Alexandru DĂNĂILĂ

A NEW SOLUTION TO REDUCE THE SPREADING RISK OF AIRBORNE INFECTIONS IN AIRCRAFT CABIN

Abstract: *At present, due to the pandemic context, air transport is being re-analysed. Especially the economy class, where most passengers travel, having six people in a row of seats becomes risky because there is no minimum distance between people. If a person is infected, they can transmit the virus very easily, even if they wear a mask. The project also contains an assessment of the possibility of transmitting the virus through the cabin ventilation system. Two ventilation solutions are simulated in Ansys Fluent, both for the current cabin configuration of a one-aisle aircraft. Next, a solution that would improve the health safety on board is proposed. The new seats and cabin configurations are designed. Firstly, the middle seat replaced with a luggage storage box, large enough to carry some "hold" luggage and secondly, a plexiglass panel support, which can be mounted on the seat backside is conceived. Finally, the air flow in aircraft cabin for this new arrangement is analysed.*

Key words: *aircraft, pandemic, Computational Fluid Dynamics (CFD), ventilation, streamlines, velocity field.*

1. INTRODUCTION

Commercial aviation is relevant to modern pandemics in two ways. First, airplanes have always been identified as relevant to transporting a disease around the world in a matter of days. Second, an aircraft can act as a strong source allowing many transmissions from a single infected person [1], [2]. Both factors combined mean that air travel during a pandemic is risky and restricting air travel is usually one of the first things done.

Four pathways have been identified of disease transmission in aircraft [3]: direct contact, airborne transmission, contaminated objects, and vectors. Among these modes, the airborne route has gained a lot of attention in air quality studies. This is mainly attributed to the very small contaminant fragments and expiratory particles that can remain airborne in the space for extended times and distances, which significantly increases the probability of exposure and/or infection when compared to the other modes [4].

Consequently, suitable ventilation strategies for air quality management must be employed to control the spread of airborne contaminants while ensuring passenger comfort. However, the current widely used air distribution system is based on an air flow with injection at ceiling level and its exhaust at floor level. As the injected flow has high momentum, mixing with cabin air takes place. Mixing is anticipated to result in the transmission of contaminants within the cabin [5].

Various experimental and numerical studies on different ventilation systems on various aircraft cabin types where published. Experimental investigations are conducted on either aircraft cabin mock-ups or on stationary aircrafts [6]. Numerical studies are conducted by using Computational Fluid Dynamics (CFD) to calculate air flow distributions [7]. Some of the research is often conducted by investigating both an experimental and CFD approach to compare and analyse the results obtained from both [8].

Especially in the economy class where most passengers travel, the risk of contamination is high, especially due to the impossibility to keep a minimum distance between passengers. An infected person can transmit the virus very easily, even if they are wearing a mask. To insulate passengers, some airlines have mounted diverse types of plexiglass panels, which are very inconvenient (locks the armrest) and inefficient keeping three passengers remarkably close. Other companies have eliminated the middle place which leads to an increase in operating costs and implicitly of tickets.

To evaluate the airborne virus transmission, a series of numerical simulations performed in the Ansys Fluent of the air flow in the passenger cabin was included. Next the paper introduces a solution that would solve a large part of issues linked to on board contaminant transmission. Firstly, a plexiglass panel was mounted on the seat backside. Another novelty is the replacement of the middle seat with a box for storing luggage. The trunk, roomy enough to hold luggage that is currently carried in the airplane hold, is made of lightweight materials. The box will be easy to assemble and disassemble, above the holes that attach the seat legs to the aircraft floor. Under the conditions of the lifting of sanitary restrictions, the luggage box can be disassembled and stored properly, being able to be reused in case of other epidemiological situations.

The results show that in the proposed improved solution, the equivalent of personalized passenger ventilation. Every passenger will have their own breathing area and the risk of airborne and the spread of the virus being is significantly diminished.

