Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 51 (2020) 313–322

Transportation Research Procedia

www.elsevier.com/locate/procedia

9th International Conference on Air Transport – INAIR 2020, CHALLENGES OF AVIATION DEVELOPMENT

Design of air circuit disinfection against COVID-19 in the conditions of airliners

Pavol Pecho[a]*, Iveta Škvareková[a], Viliam Ažaltovič[a], Michal Hrúz[a]

[a]*Air Transport Department, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia*

Abstract

The current full-range problem posed by the COVID-19 virus is being fought in every area, from health care, through economics, to technology. Designers in various fields are known for technological measures to reduce the restrictions resulting from measures against the spread of the virus. Aviation has suffered from the grounding of aircraft and the cessation of air traffic perhaps the most, so there is an effort to restart the operation of aircraft. The present article deals with the design of the implementation of air disinfection in the cockpit, to ensure the maximum possible safety during flight. During the research, the authors focused on the use of disinfection using ultraviolet radiation and its possibility of incorporation into the ventilation system of aircraft. The research results represent specific proposals and design of the installation for the aircraft Airbus A320 and represent specific proposals for general installation in aviation. Such a system could in the future increase the safety of flying due to the spread of viruses and bacteria in the cockpit of the aircraft and allow the resumption of air traffic.

Keywords: COVID-19; Disinfection; Air Condition; Aircraft; UV light; HEPA filter

1. Introduction

With the advent of the spread of the SARS-CoV-2 (covid-19) virus, there have been changes in various spheres from economy, through health care to transport. With the restriction of movement, the transport of the population

* Corresponding author. Tel.: +421918451207
E-mail address: pavol.pecho@fpedas.uniza.sk

2352-1465 © 2020 The Authors. Published by ELSEVIER B.V.

10.1016/j.trpro.2020.11.034

decreased rapidly and of all types of transport were limited, air transport remained the most affected. If airlines have to comply with one set of regulations at the departure and another set, when a flight arrives in another country, the situation will be extremely difficult for the aviation industry. Various risks in aviation was discussed by Galieriková et al. (2018). In terms of Eurocontrol statistics (Aviation recovery, 2020), the use of air transport decreased by almost 90% comparing January 2020 and April 2020 (Figure 1).

Scenario "Coordinated Measures" is based on a common approach to the implementation of operating procedures and the removal of national restrictions. This is the main requirement for airlines and airports to support their recovery. The scenario of "Uncoordinated Measures" assumes that this common approach will not be applied.

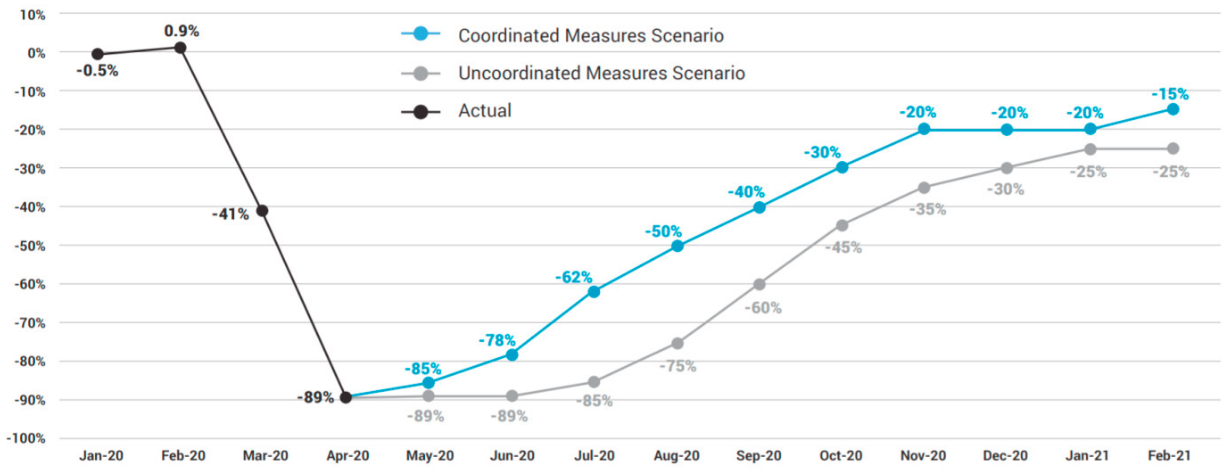

Fig. 1. EUROCONTROL Draft Traffic Scenarios - 24 April 2020 (base year 2019). Source: Aviation recovery, 2020.

