Modeling of Cough Transport in an Aircraft Cabin

Angela Davis, Stephen Trent | FAA Triennial | Atlantic City | October 18, 2022

What makes the air quality better?

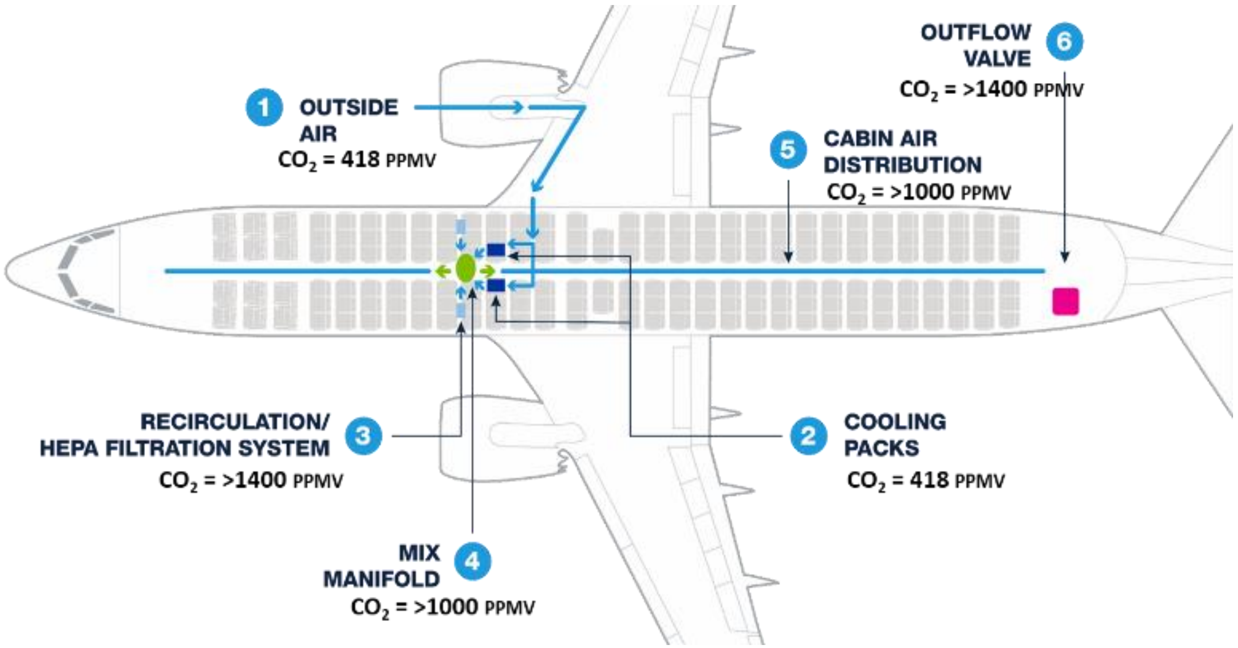
Parameters observed in Boeing modeling make the airplane cabin a low risk environment

1. Cabin air flows primarily from ceiling to floor
2. The circular air pattern limits particle movement
3. Airflow pulls cough particles down
4. The seat position acts as a barrier and minimizes particle spread
5. Airborne particles flow out through the floor grilles
6. HEPA filters trap more than 99.9% particles — including spores, bacteria, viruses
7. New fresh, filtered air constantly fills the cabin 20-30 times per hour

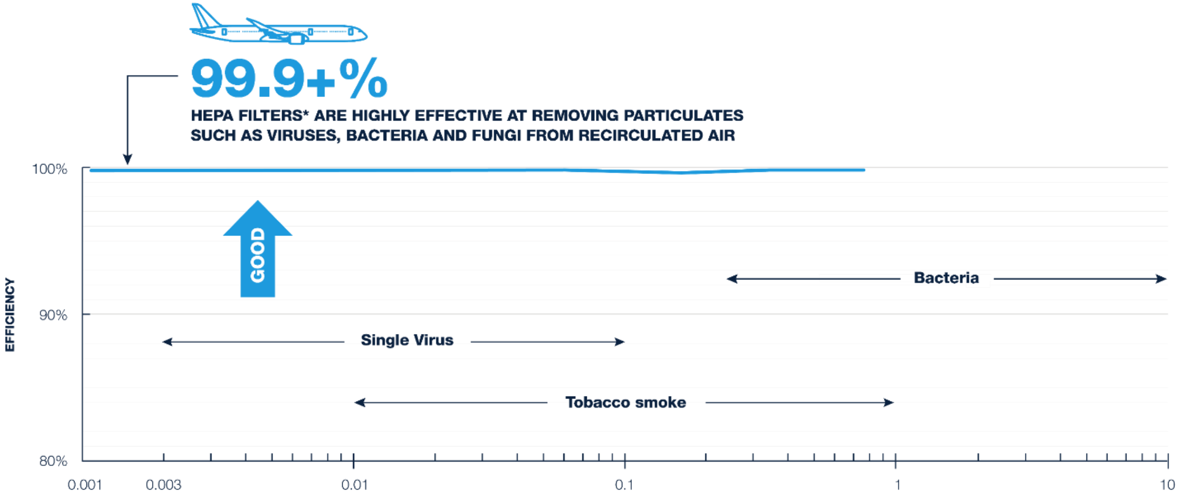
Why Boeing relies on high resolution particle modeling

CO_2 is a poor simulant for particles

- CO_2 does not settle due to the force of gravity
- CO_2 cannot be removed by HEPA filtration
- CO_2 is not removed from the atmosphere by contact with surfaces unless those surfaces have been specifically designed to remove CO_2
- CO_2 is a permanent gas and is not condensed at room temperature
- CO_2's behavior in the atmosphere changes very little as a result of relative humidity
- The size of CO_2 molecules does not change with evaporation
- CO_2's diffusion in the atmosphere is that of a permanent gas and not of a particle
- CO_2 has no complex behavior due to dissolved materials as it is not a particle and is a single compound



