**This is a brief summary and should not be taken as detailed minutes or an endorsement of any technology described.**

**Summary and Report for**

# Sensors for the Aircraft Cabin Environment

**A Workshop Organized by the FAA Center of Excellence for Airliner Cabin Environment Research**

**Held January 19 and 20, 2005**
**at Boeing, Everett, WA**

**Barton C. Prorok**
**for the ACER CoE**
**January 27, 2005**

## I. INTRODUCTION

The following is a summary report of the workshop titled "Sensors for the Aircraft Cabin Environment," held for the FAA Center of Excellence for Airliner Cabin Environment research (ACER) at a Boeing facility in Everett, WA, January 19 and 20th, 2005. This summary is organized into 6 sections, including:

I. **Introduction**
II. **Meeting Agenda**
III. **ACER Team Presentations**
IV. **Sensor Industry Presentations**
   a. Sampling Presentations
   b. Pathogen Detection Presentations
   c. IAQ Sensing and Chemical Detection
   d. Sensor Networks/Miscellaneous Topic
V. **Moderated Discussion**
VI. **Wrap-Up**

Relevant details the CoE effort and corresponding discussions of each presentation are given. The CoE is currently asking authors for permission to post copies of presentations on the CoE website. Some presentations will be available immediately and others will need to be authorized/revised by company or organizational officials before posting. The CoE will make every effort to provide the most complete information in a timely manner.

This is a brief summary and should not be taken as detailed minutes
or an endorsement of any technology described.

## II. MEETING AGENDA

### Day 1 – January 19th, 2005

| Date and Time | Activity |
|---|---|
| 8:00 a.m. – 8:20 a.m. | **Introduction to the Workshop**<br>*Objectives of the workshop, review of the agenda and identification of the participants.* |
| 8:20 a.m.– 8:40 a.m. | **Objectives of the FAA ACER CoE**<br>*A brief introduction to the FAA Center of Excellence for Airliner Cabin Environment Research, with an emphasis on sensor-rated aspects.* |
| 8:40 a.m. – 8:50 a.m. | **Contaminants of Concern — The Need for Sensing**<br>*Brief background on the contaminants of concern in the airliner cabin environment, including gaseous species, particulates and pathogens.* |
| 8:50 a.m. – 9:10 a.m. | **Sensor Requirements and Comparison Method Jack**<br>*Brief summary of the sensor requirements for aircraft cabin use and a description of the survey method to be used by the CoE in comparing sensors.* |
| 9:10 a.m. – 10:10 a.m. | **Invited Presentations — Sampling I**<br>**Chris van Netten, University of British Columbia**<br>*"History of, and Criteria for, the Development of the VN Air Sampler Used to Capture Sporadic Air Quality Events."*<br>**Edward Stuebing, US Army ECBC**<br>*"Advanced Aerosol Sampling Technologies and Bio Aerosol Testing for Aircraft Cabin Air Quality."* |
| 10:10 – 10:30 a.m. | **Break** |
| 10:30 a.m. – noon | **Invited Presentations — Sampling II and Pathogen Detection I**<br>**Erich Rupprecht, Rupprecht & Patashnick Co., Inc.**<br>"Air Sampling and Monitoring Systems for Biological Aerosols, Particulate Matter Mass and Species, Ozone and VOC's."<br>**Charles Call, MesoSystems Technology, Inc.**<br>*"Air Sampling Solutions for Aircraft."*<br>**Jerry Cabalo, US Army ECBC**<br>*"Micro-UV Low Power Biofluorescence Sensor."* |
| noon – 2:00 p.m. | **Lunch with Informal Discussions**<br>*A light lunch will be available, with participants having an opportunity to continue informal discussions.* |
| 2:00 p.m. – 4:30 p.m. | **Invited Presentations — Pathogen Detection II**<br>**Daniel Cousins, MIT Lincoln Laboratory**<br>*"Biosensing for Passenger Aircraft Protection."*<br>**R. Paul Schaudies, Science Applications International Inc.**<br>*"SAIC's Molecular Radar Reliably Identifies Organisms."*<br>**Gregory Bearman, Jet Propulsion Laboratory**<br>*"Microbial Characterization of Commercial Airliners Cabin Air."*<br>**Geoffrey Wilson, Hach Homeland Security Technologies**<br>*"Diode Laser Induced Fluorescence Sensing of Airborne Biological Particles."*<br>**D. Richard Shonk, NMS BioDefense**<br>*Title to be announced.* |
| 4:30 p.m. | **Formal Meeting Adjourns for Day 1** |
| 4:30 p.m. – 6:00 p.m. | **Informal Discussions and Poster Show/Exhibits**<br>*Opportunity for informal discussions. A poster area will be provided and space for exhibits is available.* |

