-related responses to cabin air quality (NRC 2002). Given these circumstances the current research proposed to assess existing data and collect new data on individual case reports of medical conditions possibly related to cabin air quality incidents and to generate population health data on the working population of flight attendants. Since one of the charges in Section 815 is to address the issue of reporting contaminated air incidents, an underlying cause of the inadequate data just referenced, this question is also addressed by eliciting the experience of flight attendants with air quality concerns and incidents.

With regard to exposure assessment, the NRC report identified corresponding data gaps on air contaminant levels under routine or incident conditions. Therefore, the OHRCA-ACER project aimed to collect in-flight air sampling data on potential engine oil and hydraulic fluid components, data that would ideally be correlated with health effects data in an effort to establish whether associations exist between contaminant exposures and health symptoms and effects.

At the outset it should be emphasized that the resources available and logistical challenges posed by monitoring airborne worksites and a highly mobile working population dictated that our research would largely be a test of the feasibility of collecting the necessary exposure and health data. Thus, as the research design and activities are described, the reader should bear in mind that the scope of data collection is unlikely to definitively answer questions of exposure/health associations.

The scope of the study included three main components, two related to health outcomes and the third involving exposure assessment:

1. Medical case review and reporting: Review of the scientific literature on cabin air-related medical problems; collect and review individual case reports identified through flight attendant and pilot unions, clinics, and other health providers who have treated flight crewmembers following suspected air quality incidents; develop and disseminate medical protocols so that exposed and affected crewmembers can be properly assessed and treated and the database of cases can be expanded through enhanced reporting by health care providers.

2. Flight attendant health surveillance: Collection of health data by questionnaire from flight attendants. Cross-sectional health data would be gathered by an initial recruitment through the airlines, and questionnaires would also be self-administered by recruited flight attendants on designated normal and incident flights on which air samplers have been activated.

3. Exposure monitoring of cabin air quality: a) Refinement and initial production of the van Netten (VN) sampler, a small portable air sampling device that can be carried aboard aircraft to take short-term air samples of particulate and semi-volatile contaminants; and b) deployment of VN samplers by flight attendants on a variety of aircraft and flights to collect air samples that will be subsequently analyzed in the laboratory.

The specific aims and deliverables designated in the original proposal were:

1. To collect, review, and summarize the available medical evidence provided by crewmembers that have reported exposure incident(s) to develop standardized medical evaluation protocols *(Deliverables: medical review paper and medical evaluation protocols);*
2. To develop systems to capture possible health effects related to air quality incidents and for crewmembers to report health and exposure conditions *(Deliverable: air quality health surveillance instrument);*
3. To complete development and testing of the VN sampler *(Deliverables: aircraft-ready portable particulate and aerosol filter sampler with carbon monoxide monitoring capabilities)*;
4. To conduct a feasibility study to field test the VN^{+CO} sampler and the air quality health surveillance instrument in both the cabin and cockpit environments. *(Deliverables: testing results of instruments and logistics for the implementation of future surveillance study)*
5. To design a full surveillance study of cabin crew that will establish the relationship between air quality and health effects, for which funding will be sought through a separate proposal after the completion of the activities described in this proposal.

The sporadic nature and limited characterization of air quality incidents presented particular challenges to study design and implementation, in comparison to other air quality research mandated by Congress. For example, ozone is a naturally occurring air contaminant at flight altitudes and its concentration will vary according to a number of parameters, but by knowing routes, altitude, and the functional status of installed catalytic converters, the presence of ozone is predictable within a range. Likewise if pesticides are applied to airplanes on certain routes, the assessment of crew exposure is somewhat predictable by knowing the identity of the pesticide and mode and timing of application. Bleed air contamination, on the other hand, is much less predictable and there are minimal historical exposure data on which to design an assessment protocol. This is a primary reason for the approach that was chosen, relying on the cabin crew -who are already present in these thousands of airborne workplaces daily -for much of the data collection.

II. STUDY IMPLEMENTATION AND LIMITATIONS

As noted, the primary aims of this study were to assess the feasibility of data collection methods for relevant exposure and health data. Feasibility has a number of dimensions: technological, economic, practical, and political. While these dimensions have been defined in various disciplines and contexts (see e.g. Robinson and Paxman 1991), for purposes of this study the

concepts are straightforward. The air sampling equipment and methodology evaluated is the VN sampler coupled with gas chromatography/mass spectrometry (GC/MS) filter analysis. The intent was to evaluate the feasibility of flight attendants carrying and activating the samplers and returning them to the laboratory for analysis, while preserving proper chain of custody. As in many such studies economic feasibility was not strictly evaluated, as the primary point was to test the method. Based on the findings, however, certain economic questions can be explored through extrapolation from this pilot effort.

Similarly the technical feasibility of gathering health survey data from flight attendants was tested in this research design. Economic feasibility was not directly tested, but costs for such data collection on a large scale could be estimated from our findings.

The questions of practical and political feasibility were also put to the test in this study. While these are less quantifiable than the technical and economic dimensions, they can be and were observed and described in various stages of the research. The following description of the implementation process and the issues encountered are intended to elucidate this dimension of feasibility.

The researchers were independently able to implement certain research activities and provide deliverables, while for some of the research activities, the investigators were dependent on cooperation of airline companies. Specific aims #1 and #3 above proceeded independent of the airlines while the other aims required airline cooperation. Modified versions of aims #2 and #4 were eventually conducted with limited airline cooperation in recruiting flight attendants to participate in a health survey. Because feasibility is central to the study, exploration of reasons for the airlines' reluctance to permit their employees' involvement is warranted. Discussions and negotiations over these issues took place over a period of 18 months. A chronology and documentation of these discussions is available from the lead author, but they are not included in this technical report.

Airline and Air Transport Association (ATA) representatives stated a number of objections to the original study design including:

- Involvement of on-duty flight attendants in [research] activities could distract them from their safety-related functions;
- Airlines had limited staff ability to participate in meetings and calls and engage with researchers;
- Project design should minimize the need to conduct activities during scheduled operations and should not require the assistance of cabin crews; and
- Training of flight attendants to use the samplers and complete surveys would require time that was not available.

The ATA maintained that it was not feasible for flight attendants to obtain air samples and fill out questionnaires during their on-duty flying time. Particular aspects of this conclusion will be addressed in subsequent sections of the report, based on actual data. These data suggest that air sampling under normal flight conditions would present little additional demand in relation to normal duties and safety related functions. Under upset conditions air sampling would clearly not be the flight attendant's highest priority, so other methods of exposure measurement, e.g. automated sensors or biological monitoring, may be more appropriate. Training in use of the instruments would have been done through DVD, and one airline had, in fact, agreed to provide an out-of-service aircraft for filming, and off-duty flight attendants were recruited as actors. Concerns about interference with crew duties could have been addressed in an incremental fashion, for example by attempting crew air sampling on a single flight with safeguards in place, and expanding sampling step-by-step if and when concerns were allayed by actual experience.

Unfortunately, the ATA was not able to facilitate cooperation from the airlines with the research proposed in the original study design. The absence of airline participation led to modifications in our study (see below). The difficulty of implementing the research plan to satisfy needs identified by the expert NRC panel and mandated by Congress in the FAA reauthorization act should prompt an appraisal of the authority and mechanisms for health and safety research in this industry.

II.A. STUDY DESIGN CHANGES

The inability of the research team to arrange for crewmembers to carry out in-flight data collection activities resulted in redesign of key elements of the research.

- Health data and air sampling data are not linked. Instead of in-flight air samples taken by flight attendants and correlated with symptom questionnaires completed after the sampled flights, cross-sectional self-reported health questionnaires were collected from a sample of flight attendants from two airlines by mail or in person at airports, and convenience air samples were collected on flights by researchers in the course of their regular travel. We were unable to: 1) Test the feasibility of flight attendants carrying and deploying air samplers under either routine or air quality incident conditions; and 2) Correlate health symptoms with air contaminants as measured by the van Netten sampler. Specific aim #4, therefore, could not be achieved.
- The health data collected is cross-sectional and retrospective rather than either pre- and post-flight, or pre- and post-incident. This prevented full achievement of specific aims #2 and #4 and therefore also delayed progress on specific aim #5.
- Data on the performance of crewmembers in completing pre- and post-flight questionnaires were not collected. This would have assisted in the development and testing of an incident reporting mechanism beyond what already existed through current union mechanisms.

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III. FLIGHT ATTENDANT HEALTH RESEARCH

III. A. INTRODUCTION AND BACKGROUND

When flight attendants first took to the skies in 1930, they were registered nurses working a seemingly glamorous and adventuresome job. Strict weight, age, and marital status restrictions limited the length of flight attendant careers. Little attention was paid to occupational health and safety hazards for these first waves of flight attendants as "their glamour obscured their labor." However, early unions of stewardesses in the 1950s did advocate for the safety and working conditions of their members, as inseparable from safety for passengers (Barry 2007). When marriage, age, and parental restrictions were finally eliminated in the 1970s, the tenure of flight attendants began to lengthen. By 1976 the average tenure was 6.5 years and climbing. Thus today's population of working flight attendants includes the first large cohort who is spending 40 years or more of their lives working in the aircraft cabin.

The 2002 NRC report on aircraft air quality and the health of passengers and crew cited the importance of linking health surveillance data, particularly of cabin crew, and exposure data to shed light on this relationship, calling current systems "for the collection of health data in relation to cabin air quality…woefully inadequate" (NRC 2002). These cited needs underlie the two separate but related research reported in the following sections. Dual concerns about incomplete reporting of incidents and outcomes related to air quality incidents and proper diagnosis and care of crew and passengers involved in such incidents prompted the first research project, which was a review of medical cases and development of a best practices protocol for diagnosis and treatment of crewmembers involved in air quality incidents. Details of the review and protocol are presented in Section III.B. The second research project was a health surveillance undertaking, which was an extensive questionnaire survey of a large sample of flight attendants from two US carriers. While initial efforts to link this collection of health and working conditions data to environmental exposure data were not successful, the scale of the flight attendant health survey itself provides a valuable cross-sectional database to guide more specific investigations. Methodology and findings of this survey are presented in Section III.C

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III. B. MEDICAL CASE REVIEW AND DIAGNOSTIC AND TREATMENT PROTOCOL

The report, *Exposure to Aircraft Bleed Air Contaminants Among Airline Workers: a Guide for Health Care Providers,* was finalized in August 2008 and is provided in Appendix A. This document provides information about how aircraft occupants can be exposed to pyrolyzed engine oil and hydraulic fluid on commercial aircraft, reported health effects associated with such exposures, recommended medical work-up, and treatment methods. The information is largely based on published reports in the medical and scientific literature, as well as technical aviation-related documents. It also relies on the clinical experience of one of the authors (Robert Harrison, MD, MPH) who has diagnosed and treated airline workers with reported contaminated bleed air exposure. All sources are referenced with citations to additional resources provided. This document includes an attachment providing a more detailed discussion on the toxicity of tricresylphosphates (TCPs), neurotoxic additives present in aviation engine oils currently used on the US fleet. A draft report was distributed for review to occupational and aviation medicine specialists and revisions were made based on their comments. In addition, a shorter version was prepared that is more easily accessible for health care providers (HCP) and is provided as Appendix B. The medical case review was approved by the University of California, San Francisco, Committee for Human Research.

METHOD

Medical Cases and Literature Reviewed. The health effects of exposure to pyrolyzed engine oil and hydraulic fluid on aircraft are difficult to assess for several reasons, including the absence of a centralized system to collect and analyze reported bleed air exposures, and the lack of a large scale epidemiological survey to systematically assess health effects to correlate with exposures. Furthermore, symptoms are often nonspecific and may not be reported by airline crewmembers because of the work culture in aviation and/or not recognized as work-related by health care providers (HCPs). Exposure to contaminated bleed air occurs largely through the inhalation route (, and may typically result in acute respiratory, neurological, systemic, and/or psychiatric symptoms within minutes to a few hours following the contaminated bleed air event. Symptoms may vary depending on the duration and magnitude of exposure. Medical record review of airline crew members who were examined after exposure to contaminated bleed air found acute respiratory and/or central nervous system symptoms among the most commonly reported *(Table 1)*.

In all of the cases summarized in Table 1, airline crew submitted written reports to their airlines of in-flight exposure to airborne contaminants that they suspected contained pyrolyzed engine oil or hydraulic fluid. Aircraft mechanical records confirmed the sources of exposure in a majority of these cases. All developed acute symptoms that were temporally associated with exposure and sought immediate medical care. In some cases, their symptoms persisted, necessitating long-term medical care. Many of the neurological symptoms reported by airline cabin crew following contaminated bleed air exposure are similar to those reported among other workers exposed to triarylphosphates (Schulte 1996; Krebs 1995).

A summary of acute and chronic symptoms is summarized in Table 2 (Abou-Donia 2013; Burdon 2012; Mackenzie-Ross 2011; Ozyurt 2008; Mackenzie-Ross 2006; Abou-Donia 2005; Harper 2005; Somers 2005; Winder 2005; Burdon 2005; Singh 2005; Michaelis 2003; Bobb 2003; Coxon 2002; Cox 2002; PCA 2000; van Netten 1999; Witkowski 1999; Lipscomb, 1995; Freudenthal, 1993; Rayman 1983; Montgomery 1977).

Table 1. Case Series – Acute health effects following exposure to contaminated bleed air*

Age	Exposure document	Symptoms	Signs/ Positive tests
26	Cabin Incident Report	muscle pain, chest pain, throat irritation, dizziness, loss of balance, L arm numbness, stuttering	Physical examination: decreased plantar reflexes, memory loss Psychiatric evaluation: conversion disorder
38	Cabin Incident Report	weakness, nausea, vomiting, dizziness	Physical examination: tremor, nasal congestion, throat hyperemia and edema
39	Employee Incident Report	myalgias, eye irritation, headache, disorientation	Physical examination: poor serial 7s, memory loss
38	Flew MD-80	nausea, vomiting, throat irritation, headache, lightheadedness, slurred speech, anxiety, fatigue, insomnia, wheezing, cough	Physical examination: poor serial 7s, memory loss
42	Mechanical Report	nausea, vomiting, diarrhea, headache, throat irritation, lightheadedness, slurred speech	Laboratory: decreased plasma cholinesterase Neuropsychological testing: attention and information processing deficits, learning and memory impairments
39	Mechanical Report	headache, dizziness	Physical examination: R hand tremor Psychiatric evaluation: depression, anxiety
49	Doctors First Report	nausea, vomiting, headache, chest tightness	Physical examination: wheezing, rhonchi.
36	Flew MD-80	Headache, confusion, extremity jerks	Physical examination: truncal movement disorder
32	Flew MD-80	joint pain, nausea, vomiting, confusion, loss of balance, anxiety	Physical examination: ataxia
51	Mechanical report	nausea, vomiting, throat irritation, cough, SOB, chest tightness, headache, lightheadedness, memory loss	Laboratory: decreased plasma cholinesterase
49	Pilot report	eye burning, throat irritation, headache, nausea	Physical examination: mucous membrane erythema, abnormal Romberg, tandem gait

* Cases examined and reviewed by author (Robert Harrison, MD). All cases met case definition provided in this section.

Table 2. Acute and chronic symptoms following exposure to contaminated bleed air

ACUTE SYMPTOMS				
Respiratory	**Neurological**	**Systemic**	**Psychiatric**	**Dermal**
Cough Shortness of breath Chest tightness Wheezing Eye, nose or throat irritation	Headache Dizziness Lightheadedness Memory impairment Concentration difficulty Visual changes Tremor Gait problems Paraesthesias Balance problems Slowed mental processing Difficulty multi-tasking	Nausea, vomiting Fatigue Muscle weakness Palpitations Diarrhea	Anxiety Sleep disturbance Depression Post Traumatic Stress Disorder (PTSD)	Rash
CHRONIC SYMPTOMS				
Respiratory	**Neurological**	**Systemic**	**Psychiatric**	**Dermal**
Cough Shortness of breath Chest tightness Wheezing	Headache Slowed mental processing Difficulty multi-tasking Memory impairment Concentration difficulty Visual changes Tremor Gait problems Paraesthesias Balance problems	Nausea, vomiting Fatigue Muscle weakness Palpitations Diarrhea	Anxiety Sleep disturbance Depression PTSD	Rash

RESULTS

Case definition. Based on a review of the medical literature and case series summarized above, the HCP may consider the following case definition for acute exposure to contaminated bleed air:

An *acute* health problem due to bleed air contaminant exposure should be considered if these factors are shown to be present:

- There is *either* a documented exposure to bleed air contaminants (based on evidence in the mechanical records, incident reports, or airborne

measurements) *or* a history of flying on aircraft type(s) documented to have an increased risk of air supply contamination events;

and

- Initial symptoms occur within 48 hours following exposure;

and

- There is objective documentation of acute and/or persistent respiratory, neurological, systemic, or psychiatric symptoms that follow exposure to bleed air contaminants; see Table 2.

In addition, chronic health effects may result from acute and/or chronic exposure to contaminated bleed air. These cases should be evaluated on a case-by-case basis to determine the likelihood that health problems are due to contaminated bleed air exposure.

Recommended Medical Work-ups. The following medical work-ups are detailed in the report and include: a complete history of the illnesses, assessment of the exposure with flight specific questions, past medical history, occupational history, social and family history, and a physical exam. Also, a list of recommended laboratory data and other tests are provided.

Treatment and Reporting. The acute neurological and respiratory effects of contaminated bleed air exposure should be treated primarily by prompt removal from the exposure. Hyperbaric oxygen may reduce the risk of long-term sequelae in the setting of highly elevated carboxyhemoglobin (Weaver 2002). Respiratory effects should be treated according to standard protocols for acute chemical inhalation. The report also outlines disability management and medical follow-ups.

The diagnosis of work-related illness or injury should be reported to the appropriate state and/or workers' compensation authorities according to relevant requirements. Pilots should advise their aviation medical examiner of their exposure at their next renewal examination, or as per applicable regulations. HCPs should note that crewmembers have historically not been covered by OSHA regulations (FAA 1975), although the FAA Modernization and Reform Act of 2012 (PL 112-95 2012) has finally changed this. The process of applying to flight attendants OSHA standards on recordkeeping, bloodborne pathogens, noise, sanitation, hazard communication, anti-discrimination, and access to employee exposure/medical records is underway in early 2013 just as this is being written (FAA 2012)

SUMMARY

The medical protocol was developed as a means of improving diagnosis and treatment and increasing the likelihood of reporting bleed air exposures. To accomplish these aims broad dissemination of the protocol was a priority. The finalized medical protocol and the abbreviated version were posted on www.ohrca.org so that they could be easily referred to in communications. To reach flight crew populations the following additional dissemination efforts were undertaken:

- An informational flyer and generic newsletter article were written and distributed to crewmember unions in the US (Airline Pilots' Association, Allied Pilots' Association, Association of Flight Attendants-CWA, Association of Professional Flight Attendants, International Association of Machinists District Lodge 142 and Flight Safety Department, International Brotherhood of Teamsters - Airline Division) and globally (Australian Independent Pilots' Association, Canadian Union of Public Employees Airline Division, Flight Attendants' Association of Australia, Flight Attendants & Related Services Association, Independent Pilots' Association, Global Cabin Air Quality Executive, International Transport Workers' Federation) (Sept 2008);
- The Association of Flight Attendants-CWA, AFL-CIO (AFA) distributed the flyer and newsletter article in its safety mailing to approximately 150 AFA safety and health representatives (Sept 2008);
- AFA advertised the medical protocol in *Flight Log*, which is a quarterly hard copy newsletter that goes out to all AFA members (representing about half of US flight attendants), as well as in *Interactive* and *President's Exchange* email publications. The former goes to AFA members and the latter goes to AFA leadership (Sept-Oct 2008);
- AFA posted a link to the protocol on its Air Safety, Health and Security Department (ASHSD) aircraft air quality webpage (Sept 2008);

- Judith Murawski presented the protocol at AFA's annual Safety & Health "Roundtable" meeting attended by the top level union safety and health representatives from 20 AFA-represented airlines (Oct 29, 2008);
- Steven Hecker presented the protocol at the annual meeting of the Global Cabin Air Quality Executive (GCAQE), a global organization representing 500,000 flight deck and cabin crewmembers as part of a report on the progress to date of this project. Attendees were present on behalf of crewmembers, research teams, a government agency, and an industry group (May 20, 2008).

To reach occupational physicians, the following dissemination efforts were undertaken:

- An announcement was sent out over the Association of Occupational and Environmental Clinics (AOEC) listserve directing physicians to the link.
- The short version of the protocol was sent to all AOEC clinics.
- Dr. Harrison presented on the protocol to the Southern California Safety Institute Annual International Aircraft Cabin Safety Symposium in Torrance, CA, February 2009.
- The short version of the HCP guide was distributed to emergency room (ER) physicians throughout the US.

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III. C. FLIGHT ATTENDANT HEALTH SURVEY

The health of U.S. flight attendants, a workforce of 90,500 in 2011 (BLS 2011), has not been well characterized. Change in the airline industry over the past few decades has further complicated the understanding of occupational health risks. Flight attendants are older and more diverse than in the past, and the job has changed dramatically (PRB 2009; Barry 2007). The work now includes longer flight times with quicker turnaround times between flights, circumpolar navigational routes, increased passenger loads in new jumbo-sized planes and increased occupancy aboard all flights, in addition to, new security procedures. These conditions may likely strain customer relations, (DeHart 2003; Ballard et al. 2006) add to circadian rhythm disruption (Jackson and Earl 2006; Petrilli et al. 2006; Roma et al. 2010), and intensify known occupational exposures such as ergonomic stress in restricted cabin quarters, cosmic radiation, cabin air contaminants, low pressure and humidity, noise, vibration, and gravitational forces (Nagda and Koontz 2003).

A review of studies of flight attendant health found that most were based on self-reported questionnaires, had study populations ranging from 26 to 3412, and in a relatively small percentage of

cases used objective environmental measurements (Nagda and Koontz 2003). The largest study population was limited by a relatively lower response rate (17 percent). Those that include objective environmental measurements are generally much smaller, a reflection of the resource demands to collect such data. Knowledge about flight attendant health is derived mainly from cancer studies looking at the effects of radiation and respiratory disease studies investigating past exposure to tobacco smoking in the aircraft cabin. The accumulated evidence suggests that flight attendants may be at increased risk of certain cancers, such as breast and skin cancers, although not all studies support this finding and methods differ across studies (Haldorsen et al. 2001, Linnersjo et al. 2003, Zeeb et al 2003, Zeeb et al. 2010, Paridou et al. 2003, Pickerton et al. 2012, Rafnsson 2001, Reynolds 2002) Flight attendants exposed to tobacco smoking in the cabin were found to have higher rates of respiratory disease, however, only a few studies have followed respiratory outcomes beyond the early years of the smoking ban, now over a decade old (Ebbert et al., 2007,. Beatty et al. 2011, deRee et al. 2000, 25. Reed et al. 1980, Tashkin et al. 1983, Whelan et al. 2003,)

The health surveillance portion of the current study began with the intent of estimating the incidence and prevalence of health conditions in flight crew in relation to possible exposure to bleed air contaminated with pyrolyzed engine oil or hydraulic fluid. Due to the weaknesses of a voluntary reporting system, health surveillance related to bleed air contaminant exposures necessitates new sources of data, such as:

1. Monitoring systems for the measurement of bleed air exposures (the operation and testing of the VN sampling device for this purpose is discussed in Chapter IV).
2. Periodic monitoring of flight attendant health (the use of surveys for this purpose is the main focus of this chapter.
3. Integrated data systems that incorporate exposure data, contemporary health information including health conditions coincident with bleed air contamination, and baseline health information for flight crew.

These data would permit the analysis of health changes in exposed versus non-exposed crew. The original design to monitor bleed air and flight attendant health simultaneously during flight could not be carried out. As noted above the requisite access to flight attendants as respondents to in-flight and post-flight surveys and as operators of the van Netten samplers to collect exposure data was not granted. As indicated in Chapter IV, the van Netten sampler was shown to be capable of collecting in-flight air samples for subsequent analysis, but the likelihood of capturing events with significant contaminant exposures was very small given the number of flights sampled.

In light of these obstacles project resources on were directed to 1) obtaining comprehensive cross-sectional data on prevalent health conditions; 2) comparing these data to previous studies of nationally representative samples; and 3) analyzing the correlation of health conditions with duration of exposure using job tenure as a proxy. As a data set of the largest random sample of flight attendant health of which we are aware, this information is an important first step in understanding the health impact of job demands and exposures aboard commercial aircraft.

METHOD

Survey Development

Flight Attendant Focus Groups. The survey questions were developed after several focus groups were conducted to gather data on perceptions, behaviors, attitudes and understandings of flight attendants with regard to the subject of the research, i.e. air quality and health, and the potential role of flight attendants as a group in the collection of health and exposure data. Two sets of focus groups were conducted. One set included participants who were union safety and health representatives for various airlines and the second set recruited individual flight attendants who had experienced health problems that they related to exposures on aircraft. Research team members conducted the focus groups in Chicago and Los Angeles in November 2005.

Recruitment

Participants were recruited largely through unions representing flight attendants, including the Association of Flight Attendants-Communications Workers of America (AFA-CWA), Transport Workers Union (TWU), and International Brotherhood of Teamsters (IBT). Letters were emailed to safety chairs at the various airlines from lists provided by the unions, and they were asked to

resend the letter to their members announcing the purpose, location, and time of the proposed focus groups. Additional personal recruitment took place through word of mouth among flight attendants. Specific outreach was not done to nonunionized flight attendants, but information about the focus groups was posted on the OHRCA website where a broader spectrum of flight attendants could have seen it. Participants were asked to preregister in order to optimize the numbers in each group and to direct flight attendants to the proper groups, i.e. safety representatives to the morning groups and those who had experienced health problems that they related to air quality in the afternoon (some safety representatives had themselves experienced air quality incidents, so the groups were not mutually exclusive). Participants were provided a small gift as an incentive and were also entered in a raffle drawing for a restaurant gift certificate.

Demographics

Table 3 summarizes the demographic characteristics of the 18 flight attendant participants (one retired pilot who attended is not included in the table). The safety representatives came from three different unions and represented at least seven airlines (one representative covered several different airlines). The groups represented many years of flight attendant experience, and the great majority were working flight attendants, having flown an average of 76 hours the previous month. The goal of the focus groups was to provide a rich sample of respondents so there is no expectation that these informants are representative of the flight attendant or safety representative population as a whole. It is likely that those with greater interest in cabin air quality issues made more of an effort to attend than those without such interest. Nevertheless, the data indicate a wide range of experiences and attitudes among the participants.

Results

Extensive detail from analysis of focus group transcripts is available in unpublished reports from the authors. For purposes of this chapter findings are summarized as they relate to 1) selecting content for the health survey and 2) choosing strategies for sampling and recruitment of subjects and administering the survey. Again we emphasize that these findings frame the questions for a broad-based study that would access a more representative survey sample.

Table 3. Demographics of Union Health and Safety Representatives (3 focus groups: 1 in Chicago and 2 in Los Angeles), n=18

Variable	Number or average ± sd
Gender	Male: 6 Female: 12
Age	45.1 ± 8.9 years
Race	White: 15 Black: 1 Hispanic: 0
Years as Flight Attendant	16.7 ± 8.9 years
Position (years in position)	Local Safety and Health Rep: 6 (4.5 ± 4.7 years) Safety and Health Chair: 15 (7.5 ± 8.6 years) Flight Attendant: 13 (16.9 ± 9.3 years)
Hours flown in last month	76.2 ± 23.4 (n=17 since 1 had not flown at all)

Major Health and Safety Hazards

The most frequently mentioned work-related safety or health hazards named by the flight attendant representatives were, in order of frequency, air quality, fatigue, and infectious diseases, with turbulence and on-board sanitation following. Additional issues noted by multiple individuals included ergonomics (awkward work areas and equipment) and emergency preparedness, particularly concern about capabilities of exit row passengers and inadequate exit row briefings.

Specific **air quality** issues mentioned include:

- "Bad air" incidents like smoke in the cabin
- Lack of oxygen
- Inoperative auxiliary power units (APUs) leading to high temperatures
- Lavatory odors
- Respiratory and sinus problems
- Lack of air filters.

Because air quality is a focus of this project greater probing was done on this topic. One participant categorized three subsets of air quality issues: 1) the daily problems of low humidity, low oxygen, and the discomfort and illness (colds, etc.) that these conditions can cause or contribute to; 2) possible low level contamination over long periods and chronic illness that might result; and 3) episodes of acute toxic exposure. Another described air quality episodes as isolated and

specific to certain aircraft or types of aircraft.

The primary categories of symptoms reported as related to air quality were respiratory and neurological. Chronic sinus symptoms, upper respiratory illnesses, and surgeries were reported, including three sinus surgeries in one focus group. Respiratory irritation was commonly reported. One safety representative observed that the dry air on aircraft made it more difficult to get over normal respiratory illnesses like colds. Other than respiratory the common symptoms reported are headaches, nausea, slurred speech, and memory loss. The relationship between these symptoms and the fatigue reported as a major health issue was not made explicit in the focus groups, but there was speculation as to whether such symptoms result from specific contaminants in the air, low oxygen levels, or both.

In response to inquiries about specific circumstances associated with air quality concerns or incidents, participants mentioned specific aircraft models as problematic for varying reasons. These included location of air intakes and "dead air" locations in certain cabins. There was not overall agreement on which aircraft were most susceptible, and respondents varied widely in how much experience they had working on various craft. Seasonal factors affect air quality, particularly de-icing in cold climates. Maintenance practices were frequently mentioned as well.

Fatigue was mentioned as a more serious and pervasive problem, in some cases ascribed to the poor financial condition of the airline industry. Specific elements contributing to fatigue included: quick turnaround of aircraft, extended duty days, cleaning duties added to flight attendant's (FA) responsibilities, and inadequate access to food or time to eat due to these other factors.

Infectious Diseases. Severe acute respiratory syndrome (SARS) and avian flu were high on the list of occupational safety and health concerns, but those who fly internationally were also concerned with tuberculosis, Hepatitis C, and other illnesses prevalent in some developing countries. The increasing amount of clean-up work expected of FAs was a recent exposure concern.

Incident Reporting Systems and Practices

Participants described a multiplicity of reporting systems or forms, most operated by individual carriers. Some are paper systems while others have become electronic. Similarly there is a wide variety of experiences with reporting of air quality incidents and a widespread problem, from the safety representatives' point of view, with non-reporting. Outside of the formal systems the typical first report of a cabin air problem is to the flight deck. There was general agreement that reporting to the purser or lead FA was preferred by pilots and made sense to cabin crew as well. However, there are barriers to the report being logged by the pilot. Most agreed that a report of visible smoke or contamination would be logged. However, other problems were often discouraged from being logged because of the potential of delays, or planes taken out of service.

