UNIVERSITI TEKNOLOGI MARA

EVALUATION OF AIRCRAFT CABIN VENTILATION THROUGH INLET/OUTLET MODIFICATIONS: A COMPUTATIONAL STUDY OF AIRFLOW AND CONTAMINANT DISPERSION IN A GENERIC SCALED-DOWN EMPTY AIRCRAFT CABIN

SHAHLIZA AZREEN BINTI SARMIN

Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy
(Mechanical Engineering)

Faculty of Mechanical Engineering

July 2025

ABSTRACT

The safety of air quality inside aircraft cabins, despite modern ventilation systems, remains ambiguous. This has increased uncertainty regarding personal safety among aircraft passengers, especially in the context of airborne contaminant transmission. To better understand and manage this issue, Computational Fluid Dynamics (CFD) is applied as it is a powerful tool for analysing complex airflow behaviours and predicting contaminant transport in enclosed spaces such as aircraft cabins. However, there are still critical gaps in the understanding of how different ventilation parameters affect airflow and contaminant dispersion. Therefore, this study addresses these critical gaps in understanding aircraft cabin ventilation systems through CFD to evaluate the performance of an aircraft cabin ventilation system. Specifically, the aim is to investigate the accuracy of turbulence models, the effect of the ratio of the inlet to outlet height on the air distribution and characteristics of the flow, the ventilation performance and contaminant dispersion mechanisms of the different types of mixing ventilation systems in a scaled-down generic empty aircraft cabin. The simulation is performed in Open Field Operation and Manipulation (OpenFOAM) version 2106, while the computational domain presents a commercial single-aisle aircraft cabin on a 1:11 scale. It was found that the Launder Sharma Low Reynolds Number turbulence model gives the best flow prediction. By examining different inlet-outlet configurations and ventilation systems, the inlet size significantly influences velocity distribution and flow characteristics. The sidewall mixing ventilation system (SV) performed best in delivering fresh air to the aircraft cabin, followed by ceiling mixing (CV) and combined ceiling-sidewall (CSV) configurations. The study revealed that among the CSV configurations, the ceiling-sidewall configurations with a volume flow rate of 40% ceiling and 60% sidewall inlets, CSV1, are the most effective in delivering fresh air across the cabin. The air change effectiveness (ACE) also shows that SV exhibits superior performance. The location of the contaminant source significantly influences dispersion patterns, with CSV1 showing the best containment for Case 1 (passenger standing in the aisle) and SV for Case 2 (seated passenger). Quantitative analysis of contaminant removal effectiveness (CRE) reveals higher CRE in Case 1, which is 1.15–1.79 with CSV1 at 1.79, while Case 2 has a lower CRE value of 0.65–1.0, with SV performing relatively better due to younger local air ages. Local air age directly correlates with a spatial distribution, which would affect passenger exposure risks. The SV ventilation system is a suitable configuration to remove the contaminants effectively for both cases. This research enhances the CFD method through comprehensive validation of turbulence models and evaluation of the ventilation system performance. The research provides validated simulation guidelines for OpenFOAM, enhances the understanding of mechanisms of airflow in aircraft cabins, and contributes to the safety of passengers by improving contaminant transport analysis. These findings are applicable not only to aircraft but also to other high-density transportation environments.

ACKNOWLEDGEMENT

I am grateful to my research supervisor, Associate Professor Ir. Dr Azli Abd Razak, for his vast knowledge, advice, and continuous support during the successful completion of this doctoral research study. I feel grateful to my co-supervisor, Ir. Dr Fauziah Jerai @ Junaidi and Associate Professor Dr Mohd Khir Harun, whose enlightening contributions meant much to me academically and their continuous mentorship throughout this journey.

I am so grateful to Universiti Kuala Lumpur, which provided financial support for this project. Its commitment to promoting academic and research excellence has been my motivation in accomplishing this.

I am thankful for Associate Professor Dr Mohd Faizal Mohamad and all my esteemed colleagues at WEBP for their thought-provoking discussions and constructive feedback. Similarly, I extend my heartfelt thanks to my colleagues at MIAT and the ABC PhD group, whose academic support and collaborative spirit are invaluable assets throughout this journey.