**This is a brief summary and should not be taken as detailed minutes or an endorsement of any technology described.**

## Day 2 – January 20th, 2005

| Date and Time | Activity |
|---|---|
| 8:00 a.m. – 10:00 a.m. | **Invited Presentations — IAQ Sensing and Chemical Detection**<br>**John Birks, 2B Technologies Inc.**<br>*"Portable Ozone, NO and CO Instruments for Monitoring Cabin Air of Commercial Airliners."*<br>**Richard Cernosek, Micro-Analytical Systems Department, Sandia National Laboratory**<br>*"Sandia's Micro-Chemical Analysis Systems."*<br>**H. James Harmon, Oklahoma State University**<br>*"Real-Time Reagentless Detection of Chemicals and Chemical Agents at Sub-PPB Levels."*<br>**Shekar Viswanathan, National University**<br>*"Indoor Air Analysis using GC/SAW zNose® Sensor System"* |
| 10:00 – 10:30 a.m. | **Break** |
| 10:30 a.m. – noon | **Invited Presentations — Sensor Networks/Miscellaneous Topics**<br>**Steven Sunshine, Smiths Detection Inc.**<br>*"Distributed Sensing for Cabin Air Quality."*<br>**Donna Shandle, JPM NBC Contamination Avoidance**<br>*"Department of Defense Program of Detection/Sensors."*<br>**Joseph Stetter, SRI International**<br>*"Nanotechnology for Indoor Air Quality Sensors."* |
| noon – 2:00 p.m. | **Lunch with Optional Facility Tour or Informal Discussions**<br>*A light lunch will be available, with participants having the option of either taking a brief tour of the Boeing facility or continuing informal discussions.* |
| 2:00 p.m. – 4:00 p.m. | **Moderated Discussion**<br>*Prioritization of near-term sensor technologies and future microsensor applications.* |
| 4:00 p.m. – 4:30 p.m. | **Wrap-Up**<br>*First draft of the priority lists of current sensors and future applications.* |

## III. ACER TEAM PRESENTATIONS

**NOTE:** A pdf of all presentations by the CoE personnel listed will be available on the ACER website.

### A. Introduction to the Workshop:

Bill Gale of Auburn University kicked off the workshop by briefly stating the objectives of the workshop, reviewing the agenda and identifying the participants present.

### B. Objectives of the FAA ACER CoE:

Yan Chen of Purdue University presented a brief introduction to the FAA Center of Excellence for Airliner Cabin Environment Research, with an emphasis on sensor-rated aspects.

### C. Contaminants of Concern — The Need for Sensing:

Tracy Thatcher of Lawrence Berkeley National Laboratory gave a brief background on the contaminants that might potentially be of concern in the airliner cabin environment, including gaseous species, aerosols, particulates and pathogens. Specific contaminants of interest were listed and include: ozone, CO, $CO_2$ airborne allergens, hydraulic fluids, oils, deicing agents, degradation products of these fluids, pesticides, infectious agents, other microbial agents (molds, anthrax), organic chemicals, and particles/dust. Also presented were possible applications of information garnered from the sensors. For example, Ozone — trigger controlled maintenance or evaluation compliance; Carbon dioxide — adequacy of ventilation rates; and Infectious agents — emergency medical response.

### D. Sensor Requirements and Comparison Method:

Bill Gale of Auburn University gave a brief summary of the sensor requirements for aircraft cabin use and a description of the survey method to be used by the CoE in comparing sensors.

### E. Sensor Survey Matrix

Bill Gale of Auburn presented an explanation of the sensor survey form with instructions of how to fill it out to normalize the responses of industry. The matrix includes: company, type of sensor, capture principle, transduction method and principle, target(s), lower detection limit, upper detection limit, resolution (accuracy), specificity, preconcentration or sampling requirements, system mass (volume & power requirements), response time, cost, operator skill level and calibration process.

