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Designing an airflow system for cabin test facility

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1.0 Acknowledgments

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2.0 Abstract

This report provides designs and solutions to develop an airflow system that would be placed inside the C-series cabin at Downsview testing facility. Designing a smart air quality system proved to be problematic, such as the interference with other research projects, and the requirement of having to mimic the G7500 HVAC system. However, the design proposed managed to solve those problems, in addition this report provides basic information about how ventilation system works in aircrafts, and their different types. It also provides information about the various harmful particles found inside aircraft cabins, and what kind of sensors can be used to catch and measure those particles. Finally, a sample simulation was shown to give a starting point for future research to be done.

Table of Contents

List of Figures

List of Tables

3.0 Introduction

3.1 Description of Research and Test Facility

The purpose of this paper is to design a suitable cabin ducting system for the C-Series mock-up at the Downsview test facility. The test facility's main purpose is to help finish a five-year project that is part of industrial research chair program on cabin research that is being done by Professor Jeff Xi and his team. The research focuses on five main areas: cabin interior reconfiguration, seating, noise control, visual experience, and air quality. The design will include sensors to monitor the passenger's comfort and so it can adjust accordingly. This technology will combine with customizable, modular seating that can accommodate multiple body sizes and shapes to enhance the inflight experience for travelers. A smart air system is one of the five research packages, and its goal is to develop an air quality monitoring system, therefore an air ducting system should be designed to help with the success of the project.[1]

3.2 How aircraft ventilation system works

Current research deals with the dispersion of contaminant particles inside an aircraft cabin, and it says that air distribution is one of the most important components of the ECS, Environmental control system, as it is responsible for the proper distribution of air to customers and travelers using the aircraft while maintaining their thermal and health comfort. Usually aircraft cabins have high occupancy, a very sophisticated internal geometry, and less fresh air circulation than other indoor places such as buildings and cars. The aircraft ventilation system works by getting bleed air from the atmosphere using the compressors in the engine, it is cooled down under the wing center section by air conditioning packs, and finally mixed with equal quantity of recirculated air. As shown in *Figure 1.0*. Around 20 cubic feet per minute is provided to everyone inside the cabin, in which the ratio of recirculated air and outside air is equal. In 2 to 3 minutes a full exchange of air is occurring inside the cabin, a rate of 20 to 30 air changes per hour. This is important in order to control temperature gradients, maintain air quality, prevent inactive cold areas, and most importantly to maintain the pressurization of the cabin.[2]

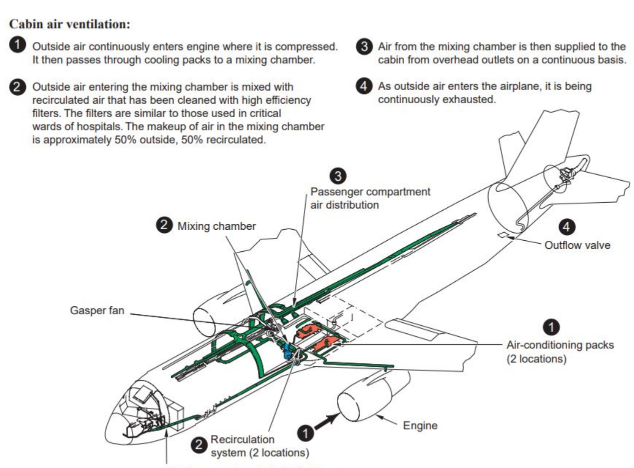

Figure 1.0: B767 Aircraft Ventilation System [2]

There is also some research on Personalized Ventilation, PV, which is essentially bringing each and every passenger their own individual thermal control. Its goal is to lessen the entrance of contaminants in the breathing zone of the passengers. This philosophy has been applied in buildings but not yet in aircraft cabins, and the only difference is the outlet system in the cabins. The outlet system is known as the gasper valves, which are not very effective in the case of individual thermal control. There are three main configurations of air distribution systems in aircrafts, the top-in and bottom-out system, The bottom-in and top-out system, and the mix of both.

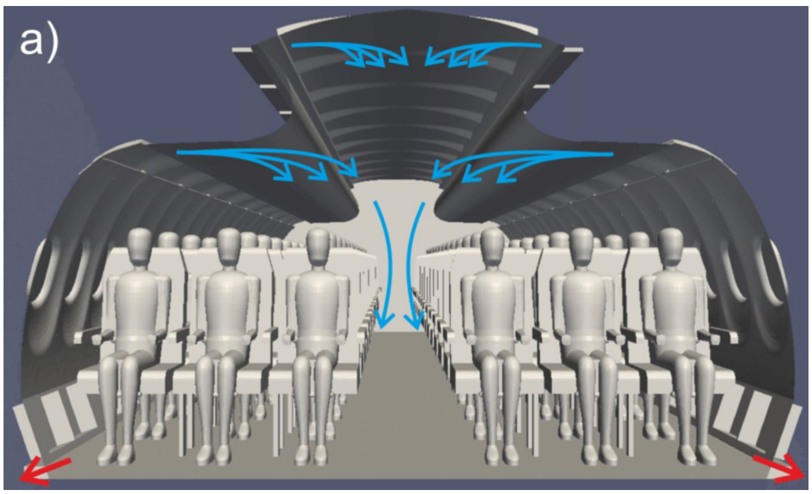

Figure 2.0: Mixing Ventilation system (Top-in and Bottom-out) [3]

