Germs, Flying, And the Truth

By Douglas S. Walkinshaw, Ph.D., P.Eng., Fellow ASHRAE

A significant number of air travelers say they are worried about germs when they travel.[1] But because incubation periods between exposure to and contraction of a communicable disease vary up to several days (typically three for influenza and colds), travelers cannot be certain if they contracted the disease on an airplane. However, research and engineering, while still in the initial stages, support this concern.

Brundage, et al.,[2] found in 1988 that febrile illness rates were 50% higher in sealed-window, air-conditioned barracks than in operable window army barracks. Brundage postulated HVAC system design could play an important role in reducing lost productivity in the U.S. due to respiratory illness, which at that time amounted to billions of dollars annually.

More recently, a study found flight attendants and school teachers report a higher prevalence of work-related upper respiratory symptoms, chest illness, and cold or flu than the general working population.[3] Other studies indicate, with some caveats, that there has been transmission of smallpox, measles, tuberculosis, SARS (severe acute respiratory syndrome) and seasonal influenza during commercial flights.[4–9]

Other evidence suggests that transmission of these diseases could have an airborne component that is susceptible to ventilation measures.[10,11] Excluding those created as bioweapons, there may still be others.[12]

Most transportation systems such as subway trains and buses, as well as passenger aircraft, have high occupancy densities (ODs; the number of people per unit volume of conditioned space) compared with buildings. With the exception of cruise ships, the intermixing of persons from different population centers and continents in aircraft is unique. Further, passenger aircraft, with their assigned seating and flights ranging up to nearly a day, prolong specific pathogen exposure times over most other venues.

A recent study by Wagner, et al.,[13] calculated the impact of one H1N1 infectious individual on board a large passenger airliner. It found airborne transmission of this pathogen in the economy section can cause two to five infections during a five-hour flight, five to 10 during an 11-hour flight and seven to 17 during a 17-hour flight.

Airborne transmission implicates HVAC systems and crowding, rather than individual responsibility. Naturally, the industry is sensitive to this. One official referred to potentially increased risk of airborne disease transmission on aircraft as "a myth."[14] Others sometimes cite misleading information, e.g., aircraft ventilation systems, as in hospitals, use HEPA (high-efficiency particulate air) filters, and air-change rates are 18 times higher than in buildings.

But, consider the facts. The aircraft ventilation system supplies only 15 to 20 cfm/p (7 L/s to 9 L/s) versus some 100 cfm/p (47 L/s) in buildings, even though its air change rate is 20 to 40 times higher. In aircraft, 50% of the ventilation rate per person is outdoor air and 50% is air recirculated through HEPA filters. In offices, 20% of the ventilation rate per person is outdoor air (two to three times that of aircraft) and 80% is recirculated through filters. New office filters (e.g., MERV 13), although some 20% less efficient than HEPA in removing 0.3 micron particles, remove 6.4 times more 0.3 micron particles than aircraft HEPA filters because the flows through them are 10 times higher.

Aircraft supply air is directed in a lateral row-wise circular fashion with initial velocities from the slot diffusers typically about 500 to 800 fpm (2.5 m/s to 4 m/s) (based on typical aircraft ventilation slot size and ventilation rates) (versus up to 300 fpm [1.5 m/s] for smaller building diffusers and up to 500 fpm [2.5 m/s] for larger ones).[15] Recent research has demonstrated the potential for these flow velocities to produce airborne particle transmission between, as well as within, rows.

Officials sometimes cite misleading information. For example, aircraft ventilation systems, as in hospitals, use HEPA filters, and air-change rates are 18 times higher than in buildings.