At present (July 2020), air transport is only slowly resuming and, despite measures at airports and airplanes, the spread of the virus is still high. Taking all these factors into account, the projected total loss of revenue in the aviation industry will be around €110 billion in 2020 for airlines, airports and ANSPs. (Aviation recovery, 2020)

From an economic point of view, it is essential to relaunch air transport to protect airlines and downstream industries from bankruptcy. The aim of the article is to analyze the use of methods to reduce the impact of the spread of the COVID-19 virus within the cockpit and thus to increase air safety during a pandemic. The proposals in the article are an attempt by the authors to contribute to the 'Coordinated Measures' section and thus increase the operation of airlines.

2. Cabin Air Propagation

At the beginning of the solution it is necessary to define the parameters that need to be worked with. The diameter of the COVID-19 virus is of the order of only *100 nm* and its survival time is approximately 1 hour in air and up to 10 hours on various surfaces. Based on these data, it is necessary to determine adequate means against its dissemination. (Bar-On et al., 2020)

During flight, it is possible to limit the transmission of the virus through contact with surfaces, but the most problematic area is airborne spread. Standard ventilation systems in aircraft allow air circulation "from top to bottom" (Figure 2). The total air distribution is supplied from the outside environment, heated by hot air from the engine compressor and then supplied to the aircraft cabin. In most cases, such as the Airbus A320, the cockpit is divided into 3 zones, which allow their temperature to be regulated independently, but the air from these zones is further recirculated together. Up to 60% of cabin air is reused in a standard aircraft. The main reason is mainly the saving of fuel to heat the air from the outside environment. This is the main reason why air travel is dangerous due to the spread of the COVID-19.

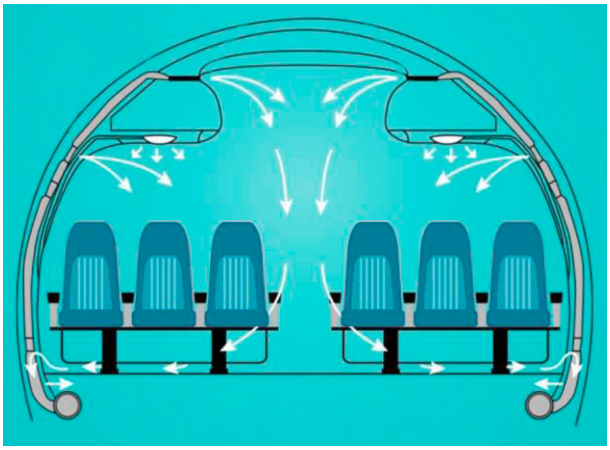

Fig. 2. Air propagation paths through the ventilation system in the aircraft. Source: Airborne Illness Risk, 2020.

2.1. Air propagation in the cabin

The modeling of air passenger flow (Matas and Novak, 2008), distribution and spread of air in the cabin is a complex problem that is currently being addressed separately and represents a field for further innovation. In addition to the COVID-19 virus, this is a general problem of spreading any disease, from the common flu to deadly diseases, and last but not least, ensuring the safety and comfort of passengers.

Air propagation simulations (Figure 3 (left)) show that the currently designed systems make it possible to eliminate contact with the ambient air by means of additional ventilation openings directly above the passenger's head (Figure 3 (right)). Their deactivation leads to the access of ambient air to the passenger and thus to the risk of inhaling contaminated air.