Safety representatives feel strongly that reporting is important. One commented that at his company, air quality (AQ) problems used to be combined with all other incident reports, but increased reporting of specific incidents has gotten them classified separately. Disincentives to reporting are many, as noted above. FAs mentioned that they can be labeled as a complainer or as sick. Undependable is a dangerous label for an FA, and missing flights because of AQ-related illness can lead to either a reprimand or demerit points. Participants noted that the risk is that much greater for pilots to report symptoms or health problems because they can "get their ticket pulled," i.e. ruled unfit to fly. The union sometimes only finds out about an alleged air quality incident when an FA is reprimanded for missing flights due to health reasons that she relates back to an in-flight exposure. One safety representative commented: "Flight attendants don't want to put anything in writing. They want to call you." There is a tendency to attribute symptoms to a "bad day" rather than something specific that happened. FAs may report safety problems but not health problems. "I think they think it's just themselves, they don't think it's really the group." There is a common sentiment at many airlines that the company doesn't do anything in response so why report. Even visible smoke reports are dismissed: "What they say is that they cannot recreate it."

Survey Instrument Development

The specific steps in preparing the survey are discussed in detail below.

Step One: Survey Content development

Survey content was outlined based on issues raised in the focus groups plus basic information needed for the study analyses. We started by

considering the following general areas:

(a) *Perceptions of job exposures*: Air contaminants, pressure, noise, motion, radiation, infection, musculoskeletal stress, psychosocial stress, circadian rhythm disruption, industry-wide organizational and procedural restructuring.
(b) *Characteristics of the employee population*: Older, predominantly female, union and non-union, mobile.
(c) *Organization of the work*: Fluctuating schedules and routes/trips, job demands and work-flow, injury reporting and workers' compensation, responsibilities for system failures, and team work.
(d) *Individual health profile:* Acute and chronic health problems, use of medications, social factors (gender, age, ethnicity, marital status, smoking), and work-related health issues.

Using the content map as a guide, we selected standardized questions from the literature or developed new questions as needed for a draft survey. We relied heavily on feedback from small-scale preliminary surveys with flight attendants to vet these questions.

Step One also included a test of the face validity of the draft instrument to ensure that the survey was not overly long and that the questions were clearly worded without misleading jargon. We consulted our research partners and union representatives to identify questions to remove, revise, or add.

Step Two: Format

This step involved further editing of the draft survey based on the feedback received. The focus on format emphasized length, appearance, clarity, order of questions and data management processes (formats, software, devices). A subsequent draft was recirculated among the experts as a small pilot.

This step also included creating several versions of the survey instrument, including one for scanning a hard copy survey and one for Web-based administration. For the online version, we reviewed security features for the data collection and submitted these procedures to the respective human subjects committees, and to the administrators for information technology security. Finally, we established procedures to ensure that no duplicate surveys would be generated; that is, that each participant would not complete more than one survey.

Step Three: Preliminary (pilot) survey

Another test version of the survey specifically assessed the reliability of results (reproducibility) and convergent validity with other validated items. Union members distributed sample surveys to flight attendants. This version of the survey was particularly important for new questions relating to specific job features. These questions were industry-specific and had to be adapted from other survey questions, rather than culled directly from previous research.

Step Four: Final revisions

Based on analysis of the preliminary version of the survey, final revisions were made. The layout of the final survey included three main sections with specific items related to the flight attendant's job, health status, and demographic information.

The final survey outline is as follows (full document is reproduced in Appendix C:

A. Tell us about your work
Question 1: work history
Questions 2-8: work history; recent job exposure history
Question 9: Job Strain Scale (associated with Cardiovascular Disease (CVD), Musculoskeletal Disorder (MSD), Disability and Injury)

B. Tell us about your health
Questions 10-12: occupational health history
Question 13: health symptoms
Questions 14, 15: medical history/health outcomes

C. Tell us about yourself
Questions 16-20: demographic

Survey questions included adaptations from the following sources: Job Content Questionnaire (Karasek et al. 1998), and CDC/NCHS, National Health and Nutrition Examination Survey (NHANES) (CDC-NCHS 2005-2008).

Survey Administration

Subject recruitment. The initial study protocol anticipated survey administration through airline channels. Focus group participants indicated the top incentives for FA participation would be 1) company support and 2) money, though others cautioned not to dismiss altruism and interest of the FAs. "You have to get the company to approve it. To me that's the biggest obstacle," said one. Several advocated a campaign that rolled out over time. "I've tried in the past to just throw everything out at once and nothing happens. It's definitely an

educational process." Others advocated that the initial approach needed to be through a "known channel."

Opinion among focus group FAs was divided on outreach through email versus hard copy letters. Some suggested email was more likely to reach people as they are mobile, but others felt emails would just be deleted. A hard copy letter with university names and logos was seen as making a stronger impression than an email. More than one person emphasized the need to "keep it simple."

We actively sought cooperation from multiple airline companies over a period of more than a year. After most companies declined to participate, we had prolonged negotiations with one carrier (Airline B) that appeared to be leading to a cooperation agreement. Ultimately the management of Airline B declined to actively participate but agreed that if the survey was done through the union, it would not interfere. Subsequently Airline A, whose management had made its cooperation contingent on Airline B's agreement, took the same position.

Survey distribution: We administered the survey in two ways (see figure 1). Surveys were mailed to a subset of addresses selected at random from a union list that included the two airlines, Airline A and Airline B. For logistical reasons we selected from only those addresses connected to five airport hubs (the three largest US hubs for airline B and two largest for airline A). We randomly chose 50% of the flight attendant addresses from those hubs to receive a survey in the mail (n=5398). There were some significant differences in procedures between the two airlines. Airline A employees had the opportunity to complete an online survey, but this mechanism was chosen by few respondents. Because Airline A employed more part-time FAs we oversampled this airline to capture more full-time workers, selecting 70% of the hub population for the mailed survey versus 50% at Airline B.

The randomized selection of addresses was important to insure that all flight attendants had an equal chance of receiving a survey. This maximized the chance of having the same distribution of flight attendant characteristics in our sample, such as age and gender, as in the overall population. In addition, selecting participants in a random way ensured respondents would be less likely to reflect only flight attendants with health interests (because they were very healthy or very unhealthy). The response frequency from the mailed survey was close to half of those we invited (48%). Although we do not have direct evidence, we considered this response sufficient to guard against significant reporting bias (such that non-participants were different from participants in way that could bias our estimates) (Groves, 2006).

A survey packet was mailed to every address selected from the master list of flight attendants in target hubs. The survey packet contained a nine-page questionnaire with a cover sheet explaining the study and a postage-paid return envelope. Besides the initial packet this group also received through the mail a reminder postcard and a second survey packet in the 6th or 7th week. The AFA union publicized the study through print materials such as newsletters, faxes and posters, and with messages on their website. Participation was encouraged by the chance to win raffle prizes with the return of a completed survey. The human subjects committees at the Harvard School of Public Health and the University of Oregon approved all protocols.

The second method of survey administration involved on-site distribution of the survey at the five target hubs. Generally this was done in public spaces close to the flight attendant crew rooms. Research team members spent approximately 250 hours on location distributing surveys along with a postage-paid envelope for return mail if the flight attendant preferred to complete it at a later time. Otherwise, we collected the surveys in the airport. As a visible draw for the survey campaign, gifts were displayed that would later be raffled among survey participants. Airline B also had an incentive donation of $1 to their flight attendant relief fund for every survey returned.

We handed out the survey in person to supplement our mailed sample because we expected very low participation in this highly mobile workforce. Both company and union sources had suggested that we should expect a response of less than 10 percent. The on-site campaign targeted flight attendants not selected by the random selection for the mailed survey. In addition, we accepted surveys from flight attendants who had received a survey by mail. All surveys were tracked with numerical codes and only one survey per flight attendant counted. All survey names selected by the random draw for the mailing were classified as such, even when the survey was collected on-site. For all participants who completed the on-site survey, our physical presence was intended as a convenience and as an invitation for participation.

In addition, by being on-site, we attracted participation from 302 flight attendants from outside the target hubs who happened to be passing through the hubs while we were on the premises.

The final tally of surveys collected by mail or at the hubs was 4011. The flight attendants in this sample included:

1. Flight attendants randomly selected for the mailed survey (n =2613);
2. Flight attendants not randomly chosen for the mailed survey, but who were employees from a target hub recruited on premises (n = 1086);
3. Flight attendants not part of the target hub populations but who were employees from other domiciles of the same airlines, "en-route or passing though" while we were on premises (n=302).

Exclusive of this last group of participants, we successfully recruited 37% of the entire population in the target hubs. Almost two-thirds of participants were based on random selection.

Survey Analysis

Descriptive statistics were calculated for the FA characteristics (Table 4). To understand how flight attendant health compares to the general population, we used data from the National Health and Nutrition Examination Surveys (NHANES) for the survey years 2005-2006 and 2007-2008. NHANES is a program from the National Center for Health Statistics (NCHS) within the Centers for Disease Control and Prevention (CDC). NCHS designed the survey to capture demographic, health, dietary, and laboratory data on a representative sample of around 5,000 US residents every year.

Figure 1. Flow chart for sample selection and distribution of the survey

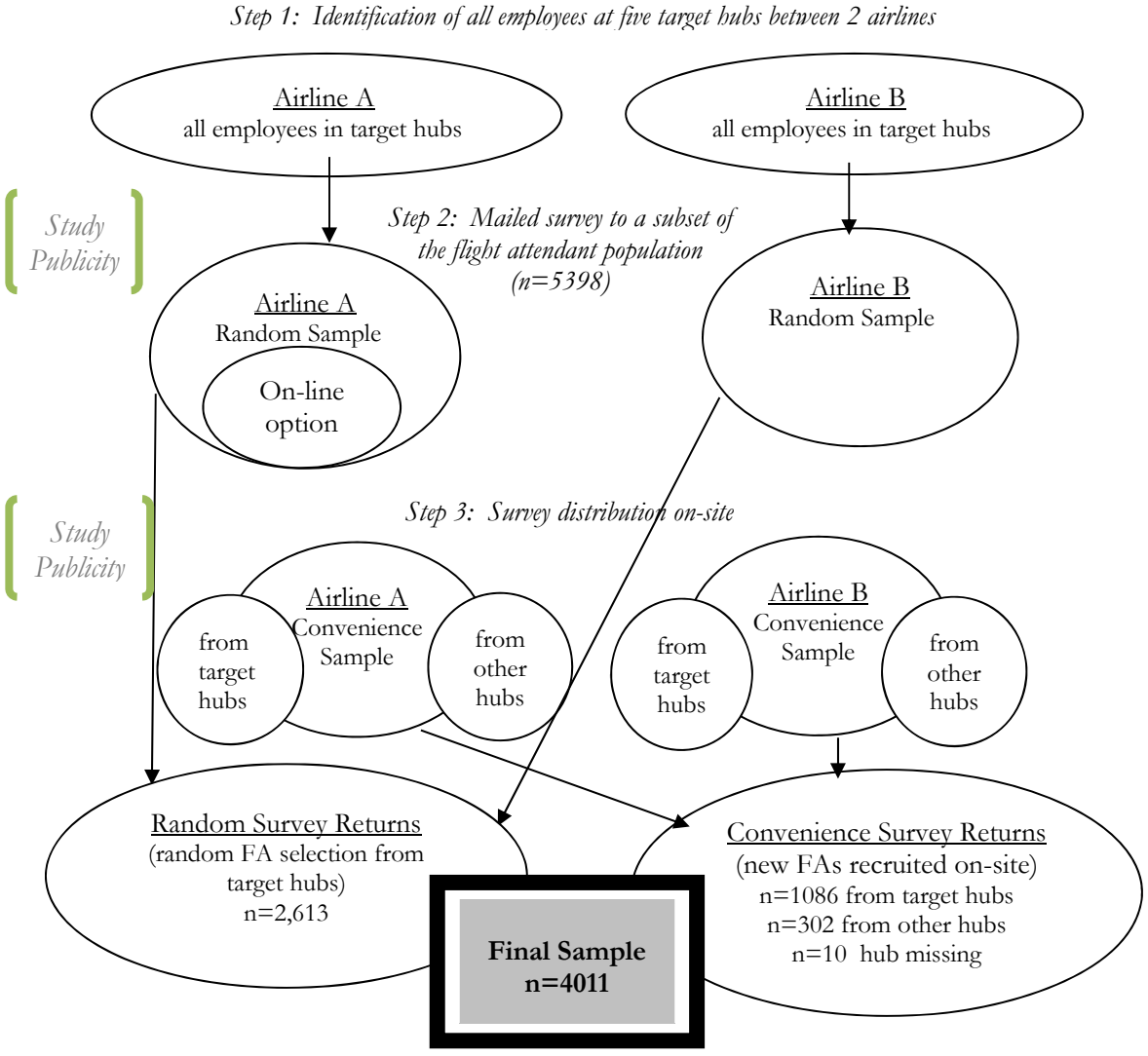


Table 4. Descriptive Statistics of the Flight Attendants (FAs) surveyed.

Characteristic	N	Percentages with 95% confidence intervals
Age (Mean = 46.7± 9.8 S.D.)	N =3985	
18 -39		24.6 (23.2-25.9)
40 -59		66.3 (64.8-67.8)
≥ 60		9.1 (8.2-10.0)
Gender	N = 3981	
Male		20 (19-21)
Female		80 (79-81)
Tenure as Flight Attendant	N = 3685	
< 6years		9.8 (8.9-10.8)
6 – 10 years		19.7(18.4-21.0)
11 - 15 years		12.9(11.8-14.0)
16 – 20 years		16.1 (14.9-17.2)
>20 years		41.4(39-8 -43.0)
Education	N = 3977	
<high school diploma		0% (n=3)
high school or GED		5.4 (4.7-6.1)
some college, no degree		35.7(34.2-37.2)
two-year college degree		14.3(13.2-15.3)
four-year college degree		36.6(35.1-38.1)
graduate education		7.9 (7.0 -8.7)
Current Smoker	N = 4011	
No		91 (90.1-91.7)
Yes		9 (8.1-9.9)
Overweight/Obese	N = 3877	
No		87.8 (86.7-88.8)
Yes		12.2(11.2-13.2)

After an extensive side-by-side review of both flight attendant and NHANES surveys, we selected common questions in the NHANES using data from the demographic, blood pressure, current health status, medical conditions, sleep disorder, smoking, and household smoking sections of the NHANES questionnaire. We weighted the NHANES data by their 4-year sample weights, primary sampling units, and strata. To match the characteristics of the flight attendants, we limited the NHANES respondents to 18 years old and over, a family income to poverty ratio of 1 or greater, high school/general education diploma (GED) education or greater, and current employment. To compare the two populations we chose the Standardized Prevalence Ratio (SPR). The SPR is stratified by gender and weighted by age (18-39, 40-59, and over 60 years). The SPR simply is a comparison of the observed to the expected rate of disease. To calculate the SPR we use the prevalence of a health condition in the flight attendant population as the observed

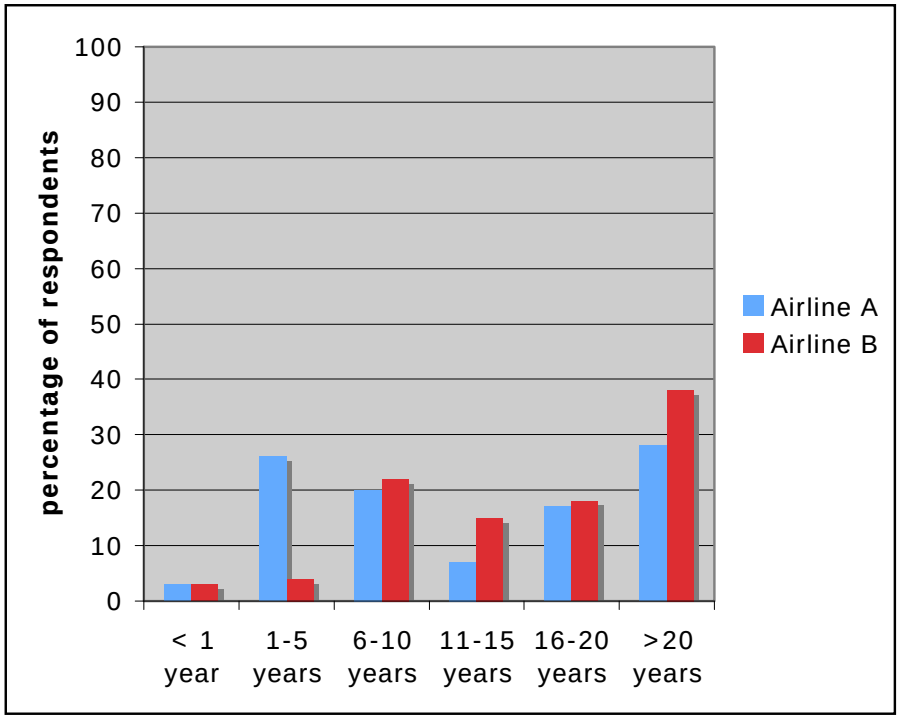
total cases, and the expected total cases are calculated with the prevalence from the NHANES survey applied to the flight attendant population.

To test the relationship between job exposures and prevalence of disease in flight attendants, we ran logistic regression models using job tenure (years in the job), categorized according to 5 year increments, to predict the odds of disease after stratification by gender and adjusting for age, education, body mass index and current smoking. Analysis was completed using STATA statistical software, version 10.

Results

Descriptive statistics on the FA characteristics are presented in Table 4. The mean age of the flight attendants was 47 years, most were female (80%) and 41% had twenty or more years on the job. Over 90% had at least some college education. Only 9% described themselves as current smokers, with 22-30% from the two airlines surveyed reporting being a former smoker, and only 12% reported being overweight. Although not shown here, no meaningful differences were found between the survey sample of flight attendants and the entire airline flight attendant population in terms of age, gender, and tenure. Comparing the randomly selected sample to the convenience sample showed no noteworthy differences either.

Figure 2. Percentages for varying levels of service by airline



Job Tenure and Hours Worked. Figure 2 suggests a bimodal distribution of job tenure with airline B having a considerably higher percentage of long-tenured FAs, almost 40 percent greater than 20 years. Number of hours worked in the past month served as a surrogate for "usual" work schedules (Figure 3). The pattern was similar when we asked about "usual" number of hours per month over the past 12 months (data not shown). Airline A had more varied work schedules than Airline B with more part-time flight attendants.

Aircraft type. The type of aircraft varied by airline (Figure 4). Airline A typically worked aboard two aircraft models only. The percentages below are based on the total number of flight attendants that responded from *each* airline.

Figure 3. Hours Worked in Past Month By Airline (n=3,999)

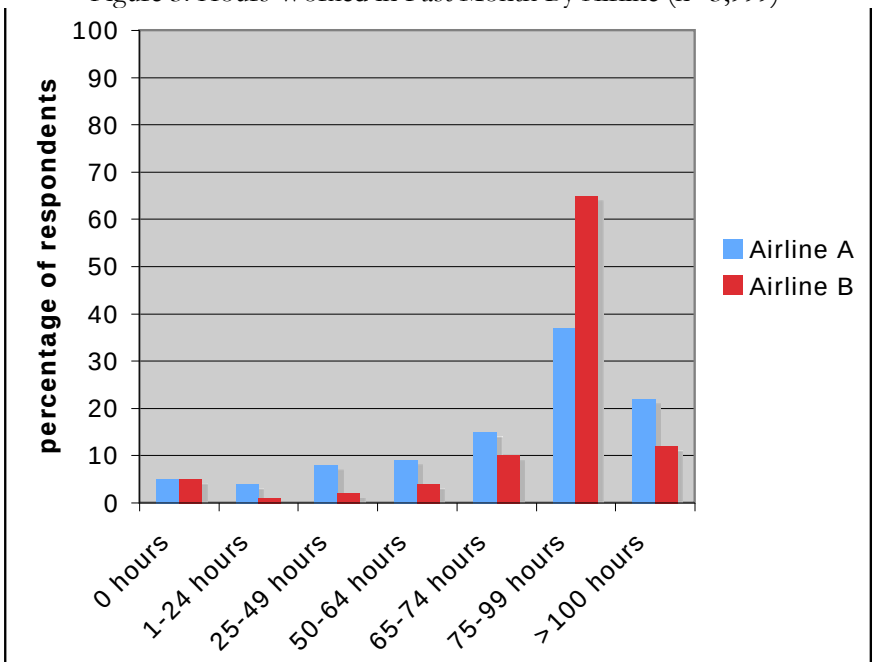
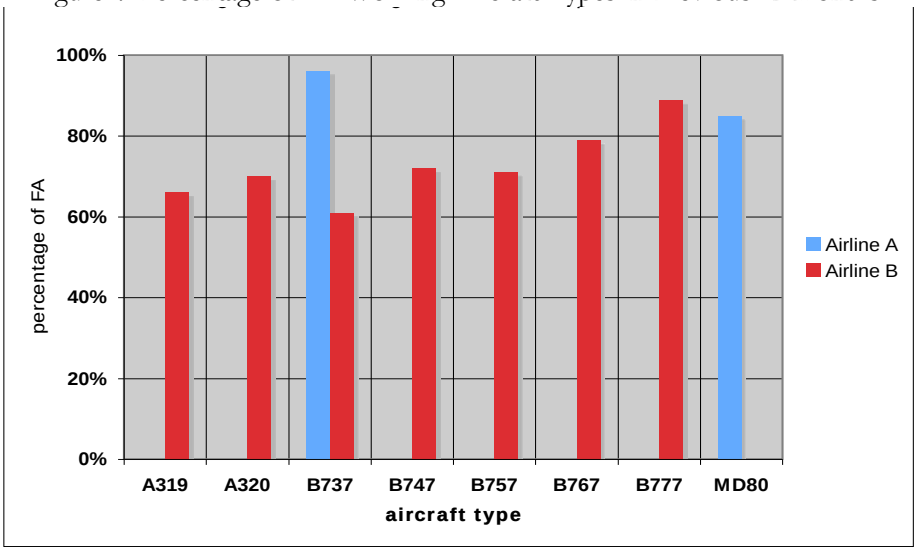


Figure 4. Percentage of FA Working Aircraft Types in Previous 12 months



Work-related injuries and illnesses in the past year. We asked the flight attendants about the number of work-related injuries or illnesses they experienced *over the past year*. Close to half of flight attendants (47%) reported that they experienced one or more work-related injuries/illnesses in the past year and 29% said they had more than one injury in the last year (n=3,667).

Respondents who experienced one or more injuries were given the opportunity to describe up to three injuries. In addition, more than one description could be selected if the injury/illness involved multiple health effects. The choices for the description of the injury included the following:

- Musculoskeletal: *strain or sprain, joint aches and pains or fracture, contusion, laceration*
- Respiratory: *trouble breathing, infection*
- Neurological: *dizziness, headaches, numbness and tingling, fatigue*
- Psychological: *anxiety, stress, depression*
- Cardiac: *chest pain or tightness, high blood pressure, clots*
- Other.

The largest number of work-related conditions were musculoskeletal in nature (33%) followed by respiratory (23%), neurological problems (17%), and psychological problems (14%).

Figure 5. Percentage of flight attendants according to number of injuries (N=3,667)

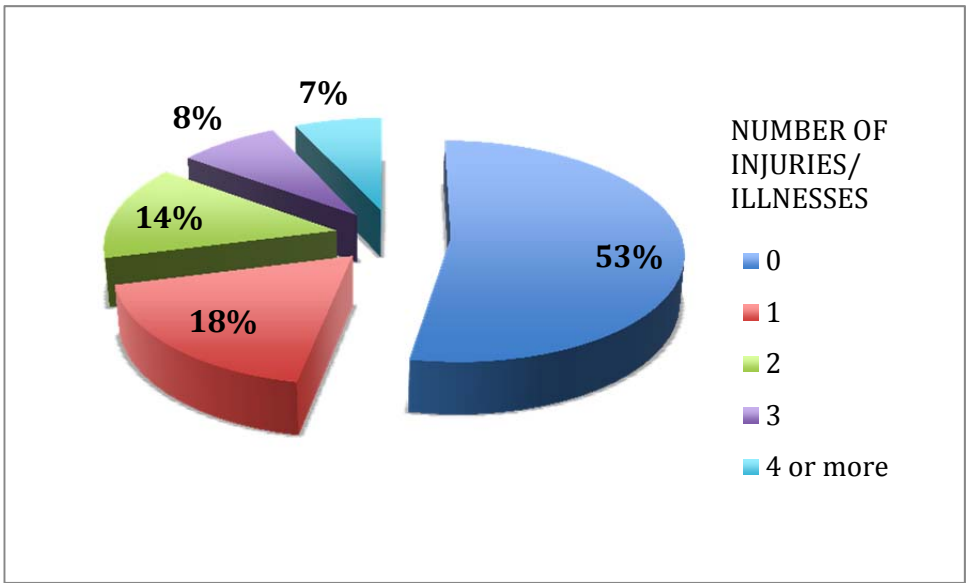
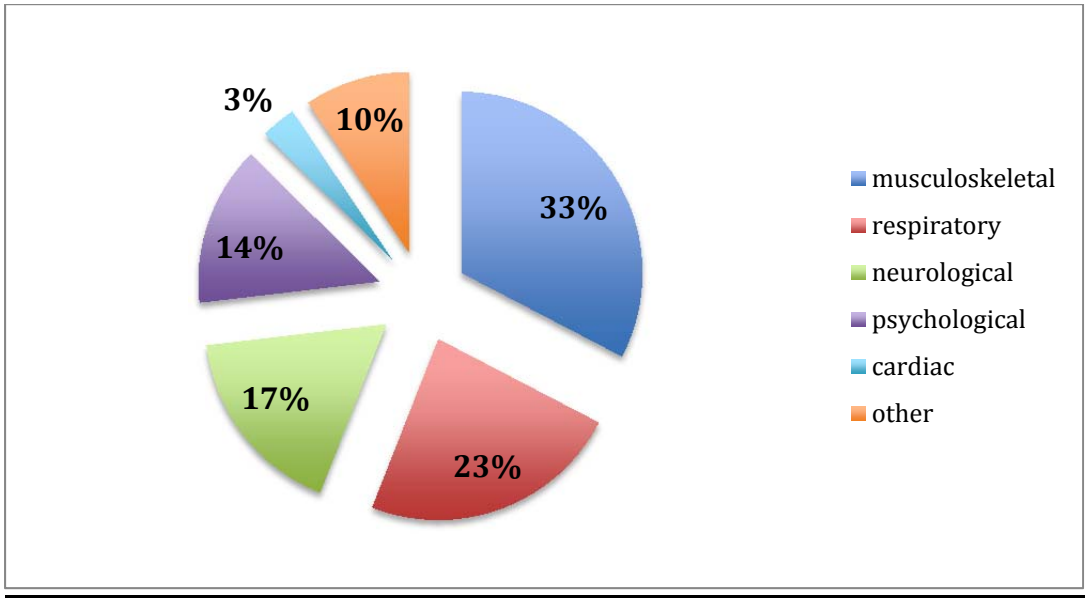


Figure 6. Distribution of the types of work-related injuries/illnesses reported in last year



Health Profile of Flight Attendants. The survey responses (listed in Table 5) provide a general profile of the most prevalent acute and chronic health conditions in the flight attendants, recorded as those conditions experienced by at least 15% of all participants. In all, these conditions fall into several major categories: respiratory, neurological, musculoskeletal, auditory, dermatological, and general systems (anxiety/depression, sleep problems, bloating and high blood pressure).

Table 5. Prevalence of health conditions reported by at least 15% of flight attendants: A. FREQUENT SYMPTOMS: *lasting 5-7* days (OVER THE PAST WEEK); B. NOTABLE CONDITIONS: *needing medical attention* (OVER THE PAST 12 MONTHS); C. DIAGNOSED CONDITIONS: told by medical provider had this condition (EVER)

	Percentage of flight attendants with 95% confidence intervals	**Number**
A. ***FREQUENT SYMPTOMS: lasting 5-7 days (OVER PAST WEEK)***		
Sinus congestion	29.0% (27.6 – 30.5)	3,789
Bloating	25.2% (23.8 - 26.6)	3,750
Fatigue	27.3% (25.9 - 28.7)	3,817
Anxiety	20% (18.7 – 21.3)	3,778
Back pain	27.7% (26.3 – 29.1)	3,787
Foot pain	28.5% (27.1 – 30.0)	3,775
Shoulder/elbow/wrist/hand pain	29.4% (28.0 – 30.9)	3,792
Generalized muscle aches	23.3% (21.9 – 24.7)	3,775
B. NOTABLE CONDITIONS: needing medical attention (OVER PAST 12 MONTHS)		
Reactive airways/sinusitis/allergies	54.7% (53.1 - 56.2)	3,850
Shortness of breath/reduced lung capacity	15.5% (14.4 – 16.7)	3,787
Other respiratory symptoms	14.6% (13.4 – 16.7)	3,436
Severe headache	23.4% (22.1 – 24.7)	3,804
Numbness/tingling of extremities	17% (15.8 – 18.2)	3,801
Dizziness/lightheadedness	19.4% (18.1 – 20.6)	3,796
Memory loss/Lack of concentration	14.7 (13.6 - 15.8)	3,783
Fatigue	36.8% (35.3 – 38.3)	3,809
Muscle weakness	16.3% (15.1 – 17.5)	3,778
Joint aches/pains	33.3% (31.8 – 38.8)	3,813
Rashes/hives	15.5% (14.3 – 16.6)	3,805
C. DIAGNOSED CONDITIONS: told by a care provider (EVER)		
High blood pressure	16.7% (15.5 – 17.8)	3,882
Chronic bronchitis	15.6% (14.5 – 16.7)	3,910
Migraines	19.4% (18.2 – 20.6)	3,934
Hearing loss	17 % (15.9 - 18.2)	3,853
Low back pain	52.6 % (51.0 – 54.2)	3,861
Sleep disturbances	33.7 % (32.2 – 35.2)	3,852
Depression/Anxiety	36.3 %(34.8 – 37.8)	3,851
Allergies	39.0 % (37.5 – 40.6)	3,831

Health of Flight Attendants Compared to General U.S. Population. Table 6 compares the prevalence of health conditions found in both the flight attendant survey and a survey of the U.S. population (NHANES survey), adjusted for age and stratified by gender. In addition, the NHANES sample excluded unemployed respondents and those below the poverty line, as well as, individuals with less than high school education in order to reflect the characteristics of the flight attendants.

Table 6. Prevalence of Health Conditions in NHANES Survey (2005-2008) and Flight Attendants' Health Survey (2007) with Standardized Prevalence Ratio.

