Influence of Source Location and Ventilation Rates on Contaminant Dispersion Pattern in an Aircraft Cabin

James Bennett **Veronica Dos Santos Teixeira** **Yanhui Zhang** **Shamia Hoque**
Member ASHRAE *Associate Member ASHRAE*

ABSTRACT

The study analyzes data from field exposure measurements in an aircraft cabin to identify at what point of time or at what distance the influence of the 'release' diminishes and if the contaminant transport transitions from being influenced by the source release characteristics to being influenced by ventilation conditions. Temporally distinct transition in the contaminant transport was noted for one source location within 200 and 400s of release. The results showed that passengers seating at a radial distance of 2 m or greater from the source may be exposed to lower levels of concentration for a shorter duration.

INTRODUCTION

This study explores the concentration data from field exposure experiments conducted in an air craft cabin as described by Wang et al. (2006) and Bennett et al.(2013). The temporal change and spatial distribution of the concentration measurements is assessed to identify two conditions 1) at what point of time or at what distance the influence of the 'release' diminishes to being negligible or 2) if the contaminant transport pattern transitions from being influenced by the source release characteristics to being influenced by the cabin parameters. There have been extensive investigations into the fate and transport of contaminants in an aircraft (Li et al. 2014). The general conclusion has been that the transport is governed by multiple variables such as ventilation conditions, cabin arrangement, source location etc. however, guidelines towards predicting or distinguishing between high 'risk' and low 'risk' zones or time frames identifying when the risk is mitigated, remain non-existent. This investigation focuses on identifying parameters that can make such distinctions.

RESULTS AND DISCUSSIONS

Briefly, summarizing the experiments conducted in (Wang, Zhang et al. 2006), a tracer gas, carbon dioxide, was released at two locations in a mock up cabin and measurements were taken at the breathing level in a plane. The tracer concentration was measured at the seat locations for 1000s. The experiments were conducted over three air change rates which were 80%, 100% and 120% ventilation of the cabin (Wang, Zhang et al. 2006). Figure 1 shows the schematic of the mockup cabin with the two source locations, 2B and 4F. In the figure the radial distance of each seat from the source is included. The radial distance (as shown with arrows in the figure) is the straight distance from

Published in ASHRAE Transactions, Volume 125, Part 2

the source to the seat of interest and calculated from the vertical and horizontal measurements of the seat locations from the source.

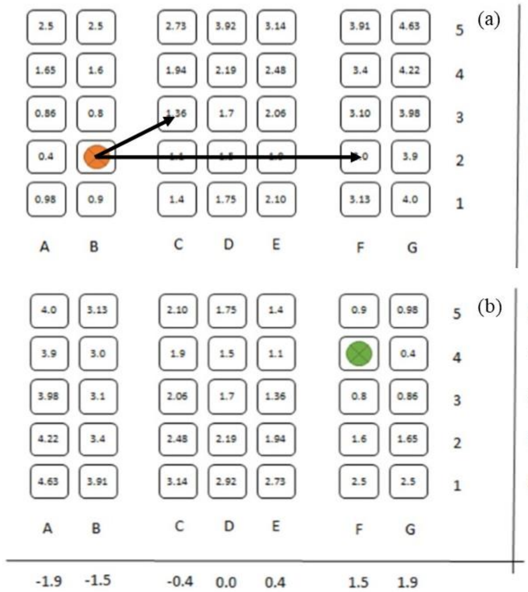

Figure 1 Cabin schematic with the radial distance (m) from the source, (a) 2B (b) 4F

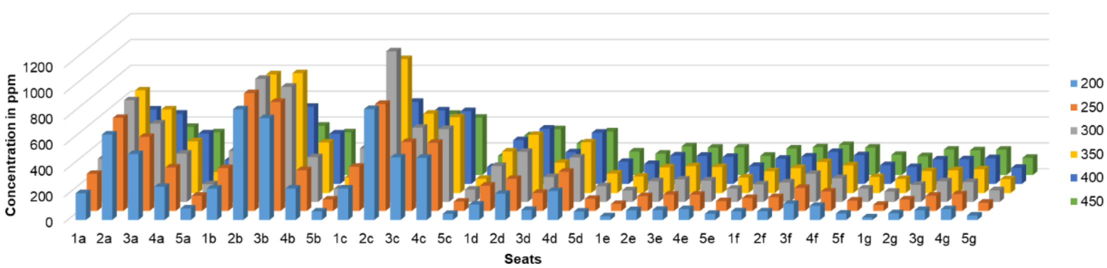

Figure 2 Temporal and spatial distribution of the contaminant released from location 2B at 80% ventilation rate