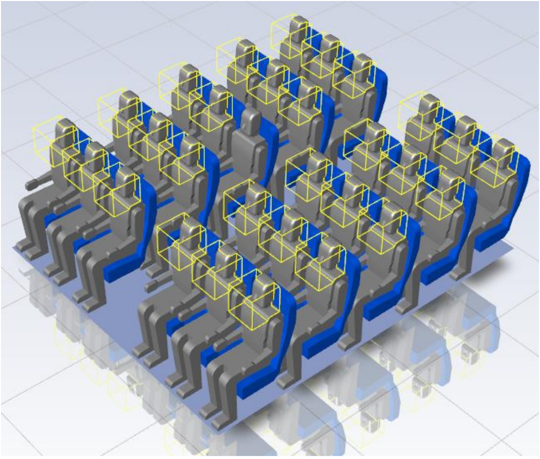
CO_2 is recirculated which is **not** the case for viruses or bacteria.

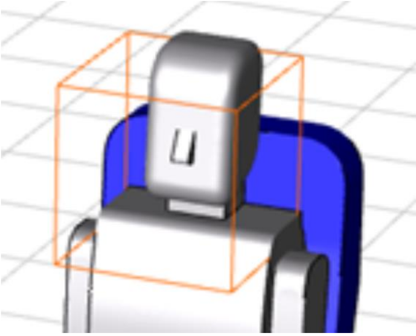


HEPA Filter Removal Mechanisms

Computational Fluid Dynamics (CFD) Model Inputs

- 737 cabin interior geometry; 5 rows and 30 passengers
- Each passenger has 1 cubic foot breathing zone
- 13M volume elements, with 106M particles modeled, on 20k cores, using 800 Ansys Fluent™ licenses
- Single cough; modeled with and without a mask
- Cumulative cough material tracked in each passenger's breathing zone
- Tabulated worse case accumulation for each passenger



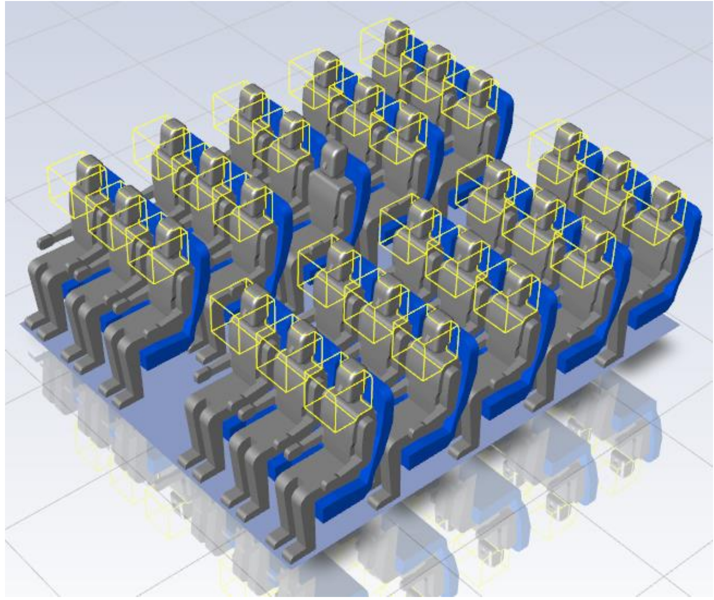


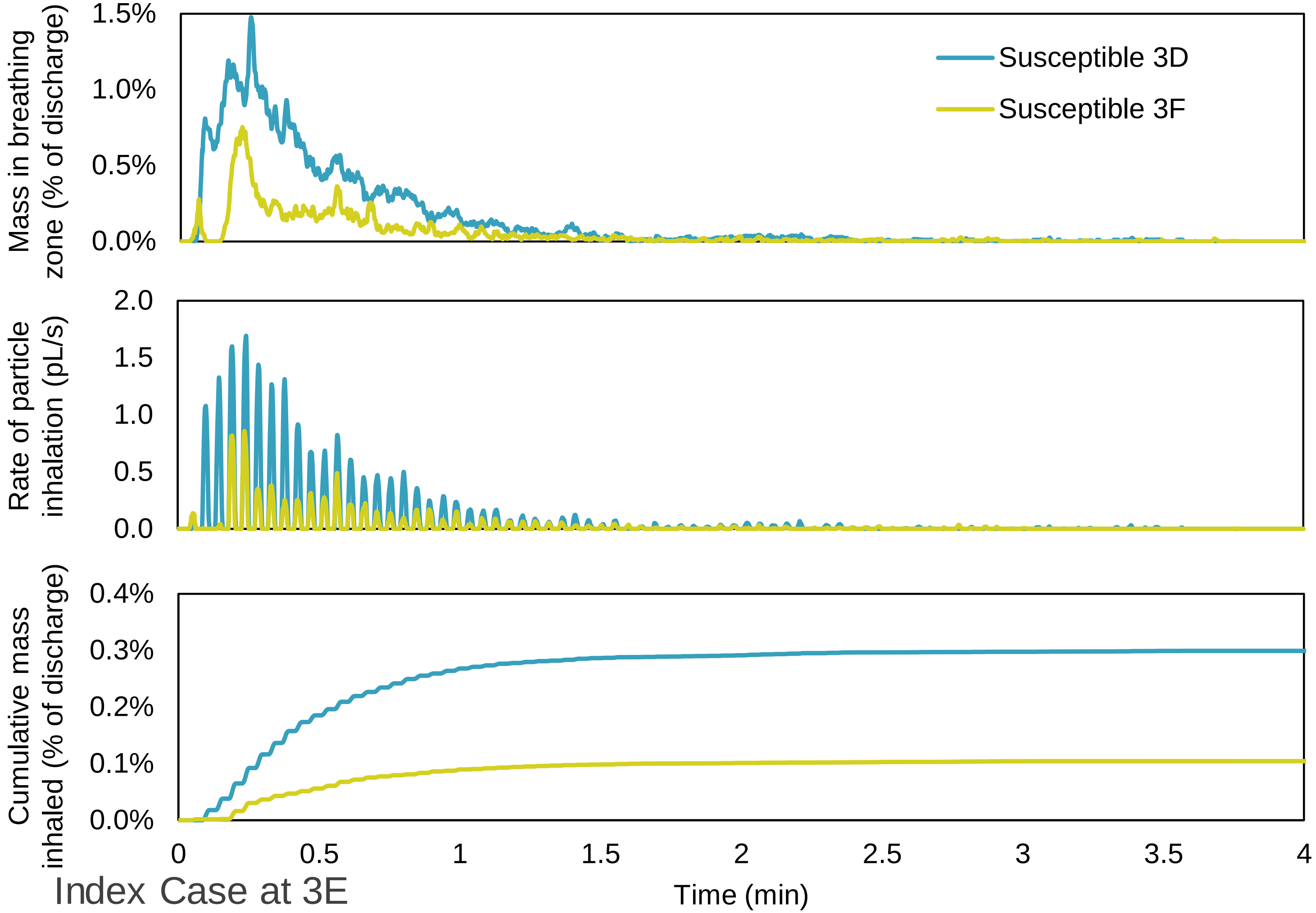
Airflow and thermal boundary conditions used for CFD simulations