		NHANES % Prevalence				Flight Attendants % Prevalence				Standardized Prevalence Ratio (Age-adjusted)	
Reported Health Conditions	Gender	% Prevalence	Weighted N	Standard Error	95% Confidence Interval (CI)	% Prevalence	N	Standard Error	95% Confidence Interval (CI)	SPR	(CI)
Respiratory Health											
Allergies†	Male	31.6%	1201	1.7	27.9 – 35.2	35%	766	1.7	31.6-38.5	1.11	(0.98, 1.25)
	Female	43.2%	1139	1.8	39.3 – 47	40%	3035	0.89	38.2-41.7	0.89	(0.82, 0.92)
Asthma†	Male	13.2%	2432	0.82	11.5 – 14.8	12%	781	1.2	9.8-14.5	0.94	(0.75, 1.12)
	Female	15.7%	2240	0.92	13.8 – 17.6	13.5%	3104	0.6	12.3-14.8	0.91	(0.82, 0.99)
Chronic Bronchitis†	Male	3.6%	2263	0.5	2.6 – 4.6	13.5%	779	1.2	11.2-16.1	3.59	(2.90, 4.28)
	Female	5.1%	2083	0.7	3.7– 6.5	16.1%	3099	0.7	14.8-17.4	2.75	(2.51, 2.99)
Current Smoker	Male	23.6%	2262	1.0	21.6-25.7	13.2%	802	1.2	10.9-15.8	0.38	(0.31, 0.45)
	Female	17.4%	2086	1.2	15.0-19.7	8.1%	3173	0.4	7.1-9.1	0.21	(0.18, 0.23)
Cardiac Health											
Heart Disease†	Male	2.3 %	2260	0.3	1.6 – 3.0	2.7%	768	0.6	1.7-4.1	1.39	(0.79, 1.98)
	Female	0.6%	2084	0.2	0.1 - 1.0	2.5%	3059	0.2	2.0-3.1	3.51	(2.72, 4.30)
High BP†	Male	23.3%	2433	1.1	21.1-25.6	25%	773	1.6	22.0-28.2	1.0	(0.86, 1.19)
	Female	22.3%	2238	1.3	19.6 -25.1	14.6%	3077	0.6	13.3-15.9	0.54	(0.49, 0.58)
Overweight†	Male	28.3%	2432	1.3	25.7 -30.9	12.6%	771	1.2	10.3-15.1	0.42	(0.34, 0.51)
	Female	33.8%	2238	1.4	30.9 – 36.7	12.2%	3075	0.6	11.1-13.4	0.33	(0.30, 0.37)
Mental Health											
Sleep Disorder†	Male	7.7%	2432	0.6	6.5 – 9.0	31.6%	766	1.7	28.3-35.0	3.69	(3.22, 4.15)
	Female	5.6%	2237	0.6	4.3 – 6.8	34.2 %	3056	0.9	32.5-35.9	5.61	(5.27, 5.95)
Fatigue*	Male	3%	2244	0.4	2.3 – 3.8	6.6%	758	0.9	4.9-8.6	2.18	(1.57, 2.78)
	Female	5.9%	2065	0.6	4.7 – 7.1	10.6%	3028	0.6	9.6-11.8	1.83	(1.63, 2.03)
Depression*	Male	0.6%	2243	0.2	0.2 – 1.0	3.7%	761	0.7	2.5-5.3	5.67	(3.57, 7.77)
	Female	1.6%	2065	0.4	0.9 – 2.4	3.8%	2961	0.4	3.2-4.6	2.18	(1.77, 2.58)
Other											
Reproductive cancer†	Female	2.9%	2080	0.5	2.0 – 3.9	5.0%	3101	0.3	4.3-5.8	1.34	(1.13, 1.56)

† Health conditions that were diagnosed by a health care provider
* Symptoms that lasted almost everyday in the past 1-2 weeks as reported by respondent

Comparing flight attendant respiratory health to the general U.S. population, flight attendants reported significantly increased prevalence of chronic bronchitis; males showed a 3.5[SPR] fold prevalence and females showed 2.75 times the age-adjusted prevalence of chronic bronchitis in the general population. This increased SPR of chronic bronchitis was remarkable given the lower prevalence of smoking in flight attendants compared to the general population in both female flight attendants (8.7% vs. 18.3%) and male flight attendants (14.7% vs. 23.1%)(CDC, 2008). In addition, asthma and allergies were significantly less prevalent in female flight attendants compared to the general population, while male flight attendants had similar prevalence rates as the general population.

Regarding cardiac health, female flight attendants had a 3.5 fold increase in cardiac disease compared to NHANES population even though they had a

significantly lower prevalence of hypertension (13.9% versus 22.3%) and being overweight (12% versus 33.8%), known risk factors for heart disease. The male flight attendants had significantly less prevalence of being overweight also, although there were no significant differences in their prevalence of hypertension and risk of cardiac disease compared to the general population.

Male and female flight attendants had 3.7 and 5.6 times the risk of diagnosed sleep disorders compared to the general population, adjusted for age. In addition, fatigue and depression in female flight attendants were about twice that of the NHANES population.

While male flight attendants had similar increased rates of fatigue compared to the general population (twice the expected prevalence), their report of depression that occurred everyday or nearly everyday showed a 5.7 times greater risk.

Female reproductive cancers, including breast, uterus and ovary, were significantly more prevalent in flight attendants (34 percent greater) compared to the general population.

Relationship Between Health Conditions and Job Tenure. Given the increased prevalence of some health conditions in flight attendants, we were interested to understand whether the prevalence of these conditions changed with longer exposure to the work environment, such as longer job tenure. To test the association between job tenure and the prevalence of disease, we examined only those conditions diagnosed by a health care provider in logistic models in order to minimize the bias of subjective report. In Table 7, the diagnoses that were most prevalent in flight attendants and those conditions that were more prevalent in flight attendants compared to the general population are shown.

Certain pulmonary and cardiac conditions showed an association with job tenure. For example, males had 43% greater odds and females had 17% greater odds of a diagnosis of chronic bronchitis per every five years of tenure, after adjusting for age, smoking, education, and being overweight. Longer tenure increased the risk of heart disease in females by 32% for every five-year increase in tenure, although males had no increased risk. Interestingly, females also had an increased risk of high blood pressure with more tenure (13% increase for every five years on the job) while males showed no increased risk.

Other notable associations with tenure were skin cancer, hearing loss, and depression/anxiety. Sleep disorders, migraines, and reproductive cancers in females were not associated with job tenure.

Table 7. The Relationship Between Job Tenure and the Prevalence of Health Conditions in Flight Attendants Adjusted for Age, Smoking, Education, Overweight

Condition		Odds Ratio	95% CI	Standard Error	z	P>|z|
Chronic Bronchitis	All	1.17	1.07-1.28	.05	3.54	.000
	Male	1.43	1.14-1.79	.16	3.18	.001
	Female	1.11	1.01-1.23	.01	2.22	.027
Heart disease						
	All	1.17	.95-1.45	.13	1.48	.140
	Male	.95	.63-1.44	.20	-0.24	.810
	Female	1.32	1.01-1.74	.18	2.04	.041
High Blood Pressure	All	1.06	.98-1.16	.04	1.49	.137
	Male	1.04	.89-1.22	.08	0.48	.631
	Female	1.13	1.02-1.25	.06	2.27	.023
Sleep Disorder						
	All	1.05	.99-1.12	.03	1.56	.118
	Male	1.13	.97-1.32	.09	1.63	.103
	Female	1.04	.97-1.12	.04	1.10	.273
Hearing Loss						
	All	1.23	1.03-1.22	.05	2.73	.006
	Male	1.12	1.02-1.23	.05	2.43	.015
	Female	1.13	.94-1.35	.10	1.30	.192
Reproductive cancer	Female	.91	.79-1.06	.07	-1.16	.246
Skin cancer						
	All	1.30	1.13-1.49	.09	3.81	.000
	Male	1.35	1.00-1.82	.21	1.98	.048
	Female	1.27	1.10-1.48	.10	3.15	.002
Migraines						
	All	1.07	.99-1.15	.04	1.68	.092
	Male	1.06	.84-1.33	.12	.49	.627
	Female	1.04	.97-1.12	.04	1.10	.273
Depression/ Anxiety	All	1.08	1.02-1.16	.03	2.49	.013
	Male	1.09	.933-1.27	.09	1.09	.277
	Female	1.07	.999-1.02	.04	1.95	.051

DISCUSSION

To our knowledge, this is the largest random sample of general health in flight attendants with comparison to the larger U.S. population (Nagda & Koontz 2003, Beatty et al. 2011). We found that compared to the general population, flight attendants have an increased risk for a number of conditions, and some of the leading diagnoses are associated with more job exposure, even after adjusting for other risk factors, such as age, smoking, education, and body mass index (BMI). Thus, several findings about flight attendant health warrant attention.

The higher than expected prevalence of chronic bronchitis in flight attendants adds further support to crew studies that found adverse respiratory consequences. The respiratory health of flight attendants has been previously studied due to significant exposure to second hand smoke (SHS) in the cabin before increasingly stricter smoking bans, starting in 1988, led to smoke-free cabins for the majority of flights to and from the U.S. by 1999 (Ebbert et al., 2007). As early as 1989, researchers found elevated levels of urinary cotinine, a tobacco by-product, evident in crew post-flight (Mattison et al. 1989).

Models generated from cotinine dosimetry estimated that the flight attendants' exposure to SHS was greater than 6 times that of the average worker and approximately 14 times that of the average person (Repace 2004) Moreover, at least one study confirmed compromised pulmonary function in 49 flight attendants who never smoked but worked in the aircraft cabin before the ban (Arjomandi et al. 2009).

Considering that 41% of flight attendants in our study had greater than 20 years on the job, their exposure to SHS is likely to be considerable. In addition, the odds of being diagnosed with chronic bronchitis increased significantly with longer tenure, even after controlling for other risk factors such as age, current smoking, BMI, and education.

Other recent studies of flight attendant health that limited the sample to individuals without a personal history of current *or past smoking* found chronic bronchitis to be prevalent also. Beatty et al. (2011) compared age-adjusted rates of chronic bronchitis in flight attendants to the general population in just one wave of the NHANES survey and found a prevalence of 11.7 percent in flight attendants versus 7.2 percent in NHANES. In addition, the rates of other respiratory illnesses, such as emphysema/chronic obstructive pulmonary disorder (COPD) and sinus problems were also increased in flight attendants. These differences were notable because the NHANES sample included unemployed individuals with likely higher rates of disease that would artificially diminish the gap in disease rates between the general population and the flight attendants. Although the researchers found respiratory diseases to be elevated in flight attendants compared to the general population, the prevalence of illnesses did not increase with tenure. This study was limited, however, by a small sample size (n = 235), grossly estimated tenure according to ten year increments, a relatively older sample, (mean age of 58.2 years), and potentially biased responses because the sample was openly recruited to investigate respiratory health. Nonetheless, the odds of daily respiratory complaints such as nasal congestion or throat or eye irritation not related to cold or hay fever *were* related to tenure in these never smokers.

Another larger study (n = 1007) by Ebbert et al. (2007) that *randomly* selected never smokers found an association between tenure and respiratory illnesses, such as sinusitis, middle ear infection, and asthma. Yet, the prevalence of diagnosed chronic bronchitis did not show the same dose-response relationship with tenure despite the high prevalence rate of 30.8% in this population. Importantly, this sample was selected for pre-1987 seniority (older flight attendants exposed to SHS before the smoking bans) with only partial blinding to the study hypotheses, in addition to, a relatively low response rate of 14%.

Older studies about respiratory health in flight attendants targeted aircraft exposures other than SHS, specifically investigating symptoms of ozone toxicity, low humidity and cabin pressure, along with other air contaminants, to explain a higher prevalence of symptoms in crew. Direct measurements were not recorded in these studies (deRee et al. 2000, Reed et al., Cone 1984)

Further, Tashkin et al. (1983) found increased symptoms of ozone toxicity in crew during flights in aircraft designed to fly at higher altitudes while a later study found no difference in four ozone-related symptoms (coughing, chest tightness, shortness of breath and "breathing hurts"), *during* flight. Whelan et al. (2003) found flight attendants were more likely than teachers or blue-collar workers in a national survey to report chest illness even though they were less likely than the comparative groups to report a diagnosis of asthma. Importantly, these studies were conducted *before* smoking was banned in the cabin.

In the current study, cardiac disease was 3.5 times greater in female flight attendants than the general population. Although the male flight attendants showed a higher prevalence of cardiac disease as well, this was not significant in the small subpopulation. The finding of any increase in cardiac disease was surprising given the lower overall prevalence of hypertension, smoking and

overweight in the flight attendants. It is important to note, however, the slight difference in the survey questions between the flight attendant survey and the NHANES survey. The flight attendants were asked if they had been diagnosed with heart disease and the NHANES survey specified a diagnosis of "coronary artery disease". Both of these labels may lead to misclassification in *either* the flight attendant survey *or* the NHANES survey, considering that only about 50% of respondents who answered affirmatively that they had been diagnosed with a myocardial infarction, also answered positively to the question about either heart disease (flight attendants) or coronary artery disease (NHANES). In other words, myocardial infarction was not interpreted as "heart disease" or "coronary artery disease" half of the time, although the prevalence of myocardial infarction in both groups was very rare given the selection of employed populations or "healthy workers". [This analysis is not shown here]. Interestingly, heart disease in female flight attendants showed a dose response relationship with tenure, as did hypertension, a major risk factor for heart disease.

Flight attendants also had a higher than expected prevalence of conditions that have been linked with cardiac disease, and with air pollution, noise, and sleep disruption. For instance, the same conditions that may be responsible for the higher than expected prevalence of respiratory illness in flight attendants, such as exposure to SHS or ozone, have been shown to increase the risk of cardiac disease as well (Katsouyanni et al. 2009).

In addition, recent evidence from population studies found that chronic exposure to occupational noise may increase the risk for cardiac disease (Wen 2011). Airplane noise has been measured at an average of 80 to 85 decibels (Spengler et al. 1994), and some researchers have noted an increased risk of hearing loss in cabin crew with exposures between 71 and 81 decibels (Lindgren et al. 2008).

Notably, in our study, the diagnosis of hearing loss in flight attendants showed a dose response relationship with job tenure even after controlling for age. Finally, circadian disruption that results from crossing time zones has been demonstrated in flight attendants using melatonin as a biomarker (Repace 2004) and, according to new research, some evidence links chronic circadian disruption to increased risk for cardiac disease. (Wang et al. 2011). In the current study, flight attendants reported significantly higher rates of diagnosed sleep disorders than the general public even though the dose response relationship with tenure was not significant. Underscoring a problem with sleep, 37% of the flight attendants surveyed had sought medical attention for frequent fatigue within the past year. In all, exposure to cabin air pollution, noise, and sleep disruption could increase the risk for heart disease in flight attendants.

Although other studies have reported problems with fatigue and depression in flight attendants, this is the first study to compare these symptoms with the experience in a general population, such as NHANES. The higher than expected prevalence of fatigue and depression in flight attendants was surprising given that only flight attendants reporting fatigue and depression *everyday* in the last week were compared with a decidedly more liberal definition in NHANES; individuals experiencing symptoms most of the time in the past 2 weeks. The different time interval and frequency criteria; daily symptoms in last week (flight attendants) versus symptoms that occurred more than half the time over past two weeks (NHANES) may be an overly conservative estimate of the flight attendant experience in comparison. Even so, a diagnosis of depression in flight attendants showed a moderate dose response relationship with tenure.

Whether the experience of chronic circadian disruption from jet lag or exposure to radiation in flight elevates the risk of cancer in cabin crew has been hotly debated because of equivocal findings. In our study, we found an increased prevalence of self-reported reproductive cancers, inclusive of breast, ovary, and uterus, in female flight attendants. In addition, the report of a diagnosis of skin cancer in flight attendants was significantly associated with tenure in flight attendants.

This finding contrasts with a recent study of cancer in 11,311 former flight attendants that found no evidence for an increased risk of breast cancer or melanoma. However, this study investigated mortality rates only in a cohort considerably different from our study sample (Zeeb et al. 2010) In particular, the median tenure of flight attendants was only 5.9 years compared to our study in which 41.4% of the flight attendants had more than 20 years in the job. Despite this limitation, an interesting finding of

this study was that the Standardized Mortality Ratio (SMR) for melanoma was increased in the highest exposure category for cumulative radiation dose, cumulative time zones crossed, and cumulative time spent working in standard [disrupted] sleep interval, although the confidence intervals were wide because of only 3 cases. In contrast, a recent study of German flight attendants found a non-significant elevated breast cancer standard mortality ratio of 1.17 compared to a control population (Zeeb et al. 2010). Paridou et al. (2012) found no elevated risk of cancer mortality in a Greek cohort of 843 pilots and 1835 cabin crew.

A recent cohort study of flight attendant health did not find breast cancer *incidence* (morbidity versus mortality) significantly different compared to NHANES however, flight attendants in this study were not randomly selected and were not compared with employed *and unemployed* persons in the NHANES survey (Beatty et al. 2011). Other cohort studies of female flight attendants did find higher than expected incidence of both breast cancer and melanoma in California, Iceland and Sweden (Reynolds et al. 2002), although the elevated risk of breast cancer in Swedish crew was not significant and was not associated with length of employment (Linnersjo et al. 2003, Rafnsson et al. 2001)

Further, two separate meta-analyses of published incidence studies also found elevated risk for breast cancer and melanoma (Buja et al. 2006, Tokumaru et al. 2006).

In considering the results of our study in total, it is important to consider that a cross-sectional survey study is not meant to explain cause and effect. Yet, the higher than expected age-adjusted prevalence of health conditions in flight attendants would suggest that occupational exposures may be at the root of the problem.

The number of self-reported work-related injuries in flight attendants was high compared to other groups and to other data sources. In the current study, we were unable to calculate exact injury rates because the injury counts were truncated by a category listed as "four of more". Even so, according to these conservative estimates, nearly half of the flight attendants experienced at least one work-related injury in the last year and 29% experienced more than one. Considering that the annual rate of injury for all industries is 4.2 per 100 workers and 10.2 per 100 for all air transportation workers in 2007 (Department of Labor. U.S. Government– http://www.bls.gov/news.release/pdf/osh.pdf), the injury experience reported by the flight attendants in our study was substantial. Apart from the question of work attribution, the burden of back problems in particular was widespread: we found that at least one in five flight attendants was receiving treatment for low back pain.

Flight attendants informed us that pushing utility carts, pulling aircraft doors, handling baggage, awkward postures, and prolonged standing or sitting in confined spaces were the most significant sources of physical exertion and injury. These physical exertions may contribute to and/or interact with the fatigue reported as a frequent condition by many in our sample. Given the frequency of injury reported by the crew, an ergonomic assessment of the job seems warranted.

CONCLUSIONS

This study has identified several significant health conditions in flight attendants compared to the general population and raises the important issue about what can be done to minimize risk. While smoking bans have limited some occupational exposures, many questions about hazardous exposures still exist. Importantly, flight attendants do not have access to exposure data: for example, there is no requirement for monitoring cabin air quality, noise, or radiation. Further, flight attendants currently are not required to participate in hearing conservation programs even though the level of noise exposure would likely warrant under Occupational Safety and Health Administration (OSHA) rules. OSHA and FAA are at this time negotiating new policies so that such standards will likely cover flight attendants in the future (FAA 2012).

Given the prevalence of fatigue and sleep disorders in flight attendants, and the overall consequences for health (particularly the risk for cardiovascular disease), quality of life, productivity, in addition to public safety, reducing the prevalence of these disorders is extremely important. Not surprisingly, Congress called for the Civil Aeronautical Medical Institute (CAMI) within FAA to study the problem in 2005 and 2008. CAMI researchers found that disrupted sleep activity between off duty and on-duty work cycles resulted in pervasive chronic sleep deprivation, fatigue, and decline in tests of

cognitive performance among flight attendants (Roma et al. 2010). CAMI cited the key variables with the potential to reduce risk of fatigue as the total length of duty day, number of flight legs/segments per day, recovery time in the hotel during a trip, consecutive duty days/trip length, and number of days off in between trips. Although not mentioned by CAMI, work factors such as the physical stress of hypobaric hypoxia at altitude (Coste 2004), workload and noise may add to the burden of fatigue(Mellert et al. 2005). Currently, FAA considers limits on duty time for fatigue mitigation choosing a focus on work/rest cycles instead of the best practices based on sleep/wake factors (Petrilli et al. 2006). In all, the management of fatigue and sleep disruption has still to be fully addressed by the airlines or the FAA.

Other conditions widely reported in our sample warrant further action as well. Even though the one-third of flight attendants reporting frequent musculoskeletal pain is consistent with other studies (Lee et al. 2006), none of these studies have tracked the trend in musculoskeletal complaints over time. It is noteworthy that as passenger loads have climbed in step with the increase in population obesity and full occupancy policies, passenger seat sizes and baggage compartment space have become smaller at the same time. We know little about the consequences of these ergonomic conditions, especially aboard new jumbo-sized aircraft such as the Airbus 380. Future studies are needed in this area.

Finally, the prevalence of general neurological symptoms in an otherwise healthy worker population is of interest. Complaints of severe headaches, dizziness or lightheadedness, numbness and tingling in extremities, and memory loss, are difficult to gauge because we did not have comparable survey questions in the NHANES survey or other worker surveys. These symptoms need further investigation also.

In summary, the prevalence of certain health conditions in flight attendants is higher than the general population and some of these conditions show a dose response relationship with tenure. While FAA is responsible for the health and safety of cabin crew, the scope of health protection programs for flight attendants is limited in comparison to other worker groups covered under OSHA. Additional environmental monitoring for air quality, noise, and radiation would afford the data needed to determine whether worker surveillance and protection programs are justified. Further investigation of ergonomic stress, fatigue risk, and general neurological symptoms are indicated as well.

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IV. CABIN AIR EXPOSURE ASSESSMENT

IV.A. AIR SAMPLING DEVELOPMENT AND TESTING

IV.A.1 VAN NETTEN SAMPLER COMPONENT REFINEMENT AND FINALIZATION

To satisfy specific aim #3 of this research, the van Netten sampler is designed to measure the presence of aerosolized engine oil and hydraulic fluid components. It was developed for use by crew in aircraft during flight and therefore designed to meet numerous criteria:

- Compact and easy to carry for extended time periods until activated during an air quality incident;
- Relatively inexpensive for mass distribution;
- Self-contained with battery power and filter media in place prior to distribution;
- Filter media protected to prevent contamination when not in use or in transport;
- Easily transported through standard mail;
- Able to meet criteria for electromagnetic interference for use during all phases of flight;
- Easily taken through security at airports;
- Easily activated with simple instructions, i.e. intuitive and user-friendly;
- Operated without any disruption of the normal duties of a crewmember;
- Operated in the main cabin with no passenger apprehension or disruption of comfort;
- Accurate and reliable capture of aerosolized oil components in the air at low levels; and
- Based on standard occupational hygiene methodology using easily obtained components such as batteries, filters, and back-up pads.

METHOD

University of British Columbia (UBC) personnel performed testing of all sampler components including the motors, fan designs, and various housing components by assembling and testing prototypes in UBC labs. A detailed description of the sampler has been published (van Netten 2009), and performance and electromagnetic testing results are provided in the following sections.

RESULTS

The final sampler configuration houses standard 37mm filters and has a DC motor that can be operated at 3V, 4.5 V and 6V depending on the battery configuration. It is operated with up to 4 standard AAA alkaline batteries. The VN sampler is 9 cm tall and 5 cm diameter. The housing was injection molded with Acrylonitrile butadiene styrene (ABS) plastic in two components, the main body and the cap. The cap has intake ports on the top with exhaust ports on the sides and slides onto the main body such that these ports are closed unless activated. The top of the main body has the filter casing with an O-ring to seal the filter into place. The cap is clicked into place on the main body in the off position and must be twisted 45 degrees to open the inlets and exhaust and activate the motor to draw air across the filter.

REFERENCE

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IV.A.2 ELECTROMAGNETIC TESTING

METHOD

To ensure the VN sampler met electromagnetic requirements for use on aircraft during all phases of flight, testing was conducted by CKC Laboratories, Inc. CKC followed the testing requirements RTCA/DO-160D as outlined in *Environmental Procedures and Test Procedures for Airborne Equipment and Test Procedure TP05-83418-0 (July 29, 1997)*. Since the sampler is battery operated and does not have Interconnecting Signal Lines or Input Power Lines, testing involving the measurement of Conducted Radio Frequency (RF) Emissions and the Injection of Conduction RF Susceptibility threat signals were not applicable. All testing was conducted at CKC Laboratories in a shielded enclosure when appropriate.

Magnetic Effect (Section 15). A compass was placed 3 meters from the VN sampler. Compass readings were recorded with the sampler off, and then turned on. The compass was moved closer in 25cm increments and measurements taken with the sampler both off and on at each location until a 1-degree deflection of the needle was observed. This

process was repeated with the VN sampler in different positions facing the compass.

Induced Signal Susceptibility (Section 19). A wire was passed within 15 cm of the sampler and extended beyond the chassis 60 cm on each side. Twenty amperes of 400 Hz current was passed through the wire and the sampler was tested for susceptibility.

Radio Frequency Susceptibility (radiated) Category T (Section 20). A signal generator, amplifier and antenna were connected per RTCA/DO- 160D Section 20.5. A field probe was placed 0.5m from the sampler, 0.5m from the chamber wall and 30cm above the ground plane. The following sweeps were then performed: an unmodulated sweep from 100MHz to 1GHz, a 1kHz squarewave modulation sweep, then the antenna polarization was changed and both sweeps repeated. The functionality of the sampler was tested throughout each sweep.

Emission of Radio Frequency Energy (radiated) Category B (Section 21). The following antennae with the frequency scan ranges were placed 1m in front of a running sampler:

- rod antenna: 2mHz to 25MHz
- biconical antenna: 25MHz to 300MHz in horizontal and vertical antenna polarizations
- bilog antenna: 300MHz to 1GHz in horizontal and vertical antenna polarizations
- high frequency double ridge guide horn antenna: 1GHz to 6GHz in horizontal and vertical antenna polarizations

Electrostatic Discharge (ESD) Category A (Section 25). An ESD generator set for 15kV from a 150pF and 330Ω source was used to apply 10 positive and 10 negative discharges to the chassis of a sampler; then the functionality of the sampler was tested.

RESULTS

Table 8 summarizes the results of the testing conducted by CKC and a full report of this testing is available from the authors (CKC Laboratories 2005).

REFERENCE

CKC Laboratories, Inc. December 20, 2005. University of British Columbia Test report for the VN sampler, Prototype.

Table 8. Electromagnetic Test Results Summary

Section	Test description	Results	Category	Outcome
15	Magnetic Effect	The compass safe distance is at least 0.3m from the front, back, top, bottom, left and right side of the sampler.	Z	PASS
19	Induced Signal Susceptibility	Sampler exhibited no signs of susceptibility during the extent of Section 19.3.1 testing.	Z	PASS
20	Radio Frequency Radiated Susceptibility	Sampler showed no signs of susceptibility during the extent of the .5m testing from 100MHz to 1 GHz in horizontal and vertical polarizations.	T	PASS
21	Emission of Radiated Radio Frequency Energy	Sampler exhibited no emissions exceeding the limit from 2MHz to 25 MHz to 6GHz in horizontal and vertical antenna polarizations.	B	PASS
25	Electrostatic Discharge (ESD)	No degradation of performance was found during the extent of testing at 15kHz on the sampler chassis.	A	PASS

IV.A.3 INCORPORATION OF CO SENSOR INTO VN SAMPLER

The 2002 National Academy of Sciences report (NRC 2002) recommended monitoring for the presence of carbon monoxide in the cabin air during flight. Concern about bleed air contamination and crew health or incapacitation prompts the need to assess multiple contaminants. The van Netten (VN) sampler is designed to measure the presence of aerosolized oil components including TCPs. The incorporation of a CO monitor into the VN sampler would make an effective combination as it would measure two contaminants which could be concurrently generated: aerosolized neurotoxic agents (TCPs) and an acutely toxic, incapacitating gas (CO). These two contaminants are not always present in tandem. TCP exposure can occur at engine temperatures insufficient to pyrolize the oil so that CO generation, dependent on temperature, may be minimal. However, when CO is present due to engine oil pyrolysis, there is likely to be TCP exposure as well, suggesting the presence of a bleed air event. The elevated level of CO, as indicated by the monitor, could be a trigger for the operator to turn the sampler on and begin collection of a filter sample.

METHOD

A custom CO sensor was developed using Figaro sensor TGS 2442. Eight prototype circuit boards were hand soldered and tested in response to a 100 ppm CO concentration calibration gas in air. The sensor was tested entering the chamber from clean air, and leaving the chamber to clean air to observe the CO sensor response.

RESULTS

Trials with the eight prototypes showed a slow response time to the CO exposure, taking from six to eight minutes. The trials also showed when CO was removed from the testing environment, it took 10 to 12 minutes for the sensor to register zero.

SUMMARY

Based on the sensor work conducted, the interim findings presented here, and the field deployment experience with the VN sampler described later in this report, the pursuit of the integration of a CO sensor into the VN sampler is not recommended. The predictive value of CO as an objective trigger for particulate and semi-volatile sampling has not been demonstrated. The slow response of the Figaro sensor to, and from, exposure to 100 ppm CO will be a problem when trying to capture fast transients of CO in the environment. This may be due to the use of a lower operating voltage than recommended during the testing. In addition, an inherent heating cycle requirement between measurements of the Figaro sensor requires more power than the electrochemical sensors. In order to optimize battery life and hence increase the time period during which the sensor is operating, the use of a different sensor such as the CiTicell CO sensor should be investigated.

Progress was made in evaluating sensors and designing electronic components, but the effort to fully incorporate a CO device into the VN sampler was not completed. While it would have been beneficial, given the time and budget of this project, the investigators chose to focus on other components of the project. This is not a judgment on the larger question of CO monitoring of cabin or cockpit, but on the wisdom of a miniaturized component for the VN sampler. Further detail on the CO sensor research is available in an unpublished report, available from the authors (van Netten et al. 2008).

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IV.B. METHOD DEVLOPMENT FOR COLLECTION AND ANALYSIS OF AIR SAMPLES USING THE VN SAMPLER

Since the VN sampler provides a new sampling platform using filter sampling technology, its

performance was tested against standard and accepted occupational hygiene sampling instruments. VN samplers were initially tested side-by-side with SKC pumps along with other sampling technologies in an environmental chamber in which some of the contaminants of interest were introduced by means of pyrolization of jet engine oil. The two rounds of environmental testing conducted are described below, but prior to testing the sampling technology, analytical procedures for tricresyl phosphates (TCPs), were investigated in two experiments. TCPs are a known anti-wear additive in jet engine oils and have been identified as neurotoxic agents of concern. For these reasons this study used the presence of TCP isomers in aircraft air as an indicator of engine oil contamination.

IV.B.1 ENGINE OIL AND HYDRAULIC ENGINE FLUID SAMPLE ANALYSIS

TCP isomers are not restricted to jet engine oils but are also used in other commercial products, including plastics (Mutsuga et al, 2003). In order to measure TCP in the cabin or cockpit air of aircraft and link it to the leakage of jet engine oil lubricants, the characteristic pattern of TCP isomers present in engine oil was identified and measured. A number of commercially available jet engine oils and hydraulic fluids were analyzed for the presence of TCP isomers and to identify their specific profiles when present. These profiles were then used to compare to similar compounds found in GC/MS analysis of aircraft air samples.