The audience members had several questions and comments during these presentations:

- A question was asked on what kinds of sensors and instruments the CoE is considering and whether autonomous operation is required? Answer: all sensors are being considered at the moment and will be narrowed down as sensing tasks are refined. Autonomous operation is essential for systems that are to be permanently installed in the cabin, as opposed to used for portable research packages.

- A question was asked on what calibration of the sensors is required? Answer: This is sensor specific and will be determined as part of the selection process.
- A comment was made that long-term operation and maintenance should be included as a requirement of the sensor system.
- A comment was made that cartridge sensors are a viable option for an aircraft system.
- A comment was made that the CoE should define conditions for resolution and accuracy of the sensors for specific agents so as to define and minimize false alarm rates.
- A comment was made that the CoE should define high-regret and low-regret responses and the borderline between them.
- A comment was made that the CoE should focus on understanding the metrics for a specific sensor as well as its role as a component in a sensor system.
- A question was posed as to whether literature currently exists for monitoring cabin air-quality? Answer: Greg Bearman from the Jet Propulsion lab was to present information is this regard that afternoon.
- A comment was made that the CoE should define two aspects of the sensors and agents to be sensed; 1) define the sensors and their ability to detect and 2) define what sensor response means for human health impact and the ramifications of positive responses.

## IV. SENSOR INDUSTRY PRESENTATIONS

During the two days of the workshop, sensor industry personnel gave 15 presentations on topics of high relevance to the CoE. These are divided into 4 categories: sampling, pathogen detection, IAQ sensing and chemical detection and sensor networks and miscellaneous topics. The CoE is currently asking authors for permission to post copies of presentations on the CoE website. Some presentations will be available almost immediately and others will need to be authorized/revised by company or organizational officials before posting. The CoE will make every effort to provide the most complete information in a timely manner.

## A. Sampling Presentations

### 1. Chris van Netten, University of British Columbia "History of, and Criteria for, the Development of the VN Air Sampler Used to Capture Sporadic Air Quality Events."

This presentation focused on the development of a handheld, portable air sampler for air quality events. The sampler can be deployed when cabin crew suspect an air quality incident is occurring. It consists of a small cylinder containing a fan that draws air through the device. A filter collects material from the air, which is analyzed later. The sampler was deployed on several different aircraft during incidents define by the crew. Here an incident is defined as any instance where the pilot or crew decided to fill out a report on the event. The speaker also discussed a passive badge for real-time CO monitoring, in the COTS stage. A helpful comment from the speaker was to keep the sensor and system simple, and do not distract the crew with unnecessary information.

Questions for the speaker:

- How long for good sampling? 20 min.
- Is it a real-time sensor? No, but can be combined with real-time sensors.
- What volume of air does it sample? Type I – 1 L per min, Type II – 3 L per min, and Type III – 15 L per min.
- Can it be integrated with an autonomous system for the aircraft? Yes provided is meets aircraft regulations.
- Has it been deployed in buildings? No, still in prototype stage.
- What are the consequences/rational for reporting the information from the sensors? Health affect for crew and passengers.

### 2. Edward Stuebing, US Army ECBC "Advanced Aerosol Sampling Technologies and Bio Aerosol Testing for Aircraft Cabin Air Quality."

This presentation, from ECBC (Edgewood Chemical Biological Center) focused on describing advanced aerosol technologies for high volume collection. They are highly applicable to serve as collectors for trigger sensor systems. Also mentioned that most collector inlets only collect ~ 3% of the actual agent, thus greatly diluting the agent. The speaker mentioned that new inlets engineered to collect more sample have improved the problem with greatly increased capture of the agent.

For their sampler the sampling efficiency peaks around 2 μm, smaller particles have too little inertia and larger particles have too much inertia. Current power draw is 500 W and they are moving to a system that draws 10 W. Draws 300 L/min. Size is significant and a scale down would be required for an aircraft. The collector will operate effectively in moderately variable pressure environments.