	737 Aircraft Cough	737 Aircraft Breathing	Indoor Commercial Space Cough
Supply flow rate [Actual ft^3/min]	323-588	588	171-683
Return flow rate [Actual ft^3/min]	Same as supply	Same as supply	Same as supply
Air changes per hour	24.7-44.9	44.9	2-8
Relative humidity [%]	0-20	0	50
Occupant heat generation [W]	70/person	70/person	70/person
Walls [°F]	55-65	65	Adiabatic
Ceiling, floor, stowage bins	Adiabatic	Adiabatic	Adiabatic
Front and back interfaces	Periodic	Periodic	Non-periodic
Supply air temperature [°F]	62-67	65	65
Environment average temperature [°F]	75-77	75	70-80
All occupants inhaling/exhaling?	Yes for simulations with relative humidity > 0%	Both	No
Recirculation?	Yes	Yes	No

Mass Inhaled

- Total mass inhaled calculated using:
  - Mass in breathing zone vs time
  - Inhalation portion of tidal breathing
- Maximum mass inhaled was 0.3% of the initial release
- Average mass inhaled over the 29 susceptible passengers was 0.05%

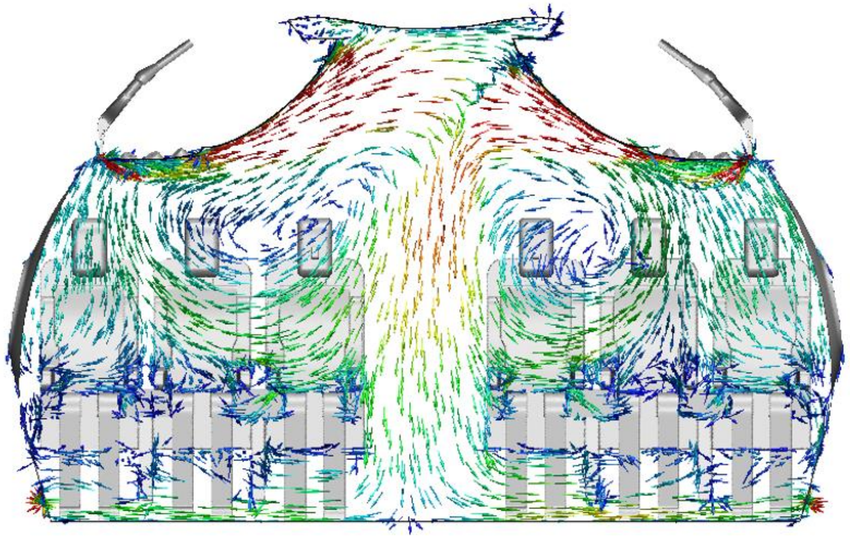




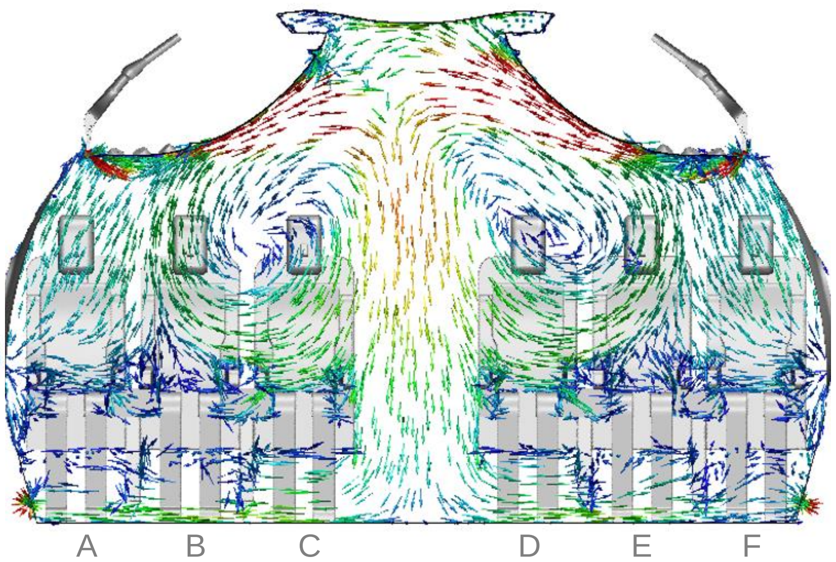
Index Case at 3E

- 95% of the mass removed from the breathing zone in 1.4 min for the occupant with the highest exposure
- Removal from breathing zone more rapid than removal from the cabin