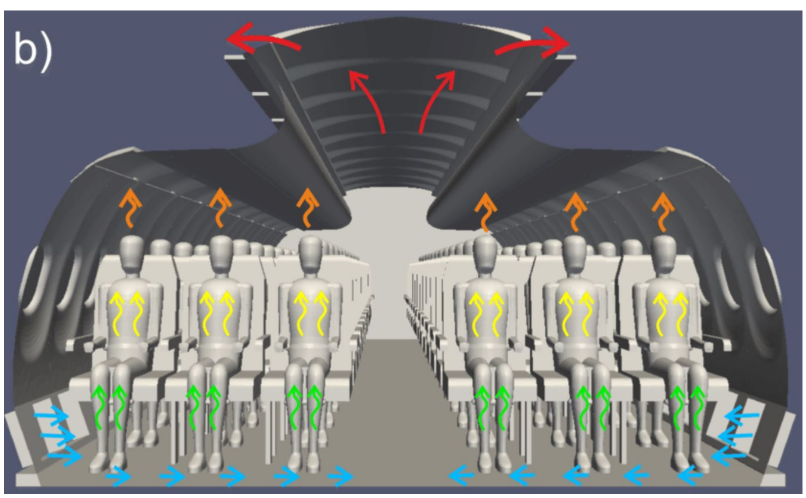

Figure 3.0: Bottom-In and Top-out ventilation system [3]

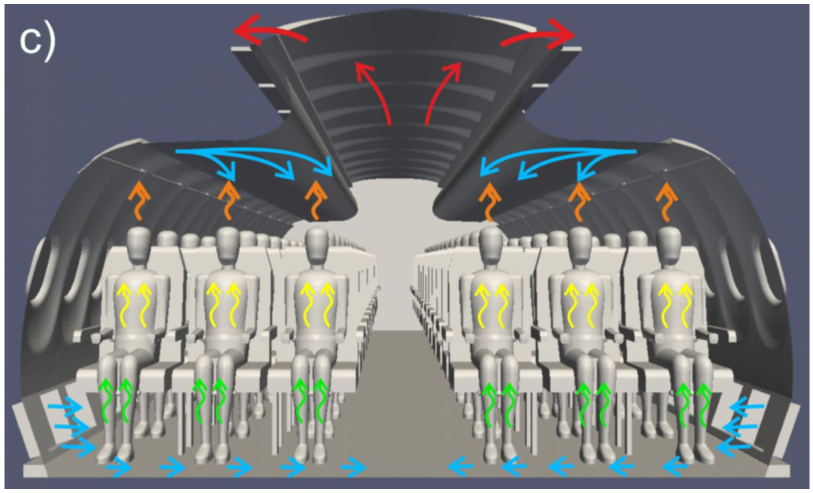

Figure 4.0: Both systems combined [3]

Standard airflow systems for passenger aircrafts are usually based on the principle of mixing ventilation, where high momentum jets are used to blow fresh air inside the cabin as shown in the figures above. There are three main configurations that air can be distributed inside the cabin, as mentioned before. Starting with the top-in and bottom-out configuration, this is a configuration that has the air supplied from the top and sucked out below the dado-panels at the floor level. This has its disadvantages because it is prone to draught at high heat load densities, and is very loud which is not comfortable to passengers. Additionally, it provides limited flexibility regarding cabin reconfigurations, *Figure 2.0* shows the top-in and bottom-out configuration. On the other hand we have the bottom-in and top-out configuration, where the air is being supplied by the floor and gets sucked out by the ceiling. This configuration is less problematic in comparison to the previous one as this would provide passengers with their own fresh air bubble, and this leads to higher efficiency in heat removal and lower fluid velocities. This configuration is illustrated in *Figure 3.0*. Finally the third type of configuration is the combination of the previous two systems. It is still not known what the advantages and disadvantages of such a system would be as there is not enough research being done to it. So far it is considered to be too complex and would require many systems for it to work which would increase weight and therefore cost on aircrafts. The combination of the two systems is shown in *Figure 4.0*.

3.3 Objectives:

- Come up with a design that would be suitable for the C-series cabin mock-up.
- The duct design should not obstruct any of the other research groups work areas.
- The ventilation system should mimic the one of the G7500:
    - 4” diameter ducts.
    - Bottom-In and Top-Out system of ventilation.

    - Determine the in-cabin location of sensors that would detect specific gas particles.
- The final design should be able to apply the pipe configurations done by other students working on the project, that would improve the overall performance of the system.

4.0 Problem Description

4.1 Downsview Cabin mock-up

4.1.1 Description of the testing facility

The C-series cabin mock-up at the Downsview test facility shown in *Figure 5.0*, currently has 5 different research areas that are being worked on: cabin interior reconfiguration, seating, noise control, visual experience, and air quality.

Figure 5.0: C-series cabin Mockup[2]

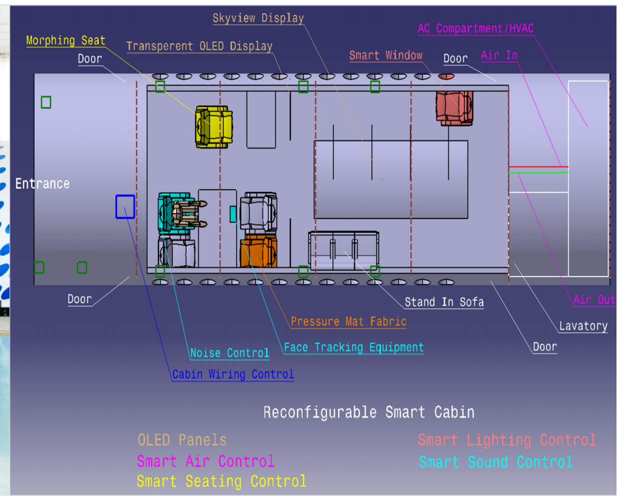

Figure 6.0: Team work space distribution[2]

As shown in *Figure 6.0*, the main problem is the lack of space, some of the projects do not require as much space as is being allocated for it. However, the air duct system needs to cover the entire cabin to properly simulate the G7500. Therefore, the required design should be able to work without interfering or damaging any of the other projects.