METHOD

The following 12 oils and fluids were obtained from the airline industry including:

1. Aeroshell Turbine Oil 560
2. BP Turbo Oil 2389
3. BP Turbo Oil 2197
4. Mobil Jet Oil II
5. Used BP Turbo Oil 2380
6. Bulk BP Turbo Oil 2380
7. Chevron HyJet 1V-A ^{Plus}, hydraulic fluid
8. Monsanto Skydrol LD-4, hydraulic fluid
9. Monsanto Skydrol LD-4 500B-4, hydraulic fluid
10. Mobil Jet Oil 291
11. Exxon 0-156, Lubricating oil
12. Mobil jet oil 254

All oils were delivered to the UBC laboratory in unopened quart cans except the used and bulk samples of BP 2380, 5 and 6 above. The latter two were delivered in glass containers.

All oil containers were opened and one to two drops were transferred to pre-weighed 25 ml. volumetric flasks and their final weights recorded. The flasks were filled to 25 ml with ethyl acetate. One ml aliquot of this solution was transferred to a GC vial and 1ul of this was injected into an Agilent GC/MS which was set for single ion monitoring mode looking for the 368 ion, characteristic for TCP isomers as described before (van Netten 2008) and using Fluka mix as a standard to which o-TCP was added.

RESULTS

The percent of TCP isomers per unit weight in the tested oils and fluids and relative percent of each isomer to the total are shown in Table 9. The TCP isomer profiles based on single ion monitoring for the m/z 368 ion of TCP isomers, are shown in figure 6 along with the profile of the Fluka standard mix to which o-TCP has been added resulting in a final mixture of the o, m, and p isomers. What are described as isomers #1, and #2 appear to have been identified in a recent study of engine oil composition as m,m,p-TCP and m,p,p-TCP (De Nola et al. 2008) This standard is repeated for every third trace as a reference in figure 7.

SUMMARY

The chromatograms in figure 7 show that the o-TCP isomer is absent in the traces of engine oils and hydraulic fluids at the resolution shown above. At a higher resolution some of these oils show a trace of ooo-TCP at the detection limit of .001μg which correspond to a fraction of a percent of the total TCP in the oils as shown in table 9 and based on the GC/MS data. The Aeroshell 560, BP 2389, and BP 2197 show a trace of ooo-TCP just at the detection limit, which corresponds to 0.01%.

The BP 2380, which was used in a BAe-146 aircraft, shows a higher percentage of total TCP isomers than the unused bulk oil. This is likely

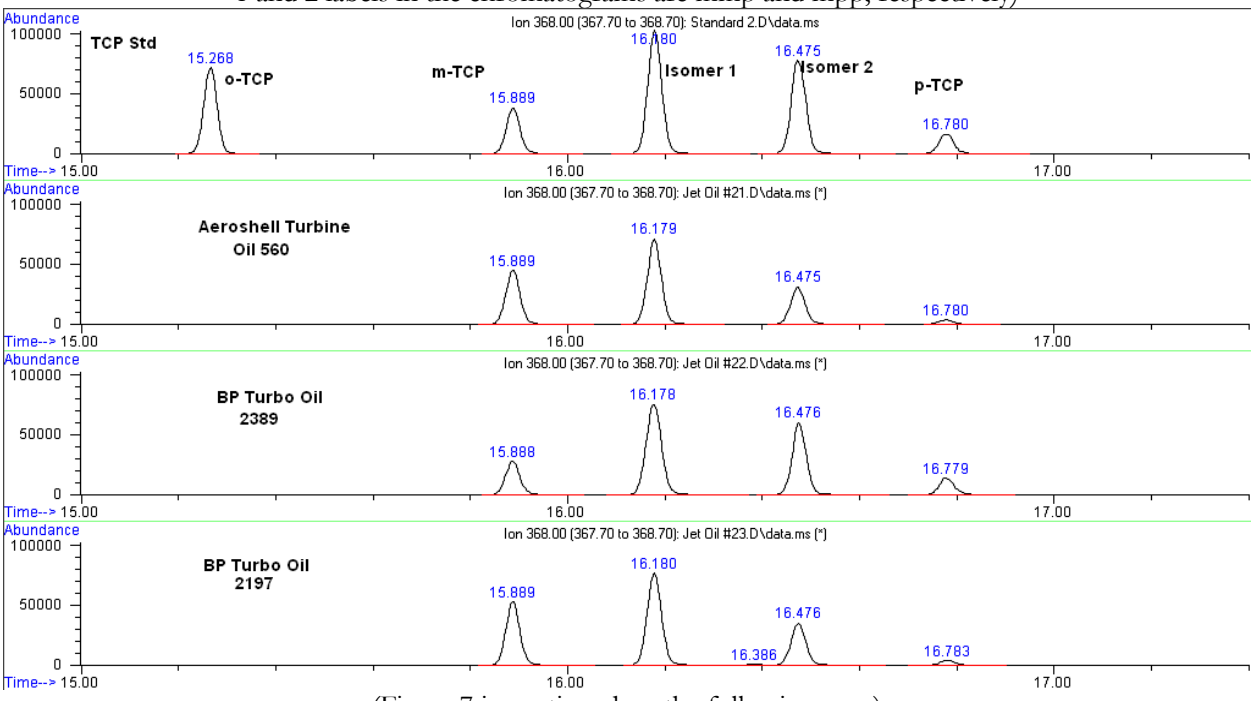
indicating the possible degradation of other oil components when used in jet engines. Chevron Hyjet hydraulic fluid did not show the presence of any of the TCP isomers. This finding differs from earlier analysis on another batch (van Netten and Leung, 2001) where ooo-TCP was found. If the current batch is an indicator of improved quality control, or a reflection of a sporadic change in the constituents, this needs to be clarified with additional testing. The other two hydraulic fluids did not show the presence of any TCP isomers and corroborates previous findings (van Netten and Leung, 2000, 2001).

All jet engine oils show relative ratios of each of the individual isomers that are very close, excluding BP 2389, which has a higher ratio of mpp-TCP. A closer look at the mmm-TCP isomer in the other oils, for instance, shows an average presence of 29.86% with a range between 24.83% and 33.58%. These values might very well indicate that these oil companies are likely to make use of the same manufacturing process. Of note is that the ≤3% level of TCP isomers that is often referred to in the Material Safety Data Sheets for these oils (Winder and Michaelis 2005), appears to have been exceeded in five of the eight oils tested (Table 9).

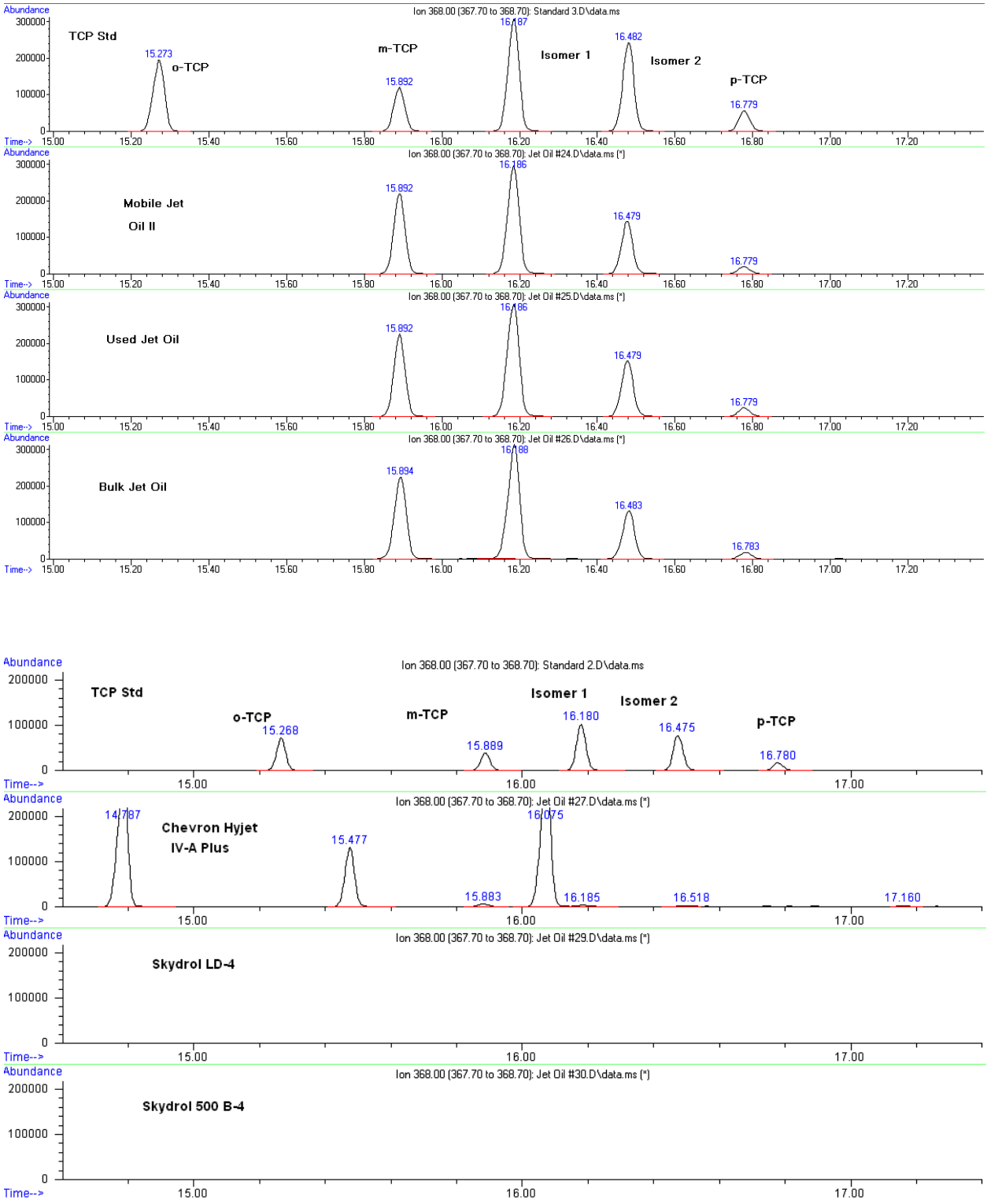
Table 9. Percent of TCP isomers per unit weight in oils and fluids as well as relative percent of each isomer to the total.

Sample ID	% TCP total	Rel. % ooo TCP	Rel. % mmm TCP	Rel. % mmp TCP	Rel.% mpp TCP	Rel % ppp TCP
Aeroshell 560	**2.23**	0.02	29.53	49.05	21.34	0.09
BP 2389	**2.80**	0.01	15.68	49.63	34.39	0.30
BP 2197	**2.85**	0.01	29.73	48.45	21.73	0.09
Mobil II	**5.23**	<0.01	31.48	47.04	21.37	0.11
Used BP 2380	**5.10**	<0.01	29.81	47.67	22.40	0.12
Bulk BP 2380	**4.70**	<0.01	32.22	47.64	20.04	0.10
Chevron Hyjet	**0.00**	<0.01	<0.01	<0.01	<0.01	<0.01
Mobil 291	**5.59**	<0.01	24.83	47.22	27.76	0.19
Skydrol LD-4	**0.00**	<0.01	<0.01	<0.01	<0.01	<0.01
Skydrol 500B-4	**0.00**	<0.01	<0.01	<0.01	<0.01	<0.01
Exxon O-156	**4.48**	<0.01	29.11	48.19	22.59	0.12
Mobil 254	**4.99**	<0.01	33.58	46.50	19.85	0.09

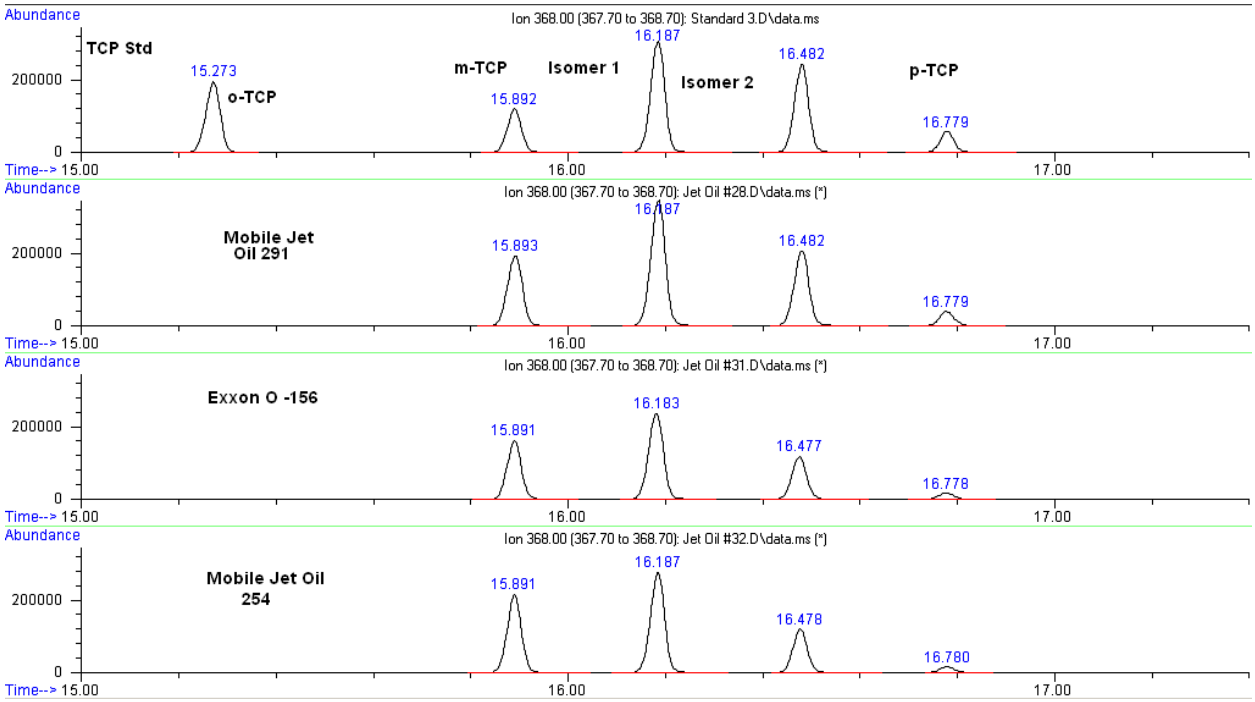
Figure 7. GC/MS Single Ion Chromatograms of TCP (m/z 368) in Jet Oil and Hydrualic Fluids (The isomer 1 and 2 labels in the chromatograms are mmp and mpp, respectively)



(Figure 7 is continued on the following page)



(Figure 7 is continued on the following page)



IV.B.2 GC/MS ANALYSIS OF TRICRESYL PHOSPHATES IN AIR

METHOD

When run in the Single Ion Monitoring mode (SIM), the GC/MS yields the selectivity and sensitivity ideal for the analysis of trace levels of TCPs in air from mixed cellulose ester (MCE) filters or wiped surfaces collected as part of a validated sampling method. The ooo, mmm and ppp TCP isomers, when run individually on the GC/MS and together in a mixture, are clearly resolved chromatographically (figure 8 – Top trace). A trace of the TCP constituents present in Mobil II jet engine oil is also shown in figure 8 as indicated. The UBC laboratory also has a TCP solution purchased from Fluka chemicals that is a mixture of 4 TCP isomers that more closely matches the profile as detected in aircraft engine lubricating oils (figure 9). Tables 10 and 11 show details of the GC/MS conditions and retention times.

The following chemical standards were used:

- Tricresyl phosphate mixture. Fluka Chemika Product # 92100 –CAS #1330-78-5
- Tri-o-cresyl phosphate (ooo). Pfaltz & Bauer Inc. Product # T20595 –CAS #78-308, 96% purity
- Tri-m-cresyl phosphate (mmm). Pfaltz & Bauer Inc. Product # T20605 –CAS #56-30-42, 96% purity
- Tri-p-cresyl phosphate (ppp). Pfaltz & Bauer Inc. Product # T20615 –CAS #78-320, 96% purity

TCP extraction method: mixed cellulose ester filters. The extraction procedure was performed using ultrasonication. The MCE filters are removed from the filter holder in the sampling pump and transferred to clean 8 mol test tubes complete with Teflon lined screw caps. Three to four ml of methylene chloride is added to each tube so that each sample is completely covered by the solvent. The samples are then ultrasonicated for 30 minutes. The extracts are then transferred by Pasteur pipette to another set of labeled clean test tubes and then blown down to dryness aided by applying heat (40°C) and a gentle stream of nitrogen. After drying, a 1 ml aliquot of ethyl acetate is added and vortexed for 30 seconds prior to transferring to a GC vial. The samples are then run on the GC/MS in SIM as a batch that includes appropriate calibration standards, QC's (spikes), blank solvent and method blanks. This

GC/MS analysis procedure was used for all analyses described in this report.

IV.B.3 INTER-LABORATORY ANALYSIS FOR QA/QC

METHOD

TCP analysis. Interlaboratory comparisons of the analysis of TCP spiked samples were conducted by the analytical laboratories at the University of British Columbia (UBC) and Harvard School of Public Health (HSPH) in March 2007. Blanks and spiked samples were prepared by a third party and sent blinded to each laboratory. Prior to receiving the QA/QC samples, the laboratories collaborated to harmonize sample handling and analysis protocols. For the QA/QC samples, two sets of 15 samples were created. Each set of samples was identical and sent to each lab. The 15 samples included triplicates of the following levels of TCP in the spiked samples (spiked samples included three TCP isomers [ooo, mmm, and ppp] standards together):

- blank (0ng TCP/filter)
- 5ng TCPs/filter
- 10ng TCPs/filter
- 15ng TCPs/filter
- Mobil Jet Oil II (3ng TCP)

Filter media testing. UBC completed testing of two different filter media with the VN sampler, the MCE filter and QMA filter, during chamber testing experiments, which are detailed in section IV.D. of this report. HSPH also completed filter recovery testing and storage stability testing (Vallarino et al 2009). HSPH tested three types of filters Teflon, MCE and the QMA filter, which were spiked with each TCP isomer at 0.5ng and 5.0 ng. To test storage stability, HSPH spiked MCE filters with each TCP isomer at 20ng and immediately extracted one set of filters with each isomer and let three remaining sets of filters sit either refrigerated or at ambient temperature for 1, 2 and 4 weeks.

RESULTS

TCP analysis. Table 12 shows results from UBC and HSPH for the three TCP analytes. Both laboratories were able to detect the analytes on the spiked filters. The relative error ranged from 25.9% to 31.3% for UBC and from 11.4 to 46.9% for HSPH.

Filter media testing. Both UBC and HSPH determined independently that the QMA filters demonstrated best recovery for the TCP analytes. Full results for UBC can be seen in Section IV.D. and for HSPH in Vallarino et al (2009). HSPH determined that TCP analytes were stable on MCE filters after one month stored at ambient temperatures. They reported slightly better stability when stored in refrigeration and recommended refrigeration when sending samples in the field since temperatures may be unknown.

SUMMARY

The interlaboratory TCP analysis showed that both UBC and HSPH could detect TCP in filters spiked with TCP isomers with a relative error between 11.4% and 46.5%. Both labs agreed that the QMA was the appropriate media to sample TCP in the field. HSPH determined that the TCP analytes were stable on filter media for the one-month testing period at ambient temperature.

Table 10. GC/MS Conditions: Agilent Technologies GC/MS 5973

GC parameters	
GC column:	HP-5 30 m x 0.25 mm I.D. with 0.25 um film thickness
GC Oven Temperature Program:	65°C (1 min hold) to 300°C @ 10°C/min (3 min final hold time)
Injection Port Temperature:	300 °C
Injection Volume (uL):	1 uL
GC/MS Interface Temperature:	290 °C
Splitless Injection Time:	0.50 min
Inlet Pressure (Constant Flow Mode):	10 psi
MS Parameters	
Ion Source Temperature:	230 °C
MS Quadupole Temperature:	150 °C

Table 11. Retention times using Single Ion Monitoring (SIM)

Isomer Standards	**Retention Time (mins)**	**Quan Ion (m/z)**	**Qualifier Ions (m/z)**
Tri - o - cresyl phosphate	22.631	368	107, 67
Tri - m - cresyl phosphate	23.083	368	107, 165
Tri - p - cresyl phosphate	23.785	368	107, 165
Fluka Chemika - TCP Standard Mixture			
Peak #1 (mmm-TCP)	23.072	368	107, 165
Peak #2 (mmp -TCP)	23.302	368	107, 165
Peak #3 (mpp -TCP)	23.535	368	107, 165
Peak #4 (ppp-TCP)	23.776	368	107, 165
Dwell Time: 70 msecs/ion			

Figure 8. Chromatograms of TCP isomer standards and constituents in Mobil II jet engine oil

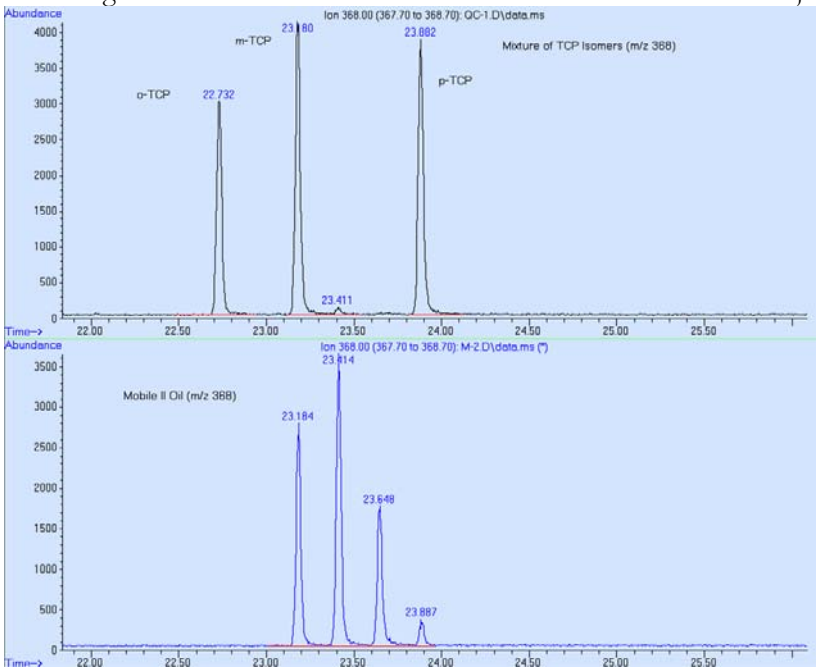


Figure 9. Fluka Chemika TCP standard solution – diluted with ethyl acetate and run for retention time checks

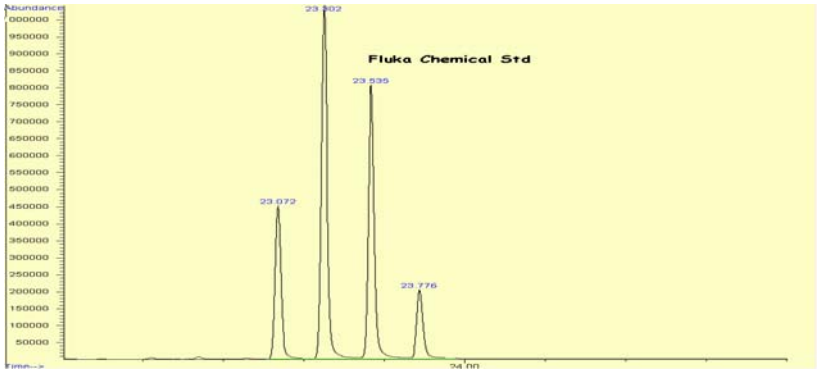


Table 12. Mean (ng/filter) and percent relative error (%) of the sample results for interlaboratory comparison of spiked filters.

Spiked Sample		0 ng/filter	5 ng/filter		10 ng/filter		15 ng/filter		Mobil Jet Oil 3ng/filter
Results		ng/filter	ng/filter	% RE	ng/filter	% RE	ng/filter	% RE	ng/filter
ooo	UBC	<0.5 <0.5 <0.5	6.29 6.09 6.69 **6.36** ± 0.31	27.1	13.77 12.62 13.00 **13.13** ± 0.59	31.3	18.67 20.02 19.58 **19.42** ± 0.69	29.5	<0.5 <0.5 <0.5
	HSPH	<0.5 <0.5 <0.5	6.55 6.11 8.26 **7.01** ± 1.11	40.1	10.15 11.12 14.70 **11.99** ± 2.39	19.9	17.94 18.84 19.95 **18.43** ± 1.00	22.9	<0.5 <0.5 <0.5
mmm	UBC	<0.5 <0.5 <0.5	6.69 6.45 6.53 **6.56** ± 0.12	31.1	12.81 12.57 12.76 **12.71** ± 0.13	27.1	18.36 19.89 19.77 **19.34** ± 0.85	28.9	<0.5 <0.5 <0.5
	HSPH	<0.5 <0.5 <0.5	6.57 6.44 6.42 **6.47** ± 0.08	29.5	10.76 11.91 14.30 **11.14** ± 0.73	11.4	17.94 18.84 19.95 **18.91** ± 1.01	26.1	<0.5 <0.5 <0.5
ppp	UBC	<0.5 <0.5 <0.5	6.24 6.57 6.28 **6.36** ± 0.18	27.3	12.67 12.22 12.89 **12.59** ± 0.34	25.9	18.46 20.17 19.70 **19.44** ± 0.88	29.6	<0.5 <0.5 <0.5
	HSPH	<0.5 <0.5 <0.5	6.90 6.57 8.51 **7.33** ± 1.04	46.5	10.76 11.91 14.30 **12.32** ± 1.81	23.2	17.03 18.08 18.15 **17.75** ± 0.63	18.3	<0.5 <0.5 <0.5

% RE = relative error = the measure of expected in terms of percentage bias of what is measured = (Measured-Expected)/Measured X 100

IV.B.4 ENVIRONMENTAL CHAMBER TESTING OF THE VN SAMPLER

METHOD

Round 1 Environmental Chamber Testing

Round 1 of the environmental chamber testing was conducted in March 2007. A one cubic meter stainless steel/plexiglass environmental chamber was used to generate varying concentrations of Mobil II jet engine lubricating oil. Triplicate sets of SKC pumps and VN samplers were exposed with two levels 3 sets on the top shelf and 3 on the bottom shelf of the chamber as shown in figure 10. The shelves were open stainless steel wire construction. A standard hotplate set at 420ºC as verified by a thermometer was placed in front of the samplers on the bottom shelf. On the top shelf, behind the samplers, was a fan that provided air circulation throughout the chamber.

Figure 10. Arrangement of VN and SKC sampling systems for round 1 testing

Sampling device setup for round 1. Twenty-one VN samplers and SKC sampling trains were outfitted with a mixed cellulose ester (MCE) 37mm 0.8 micron filters using Nucleopore porous plastic backup pads. The SKC sampling cassette was outfitted with a closed cassette configuration. Each SKC sampling train and VN sampler was calibrated for airflow using a TSI model 4146 primary calibrator. Since the configuration of the VN sampler that was tested used a four AAA battery power supply (Duracell) that resulted in a flow rate close to 1 liter/minute, the SKC pumps were calibrated to match this flow rate. In addition since the 4 AAA cells in the VN samplers would provide power for approximately 60 minutes, each experiment was terminated after 45 minutes, allowing for ample battery power in the VN samplers for flow rate calibration to take place after each experiment.

A set of control samples was taken (1 SKC and 1 VN sampler) prior to each experimental condition. Controls were taken between experiments for 45 minutes with the hot plate and empty weighing boat at 425ºC, which reflected the conditions of the exposure experiments. Since there were three experimental conditions, three sets of controls were collected.

For the experimental conditions, three aluminum-weighing boats were provided with 0.00175, 0.01008, and 0.10310 g of Mobil II. After the first control samples six new sets of sampling equipment were introduced into the chamber, and the weighing boat with the lowest quantity of oil (0.00175 g) was placed on the surface of the hotplate. The door to the chamber was then closed. Environmental temperature readings were taken on the upper and lower shelves. After 45 minutes the door was opened and all samplers and pumps switched off and removed from the chamber. After a 5-minute aeration of the chamber the next set of controls were introduced and allowed to sample the air for 45 minutes. This was followed with the next higher quantity of oil (0.01 g) and exposure of another six sampling units as before, followed by another control after 45 minutes (control #3 included a duplicate VN sampler). After these final controls, the last six sets of samplers and pumps were placed inside the chamber and the highest quantity of oil (0.1 g) was introduced. All weighing boats were reweighed at the end of the experiment to obtain a measure of the residue left. All samplers that were used had never been exposed to TCP prior to these experiments and were used only once.

Round 2 Environmental Chamber Testing

Round 2 Environmental Chamber Testing was conducted in September 2007.

Sampling device setup for round 2. In round 2 testing, Whatman quartz filters (Whatman QMA/cat 1851-037) were tested along with MCE filters, and another collection device, impingers filled with 10 ml of an ethanol/isopropanol mixture (95/5%), were also used. The impingers were held in an ice bath throughout the experiment and ran at calibrated flow rates close to 1 liter/minute. SKC pump flow rates for the MCE and quartz filters

were matched as closely as possible to those obtained by the VN samplers. The filter assembly component of VN samplers that had previously been used in the chamber test were taken apart and thoroughly cleaned using isopropanol. These were then reassembled and provided with a MCE filter and left in a normal office environment for 14 days. At the end of this period these filters were used as controls and analyzed for potential contaminants after removal from the samplers. New filters were put into the samplers followed by the standard calibration procedure prior to use in the chamber tests.

At the time of these experiments a United Kingdom (UK) study of cabin air contamination was proposing the use of solid phase micro-extraction technology for similar air sampling so we elected to test solid phase microextraction (SPME) technology in the chamber using the commercially available fibers that are housed in a syringe type assembly. The fibers are normally retracted into a hollow stainless steel needle after they have been thermally activated at 230ºC prior to use. When used to monitor the chamber environment, the SPME fibers were pushed out of their protective needle environment and exposed to the chamber atmosphere for the same duration as all other monitoring equipment. After exposure the fibers were retracted followed with thermal desorption onto the GC/MS column at 230ºC and analyzed similar to the other samples. Activated fibers were also thermally desorbed at 230ºC and analyzed for TCPs prior to use and provided a control.

Experimental procedure for round 2. Using the same method as in round 1, a set of control samples was taken using all types of sampling devices used for round 2. Experimental samples were taken with the MCE filter and Whatman QMA filter. A total of 7 VN samplers, 6 SKC samplers and 2 SMPE samplers were used. For the experimental condition, an aluminum-weighing boat containing 0.0090 g of Mobil II was introduced into the chamber on a hot plate. The temperature of the hotplate was raised to 420° for 50 minutes. Special care was taken in assembling the SKC samplers to secure the filter cassette after round 1 data showed consistently lower contaminant levels in the SKC trains, and poor cassette assembly was hypothesized as a cause of the lower contaminant detection.

RESULTS

Round 1 environmental chamber results

The results of Round 1 of the chamber experiments are shown in Table 13. Comparative results have been identified in bold. In the Test ID codes, the side-by-side samplers were given the same letter and the VN sampler was labeled 1 and the SKC labeled 2. The temperature of the chamber throughout each of the conditions ranged between 39ºC and 40ºC.