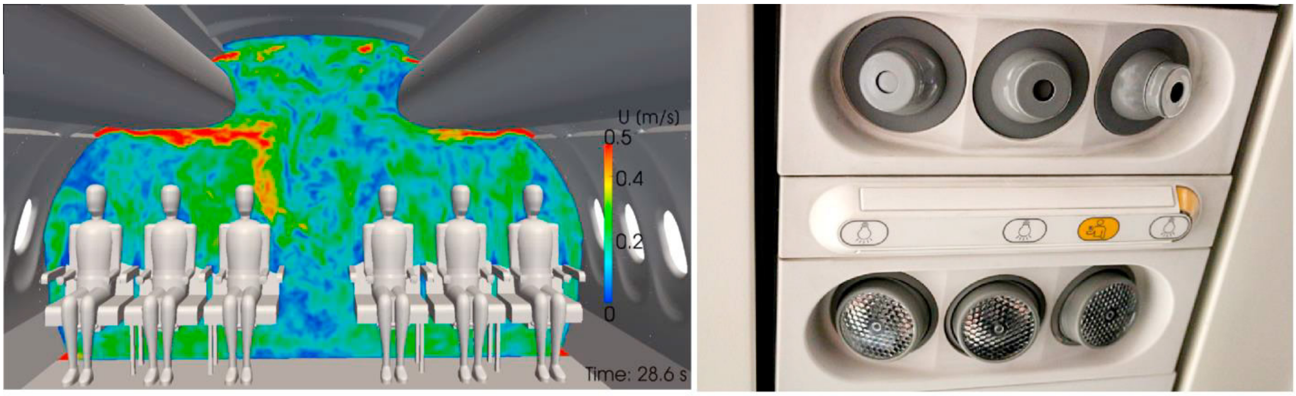

Fig. 3. Simulation of air velocity and air distribution of the ventilation system in the aircraft cabin (left) air vents for air distribution above the passenger seat (right). Source: Aerospace Examples And Applications, 2020.

As shown in Figure 4, the diagram describes the control of air circulation and supply via the "Air Condition Pack 1 & 2" unit. In these units, the hot bleed air heated by engines compressors is mixed with the outside cold air to ensure the optimum temperature. The airflow, heating and start-up parameters are displayed in the cockpit via the Electronic Centralized Aircraft Monitor (ECAM) screen on a page called "Pneumatic System Display" section - Bleed Air. In Figure 2 and Figure 4 air circulation paths for entering and leaving the cab are shown. (IATA, 2018) The pale blue path represents the ingress of air from the "mixer unit" and the air from the "bleed air" into the cabin and the dark blue path represents the recirculation through the fans and filters back to the "mixer unit".

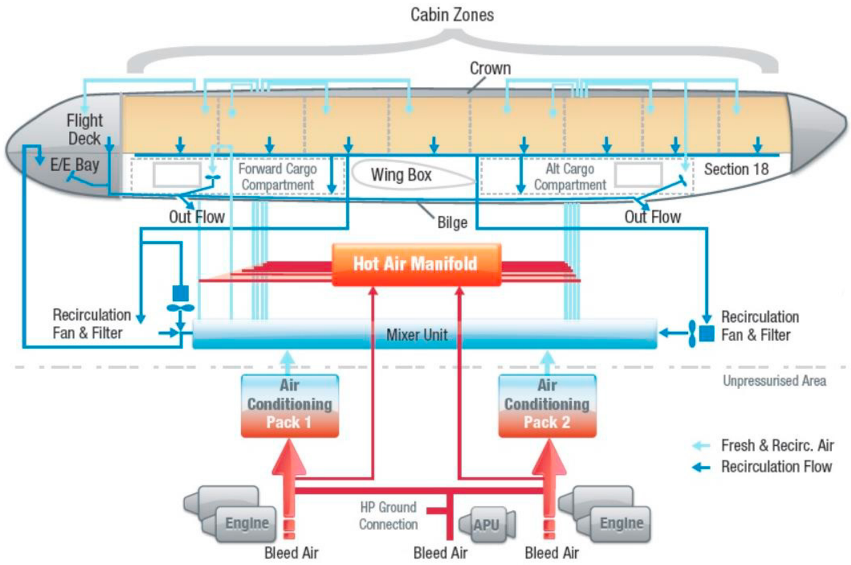

Fig. 4. Air distribution scheme on board the Airbus A320. Source: Aircraft air generation, 2016.

Depending on the type of aircraft and the number of passengers, the number of filters used in the air recirculation system also varies. The following Table 1 shows the number of filters for specific types of Airbus and Boeing aircraft.