Starting at the red line marked in *Figure 6.0*, the inlet ducts should be coming out from there, and to satisfy the bottom-in and top- out requirement the duct will have drop to the ground. This would solve the first problem which is avoiding the OLED panels at the top. Secondly, the ducts will have to pass on the floor near the windows, and would go all the way to the first divider. The ducts will take about 4 inches of space on the ground and will require an extra 2 inches of space for clearance, this is to ensure that it does not interfere with the other projects.

Now looking at the green line in *Figure 6.0*, this is where the return ducts should be, however the same problems occur. The solution to that would be by diverting the outlet ducts and making them come from the sides. The return air ducts would still be at the top of the cabin, avoiding the OLED ducts and meeting safety standards.

4.1.2 Problems with the AC unit

Figure 7.0: AC unit placed at the back of the Cabin.

The AC unit shown in *Figure 7.0* has an inlet that comes from the top, but without any ducts attached to the inside of the cabin, so the air is just being blown into the cabin with no ducts to guide the flow. Therefore, ducts should be attached to it in order for the research team to guide the air inside the cabin and be able to carry on with research for the smart air control project.

4.1.3 Obstruction of the OLED Panels

The OLED panels that are being worked on by other research groups, are very sensitive and fragile so they should not be touched or maneuvered. In order to bypass them, the inlet should be brought down in a way that would make it come from underneath the panels as mentioned before.

Figure 8.0: The galley that separates the Inside of the Cabin from the AC unit compartment.

The distance measured from the cabin floor to the ceiling, where the panels are placed, was 80 inches. The distance from the cabin floor to the top of the AC unit shown in *Figure 8.0* was found to be 71 inches, which gives 9 inches to use in order to place a duct that would come out from the middle of the two top cabinets.

4.2 G7500 Ventilation System

The design should mimic the G7500 ducting system by having a supply air inlet coming from the bottom of the cabin, and a return outlet that has to be sucking in the air from the top. That would give us a bottom-in and top-out ventilation system. The design that will be used would satisfy this requirement, however the outlet ducts will be positioned lower than what is shown in *Figure 9.0*. That would not be a problem as the cabin mockup is bigger than the G7500, and it will be positioned in the same way that the G7500 would.

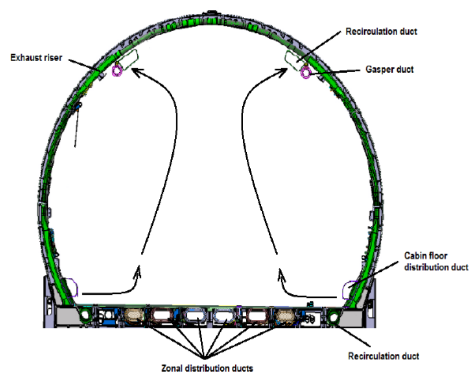

Figure 9.0: Desired Bottom-in and Top-out ventilation system.[3]

The testing would be performed on the inlet ducts mainly, and in order to have a simple design that could be changed and tested easily, the ducts on the ground would be placed on a V-type holders, as that would make the ducts replaceable incase there was any damage or if any more detailed changes needs to be made. *Figure 10.0* shows the general design of the holders, and the details of it can be seen in the Appendix section.