Comparison of TCP concentrations detected by the VN sampler under the three experimental conditions shows a fairly consistent pattern over the 1000-fold concentration range tested (figure 11). From condition #1 to 2 there was a 5.56 fold increase in the amount of Mobil II oil released and an increase of 4.15-fold in concentration detected. From condition #2 to 3 there was a 10.37-fold increase in Mobil II oil released and a 10.96-fold increase in concentration detected.

Although an air circulation fan was operating in the chamber, the data presented here seem to suggest that there were differences in concentrations captured depending on the sampler's location within the chamber, resulting in higher exposure in condition #1 at top right position D-1 (19 $\mu g/m^3$), declining toward the top left position B-1 (15 $\mu g/m^3$). This trend is also apparent in condition #2 where top right J-1 (72 $\mu g/m^3$) was again higher than top left H-1 (66 $\mu g/m^3$). Condition #3 did show this trend for N-1 (821 $\mu g/m^3$) and O-1 (983 $\mu g/m^3$) but P-1 (667 $\mu g/m^3$), which was in the position that got the highest concentrations in the previous conditions, was the lowest. This sampler had a higher flow rate compared to the others, which might have had an effect on the overall amount of TCP captured and the total volume of air that was filtered. The bottom shelf also showed a similar trend as the top shelf but in the opposite direction i.e. higher levels on the left E-1 (18 $\mu g/m^3$) and somewhat lower levels towards the right (17 $\mu g/m^3$). Consistent similar trends can be observed in the other two conditions between K-1 and M-1 as well as Q-1 and S-1.

Based on the above observations and the pattern shown, the variation in contaminant capture between the VN samplers may in part reflect local differences in air concentrations due to the action of the ventilation fan in conjunction with the convection air currents generated by the hotplate at 425ºC. The total of 12 samplers operating concurrently in the $1m^3$ space during each condition also undoubtedly produced air currents.

The TCP volatilization in the chamber is from a single sample of Mobil II oil at a point source, which was released into the environment at the start of the experiment. If one or more of the samplers or pumps captures this release preferentially, due to its location relative to the source and /or chamber airflow characteristics, the environmental exposures to all other monitoring equipment will be lower.

Only results from side-by-side samplers with matched flow rates should be compared since a sampler with a much higher flow rate will initially capture more of the contaminant. If the contaminant is present for a brief period of time and the higher flow rate is sustained over the full sampling period, the volume of relatively "clean" air filtered by the high-flow samplers could reduce the overall concentration measured. This could explain the pattern of variation in concentrations found in experiment #3.

While VN samplers were relatively consistent with each other, the major discrepancy in sampling results is between the side-by-side VN samplers and SKC pumps and cassettes. With the exception of two SKCs in experiment #2 (J2 and M2) which produced concentrations roughly similar to the VN findings, SKC cassettes found concentrations an order of magnitude lower than their comparison VN samplers. We hypothesized that a systematic error explains this discrepancy, possibly that the SKC cassette parts were not properly seated resulting in air leakage around the filters.

Sensitivity in round 1 testing. The lowest concentration that was used in our experiments, i.e. the release of TCP from 0.00175 grams of oil @ 3% TCP content, is 0.524 μg of total TCP isomers. Pyrolysis of this amount resulted in a signal that was well over 100 times the detection limit of the GC/MS. Based on this detection limit, the current GC/MS is capable of measuring TCP concentrations well within the range of 0.00524 μg or 5 nanograms per filter, if not lower. When one considers that the 0.524 μg of TCP material was released into a $1m^3$ environment which was actively sampled by 12 air filtering pumps all of which were capturing TCP, reducing the environmental concentration over time, the sensitivity of the VN sampler along with the analytical capabilities of the GC/MS are likely to be lower than the 5 nanogram /filter range mentioned above. If such a filter had been exposed to a flow rate of 1 liter/minute for 60 minutes this would translate to an air concentration of 83 nanograms of TCP/m^3.

Round 2 environmental chamber results

The results obtained from Round 2 are summarized in Table 14. The cassettes with SKC pumps provided consistent results, which supports the hypothesis that SKC data from round 1 was due to improper assembly of cassettes. The SKC results in this round were in the same range as those obtained by the VN sampler. The SKC/cassette arrangement using the MCE filters gave slightly higher values than the VN samplers. This might have been due to the location of the VN samplers in the chamber, which was in close proximity to the circulating fan. The VN samplers using the Whatman QMA filters are close in value to those obtained by the SKC cassette sampling trains. As before, the VN samplers showed a slightly higher degree of variation among samples as can be expected from individually made prototypes. The Whatman QMA filters presented a less restricted airflow compared to the 0.8 micron MCE filters with flow rates in the VN samplers of 2 l/min for quartz compared to an average of 0.8 l/min with the 0.8 micron MCE filters.

Table 13. Results from round 1 of chamber experiments

Description	Test ID	Pre flow rate (L/min)	Post flow rate (L/min)	Avg flow rate (L/min)	Sampling Time (minutes)	Total Volume (L)	µg/filter	Tot. TCP µg/m3 SKC	Tot. TCP µg/m3 VN
Control 1	**A-1**	1.14	0.87	1.01	45	45.23	0.033		**0.730**
	A-2	1.00	0.93	0.97	45	43.43	0.007	0.157	
	Introduction of 0.00175 g of Mobil II oil (all released)								
Condition #1	**B-1**	0.98	0.65	0.82	45	36.68	0.551		**15.016**
	C-1	0.71	0.57	0.64	45	28.80	0.443		**15.374**
	D-1	0.80	0.58	0.69	45	31.05	0.612		**19.719**
	E-1	0.74	0.55	0.65	45	29.03	0.529		**18.211**
	F-1	0.99	0.70	0.85	45	38.03	0.721		**18.954**
	G-1	0.83	0.75	0.79	45	35.55	0.610		**17.156**
	B-2	0.99	0.97	0.98	45	44.10	0.156	3.542	
	C-2	1.01	1.01	1.01	45	45.45	0.022	0.490	
	D-2	0.99	0.98	0.99	45	44.33	0.019	0.432	
	E-2	0.98	0.94	0.96	45	43.20	0.055	1.283	
	F-2	1.00	0.96	0.98	45	44.10	0.014	0.317	
	G-2	1.00	0.97	0.99	45	44.33	0.015	0.345	
Control 2	**A-11**	1.30	1.01	1.16	45	51.98	0.037		**0.709**
	A-21	1.01	1.09	1.05	45	47.25	0.009	0.185	
	Introduction of 0.01008 g of Mobil II oil (0.00973 g released)								
Condition #2	**H-1**	0.72	0.66	0.69	45	31.05	2.063		**66.430**
	I-1	0.76	0.62	0.69	45	31.05	2.110		**67.962**
	J-1	0.81	0.76	0.79	45	35.33	2.565		**72.609**
	K-1	0.69	0.60	0.65	45	29.03	2.278		**78.482**
	L-1	1.00	1.01	1.01	45	45.23	3.568		**78.886**
	M-1	0.81	0.74	0.78	45	34.88	2.413		**69.183**
	H-2	1.00	1.02	1.01	45	45.45	0.066	1.446	
	I-2	0.97	1.00	0.99	45	44.33	0.056	1.258	
	J-2	0.93	0.97	0.95	45	42.75	2.882	**67.41**	
	K-2	0.95	0.97	0.96	45	43.20	0.069	1.608	
	L-2	0.95	0.97	0.96	45	43.20	0.170	3.927	
	M-2	0.97	0.99	0.98	45	44.10	2.279	**51.68**	
Control 3	**A-12**	1.40	1.03	1.22	45	54.68	0.029		**0.535**
	A-22	0.99	1.07	1.03	42	43.26	0.012	0.266	
	A-32	0.77	0.67	0.72	45	32.40	0.020		**0.616**
	Introduction of 0.10310 g of Mobil II oil (0.10098 g released)								
Condition #3	**N-1**	0.88	0.72	0.80	45	36.00	29.580		**821.678**
	O-1	0.80	0.70	0.75	45	33.75	33.203		**983.788**
	P-1	1.39	1.01	1.20	45	54.00	36.045		**667.502**
	Q-1	0.95	0.95	0.95	45	42.75	30.055		**703.046**
	R-1	0.73	0.66	0.70	45	31.28	28.571		**913.549**
	S-1	1.13	1.02	1.08	45	48.38	32.047		**662.463**
	N-2	1.00	1.01	1.01	45	45.23	0.930	20.563	
	O-2	0.96	0.95	0.96	45	42.98	1.504	35.003	
	P-2	0.94	0.94	0.94	45	42.30	3.191	75.440	
	Q-2	0.79	0.70	0.75	45	33.53	1.037	30.922	
	R-2	0.96	0.96	0.96	45	43.20	0.994	23.005	
	S-2	0.98	0.97	0.98	45	43.88	2.134	48.646	

Figure 11. Mobil II released and the TCP concentration detected with the VN sampler. *Note: the two lines were purposely staggered to show identical trends, not coincidence. Please use the units on the right side for the TCP detected.*

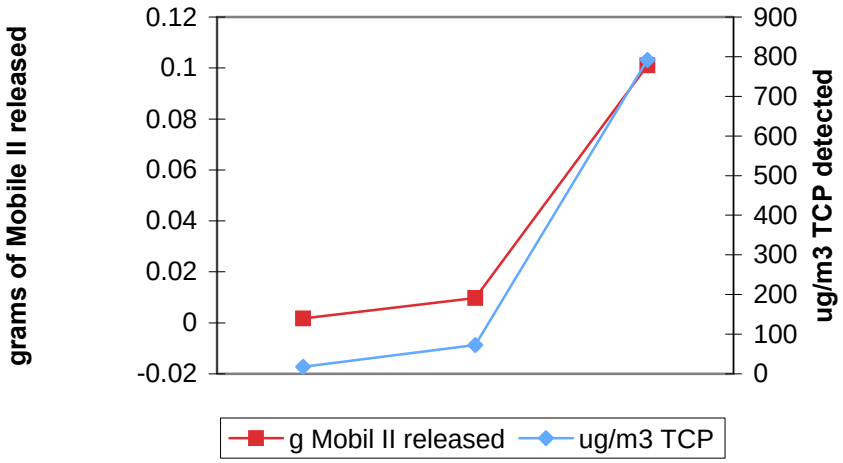


Table 14. VN and SKC sampler results from round 2 of chamber experiments

	VN sampler ID	pre flow rate(l)	post flow rate(l)	avg flow rate(l)	Volume (l)	µg/m^3 air
Control Experiment, Chamber at 40ºC, 45 minute exposure, hotplate @ 420ºC						
VN sampler	VN- 15 MCE	0.79	0.70	0.75	37.28	**ND**
	VN- 17 MCE	0.88	0.70	0.79	39.48	**ND**
SKC sampler	S-1 MCE	0.88	0.83	0.85	42.67	**ND**
	S-2 MCE	0.90	0.87	0.88	44.00	**ND**
Experimental release of Mobil II, 50 minutes, hotplate @ 420ºC, MCE filters .8 microns						
VN sampler	VN-12 MCE	0.82	0.58	0.70	35.00	**22.1**
	VN-15 MCE	0.79	0.70	0.75	37.28	**25.8**
	VN-17 MCE	0.92	0.65	0.79	39.25	**26.1**
SKC sampler	S-3 MCE	0.86	0.88	0.87	43.48	**30.9**
	S-4 MCE	0.87	0.87	0.87	43.28	**34.1**
	S-5 MCE	0.89	0.86	0.87	43.73	**33.9**
Experimental release of Mobil II, 50 minutes, hotplate @ 420ºC, Quartz filters						
VN sampler	VN-3-3	2.13	1.73	1.93	96.50	**37.4**
	VN-20-3	2.2	1.51	1.85	92.62	**38.8**
	VN-5-3	2.31	1.71	2.01	100.50	**44.7**
	VN-22-3	2.36	1.72	2.04	102.00	**30.8**
SKC sampler	S-6	2.05	1.98	2.01	100.65	**36.6**
	S-7	2.01	1.96	1.98	99.20	**38.2**
	S-8	2.27	2.03	2.15	107.60	**36.1**

Thermal desorption of the SPME fibers showed no traces of TCP. One SPME fiber showed traces of TCP when thermally desorbed as a control prior to the experiment indicating not only the importance of control samples but also the difficulty of cleaning SPME fibers previously exposed to TCP. Since the initial SPME samples were negative, a repeat chamber experiment was set up to retest SPME in a TCP environment. Again the results were negative. As anticipated from the literature, SPME appears to be better suited for the more volatile agents and is not particularly useful to trap semi- and non-volatile agents such as TCP. In addition, since the SPME fiber is a passive sampler, even if it was capable of capturing airborne TCP, this method would have to be fully calibrated under controlled conditions in conjunction with an active sampling system in order to provide an exposure measurement of TCP per m^3 of air. Unless SPME is available in another configuration that has an affinity for TCP and lends itself to active air sampling methodology, this method, in its configuration tested here, is only useful for qualitative measurements of volatile agents.

SUMMARY

The VN samplers operated in a reliable and predictable fashion during the chamber experiments. Considering that the temperature in the chamber reached up to 40ºC, the VN samplers functioned well. In round 1 of chamber testing, the SKC system performed inconsistently as a comparator. A number of possibilities could explain this discrepancy, including inconsistent compression of the cassette components onto the filter assembly resulting in air bypassing the filter. The experiments were then repeated in round 2, using one concentration of TCP in an additional chamber experiment. Other tests were conducted at the same time allowing a comparison between different filters and capturing methods. These included the addition of Whatman quartz filters along with Mixed Cellulose Ester 0.8µ filters used previously and solid phase micro extraction (SPME) technology to measure TCP. The following points summarize the results of the chamber experiments.

- The inconsistent results in round 1 regarding the SKC cassette sampling trains were likely due to improper assembly of the filter cassettes allowing air to bypass the filter media. Good agreement was observed between the VN samplers and SKC cassettes trains in round 2 using two different filter types and two different flow rates.
- SPME technology, as used in these experiments, was not useful in assessing TCP exposure.
- Whatman quartz filters (Whatman QMA/cat 1851-037) allowed for considerably higher flow rates in the VN sampler and were found to provide exposure measurements more in line with the SKC samplers and slightly higher, which is more accurate in this case, than was obtained with VN samplers using MCE filters.
- Whatman QMA filters are a good alternative to the use of MCE filters using either the VN sampler or the standard SKC/cassette sampling train systems.
- TCP appears to be a difficult agent to fully remove from measuring equipment, and proper cleaning procedures should be employed, followed with control samples prior to field use.

IV.B.5. FLOW RATE MEASUREMENT OF THE VN SAMPLERS

Since the VN sampler is intended for sampling by crewmembers, it was important to understand the flow-rate characteristics over time and in relation to battery life. VN samplers had different wiring configurations, and varying the number of batteries could produce different voltages, changing the flow rate and duration of the sampling. The specific aims were as follows:

1. To measure the flow-rate behavior of the various configurations of VN samplers over time.
2. To investigate the flow rate and duration over multiple trials to define performance reproducibility.
3. To investigate, using the sampler flow rate, duration of sampling and altitude, a method for estimating the volume sampled in the field if only the initial flow rate was known.

METHOD

VN sampler. Each sampler was outfitted with a filter and support pad as per the sampling protocol. The Whatman Quartz filters (QMA) 37mm filter

media was used with two different support pads, either a Nucleopore 37mm porous plastic support pad or a SKC support screen 37mm stainless steel 100 mesh. Each sampler was outfitted with new AAA Duracell alkaline batteries prior to testing. The testing was conducted at the University of Oregon (UO) in December 2007.

Flow meter. A TSI 400 series flow meter was used with a custom attachment that sealed onto the top of the VN sampler, covering the inlets. The custom attachment was easily placed firmly on top of the sampler as it sat on the countertop.

Protocol. A stopwatch was started at the activation time of a sampler. Flow rates were measured at the time of activation, then at ten-minute intervals until the estimated battery life limit, when it was sampled more frequently until the battery completely died and the flow rate dropped to zero. Multiple samplers for each configuration were tested and each device tested at least twice. Between the trials the batteries were replaced, but the filter and pad were not.

Analysis. To determine the flow-rate performance, the percent difference of the initial flow rate and percent change in flow before the battery completely died was calculated. Since in many cases the samplers are sent into the field and either turned off at the end of the flight, within the battery life time period, or the batteries died during the flight and the sampler did not collect for the entire flight, a method was developed of estimating the volume of air sampled using only the initial flow rate by calculating summary statistics from these flow-rate testing trials.

Taking into account the time the sampler ran with significant flow rate and the percent drop in flow rate immediately prior to the battery power drop, an estimate of the flow rate was calculated. In all of the flow-rate testing trials, after a certain running time (which varied with voltage level), the battery power dropped quickly; a distinct change in the sound of the motor occurred indicating battery power loss. In industrial hygiene, when employing a sampler that does not log flow rate continuously, flow is measured initially and then again at various time points or at the end of the sampling. The flow rates collected, measured in liters/minute (L/min), are averaged and then multiplied by the duration, measured in minutes, to obtain the volume in liters. Using the average percent drop in flow rate of each VN sampler configuration and the average time they ran before losing significant power, an equation was determined to estimate the volume of air sampled using the initial flow rate. This estimate was then compared to the actual volume calculated by taking the flow rate at each time interval and calculating the volume for that time interval, then summing all of the 5-minute and 2-minute volumes. A total of nine trials were collected at 3V (two batteries) with five samplers, 11 trials were collected at 3V (4 batteries) with five samplers, eight trials were collected at 4.5V (three batteries) with four samplers and four trials were collected at 6V (four batteries) with two samplers.

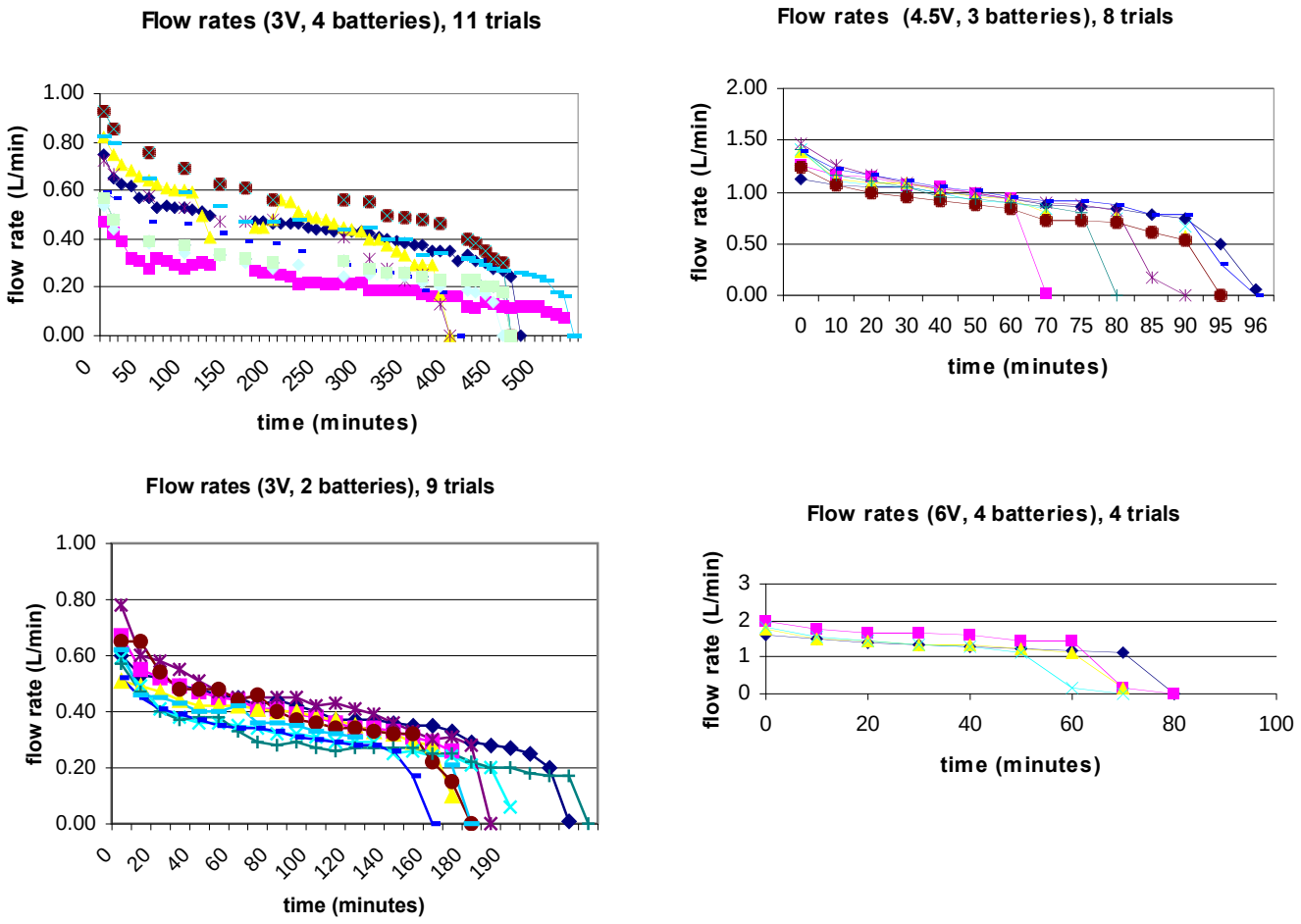
RESULTS

Flow-rate characterization. Table 15 shows the average of the trials for each sampler configuration for the initial flow rate in liters/minute (L/min), percent change in flow rate during sampling before the flow rate dropped to zero, and the duration of the battery life, i.e. the potential sampling time. Figure 12 shows the graphs of all the trials for each configuration for flow rate over time. The figures demonstrate how the flow rate decreases slowly over time then drops to zero quickly when the batteries die. Also, samplers in each configuration vary in the duration of the battery life, perhaps due to battery variability and motor efficiency differences.

Table 15. Battery configurations with average flow rates and sampling durations and standard deviations (sd)

Sampler Voltage (V) capacity	Actual Voltage	# batteries	initial flow rate ± s.d. (L/min)	% change in flow rate before battery drop ± sd	duration of battery life (sampling time) ± sd (minutes)
	3V	2	0.61 ± 0.08	60.2% ± 8.0%	186.1 ± 24.51
6V	4.5V	3	1.34 ± 0.12	47.5% ± 10.1%	96.3 ± 14.44
	6V	4	1.79 ± 0.15	33.2% ± 4.1%	65 ± 7.07
3V	3V	4	0.7 ± 0.16	67.5% ± 4.3%	442.5 ± 58.89

Figure 12: VN sampler flow rates for various configurations



Sampled volume prediction. Linear regression, which included an autoregressive correlation term, was then performed for each sampler configuration. Parameters were obtained from this and applied to a linear model where the initial flow rate and the sampling duration were input to predict the post flow rate. For each in-flight sample result, the actual pre- and estimated post- flow rate was averaged to determine the average flow rate.

Altitude correction factor. Another factor taken into consideration for the sampling flow rate was that the initial flow rate was tested at ground level, but the samplers were used in aircraft that could be pressurized to an equivalent altitude as high as 8,000 ft. Calibrating a sampling device at the altitude where the sampling will take place is the best solution. Following van Netten (2009) a correction factor of 1.18 was applied to estimate concentration of in-flight samples.

SUMMARY

Profiles of the VN sampler with different battery configurations were obtained and demonstrated common profiles of flow rate over time with battery life. From the starting rate the flow drops continuously until the battery completely dies and flow drops to zero rapidly. Post flow-rate measurements are not reliable in this study since the protocol sends samplers back to the UO and several days may pass between sampling and receiving the sampler at UO, allowing for battery "recovery". Based on the flow-rate profiles of samplers tested in the lab, an estimation of the post flow rate is calculated using the duration of the sample and the initial flow rate. Also an altitude correction factor

should be applied to any concentration result, since pressure affects flow rate and the samplers were calibrated near sea level.

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IV.C. COLLECTION AND ANALYSIS OF IN-FLIGHT SAMPLES AND CONTROLS

In-flight samples using the VN sampler were collected for this project. Initial rounds of samples were collected and analyzed in three different batches at the UBC laboratory. With each round of samples, details of the sampler configuration and protocol were modified to optimize data collection and the analytical method. The final round was a set of duplicate samples, which were split and analyzed by three different labs. Details of these in-flight sampling rounds and sampling procedures are described in this section.

METHOD

All samplers used for collection of in-flight samples and sampling packets were prepared at the UO in an office environment with no known potential contaminants of interest.

Samplers were cleaned prior to inserting a filter. They were prepared with clean gloves and on a surface covered with sterile paper, both of which were changed between every sample preparation. Filter media were handled with tweezers that were cleaned between uses with a 95% isopropyl alcohol solution on a clean kimwipe®. All components of the samplers were cleaned with kimwipes® and Q-tips® with the isopropyl solution. .

After the sampler was cleaned thoroughly, a support pad, filter media and O-ring were placed in the filter casing area. The O-ring was pressed into a groove on the side of the filter casing area, securing the filter tightly when the top section of the sampler was replaced. With the top in place, the sampler was in the "off" mode and the inlets did not expose the filter media.

After batteries were placed in the VN sampler and prior to sending the sampler into the field, it was activated briefly to ensure it was operating properly and to record the initial flow rate. The pre-sample flow rate was measured using a TSI 4046 Primary Calibrator with a custom adapter attached that fit tightly around the top of the sampler where the inlets are located. The flow meter adapter was cleaned with isopropyl alcohol before each use. The measurement of the flow rate lasted only a few seconds to minimize filter media exposure prior to sampling and to preserve battery life. The recruited air travelers were instructed to sample the duration of the flight or until the battery died and the sampler shut down automatically. Several days would pass from the flight sampled to the return of the sampler to the UO, so the post flow-rate measure was not necessarily an accurate reflection of what the flow was at the end time of the sample. Therefore, an estimate of the ending flow rate was calculated as described in section IV.B.5.

Sampler documentation. A sampler number was located on the bottom of each sampler and a sticker with the sample number was placed adjacent to this label. These numbers were entered into the database as well as documented on the paperwork that accompanied each sampler. For each in-flight sample, flight documentation that included pre- and post-flight information and sampler documentation was completed by the traveler carrying the sampler.

The pre-flight information included the date and time of the flight, the flight number, aircraft tail number, aircraft type, seat assignment, origin and destination airport, flight duration, number of flight segments in current route, and any comments. The post-flight information included the date and time as well as ratings of cabin temperature, noise, turbulence, and overall air quality before the take-off, in-flight, and after landing. These were all rated from 1 to 5 with 1 being "very cool, quiet, no turbulence and poor" respectively, to 5 being "very hot, loud, a lot of turbulence, or good." The post-flight information also included satisfaction with the humidity, odor, and airflow rated on a scale of 1 to 4, with 1 being "very satisfied" to 4 being "very dissatisfied." Finally, the questionnaire asked if the individual noticed visible air contamination, unusual odors, delays or interruptions for the take-off, or any other extraordinary circumstances.

The sampler documentation included the sampler and sample numbers, the time (and time zone) the sampler was activated and turned off, and if it turned off on its own. It was confirmed that the sampler was activated according to instructions and if it was not, details of how it was activated were requested. Also, the placement of the sampler was documented along with any other comments about the sampling.

Sampling packets and instructions to researchers. Once samplers were numbered and prepared, they were each placed into a Ziploc plastic bag. If a transport blank was to be sent, it was prepared the same way and included in the sampling packet and clearly labeled. Sampling materials for each traveler were packed into a mailing box that included:

1. Consent form with a postage paid return envelope along with a copy of the consent form for the participant to keep (unless a consent was obtained previously)
2. Letter explaining the study from an FAA official
3. Letter to the traveler from the principal investigator of the study
4. Standard response to questions from other passengers or crew
5. Samplers clearly labeled
6. Sampler instructions
7. Coffee gift cards for flight attendants, who were contacted by the traveler at beginning of flight to be sampled.
8. Flight documentation for each flight segment to be tested
9. Sampler documentation
10. Return postage.

According to the sampling instructions, each traveler carried the entire sampling packet with them to their flight. He or she was told to notify the flight crew about the sampling as soon as possible upon boarding the plane, including presenting the letter from FAA and showing the sampler. After being seated, the traveler was to explain the process and instrument to their neighboring passengers and answer any questions. A standard response text was given to help the researcher best explain the sampling and the data availability. The researcher was to fill in the pre-flight documentation at any time prior to the flight. After the safety demonstration was given, the samplers were to be activated by turning the top of the sampler. Where duplicate samplers were being run simultaneously, the samplers were to be placed side by side, using the clips or Velcro, on the back pocket of the seat in front of the traveler. When the samplers were activated, the start time was entered on the sampler documentation form. If a transport blank was included in the packet, the traveler left that sampler in its Ziploc bag and did not activate it, but kept it in the packet. At the end of the flight or if the sampler's batteries died, the sampler was to be turned back off by twisting the top and seeing the inlets close. The sampler was replaced back into its Ziploc bag (each bag was numbered to match the sampler number). Then the post-flight information and the rest of the sampler documentation were to be completed.

Travelers doing the sampling were usually sent at least two sets of sampling packets, if they had an outbound flight and a return soon after, or they were sent more if their itinerary had more flight segments. After their return flight, they were instructed to pack the samplers back into the mailing box with all of the paperwork and affix the

return label. They then took the package to the nearest drop-off location for the courier for overnight delivery.

Return of samplers. When samplers were returned to the UO, flight and sampler documentation were also entered into the database. The initial three rounds of samples were sent to the University of British Columbia (UBC) for analysis. The duplicate samples (round 4) were split randomly and sent to either the University of British Columbia (UBC) or Harvard School of Public Health (HSPH). HSPH further divided its samples and sent half to University of Medicine and Dentistry New Jersey (UMDNJ). Since HSPH did not know the sample codes, these samples were randomly split.

As soon as possible after arrival at UO, the filters were removed from the sampler and the samplers cleaned thoroughly and stored until next use. Just as in preparation of the sampling media, each filter was removed in a sterile environment with sterile paper and gloves used for handling. Filters were removed from the filter casing with tweezers, folded in half with the exposed side inside, and placed in a small plastic storage bag that sealed. The sticker with the number of the sample was removed from the bottom of the sampler and placed on this plastic bag for identification. Each active control sample for the duplicate samples was kept with the corresponding in-flight sample when sent to UBC and HSPH for analysis.

Round 1 of In-Flight Sampling. The first round of in-flight sampling took place beginning in October 2007. Three members of the OHRCA research group were recruited to sample on their regularly scheduled flights with paid tickets. Initially two versions of the VN samplers were going to be used, one configured for 3 volts (low flow) and one for 6 volts (high flow).

Round 2 of In-Flight Sampling. The second round of sampling had already begun (end of October 2007) when the first round results were determined, so post-sampling controls were collected at UO by running the samplers in a clean office environment unlikely to be contaminated with TCPs. These additional controls were collected due to evidence of TCP contamination in the first round of samplers, including blanks; contamination that was independent of the aircraft environment, likely samplers that had not been cleaned properly prior to being released for aircraft sampling.