2. AIRCRAFT VENTILATION SYSTEMS

Typical commercial aircraft cabin ventilation systems rely on air recirculation. Fresh air (in the proportion of 50%) which is supplied from either the engine's low-pressure compressor or the auxiliary unit is mixed with the recirculated air. The high-temperature air from the compressor is cooled by the Climate Control System (ECS- Environmental Control System) to comfortable levels before entering the passenger cabin. The supply and exhaust inside the cabin are done through the air supply/exhaust ducts and the distribution in the cabin is done through a series of holes that can be arranged differently. There are mainly three main types of ventilation configurations, namely mixing, displacement and personalized [9].

In the mixing ventilation fresh air is supplied through a series of holes placed above and below the luggage compartment. This creates an air circulation that ensures mixing with the air in the cabin. Afterwards, the air is evacuated through the floor drain near windows. This type of ventilation is the most common, being preferred by aircraft manufacturers and airlines. However, mixed ventilation is prone to spreading contamination from an infected passenger. Also, the circulated air flows are higher than with other types of ventilation.

In displacement ventilation, fresh air is supplied through a series of openings at floor level.

The fresh air in the area under the seats creates a "plenum chamber" from where it moves towards the ceiling under the effect of the pressure difference, but also under the effect of the temperature difference towards the ceiling. At the ceiling level the contaminated air is evacuated from the cabin.

Personalized ventilation provides fresh air directly to passengers. This creates a barrier of fresh air around and protects from contaminants. This method provides the passenger with a healthy and pleasant feeling of fresh air in the vicinity of the breathing area. Several methods of fresh air supply are possible, such as nozzles on the front seat or overhead nozzles in the luggage compartment. Higher injection rates may lead to discomfort with prolonged exposure.

3. PROBLEM FOMULATION

3.1 Objectives

The main objective of the present paper is to evaluate the ventilation systems in the cabin of a commercial passenger aircraft from the perspective of the probability of contaminant spread. The adopted model is that of an aircraft with a single medium courier aisle (Airbus A320), populated with a series of mannequins as passengers.

The CFD simulations were done Fluent. Stating the hypothesis that the transmission of the virus (and other contaminants in general) is carried out by air through the transport provided by air flow, the simulations were mainly aimed at determining the distribution of velocities (and current lines) in the cabin. It was thus possible to highlight the mutual interaction of the passengers' breathing zones.

To simulate the air flow in the aircraft cabin, a project in the Ansys workbench was defined. The project contains the following stages: a) Geometry definition, b) Creating the calculation grid in Fluent Meshing, c) Setting the Fluent solver and d) Analysis of the numerical results.

3.2 Geometry definition and limitations

The first step in the Ansys project was to define the computational domain in Ansys Design Modeler was chosen to define the geometry.

A single-aisle aircraft cabin geometry of Airbus A320 was treated. The dimensions and the seats arrangement of the economic class were extracted from the Maintenance Manual [10]. Given the limited hardware capability a simplified model was adopted. The cabin model is section of fuselage with one seat row. In addition, it was assumed that the geometry (and the air flow) is symmetrical, so that only half section was designed. This simplification will require imposing periodicity conditions on the crosswise faces and symmetry conditions on the corresponding plane (Figure 1).

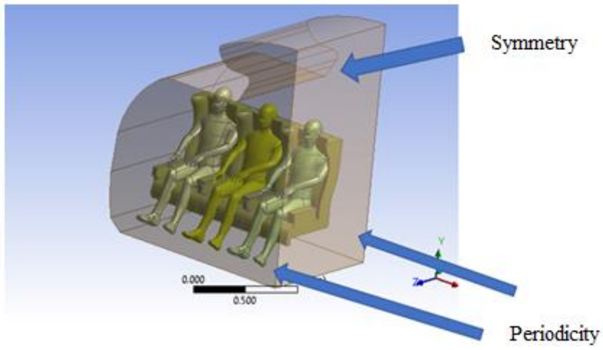


Figure 1 Simplified model with one row of seats and boundary conditions.

