International Aviation Conference
Air Quality in Passenger Aircraft:
Providing a safe and comfortable cabin environment
Royal Aeronautical Society, Oct. 16-17, 2003

ASHRAE and FAA
Cabin Environmental Research

David R. Space

Boeing Commercial Airplanes
Cabin Environment
Comfort and Air Quality
Overview

- ASHRAE Aviation Research Plan
- ASHRAE Research Project 1262-RP
  - Objectives
  - Tasks
- Combined ASHRAE/CabinAir Research
- FAA Research and Integration With ASHRAE Research
- Conclusions
ASHRAE

- ASHRAE – American Society of Heating, Refrigeration and Air-Conditioning Engineers

- ASHRAE Transportation Committee TC 9.3 Aviation Research Subcommittee
  - Membership: airlines, component suppliers, flight attendant unions, government agencies, manufacturers, researchers and universities
ASHRAE Aviation Research Committee
Cabin Air Quality Research Plan Outline

Areas of proposed research

- Methodologies for measurement and assessment
- Airplane system generated air contaminants
- Thermal environment and cabin air quality
- Synergism of multiple factors, including environmental and others that can cause symptoms
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<th>Research Teams</th>
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<tr>
<td><strong>Test Methods and Equipment</strong></td>
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<td>Method: ASTM standard process</td>
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Cabin Air Quality Research Plan (Continued)

### Research Teams

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<tr>
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<th>Cabin Air Quality: Multiple Personal and Environmental Factors</th>
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- ASTM standard for selection of air quality instruments - ASTM D6399-99
- Two ASHRAE pilot projects designed to develop methodologies and protocols necessary for a comprehensive study

**957-RP Multiple Factors**
- Explored relationships between measured air quality data and perceived symptoms – 1998 – published, ASHRAE Journal

**959-RP Bleed Air Contaminants**
- Focused on measuring bleed air contaminants – 1999/2000 – published ASHRAE Insights
### Research Teams

#### Test Methods and Equipment

- **ASTM D6399-99**

#### Airplane System Generated Air Contaminants

- ASHRAE Research 959-RP (Pilot Study)
  - Developed protocol and methods
  - Selected equipment
  - Initiated Data-base

#### Thermal Comfort and Cabin Air Quality

#### Cabin Air Quality: Multiple Personal and Environmental Factors

- ASHRAE Research 957-RP (Pilot Study)
  - Developed protocol and methods
  - Reviewed literature and equipment
  - Established data-base

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### Comprehensive Research Study 1262-RP
ASHRAE Research Project 1262-RP

- Relate air quality and other factors to comfort and health-related symptoms reported by passengers and crew on commercial transport aircraft

Principal Aim

To relate perceptions of discomfort or health-related symptoms of flight attendants and passengers to possible causal factors, including cabin and bleed air quality, air pressure, jet lag, inactivity, humidity, flight attendant duty schedule and fatigue, circadian rhythm, stress, and noise
ASHRAE 1262-RP Research Objectives

1. Conduct a literature review of chemical and other factors known to cause symptoms

2. Measure and characterize contaminants in cabin air that are introduced via ECS in a variety of airplane types

3. Measure and characterize contaminants in cabin air that are not introduced via ECS (e.g., bioeffluents)

4. Quantify the effect of aircraft type, maintenance, APU, engine age, and operations-related parameters on cabin and bleed air quality

5. Investigate the relationship of the measured cabin air contaminants, ventilation rates, and other factors with reported symptoms

6. Coordinate with FAA study to install test equipment on two airplanes
ASHRAE Research Project 1262-RP

Two-part study that will use objective measurements in combination with comfort and health symptom measurements

Part 1
- Literature review
- Development of equipment package and protocols
- Preparation comfort/health questionnaires
- “Pilot test” on two aircraft types to evaluate protocols

Part 2
- Protocol and equipment package developed in Part 1
- Multiple aircraft types from three airlines representing the world fleet
- Link with FAA air quality monitoring study
Development of Protocol

- Test equipment package and correction factors
- Questionnaires
- Logistics
- Methodology for flight selection
- Measurement methodology will be submitted to American Society of Testing and Materials (ASTM)
Measurements