The speaker described where aerosols end-up in the human body based upon their size, particles < 0.5 μm settle in the deep lung while those > 0.5 μm settle in the head's airways. Moreover, depending on their size particles remain suspended in the air for different times. For example:

| | |
|---|---|
| 0.5 μm | 41 hours |
| 1.0 μm | 12 hours |
| 3.0 μm | 1.5 hours |
| 10 μm | 8.2 minutes |
| 100 μm | 5.8 seconds |

Another important fact was that viruses tend to ride other particles in aerosols rather than remain on their own. The volume flow rate through an aircraft can be calculated as (10 ACH)*(2m$^3$ per person)*(150 passengers per cabin) = 3000 m$^3$ h$^{-1}$ = 50 m$^3$ min$^{-1}$.

The speaker offered that ECBC offers an impartial governmental test bed for aerosol sampling & analysis in both BL-2 & BL-3 laboratories. Finally the speaker discussed a puff generator, of the kind used by asthmatics, which can be loaded with an agent to emulate a sneeze or cough. This is contracted to a company in Switzerland.

3. **Erich Rupprecht, Rupprecht & Patashnick Co., Inc. "Air Sampling and Monitoring Systems for Biological Aerosols, Particulate Matter Mass and Species, Ozone and VOC's."**

This presentation described a series of personal sampling system for aerosoled agents: 1) TEOM personal dust monitor, measures mass loading of filter on a continuous basis during sampling; 2) ChemPass small sampler for monitoring gases (mechanism not given); 3) Ogawa & Radiello passive sampling system for VOCs and other gases, no motors or electrical parts, hourly monitoring.; 3) ASAP system for biological agents, rapid deployment, small footprint 1ft$^3$ at 30 lbs, 200 L/min, 1-10 μm particles, automated chain-of-custody features, using RFID, compatible with PCR and other techniques, 8 hrs of sampling for battery, samples captures in polyurethane foam (PUF) that does not clog, extraction efficiency of 95%, battery operated.

4. **Charles Call, MesoSystems Technology, Inc. "Air Sampling Solutions for Aircraft."**

This presentation described a hand-held bio-capture device currently under development. The device can process 200 L of air per min using a rotating impactor collector. Particles are collected in a filter that is in cartridge format that marker for $30. Few details of the devices metrics were given.

A small unit is under development in badge format with the capabilities of: 40 L/min at 2 W with a battery life of 9 hours, using low ΔP impaction, with good collection efficiency, ~ 60%, for > ~ 3 μm.

## B. Pathogen Detection

### 1. Jerry Cabalo, US Army ECBC "Micro-UV Low Power Biofluorescence Sensor."

This presentation focused on describing a the MicroUV biosensor under development. It is based on fluorescence and light scattering of spore forming agents or any particle possessing fluorescent properties. Employs multiple wavelength analysis using several light emitting diodes (LEDs) and a photomultiplier combined with an optical filter for spectral analysis. Able to handle 100-500 particles per L in 15 seconds of time. No consumables are required unless it is battery operated, footprint of 800 $cm^3$, I kg with battery, draws 500 mW of power. Discriminates between biological and nonbiological particles. The techniques has to potential to provide ultra low cost and size for ubiquitous aircraft deployment.

This was a new concept, and for many in the room it was their first introduction to it. The audience asked numerous questions and were moderately excited about the concept.

### 2. Daniel Cousins, MIT Lincoln Laboratory "Biosensing for Passenger Aircraft Protection."

This proposal described three systems currently under development, the BAWS, BASS, and Canary devices. The BAWS system is fluorescent based and is the main trigger for the military. It employs a UV laser based excitation for multiple wavelength spectral analysis. The BASS system is similar in makeup. Both are detailed in the DARPA report J Carrano & T Jeys, DARPA Microsystems Technology Office, 2004, "Chemical Biological Sensor Standards Study" The Canary device employs genetically modified immune cells from mice to tailor receptors for target bacteria or viruses. These cells are known to send signals when their receptors are triggered.

The speaker advised the CoE should focus on 4 issues: (1) develop realistic scenarios; (2) characterize cabin environment; (3) biosensing; (4) develop concept of operations. It was also advised to define the minimum infectious dose issues (low to high) for: Q fever, smallpox, plague, anthrax, botulism.