For mixing ventilation, the air supply in the cabin is ensured by a system of nozzles located above and below the luggage compartment and generating jets of fresh air. In the numerical simulations, it was considered that the supply is made along some surfaces that extend along the entire length of the section, having a total flow that was approximated to the real flow, Figure 2a.

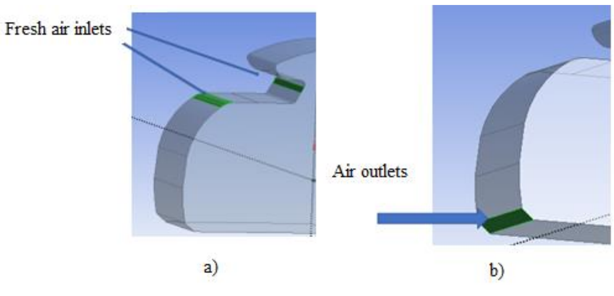


Figure 2 Air inlets and outlets surfaces in mixing ventilation.

Similarly, the outlet, placed at floor level, was supposed to be made through a surface that extends along the entire length of the section, Figure 2b. It should be noted that in the displacement ventilation simulations the supply and exhaust surfaces were reversed. These simplifications allow for a significant reduction in computational cost.

A mannequin is modelled to mimic a passenger seated in an aircraft cabin seat, Figure 3. Thus, the spread of contagion in the cabin and interactions between passengers can be evaluated.

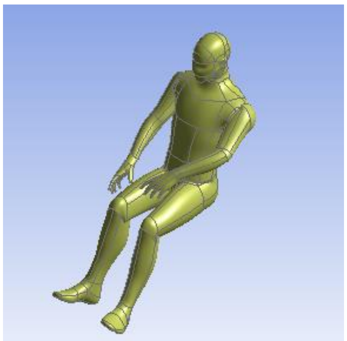


Figure 3 Geometric model of the passenger (dummy).

3.3 Mesh

The fluid domain created in Design Modeler is imported into Fluent Meshing for the construction of the three-dimensional volume grid. We performed a special attention of cell size on vicinity of the key surfaces of the computational domain, (especially the surfaces of mannequins and chairs). For all cases analysed in the present paper, a minimum size of 1 mm was adopted, and the reference size was of 200 mm.

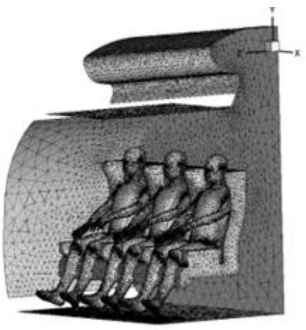


Figure 4 Detail of computational mesh.

The mesh configuration on the interior surfaces (seats and mannequins) can be seen in Figure 4.

3.4 Flow solver settings

The main Fluent settings are:

a) Since the velocities in the domain are relatively low, the "pressure based" solver is chosen. The configuration of the fluid domain being complex and sensing the existence of recirculation zones caused by detachments, the "transient" option is chosen because a stationary state is practically impossible to achieve. The influence of gravitational acceleration is also activated, which would mainly allow simulating the convection effect due to the temperature of the human body.

b) A k-epsilon type turbulence model and boundary conditions expressed by wall functions are chosen. Turbulence model constants are kept from the Fluent default.

c) The material is air with constant proprieties (density and molecular viscosity).

d) The following boundary conditions were imposed. For mixing ventilation on the inlet surfaces (considered "velocity inlet", Figure 2), an inlet velocity of 0.5 m/s is set, approximated to achieve a total flow of fresh air of 9g/s for each passenger. On the output surfaces, Figure 2, considered of the "pressure outlet" type, the pressure was considered equal to the reference pressure that is imposed in "operating conditions". The pressure at sea level 101325 Pa was chosen as reference. Symmetry conditions and periodicity conditions are imposed on the corresponding surfaces as in Figure 1. It should be noted that for the displacement ventilation simulations, the inlet and outlet surfaces were reversed.

e) The SIMPLE method was chosen for flow equations discretization.

f) For unsteady simulations a constant time step of 0.01 s and ten intermediate iterations at each time step, were set. A maximum number of 12000-time steps is chosen, which corresponds to a simulation time of 2 minutes.