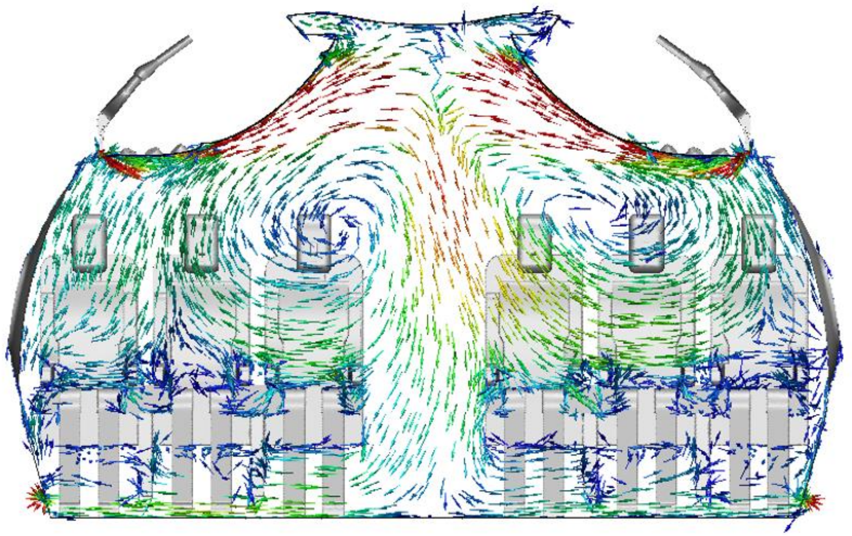
Influence of Initial Condition Velocity Vector