### 3. R. Paul Schaudies, Science Applications International Inc. "SAIC's Molecular Radar Reliably Identifies Organisms."

This presentation focused on an emerging technique called molecular radar. The technique employs a microarray process that uses spectral techniques to examine approximately 5000 oligonucleotide base-pairs to detect biological species, takes 4 hours. Device is capable of performing genetic identification of unknowns into the relevant strains and categories. Develop libraries of known agents for quick comparisons. Can also determine signs of genetic engineering. False IDs are 1 in $10^{10}$! The device is in the early stages of development. The downside is that it will be expensive 20-40K and the microarrays are rather expansive ~ $500 each and that it will likely not be suitable to deploy on an aircraft. Rather, the technique will be an after the incident confirmation technique that would be exceptionally faster than PCR.

4. **Gregory Bearman, Jet Propulsion Laboratory "Microbial Characterization of Commercial Airliners Cabin Air."**

This presentation focused on a study that collected and analyzed air samples on 4 different flights. The study was performed in association with ASHRAE and used the Mesosystems 650 air sampler. Both the sampling locations and sampling time were varied. Culture methods were employed and biochemical and DNA marker methods were used to identify species. The study found on the order of 100 viable microbes per liter of air, most of which consisted of *streptococcus* and *neisseria* bacteria. Other recovered pathogens included pathogenic species of *abiotrophia*, *gemella*, *haemophilus*, *terrahaemophilus*, *rothia*, *fusobacterium*, and *prevotella* were recovered in varying abundance. Cost for 4 flights was approximately $250k, mostly to do the analytical work.

5. **Geoffrey Wilson, Hach Homeland Security Technologies "Diode Laser Induced Fluorescence Sensing of Airborne Biological Particles."**

This presentation focused on describing a diode laser induced fluorescence sensing of airborne biological particles. Its operation is similar to that of the Micro-UV Low Power Biofluorescence Sensor described in 1. above. Here, the device employs multiple wavelength analysis using several light emitting diodes (LEDs) and a photomultiplier combined with an optical filter for spectral analysis. Proposed as a very inexpensive trigger for prompting detailed sensing analysis. Has a sampling rate of 30 L/min. Has a response time of 30s with a capability of 20-40 particles/L and a detection probability of 98%.

6. **Clement Furlong, University of Washington "Surface Plasmon Resonance"**

This presentation focused on describing the Spreeta$^{tm}$ surface plasmon resonance detector. The device is commercially produced by Texas Instruments and has an ultra low footprint and cost. Surface plasmon resonance (SPR) is a phenomenon occurring at metal surfaces (typically gold and silver) when an incident p-polarized light beam strikes the surface at a particular angle, greater than the total internal reflection (TIR) angle. At the specific resonance wavelength, the incident light is almost completely absorbed, which results in the creation of a plasmon, a group of collectively oscillated electrons, which behave like a single electrical entity. The evanescence electromagnetic field extends several hundreds of nanometers above the metal surface (depends on wavelength of incident light). The characteristic of this phenomenon, which makes SPR an analytical tool is that any change in the chemical composition of the environment within the range of the plasmon field causes a change in the wavelength of light that resonates with the plasmon.

In experiments the Spreeta sensors produced by Texas Instrument was used. This inexpensive dual channel highly sensitive (up to 2 x 10-6 RIU) and miniature sensors are very suitable for fundamental investigations as well as for hand-handled devices development.

Staphylococcus aureus enterotoxin B (SEB), a small protein toxin was directly detectable at sub-nanomolar levels and with amplification at femtomolar levels in buffer, as well as in more complex solutions, including milk, urine, and seawater.

In another experiments, an antibody-based competition assay has been developed using a surface plasmon resonance (SPR) sensor platform for the detection of trinitrotoluene (TNT). The objective of this work was to develop a sensor-based assay technology to use in the field for real-time detection of land mines. The device is reliable, however it employs antibody capture and thus requires a DI water supply for the capture process, requires frequent washing before measurements, and requires a collector.

## C. IAQ Sensing and Chemical Detection

### 1. John Birks, 2B Technologies Inc. "Portable Ozone, NO and CO Instruments for Monitoring Cabin Air of Commercial Airliners."