At a recent international symposium jointly organized by the U.S. Transportation Research Board (TRB) and the National Academy of Sciences (NAS), experts in infectious diseases and aircraft ventilation systems discussed the movement of potentially infectious particles between rows fore and aft of the source.[16] Two studies (following up on earlier studies, including work by Boeing[17–19]) found that these air velocities, and the turbulence induced at the airflow boundaries, disperse particle and gaseous contaminants from a single source in two ways: past others in the same row and in other rows in measurable quantities six or more rows forward and backward. The contaminant flows in the area immediately surrounding the source are relatively chaotic, and then more ordered several rows away.[20,21]

At the symposium, several field investigations found that aisle seats and those near lavatories were most prone to disease transfer. Mathematical modeling used to investigate how the SARS virus was transmitted as far as seven rows away in the Air China flight 117 from Hong Kong to Beijing in 2003, found that the wake created by occupant movement in the aisles can carry an airborne contaminant this distance and when the movement stops the contaminant is distributed to the passengers seated in the adjacent aisle seats.[22]

A study by Fabian[23] found between <3.2 to 20 influenza virus RNA copies per minute (up to 1,200 viruses per hour) in the exhaled normal at rest breath (tidal breathing) of infected persons, indicating that sneezing and coughing are not the only potential source of infectious aerosols. Seventy percent of the 67 to 8,500 particles/L in the breath had diameters between 0.3 and 0.5 microns, with rarely any larger than 5 microns.[23] By way of comparison, Duguid reported 6,200 cold viruses per hour emitted by an infected person at rest.[24] Combined, the symposium findings demonstrated that no systems or measures are in place to prevent the airborne spread of infectious agents over several rows, and that infectious disease transmission within an aircraft cabin occurs before airborne pathogens are directed to the HEPA filters or exhausted outdoors.

Humidity also can play a role. Research published in 2007 indicates that lower levels of relative humidity (RH) such as that in aircraft cabins shortly into cruising flight, increases the potential for influenza and possibly other respiratory infections when a source is present.[25] In contrast, higher levels of RH may favor the survival and spread of the common cold.[26]

Relevant HVAC engineering calculations also serve to correct misperceptions about risk of disease transmission on aircraft.

Although aircraft air change rates are higher than in office buildings, ventilation and recirculation flow rates *per person* are lower and engineering equations indicate that airborne 0.3 micron and larger pathogen concentrations will be at least four times higher in passenger aircraft equipped with HEPA filters than in typical office environments with MERV 13 filters, for the same pathogen emission rates and a uniformly mixed system.

Because passenger aircraft cabin ODs are 20 to 40 times higher than in office buildings, their pathogen concentrations will reach peak equilibrium values sooner, with the result that time-weighted exposure ratios will be at least five times higher than in offices, depending upon exposure duration, when the same number of pathogens are emitted in each. In another comparison, aircraft cabin occupancy densities are more than three times higher than classroom ODs.

Here are the calculations:

Using the equation for average pathogen concentration C in a uniformly mixed system at time t in a space

$$C = [N/(V \times V_e)][1 - \exp(-V_t/v)] \quad (1)$$

where

C = bioeffluent pathogen concentration in the space at time t

N = rate of bioeffluent pathogen generation/person in the space

V = total ventilation air supply rate with no pathogens

V_e = efficiency of supplying the ventilation air to each occupant's breathing zone

v = spatial volume/person

And using v and V values typical of aircraft cabins and offices,

v = 32 ft^3/p for the aircraft cabin

v = 1,430 ft^3/p for the office

V = 15 cfm/p for the aircraft cabin (based on ASHRAE Standard 161 and 100% influenza filtration by the HEPA filters)

V = 84 cfm/p for the office (based on 20 cfm/p outside air and 80% virus filtration by MERV 13 filters for 80 cfm/p recirculation air)

And, using the average Fabian influenza generation rate:

N = 11 influenza virus generated per minute continuously in the exhaled breath of one influenza infected person, not including coughing generation

And, using:

V_e = 1 for both settings

Solving *Equation 1*, and incorporating at rest awake inhalation and exhalation rates of 0.28 cfm/p (0.13 L/s), the numbers of influenza virus particles inhaled by office and aircraft groups exposed to the exhaled breath of one infected person versus exposure time are shown in *Figure 1*. It can be seen that after eight hours in the aircraft cabin, there will be 98 influenza virus particles inhaled by previously uninfected persons, and up to nine infections for a 10 virus particle dose criterion. By comparison, for the same exposure

period in the office, there will be 17 virus particles inhaled and up to one infection. The location of persons most likely to be infected will be determined by proximity to the infected person, susceptibility, air current patterns, and aisle or not seat location.

