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Investigation of a typical aircraft recirculating air filter for nanoparticles and viruses

Report NCA 04.1e/20

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Summary

A filter of the type Pall QA06423-01, as used in the Airbus A320, was tested for its efficiency in separating aerosol particles. The test aerosol was flame soot, which was produced with a CAST burner, and the size range from 10 to 200 nm was measured. When used in the Airbus, the flow velocity is a maximum of 4.8 cm/s (when the maximum amount of air is recirculated). The measurements were carried out at flow velocities of 8 and 27 cm/s, i.e. under more difficult conditions for the filter. Nevertheless, the separation efficiency was very high, 99.9% at 27 cm/s, almost 100% at 8 cm/s. Since the detection limit was already reached here, no measurements were made at even lower velocities.

Content

1 Information on the filter and ventilation concept

The measurements are carried out with a filter of the company Pall of the type QA06423-01, as it is used in the Airbus A320.

dimensions:

- Filter height 500 mm
- Pleat width. 62 mm
- Number of pleats: 209

1. The Airbus A320 has two filters of this type (see Figure 1)

2. the filters are flown through from the outside to the inside From the outside, the filters under the cabin floor are exposed to a free flow, without any obstructions, i.e. without casing or similar: (Figure 2, in the picture the symmetrical structure with the second filter would be on the right).

3. downstream there is a pump (fan) for each filter, which creates the negative pressure, so that the cabin air flows into the filter. The flow can be varied depending on the degree of recirculation

4. the air that has passed through the filter passes through a fan into a mixing chamber where it is mixed with outside air (Figure 2, top).

Figure 1: investigated Pall Filter

Performance data for the Airbus A320 (both filters together):

Cabin volume: 139 m^3

At 24°C cabin temperature and "8000 feet" cabin pressure the flows are for the worst case (maximum air through the filter):

- Total flow: 1.13 kg/s
- fresh air (from outside): 0.582 kg/s
- Maximum recirculated air through both filters: 0.548 kg/s. At a pressure of 75270 Pa (equivalent to 8000 feet of altitude) and 24°C cabin temperature, the density is 0.88 kg/m^3. This results in a flow rate of 622 l/s.
  The filter area of a filter (calculated from height, pleat width and number of pleats) is 12.9 m^2. With a flow rate of 622 l/s through both filters, this results in a maximum face velocity of 4.8 cm/s.

This corresponds to 49% of the recirculated air volume of the total amount of air flowing through the system. The replacement of this part of the air is due to the fact that the aircraft cabin is like a ball with a hole in it, which is constantly pumped to keep the pressure at a certain level (the cabin pressure)

The "best case" settings, i.e. where you pump with as much air from the outside as possible, lead to a decrease of the recirculation rate to about 37%. This setting is primarily selected when the aircraft is fully occupied. The filter face velocity then drops to 3.6 cm/s.

The air exchange rate in the cabin for fresh air is about 17 times per hour in the worst case and about 26 times per hour in the best case.

For the mixture (fresh air and recirculated air) the exchange rate is about 33 times per hour in the worst case and about 40 times per hour in the best case.

The total number of seats including flight attendants is about 168 in a standard configuration of this aircraft.

The worst case setting is made in case of low seat occupancy (around 50% seat occupancy). However, airlines do not fly profitably for a long time with such low seat occupancy rates and in Switzerland the seat occupancy rate (without the special case Corona) is in the region of 80%.