4. NUMERICAL RESULTS

4.1 Computational cases

For mixing ventilation and displacement ventilation, two arrangements: row with six passengers and row with four passengers (middle seat is free) were analysed. So, four computational case result as follows:

Case 1: Cabin with six passengers per row and mixing ventilation, Figure 4a;

Case 2: Cabin with six passengers per row and displacement ventilation, Figure 4b;

Case 3: Cabin with four passengers per row (middle seat free) and mixing ventilation, Figure 4c;

Case 4: Cabin with four passengers per row (middle seat free) and displacement ventilation, Figure 4d.

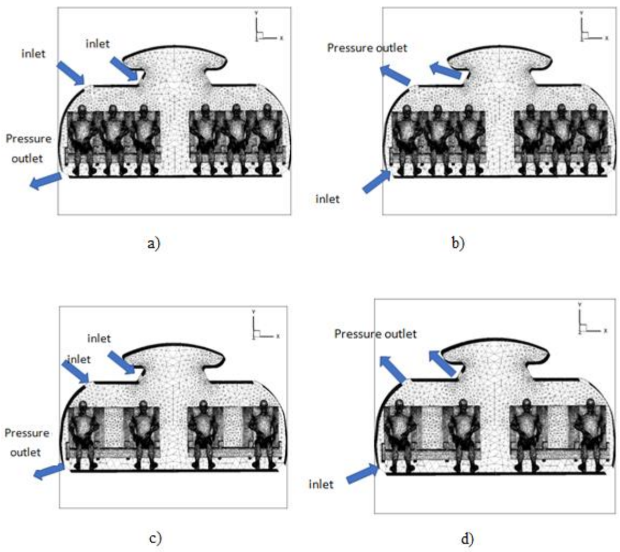
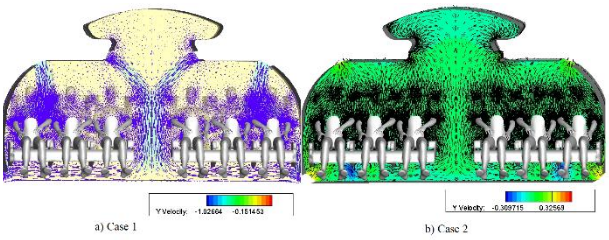


Figure 5 Definition of computational cases.

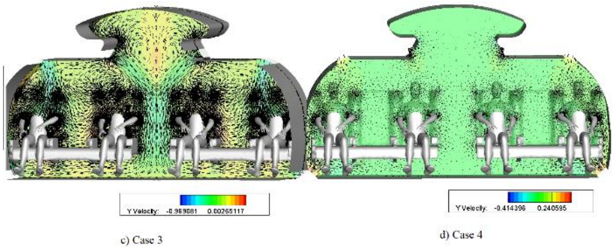
4.2 Air flow in cabin

To emphasize the interaction between the passengers through the air flow, the velocity distributions were represented in a transverse plane positioned at 1 mm in front of the mannequin nose (called reference plane in the following).

For displacement ventilation, Figure 6b and Figure 6d, independent breathing zones for passengers can be better separated, the risk of contagion being obviously reduced. More, Figures 6 a) and 6b) show that mixing ventilation allows, even if the middle passenger is missing, transmission of the virus between passengers can occurs.



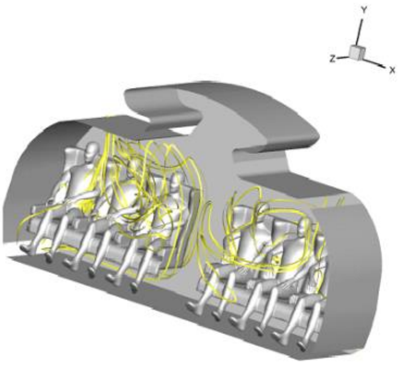
a) Case 1 b) Case 2



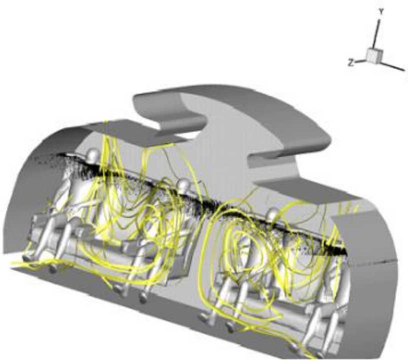
c) Case 3 d) Case 4

Figure 6 Velocity field in the reference cross-section.

