Carbon Dioxide Concentrations on Airplanes- Sources, Causes & Relevance:

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For most indoor spaces, carbon dioxide is a good indicator of outside air ventilation. It has been used by many scientists, engineers, and experts as a correlate to risk of inhaling infectious agents.

However, on-board large passenger airplanes there are a number of factors that make carbon dioxide a poor indicator for infectious agent risk.

This is predominantly due to two factors. Carbon dioxide on airplanes is produced by a variety of sources on-board passenger aircraft beyond occupants including dry ice, outside air, and various cargo. Second, a high proportion of the airflow passes through HEPA filters, which effectively remove particles that contain viruses and bacteria but do not remove CO_2. As a result, the level of CO_2 in the aircraft cabin is not a good proxy for the level of infectious particles in the aircraft cabin.

CO_2 Sources in Commercial Aircraft

CO_2 Sources from Atmosphere:

The National Oceanic & Atmospheric Administration's measurements at Mauna Loa, HI, USA, report a monthly average concentration of 418 parts per million. [1] This can be significantly higher on the ground in the airport environment.

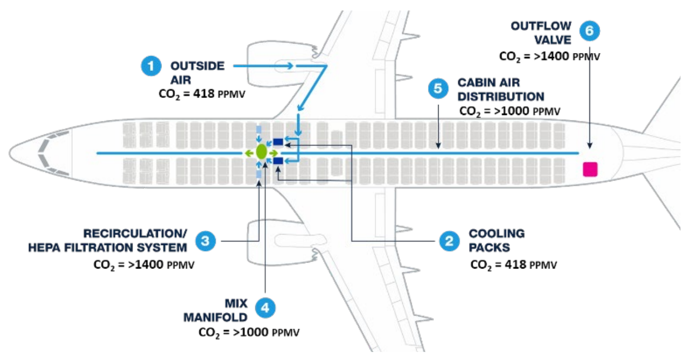

Figure 1: Carbon dioxide concentrations by location in commercial airplanes

CO_2 Sources from Occupants:

ASHRAE Standard 62.1 uses a source generation rate from occupants of 0.003-0.006 liters per second per occupant (L/s/occ) [2]. This aligns with Persily & de Jong's measurements of CO_2 generation rates of 0.003-0.0055 L/s/occ in their 2017 study [3] where a reasonable value for aircraft can be assumed to be 0.0041L/s/occ.

To estimate the bulk steady state concentration of carbon dioxide from occupants, the concentration can be determined as $(C_{steady\ state-occupant} - C_{outside}) = G/Q_{outside-per\ occupant}$ where G is the source generation rate, and $Q_{outside}$ is the outside cabin airflow.

Per FAA regulations [4], and ASHRAE ventilation standards [5] airplanes are required to supply 0.55 lb/min of outside airflow per occupant. In terms of a volumetric airflow this results in an outside airflow of 7.5 CFM/occ (3.53 L/s/occ) at sea-level and 10 CFM (4.71 L/s/occ) at a maximum cabin altitude of 8000 feet. For most of the flight in cruise, the cabin altitude is typically between 4000 & 6000 feet [6], resulting in a typical airflow of approximately 8.7-9.3 CFM/occ (4.10-4.38 L/s/occ). This results in a CO_2 contribution from occupants of approximately 1000 parts per million by volume.

During normal cruise, a typical concentration of CO_2 on-board aircraft is roughly 1400 parts per million by volume. This is similar to or lower than other indoor spaces such as lobbies, lecture halls, and conference rooms [2],[3]. If the comparison stopped here, CO_2 would be a reasonable marker compound to compare for buildings. However, both additional sources of CO_2 and HEPA filtered recirculation airflow are present on aircraft that significantly affect that assumption.

Other CO_2 Sources:

Passenger airplanes typically carry more than just passengers. One crucial service that airplanes have provided during the COVID-19 pandemic in particular is delivery of vaccines around the globe. These vaccines need to be packed in dry ice to maintain their viability. Dry ice is made entirely of CO_2 and when it sublimates, it elevates the concentration of CO_2 within that space. Dry ice is also used for cold storage of meals in galleys. In all cases, Boeing works with our airline operators to ensure that CO_2 produced from these sources remains at safe levels.

Other cargo also can be a source of CO_2. Cabin located cargo compartments may carry things such as fresh foods & animals around the globe, which also produce CO_2. These can combine to elevate the concentrations of CO_2 in the cabin both in flight and on the ground.

Differences between Behavior of CO_2 & Particulates in Airflow

Particulates such as viruses and bacteria inherently have mass to them, and are often found in solution with other constituents such as moisture or larger particles. Even at their smallest they are still 100-1000 times larger than gases such as CO_2 which isn't significantly larger than air itself. Particles (such as viruses) do not mix freely with air molecules, due to their mass, and often will be removed from the air by the forces of settling, electrical charge, and gravity. In most instances, viruses are also in solution with larger bioaerosols which increase the effects of these forces.

HEPA Filtration

HEPA filters contribute significantly to a safe and comfortable cabin- especially during the COVID-19 pandemic. Roughly 50% of the total airflow in Boeing aircraft is outside air, while the remaining 50% of total airflow is recirculated through HEPA filters. HEPA filters remove effectively all particulates, including viruses and bacteria, with 99.97% efficiency at removing the most penetrating particle size of 0.3 µm, and even greater efficiency for particle sizes smaller or larger. For more information, see Perry et al (2016) [7], which describes the mechanisms by which HEPA filters remove particles.

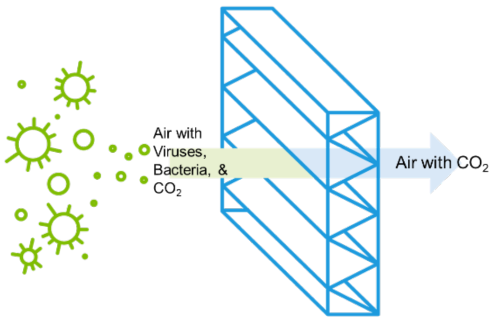

Figure 2: HEPA filters do not remove CO_2 from air

However, HEPA filters do not remove carbon dioxide. This results in a carbon dioxide concentration that does not correspond to the level of particulates, viruses, or bacteria present within the airplane cabin. As a result, airplane cabins will have a much lower risk of disease transmission compared to other indoor spaces with a similar CO_2 concentration. The risk is further reduced when mitigating features such as top-down airflow and the geometry of the cabin are taken into account.

HEPA filtration occurs whenever there is any power to the airplane, including at the gate. Carbon dioxide concentrations are typically higher when boarding the airplane compared to any other time in flight because of lower outside airflow flow rates and higher CO_2 concentrations in the outdoor air that is being supplied to the cabin. Boeing CFD studies [8] have performed cases where HEPA-filtered, recirculated air is the only source of air being supplied to the cabin. Even in these cases, and despite elevated CO_2 concentrations, the risk of disease transmission is still low because the amount of recirculated HEPA filtered air is still high compared to other indoor environments.

This HEPA filtered airflow, alongside beneficial cabin geometry and top-down airflow patterns, is a significant factor in why airborne transmission on airplanes has not been widely reported- despite elevated CO_2 concentrations compared to some buildings. [9]

References:

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