The ratio of virus inhalation for the two exposure settings is shown in *Figure 2*. It can be seen that for exposures over two hours, V_e for the aircraft must be doubled and V tripled to provide an office building equivalent level of protection for the same activity level of occupants. However, breathing rates on aircraft typically will decrease as the flight duration increases and more people are dozing. If the infected person also dozes, this could result in up to one-third reduction in average breathing rate and virus inhalation as the flight progresses. This commensurately decreases the aforementioned V and V_e multiples required to reduce virus inhalation rates in aircraft by a four times rather than a six times reduction factor to provide office building level equivalent protection. Other pathogens aerosolized by passenger movement also would decrease as fewer passengers move about the cabin. A leveling off of airborne viable bacterial abundance after midflight has been noted by La Duc, et al.[27]

To date, the role of HVAC system design and operation to help control infectious disease transmission has been mainly limited to the use of HEPA filtration and air purification in the main recirculation system and, in the case of health-care facilities, isolating infectious patients in separately ventilated, depressurized rooms.

The effectiveness of HEPA filters in trapping airborne cold virus was tested in a study of passenger aircraft, where some flights had no recirculation and some had 50% recirculation through HEPA filters.[28] This study found no difference in the rates of transmission of upper respiratory illness symptoms, runny nose and colds, in two-hour flights. Although the flight durations were short, this suggests air filtration can be a useful measure in the prevention of these illnesses.

In a related development, the aircraft cabin air supply that is used to ventilate and pressurize the cabin, is also used to filter the air from around the occupants using the flow entrainment created by the high velocity airflows out of the gaspers. This technique effectively doubles the cabin air filtration rate and increases the ventilation effectiveness without adding local air circulation fans or using extra energy.[29]

It is time for ASHRAE to begin the multidisciplinary research and development necessary to identify infectious disease mitigation measures for critical settings, and set criteria that will effectively limit airborne infections of most concern. These would include:

- Design exposure periods to be used for different settings;
- Design occupancy densities to use for different settings;
- Design humidity conditions to use for different settings;
- Occupant breathing rates to be used for different settings;
- Pathogen dose criteria to be used for pathogens of airborne concern;
- Coughing and breathing aerosol size ranges, dispersion distances and settling rates for different settings for each pathogen of concern;

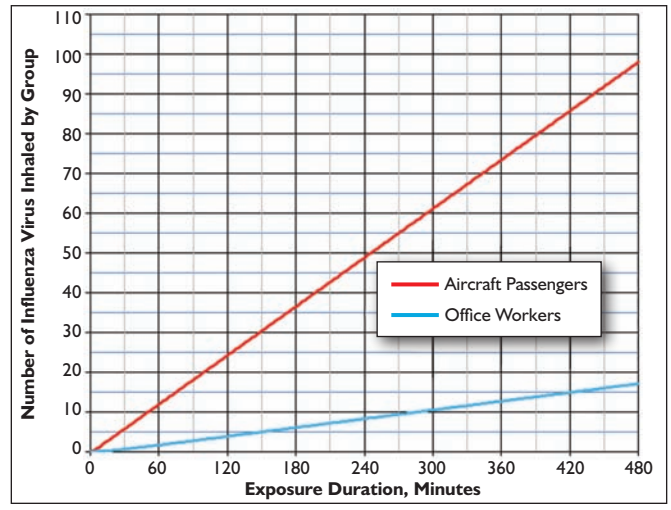

Figure 1: Number of influenza virus particles inhaled by office worker and aircraft passenger groups exposed to the exhaled breath (coughing not included) of one infected person for the same "at rest awake" activity level in each.