Table 1. Number of air ventilation filters on board according to aircraft type and number of passengers. Source: Michaelis & Loraine, 2005.

Aircraft type	**Maximum number of passengers**	**No. of Filters**
Airbus A300-600/A310	298/247	3
Airbus A318/A319/A320/A321	117/134/164/199	2
Airbus A330/A340	From 293 for A330-200 up to 419 for A340-600	4 (8 on extended range type)
Boeing 737 -300, -500, -600, -700	Up to 149	1
Boeing 737 -400, -800, -900	Up to 189	2
Boeing 747-400	Up to 524 in 2nd class layout	10
Boeing 757	228 (-200), 280 (-300)	2
Boeing 767	Up to 375	2
Boeing 777	Up to 550	8

In the context of air filtration and the filters used, these are High-Efficiency Particulate Arrestors (HEPA) filters with a stated efficiency of 99%. The main advantages of using these types of filters in aircraft include: minimum weight, C check filter element service life, control of microbial and viral contaminants without the need for chemical additives, coatings, or other surface treatments, odor/VOC removal available as an option, high dirt-holding capacity, minimum pressure loss, high collapse strength. The interval varies by aircraft. Most airlines replace cabin air filters at regular "hard time" intervals to fit in with routine scheduled maintenance periods (Bugaj, 2005), as long as these intervals do not exceed filter manufacturers' recommendations (IATA, 2018).

2.2. Heating, Ventilation, and Air Conditioning Duct System

It is clear from Figures 2 and 4 that the HEPA filters are located in the cargo space below the aircraft deck. (Lim & Blatchley, 2009) The following Figure 5 (right) shows a view of an exposed part of the wall in the cargo space, behind which is a ventilation system. It is the Airbus A320 with two filters used, which are directly connected to the recirculation fan. Figure 5 (left) 47/5000 shows a dimensional drawing of the HEPA filter in section view in software Autodesk Inventor 2019.

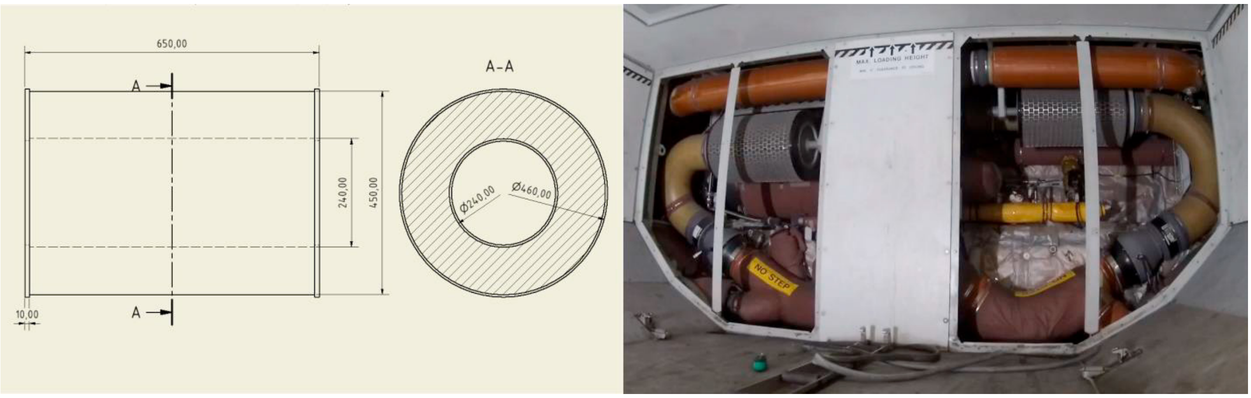

Fig. 5. Mixer unit of recirculating cabin air with HEPA filters and recirculating fans inside Airbus A320 (right). Source: Win, 2018. Dimensional drawing of the A320 HEPA filter in section view (left). Source Authors.