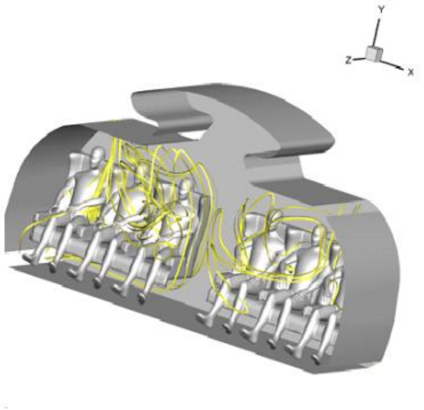
The displacement ventilation "insulates" the passengers. Obviously, as show in Figures 7b and 7d, where the streamlines in the model passenger cabin are plotted, the most favourable case corresponds to the displacement ventilation without the passenger in the middle seat.



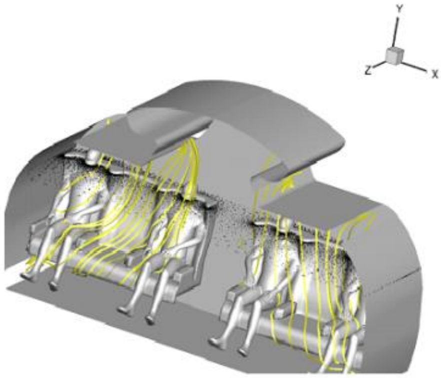
a) Case 1



b) Case 2



c) Case 3



d) Case 4

Figure 7 Streamlines in passenger cabin.

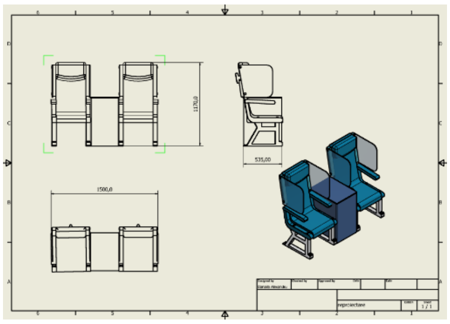
We mention that currently for all commercial aircraft have only mixing ventilation is available. Displacement ventilation is only studied as a possible solution, its implementation being extremely expensive. These conclusions are consistent with a series of critical analyses of the aircraft ventilation system published recently [11].

5. PROPSED IMPROVED CABIN CONFIGURATION

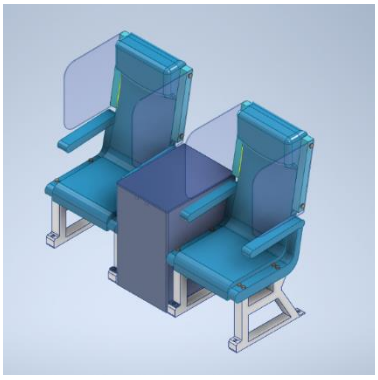
5.1 Seats reconfiguration

In the present paper we propose a new solution for remodelling the interior space of the passenger cabin that reduces the risk of airborne transmission of diseases. There are two proposed new elements. First, a separating plexiglass panel is mounted on the backsides of the seats. The panels will not block passengers' access to their seats, and their comfort during the flight will be increased. Secondly, it is planned to replace the middle seat with a luggage box. This box is large enough to store passenger luggage that was traditionally carried in the cargo hold of the plane. In addition, passenger comfort will again increase because the available legroom will be greater.