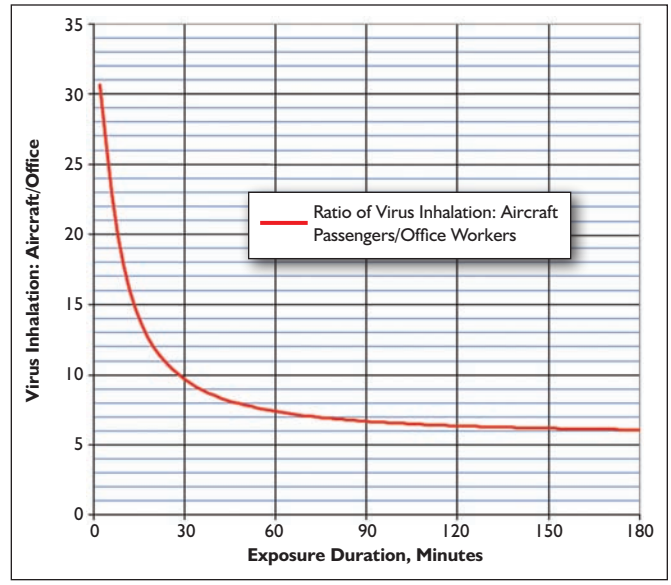

Figure 2: Ratio of virus inhalation by aircraft passengers to office workers versus exposure time for the same number of infected persons and "at rest awake" activity level in each group.

- Viability time limits for pathogens of concern;
- Total pathogen-clearing airflow per person to be provided to the breathing zone in proportion to airflow effectiveness (V_e) in diluting and removing pathogens in the breathing zone;
- V_e for each occupant's breathing zone to be used for different spaces and diffuser types and arrangements; and
- Removal/immobilization rates per unit airflow to be used for each pathogen of concern for the various air filters and purifiers available.

Regarding pathogen aerosol size range, settling rates, and viability time limits, the higher the OD the sooner the equilibrium

concentration is reached and the less important these factors are in limiting pathogen dispersion distances and exposures. The larger the number of persons to whom pathogens are dispersed, the lower the average exposure, but the greater the chance of affecting more susceptible persons.

The development of these criteria for specific pathogens will require dedicated multi-year committee work by individuals from the ASHRAE disciplines and from infectious disease disciplines. It will need to involve collaboration with health agencies as well.

Thanks to the leadership of Richard Fox of Honeywell, representatives of TC9.3, TC9.6, TC2.4, the Environmental Health Committee and health scientists and professionals outside of ASHRAE, the scope of ASHRAE's pathogen research has been defined for the next five years and research is beginning.

While ASHRAE is working on new standards, industry spokespersons could recommend some simple-to-implement precautionary measures that passengers might take. Preflight measures could include getting vaccinations as appropriate; being rested before traveling; and taking disinfectant wipes, hand sanitizers and face breathing masks on board.

In-flight measures could include ill passengers wearing masks to protect others (airlines might even offer these to coughers); coughing into sleeves for those not wearing masks; refraining from touching one's face (wearing a mask helps here); periodically sanitizing your hands and surrounding hard surfaces such as the tray table and armrests; refraining from facing nearby passengers when talking; using a face mask to raise the humidity in your breathing zone if nasal passages are dry; wearing a mask if in an aisle seat or near a washroom; and turning on and pointing overhead air vents to make the air jet flow between you and nearby passengers (do *not* point it at your face and entrain your neighbor's breath into your breathing zone).

This latter measure will help prevent exchange of airborne pathogens with neighboring persons, and will draw airborne pathogens to the floor returns where they can be exhausted or filtered out. Such measures can be simply and easily described by flight attendants as part of the safety instructions given at the beginning of the flight.