Round 3 of In-Flight Sampling. Round 3 sampling occurred between November and December 2007. After the results from rounds 1 and 2 were reported, a thorough cleaning of all samplers was conducted and the determination was made that for subsequent samples each sampler required to be tested with filter media prior to be being used for in-flight sampling

Duplicate In-Flight Sampling. Duplicate in-flight data was collected on commercial aircraft over a 7-week time period from January to March 2008. OHRCA and ACER researchers were recruited to carry samplers on paid flights they had scheduled during this time period. Samples were collected in duplicate, with the intention of different labs blindly analyzing the data from the same flight along with controls. For all duplicate samples, the support pads used were either the SKC support screen 37mm stainless steel 100 mesh or Nucleopore 37mm porous plastic pads, and the filter media were Whatman Quartz filters (QMA, 37mm).

A total of 18 duplicate in-flight samples were collected along with six transport blanks and four UO blanks. In addition, there were seven samples that were sent to a researcher but never taken on a flight or activated and two samples that were not collected in duplicate. VN samplers used as transport blanks were prepared and transported in the identical manner as in-flight VN samplers, but not activated in flight. The UO blanks were filters never placed in a VN sampler and never sent to researchers. These blank samples were placed directly into a plastic storage bag in the same manner as were the in-flight filters after exposure. In addition, active control samples were collected for each in-flight and transport sample. Some of the quality control blanks were active controls, which were the VN sampler in the same configuration activated in the UO office for 2 hours. The active control filter was removed from the sampler and placed in a plastic storage bag, and the VN sampler was cleaned again prior to preparing it for the in-flight sample filter. Other control samples were passive, where the VN sampler was not activated, but kept in a sealed plastic bag for 1 month, then the filter removed and VN sampler cleaned and sent to UO for future deployment. All samples were identified with a number code that was known only to the project manager at UO until after analysis. A database with all sample information including the sample

number, VN sampler number, sampler configuration, pre-flow rate, date prepared and sent to researcher, and the date returned to the UO after sampling was kept at UO.

Filter Extraction and Analysis Method. As reported by UBC, 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 mAgilent HP5MS capillary column 250 µm diameter 0.10 µm film situated on a Agilent 6890GC gas chromatograph operating in the splitless mode with a 0.5 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°C /minute to a final temperature of 325°C. Carrier gas was helium at a pressure of 2.57 psi and at a flow of 1.3 ml/min. TCP Standards were obtained from Fluka Chemicals.

HSPH reports the same procedure in detail for its lab in Vallarino (2009), including its method and results for the determination of instruments detection limits (IDLs) and determination of method detection limits (MDLs). Each lab independently derived its MDLs.

RESULTS

Rounds 1-3 of in-flight sampling were part of the protocol development and were only analyzed by one lab. These results are only discussed for this purpose and data are not shown from these rounds in favor of reporting the duplicate sampling, where results are provided from multiple labs.

Round 1 of In-Flight Sampling Results. Three traveling researchers took samplers on their scheduled flights. The presence of TCP contaminants in four of five in-flight samples, the unactivated transport blanks, and a lab blank raised concern about prior contamination of the samplers. As a result the protocol was modified adding in the active control sample for each sampler prior to deployment. In addition, experience in the first round revealed that the 6-volt samplers were too loud to be used in the passenger seating areas without disturbing passengers. Subsequent in-flight sampling was restricted to 3-volt devices because of the noise, and samples were collected where the researcher was sitting.

Round 2 of In-Flight Sampling Results. Four in-flight samples were collected in this round. Each sampler in this round was tested after it was returned to UO and a post-experimental sample was collected. These post-experimental filters showed the presence of TCP, confirming the need to ensure samplers are not contaminated prior to subsequent in-flight sampling.

Round 3 of In-Flight Sampling Results. This round confirmed that a thorough cleaning of each sampler resolved the sampler contamination problem as all of the active controls were below the detection limit. Three transport blanks were also collected, all below the detection limit. In this round at least one TCP isomer was detected in 14 of the 38 in-flight samples. It should be noted that for four of these, the sampling times were lengthy (330-534 minutes), far longer than the active control sample.

Duplicate In-Flight Sampling results. Tables 16 and 17 show the results of the duplicate sampling. Table 16 are the in-flight samples in ng/filter, and table 17 shows the duplicate results in $\mu g/m^3$. UBC detected the ooo TCP isomer on every sample, including the blanks, while HSPH detected it on one sample, barely above the level of detection (LOD) (0.43 compared to 0.40). Subsequent examination of UBC lab records revealed that a recovery experiment involving ooo TCP isomer samples prior to analysis is likely responsible for a systematic error in finding the ooo isomer. These values are reported here but are not used in the interpretation of the results since it is not a constituent of the engine oils tested and the UBC laboratory controls identified this as a laboratory contaminant. UBC detected the mmm TCP isomer for six of the samples, with HSPH also detecting it on three of the same samples and on two additional samples. Neither UBC nor HSPH detected the ppp TCP isomer on any sample. UBC was the only lab to look for the mmp and mpp TCP isomers, and detected them both on eight of the samples and the mmp on one of the samples.

The four UO lab blanks and the seven samples that were returned without being taken on a flight nor activated, were all below the detection limit for the TCP isomers. Of the six transport blank filters, at least one TCP isomer was detected on two. However, two of the other blanks cannot be interpreted because they were inadvertently analyzed at a much higher limit of detection at the third lab (see discussion below).

Table 16. Results of the in-flight duplicate sampling in ng per filter

Duplicate #	Lab	Sample Description	TCP isomers (ng/filter)				
			ooo	mmm	ppp	mmp	mpp
1	UBC	Active control	7.87	<0.40	<0.40	<0.40	<0.40
	UBC	CRJ-100	8.44	**0.64**	<0.40	**1.30**	**0.96**
	UMDNJ	Active control	<10	<10	<10	NA	NA
	UMDNJ	CRJ-100	<10	<10	<10	NA	NA
2	UBC	Active control	14.37	<0.40	<0.40	<0.40	<0.40
	UBC	B757	14.79	**0.46**	<0.40	**1.36**	**1.04**
	UMDNJ	Active control	<10	<10	<10	NA	NA
	HSPH	B757	0.43	<0.40	<0.40	NA	NA
3	UBC	Active control	2.56	<0.40	<0.40	<0.40	<0.40
	UBC	B737-800	3.25	**0.79**	<0.40	**1.23**	**0.74**
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737-800	<0.40	**0.62**	<0.40	NA	NA
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	Transport blank	<0.40	<0.40	<0.40	NA	NA
4	UBC	Active control	2.75	<0.40	<0.40	<0.40	<0.40
	UBC	B737-800	3.29	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737-800	<0.40	<0.40	<0.40	NA	NA
	UBC	Active control	2.37	<0.40	<0.40	<0.40	<0.40
	UBC	Transport blank	2.07	**0.53**	<0.40	**0.50**	<0.40
5	UBC	Active control	2.85	<0.40	<0.40	<0.40	<0.40
	UBC	B737-800	3.57	**0.70**	<0.40	**1.27**	**0.83**
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737-800	<0.40	**0.40**	<0.40	NA	NA
6	UBC	Active control	2.00	<0.40	<0.40	<0.40	<0.40
	UBC	B737	3.03	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737	<0.40	<0.40	<0.40	NA	NA
7	UBC	Active control	2.72	<0.40	<0.40	<0.40	<0.40
	UBC	B737-800	3.74	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737-800	<0.40	<0.40	<0.40	NA	NA
8	UBC	Active control	4.00	<0.40	<0.40	<0.40	<0.40
	UBC	B737-800	4.16	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737-800	<0.40	**0.43**	<0.40	NA	NA
9	UBC	Active control	8.59	<0.40	<0.40	<0.40	<0.40
	UBC	B757	8.18	<0.40	<0.40	<0.40	<0.40
	UMDNJ	Active control	<10	<10	<10	NA	NA
	HSPH	B757	<0.40	<0.40	<0.40	NA	NA
10	UBC	Active control	9.16	<0.40	<0.40	<0.40	<0.40
	UBC	A319	7.24	<0.40	<0.40	**1.15**	**1.13**
	UMDNJ	Active control	<10	<10	<10	NA	NA
	HSPH	A319	<0.40	**0.54**	<0.40	NA	NA

Duplicate #	Lab	Sample Description	TCP isomers (ng/filter)				
			ooo	mmm	ppp	mmp	mpp
11	UBC	Active control	9.37	<0.40	<0.40	<0.40	<0.40
	UBC	A320	10.15	<0.40	<0.40	**0.73**	<0.40
	UMDNJ	Active control	<10	<10	<10	NA	NA
	HSPH	A320	<0.40	<0.40	<0.40	NA	NA
12	UBC	Active control	7.26	<0.40	<0.40	<0.40	<0.40
	UBC	A320	7.88	**0.70**	<0.40	**1.08**	**0.84**
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	A320	<0.40	<0.40	<0.40	NA	NA
13	UBC	Active control	6.46	<0.40	<0.40	<0.40	<0.40
	UBC	Embraer 145	7.50	<0.40	<0.40	**0.72**	**0.65**
	UMDNJ	Active control	<10	<10	<10	NA	NA
	HSPH	Embraer 145	<0.40	<0.40	<0.40	NA	NA
	UBC	Active control	21.60	<0.40	<0.40	<0.40	<0.40
	UBC	Transport blank	3.76	<0.40	<0.40	<0.40	<0.40
14	UBC	Active control	8.00	<0.40	<0.40	<0.40	<0.40
	UBC	Embraer 145	7.14	**1.16**	<0.40	**2.36**	**1.36**
	UMDNJ	Active control	<10	<10	<10	NA	NA
	HSPH	Embraer 145	<0.40	**1.01**	<0.40	NA	NA
	UMDNJ	Active control	<10	<10	<10	NA	NA
	UMDNJ	Transport blank	<10	<10	<10	NA	NA
15	UBC	Active control	3.86	<0.40	<0.40	<0.40	<0.40
	UBC	B737-300	1.92	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	B737-300	<0.40	<0.40	<0.40	NA	NA
16	UBC	Active control	5.18	<0.40	<0.40	<0.40	<0.40
	UBC	A319	3.62	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	A319	<0.40	<0.40	<0.40	NA	NA
17	UBC	Active control	4.13	<0.40	<0.40	<0.40	<0.40
	UBC	A320	3.48	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	HSPH	A320	<0.40	<0.40	<0.40	NA	NA
	UMDNJ	Transport blank	<10	<10	<10	NA	NA
18	UBC	Active control	4.09	<0.40	<0.40	<0.40	<0.40
	UBC	B737-300	3.97	<0.40	<0.40	<0.40	<0.40
	HSPH	Active control	<0.40	<0.40	<0.40	NA	NA
	UMDNJ	B737-300	<10	<10	<10	NA	NA
	UBC	Transport blank	5.45	**1.57**	<0.40	NA	NA

NA = not applicable since HPSH and UMDNJ did not analyze for the mmp and mpp isomers in the samples.

Table 17. Estimation of concentration of in-flight duplicate sample results in μg/m³ (corresponds to Table 16)

Dup #	Lab	Sample Description*	Avg flow** (L/min)	Sample time (min)	Total volume (L)	TCP isomers estimated concentration (μg/m³)***			
						mmm	ppp	mmp	mpp
1	UBC	Active control	0.46	120	54.60	--	--	--	--
	UBC	CRJ-100	0.39	98	38.22	**0.0198**	--	**0.0401**	**0.0297**
	UMDNJ	Active control	0.44	120	52.80	--	--	NA	NA
	UMDNJ	CRJ-100	0.54	98	52.43	--	--	NA	NA
2	UBC	Active control	0.4	120	48.00	--	--	--	--
	UBC	B757	0.22	201	43.22	**0.0126**	--	**0.0371**	**0.0284**
	UMDNJ	Active control	0.34	120	40.80	--	--	NA	NA
	HSPH	B757	0.30	201	60.30	--	--	NA	NA
3	UBC	Active control	0.60	133	79.14	--	--	--	--
	UBC	B737-800	0.61	256	156.16	**0.0060**	--	**0.0093**	**0.0056**
	HSPH	Active control	0.69	130	89.70	--	--	NA	NA
	HSPH	B737-800	0.65	256	165.12	**0.0045**	--	NA	NA
4	UBC	Active control	0.58	123	70.73	--	--	--	--
	UBC	B737-800	0.53	297	155.93	--	--	--	--
	HSPH	Active control	0.47	120	55.80	--	--	NA	NA
	HSPH	B737-800	0.29	292	83.22	--	--	NA	NA
5	UBC	Active control	0.59	122	71.37	--	--	--	--
	UBC	B737-800	0.60	135	81.00	**0.0102**		**0.0185**	**0.0121**
	HSPH	Active control	0.54	120	64.20	--	--	NA	NA
	HSPH	B737-800	0.49	135	66.15	**0.0072**	--	NA	NA
6	UBC	Active control	0.76	120	91.20	--	--	--	--
	UBC	B737	0.52	150	77.25	--	--	--	--
	HSPH	Active control	0.46	120	55.20	--	--	NA	NA
	HSPH	B737	0.53	150	78.75	--	--	NA	NA
7	UBC	Active control	0.62	120	73.80	--	--	--	--
	UBC	B737-800	0.53	193	101.33	--	--	--	--
	HSPH	Active control	0.61	121	73.21	--	--	NA	NA
	HSPH	B737-800	0.51	193	97.47	--	--	NA	NA
8	UBC	Active control	0.53	120	63.00	--	--	--	--
	UBC	B737-800	0.42	235	98.70	--	--	--	--
	HSPH	Active control	0.71	120	85.20	--	--	NA	NA
	HSPH	B737-800	0.60	235	141.00	**0.0036**	--	NA	NA
9	UBC	Active control	0.59	125	73.13	--	--	--	--
	UBC	B757	0.40	230	92.00	--	--	--	--
	UMDNJ	Active control	0.89	120	106.20	--	--	NA	NA
	HSPH	B757	0.45	230	103.50	--	--	NA	NA
10	UBC	Active control	0.66	120	78.60	--	--	--	--
	UBC	A319	0.46	296	134.68	--	--	**0.0101**	**0.0099**
	UMDNJ	Active control	0.70	120	84.00	--	--	NA	NA
	HSPH	A319	0.53	296	156.88	**0.0040**	--	NA	NA
11	UBC	Active control	0.58	120	69.00	--	--	--	--
	UBC	A320	0.52	351	182.52	--	--	**0.0047**	--
	UMDNJ	Active control	0.52	120	61.80	--	--	NA	NA
	HSPH	A320	0.39	351	135.14	--	--	NA	NA

Dup #	Lab	Sample Description*	Avg flow** (L/min)	Sample time (min)	Total volume (L)	TCP isomers estimated concentration (μg/m^3)***			
						mmm	ppp	mmp	mpp
12	UBC	Active control	0.67	120	80.40	--	--	--	--
	UBC	A320	0.63	325	204.75	**0.0040**	--	**0.0062**	**0.0048**
	HSPH	Active control	0.62	120	74.40	--	--	NA	NA
	HSPH	A320	0.54	325	173.88	--	--	NA	NA
13	UBC	Active control	0.67	120	80.40	--	--	--	--
	UBC	Embraer 145	0.67	130	86.45	--	--	**0.0098**	**0.0089**
	UMDNJ	Active control	0.69	120	82.20	--	--	NA	NA
	HSPH	Embraer 145	0.48	130	61.75	--	--	NA	NA
14	UBC	Active control	0.57	120	67.80	--	--	--	--
	UBC	Embraer 145	0.56	152	85.12	**0.0161**	--	**0.0327**	**0.0189**
	UMDNJ	Active control	0.51	110	56.10	--	--	NA	NA
	HSPH	Embraer 145	0.57	152	86.64	**0.0138**	--	NA	NA
15	UBC	Active control	0.79	120	94.80	--	--	--	--
	UBC	B737-300	0.78	126	98.28	--	--	--	--
	HSPH	Active control	0.90	120	107.40	--	--	NA	NA
	HSPH	B737-300	0.82	126	103.32	--	--	NA	NA
16	UBC	Active control	0.66	120	78.60	--	--	--	--
	UBC	A319	0.63	125	78.13	--	--	--	--
	HSPH	Active control	0.61	120	72.60	--	--	NA	NA
	HSPH	A319	0.57	125	70.63	--	--	NA	NA
17	UBC	Active control	0.74	120	88.20	--	--	--	--
	UBC	A320	0.69	228	156.18	--	--	--	--
	HSPH	Active control	0.72	120	85.80	--	--	NA	NA
	HSPH	A320	0.72	228	164.16	--	--	NA	NA
18	UBC	Active control	0.58	120	69.00	--	--	--	--
	UBC	B737-300	0.54	201	107.54	--	--	--	--
	HSPH	Active control	0.66	120	79.20	--	--	NA	NA
	UMDNJ	B737-300	0.62	201	124.62	--	--	NA	NA

* The transport blanks and their corresponding active control are not included in this table since the transport blanks were not activated and therefore had no volume of air.
** The average flow rate is calculated from the actual pre-flow rate, measured prior to sampler deployment, and an estimated end flow rate calculated from a regression model based on lab testing of flow rate.
*** These data are an estimated concentration since the exact flow rate characterization is not known, the amount of TCP isomers detected on the filters were low and a pressure correction factor of 1.18 was applied. For any isomer that was below the detection limit, no concentration was calculated.
NA = not applicable since HPSH and UMDNJ did not look for the mmp and mpp isomers in the samples.

Self-reported results from pre- and post-flight information. The self-reported flight information was simple to record under the conditions of this experiment. The form could be filled in easily by the researchers carrying the samplers. Some reports were not filled in completely. Since there were no visible fume incidents, nor TCP concentration findings indicating observable exposure incidents, there is no way to analyze the self-reported flight conditions in relation to the samples in any meaningful way. In one case a particular odor was noted throughout the flight and reported. Select results from the duplicate round are shown in table 18. These results are from the samples where either or both labs detected TCP and are shown as an example of the questions and responses. Due to the small sample, no formal statistical analysis could be performed.

Table 18. Select self reported in-flight condition results from the duplicate samples

Duplicate #	1	2	3	5	8	10	11	12	13	14
Rating of: (1 = very cold, no noise, no turbulence and 5 = very warm, uncomfortably loud; 4 = a lot of turbulence)										
Temperature	3	3	3	2	3	2	1	2	3	4
Noise level	3	3	4	4	2	4	4	4	3	4
Turbulence	2	2	3	2	3	2	2	1	1	
Rating of overall air quality: (1 = very poor and 5 = very good)										
Before take-off	1	3	3	3	4	3	4	3	4	2
During flight	1	3	3	3	4	3	3	3	5	4
After landing	1	3	3	3	4	2	4	3	5	
Overall satisfaction with: (1 = very satisfied and 4 = very dissatisfied)										
Humidity	2	3	3	2	2	2	1	1	1	2
Odor					2					
Air flow	2	2	1	2	2	2	2	1	1	1
See any visible contamination?	no	no	no	no	no	no	no	no	no	no
Notice any unusual odor?	yes[1]	no	no	no	yes[2]	no	yes[3]	no	no	yes[4]

(Comments written associated with reporting unusual odor)
[1] "Dirty socks" odor through flight
[2] At the beginning of the flight-slight exhaust odor.
[3] Some "burnt coffee" smell during flight- I was sitting by galley
[4] Very distinct ozone smell -CLE strong cold front to East

DISCUSSION

The collection of in-flight air samples, while subject to a number of challenges, was largely successful, though resource intensive, which may make it impractical. The process of delivering sampling kits to traveling researchers and having them returned to UO with chain of custody maintained and documented went smoothly. Travelers reported no problems carrying samplers through security, and in only one flight out of 67 did a pilot deny the researcher the opportunity to activate the sampler. The process of alerting the cabin crew and neighboring passengers to the purpose of the sampling, and preparing them for the noise of the device was effective, and in no cases did the air-sampling process appear to cause any alarm, confusion or discomfort among passengers and crew. In far more cases, in fact, passengers and some crew members expressed considerable interest in and support for air monitoring.

The sample analysis portion of the experiment encountered greater challenges. Some resulted from inadvertent logistical and communication lapses between labs, and others were inherent to the task of measuring the contaminants of interest at levels so close to detection limits. The expectation going into this sampling and analysis experiment was an extremely low likelihood of detecting measurable levels of bleed air contaminants in air samples from 50 to 100 random flight segments, especially in the absence of an observable "smoke in the cabin" event. Rather the primary intent was to assess the feasibility of collecting in flight samples and the analytical capability of laboratories to measure the contaminants of primary interest, TCPs, at whatever levels were found. The purpose of this discussion is to interpret the lab findings in light of these aims.

Prior to the duplicate sampling, in which side-by-side samples were taken and sent to the UBC and HSPH labs for comparative analysis, the first rounds of samples were all sent to the UBC lab. This tested various components of the sampling/analysis system including transport and handling of samplers and filters, chain of custody, control practices, and the Oregon data management center. Adjustments were made to the procedures over the first two rounds of 10 in-flight samples as evidence of contamination of sampling devices turned up between uses. By the third round a smooth process of active and passive control samples to accompany each in-flight filter sample was developed, and this round resulted in 38 in-flight samples collected on nine different models of aircraft.

The analytical protocol, however, had been developed from early in the project with the intent of insuring comparable procedures in at least two laboratories for the measurement of TCP isomers. These two labs would then provide analysis for a subsequent round of in-flight testing in which side-by-side samples were taken under identical conditions. While blinded inter-laboratory testing and subsequent communication did produce agreement on a number of procedures and practices (Vallarino et al 2009), when the time came for the duplicate sampling protocol to be implemented, three unintended discrepancies arose. In one case a portion of the samples sent to the HSPH lab were sent on to a third lab. While the intent was to expand the capabilities for this kind of analysis, this third lab inadvertently ran the samples in a scan mode with a detection limit 25 times higher than the UBC and HSPH labs, resulting in no contaminants being detected, as is expected at the low levels HSPH and UBC reported.

A second discrepancy occurred because UBC indentified five different TCP isomers in its analysis while HSPH identified only three of these. Thus comparisons could be made only for those three while there were detectable findings for the other two isomers in nine of the samples. A third issue, the systematic finding in the UBC analytical process of the ooo-TCP isomer in both in-flight and control samples, has been resolved as described above, and we are confident that the ooo- findings do not reflect bleed air contamination nor do they call into question the other analytical findings.

Also lending credence to the ability of the analytical method to identify TCP isomers near the limit of detection is the fact that the results discriminated between in-flight

samples and active controls in blinded analysis. In other words the finding of detectable TCP isomers took place in samples collected on a number of flights while the paired active control sample collected pre-flight in a non-cabin environment came back negative in all cases. Furthermore, the correspondence of the pattern of the engine oil TCP isomer peaks and in-flight sample peaks strongly suggests that some of the TCP did come from engine oil contamination, even though such conclusions are limited by the measured levels being between the MDL and the batch detection limit. The interlaboratory QA/QC testing of spiked samples reported in table 12 found relative error of detecting TCP of 11.4% to 46.5%, Therefore, it would not be unexpected that the two labs would have reported results higher, if TCP at the level of the spiked samples (between 5 to 15 ng/filter) was present. Firm conclusions are also tempered by the finding of mmm-TCP in two transport blanks. It is not possible to exclude a source of contamination other than cabin air based on these findings.

If we look only at the fully comparable results between the labs, we find that in three duplicate sampling pairs out of 18 both labs found levels above the analytical detection limits of the same TCP isomers. In all of these instances UBC also found mmp and mpp isomers as well, which HSPH did not measure. UBC found detectable TCP in an additional six samples while HSPH found it in two others. UBC found detectable TCP in 9 samples out of 18 in the duplicate round while HSPH found 5 of 18 with detectable TCP. Given how close to the detection limit some of the positive duplicate findings are, for example duplicate samples 2 and 8, it is possible that in some cases variation between the two simultaneous samples slightly above and below detection limits masks additional agreement. Given that in all cases these measurements are assumed to be background ambient levels of cabin air, further investigation of the source of these TCP isomers is clearly warranted. The analytical techniques demonstrated themselves to be sensitive with background conditions (i.e. no perceived or reported air quality incident). With background levels, however, we are dealing with the problem of low signal-to - noise ratios. As the environmental chamber experiments demonstrated when sampling higher levels of engine oil intentionally pyrolyzed into the chamber environment, the difference between measured levels of incident versus control filters would be expected to be more easily distinguished.

SUMMARY

The VN sampler demonstrated its ability to capture TCP at trace levels, but its measurements must at this point be considered semi-quantitative. The results presented in table 16 as nanograms per filter represent definitive measures of TCP isomers, but the air concentration measures in table 17 are only estimates. One reason for this is the variability in flow rate that may be the result of battery and/or motor variability. This should not be a serious problem if the main concern is determining presence or absence of TCP in cabin or cockpit air, but is a limiting factor if more precision is desired. The original intent of the VN sampler was as a tool for capturing concentrations during observable bleed air infiltrations. In this case we would expect significant levels of contamination, making the determination of the presence of TCPs more clear-cut than the present experiments, in which we must assume we are measuring TCPs near the detection limit under normal or background conditions.

The practical question of the capability of the VN sampler to function in the cabin environment is answered in the affirmative. Whether a crew member could activate and deactivate the sampler while in the course of his/her regular job duties was not formally answered because the airlines believed *a priori* that the sampling activity would interfere with those duties. However, the operation as carried out nearly 100 times in this study was found to be simple enough that we can say with some confidence that under normal conditions this should pose little difficulty. The question remains of whether crew members could be relied on to do this in the midst of a true visible fume incident when crew must prioritize passenger safety above all

else. A further question is the stability of batteries in the VN samplers over time. If they are to be deployed for incident measurement and especially if they are kept aboard aircraft, a protocol would need to be developed to insure they were ready to perform when needed. This would require a periodic testing and maintenance program for the devices.

The meaning of these background levels of TCP in cabin air remains unclear, but the characteristic isomer pattern found in the in-flight samples matches the jet engine oil analysis. The clinical significance of potentially chronic exposure to the low background levels of TCPs that were measured during some flights in this study is not clear.

V. OVERALL RECOMMENDATIONS

1. **Reporting of air contamination events and work-related injuries/illnesses**: The FAA, airlines, and flight crew unions should come together with independent experts in occupational injury and illness surveillance to design a proactive surveillance system for reporting air contamination events and work-related injuries and illnesses. This recommendation echoes that from the National Research Council committee report regarding the airliner cabin environment (2002) and, more recently, the 2012 FAA Reauthorization Act which calls on the Agency to "develop a systematic reporting standard for smoke and fume events in aircraft cabins." (HR 658, 2012) Both qualitative and quantitative data from our focus groups and health survey provide a starting point in understanding the barriers to reporting and the wide variation between official (BLS) statistics and what flight attendants told us about work-related injuries and illnesses.

   a. **Employee education and training:** Reporting, and hence improved and expanded information about bleed air events, would be enhanced by an educational campaign intended to better prepare both flight crew and airline mechanic employees to recognize and document these events.

2. **Exposure monitoring:** The exposure monitoring aims of the current research were not fully realized due to funding limitations and the failure of the airlines to allow the original protocol of flight attendants taking air samples to go forward. However, this research did establish the following:

   a. The VN sampler was shown to be capable of replicating accepted industrial hygiene sampling methods for tri-cresyl phosphates and of capturing for analysis levels of contaminants near the method and instrument detection limits.
   b. The VN sampler was activated on approximately 80 domestic and international commercial flights by researchers traveling as passengers in the main cabin. No disruptions to other passengers, crew or to flight operations occurred with the operation of the VN sampler, and the sampler passed through TSA security checkpoints literally hundreds of times without being questioned.
   c. Low levels of TCPs were detected under normal operating conditions and were validated with two labs processing the samples. The TCP isomeric pattern of the chromatographic fingerprint suggest engine oil as the source, but it must be noted that the TCP sampling data cannot be viewed in isolation, given that the TCPs are but one component of engine oil fumes. Exposure to low-level TCPs was detected under apparently normal operating conditions, where some oil leakage may occur. Further air sampling should be conducted to verify these findings. It should be considered that pilots may be in the best position to carry out such sampling and to be able to record other conditions during the sampling, including the status of the environmental control systems. This will require FAA and airline involvement in designing the sampling protocols and insuring that they are carried out as designed.
   d. Commercial airplanes as working environments pose some unique challenges to exposure monitoring for employee (and passenger) protection using traditional occupational hygiene methods and instruments. The difficulty of monitoring many different aircraft for largely unpredictable exposures to bleed air contaminants could be addressed by the development and deployment of biomarker tests, including exposure to specific air contaminants (e.g., TCPs) Since data collection in this study took place, potential blood markers for TCPs have shown promise and should be further explored (Marsillach et al 2013).

3. **Engineering controls:** While further research to characterize air contaminant exposure should go forward, funding should also support research into engineering, design, and administrative controls for reducing risk of exposure to engine oil contaminants in the cabin and cockpit. These include:

- Alternative oils with reduced toxicity anti-wear additives;
- Improved engine seal designs to minimize leakage;
- Filtration systems between the bleed air intake and cabin air supply system;
- Improved maintenance practices and more frequent inspections of aging parts;
- On-board sensor systems to ensure that engineering and administrative controls are having their intended effects; and
- Mandatory education and training for flight and cabin crew to ensure that workers can adequately recognize and respond to the presence of air supply system-sourced smoke/fumes, in order to mitigate/prevent exposure.

4. Other flight attendant health issues: While the focus of our exposure and health effects research design was bleed air concerns, our health survey data suggest a range of symptoms, outcomes, and possibly related exposures worthy of further investigation. We should note that since our studies were conducted FAA and OSHA have been negotiating policies for further application of OSHA standards to cabin crew in flight, pursuant to the FAA Modernization and Reform Act of 2012 (HR 658 2012). As of this writing (Jan. 2014), OSHA has partial jurisdiction over occupational safety and health of flight attendants, including hearing conservation, blood-borne pathogen protections, hazard communication, employee access to exposure records, injury/illness recordkeeping and reporting, and whistleblower protections (78 Federal Register 2013). Some of the health concerns listed below may be more effectively addressed as a result of this development.

a. **Fatigue and sleep problems**: These are recognized by FAA as highly prevalent conditions among flight attendants and are important because they may bear directly on the performance of the crew and the safety of passengers. The current study offers further evidence that fatigue and sleeping problems are widely experienced among flight attendants. Further data collection about specific causes of fatigue and testing of interventions to mitigate fatigue are both warranted.

b. **Noise exposure and hearing conservation**: Noise induced hearing loss has been not been monitored in flight crew even though previous studies of flight attendants, including the current study, suggest an unusually high prevalence of hearing loss in this group. Such a program needs to be universal and mandatory as voluntary screening programs run the risk of stigmatization.

c. **Neurological problems**: The prevalence of neurological symptoms (e.g., severe headaches, dizziness, numbness/ tingling in extremities, memory loss) that were described as serious enough to seek medical treatment, is cause for concern. Causes of these symptoms need further investigation. Potential occupational factors include exposure to oil-based airborne contaminants, reduced cabin pressure, noise, and pesticides.

d. **Musculoskeletal disorders:** The reported incidence of musculoskeletal injuries and the percentage of FAs reporting treatment for low back pain in our sample suggest a focus on MSD prevention would have benefit for both flight attendants and airlines. Numerous ergonomic risk factors are present in flight attendant tasks, including pushing and pulling carts, handling baggage, and prolonged sitting and standing. The close involvement of airlines and commercial aircraft manufacturers in cabin layout would seem to provide opportunities for ergonomic prevention through design efforts for flight attendant work.