For a better understanding of the ventilation system, it is also necessary to know its performance or flow parameters. The flow rate of outside air per seat ranges from 5.9 to 9.6 *L/s* (12.4 to 20.4 *cfm* [Cubic Feet per Minute]) on older aircraft without recirculation and from 3.6 to 7.4 *L/s* (7.6 to 15.6 *cfm*) on aircraft with recirculation. (Brady, 2020). The percentage of recirculated air distributed to the passenger cabin typically is 30–55% of the total air supply. Some models of aircraft can use different amounts of recirculation or turn recirculation off. Other models are programmed to use different amounts of recirculated air during climb or descent compared with cruise. Referring to Table 1, these parameters can be applied to the Airbus A320 and the number of passengers 164. The following Table 2 shows the total air consumption per passenger or per filter (per circuit).

Table 2. Air volume flow of the Airbus A320 ventilation system in various variants. Source: Authors.

	Air per Passenger (l/s)	**No. Of Passengers**	**Air per Cabin (*L/s*)**	**Recirculated Air (30-55%)**	**Air for one recirculation branch (per 1 filter) [30-55%]**
max.	3.6	153	550.8	165.2 – 302.9	82.6 – 151.45
min.	7.4	180	1332	399.6 – 732.6	199.8 – 366.3

It can be seen from Table 2 that in the case of the A320, the amount of air required, depending on the model variant and the type of recirculation unit, is from 550 to about 1300 litres per second using air, from which it is reused for recirculation from 30 to 55%. This information is needed when calculating the disinfection unit to supplement the original HEPA filter. In the research, the authors dealt with two possibilities of additional disinfection of air commonly available for civilian use. It was disinfection using ozone generators and disinfection using UV radiation. Based on the facts about ozone inhaling (Kandera et al., 2019) for the human body, further research has focused on the use of UV radiation (Anderson, 2020).

2.3. Germicidal Ultraviolet air disinfection

In the area of disinfection, UV radiation distinguishes between disinfection of surfaces or air. These areas are quite different from each other, because while it is necessary to know the area and time of action at a given radiator output, the volume flow must be known when disinfecting the air. In the case of UV radiation, it is also necessary to distinguish the types of radiation according to wavelength and efficiency in eliminating organic constituents:

- A - ultraviolet (UV) rays 100 - 400 nm,
- B - visible (light) rays 400 - 700 nm,
- C - infrared (IR) rays 700 - 800 000 nm.

As part of air disinfection, germicidal radiation is used – UV-C wavelength 253.7 nm, which is invisible. (Bar-On, 2020) This radiation in the UV-C spectrum causes the death of microorganisms by disrupting their DNA, damaging their reproductive system and subsequently destroying them. The germicidal effect of UV-C radiation affects bacteria, viruses, spores, fungi, molds and mites. When disinfecting surfaces, the radiation intensity is calculated according to the relation:

$$UV\ Dose\ (\mu WSec/cm^2)\ =\ UV\ Intensity\ (\mu W/cm^2\ )\ x\ Exposure\ Time\ (seconds) \qquad (1)$$

which characterizes the exposure time as the time during which the UV light is turned on and delivers the UV surface to the surface. (Arguelles, 2020) In the case of air disinfection, the criteria are more demanding and thus the relationship in the calculation of radiation source parameters is different. Microorganisms exposed to UVGI experience an exponential decrease in population similar to other methods of disinfection such as heating, ozonation, and exposure to ionizing radiation. (EPA, 2020) The single stage exponential decay equation for microbes exposed to UV irradiation is as follows:

$$S = e^{-kIt} \qquad (2)$$

where S = surviving fraction of initial microbial population, k = standard rate constant (cm^2 = mJ), I = UV intensity (mW = cm^2), t = time of exposure (seconds) and where 1 mJ = 1 mW*s^{-1}. (Arguelles, 2020) From equation (1) it is possible to determine the minimum exposure time. According to the source (Kowalski et al., 2002), the radiation dose for elimination of SARS-CoV-2 is D = 36144 J/m^2. From the available information and adjustments to the relationship of radiation intensity, it is possible to determine the relationship to the approximate time of radiation exposure at a given source power:

$$t \approx 1.5\ x\ 10^6 \left(\frac{\pi r^2}{P}\right) \qquad (3)$$

where P is the power rating of the germicidal bulb, η is a coefficient representing heat and scattering losses, and t is expressed in seconds. (Kowalski et al., 2002) The following table shows the minimum exposure time for complete disinfection of the surface with a given radiation power while maintaining 100% surface disinfection.