Lastly, I am very grateful for my loving family, for their unconditional love, encouragement, and strong belief in my abilities. To my loving mother and father, both of whom always pray for my success. Equally, I would like to give the deepest of my gratitude to my dearest husband Faizal and the children: Iman, Najwa, Nazran, Naufal, Najmah, Nuqman, and Naoki. Their patience, kindness, and steady support have been the core of my strength and determination. To all of them, here's to your warm hugs, immeasurable prayers, and gentle words, which saw me through the harshest moments and now making this achievement possible.

TABLE OF CONTENTS

		Page
CONFIRMATION BY PANEL OF EXAMINERS		**ii**
AUTHOR'S DECLARATION		**iii**
ABSTRACT		**iv**
ACKNOWLEDGEMENT		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**x**
LIST OF FIGURES		**xi**
LIST OF SYMBOLS		**xvi**
LIST OF ABBREVIATIONS		**xx**
CHAPTER 1 INTRODUCTION		**1**
1.1	Background of Study	1
1.2	Problem Statement and Research Questions	3
1.3	Objectives	5
1.4	Scope and Limitation of Work	6
1.5	Significance of Study	7
1.6	Thesis Outlines	7
CHAPTER 2 LITERATURE REVIEW		**9**
2.1	Introduction	9
2.2	Aircraft Cabin Environment	9
	2.2.1 Aircraft Ventilation System	11
2.3	Numerical Investigation	16
	2.3.1 Computational Fluid Dynamics Method	16
	2.3.2 OpenFOAM	18
	2.3.3 Fluid Flow Field	19
	2.3.4 Experiment and Numerical Studies on Scaled-down Model	29
	2.3.5 Grid Creation	30
	2.3.6 Validation Metrics	32

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In the past decades, the airline industry has witnessed unprecedented growth that significantly changed the mobility and connectivity of the world. This expansion has increased the number of passengers travelling short and long distances. As illustrated in Figure 1.1, the number of scheduled passengers in the global airline industry has increased each year. However, in 2020, the outbreak of Coronavirus Disease 2019 (COVID-19) caused a significant decline in passenger numbers, resulting in a 60% decrease due to catastrophic delays in the aviation industry. By 2024, the industry expects record revenues with 5 billion passengers [1].

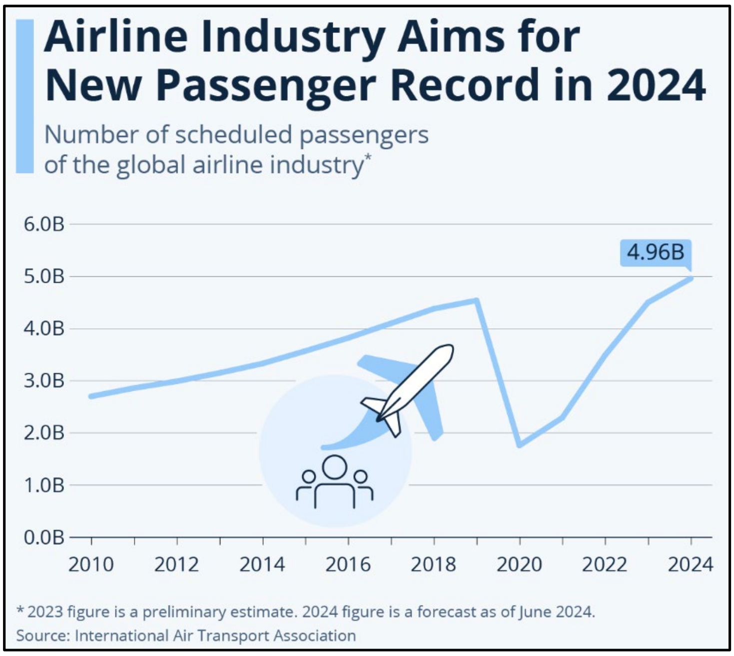

Figure 1.1 Number of scheduled passengers in the global airline industry [1]

Furthermore, according to the International Air Transport Association (IATA), global air passenger traffic is projected to double by 2040, growing at an annual average rate of 3.4% [2]. Origin-destination passengers are expected to grow from about 4 billion in 2019 to over 8 billion by the end of the forecast period. This steep growth has consequently placed additional burdens on aircraft cabin ventilation systems, with