Figure 2 is a bar chart representing the concentration distribution over time at the different positions when the source of the tracer gas is seat 2B and the air change is at 80% ventilation. At 2B after 200s of release the concentration is at ~800ppm, which declines at 400s. The concentration trend across columns A, B, and C shows an increase from 200s to 350s and then a decline. For columns D, E, F and G the concentration trend increases up to 400s indicating the travel of the tracer plume towards these regions of the cabin but at much lower concentrations. Figures 3 (a) and (b) shows the percent of locations with less than 5ppm concentration levels for all ventilation rates at the source locations 2B and 4F respectively. 5 ppm was arbitrarily chosen as a very 'low level' assuming the possibility that infection risk may be less at such levels. At 120% the percentage is highest compared to 80% and 100% but there also appears to be a steeper decline. 200s to 600s after release none of the locations have concentration levels less than 5 ppm. Comparatively for 4F source the duration is 400 s to 600 s and different ventilation rates perform similarly. At 1000s for both scenarios the number of locations with concentration levels < 5ppm has not returned to the original levels.

Published in ASHRAE Transactions, Volume 125, Part 2

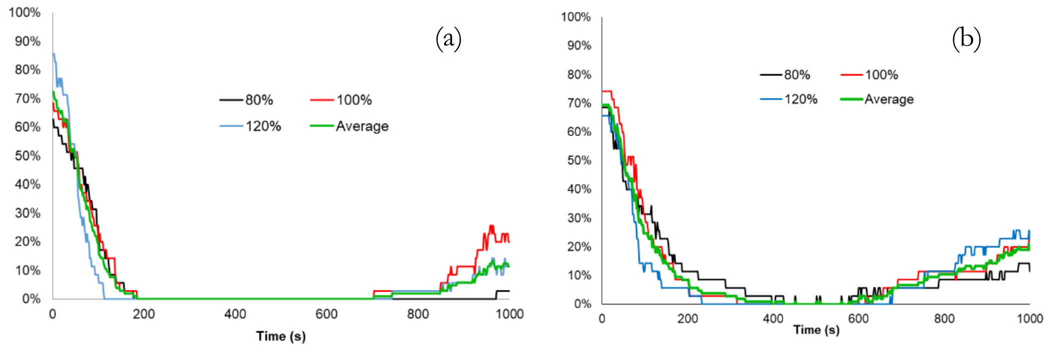

Figure 3 Percent of locations with concentrations < 5ppm a) source 2B, b) source 4F

The change of concentration over time at the different seat locations for air changes of 100% and of the air change rates are shown in Figures 4 (a) and 4 (c) for source locations 2B and 4F. Exponential decrease occurs until a certain point of time, when the concentration reduction becomes linear. When the source location is 2B, figure 4 (a) for all ventilation conditions, the decreasing trend of the concentration profile tends towards linear spatially typically when the radial distance is in the range of 2.0 to 4.0 at 200s, 250s, and 300s. The distance of 2.48 m was also noted by Bennett et al. (Bennett, Jones et al. 2013) to separate near and far fields for the concentration profile.

