Nature to the Rescue: Aircraft Cabin Exposures vs. Bipolar Ionization

By: Brianna Chilton, PhD

The commercial aircraft cabin is an indoor environment that presents both similar and different characteristics of the everyday indoor environments people live in. Like in homes and offices, the airplane interior consists of a mixture of outside and recirculated air. Due to this, needs, such as adequate ventilation, clean air, and appropriate temperature/humidity levels, must be accomplished while being as energy efficient as possible. This leads to problems that are similar across all indoor environments (1).

The similarities are strong enough that the indoor environments in buildings are seen as a potentially valuable research model for studying aircraft cabin air quality. As such, "building-related symptoms (BRS)" are used to provide information on air quality by describing nonspecific symptoms that are not associated with a well-defined cause but are linked to time spent in a specific indoor environment, in this case, the aircraft cabin. Symptoms often include eye, nose, or throat irritation, headache, fatigue, or other discomforts. These symptoms are reported as coming from one indoor environment, or a part of that environment, and mostly resolve shortly after leaving the noted area (1). For years, the focus of aircraft air quality concerns was on the occupational exposures of cabin crews, with past investigations finding 21% of surveyed crew members rating overall air quality as poor and 50% reporting the aircraft had a distinct, unpleasant odor. However, with the increasing numbers of air travelers in the past few decades, focus has shifted to include the safety and comfort of both the crew and the passengers, in part due to customer complaints received about cabin air quality. A common complaint indicating that passengers find their air travel resulting in "catching a cold" (2).

However, unlike indoor settings such as homes and offices, the aircraft cabin's high occupant density and need for pressurization combine with in-flight environmental characteristics, like low humidity, low air pressure, and possible air contaminants, to create a domain in which aircraft inhabitants experience increased chances of contaminant exposure. Contaminants, originating from either outside the aircraft, inside the aircraft, or from the environmental control system (ECS), enter the cabin in various ways, such as carbon monoxide from engine exhaust, ozone (O_3) from outside air, organic compounds generated by emissions from materials in the cabin and the human body, and allergens, pathogens, irritants, and other contaminants brought aboard the aircraft by passengers or crew members. Over time, concern about exposure to these various contaminants, both chemical and biological, in the aircraft cabin have been expressed by both passengers and crew, who use diagnosable diseases and BRS as evidence for their concerns (1).

Volatile Organic Compounds (VOCs)

Exposure to specific volatile organic compounds (VOCs) is known to be harmful to humans and the environment as well as potentially disruptive to the comfort of passengers and crew members when onboard an aircraft (3, 4). One main contribution to the presence of VOCs found in an aircraft cabin is pollutants from materials used in the construction or maintenance of the cabin, such as acetone, ethanol, benzene, toluene, and n-butanol. While there is little evidence to show a direct relationship between a documented health problem and the use of these chemicals on an airplane, established health connections in other environments and the established presence of VOCs in the aircraft cabin create reasonable concern for the safety of aircraft passengers and crew (1). Further contribution to key VOCs identified in the aircraft cabin, such as formaldehyde, benzene, tetrachloroethylene, naphthalene, trichloromethane and 1,2-dichloroethane, are believed to arise from engine combustion, oils, and lubricants, These chemicals have been found in the aircraft cabin in quantities high enough to merit priority attention based on the US EPA acceptable levels (5).

Outside of compounds originating from chemical materials, human beings are a source of VOCs in indoor environments with several hundred VOCs documented as being introduced to surrounding air via exhalation and dermal emissions (6). Besides the more well-known biological chemicals produced from humans, microbial volatile organic compounds (mVOCs) are volatile chemicals produced by the metabolism of fungi and bacteria and characterized as having distinctive odors with negative health effects of eye and upper-airway irritation (1). A recent study looking at mVOCs concentrations in the aircraft cabin environment showed the sum of MVOCs in cabin air to be 3.7 times higher than in homes (7).