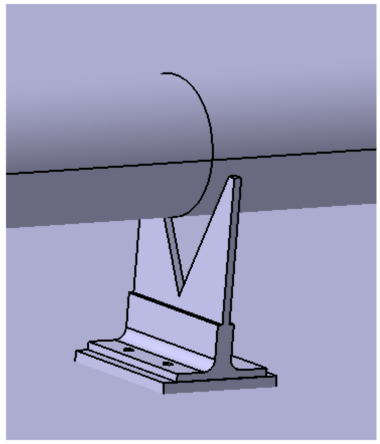

Figure 10.0: V-bracket duct holder

4.3 Current design solutions for the problem

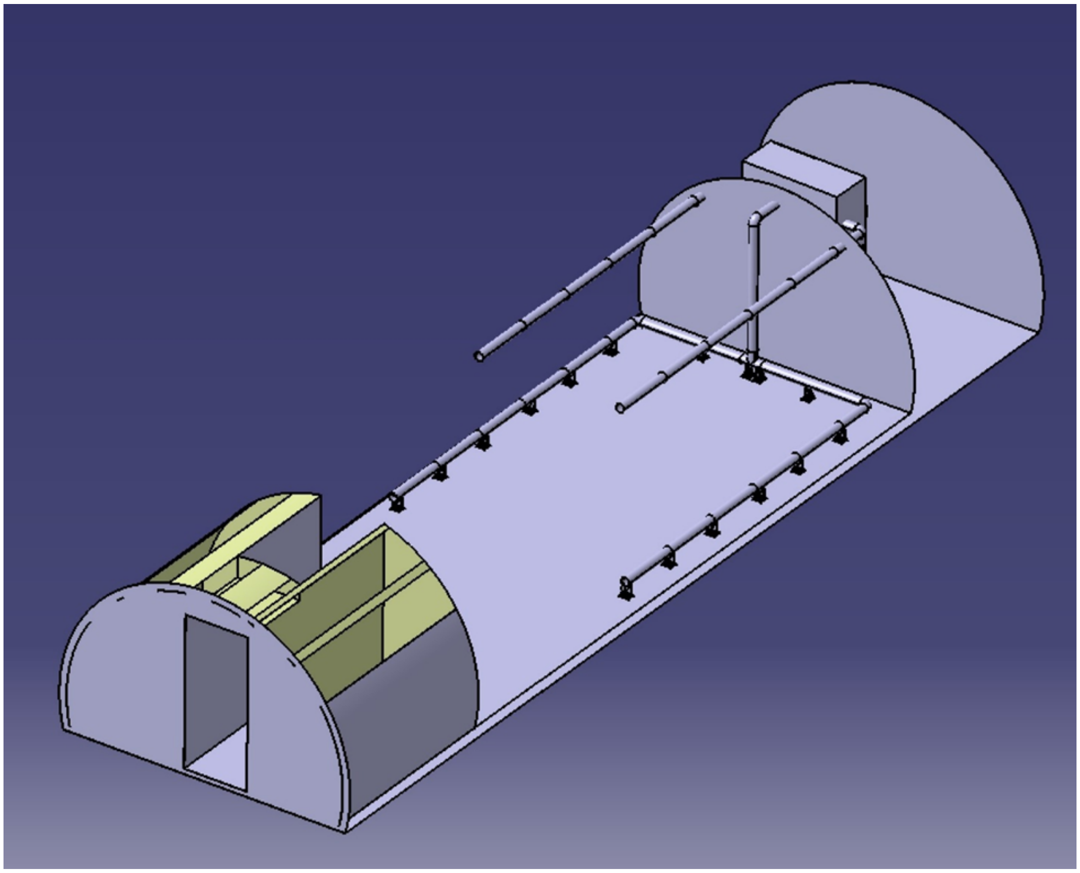

Figure 11.0: The in-cabin design with only the supply of inlet air.

In order to perform research on air quality control systems in the cabin at the Downsview facility, the following designs are being proposed. *Figure 11.0* shows an overall view of the design. As seen the ducts will only cover a certain section of the cabin, as mentioned before these ducts will travel as far as the divider. The inlet ducts are being directed downward towards the floor and then being split to the sides, in order to satisfy the requirement of having a system that mimics the G7500 HVAC system. Cuts should be made at the back for the ducts to be attached to the AC unit, the outlet ducts will be connected to the unit from the sides, and the inlet duct will be connected from the middle.

The V-bracket holders will be placed on the floor of the cabin, about 30 inches apart, to support the inlet ducts, and make it easy to perform changes with the design later as the research progresses. Regarding the outlet ducts, there are two possible ways to hold them in place. They are, connecting them to zip ties at the top, or ground support like the inlet ducts that are taller. The second solution would be more reasonable to have as it will also give the ability for other researchers to change the designs of the ducts, and it will be steadier as a support in comparison to the zip ties.

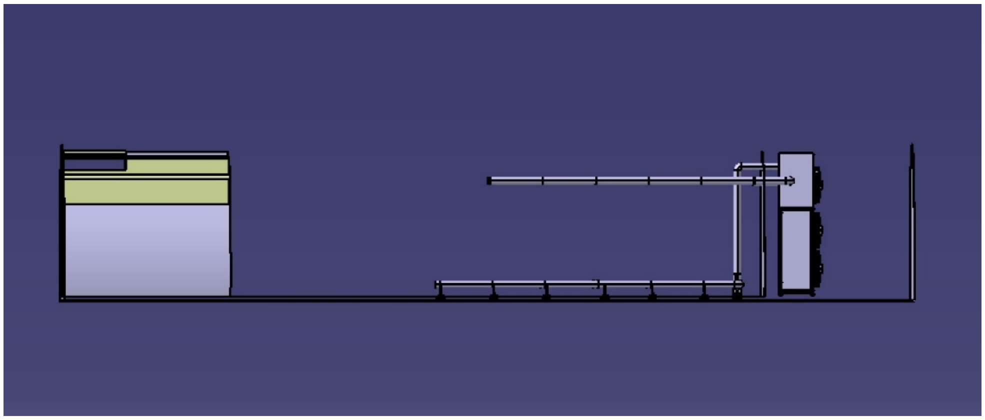

Figure 12.0: Side View of the assembly

Figure 12.0 shows a side view of the final design, and as shown the ducts at the top will not be too close to the ceiling and therefore will not have any problems with the OLED panels attached to the ceiling. For details about the suggested dimensions for this design and detailed drawings please see the appendix section.