This presentation focused on describing an Ozone detector that has been flight-tested in an outdoor setting. It operated by UV absorption using a 254 nm lamp. So far the company has sold ~ 250 ozone monitors, 2 NO monitors and are working on CO and $CO_2$ monitors.

The Ozone device has been deployed previously on Italia airlines, but no data has been retrieved from this deployment yet. The device has a:

- Footprint of 3x8.5x11
- 2.2 kg, 5 lbs
- 4 watt draw
- operates on a 12 V DC battery, 8-12 hour recharge
- Precision = 1.5 ppb (0.8 ppb in practice)
- Accuracy = 1.5 ppb or 2%; absolute method
- GPS capable
- Flash memory interface

Standard features: real-time clock; averaging 10 s – 1 h intervals; serial & USB ports; internal datalogger with 28,000 lines of data. Selectivity: same method as used by EPA and worldwide for air pollution compliance. Also performed stratospheric folding — vertical profiling data at Ferryland, Newfoundland. Elevated ozone in the troposphere. Seema: check website: www.twobtech.com

2. **Richard Cernosek, Micro-Analytical Systems Department, Sandia National Laboratory "Sandia's Micro-Chemical Analysis Systems."**

This presentation focused on a microelectromechanical systems (MEMS) biochemical detection & analysis probe in portable and handheld packages for either bench scale analytical instruments or spectrometers. The device contains 3 components, a preconcentrator (silicon microhotplate), a spiral column on silicon (1 $cm^2$; 86 cm column length) and a surface acoustic wave (SAW) device (4 devices, variously coated). Basically, a mini GC column. The overall package size is comparable to a brick and offers 2-min analysis and draws 4 W of power. Detection discrimination is by means of retention time or differential SAW response. The device is capable of performing 24 assays at one time with a cost of ~ $5-10K per unit. The device has been deployed in airports and subways, with one in the Boston subway system for 2 years that has processes 250K samples to date. The device is capable of 4 - 8 channels in a handheld unit.

3. **H. James Harmon, Oklahoma State University "Real-Time Reagentless Detection of Chemicals and Chemical Agents at Sub-PPB Levels."**

This presentation was focused on a device that employs evanescent wave excitation measurements to detect chemical and biological agents at sub-ppb levels. In this method, the electromagnetic field for the interrogating laser light will shift the evanescence wavelength of surface molecules and excite suitable fluorophors and create a variable-intensity fluorescent image of sensor surface, with local intensity modulated by the presence of agents. The device used porphyrin surfaces, which are usable for over 4 years without special storage (room temperature, unsealed). The measurement occurs in less than 1 second with 7 ppm accuracy depending on the analyte. No calibration is needed and no preconcentration of the sample is required. The system consists of a 9V battery, blue LED, reactive porphyrin surface, and commercial spectrophotometer. The battery lasts 8 h. No reaction time is required and the device can operate autonomously. Expected cost is $3500 per unit.

4. **Shekar Viswanathan, National University "Indoor Air Analysis using GC/SAW zNose® Sensor System"**

This technology is similar to that presented by the Sandia speaker, #2 directly above. It proposes indoor air analysis using the GC/SAW zNose Sensor System, a commercialized device based upon surface acoustic wave (SAW) devices combined with gas chromatography. It can obtain results in as little as 10 seconds for a specific analyte. The device monitors several chemical components of several agents, enabling generation of a fingerprint map, which can be stored in library format for identification purposes. Also will have problems when the agent is not isolated from other agents with similar chemical constituents. Limits of detection are not too good for IAQ applications, 10s of ppb. See znose.com for more information.

## D. Sensor Networks/Miscellaneous Topics

### 1. Steven Sunshine, Smiths Detection Inc. "Distributed Sensing for Cabin Air Quality."

This technology uses the chemiresistor approach to detection. Here, conductive nanoparticles are dispersed in a nonconductive matrix. Vapor from the target agent causes swelling, which causes disconnects in the conductive pathways and results in a change in base resistance. Response times are in seconds (including response and recovery). Sensors are formed in parallel arrays to achieve sensitivity. Changing the polymer enables sensing of different analytes. By making large arrays with a numerous variety of polymers, a pattern of responses is produces and interpreted using pattern matching algorithms to identify agents, almost like a spectroscopic fingerprint. Has potential for very low cost system, ~$1000; however, it is not very sensitive. Detectable concentrations are 10-1000 μg $m^{-3}$. Minimum detection limit is 2-3 O/M below immediately dangerous to health levels. An effort was described to develop detectors based on single wall carbon nanotubes and inherently conducting polymers.