Initial Condition 1

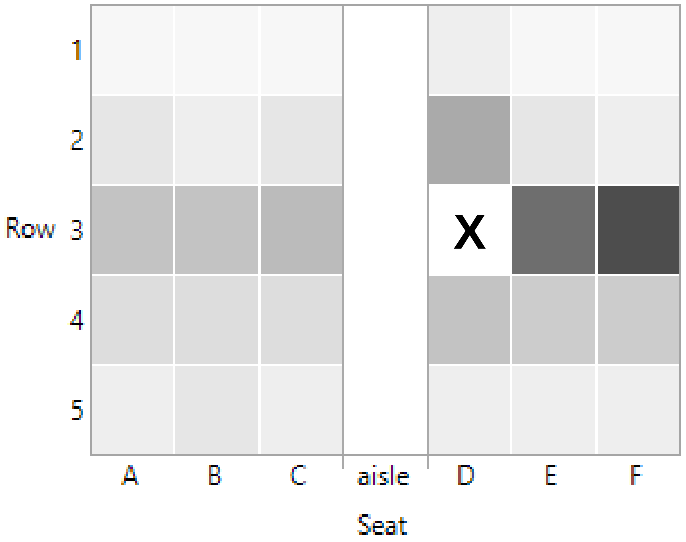


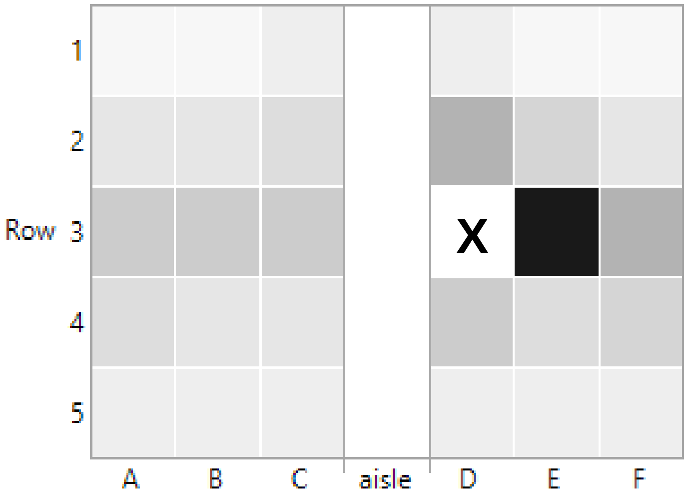
Initial Condition 2

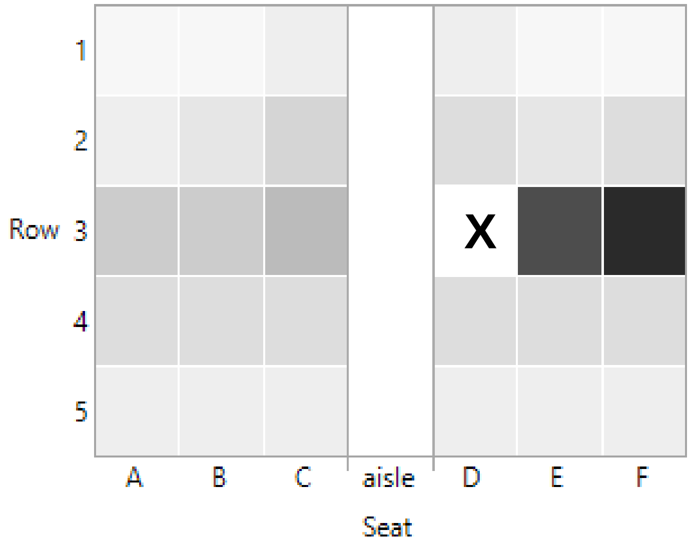


Initial Condition 3

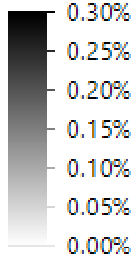
Exposure Seat Maps







Mass inhaled
% of release

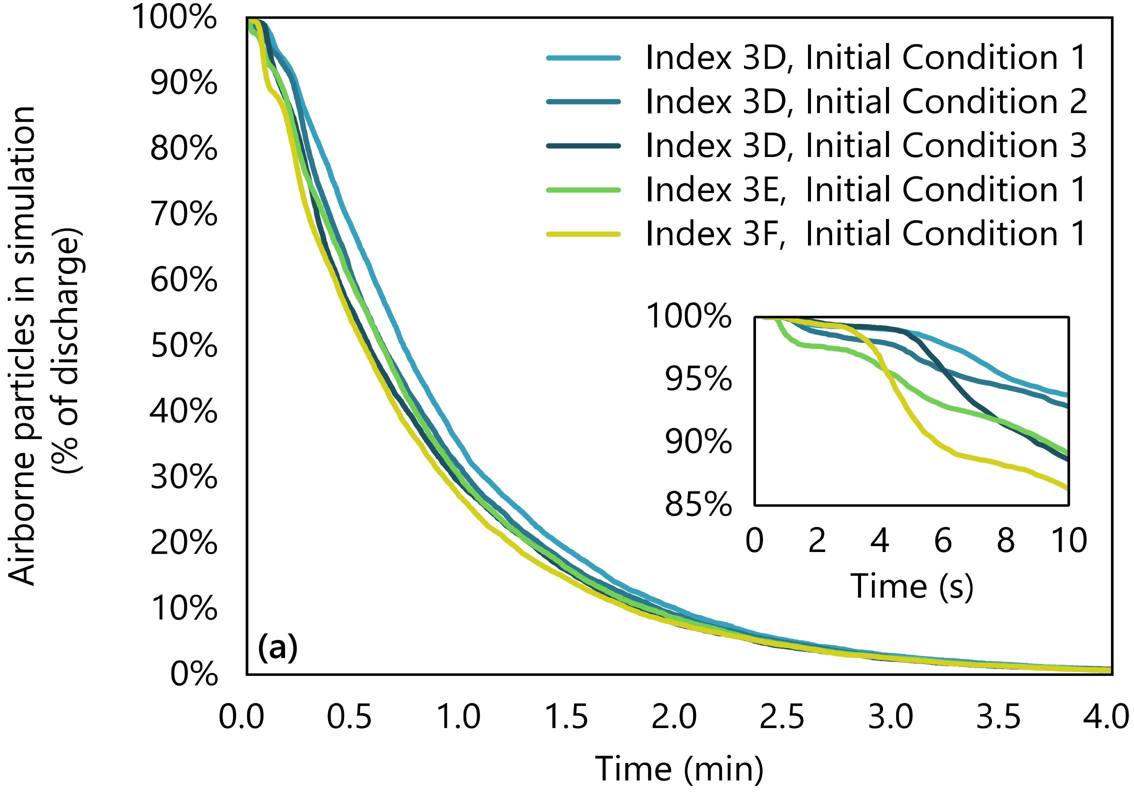


Airborne Particle Decay

1A	1B	1C
2A	2B	2C
3A	3B	3C
4A	4B	4C
5A	5B	5C

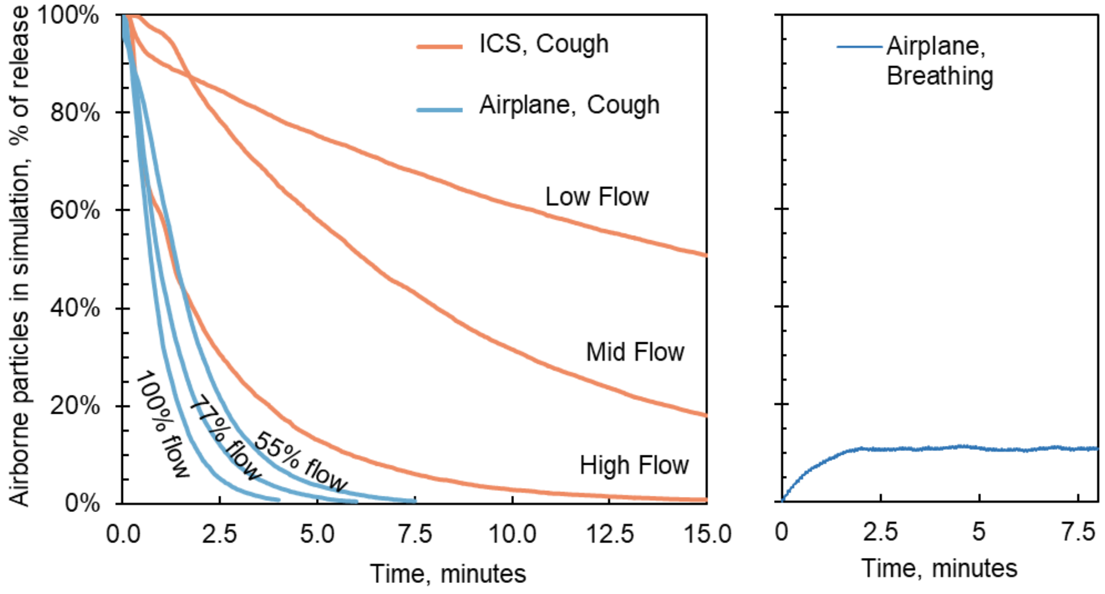
1D	1E	1F
2D	2E	2F
3D	3E	3F
4D	4E	4F
5D	5E	5F

Constant flow rate, varying index & initial conditions



- Initial differences due to surface deposition
- At 100% flow rate, 95% particle removal from the cabin in 2.4-2.5 minutes