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Appendix A:

Exposure to Aircraft Bleed Air Contaminants Among Airline Workers: a Guide for Health Care Providers

EXPOSURE TO AIRCRAFT BLEED AIR CONTAMINANTS AMONG AIRLINE WORKERS

A GUIDE FOR HEALTH CARE PROVIDERS

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SUMMARY: The outside air supplied to the cabin/flight deck on commercial aircraft ("bleed air") may sometimes be contaminated with pyrolyzed engine oil and/or hydraulic fluid. As a result of this contamination, airline workers may develop acute and/or chronic health effects and seek attention from health care providers. This document provides information about the health effects that may result after exposure to aircraft bleed air contaminants, and makes recommendations regarding treatment methods. The information in this document is largely based on information that has been published in the medical and scientific literature, and also relies on the clinical experience of one of the authors (Robert Harrison, MD, MPH) who has diagnosed and treated airline workers with contaminated bleed air exposure. A more detailed discussion on the toxicity of tricresylphosphate (TCP) engine oil additives can be found in **Attachment 1**. For more information, web links to additional resources and detailed references are provided at the end of the document.

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I BACKGROUND

A EXPOSURE TO PYROLYZED ENGINE OILS AND HYDRAULIC FLUIDS

During flight, high-temperature compressed air is bled off the engines and, after being cooled, is supplied to the cabin and flight deck. On the ground, airlines often rely on a smaller compressor located in the aircraft tail called the auxiliary power unit (APU). Pyrolyzed engine oil or hydraulic fluid may contaminate the air in these compressors as a result of mechanical failures, maintenance irregularities, and faulty designs (ASHRAE, 2007; van Netten, 2000; BAe Systems 2000) ***(Table 1).*** The most recent National Research Council (NRC) study of this subject concluded that, under certain failure conditions, toxicants such as pyrolyzed engine oils and hydraulic fluids may leak into the aircraft cabin and flight deck air supply systems, and that these toxicants may be associated with health effects (NRC, 2002). The NRC report characterized the need to define the toxicity of these airborne contaminants and investigate the relationship between exposure and reported ill health as a high priority.

TABLE 1: MECHANISMS FOR AIRCRAFT BLEED AIR CONTAMINATION

Type of fault	Example
Mechanical failures	Oil seals that otherwise separate the "wet side" of the air compressor from the "dry side" can leak or fail
Maintenance irregularities	Workers may overfill the oil/hydraulic fluid reservoirs or may spill oil/hydraulic fluid when filling the reservoir
Faulty designs	Some oil seals may be less effective during transient, high-temperature engine operations; the air supply inlet may be in the flow of hydraulic fluid that drips through bilge relief ports and is carried towards the aircraft tail

The airborne toxicants to which aircraft crewmembers and passengers may be exposed when the air supply is contaminated with pyrolyzed engine oil/hydraulic fluid form a complex mixture, including 1-5% tricresylphosphates (TCPs) (added to aircraft engine oils and at least one hydraulic fluid) and N-phenyl-L-naphthylamine (PAN) (Bobb, 2003). If the air supply system temperature is high enough, then the pyrolyzed engine oil/hydraulic fluid may also generate carbon monoxide (CO) (van Netten, 2000).

The tri-ortho isomer has been the most studied of the ten TCP isomers. It is known to cause peripheral neuropathy and is the only isomer for which there is an exposure limit (e.g., OSHA PEL: 0.1 mg/m^3). One manufacturer reported that it has reduced the content of the tri-ortho isomer in engine oil formulations (Daughtrey, 2002), but there are nine other TCP isomers of toxicological concern. For more information on the toxicity of the TCPs, see **Attachment 1**.

There is a relative paucity of publicly available sampling data collected *during* bleed air contamination events on commercial aircraft. Recently, researchers commissioned by the UK Department for Transportation conducted a small-scale survey on two aircraft to test the air sampling equipment (Muir, 2008). During short-term sampling on a single flight (B757 aircraft), airborne TCPs and a wide range of aliphatic and aromatic hydrocarbons were identified as the aircraft reached the top of its climb. Ground-based data collection during APU operation on the other aircraft (BAe146) identified tributylphosphates, lubrication oil-related compounds, and ultra-fine particles.

In another study, air sampling was conducted aboard an aircraft with a history of oil odors, but the supply air was passed through a charcoal filter before it was sampled which does not reflect conditions on the vast majority of commercial aircraft. Tributylphosphates were detected on the flight deck air supply filter (Fox, 2000). An unpublished but later-released report on that same sampling survey cited the presence of some TCP isomers on that same aircraft (PCA, 2007). Some additional data refer to air sampling conducted on an aircraft (and on the engine) after a high-profile oil fume event during which the pilot was incapacitated (SHK, 2001), and include TCP isomers and triphenylphosphate (ACARM, 2007a). On military aircraft, TCPs have been found in recirculating air filters (Kelso, 1988) and in the flight deck air (Hanhela, 2005). Finally, TCPs have been identified in wipe sampling data on the cabin and flight deck walls of commercial aircraft (van Netten, 2005).

The concentration of airborne contaminants is expected to vary according to the source of contamination (engine or APU type), aircraft type, and airline maintenance practices (ASHRAE, 2007; NRC, 2002). Crewmembers report that the majority of bleed air contamination events are during taxi/take off or upon descent (Witkowski, 1999), although in airline reports to the FAA, the majority of events were identified during climb (Murawski, 2008). Crewmembers may report a visible haze or smoke in the cabin/flight deck, and/or a smell often described as "dirty socks" (carboxylic acids in burning engine oil), "chemicals", "vomit", or "burning oil". Exposure may be greater in the flight deck than the cabin because of the higher per person bleed air flow. However, pilots' exposure may be reduced as they have immediate access to 100% oxygen while cabin crewmembers do not. In the UK, there have been documented incidents where the pilots were impaired inflight as a result of breathing oil-contaminated air (AAIB, 2007; AAIB, 2004; CAA, 2002; CAA 2000). As a result, airlines have been instructed to develop and enforce operating procedures for pilots to breathe 100% oxygen if they suspect that the air supply is contaminated and ensure that pilots practice incapacitation procedures at their annual training (AAIB, 2007; SAAIB, 2006; CAA, 2002; CAA, 2001; CAA, 2000). Cabin crew have access to short-term oxygen bottles to ensure they stay functional during emergencies, but may be reluctant to use them, largely because they do not know if the source of the air contamination in the cabin is a fire.

There is no independent and standardized reporting system for air supply contamination events, for either passengers or crew. In the US, there are approximately 160,000 flight attendants and pilots in active employment. Most of these employees work at one of 13 large airlines or 14 regional airlines. Bleed air contamination events are underreported (ACARM, 2007b; FAA, 2006) and estimates are based on fragmentary data. Based on data from three airlines in the United Kingdom (UK), members of the UK Committee on Toxicity recently estimated that pilots report smoke/fume events on 1% of flight segments and maintenance workers conduct engineering investigations into smoke/fume events on 0.05% of flight segments, noting that the frequency of events may vary by airframe, engine type, and maintenance practices (COT, 2007). In the past year, US airlines served an average of 1.8 million passengers on 28,200 daily departures (BTS, 2007). So, applying the UK incident data to the US fleet (assuming comparable conditions), translates into approximately 280 bleed air contaminations events each day aboard US aircraft. A recent analysis of bleed air events on the US fleet found documentation for almost one bleed air contamination event per day over an 18-month period (Murawski, 2008). Most of these events were documented by airlines and reported to the FAA per the Service Difficulty Reporting (SDR) system regulations. This figure is an underestimate for a variety of documented reasons, including the fact that airline compliance with the SDR regulations is poor (Ballough, 2006; FAA, 2006). According to several years' data obtained from three airlines in Canada and the US, frequency estimates of bleed air contamination events range from 0.09 to 3.88 incidents per 1,000 flight cycles (NRC, 2002). Thus, the lowest estimate

of 0.09 events per 1,000 flight cycles translates into an average of two to three contaminated bleed air events each day on the US fleet. Finally, an assessment of contaminated bleed air events on one aircraft type operated by an Australian airline reported 15 oil fume events per 1000 flight cycles (PCA, 2000).

B DOCUMENTATION OF EXPOSURE TO BLEED AIR CONTAMINANTS

It is often difficult for health care providers (HCPs) to document the nature and extent of airline cabin crew exposure to pyrolyzed engine oil or hydraulic fluid. There is typically no sampling of airborne contaminants that has been performed, or any data for similar incidents that can be used for reference purposes. There are no reference criteria (e.g., PELs, TLVs, MAKs) for many TCP isomers, making evaluation of the extent of exposure difficult. Industrial exposure standards were not developed for application on aircraft (Rayman, 2002; Fox, 2000) and little is known about the health effects of exposure to mixtures of contaminants.

As noted above, in addition to the chemical constituents of pyrolyzed engine oil and/or hydraulic fluid, contaminated bleed air may also contain CO as a byproduct of incomplete combustion. Acute exposure to CO may cause symptoms of nausea, headaches, dizziness, and drowsiness. Chronic neurological sequelae have been reported after acute high-level exposure to CO (Prockop, 2007).

The HCP may obtain several sources of information that may aid in assessing exposure ***(Table 2).*** In addition to obtaining the Material Safety Data Sheet (MSDS) for engine oils and/or hydraulic fluids, other documents may provide clues about the mechanism and source of exposure. Each of these sources is subject to several limitations, however.

TABLE 2: INFORMATION SOURCES FOR ASSESSING EXPOSURE TO CONTAMINATED BLEED AIR

Source	Documentation	Limitations
Airline	Pilot logbook entries that describe conditions in the cabin/flight deck and possible mechanical irregularities (reportable per 14 CFR 121.563).	Pilots need not log the symptoms reported by aircraft occupants, and airlines need not release the aircraft logbook to employees or HCP.
Airline	Aircraft maintenance records, in particular those found in Air Transport Association Maintenance Manual chapters 5, 21, 29, 36, 49, 78, and 79 and covering the period 60 days prior to the event and 30 days after.	Difficult to obtain because OSHA's Access to Exposure and Medical Records Standard (29 CFR 1910.1020) does not apply to crewmembers. These records can prove air supply contamination but may require the interpretation of an airline mechanic.
FAA SDR/online	Online and searchable Service Difficulty Reporting System to which airlines are required to report smoke/fume events per 14 CFR 703(a)(5).	Airline compliance with reporting requirements is poor (Ballough, 2006; FAA, 2006).
Employee/ Online	MSDSs for particular engine oil or hydraulic fluid suspected to have contaminated air supply system. The employee should be able to obtain the name of the product in question. All aviation engine oils used in the US fleet contain 1-5% TCPs and a complex mixture of hydrocarbons. The latest version of a MSDS should be posted on the manufacturer's website. HCPs are also encouraged to identify independent product information.	MSDSs typically provide incomplete toxicity information that is based either on ingestion or dermal toxicity, or on animal data limited to assessing motor skills, not more subtle cognitive functions. OSHA's Hazard Communication Standard (29 CFR 1910.1200) does not apply to crewmembers but the MSDS for a given oil or hydraulic fluid is typically easy to obtain.

C HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO CONTAMINATED BLEED AIR

The health effects of exposure to pyrolyzed engine oil and hydraulic fluid on aircraft is difficult to assess for several reasons, including the absence of a centralized system to collect and analyze reported bleed air exposures, and the lack of a large scale epidemiological survey to systematically assess health effects and correlate these with exposures. Furthermore, symptoms are often nonspecific and may not be reported by airline cabin crew or recognized as work-related by HCPs.

Exposure to contaminated bleed air occurs through the inhalation route, and may typically result in acute respiratory, neurological, systemic, and/or psychiatric symptoms typically occur within minutes to a few hours following the contaminated bleed air event, and may vary depending on the duration and magnitude of exposure. Medical record review of airline crew members who were examined after exposure to contaminated bleed air found acute respiratory and/or central nervous system symptoms among the most commonly reported ***(Table 3)***.

TABLE 3: CASE SERIES – ACUTE HEALTH EFFECTS FOLLOWING EXPOSURE TO CONTAMINATED BLEED AIR*

Age	Exposure document	Symptoms	Signs/ Positive tests
26	Cabin Incident Report	muscle pain, chest pain, throat irritation, dizziness, loss of balance, L arm numbness, stuttering	PE: decreased plantar reflexes, memory loss Psychiatric evaluation: conversion disorder
38	Cabin Incident Report	Weakness, nausea, vomiting, dizziness	PE: tremor, nasal congestion, throat hyperemia and edema
39	Employee Incident Report	Myalgias, eye irritation, headache, disorientation	PE: poor serial 7s, memory loss
38	Flew MD-80	Nausea, vomiting, throat irritation, headache, lightheadedness, slurred speech, anxiety, fatigue, insomnia, wheezing, cough	PE: poor serial 7s, memory loss
42	Mechanical Report	Nausea, vomiting, diarrhea, headache, throat irritation, lightheadedness, slurred speech	Laboratory: decreased plasma cholinesterase Neuropsychological testing: attention and information processing deficits, learning and memory impairments
39	Mechanical Report	Headache, dizziness	PE: R hand tremor Psychiatric evaluation: depression, anxiety
49	Doctors First Report	Nausea, vomiting headache, chest tightness	PE: wheezing, rhonchi.
36	Flew MD-80	Headache, confusion, extremity jerks	PE: truncal movement disorder
32	Flew MD-80	joint pain, nausea, vomiting, confusion, loss of balance, anxiety	PE: ataxia
51	Mechanical report	Nausea, vomiting, throat irritation, cough, SOB, chest tightness, headache, lightheadedness, memory loss	Laboratory: decreased plasma cholinesterase
49	Pilot report	eye burning, throat irritation, headache, nausea	PE: mucous membrane erythema, abnormal Romberg, tandem gait

**** Cases examined and reviewed by author (Robert Harrison, MD). All cases met the case definition below.***

In all of these cases, airline crew submitted written reports to their airlines of in-flight exposure to airborne contaminants that they suspected to be engine oil or hydraulic fluid. The sources of exposure were often confirmed by aircraft mechanical records. All developed acute symptoms that were temporally associated with exposure and sought immediate medical care. In some cases, their symptoms persisted, necessitating long-term medical care. Many of the neurological symptoms reported by airline cabin crew following contaminated bleed air exposure are similar to those reported among other workers exposed to triarylphosphates (Schulte, 1996; Krebs, 1995). Pilot impairment or incapacitation inflight has been attributed to exposure to oil fumes (AAIB, 2007; SAAIB, 2006; FAA, 2004; CAA, 2002; CAA, 2001; CAA, 2000; Rayman, 1983; Montgomery, 1977).

A summary of acute and chronic symptoms is summarized in ***Tables 4 and 5*** (Mackenzie-Ross, 2006; Abou-Donia, 2005; Harper, 2005; Somers, 2005; Winder, 2005; Burdon, 2005; Singh, 2005; Michaelis, 2003; Bobb, 2003; Coxon, 2002; Cox, 2002; PCA, 2000; van Netten, 1999; Witkowski, 1999; Rayman, 1983; Montgomery, 1977).

TABLE 4: ACUTE SYMPTOMS FOLLOWING EXPOSURE TO CONTAMINATED BLEED AIR

Respiratory	Neurological	Systemic	Psychiatric	Dermal
Cough	Headache	Nausea, vomiting	Anxiety	Rash
Shortness of breath	Dizziness	Fatigue	Sleep disturbance	
Chest tightness	Lightheadedness	Muscle weakness	Depression	
Wheezing	Memory impairment	Palpitations	PTSD	
Eye, nose or throat irritation	Concentration difficulty	Diarrhea		
	Visual changes			
	Tremor			
	Gait problems			
	Paraesthesias			
	Balance problems			
	Slowed mental processing			
	Difficulty multi-tasking			

TABLE 5: CHRONIC SYMPTOMS FOLLOWING EXPOSURE TO CONTAMINATED BLEED AIR

Respiratory	Neurological	Systemic	Psychiatric	Dermal
Cough	Headache	Nausea, vomiting	Anxiety	Rash
Shortness of breath	Slowed mental processing	Fatigue	Sleep disturbance	
Chest tightness	Difficulty multi-tasking	Muscle weakness	Depression	
Wheezing	Memory impairment	Palpitations	PTSD	
	Concentration difficulty	Diarrhea		
	Visual changes			
	Tremor			
	Gait problems			
	Paraesthesias			
	Balance problems			

D SIGNS AND SYMPTOMS ASSOCIATED WITH OTHER EXPOSURES ON BOARD COMMERCIAL AIRCRAFT

In addition to contaminated bleed air, airline cabin crew may also be exposed to other environmental hazards aboard commercial aircraft ***(Table 6).*** The symptoms and health effects of these exposures should also be considered by the HCP in evaluating the airline cabin crew member (Murawski, 2005a).

TABLE 6: EXPOSURES AND DOCUMENTED HEALTH EFFECTS

Exposure	Source/description	Symptoms/health effects	References
Reduced oxygen	The cabin is typically pressurized between 6,000 and 8,000 feet, which can cause symptoms of hypoxia and exacerbate the effects of some chemical exposures.	Dizziness, headache, fainting, cardio/pulmonary complaints, possible increased risk of DVT	Schreijer, 2006; Muhm, 2004; Crosby, 2003; NRC, 2002; Waters, 2002; Schobersberger, 2002; Christensen, 2000; Casley-Smith, 1996; Cottrell, 1995 and1988
Ozone	Many commercial aircraft operate within the ozone layer. Ozone levels increase with altitude and latitude and are highest in late winter and early spring. Sampling on aircraft equipped with catalytic converters reported gate-to-gate average levels of ozone ranging from < 0.05 to 0.24 ppm.	Chest tightness, wheezing, cough	Spengler, 2004; Waters, 2002; Tashkin, 1983
Insecticides	Applied for domestic insect control and to comply with foreign quarantine requirements, typically 2% permethrin or phenothrin, sometimes with piperonyl butoxide, sprayed when the aircraft is occupied or shortly before boarding and then routed domestically. History of DDT application on commercial aircraft.	Respiratory irritation, shortness of breath, wheezing, skin rash, headache, irritability, neuropathy, dizziness, ataxia, confusion, weakness, sweating	Sutton, 2007; Carlson, 2006; DOT, 2006; Murawski, 2005b; NRC, 2002; ICAO, 2001; EPA, 1996; ACAP v. USDA, 1977
Deicing fluids	Contain propylene glycol, diethylene glycol, or methylene glycol; can be entrained into the supply air during ground operations.	Respiratory irritation, headache	SAE, 1997
Exhaust fumes from ground service vehicles/other aircraft, fuel vapor	Exhaust contains nitrous oxides and ozone; can be entrained into the supply air. Fuel vapor may enter aircraft air supply systems during ground operations.	Respiratory irritation, headache	
Disinfectants, deodorizers	Cleaning staff sprays disinfectants and deodorizers in the cabin containing active ingredients, solvents, and propellants.	Respiratory irritation, skin sensitization	

II EVALUATION OF HEALTH EFFECTS

A CASE DEFINITION

Based on review of the medical literature and the case series as summarized above, the HCP may consider the following case definition for acute exposure to contaminated bleed air:

An *acute* health problem due to bleed air contaminant exposure should be considered if these factors are shown to be present:

- There is *either* a documented exposure to bleed air contaminants (based on evidence in the mechanical records, incident reports, or airborne measurements) *or* a history of flying on aircraft type(s) documented to have an increased risk of air supply contamination events;

  and

- Initial symptoms occur within 48 hours following exposure;

  and

- There is objective documentation of acute and/or persistent respiratory, neurological, systemic, or psychiatric symptoms that follow exposure to bleed air contaminants; see Tables 4 and 5.

In addition, chronic health effects may result from acute and/or chronic exposure to contaminated bleed air. In some cases, the individual crewmember may not recall symptoms

occurring many months or years prior to examination by the HCP. These cases should be evaluated on a case-by-case basis to determine the likelihood that health problems are due to contaminated bleed air exposure.

Whenever possible, the clinician should attempt to identify the exposure and make a precise diagnosis (e.g., avoid generic terminology such as “inhalation exposure”) based on a combination of symptoms and objective evidence of health effects (physical examination findings and/or medical tests).

B HISTORY OF ILLNESS

The clinician should obtain a complete history of the circumstances aboard the aircraft on the flight in question, including symptom onset, medical history, whether other crewmembers were affected, and any emergency treatment rendered. Acute symptoms of respiratory, neurological, and systemic toxicity, as well as psychiatric effects, should be documented. Skin rash may occur but is not likely in the absence of other symptoms.

C ASSESSING EXPOSURE AND RISK

Information about the nature and extent of the exposure to bleed air contaminants is critical to establishing the diagnosis. The clinician should attempt to collect the details listed in ***Table 7***.

TABLE 7: FLIGHT-SPECIFIC QUESTIONS TO ASK THE CREWMEMBER

What was the date, flight number, aircraft number, and aircraft type?
During what phase(s) of flight was the problem noted (ground operations, taxi, climb, cruise, descent, landing, taxi in, off duty/post-flight)?
Was there a noticeable odor or any visible fumes/smoke/mist?
How long did the exposure last (if known)?
Is the employee aware of a possible cause suggested by maintenance workers or airline officials?
Is the crewmember aware of whether their aircraft had been sprayed with pesticides?

D PAST MEDICAL HISTORY

The past medical history should be obtained to determine preexisting conditions and/or risk factors that may predispose the individual to illness caused by exposure to bleed air contaminants, as well rule out alternative explanations for presenting signs and symptoms. This should include respiratory conditions (asthma, COPD), neurological problems (including headaches), psychological disorders (panic disorder, PTSD, depression), and medication use. To evaluate risk factors for neurobehavioral disorders, the HCP should obtain a history of prior head injury, prior neurological illnesses (such as meningitis), systemic disorders (e.g., diabetes, liver disease, metabolic disorders), caffeine and alcohol intake, use of recreational drugs, and family history of memory, cognitive or emotional problems. For pilots, the date of last aviation medical examination may provide useful data regarding fitness for duty. Previous medical records should be obtained and reviewed as appropriate.

Differences in individual susceptibilities to the effects of exposure to particular organophosphates may be influenced by genetics, levels of particular hormones associated with menstruation and pregnancy, liver disease, age, obesity, certain medications, and exposure to mixtures of particular chemicals that can influence the availability and efficacy of enzymes involved in their metabolism, and could thereby influence the degree of toxic effect (NRC, 2002; Haley, 1999; Gene, 1997; Mutch, 1992; Howard, 1978; Davis, 1948).

E OCCUPATIONAL HISTORY

The HCP should obtain an occupational history, including the factors listed in **Table 8**.

TABLE 8: OCCUPATIONAL FACTORS

Employment prior to airline work, including occupations in which inhalation and/or dermal exposure to chemicals may have occurred.
The duration of employment as a flight attendant or pilot.
History of previous exposure episodes (including exposures to pesticides used aboard aircraft), prior workers' compensation claims, and previous lost work time incidents due to bleed air exposures.

It has also been suggested that previous chemical exposures can increase susceptibility to toxic effects of subsequent exposures, resulting from a loss of tolerance following exposure to various toxicants, and subsequent triggering of symptoms by extremely small quantities of previously-tolerated chemicals (Miller, 1997).

F SOCIAL AND FAMILY HISTORY

Several non-occupational factors are important to evaluate in the context of examining the airline cabin crew member with contaminated bleed air exposure, as these may affect the interpretation of signs and symptoms; see ***Table 9.***

TABLE 9: SOCIAL AND FAMILY FACTORS

Personal hobbies with exposures to chemicals.
Smoking status and exposure to second hand smoke (may increase the likelihood of respiratory symptoms).
Family history of asthma (if respiratory symptoms or signs are present).
Frequency of ingestion and quantity of alcohol (excessive use may contribute to neurological dysfunction).

G PHYSICAL EXAMINATION

The physical examination should focus on the respiratory tract, with attention to mucous membrane erythema and mucous discharge (upper), and wheezing, rhonchi and crackles (lower). A neurological examination should be performed, with assessment of cerebellar function, tremor and gait disturbance.

A neuropsychological screening examination may be useful if symptoms suggest cognitive dysfunction, with assessment of short-term memory function, concentration and color vision loss.

H LABORATORY DATA AND OTHER TESTS

A blood test specific to the TCP additives in aviation engine oils and some hydraulic fluids is under development but is not yet available for routine use (Furlong, 2007). Currently, the only available tests are listed in ***Table 10.*** These tests may provide objective evidence of exposure that will assist with confirming the diagnosis and guiding treatment. Red blood cell/acetyl cholinesterase (AChe) is not a useful blood test because the TCP engine oil additives have only a minor effect on AChe levels.

TABLE 10: TESTS TO ASSESS EXPOSURE TO BLEED AIR CONTAMINANTS

Test	Timeframe	Interpretation/limitations
Plasma cholinesterase (PChe)	Within 24 hours if suspected exposure to engine oil or hydraulic fluid that contains TCPs, although initial sample collection within seven days may still yield useful data. Proper collection and transport techniques must be followed. Repeat tests at intervals over one month to properly interpret changes.	Interpretation of PChe results are complex: PChe can be initially depressed, followed by a "rebound effect." The "normal" range of PChe is broad, and therefore an initial result within the "normal" range may be below the individual's baseline or pre-exposure level, which is another reason that subsequent testing can be helpful.
Oxygen saturation	Within an hour if crewmember took oxygen during the flight; otherwise, within four hours.	Care must be taken in interpreting results if more than a few hours have passed since the exposure has ceased, or with the prior administration of supplemental oxygen.
Arterial carboxyhemoglobin	Immediately following suspected exposure to pyrolyzed organics (likely oil or hydraulic fluid)	Carboxyhemoglobin does not provide a sensitive measure of the extent of contaminated bleed air exposure because the bleed air temperature is not always high enough for CO to be present.
Pulmonary function tests (spirometry)		Tests with pre/post bronchodilators should be obtained in the presence of respiratory symptoms or relevant physical examination findings.
Chest xray		Suggested if pulmonary edema and/or infiltrates are suspected (ARDS).

I TREATMENT AND REPORTING

The acute neurological and respiratory effects of contaminated bleed air exposure are treated primarily by prompt removal from the exposure. Some evidence suggests that

hyperbaric oxygen may reduce the risk of long-term sequelae in the setting of highly elevated carboxyhemoglobin (Weaver, 2002). Respiratory effects should be treated according to standard protocols for acute chemical inhalation; this includes the use of aerosolized bronchodilators and supplemental oxygen where bronchospasm and/or pneumonitis is present. The use of intravenous corticosteroids after acute chemical inhalation with bronchospasm may improve prognosis.

The diagnosis of work-related illness or injury should be reported to the appropriate state and/or workers' compensation authorities according to relevant requirements. A few states (e.g., CA) require pesticide illnesses to be reported separately as well. Pilots should advise their aviation medical examiner of their exposure at their next renewal examination, or as per applicable regulations. HCPs should note that crewmembers are not covered by OSHA regulations (FAA, 1975) and the FAA has not promulgated comparable occupational safety and health regulations since assuming jurisdiction in 1975 (FAA-OSHA, 2000).

J DISABILITY MANAGEMENT AND FOLLOW-UP

The course of improvement for acute respiratory, neurological, systemic, and psychiatric effects varies, but symptoms often improve and resolve within a few weeks. Exposure to contaminated bleed air may result in chronic health effects in some airline workers. Immediately following acute exposure, the airline worker should avoid exposure to contaminated bleed air. This may entail removal from work, or modified or restricted duty if available. In addition, workers should avoid exposure to other airborne contaminants such as diesel exhaust, jet fuel, and cleaning products (Miller, 1997). Follow-up medical evaluation and return to work clearance should first be performed after one to two weeks. If all respiratory, neurological, systemic, and psychiatric symptoms have resolved, the airline worker can be cleared to return to work on full duty.

If symptoms have not resolved within 1 to 2 weeks, the airline worker should continue to be examined to assess the course of recovery; see ***Table 11*** for additional guidance. Some airline workers may have recurrent symptoms on return to work due to re-exposure to contaminated bleed air, and/or ongoing exposure to other airborne contaminants in the aircraft environment. If symptoms have not completely resolved within 2 months following one or more contaminated bleed air exposures, the clinician should consider the likelihood that persistent health effects have occurred and will need additional evaluation and/or treatment. If symptoms persist, the airline worker should remain off work or on modified duty until complete evaluation can be performed. Depending on severity, persistent respiratory, neurological, systemic and psychiatric problems may preclude the airline worker from return to his/her usual job. Modified duty (such as a ground job) may be suitable for some crewmembers depending on their functional status.

TABLE 11: TIME COURSE FOR MEDICAL FOLLOW UP

Time course, post-exposure	Suggested medical follow up
Within 1-2 weeks	Will require follow up medical evaluation and return to work assessment. If all respiratory, neurological, systemic, and psychiatric symptoms have resolved, then the airline worker can be cleared to return to work on full duty.
Beyond 1-2 weeks	If symptoms have not resolved, airline worker should continue to be examined to assess the course of recovery.
Two months and beyond	If symptoms have not completely resolved, consider the likelihood that persistent health effects have occurred and will need additional evaluation and/or treatment. Persistent health problems may preclude the airline worker from return to his/her usual job. Modified duty (such as a ground job) may be suitable depending on functional status.

The most common chronic respiratory, neurological, systemic and psychiatric health effects are described below:

(1) **Irritant-induced asthma** may occur after an acute, single episode of chemical inhalation where symptoms of asthma persist for greater than 3 months following the exposure episode. Airline cabin crew with acute respiratory symptoms after bleed air exposure should be advised to seek medical follow-up if their respiratory symptoms persist. Spirometry (pre/post bronchodilator administration) and methacholine inhalation challenge should be performed to document the presence of persistent asthma. Chemical bronchitis

that gradually resolves is more likely to occur after an irritant exposure than persistent asthma. Complete pulmonary function testing with lung volumes and diffusing capacity as well as chest imaging should be obtained if respiratory disease other than asthma or bronchitis is suspected. The treatment for persistent asthma is inhaled bronchodilator and inhaled corticosteroids following the Global Initiative for Asthma guidelines (GINA 2006).