Table 3. Power of the UV emitter for the necessary disinfection of the surface at a given time (3) at a distance of 15 *cm* from the source. Source: Authors.

Iridation power (W)	15	100	200	500	700	2000
time (s)	7065.0	1059.8	529.9	212.0	151.4	53
time (min.)	117.8	17.7	8.8	3.5	2.5	0.9

The surface of the filter is derived from Figure 5 (left), which represents the dimensions of one filter. Twice times the area was used for the calculations due to the use of two filters in the system. Table 3 shows that even at a power of 2000W, less than a minute is still required to completely disinfect the surface at a distance of 15 *cm* from the source. With regard to Table 2, it is possible to determine that at the maximum occupancy of the A320 aircraft and the use of 2 filters, the maximum flow of recirculated (potentially contaminated) is 366 l/s. For the purpose of calculating the mass flow of air in the duct, the following relation was used:

$$velocity = \frac{4 \cdot flow\ rate}{\pi \cdot filter\ diameter^2} \quad (4)$$

from which all the quantities from Figure 5 (Left) as well as from Table 2 are known. While maintaining the values from Table 2 on air recirculation in values from 30% to 50% and the values of maximum and minimum air flow rates in the cabin, the available values from Table 2 were used to calculate the velocity in the filter. The calculations resulted in speeds ranging from 1.8 to 8 meters per second. The authors decided to use a mathematical model for surface disinfection for difficult and inaccurate methods of calculating the mass flow through the filter.

2.4. Implementation of UVC in HVAC systems

From the point of view of the choice of the location of the UV emitter, it is necessary to take into account in particular the air flow factor in order to allow the contaminated air to remain at the source of UV radiation for as long as possible. It is necessary to place the source of UV radiation out of reach of passengers and staff of the pole to avoid damage to the skin or eyes. A suitable place for placement would seems part of the HEPA filter. This location provides several benefits such as:

- easy availability,
- the place with the lowest air flow,
- ensuring cooling of the UV source (place with low temperature).

While maintaining the dose, we would achieve a total disinfection performance of 3.6 W/cm^2. Considering the total air flow, the consumption of such an additional system must be taken into account. When placing the proposed component in the ventilation system with two filters and with a power of 2000 W, the total consumption would be 4000 W. When transforming energy via two Constant speed drive (CSD) and Generator Control System (GCS), approximately 150 kW at a voltage of 115 V (for A320) (More Electric Aircraft, 2020) is supplied from the mechanical energy to the on-board network. (Win, 2018). When a 50 kW air disinfection source is connected, the power consumption from the on-board network would be 8%. Taking into account the full potential of electricity generators, the consumption of UV lamps for the on-board network would be only about 2.6%. An overall view of the on-board power consumption using a 4000W emitter is shown in Figure 6.

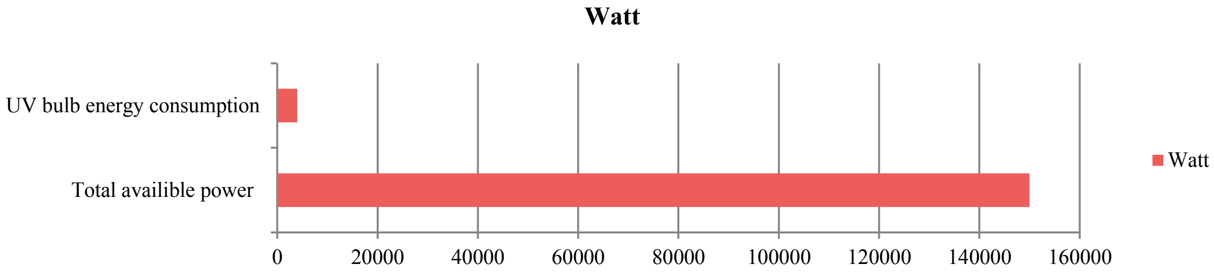

Fig. 6. An overall view of the on-board power consumption using a 4000W emitter. Source: Authors.