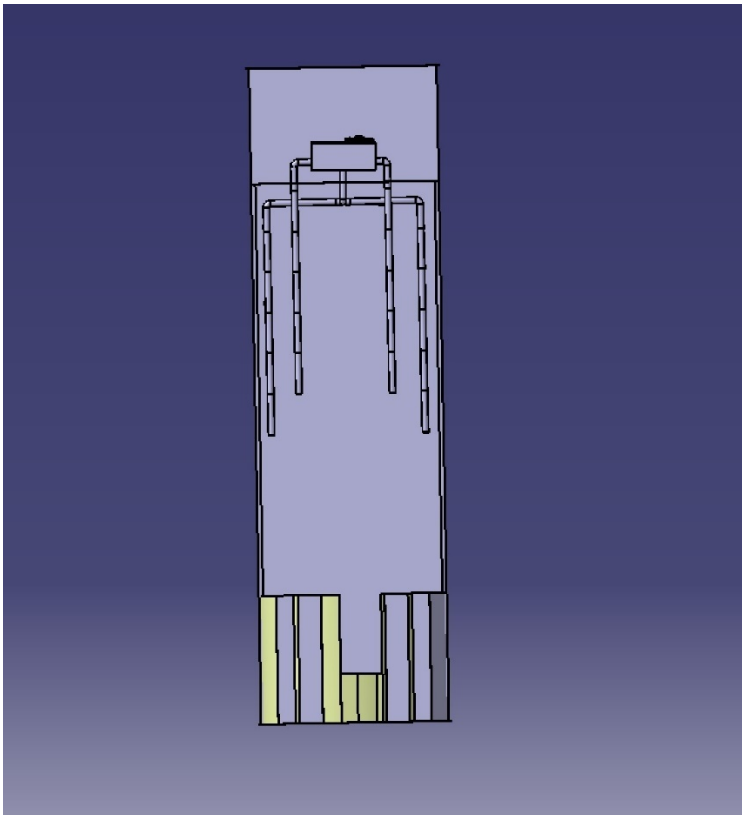

Figure 13.0: Top View of the assembly

Figure 13.0 shows the top view of the design, to give more visualization about the final design.

5.0 In room air quality sensing

5.1 Harmful Particles classification

Ozone is one of the harmful particles that can be inside an aircraft cabin, it is basically a molecule composed of the oxygen atoms, two of those atoms are the regular oxygen that humans breath, however the third one tends to detach and re-attach to other molecules of different substances, and here is where it becomes harmful, because once it attaches to other molecules it can form harmful particles that usually results in damage to the lungs when inhaled. Research has showed that low amounts of ozone can cause chest pains, coughing, and shortness in breath. It can also make chronic respiratory diseases worse such as asthma. [4]

VOCs are volatile organic compound and they are also particles found inside aircrafts, or any indoor places in general. One of the common forms of VOCs is formaldehyde, and it is a colorless gas that has a bitter sharp smell. Sources of VOCs include burning kerosene, which id frequently used in the aerospace industry as fuel. The effects of such particles are that it can cause irritation to the nose, eyes, and throat, and can also cause headaches and shortness of breath. Long-term exposure to VOCs could result in permanent damage to the kidneys, liver, and central nervous system.[5]

Carbon monoxide is another particle that could be found in closed spaces, it is a highly toxic gas that cannot be seen and has no smell. CO is usually given off when carbon-based materials are burnt, so whenever fuel is being burned CO can be found. Therefore it is very important to have a proper ventilation system that can get rid of CO as much as possible, because inhaling it can cause headaches, vomiting, and nausea. However if the carbon monoxide levels are high enough it can cause death, thus the name given to it, the silent killer. In the long exposure to CO gas can cause poisoning and increase the risk of heart disease.[6]

Carbon dioxide is a well-known gas that comes from humans exhaling, its levels is usually related to the amount of fresh air being brought to the closed volume. However, the higher the levels of CO_2, would mean the lower the amount of fresh air inside a cabin. Therefore, examining the levels of carbon dioxide is important to test the efficiency of the HVAC system. Similarly, exposure to high levels of CO_2 could also result in various health effects, which include headaches, dizziness, and difficulty in breathing.[7]

Gas Particles	**Size (microns)**
Ozone	0.1-0.4 microns
VOC	0.0003 – 2 microns

CO	0.03 – 1 microns
CO_2	0.00065 microns

Table 1: Gas particles classified by size[8]

5.2 Particle Sensors

Before going through the process of choosing what kind of sensors to use, the following specifications need to be considered. Firstly the sensor systems must be able to provide data in a very simple manner, as it should not need any attention by crew members or maintenance staff. Secondly, the sensors should be able to be placed in many locations in the bleed air and cabin air supply ducts. Thirdly and most importantly, the accuracy of the sensors should be high, and should have a sampling interval of less than 60 seconds. The size of the sensor should be small, of sizes no greater than 3/8 inches in diameter.[9]

Some research has been done by other researchers on different sensors, which include the electrical low-pressure impactor (ELPI), the diffusion charger, the photoelectric aerosol sampler, and CPC. The ELPI designed by Dekati LTD is used to measure the article size distributions. It measures the aerodynamic diameter using twelve stages. The aerodynamic diameter is important as it is related to the mobility and geometry of the particle. Additionally, the sensor has a response time of 1 to 20 seconds, which makes it very effective at capturing real time changes in particle distributions. On the other hand, the diffusion charger is another sensor that can be used, it is a measure of aerosol active surface area. It employs a unipolar charger that charges particles and measures the total current carried by the particles. This can be used to detect CO_2 concentrations. The third kind of sensors is the photoelectric aerosol sensor, it provides a measure of chemical surface properties of sampled particles, this is good for measuring hydrocarbons. Finally, CPC, is a sensor that can be used as a condensation particle counter. It can measure particles that vary in sizes from 7nm to 2.5um. This sensor is designed by TSI Inc. model 3022A. [10]

5.3 Strategic Placement of Sensors

The placement of sensors inside the cabin should be strategic as it should be able to collect as many particles as possible. Therefore, some sensors would be placed inside the ducts and others would be placed in different places inside the cabin.