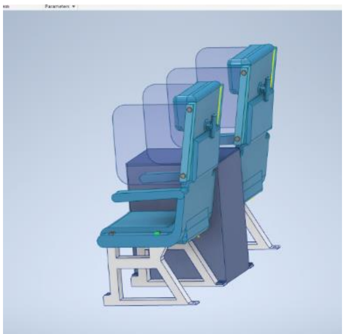
The design of the new cabin architecture, presented in detail in a previous work [12], was done in AutoDesk Inventor and illustrated in Figure 8 (8a - technical drawing, 8b - Isometric view, 8c - lateral view).



a)



b)



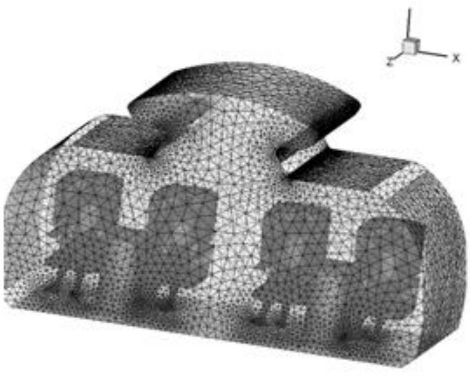
c)

Figure 8 Proposed design of aircraft seats.

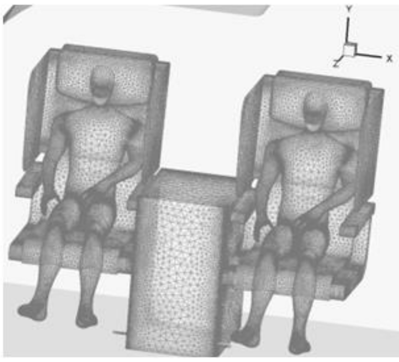
5.2 Geometric model, mesh and solver setting

The overall geometry of the cabin computational model is the same as presented previously. Therefore, due the limited computational hardware, the legs seats are suppressed. The computational mesh grid shown in Figure 9a) and a detail of the is plotted in Figure 9b.

The solver settings are the same as in the previous simulations.



a)



b)

Figure 9 Computational mesh.

5.3 Results

In this paper we present the results for mixing ventilation. In Figure 10 the velocity field in the reference cross-section is plotted. Appears clearly that the effect of the Plexiglas panels combined with the effect of the luggage box positioned between the passengers leads to the definition of "custom" passenger breathing zones. Practically every passenger is subject to its own air flow that does not affect the neighbouring passengers.

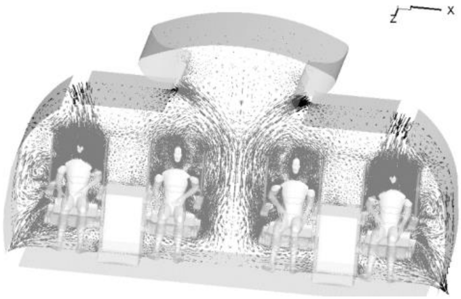


Figure 10 Velocity distribution in the reference section

It is found that in area of the window passenger flow velocities are slowly higher. However, there is an available adjustment parameter, namely the feed flow through the nozzles under the overhead luggage compartments. Also, the direction of these supply jets could be optimized.

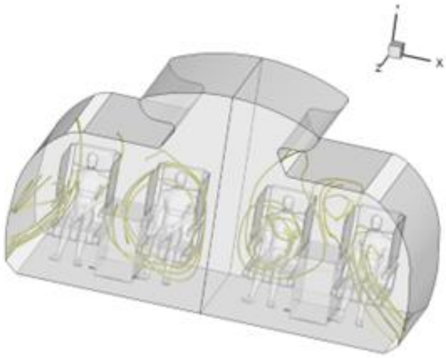


Figure 11 Streamlines in aircraft cabin.

In Figure 11 the three-dimensional image of the streamlines in the passenger area is shown. The blockage caused by the luggage box causes the air to be discharged from the passenger area from the aisle, mainly through the back of the seats, which contributes favourably to the minimization of the interaction between passengers.