(2) **Persistent neurological problems** may occur following bleed air exposure, and can include headaches, confusion, loss of balance, lightheadedness, muscle weakness, movement disorders, numbness, and paraesthesias. Neurobehavioral problems include cognitive dysfunction, post-traumatic stress disorder, emotional lability, depression, sleep and anxiety disorders. Neurological, neuropsychological or psychiatric consultation should be obtained if symptoms persist for greater than 1 to 2 months following bleed air contaminant exposure. Testing should include visual, somatosensory, and brainstem audio evoked potentials, and color desaturation that may be sensitive measures of neurotoxic injury. A psychologist with experience evaluating brain injury following neurotoxic exposure should perform a complete neuropsychological evaluation (Coxon, 2002; Mackenzie-Ross, 2005). The neuropsychological tests may assist in the differentiation of organic brain injury and psychiatric disorder. The brain MRI can be useful to rule out the presence of space occupying lesions and demyelinating diseases, but it is not sensitive enough to characterize more subtle changes in brain chemistry or receptors, so it is usually normal after neurotoxic exposure (Menon, 2004; Meyerhoff, 2001; Haley, 2000a; Haley, 2000b). EEG results are usually nonspecific and not useful in confirming the diagnosis of neurotoxic injury, but may be helpful in excluding other conditions. Although unusual, if symptoms suggest peripheral nerve damage, NCVs, EMGs and quantitative sensory testing should be performed to assess the presence of sensory loss. A SPECT or PET scan may be helpful confirm the clinical diagnosis of neurotoxic brain injury (Heuser, 1998), but should not be utilized solely for diagnostic purposes.

Treatment for neurotoxic injury is directed by the specific diagnosis. Avoidance of any triggering agents in the general environment is recommended. Headaches are often vascular in nature and may require the use of various analgesic and other medications directed at this condition. Treatment of persistent neurological and neuropsychological problems is directed at improvement of functional status. Crewmembers who have cognitive impairment should seek advice from neuropsychologists who have expertise in rehabilitation following neurotoxic injury or traumatic brain injury. As there are limited treatment options available, some individuals may seek alternative treatment techniques that have not generally been subjected to clinical studies. Although treatment techniques such as high dose intravenous vitamin and nutritional supplementation, oxygen therapy, yoga, and sauna detoxification have been anecdotally reported to be of limited benefit in individual cases, these have not confirmed as effective in clinical trials. The HCP should encourage Improvement of functional status through exercise, adequate sleep, well balanced diet, and adequate hydration.

(3) **Systemic symptoms**. Other long-term effects reported by some patients include persistent gastrointestinal problems, increased sensitivity to chemicals, myalgias, arthralgias, palpitations, and unusual fatigue. The presence of underlying hematological, immunological or gastrointestinal disorders should be evaluated by appropriate testing and/or referral to relevant specialists.

(4) **Post-exposure psychiatric problems** such as PTSD, depression and anxiety should be referred for psychiatric evaluation and treatment. Pharmacological treatment and counseling may be helpful in the management of these disorders.

There are currently no tests of sufficient sensitivity and specificity to assess exposure/health affects outcomes. Various biomarkers and other assays to assess target organ and physiological effects from exposure to cabin air contaminants are currently under development (Furlong, 2007). Preliminary research suggests tests of the autonomic nervous system and autoantibodies may be useful in evaluating exposure and chronic neurotoxicity (Abou-Donia, 2005; Julu, 2005). However, these assays are not routinely available to the health care provider. In the future, these tests may prove to be useful in confirming exposure and/or risk of subsequent disease, but additional research is needed before they can be routinely used in the clinical setting.

II ATTACHMENTS

ATTACHMENT 1 – TOXICITY OF TRICRESYLPHOSPHATE ENGINE OIL ADDITIVES

III ADDITIONAL RESOURCES

Association of Flight Attendants-CWA, AFL-CIO – see http://ashsd.afacwa.org.

Association of Occupational & Environmental Clinics – see http://www.aoec.org.

Aviation Organophosphate Information Site – see http://www.aopis.org.

Poison Control & Prevention Center – see http://www.aapcc.org/findyourcenter.htm.

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ATTACHMENT 1

TOXICITY OF TRICRESYLPHOSPHATE ENGINE OIL ADDITIVES

Tricreslyphosphates (TCPs) are added to most synthetic jet engine oils and at least one hydraulic fluid (van Netten, 2001; van Netten, 2000; van Netten, 1999) primarily because of their anti-wear properties. According to a sample of Material Safety Data Sheets of commonly used products, the total concentration of TCPs varies between 1 and 5% (Exxon-Mobil, 2006; Anderol, 2004; Exxon-Mobil, 2003; BP, 2001). Exceptions to this rule include aviation engine oils manufactured by the French oil company, NYCO SA. When it was formulating aviation engine oils in the 1970s, NYCO opted to replace TCPs with triisopropyl phenyl phosphate (TIPP) because of health concerns raised by the French health authority over exposure to TCPs (NYCO, 2008). Key product lines include Turbonycoil 160, Turbonycoil 400, and Turbonycoil 600.

The inhalation toxicity of pyrolyzed and aerosolized aircraft engine oil during commercial airline flights is a subject that has received increasing attention over the past 10 years, not only in the US, but internationally (see above “Guide for Health Care Providers”). Even though the inhalation toxicity of these products has not been published, the material safety data sheets (MSDS) typically warn the user of hazards associated with exposure to heated byproducts; for example, “toxic fumes may be evolved on burning or exposure to heat” (BP, 2001) or “the product may decompose at elevated temperatures or under fire conditions and give off irritating and/or harmful (carbon monoxide) gases/vapors/fumes” (Exxon-Mobil, 2006). The MSDS also typically cite “hazardous combustion products [such as] carbon monoxide, phosphorus oxides, aldehydes, smoke, fumes, and incomplete combustion products (Exxon-Mobil, 2006). Some of the MSDS include specific warnings about “overexposure to TCPs by swallowing, prolonged or repeated breathing of oil mist, or prolonged or repeated skin contact [that] may produce nervous system disorders including gastrointestinal disturbances, numbness, muscular cramps, weakness, and paralysis” that may be delayed (Exxon-Mobil, 2003).

The TCP additives are by no means the only toxic component of these oils, but it is important for HCPs to understand the inhalation toxicity of TCPs because it has been a source of misunderstanding and debate. The levels or nature of airborne TCPs during an air supply contamination event have not been characterized on commercial aircraft, although a recent study on military aircraft identified total TCP levels between 0.5 and 49 ug/m^3 (Hanhela, 2005). Interestingly, TCP concentrations did not correlate with visible smoke/fume or odor detection.

The three cresyl groups in a given molecule of TCP can attach to the phosphate in different configurations; these are called isomers. In total, there are ten TCP isomers (Table A1), including a tri-ortho isomer (TOCP), two di-ortho isomers (DOCP), three mono-ortho isomers (MOCP), and four meta/para isomers. The relative amounts of these different isomers can vary between brands and batches of aviation engine oil, but some combination of some or all of these isomers will be present in a given sample. Although engine oil manufacturers consider the specific isomeric blend to be proprietary, it is known that the ortho isomers make up about 0.3% of the TCP and the vast majority (99.97%) of the ortho isomers are MOCP and DOCP, while there is very little TOCP (PCA, 2000). Little is known about the relative amounts of the remaining meta and para isomers.

Table A1: DESCRIPTION OF THE TEN ISOMERS OF TCP

Category of isomer	Description of isomers
Tri-ortho: TOCP (1)	o-o-o
Di-ortho: DOCP (2)	o-o-m; o-o-p
Mono-ortho: MOCP (3)	o-m-p; o-m-m; o-p-p
Meta and/or para (4)	m-m-m; p-p-p; m-m-p; m-p-p

Probably because of some highly publicized TOCP mass poisonings resulting from adulteration of a popular alcoholic drink called "Ginger Jake" in the 1920s and a large batch of cooking oil in 1959, this single isomer has received the most attention, and it is the only isomer for which an exposure limit exists (e.g., OSHA PEL: 0.1 mg/m^3). These mass poisonings involving TOCP highlighted the risk of peripheral neuropathy and paralysis, which has been confirmed in laboratory studies involving animals that ingested TOCP or absorbed it through their skin.

Symptoms of peripheral neuropathy measured in test animals following dermal or oral exposure to aviation engine oils (Craig, 1999; Mackerer, 1999; Weiner, 1999; Daughtrey, 1996), and assurances of low ambient levels of TOCP during fume events are of little relevance to the concerns raised over exposure to aerosolized engine oil on aircraft for the following reasons:

- There is little, if any, TOCP in the engine oil formulations;

- The mono- and di-ortho isomers of TCP are five and ten times more toxic (using peripheral neuropathy as an endpoint; Mackerer, 1999; Henschler, 1958) than TOCP, respectively, but are still only present at low concentrations (PCA, 2000) such that peripheral neuropathy should not the primary endpoint of interest following inhalation exposure to pyrolyzed engine oils;

- The meta and para isomers of TCP dominate commercial engine oil formulations and are not expected to cause peripheral neuropathy, but may cause chronic neurotoxicity (The ortho isomers have been implicated in chronic neurotoxicity in addition to peripheral neuropathy.)

- Peripheral neuropathy is not the primary endpoint of concern reported by exposed aircraft crews. Of interest is that evidence of the potential for chronic symptoms of neurotoxicity associated with either acute exposures or chronic, low level exposures has been suggested for organophosphates in general (Jamal, 2002) and TCPs on the aircraft in particular (Abou-Donia, 2003).

- Aircraft occupants are primarily exposed to engine oil via inhalation with only limited potential for dermal exposure and no real potential for ingestion, but despite this, controlled studies that assess the health impact of inhalation exposure have not been published. The toxicity associated with inhalation may be different to that associated with dermal exposure or ingestion. Certainly, there is no evidence that ground-based dermal/oral research data for these oils can be applied to inhalation exposures that are often incurred in a reduced oxygen environment.

The tri-ortho content of TCP has been successfully reduced in the last few decades but exposure to the mono and di ortho isomers, as well as the meta and para isomers, are still of

toxicological concern to aircraft crews and passengers (Hanhela, 2005; Bobb, 2003). Inhalation toxicity testing in a controlled laboratory setting, with post-mortem brain analysis of exposed animals may be necessary to confirm the observations of chronic neurotoxicity among exposed aircraft occupants.

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Appendix B:

Quick reference guide for health care providers: health impact of exposure to contaminate supply air on commercial aircraft

QUICK REFERENCE GUIDE FOR HEALTH CARE PROVIDERS: HEALTH IMPACT OF EXPOSURE TO CONTAMINATED SUPPLY AIR ON COMMERCIAL AIRCRAFT

Summary: Outside air is bled off the engines/auxiliary power unit and supplied to the cabin/flight deck on commercial aircraft. Under certain failure conditions, toxicants such as pyrolyzed engine oils and hydraulic fluids may leak into the aircraft cabin and flight deck air supply systems. Airline workers may develop acute and/or chronic health effects and seek attention from health care providers. This quick guide focuses on oil exposures.

Exposures: The "bleed air" is not filtered and contaminant levels are not monitored. Airborne toxicants include a complex mixture of oil-based compounds, irritant gases, and ultra-fine particles. Particular concerns include 1-5% tricresylphosphates (TCPs), N-phenyl-L-naphthylamine (PAN), and carbon monoxide. Primary exposure pathway is inhalation. Some crewmembers describe low-level chronic exposures to fumes (e.g., routine and transient fumes on engine start up); others describe acute, visible fume events, the majority of which result in a flight diversion or cancellation. Alternate or co-exposures in the cabin/flight deck include reduced pressure, ozone gas, insecticides, deicing fluid, exhaust fumes, fuel fumes, and cleaning products.

Documentation: Crewmembers submit written reports of smoke/fumes/odor to their airline. Aircraft mechanical records and pilot log book entries sometimes document air supply contamination. Crewmembers can provide Material Safety Data Sheets for the particular oil/hydraulic fluid. Ask for the date, flight number, aircraft number, aircraft type, phase of flight when the problem was noted, whether odor or visible smoke/fumes, duration, whether aircraft was sprayed with insecticides, and any supplementary documentation from the airline/maintenance regarding cause. Obtain past medical history, occupational history, and family/social health history.

Health effects: Most common symptoms reported are acute respiratory, neurological, systemic, and/or psychiatric symptoms, typically occurring within minutes to a few hours following the contaminated bleed air event. Symptoms vary depending on the duration and magnitude of exposure, plus individual factors. Chronic and sometimes delayed neurological, psychiatric, respiratory, systemic, and dermal symptoms are reported, and may last for years after the exposure.

Suggested case definition: There is *either* a documented exposure to bleed air contaminants *or* a history of flying on aircraft type(s) documented to have an increased risk of air supply contamination events; ***and*** Initial symptoms occur within 48 hours following exposure; ***and*** there is objective documentation of acute and/or persistent respiratory, neurological, systemic, or psychiatric symptoms. Note that crewmembers with routine, low-level exposures may also develop chronic symptoms but may not have documented acute, individual exposure events. Symptoms may have started many months or years prior to examination by the HCP. Evaluate cases individually to determine the likelihood that health problems are caused by contaminated bleed air exposure. Attempt to identify the exposure and make a precise diagnosis (e.g., avoid generic terminology such as "inhalation exposure") based on a combination of symptoms and objective evidence of health effects (physical examination findings and/or medical tests).

Examination: Focus on the respiratory tract, with attention to mucous membrane erythema and mucous discharge (upper), and wheezing, rhonchi and crackles (lower). Neurological examination should be performed, with assessment of cerebellar function, tremor and gait disturbance. Neuropsychological screening examination may be useful if symptoms suggest cognitive dysfunction, with assessment of short-term memory function, concentration and color vision loss.

Lab data and other tests: Blood test specific to the TCP additives in aviation engine oils is under development but is not yet available for routine use. Available tests include: plasma butylcholinesterase (PChe; initially depressed and then rebound effect); oxygen saturation (within hour if crewmember took oxygen or four hours if not); arterial carboxyhemoglobin (remembering that CO may not have been present); pulmonary function tests (per symptoms) with pre/post bronchodilators; chest x-ray (if pulmonary edema or infiltrates suspected). There are currently no tests of sufficient sensitivity and specificity to definitively assess exposure or other health outcomes. Preliminary research suggests tests of the autonomic nervous system and autoantibodies may be useful in evaluating exposure and chronic neurotoxicity.

Treatment: Prompt removal from aircraft environment and other airborne contaminants such as diesel exhaust, jet fuel, and cleaning products. Respiratory effects should be treated according to standard protocols for acute chemical inhalation, including aerosolized bronchodilators and supplemental oxygen where bronchospasm and/or pneumonitis is present. The use of intravenous corticosteroids after acute chemical inhalation with bronchospasm may improve prognosis. Following CO exposure, hyperbaric oxygen may be appropriate. As limited treatment options are available for neurotoxic injury, some individuals may seek alternative treatment techniques. Although they have generally not been subjected to clinical study, vitamin and nutritional supplementation, nebulized glutathione, oxygen therapy, yoga, and sauna detoxification have anecdotally been reported to be of some benefit in individual cases. The HCP should encourage Improvement of functional status through exercise, adequate sleep, well balanced diet, and adequate hydration.

Disability management: Prognosis varies widely. Symptoms often improve and resolve within a few weeks. If all respiratory, neurological, systemic, and psychiatric symptoms have resolved, the airline worker can be cleared to return to work on full duty. If symptoms have not completely resolved within two months following one or more contaminated bleed air exposures, the clinician should consider the likelihood that persistent health effects have occurred and will need additional evaluation and/or treatment. Depending on the severity, persistent respiratory, neurological, systemic and psychiatric problems may preclude the airline worker from return to his/her usual job. Modified duty (such as a ground job) may be suitable for some crewmembers depending on their functional status. Most common chronic conditions are: irritant-induced asthma, persistent neurological problems, persistent GI problems, increased sensitivity to chemicals, myalgias, arthralgias, palpitations, unusual fatigue, PTSD, depression and anxiety.

Send correspondence to: Robert Harrison, MD, MPH, University of California, San Francisco, Division of Occupational and Environmental Medicine, 2380 Sutter Street, 3rd Floor, San Francisco, CA 94115; Robert.Harrison@ucsf.edu. **Funding**: Provided by the Federal Aviation Administration Office of Aviation Medicine as part of a collaborative project between the Occupational Health Research Consortium in Aviation (OHRCA) and the Airliner Cabin Environment research (ACER) Center of Excellence.

Appendix C:

Flight Attendant Health Survey

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FLIGHT ATTENDANT HEALTH SURVEY

Instructions: Use a black ballpoint pen or pencil.
Make heavy dark marks.

Shade circles like this: ●

Place one digit per space in boxes.

Example: 4 years | | 4 |

Example date: 1978 | 1 | 9 | 7 | 8 |

Please complete the FRONT and BACK of each page - there are 9 pages in total.

The survey should take approximately 20 minutes to complete.
Please make a line through questions you do not want to answer.

Today's date | | | / | | | / | | | | |

SECTION 1: Tell us about your work

1. For how many years have you...

	less than 1 year	*1-5 years*	*6-10 years*	*11-15 years*	*16-20 years*	*more than 20 years*
been a flight attendant with your current company?	O	O	O	O	O	O
worked as a flight attendant?	O	O	O	O	O	O

2. How many flight hours did you work in the **last 3 days**? **(Select one for each day.)**

	0 hours (not on duty)	*1-6 hours*	*7-12 hours*	*13-18 hours*	*19-24 hours*
today (at the end of your work hours)	O	O	O	O	O
yesterday	O	O	O	O	O
2 days ago	O	O	O	O	O

3. How many flight hours did you work in the **last month**?

- O 0 hours
- O 1-24 hours
- O 25-49 hours
- O 50-64 hours
- O 65-74 hours
- O 75-99 hours
- O 100 or more hours

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4. Do you regularly work 65 flight hours per month or more?
   - O yes
   - O no

5. How many flight hours did you work per month on average in the **last 12 months**?
   (Please exclude months in which you had extended absences for personal or medical reasons).
   - O 0 hours
   - O 1-24 hours
   - O 25-49 hours
   - O 50-64 hours
   - O 65-74 hours
   - O 75-99 hours
   - O 100 or more hours

6. In the **past 12 months**, which best describes your flight schedule?
   - O single segment, long haul duty periods
   - O multiple segments in one duty period
   - O combination of long and short segments with layovers
   - O other (specify): _____

7. In the **past 12 months**, which cabin of the plane did you work most often? **(Select one only.)**
   - O none more than others
   - O first class
   - O business class
   - O economy

8. In the **last 12 months**, on which aircraft have you worked? **(Mark ALL that apply.)**

O AVRO RJ	O BAe146	O CRJ	O Fokker
O A319	O B727	O Dash 8	O MD80
O A320	O B737	O DC9	O MD88
O A330	O B747	O DC10	O MD90
O A340	O B757	O Dornier	
O A350	O B767	O EMB	
	O B777	O ERJ	

9. Please describe your job over the **last 12 months**.

	Strongly disagree	*Disagree*	*Agree*	*Strongly agree*	*No opinion*
My job requires working very fast...	O	O	O	O	O
My job requires working very hard...	O	O	O	O	O
My job requires long periods of intense concentration on the task...	O	O	O	O	O
My job is very hectic...	O	O	O	O	O
My work requires rapid and continuous physical activity...	O	O	O	O	O
I have enough time to get the job done...	O	O	O	O	O
I have a lot of say about what happens on my job...	O	O	O	O	O
My job requires lots of physical effort...	O	O	O	O	O
I am often required to lift very heavy loads on my job...	O	O	O	O	O
My job allows me to make a lot of decisions on my own...	O	O	O	O	O
On my job, I have very little freedom to decide how to do my work...	O	O	O	O	O

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SECTION 2: Tell us about your health

Please remember that all of your responses are completely confidential.

10. Are you currently out of work for personal or medical reasons?

- O yes
- O no

11. In the **past 12 months**, have you been out of work for health reasons for more than 6 weeks?

- O yes
- O no

12. In the **last year**, how many separate work-related injury/illness episodes did you have?
A "separate episode" is either a new injury/illness or an injury/ilness that has recurred after you have returned to work for at least 2 weeks.

- O 0 ***If you have had no episodes in the last year, please skip to Question 13.***
- O 1
- O 2
- O 3
- O 4 or more

Please describe up to 3 separate episodes from the last year.
If you have had more than 3 separate episodes in the last year, please describe the three most significant episodes.

Injury or Illness #1

A. Please describe the injury/illness. (Mark ALL that apply.)

- O musculoskeletal: strain or sprain, joint aches and pains
- O musculoskeletal: fracture, contusion, laceration
- O respiratory: trouble breathing, infection
- O neurological: dizziness, headaches, numbness and tingling, fatigue
- O psychological: anxiety, stress, depression
- O cardiac: chest pain or tightness, high blood pressure, clots
- O other (specify):

B. How did this injury/illness affect you?

- O It DID NOT AFFECT my ability to perform my regular job duties.
- O It DID AFFECT my ability to perform my regular job duties.

C. What did you do as a result of the injury? (Mark ALL that apply.)

- O sought medical care
- O applied for worker's compensation
- O traded flight schedules
- O took sick, personal, vacation or uncompensated time

D. Did you lose time from work?

- O no time lost
- O 1 day
- O 2-6 days
- O 1 week -1 month
- O more than 1 month
- O don't know

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Injury or Illness #2

A. Please describe the injury/illness. (Mark ALL that apply.)

- O musculoskeletal: strain or sprain, joint aches and pains
- O musculoskeletal: fracture, contusion, laceration
- O respiratory: trouble breathing, infection
- O neurological: dizziness, headaches, numbness and tingling, fatigue
- O psychological: anxiety, stress, depression
- O cardiac: chest pain or tightness, high blood pressure, clots
- O other (specify):

B. How did this injury/illness affect you?

- O It DID NOT AFFECT my ability to perform my regular job duties.
- O It DID AFFECT my ability to perform my regular job duties.

C. What did you do as a result of the injury? (Mark ALL that apply.)

- O sought medical care
- O applied for worker's compensation
- O traded flight schedules
- O took sick, personal, vacation or uncompensated time

D. Did you lose time from work?

- O no time lost
- O 1 day
- O 2-6 days
- O 1 week -1 month
- O more than 1 month
- O don't know

Injury or Illness #3

A. Please describe the injury/illness. (Mark ALL that apply.)

- O musculoskeletal: strain or sprain, joint aches and pains
- O musculoskeletal: fracture, contusion, laceration
- O respiratory: trouble breathing, infection
- O neurological: dizziness, headaches, numbness and tingling, fatigue
- O psychological: anxiety, stress, depression
- O cardiac: chest pain or tightness, high blood pressure, clots
- O other (specify):

B. How did this injury/illness affect you?

- O It DID NOT AFFECT my ability to perform my regular job duties.
- O It DID AFFECT my ability to perform my regular job duties.

C. What did you do as a result of the injury? (Mark ALL that apply.)

- O sought medical care
- O applied for worker's compensation
- O traded flight schedules
- O took sick, personal, vacation or uncompensated time

D. Did you lose time from work?

- O no time lost
- O 1 day
- O 2-6 days
- O 1 week -1 month
- O more than 1 month
- O don't know

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Please take care to answer #13, 14 and 15 COMPLETELY. These questions are essential to our understanding of flight attendant health.

13. In the **past week**, how many days did you experience the following symptoms?

	Never (0 days)	*Rarely (1-2 days)*	*Sometimes (3-4 days)*	*Often (5-6 days)*	*Every day (7 days)*
eye irritation, eye pain	O	O	O	O	O
blurred or altered vision	O	O	O	O	O
sinus congestion	O	O	O	O	O
ear pain/blockage	O	O	O	O	O
nosebleeds or irritation	O	O	O	O	O
irritated/burning/sore throat	O	O	O	O	O
cough	O	O	O	O	O
hoarseness/voice loss	O	O	O	O	O
shortness of breath	O	O	O	O	O
chest tightness	O	O	O	O	O
chest pain	O	O	O	O	O
heart racing or pounding	O	O	O	O	O
stomach pain	O	O	O	O	O
nausea	O	O	O	O	O
vomiting	O	O	O	O	O
diarrhea	O	O	O	O	O
bloating	O	O	O	O	O
fainting	O	O	O	O	O
dizziness	O	O	O	O	O
loss of coordination/balance	O	O	O	O	O
shaking or tremors	O	O	O	O	O
numbness or tingling in the face or extremeties	O	O	O	O	O
severe headache	O	O	O	O	O
confusion/difficulty finding words, counting, thinking	O	O	O	O	O
difficulty concentrating	O	O	O	O	O
unusual tiredness or fatigue	O	O	O	O	O
anxiety or stress	O	O	O	O	O
depressed mood	O	O	O	O	O
apathy	O	O	O	O	O
irritability	O	O	O	O	O
sleep disturbances, inability to stay awake or go to sleep	O	O	O	O	O
alterations in taste or smell	O	O	O	O	O
chemical sensitivity	O	O	O	O	O
calf pain	O	O	O	O	O
back pain	O	O	O	O	O
foot pain	O	O	O	O	O
shoulder/elbow/hand/wrist pain	O	O	O	O	O
generalized muscle aches	O	O	O	O	O
muscle weakness	O	O	O	O	O

THANK YOU - just a few more minutes to finish the survey!

14. In the **last 12 months**,have you sought treatment for any of the following symptoms?

		***IF "YES"** you sought treatment, are you currently being treated?*
reactive airways, sinusitis or allergies	O yes O no	O yes O no
shortness of breath or reduced lung capacity	O yes O no	O yes O no
other respiratory symptoms (specify): _____	O yes O no	O yes O no
severe headaches	O yes O no	O yes O no
loss of coordination/balance	O yes O no	O yes O no
tremors or shaking	O yes O no	O yes O no
seizures or loss of consciousness	O yes O no	O yes O no
loss of memory or concentration	O yes O no	O yes O no
altered vision (unrelated to glasses or contact lenses)	O yes O no	O yes O no
numbness or tingling in the face or extremities	O yes O no	O yes O no
dizziness/lightheadedness	O yes O no	O yes O no
rashes or hives	O yes O no	O yes O no
unusual tiredness or fatigue	O yes O no	O yes O no
muscle weakness	O yes O no	O yes O no
diffuse joint pain or aches	O yes O no	O yes O no
nausea	O yes O no	O yes O no

15. Has a health care provider **ever** told you that you have any of the following?
PLEASE provide an answer, "yes" or "no" to EVERY illness listed.

		***IF "YES"** you have been told you have this, are you currently being treated?*
Overweight/obesity	O yes O no	O yes O no
High blood pressure	O yes O no	O yes O no
Heart disease	O yes O no	O yes O no
Heart attack	O yes O no	O yes O no
Stroke	O yes O no	O yes O no
Aneurysm	O yes O no	O yes O no

Has a health care provider **ever** told you that you have any of the following?

IF "YES" *you have been told you have this, are you currently being treated?*

Chronic Obstructive Pulmonary Disease (COPD)	O yes O no	O yes O no
Lung fibrosis	O yes O no	O yes O no
Pneumonia	O yes O no	O yes O no
Pulmonary embolus, blood clots, Deep Vein Thrombosis (DVT)	O yes O no	O yes O no
Chronic bronchitis	O yes O no	O yes O no
Asthma	O yes O no	O yes O no
Cancer		
Skin (i.e. melanoma)	O yes O no	O yes O no
Bone	O yes O no	O yes O no
Blood (i.e. leukemia)	O yes O no	O yes O no
Lung	O yes O no	O yes O no
Brain	O yes O no	O yes O no
Reproductive (i.e. breast, ovary, uterus)	O yes O no	O yes O no
Gastrointestinal (i.e. rectal, stomach, pancreas)	O yes O no	O yes O no
Kidney	O yes O no	O yes O no
Liver	O yes O no	O yes O no
Kidney disease	O yes O no	O yes O no
Liver disease	O yes O no	O yes O no
Parkinson's Disease	O yes O no	O yes O no
Multiple Sclerosis (MS)	O yes O no	O yes O no
Epilepsy/seizure disorder	O yes O no	O yes O no
Migraine headache(s)	O yes O no	O yes O no

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Has a health care provider **ever** told you that you have any of the following?

IF "YES" *you have been told you have this, are you currently being treated?*

Infertility	O yes O no	O yes O no
Dysmenorrhea	O yes O no	O yes O no
Adverse pregnancy outcome	O yes O no	O yes O no
Hormonal irregularities	O yes O no	O yes O no
Hearing loss	O yes O no	O yes O no
Vertigo	O yes O no	O yes O no
Meniere's Syndrome	O yes O no	O yes O no
Low back pain	O yes O no	O yes O no
Rheumatoid arthritis	O yes O no	O yes O no
Osteoarthritis	O yes O no	O yes O no
Fibromyalgia	O yes O no	O yes O no
Chronic fatigue symdrome	O yes O no	O yes O no
Thyroid disorder(s)	O yes O no	O yes O no
Sleep disturbance(s)	O yes O no	O yes O no
Depression/anxiety	O yes O no	O yes O no
Multiple chemcial sensitivity disorder	O yes O no	O yes O no
Autoimmune disorder (i.e. lupus, i.e. HIV) (specify): _____	O yes O no	O yes O no
Eczema	O yes O no	O yes O no
Psoriasis	O yes O no	O yes O no
Allergies (specify): _____	O yes O no	O yes O no
Chronic intestinal/stomach disease	O yes O no	O yes O no
Other illness specify): _____	O yes O no	O yes O no

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SECTION 3: Tell us about yourself

16. How old are you?

☐☐ years

17. What is your gender?
- ○ female
- ○ male

18. Have you ever smoked more than 100 cigarettes (5 packs) in your lifetime?
- ○ no ***If "no," skip to Question 19.***
- ○ yes

If "yes," please complete Questions 18a, 18b, and 18c.

18a. Do you currently smoke, or did you smoke in the past?
- ○ Yes, I currently smoke.
- ○ No, I currently do not smoke, but I did smoke in the past.

18b. For how many years have you smoked or did you smoke in the past?
- ○ <5 years
- ○ 5-10 years
- ○ 11-20 years
- ○ >20 years

18c. How many cigarettes do you smoke or did you smoke in the past?
- ○ less than 1/2 a pack per day
- ○ 1/2-1 pack per day
- ○ more than 1 pack per day

19. Does anyone who **currently** lives in your home smoke cigarettes or cigars, or smoke other tobacco products while they are in your home?
- ○ yes
- ○ no

20. How much schooling have you completed?
- ○ less than high school
- ○ high school or GED
- ○ some college but no degree
- ○ two-year college degree
- ○ four-year college degree
- ○ graduate school education

WOULD YOU CONSIDER PARTICIPATING IN A STUDY TO UNDERSTAND CABIN AIR AND FLIGHT CREW HEALTH THAT WOULD INVOLVE A MINIMAL AMOUNT OF YOUR TIME AND BE IN CONNECTION WITH YOUR REGULAR FLYING DUTIES?
- ○ yes
- ○ no

Thank you! Return the survey in the postage paid envelope to:
Eileen McNeely, PhD, MS, RNP
Harvard School of Public Health, Building 1 - Annex
665 Huntington Avenue, Boston, MA 02115

Survey questions include adaptations from the following sources:
Job Content Questionnaire
CDC, NCHS, National Health and Nutrition Examination Survey (NHANES)