3. Results

The space for mounting the UV emitter can be within the HEPA filter from two perspectives. The first is the entrance to the filter when the virus particles are trapped on its surface or at its outlet, when the flow rate is relatively reduced and clean air comes out of the filter. From the point of view of using an UV emitter as an additional disinfection, it is more advantageous to place it inside the HEPA filter, i.e. at the air outlet from the filter towards its re-use in the cabin. The following Figure 7 shows the mist situation of the HEPA filter without additional UV disinfection (left) and with the radiator added (right).

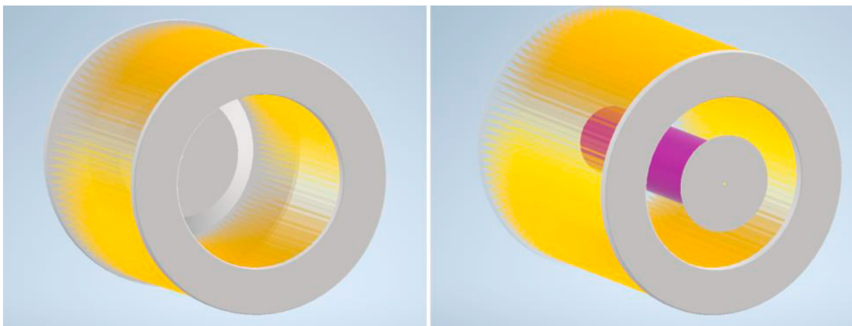

Fig. 7. Comparison of a 3D model of a HEPA filter without additional disinfection (Left) and with an additional UVC emitter (right). Source: Authors.

As the UVC radiation is harmful not only to organic substances but also to technical materials, there is a presumption of damage to the filter (Irving et al., 2016), which is usually made of materials such as PP or PET. It is clear from the operating procedures that the HEPA filters are changed regularly during heavy maintenance and the time that the UV emitter is left between maintenance does not represent massive degradation effects in the long run. It is assumed that the UV emitter will only be in operation after the cabin has been filled with passengers and for a maximum of 20-30 minutes after leaving it for additional air disinfection as well as the inner surface of the filter to prevent the spread of micro-organisms in the filter. Despite the high energy required of the radiator, the topic of the UV disinfection is open and even when applying the source with adequate power to the total consumption of the on-board network, such a system is only ancillary. (Bugaj et al., 2019) Overall, the implementation of the UV emitter will only increase safety and reduce the risk of transmitting COVID-19 viral disease.

4. Conclusion

At a time when the number of cases of COVID-19 is constantly increasing in the world, it is necessary to perceive not only from a health point of view but also the economic effects of the pandemic and to create efforts to alleviate it. The article, which focuses on the design of air disinfection in airliners, focuses on currently available solutions to reduce the spread of the viruses and bacteria in the cabin. In the article, the authors analyzed the air diffusion in the aircraft cabin and, with regard to the properties of the flow, proposed additional air purification by means of the UVC radiation into the air distribution system. The proposed system reduces the risk of transmission of COVID-19 and other diseases and increases the efficiency of the overall filtration of recirculated air. With regard to the properties of the proposed system, the authors worked with the total energy consumption while maintaining the parameters of air disinfection with the current air flow for a given type of the Airbus A320 aircraft. The result of the design is a system that can be implemented in the aircraft without significant intervention in the aircraft design, but with low effect of the energy consumption of on-board systems. With regard to the current situation, the authors recommend experimental verification of the effectiveness of the system in practice with acceptable performance and, in the case of successful verification, subsequent application to aviation technology.

Acknowledgement

This paper is an output of the project of the Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA No. 048ŽU-4/2020 "Increasing key competences in aircraft maintenance technology by transferring progressive methods to the learning process".