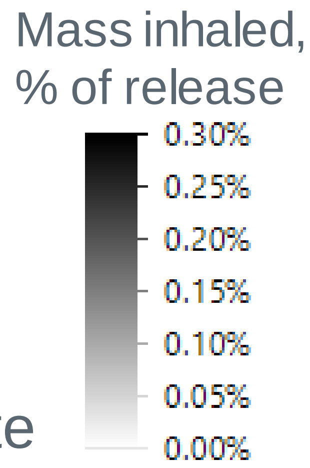
Constant index, varying flow rate

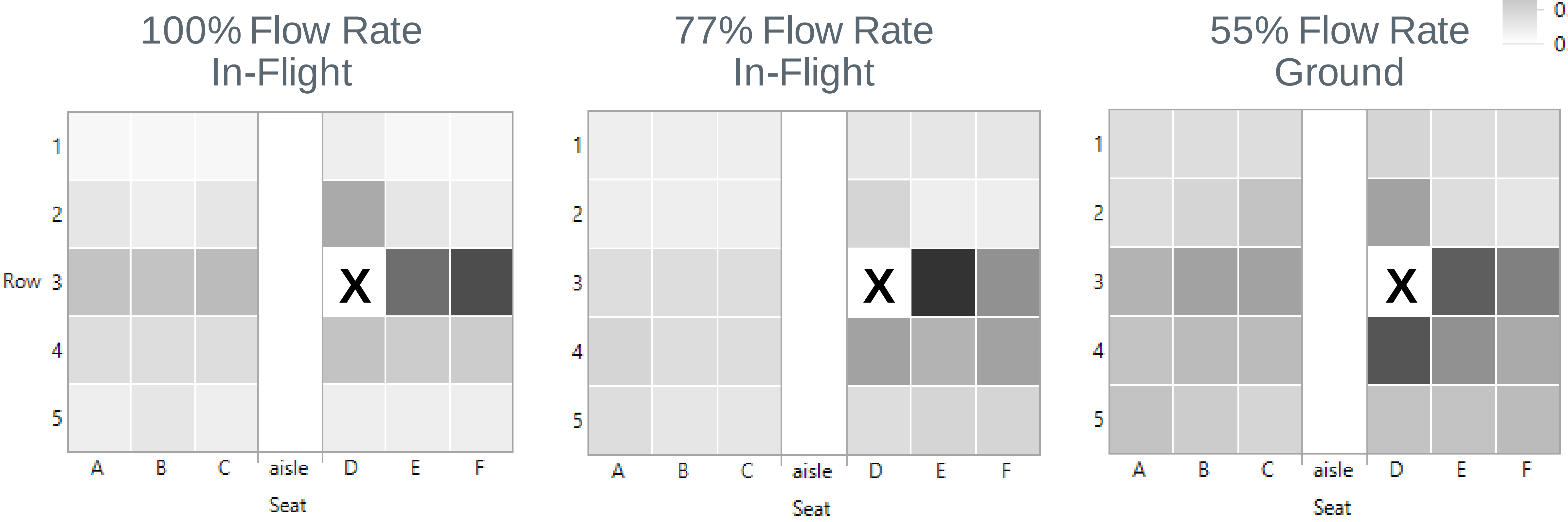


- Reducing flow rate increased removal time
- At 55% flow rate, 95% particle removal from the cabin in 4.5 minutes

Effect of Flow Rate

- Reducing the flow rate resulted in more particle spread throughout the cabin
- Average mass inhaled increased with reduced flow rate
- Maximum mass inhaled did not increase with reduced flow rate





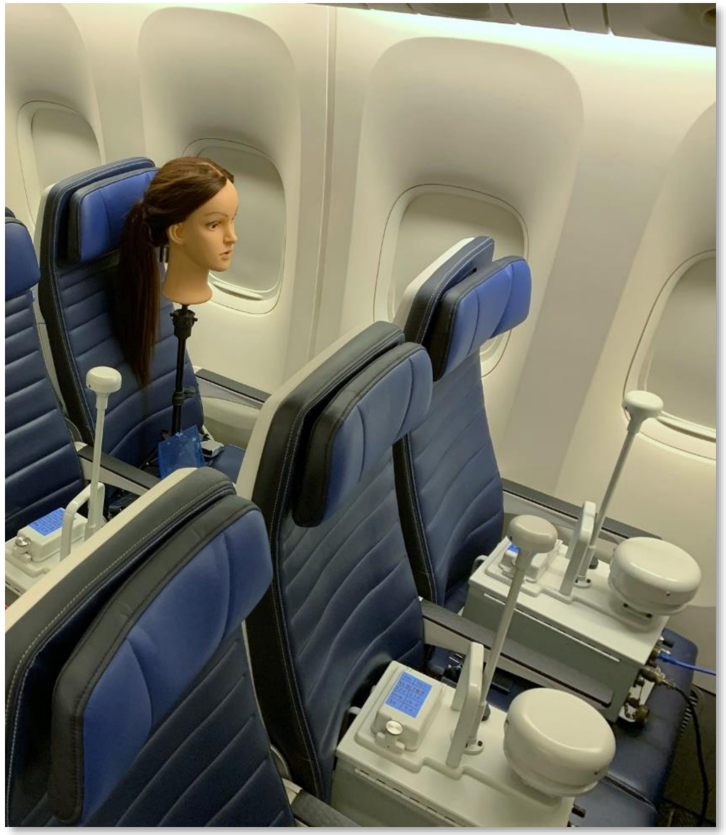
Airplane testing validates Boeing's cabin airflow modeling