### 2. Donna Shandle, JPM NBC Contamination Avoidance "Department of Defense Program of Detection/Sensors."

This presentation dealt with a review of fielded instruments in support of military activities, with some civilian applications. Offered to consult for the CoE in areas of her specialty. Has knowledge in DoD process: spec requirements, build, test, etc.

### 3. Joseph Stetter, SRI International "Nanotechnology for Indoor Air Quality Sensors."

This presentation focused on nanotechnology solutions to sensing in the air cabin environment. Described a CO sensor that was based on carbon nanotubes (CNTs) and cyclic voltometry, which is capable of sensing 1-1000 ppm. The device weighs 20 grams, requires minuscule power, and can operate for more than one year at a cost of $100. See Transducer Technology, Inc. www.transducertech.com orwww.kwjengineering.com.

## V. MODERATED DISCUSSION

This part of the workshop was presided over by Byron Jones of Kansas State University and designed to solicit opinions of the sensor and system components experts attending the workshop. The hope was to examine each agent to be detected and list all requirements and COTS/GOTS solutions as well matters and concerns for particular agents. Since the devices will be installed in the air cabin environments it is assumed that all devices must adhere to all requirements mandated by the FAA for such installation. Thus, the focus of this discussion was limited to only the agents and corresponding sensing methodologies and particulars. The discussion was broken into several themes including: ozone, CO, multi-functional sensors, hydraulic fluid etc., pathogens (infectious and non-infectious), and organics (including chem. agents). Responses from the audience are listed after each section.

### Ozone

- 0.25 ppm peak, 0.1 ppm time averaged over 3 hours limit. This is the target for operation, but not necessarily ACER's research need.
- Electrochemical sensors $ 200 – 300.
- UV technology $ ~ 4 k.
- HMOS $ 1 – 1.5 k.
- Ogawa passive badges (limits TBD, order of 10 ppb).
- Sample tubes (not real time).
- All except sample tubes give real time data.
- Electrochemical sensors lower detection limit at ~ 0.02 ppm.
- Resolution similar to sensitivity.
- UV is ppb level.
- Stability.
- Longevity.

### CO

- Need 10 ppm accurately, 1 ppm reasonably, 100 ppb or lower for pre-incident detection.
- Nanotubes (Relatively immature).
- Solid electrolyte sensors (Capabilities?).
- Wet electrochemical 1 ppm @ $ 200 (or less). Easy to buy in quantity.
- Available as COTS, but need packaging, implementation, interfacing. No further technology development at the $ 100 – 200 level.
- False alarm rate relatively low, can put in a carbon prefilter to remove organics that might cause false positive.
- Like most other sensors need certification for EMI, vibration.
- Colorimetric.
- Least of the problems as can buy one that works and repackage at a reasonable price. Do need to downselect from competing designs to fast-track the best choice.

- Manufacturers unlikely to absorb certification costs, since a small volume application.
- There is a certified unit (ref: Richard Fox, made in AZ), but can only do 50 ppm, do we meet the standard, which is inadequate for research use.
- $ 600 fully packaged and ruggedized, with data logger.

**Multifunctional Sensors**
- Mining industry, first responders use multiple integrated sensors (CO, plus a couple of others).
- Probably can't find a one size fits all commercial unit.