- Monitoring on ground and cruise
- Measurement locations include passenger cabin, aisles, galleys, and crew rests
- Measurements:
  - CO₂, CO, O₂, O₃
  - Individual VOCs, semi-vocs
  - Bioeffluents: ethanol, toluene, acetone
  - Pressure
  - Humidity
  - Particulates (RSP)
  - Temperature
  - Ventilation rates
Other Measurements

- Other measurements for consideration:
  - Blood oxygen saturation of cabin crew
  - Multi-point temperature and air velocity
  - Turbulence, 3-D motion
  - Noise
  - Lighting
  - Ventilation effectiveness
  - Biological agents (aeroallergens and toxins)

- Carry-on equipment will be EMI certified
Questionnaires

- Intended to look at comfort and health-related symptoms in relation to air quality, work-related factors, and individual factors
  - Possible correlations
  - Relative importance of factors

- Surveys developed for passengers and cabin crew
  - General information
  - Comfort/health symptoms on flight
  - Background information
Flight Information for Part 1

Part 1
- Four to Six flights
- More than three hours in duration
- Minimum of two different types of aircraft
- Record part numbers for recirculation filters, ozone converters, service, and operational information
- Request data on engine oil and hydraulic fluid consumption
- Record engine, APU operating hours, and maintenance history
- Note airplane configuration (e.g., packs off for no pack takeoff)
Flight Information for Part 2

Part 2

- Protocol and procedures developed in Part 1 will be used in Part 2
- Airplanes will be selected from three different airlines
- Flight selection will consider aircraft type, operating hours on engines, and flight routes
- The total number of flights to be determined by the results of Part 1 and the availability of research funds for Part 2
1262-RP
Tentative Schedules

Part 1
- May 2003 – Pre-bid meeting
- June 2003 – Bids due
- July 2003 – Principal Investigator selected
- **Sept. 2003 – Contract signed**
- Dec. 2003 – Protocols instruments approved by all
- April 2004 – Pilot test and data analysis complete
- June 2004 – Part 1 draft final report submitted for review and approval

Part 2
- Dec. 2004 – Complete Part 2 bid documents, identify three airlines, obtain additional funds
- Jan. 2005 – Obtain approval to bid
- May 2005 – Bids due
- June 2005 – Principal Investigator selected
- Sept. 2006 – Testing and data analysis complete
- Dec. 2006 – Part 2 draft final report submitted for review and approval
Benefits of Combined Research: ASHRAE/CabinAir

- Increase of statistical analysis power by including 100 to 150 flights (50 to 100 ASHRAE /50 CabinAir) on multiple airplane types flying multiple routes from the United States and Europe
- Establish a baseline for a wide range of airplane types and age under normal flight conditions
- Improved basis for air quality standards in Europe and United States
- Improved basis for future regulatory actions
Benefits of Combined Research: ASHRAE/CabinAir

Differences in CabinAir and ASHRAE Multiple Factors Research

<table>
<thead>
<tr>
<th>Task</th>
<th>ASHRAE</th>
<th>CabinAir</th>
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</thead>
<tbody>
<tr>
<td>Endotoxin and microbial measurements on ground and during flight</td>
<td>Limited</td>
<td>Yes</td>
</tr>
<tr>
<td>Bleed air contaminant measurements</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Passenger questionnaire</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Flight deck measurements</td>
<td>None</td>
<td>Yes</td>
</tr>
</tbody>
</table>
FAA Sponsored Research, NRC Recommendations

- FAA is sponsoring cabin environment research to be complementary to the ASHRAE 1262-RP
  - Result of National Research Council recommendations
    - Project ID # BEST-K-00-01-A

- National Research Council recommended research:
  - Establish a health surveillance program (no. 8)
    - To evaluate the relationship between health effects or complaints and cabin air quality
Complementing FAA Study

- Baseline air quality data for possible use for follow-on chem.-bio sensor studies
  - Utilization of installed measurement equipment

- Instrument concepts developed by Johns Hopkins University Applied Physics Lab

- Raw data will be provided to ASHRAE principal investigator (PI)