References

1. Nishimura, S., B. Cox. 2009. "Travelers are worried about germs and expect to pay for in-flight extras, survey says." Sky Talk, *Star Telegram*, Fort Worth, Texas. Dec. 9, 2009.
2. Brundage, J.F., et al. 1988. "Building-associated risk of febrile acute respiratory diseases in Army trainees." *JAMA* 259(14):2108–2112.
3. Whelan E.A., et al. 2003. "Prevalence of respiratory symptoms among female flight attendants and teachers." *Occup Env Med* 62:929–934.
4. Jones, R.M., et al. 2009. "Characterizing the risk of infection from *mycobacterium tuberculosis* in commercial passenger aircraft using quantitative microbial risk assessment." *Risk Analysis* 29(3):355–365.
5. Mangili, A., M.A. Gendreau. 2005. "Transmission of infectious diseases during commercial air travel." *Lancet* 365:989–996.
6. Driver, C.R., et al. 1994. "Transmission of *Mycobacterium tuberculosis* associated with air travel." *JAMA* 272:1031–1035.
7. Tracy, M. 1996. "Transmission of tuberculosis during a long airplane flight [letter]." *N Engl J Med.* 335:675.
8. Kenyon, T.A., et al. 1996. "Transmission of multidrug-resistant mycobacterium tuberculosis during a long airplane flight." *N Engl J Med.* 334:933–938.
9. Moser M.R., et al. 1979. "An outbreak of influenza aboard a commercial airliner." *Am J Epidemiol.*110:1–6.
10. Li, Y., et al. 2007. "Role of ventilation in airborne transmission of infectious agents in the built environment—a multidisciplinary systematic review." *Indoor Air* 17:2–18.
11. Blachere, F.M., et al. 2009. "Measurement of airborne influenza virus in a hospital emergency department." *CID* 48:438–440.
12. Sattar S.A., M.K. Ijaz. 2007. "Airborne viruses." In *Manual of Environmental Microbiology,* (C. Hurst, et al. eds.) 3rd edition, pp. 1016–1030. Washington, D.C.: Am. Soc. Microbiol.
13. Wagner B.G., B.J. Coburn and S. Blower. 2009. "Calculating the potential for within-flight transmission of influenza A (H1N1)." *BMC Medicine*, 7:81doi:10.1186/1741-7015-7-81.
14. Freeman, L. 2009. "Fear of flu no reason to avoid flying, area health and airline officials say." *Naples News,* Naples, Fla. Nov. 21.
15. ANSI/ASHRAE Standard 161-2007, *Air Quality Within Commercial Aircraft.*
16. Transportation Research Board. 2009. Reference materials for "Research on the Transmission of Disease in Airports and Aircraft: A Symposium." http://onlinepubs.trb.org/onlinepubs/conferences/2009/SOD/SODReferences.pdf.
17. Horstman, R.H. 1988. "Predicting velocity and contamination distribution in ventilated volumes using Navier-Stokes equations." IAQ88.
18. Lin, C., et al. 2005. "Numerical simulation of airflow and airborne pathogen transport in aircraft cabins—part I: Numerical simulation of the flow field." *ASHRAE Transactions* 111(1):755–763.
19. Lin, C., et al. 2005. "Numerical simulation of airflow and airborne pathogen transport in aircraft cabins— part II: Numerical simulation of airborne pathogen transport." *ASHRAE Transactions* 111(2):764–768.
20. Bennett, J., J. Topmiller, Y. Zhang, W. Dietrich. 2009. "Summarizing exposure patterns on commercial aircraft." Research on the Transmission of Disease in Airports and Aircraft: A Symposium.
21. Jones, B. 2010. "Advanced models for predicting contaminants and infectious disease virus transport in the airliner cabin environment: Experimental dispersion data." Research on the Transmission of Disease in Airports and Aircraft: A Symposium.
22. Chen, Q. 2010. "Advanced models for predicting contaminants and infectious disease virus transport in the airliner cabin environment." Research on the Transmission of Disease in Airports and Aircraft: A Symposium.
23. Fabian, P., et al. 2008. "Influenza virus in human exhaled breath: An observational study." PLoS ONE 3(7):e2691.doi:10.1371/journal.pone.0002691.
24. Duguid, J.P. 1945. "The size and the duration of air carriage of respiratory droplets and droplet-nuclei." *Journal of Hygiene* 54:471–479.
25. Lowen, A.C., et al. 2007. "Influenza virus transmission is dependent on relative humidity and temperature." PLoS *Pathogens* 3(10):1470–1476.
26. Karim, Y.G., et al. 1985. "Effect of relative humidity on the airborne survival of rhinovirus-14." *Can. J. Microbiol* 31:1058–1061.
27. La Duc, M.T., T. Stuecker T, K. Venkateswaran. 2007. "Molecular bacterial diversity and bioburden of commercial airliner cabin air." *Can. J. Microbiology* 53:1259–1271.
28. Zitter, J.N. 2002. "Aircraft cabin air recirculation and symptoms of the common cold." *JAMA* 288(4):483–486.
29. Walkinshaw, D.S., R.H. Horstman. 2007. "Personal environment airflow controller." European patent office, WO2007134443 (A1).

Douglas S. Walkinshaw, Ph.D., P.Eng., owns three companies involved in indoor air quality investigations and ventilation technologies and lives in Bonita Springs, Fla., Ottawa and PEI, Canada.