**Hydraulic Fluid *etc.***
- Detect before visible misting.
- TCP, or organophosphates generically? Not all contaminants contain TCP.
- Detecting a leak, versus health monitoring. FAA is interested in whether TCP can be monitored at the level where it has health implications. Still in the fact finding stage. Detecting incipient seal failures will only receive federal support if a health problem is demonstrated.
- Some information on TCP exposure exists, but not agglomerated into a single body.
- Requirement is a data collection capability.
- Airlines would perhaps like a sensor that could isolate the problem to a specific unit and the problem could then be corrected.
- Don't currently know what TCP level is in the cabin.
- Need to worry about breakdown of fluids in contact with hot surfaces, so that byproducts are different and possibly more toxic than the primaries. Hence, don't want to be too specific in choosing a detection capability.
- Better to put a sampling system in (can do with 12 V power) and do detailed lab analysis. Might need a trigger device.
- Provide personal samplers to flight crew to activate after a perceived incident.
- Maybe start with a known problem aircraft. Check to determine that aircraft does/doesn't have fix packages.
- Create an artificial leak and see what comes out.
- TBP toxicity versus TCP. WHO says TBP is not a neurotoxin, whereas TCP is a much bigger issue.
- Broad spectrum survey instrument combined with a second tier or specific detection.

**Pesticides**
- Large genetic variability in human sensitivity.
- Can easily do antibody based sensing. At least some antibodies are already out there. Smallest molecules may be difficult to immunosense.
- Could just do sampling plus lab analysis.
- FAA will provide ACER with info on the regulatory process for pesticides (C/O Jean Watson).

- International list of pesticides is different than US list. Patchwork of nation to nation agreements.
- Pesticides used at international destinations may not be known to the FAA.
- Lots of FAA/EPA info on pesticides, but for aircraft cabin spraying, nothing specifically approved for US cabin use on **occupied** aircraft.
- Residual spraying more complex a problem for characterization than aerosol sprays for instantaneous disinsection.
- Need a control group to eliminate non aircraft environmental exposure, compare flight attendants on sprayed routes with non-sprayed.
- Enzyme based sensing can do broad classes or specific.
- Finite list of approved pesticides (US and international may differ).
- Passenger exposure history has a large effect on sensitivity.
- Large variety of pesticides with widely varying sensitivity.
- IMS rugged and cheap as a survey instrument (as used by DoD).

**Pathogens (Infectious and Non-Infectious)**

- For research level could just sample.
- Sensors for intentional release:
    - Need near real time.
    - Deploying at the airport, not on plane. Works for explosives due to vapor emission, but *e.g.* anthrax will not show up until released into the atmosphere.
    - Look at the previously weaponized pathogens. Do a small array to cover the most likely.
    - Could sample a massive release at the return air duct.
    - Even non-infectious agents can be shed from clothing *etc.* and spread this to a multiple of the number of passengers on the plane.
- Sensors for epidemics:
    - Need near real time.
    - Thermal screening may have discouraged infected persons from traveling, but doesn't help with pre-symptom cases. Also public policy concerns. So thermal may not be the best trigger.
- Sensors for routine disease transfer
    - To determine if ECS is effective and to study health effects, need to sample near the passengers.
    - Sampling return air is not going to answer this.
- DoD type technologies. Collector plus assay strips can do in real time.
- Need to catch problem before passengers disperse (physical carriers or infectious cases).
- Need to make sure that terrorist doesn't have an opportunity to release within the analysis time (*e.g.* the last hour of flight). At least need a fast acting trigger sensor for potential cases.
- False alarm rates must be very low!! Redundant systems, high thresholds.

**Organics (including chem. agents)**

- What is the sensor for (pilot protection, deploy oxygen masks *etc.*)?
- Can the sensor work fast enough to have any impact?

## VI. WRAP-UP

A wrap-up session was presided over by Bill Gale from Auburn University in order to solicit general opinions and information to help aid the CoE in its effort to develop the air cabin sensor system.

Are we ready to down select any technologies? NO

- Further expanded list of agents/chemicals/etc to sense.
- Use cost as a discriminator; however, may limit ability to cover key needs.
- All in one sensor suite could cost $20k. What is the real limit of reasonable cost per unit to place on every aircraft? $10k for 6000 units or $20k for 6000 units. However, some larger models will require several units.
- Also costs of qualification and maintenance must be considered.
- Further define the requirements on a case by case basis.
- The future of air travel will likely focus on only the most basic of services and move away from tailored services.
- Too early to discuss cost, down selecting technologies, we must define the mission before these issues become important. Develop a combined statement of what we want to achieve.
- Devine the environment the sensors will operate in and the particular requirements for the system and the sensors for each specific analyte.
- High-end and low-end sensors.
- Investigate technologies that other countries are developing, Airbus and carriers.
- Define the real treats, both high and low end threats.