Airborne Particulate

Airborne particulate comprises of coarse particles, those with a diameter over 2.5 µm, fine particles, those with a diameter less than 2.5 µm, and ultrafine particles, those with a diameter less than 0.1 µm. In the aircraft environment, coarse particles consist of powders, dust, dirt, and hair while fine and ultrafine particles are generally products of the combustion of materials such as fuels, engine oil, and hydraulic and deicing fluids. Due to their size, coarse particles are deposited in the upper respiratory airways and cause coughing, sneezing, and nasal irritation. Fine and ultrafine particles are deposited in the lower regions of the respiratory tract deep in the small lung airways and, even with limited data available, have been linked to heart rate variability and possible coughing (1). For the past 2 decades, studies have shown that particulate matter imparts a negative health effect on humans but a recent study from 2019 shows that ultrafine soot particles originating from kerosene combustion from the exhaust of a CFM56-7B turbofan, the most used aircraft turbine engine globally, can cause irreversible damage to lung tissue when the inhaled particles overcome the lung's normal defense mechanisms (8).

Allergens

One of the two main causes of potential concern involving the effects of travel on human health is allergens coming from internal aircraft sources (1). With respiratory infections being common in humans, the considerable number of humans who are sensitive to one or more airborne allergens, and the overwhelming percentage of allergens originating from aircraft passengers and crew, the aircraft cabin has created great concern regarding the spread of airway infections with contaminants being shed from clothing and/or skin or expelled from oral, nasal, or rectal orifices (1, 9). While often seen in lower concentrations, arthropods, specifically dust mites and cockroaches, and pets/service animals are other biological sources of allergens. While allergens originate from a biological source, it is the presence of airborne particulate, specifically dust, that creates a reservoir for these allergen particles to become circulated around the cabin (1).

Pathogens

Infectious agents are the other note-worthy cause of potential concern when looking at the effects of travel on human health (1). Travel is a large factor in both the emergence and spread of disease (10). With over 3 billion airline passengers annually, the current volume, speed, and reach of travel, and the increasing ease and affordability of airline travel, the spread of infectious diseases, including emerging infections and pandemics, transmitted during commercial air travel are an important public health issue (10,11,12).

Pathogens are defined as organisms that can cause disease in their hosts and include viruses, bacteria, and fungi. Transmission takes place through the consumption of contaminated food and water, by airborne particles, such as dust, droplets, and aerosols, contact between animals hosts and people, or by contact with bodily fluids or contaminated surfaces (13). Transmission on airplanes is characterized by 3 of the 4 routes mentioned: through close human-human contact and large droplets; airborne spread through small-particle aerosols, as evident with severe acute respiratory syndrome (SARS); or contaminated food. While the added complexity of avoiding or distancing oneself from a mobile sick person increases the transmission rate in the airplane cabin, the greatest concern globally is the ability of a person with a contagious illness to travel to almost any part of the world within 24 hours (12,14). While the studies showing in-flight transmission of pathogens, such as the FlyHealthy™ Study, are limited, an essential component of understanding the public health risks associated with flying involves identifying and characterizing the background microbial communities present both in the air and on common touch surfaces in the aircraft cabin. Thus, creating a defined "airplane cabin microbiome" that has large flight-to-flight variations (12).

Ozone

Ozone is an established respiratory irritant (15). Studies have shown that human exposure to ozone is strongly associated with adverse respiratory and cardiovascular effects. Short-term exposure Is linked to acute symptoms including breathing discomfort, respiratory irritation, and headaches in healthy adults and asthma exacerbation and premature mortality in compromised individuals. Long-term exposure is linked to chronic symptoms such as increased oxidative stress, reduced lung function, and adult-onset asthma in males (16). Pollutants in the ambient air surrounding the airplane can be introduced inside the passenger cabin via ventilation air provided by the ECS during various times throughout a flight. Ventilation air can be contaminated by high ozone concentrations in the upper troposphere or lower stratosphere (1). Ozone can be removed from the cabin with the use of a catalytic converter. However, many aircrafts are not equipped with converters, and they do not always perform well. Effectiveness can be hindered due to 'surface poisoning' by contaminants and imperfect refurbishing of catalysts during scheduled replacement (15).