For the ones placed inside the cabin, the sensors should be placed near the outlet ducts as it can show the type of harmful particles that are being extracted from the cabin. In addition, some sensors should be placed near the inlet ducts in order to make sure that the air being supplied to the cabin is not contaminated with harmful particles such as ozone and carbon monoxide. Thirdly, the sensors should be placed in a location where the fresh air is being mixed with circulated air, in order to determine what happens when particles from both are being mixed. To know the exact locations of sensor placement simulations should be performed, which are shown in the next section.

6.0 Simulation

6.1 ANSYS (Fluent) Simulation and how strategic the sensors are placed.

To place sensors in their accurate position simulations must be done, ANSYS fluent is one of the software's that can be used to simulate the air distribution inside the cabin. It can help with studying different designs before applying them in real life, this would be very cost efficient, and could show results that were not taken into consideration before. In addition, after simulating the model the exact location of sensors could be determined.

Taking *Figure 14.0* as an example, the air is being distributed inside the cabin in such a manner where the air is being supplied from the bottom and then sucked out from the top. It can be seen that the air would have some kind of circulation inside the cabin, therefore in this case placing them in the dark blue area would be the most suitable position as the highest concentration of air is mixed there.

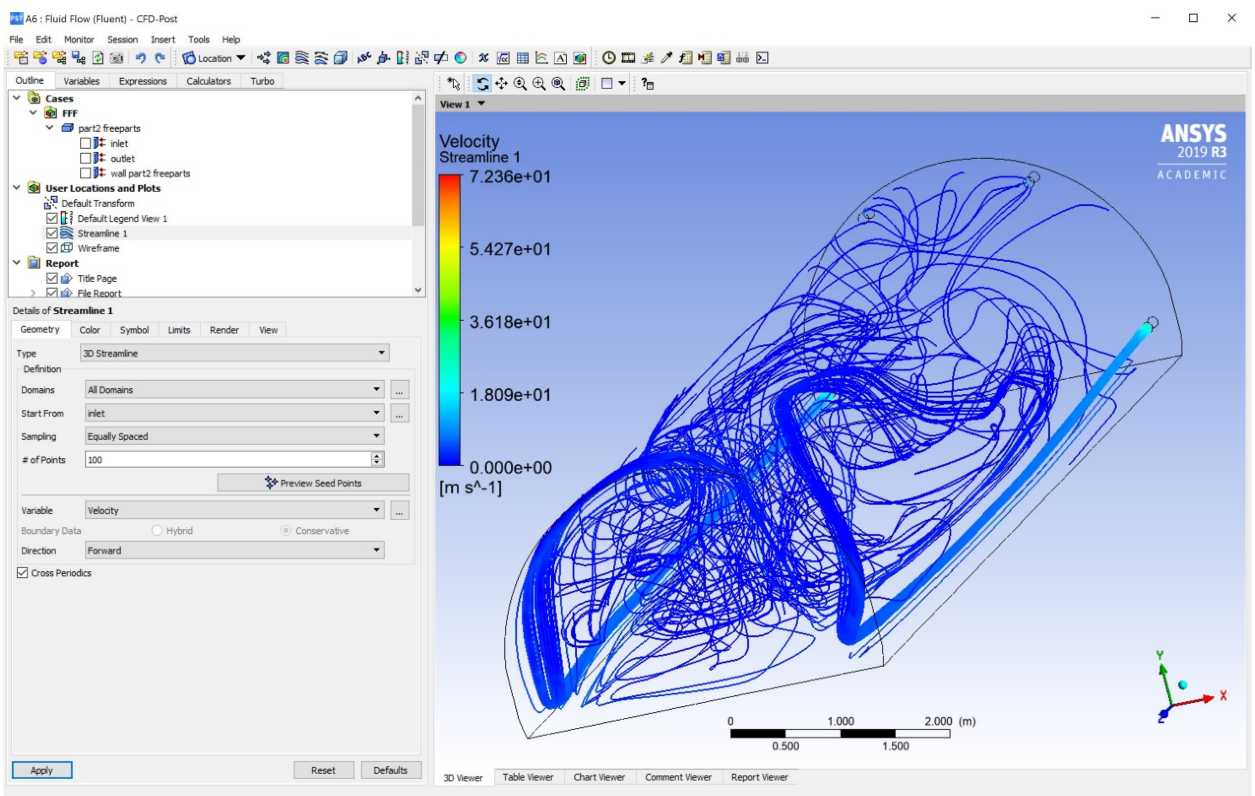

Figure 14.0: Sample simulation of air flow distribution

Please note that the simulation shown in *Figure 14.0* is just used to explain how the air could be simulated using software. However, the boundary conditions were not the actual ones used in the cabin as it is still not known what the boundary conditions at the testing facility are. This could be a starting point to be used in future research regarding air quality designs.

7.0 Conclusion

The testing facility at the Downsview airport is used for different research projects, however the smart air quality research project supervised by Professor Jeff Xi had some problems. It needed to mimic the HVAC system of the G7500 by having a bottom-in and top-out ventilation system. And, a way to direct air inside the cabin without interfering with the other projects that are being worked on. In order to solve that problem, the inlet ducts were redirected to the floor from the middle of the system, and the outlet ducts were placed at the top but lowered in a way to not affect the OLED panels. This report also included much information about different kinds of harmful particles that can be found inside an aircraft cabin, and sensors which could possibly be used to measure those particles. Also, a sample simulation was presented in order to show how to determine the placement of sensors strategically in order to reduce cost and time.