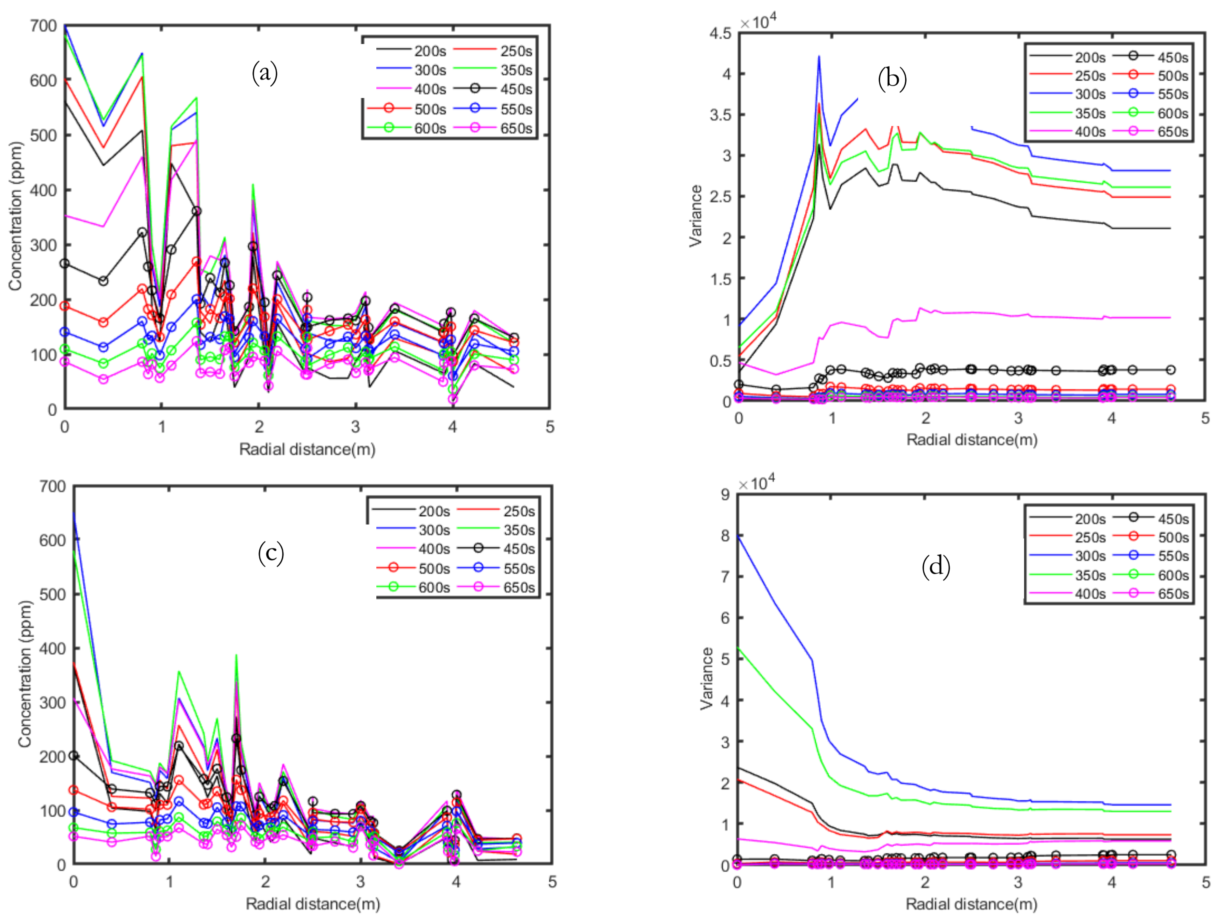

Figure 4 (a) Concentration change at 100% for 2B(b) Variance at 100% for 2B (c) Concentration change at 100% for 4F (d) Variance at 100% for 4F

A specific distance is harder to designate for the scenario of release from 4F as seen in Figure 4 (c). Overall, for both sources the concentration levels decrease to below 50 ppm at all seat locations by 650s when the air change rate is 120% of ventilation. For 80% conditions the concentration levels at radial distance < 1.0 m is ~100 ppm and continues to decrease linearly after 650s of release. The corresponding variance plots Figures 4 (b) and (d) shows how the variance changes across the seat locations and at the different times when ventilation conditions are at 100% of the air change rate and sources are at 2B and 4F respectively. A distinct transition can be seen temporally occurring between the time frames of 200 to 400s and from 450s onwards for source 2B as seen in Figure 4 (b). The variance spatially also becomes 'smoother' after a radial distance of 1.5 m from the source when time is <400s. When time is > 400s the variance becomes smooth after 2.5 m. A similar distinct temporal transition is not seen for the source 4F in figure 4 (d), though after 400s the variance is nearly zero. And spatially the variance decreases smoothly and exponentially until at a radial distance of 1.5m when release time is less than 350s. Beyond 1.5 m the decreasing trend is linear. At 400s and afterwards the variance trend is similar to what is seen for 2B, linear and negligible change over the distance.

CONCLUSION

The interaction of the source release and ventilation conditions, i.e. air flow changes determine the subsequent plume behavior after contaminant release. Generally, after 400s, the parameters influencing the plume characteristics changes probably transitioning from the influence of the physics governing the release to the physics governing the airflow dynamics. Passengers seating at a radial distance of 2 m from the source i.e. two columns away; right if source locaiton is 2B or left if source location is 4F and one row above or below (Figure 1), may be exposed to lower levels of concentration for a shorter duration. The correlation between airflow pattern in the cabin and the influence of the source location is being assessed to predict the contaminant distribution.

REFERENCES

Bennett, J. S., B. W. Jones, M. H. Hosni, Y. Zhang, J. L. Topmiller and W. L. Dietrich (2013). "Airborne exposure patterns from a passenger source in aircraft cabins." HVAC&R research **19**(8): 962-973.

Li, F., J. Liu, J. Pei, C.-H. Lin and Q. Chen (2014). "Experimental study of gaseous and particulate contaminants distribution in an aircraft cabin." Atmospheric Environment **85**: 223-233.

Wang, A., Y. Zhang, J. L. Topmiller, J. S. Bennett and K. H. Dunn (2006). Tracer study of airborne transmission of an aircraft cabin mock up. Annual Meeting of the American Society of Heating, Refrigerating and Air - Conditions Engineers, ASHRAE, Quebec City, QC, Canada.

Published in ASHRAE Transactions, Volume 125, Part 2