Hundreds of cough tests show **passenger risk is extremely low**

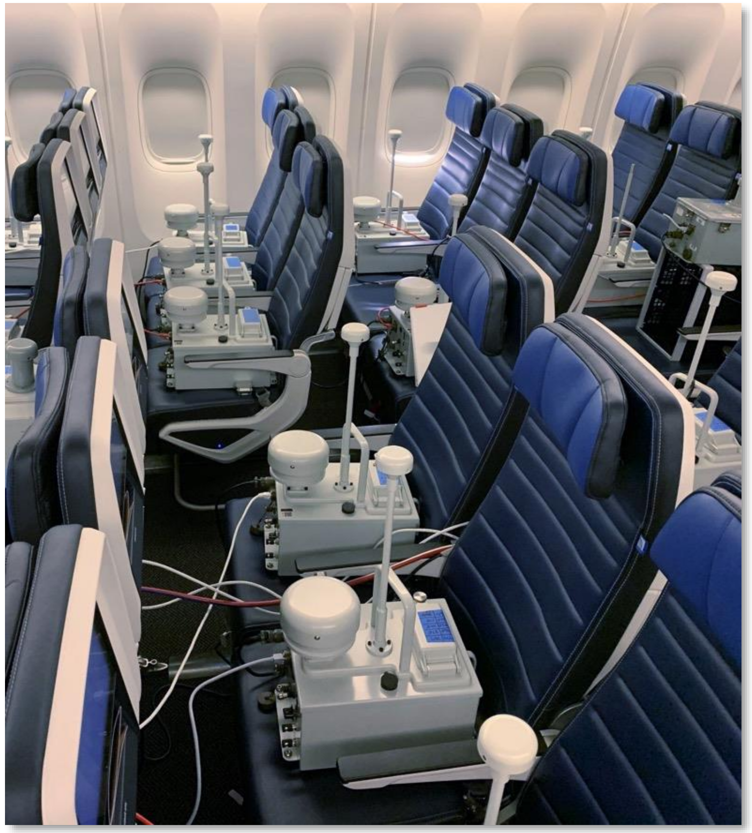
The US Department of Defense conducted **over 300 tests** in-flight and on the ground.

A robotic manikin released 180 million particles, the **equivalent of multiple coughs,** in each test.

Particles were tracked and showed only a **0.3% maximum risk of exposure** to infected particles even when seats are full.



Coughing manikin

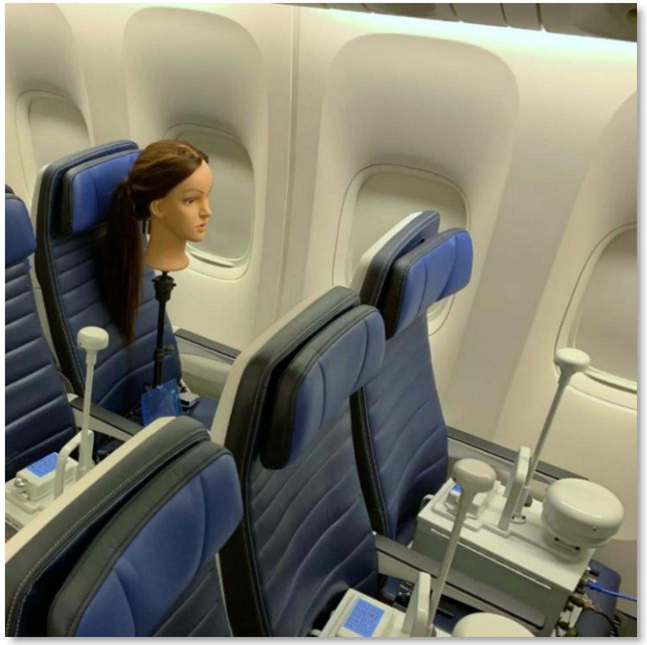


Bioaerosol sensors

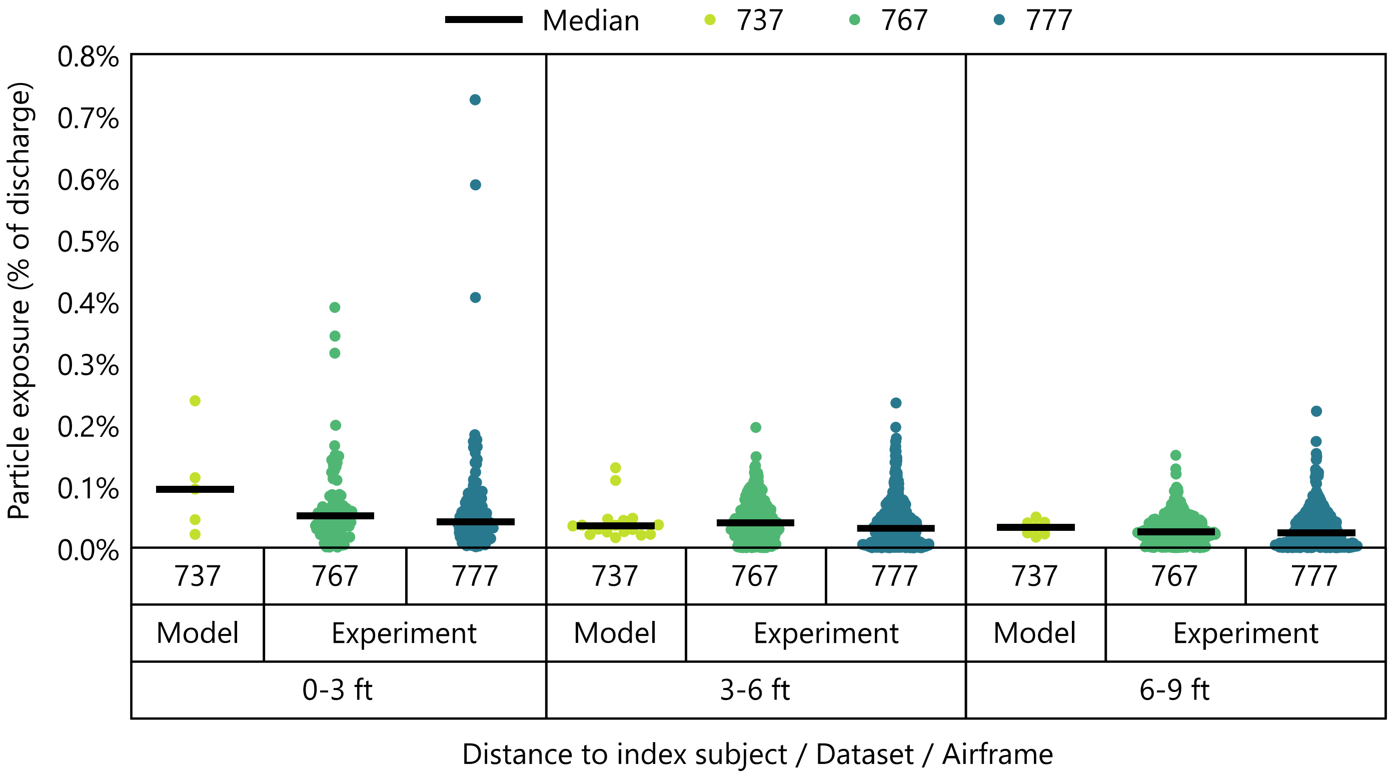
Testing conducted on 767 and 777 aircraft