- ASHRAE PI will use sensors and instruments in a portable package, which are the same quality or a comparable quality to those used in the FAA study
Complementing FAA Study: Benefits to ASHRAE Study

- Data can be collected on
  - Ground and in-flight long-term
  - Multiple flights with different crews and passengers
  - Potentially different routes using the same instrumented aircraft

- Concealed miniaturized sensors can be used to
  - Evaluate the performance of the ASHRAE carry-on sensors
  - Evaluate questionnaire responses of the passengers and crew to visible air monitoring equipment
FAA Measurement Objectives

- **Minimum set recommended by ASHRAE (<1-min)**
  - Ozone \(\text{(2–1000 ppb, 2% accuracy)}\)
  - Carbon dioxide \(\text{(100–10,000 ppm, 2% accuracy)}\)
  - Carbon monoxide \(\text{(1–500 ppm, 2% accuracy)}\)
  - Fine particles \(\text{(1–100 ug/m}^3, 2\% \text{ accuracy)}\)
  - Temperature \(\text{(0–40}^\circ \text{C, 0.5}^\circ \text{C accuracy)}\)
  - Relative humidity \(\text{(3–98\%, 3\% RH accuracy)}\)
  - Pressure \(\text{(525–860 mm Hg, 1\% accuracy)}\)

- **Desirable additional measurements (as possible)**
  - Oxygen \(\text{(time resolved, 2\% accuracy)}\)
  - Volatile organic compounds \(\text{(sensitivity < 10 ppb)}\)
  - Biological aerosols \(\text{(bacteria, fungi, pollens)}\)
Proposed Notional Instrumentation System
(Mix Bay System)

- Preconcentrator and manifold
- Uninterruptible power supply
- Ozone monitor
- Pressure sensor
- Temperature sensor
- Allotted space
- Framing
- Two channel varian GC
- PXI-1002
- Aerosol monitor
- Carrier gas tank
- Vibration isolation mount
Proposed Notional Instrumentation System
(Mix Bay System)

- Preconcentrator and manifold
- Ozone monitor
- Pressure sensor
- Temperature sensor
- Aerosol monitor
- Uninterruptible power supply
- PXI-1025
- Allotted space
- Carrier gas tank
- Vibration isolation mount
- Framing
- Four-channel varian GC
Conclusions

The ASHRAE, CabinAir and FAA research projects will increase our understanding of the relationship of multiple factors that can influence comfort and health-related symptoms.

Research will support

- Development of air quality standards for commercial aircraft
- Airframe manufacturers in future designs
- Medical community in educating patients about the unique cabin environment
- Guidance for airline operations and maintenance
Backups
Symptoms Related to Cabin Air Quality

- Symptoms of eye irritation, stuffy nose, headache, fatigue, dizziness, and nausea have been reported by flight attendants and passengers.

- Symptoms have often been attributed to poor cabin air quality.
### Complaints/Symptoms Versus Possible Causes

<table>
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<tr>
<th>Symptoms/Complaints</th>
<th>Possible Causes</th>
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<tbody>
<tr>
<td></td>
<td>Cabin Environment</td>
</tr>
<tr>
<td></td>
<td>Air Quality</td>
</tr>
<tr>
<td>Aching Legs</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td>X</td>
</tr>
<tr>
<td>Dryness</td>
<td>X</td>
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<tr>
<td>Ear Pain</td>
<td></td>
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<tr>
<td>Fainting</td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td>X</td>
</tr>
<tr>
<td>Feet/Leg Swelling</td>
<td></td>
</tr>
<tr>
<td>Gastro-Intestinal Problems</td>
<td>X</td>
</tr>
<tr>
<td>Headaches</td>
<td>X</td>
</tr>
<tr>
<td>Increased Medical Emergencies</td>
<td>X</td>
</tr>
<tr>
<td>Irritated Eyes</td>
<td>X</td>
</tr>
<tr>
<td>Light Headedness</td>
<td>X</td>
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<tr>
<td>Nausea</td>
<td>X</td>
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<tr>
<td>Nose bleeds</td>
<td>X</td>
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<tr>
<td>Respiratory Problems</td>
<td>X</td>
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<tr>
<td>Stuffy Nose</td>
<td>X</td>
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<tr>
<td>Swollen Stomach</td>
<td>X</td>
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## Complaints/Symptoms Versus Possible Causes