8.0 References

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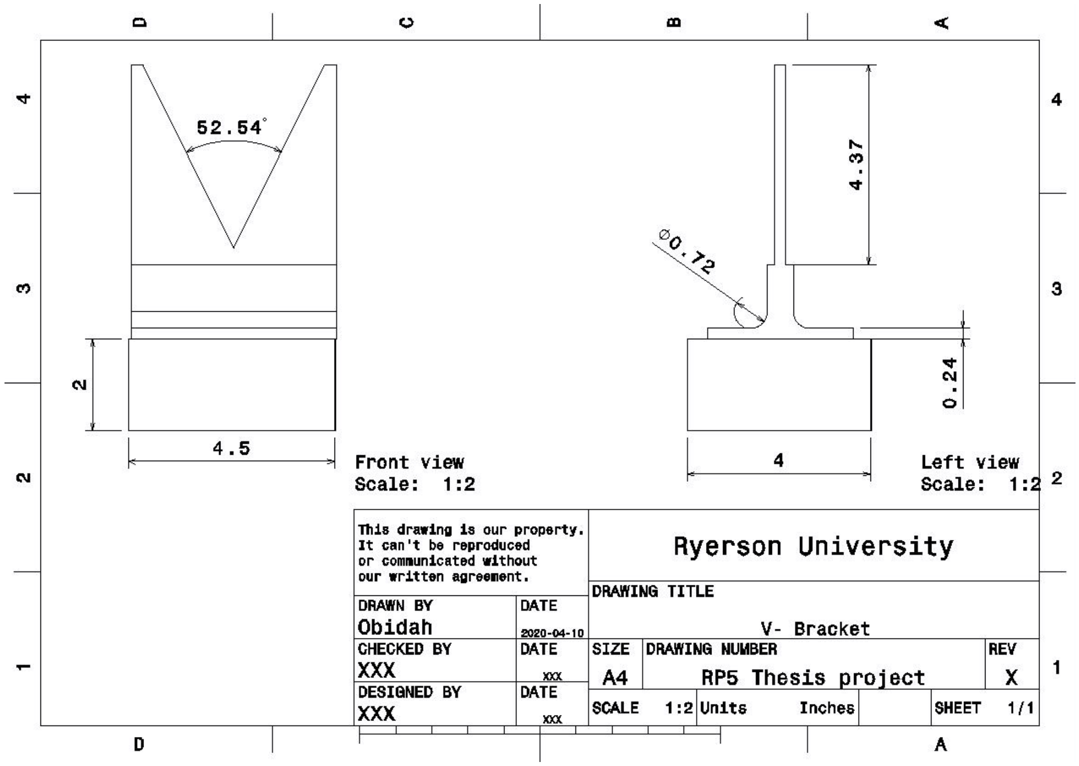
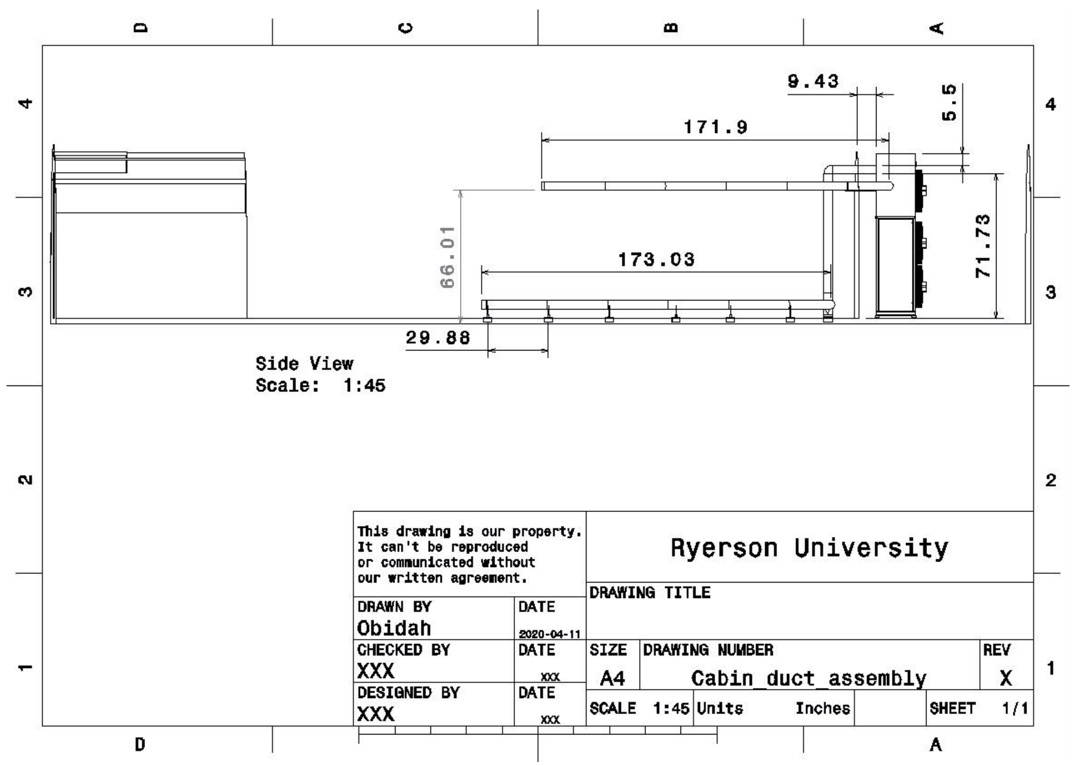
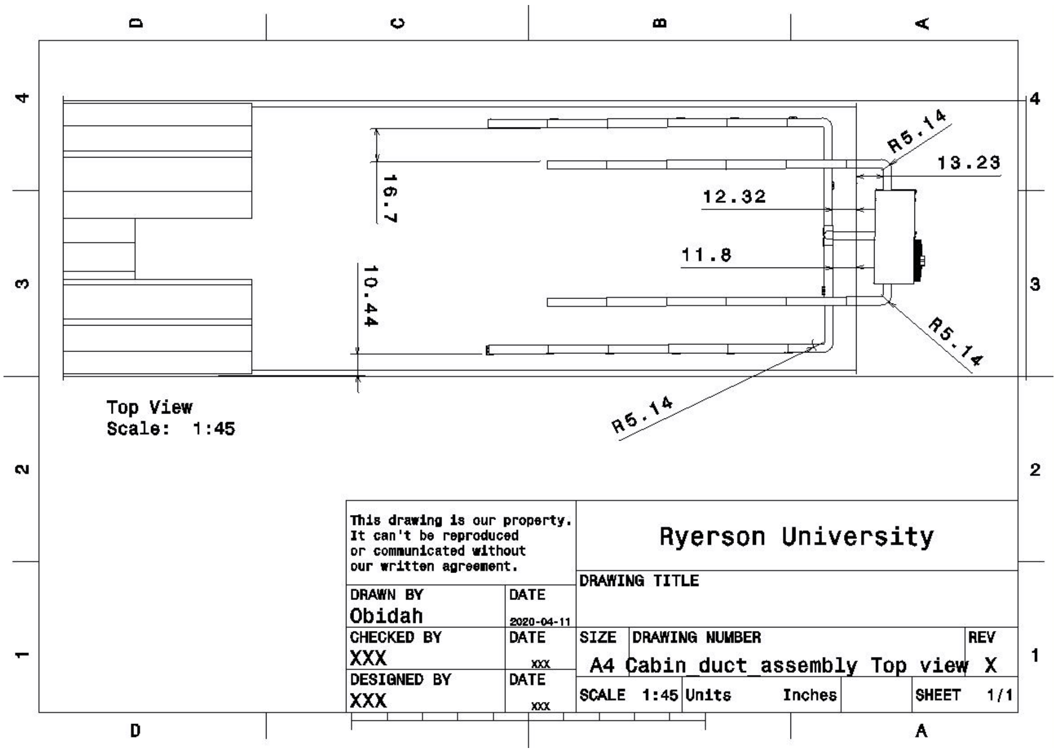
9.0 Appendix