Cough Comparison to USTRANSCOM Experiments

- 75 releases with conditions most similar to CFD were compared to one 77% flow rate simulation
- Adjusted USTRANSCOM inhalation rate to match model



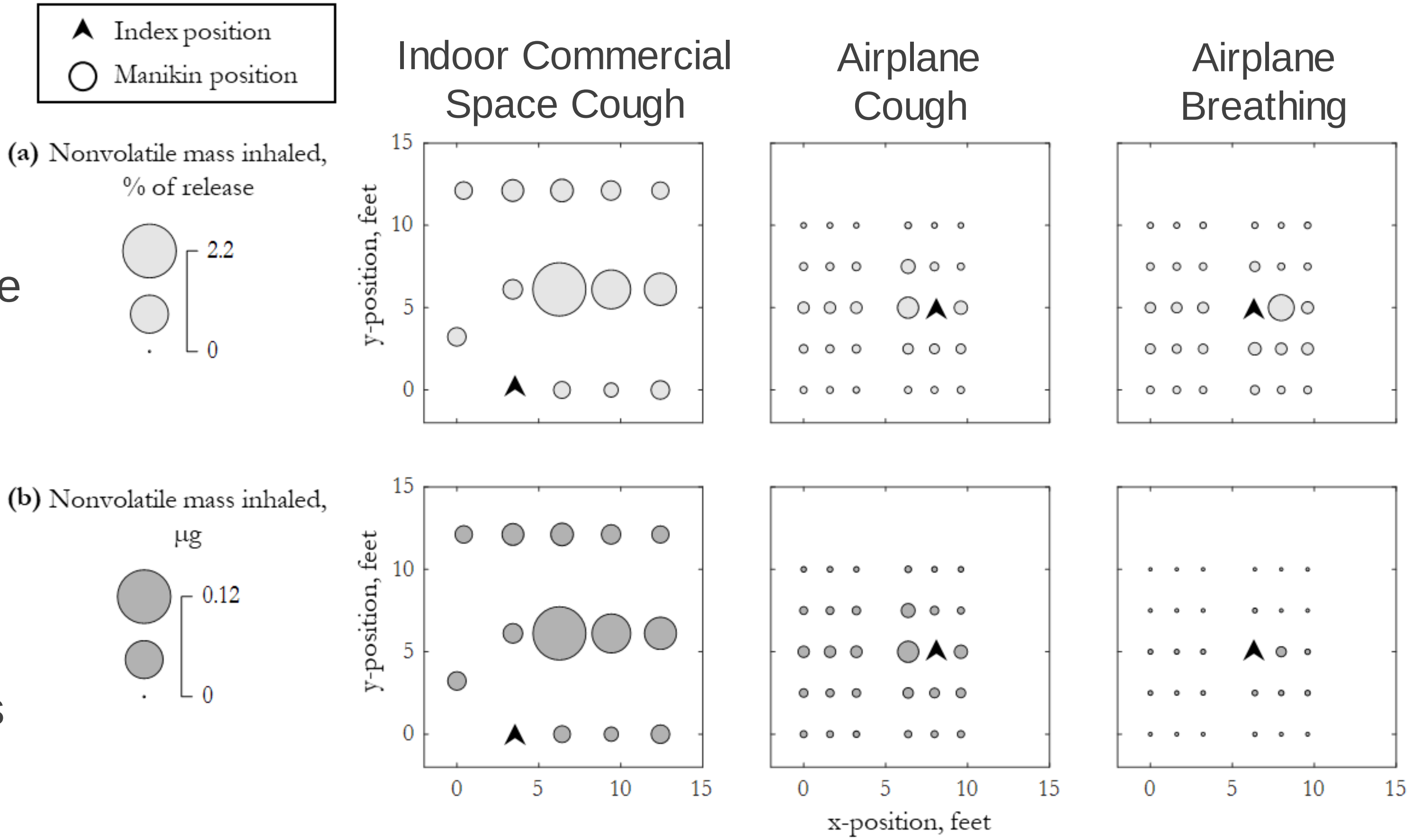
For more details:
https://www.ustranscom.mil/cmd/docs/TRANSCOM%20Report%20Final.pdf



- Experiment resulted in higher maximum exposure
- Model resulted in higher median exposure at close distances
- Both studies concluded low exposure

Findings from both empirical study and CFD modeling

- **Airplane cabins do not have a well-mixed atmosphere**
- This is due to high seatbacks, overall ceiling to floor airflow and positioning of the air inlets and return air grilles
- When a release such as a cough occurs, they are neither well-mixed nor steady state
- There is no simple relationship between distance and exposure to aerosol particles on aircraft
- HEPA-filtered and outside air sources are equivalent from a virus perspective on aircraft as the most penetrating size is retained by the filters at 99.97%



Exposure seat maps for CFD simulations with the highest individual occupant exposure to a single cough in the ICS and airplane, and exposure to eight hours of breathing in the airplane. Each bubble represents the position of an occupant, and the size of the bubble represents the nonvolatile mass inhaled as (a) a percentage of the mass released, and (b) the total mass inhaled, µg. (Trent et al.)


Travel Confidently.
boeing.com/confident-travel