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<td>Air Quality</td>
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<tr>
<td></td>
<td>Thermal Comfort</td>
</tr>
<tr>
<td>Relative/humidity</td>
<td>X</td>
</tr>
<tr>
<td>Temperature</td>
<td>X</td>
</tr>
<tr>
<td>Cabin pressure</td>
<td>X</td>
</tr>
<tr>
<td>Contaminants/ozone</td>
<td>X</td>
</tr>
<tr>
<td>Long haul/short haul</td>
<td>X</td>
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<tr>
<td>Jet lag</td>
<td></td>
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<tr>
<td>Flight length</td>
<td></td>
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<tr>
<td>Stress/fear</td>
<td></td>
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<tr>
<td>Health status</td>
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- **Stuffy nose**: X X X X X
- **Fatigue**: X X X X X X X X X
- **Headaches**: X X X X X X X X X
# Cabin Air Contaminants Have Been Studied by Many Organizations

<table>
<thead>
<tr>
<th>Category</th>
<th>Study</th>
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<td>(National Academy Press, 2001 The airliner cabin environment and the health of passengers and crew)</td>
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<tr>
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<td>Centers for Disease Control (CDC) – 1995</td>
<td>(Centers for Disease Control and Prevention, March 1995. Press release)</td>
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<tr>
<td></td>
<td>U.S. Department of Transportation (DOT) – 1989</td>
<td></td>
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<tr>
<td><strong>Industry studies</strong></td>
<td>Environmental Science and Technology – 1987</td>
<td>(Environmental Science and Technology. Vol.21, Estimation of effect of environmental tobacco smoke on air quality within passenger cabin of commercial aircraft)</td>
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<td>Southwest Bioscience Laboratories (SBL) – 1987</td>
<td>(Aviation, Space, and Environmental Medicine, March 1995. The microbiological composition of airliner cabin air)</td>
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<td>Air Transportation Association (ATA) – 1994</td>
<td>(Air Transportation Association, April 1994. Airline cabin air quality study)</td>
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<td></td>
<td>Airbus – 1996</td>
<td>(Dechow, M. Measurement results of selected contaminants within cabin air of Airbus aircraft, February 1996)</td>
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<td>British Airways and KLM Royal Dutch Airlines – 1998</td>
<td>(ASTM STP 1393, October 2000. Ozone and relative humidity in airline cabins on polar routes)</td>
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<tr>
<td><strong>Consumer group study</strong></td>
<td>Consumer Reports (CU) – 1994</td>
<td>(Consumer Reports, August 1994. Breathing on a jet airplane)</td>
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<tr>
<td><strong>University study</strong></td>
<td>Harvard University – 1997</td>
<td>(Harvard Comparative Study on Transportation Vehicles)</td>
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<td></td>
<td>Hong Kong Polytechnic University – 1997</td>
<td>(Indoor Air, September 1999. Indoor air quality investigation on commercial aircraft)</td>
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<td>(ASTM STP 1393, October 2000. Questionnaire survey to evaluate the health and comfort of cabin crew)</td>
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<td>Concordia University – 1996</td>
<td>(Indoor + Built environment, No 8, 1999. Measurement of thermal comfort and indoor air quality aboard 43 flights on commercial airlines)</td>
</tr>
<tr>
<td><strong>Independent non-profit organization studies</strong></td>
<td>ASHRAE – 1998</td>
<td>(ASHRAE Journal, Fall 1999. IAQ in airplanes)</td>
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</table>
Limitations of Air Quality Studies

- Research in general has not shown elevated concentration of contaminants or correlations between cabin air quality and reported symptoms.
- Monitoring data has consisted of a small sampling of flights.
- Data is limited on some contaminant species.
- Studies have varied considerably in sampling strategies, environmental factors monitored, and measurement methods.
- Impact on air quality of aircraft age, and maintenance practices is not well understood.
- No published data of objective measurements taken during an upset condition.