6. CONCLUSIONS

Since the transmission of the SarsCov2 virus is through the air, the paper contains an assessment of the possibility of transmission of the virus through the cabin ventilation system. Two ventilation solutions (mixing ventilation and displacement ventilation) are simulated in Ansys Fluent, both for the current configuration of the cabin of an aircraft with one aisle.

Making the plausible hypothesis that the virus is spread through air currents generated by the ventilation system, the flow in a cabin model with the current layout and the flow in the redesigned cabin were compared.

The results show that the proposed solution is clearly superior in the case of mixing ventilation which is implemented on all commercial aircraft. The presence of Plexiglas panels and the box between the seats practically leads to the elimination of interactions between passengers. The breathing areas of the passengers become independent, which allows us to appreciate that a great advantage of our proposal is to obtain personalized ventilation, without any constructive modification to the current ventilation system.

REFERENCES

[1] Mangili, A., Gendreau, M. A. (2005). *Transmission of infectious diseases during commercial air travel*, Lancet 2005, Vol. 365, March 12, pp. 989–996, ISSN 0140-6736.

[2] Wilson, N. M., Norton, A., Young, F. P., Collins, D. W. (2020). *Airborne transmission of severe acute respiratory syndrome coronavirus-2 to healthcare workers: a narrative review*, Anaesthesia, Vol. 75, Aug. 2020, pp. 108-1095, Jon Wiley & Sons, ISSN 0003-2409.

[3] ASHRAE (2014). *Position Document on Airborne Infectious Diseases.* Atlanta, GA: ASHRAE.

[4] Aliabadi, A.A., Rogak, S.N., Bartlett, K.H., Green. S.I. (2011). *Preventing airborne disease transmission: Review of methods for ventilation design in health care facilities*. Advances in Preventive Medicine, Vol. 2011, ID 124064, pp. 1-21, https://doi.org /10.4061/2011/ 1240641–21.

[5] Mboreha C.A., Abdallah C.S., Kumar, K. (2020). *Risk and preventing of COVID 19 in a commercial aircraft cabin: an overview*, International Journal of Engineering Applied Sciences and Technology, Vol. 5, Issue 3, pp. 661-670, ISSN 2455-2143.

[6] Kuhn, M., Bosbach, J., Wagner, C. (2009). *Experimental parametric study of forced and mixed convection in a passenger aircraft cabin mock-up*, Building and Environment, Vol. 44, No. 5, pp. 961-970, ISSN 0360-1323.

[7] Farag, A. M, Khalil, E. E. (2015). *Numerical analysis and optimization of different ventilation systems for commercial aircraft cabins,* IEEE Aerospace Conference 2015, pp. 1-12.

[8] Zhang, Z., Chen, X., Mazumdar, S., Zhang, T., Chen, Q. (2009). *Experimental and numerical investigation of air flow and contaminant transport in an airliner cabin mockup.* Building and Environment, Vol. 44, No. 1, pp. 85-94.

[9] Elmaghraby, H.A., Chiang, Y.W., Aliabadi, A.A. (2018). *Ventilation strategies and air quality management in passenger aircraft cabins: A review of experimental approaches and numerical simulations,* Science and Technology for the Built Environment, Vol. 24, No. 2, pp. 160-175.

[10] *** *AIRBUS A320, Aircraft Characteristics Airport and Maintenance Planning*. (2005). AIRBUS S.A.S. Customer Services Technical Data Support and Services, 31707 Blagnac Cedex, France.

[11] Scholz, D. (2021). *Airbus' Cabin Air Explanations during the Corona Pandemic – Presented, Analyzed, and Criticized*, available at: http://AERO. ProfScholz.de, *Accessed:* 2023-02-15.

[12] Dănăilă, A. (2022). *Research Rapport No. 2,* University Politehnica of Bucharest, unpublished.

Author:

Eng. Alexandru DĂNĂILĂ, Master student, University Politehnica of Bucharest, Faculty of Aerospace Engineering, Department of Engineering Graphics and Industrial Design, E-mail: alex.danaila21@gmail.com