Design Drawings



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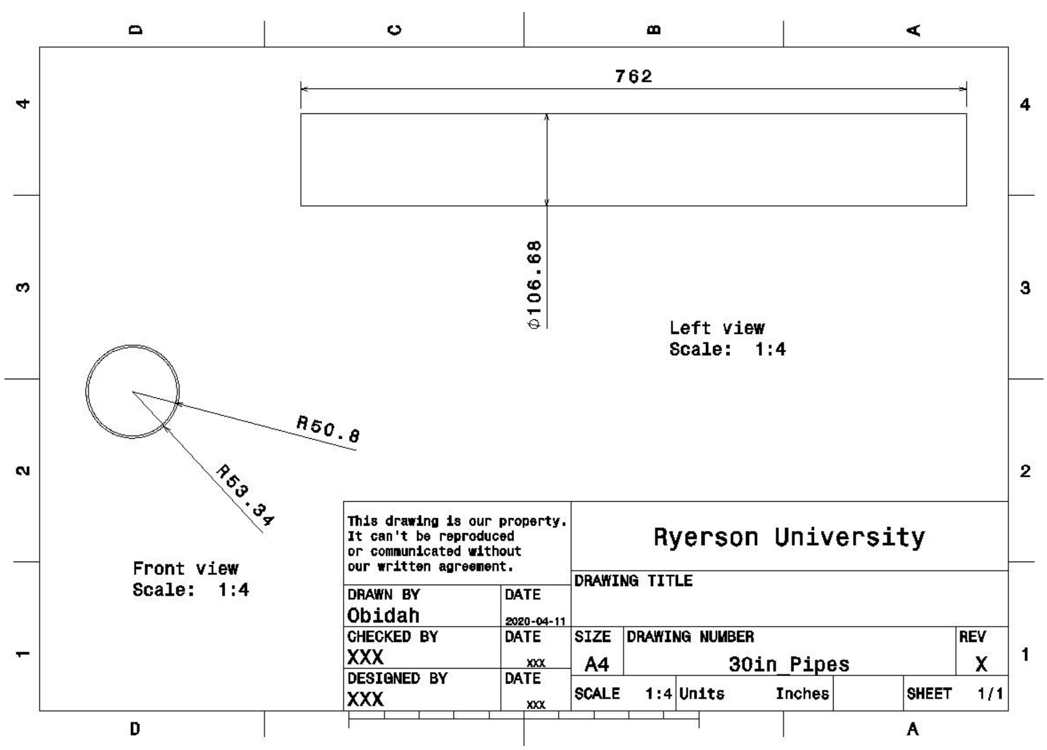
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ANSYS FLUENT simulation