References

Aerospace Examples And Applications, 2020. Viewed 5 July 2020 [online: https://engys.com/applications/aerospace]
Airborne Illness Risk Reduction from Air Filter System on Aircraft, 2020, viewed 5 July 2020 [online: https://asianjourneys.com.sg/18-Feb-2020/airborne-illness-risk-reduction-from-air-filter-system-on-aircraft]
Aircraft air generation and distribution A340-600, 2016, viewed 5 July 2020 [online: http://ase-resetsg.blogspot.com/2016/03/aircraft-air-generation-and.html]
Anderson, B., 2020. HEPA filter & UVC? Or a choice of one or the other?, viewed 1 June 2020 [online: http://www.puravent.co.uk/blog/hepa-filter-uvc/]
Arguelles, P., 2020. Estimating UV-C Sterilization Dosage for COVID-19 Pandemic Mitigation Efforts. Unpublished. https://doi.org/10.13140/RG.2.2.12837.65761
Aviation recovery – Importance of a coordinated approach, 2020, viewed 10 June 2020 [online: https://www.eurocontrol.int/sites/default/files/2020-04/eurocontrol-aviation-recovery-factsheet-27042020.pdf]
Bar-On, Y. M., Flamholz, A., Phillips, R., & Milo, R., 2020. SARS-CoV-2 (COVID-19) by the numbers. ELife, 9. https://doi.org/10.7554/elife.57309 [online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7224694/]
Brady, Ch., 1999. Air Conditioning, viewed: 5 July 2020, [online: http://www.b737.org.uk/airconditioning.htm#Recirculation_Fan_(3-900)].
Bugaj, M., 2005. Aircraft maintenance - New trends in general aviation. Promet - Traffic – Traffico 17(4), 231-234.
Bugaj, M., Urminský, T., Rostáš, J., & Pecho, P., 2019. Aircraft maintenance reserves – new approach to optimization. Transportation Research Procedia, 43, 31– 40. https://doi.org/10.1016/j.trpro.2019.12.016
EPA, 2020. Health Effects of Ozone Pollution, viewed 25 May 2020 [online: https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution]
Galieriková, A., Materna, M., Sosedová, J., 2018. Analysis of risks in aviation. Transport Means - Proceedings of the International Conference, 2018-October, 1427-1431.
IATA, 2018. Cabin air quality – Risk of communicable diseases transmission, 2020, viewed 5 July 2020 [online: https://www.iata.org/contentassets/f1163430bba94512a583eb6d6b24aa56/cabin-air-quality.pdf]
Irving. D., et. al., 2016. A comparison study of the degradative effects and safety implications of UVC and 405 nm germicidal light sources for endoscope storage, Polymer Degradation and Stability, Volume 133, 249-254, ISSN 0141-3910, https://doi.org/10.1016/j.polymdegradstab.2016.09.006.
Kandera, B., Škultéty, F., Mesárošová, K., 2019. Consequences of flight crew fatigue on the safety of civil aviation. Transportation Research Procedia, 43, 278–289. https://doi.org/10.1016/j.trpro.2019.12.043
Kowalski, W. J., et al., 2002. Mathematical Modeling of Ultraviolet Germicidal Irradiation for Air Disinfection, Quantitative Microbiology 2, 249–270, [online: https://www.berriman-usa.com/pdf_brochures/math_modeling_of_uvgi_for_air_disinfection.pdf]
Lim, S. & Blatchley, E. R., III., 2009. UV disinfection system for cabin air. Advances in Space Research, 44(8), 942–948. https://doi.org/10.1016/j.asr.2009.06.001.
Matas, M., Novak, A., 2008. Models of processes as components of air passenger flow model. Komunikacie Volume 10, Issue 2. 50-54.

Michaelis, S. & Loraine, T., 2005. Aircraft Cabin Air Filtration and Related Technologies:Requirements, Present Practice and Prospects. In The Handbook of Environmental Chemistry, 267–289. Springer-Verlag. https://doi.org/10.1007/b107248.

More Electric Aircraft: How does electricity work on a plane?, 2020, viewed 10 June 2020 [online: https://www.safran-electrical-power.com/media/20151109_more-electric-aircraft-how-does-electricity-work-plane?fbclid=IwAR0LTp9FFIX4Cg9R_jE7ytGUbsrn_YPW6flWMQyg3ESNeilto-59jrOvRcs]

Win, T., T., 2018. Generator Control System Used in Aircraft Power Supply; International Journal of Scientific and Research Publications (IJSRP) 8(8) (ISSN: 2250-3153), DOI: http://dx.doi.org/10.29322/IJSRP.8.8.2018.p8065.