Bipolar Ionization

An ion is a charged atom or molecule that has an unequal number of electrons and protons; thus, giving the atom a positive charge if there are more protons than electrons or a negative charge if there are more electrons that protons. This results in either a cation (+) or an anion (-). Charged atoms/molecules are attracted to oppositely charged atoms/molecules given their energy potential. Ions are formed naturally in outdoor environments and the air we breathe (17). The use of ions in indoor environments has gained significant interest in the form of air cleaning technology using air ionization. Devices that use both negative and positive ions are known as bipolar ionizers (18). For the past 10+ years, bipolar ionization devices have been used for particle reduction, odor control, pathogen control, and static electricity control. Airflow is used to distribute the charged ions into the chosen environment, making ionization different from HEPA filtration in which contaminants must make their way into the filter (19).

Once the charged ions are delivered to the desired environment, they have an effect on particles, allergens, VOCs, and pathogens found on surfaces and in the air through different processes. One process, called agglomeration, results from oppositely charged ions attracting to others. These now heavier molecules will drop out of suspension and onto surfaces or the floor, making them less likely to be breathed in (19). While most HEPA filtration is described as removing 99.97% of airborne particles with a size of 0.3 microns (µm) and larger, there have been multiple studies demonstrating the ability of various ionizers to significantly reduce the concentration of ultrafine, airborne particles (<0.15 µm) (18, 20). With ultrafine particles' ability to cause respiratory distress, spread pathogens, and transport allergens, the removal of smaller particulate matter is multifunctional in air purification (1,13). In a different process, bipolar ionization works to neutralize

VOCs and off-gases not removed from the modern air filtration system by breaking down the molecules hydrocarbon chains into varying amounts of carbon dioxide and water vapor (19).

When it comes to microorganisms, various microbial remediation pathways using ions have been described. Bipolar ions interrupt the reproductive ability of the organism which immediately decreases the spreading capabilities of microbes in the aircraft cabin. Negative and positive ions are also able to cluster around the pathogenic particles, such as airborne mold, viruses, bacteria, and allergens. While clustered, a chemical reaction occurs in which a hydrogen atom (H) is stolen from the cell membrane and an -OH radical is left. This causes holes to form in the cell membrane; thus, destroying the organism. Thus, being used to decontaminate both airborne and surface pathogens. An important note here is that bipolar ionization does not destroy any DNA in order to kill the pathogenic cell (18). This clustering also creates agglomeration as described before (19). Specific examples of pathogenic remediation of infectious disease hosts via bipolar ionization that have been tested and documented include influenza, SARS-CoV-2, SARS-CoV-2 delta variant, human rhinoviruses (HRVs), respiratory syncytial virus (RSV), methicillin-resistant *Staphylococcus aureus* (MRSA), *Staphylococcus aureus*, *Escherichia coli*, and *Aspergillus niger* (21-37). The specific pathway causing this reduction of microbes has not been described.

Conclusion

While ionization technology as a disinfection process has been around and studied for decades, the lack of peer-reviewed studies solely establishing ions as the source of the decrease in viability of pathogens causes doubt in the effectiveness of the technology (38). Furthermore, there is limited research and testing looking at the outcomes of using bipolar ionization specifically in the aircraft cabin environment. However, based on reviewing existing research and documentation for the efficacy of ionization in parallel indoor environments with respect to the technology's similar effectiveness for ground and aircraft cabin environment applications, there are sufficient research and documentation to provide the evidence needed to draw conclusions about the efficacy of bipolar ionization in purifying the air and surfaces and neutralizing/reducing pathogens throughout the aircraft. After reading the published research surrounding this topic, it is my opinion that ACA's ionization component provides constant decontamination of the aircraft interior without impacting the cabin's pre-existing ozone level (39-40); thus, addressing concerns expressed by both passengers and crew.

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