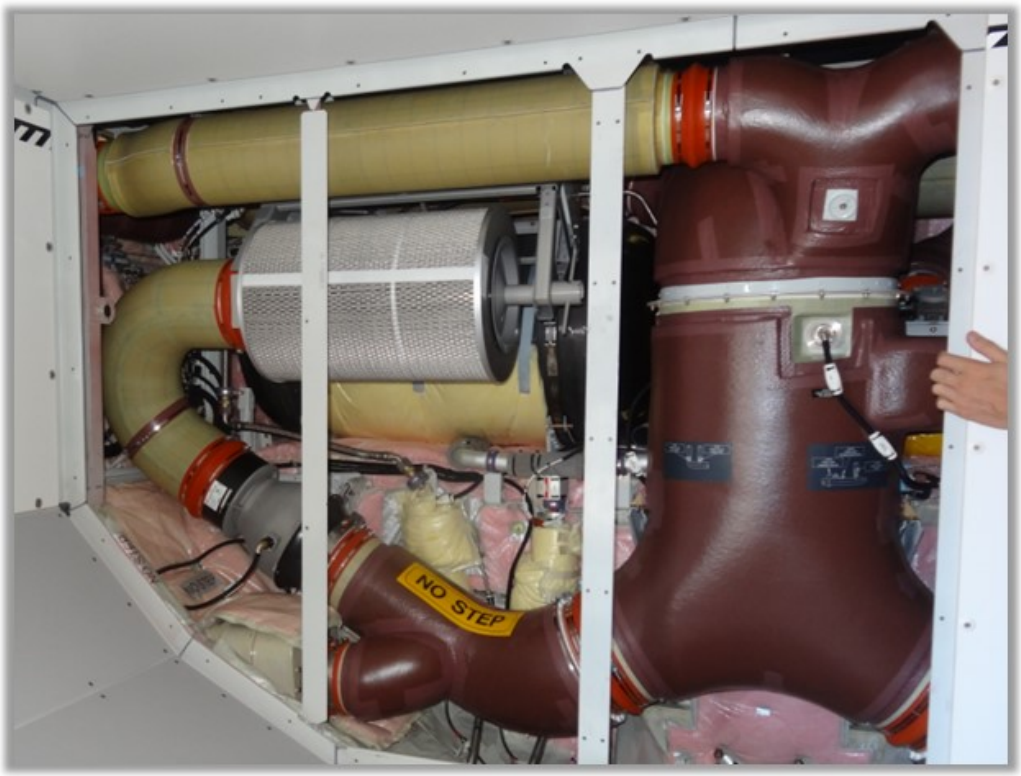

Figure 2: Installation of the filter in the cabin floor

2 Setup of test measurements with CAST aerosol

For the test measurements, the filter as a whole is not measured, only material samples. Circular cutouts with an active diameter of 20mm are used in a standard filter holder

To do this, the filter was cut open (Figure 3)

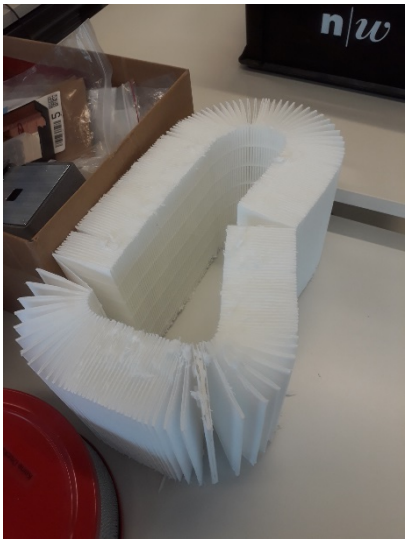

Figure 3: Cut filter

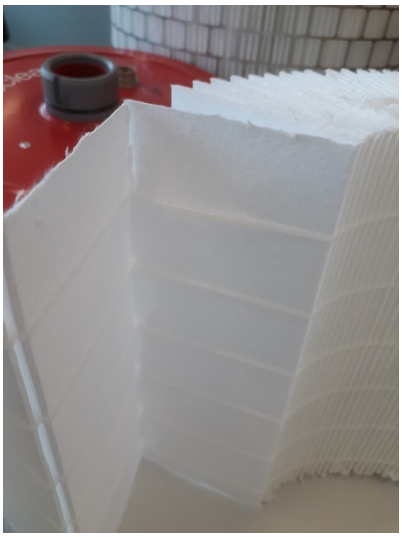

Figure 4: Pleated filter material, plastic bars are attached at intervals of approx. 28mm.

The goal was to cut out samples for a 47mm filter holder. However, since plastic bars are attached to the filter at a distance of approx. 28 mm as spacers and the filter material is damaged when the plastic bars (see Figure 4) are removed, a maximum of 25 mm is available. Therefore, a screen was built into the filter holder, which has a circular cutout with a diameter of 20mm as an opening.

The measurements were carried out with CAST aerosol. The measurement setup is sketched in Figure 5. Figure *6* shows a picture of the setup. A first test measurement was carried out with a flow velocity of 27 cm / s (flow 5 l / min), followed by a series of measurements with 8 cm / s (flow 1.5 l / min, flows as indicated in Figure 5)

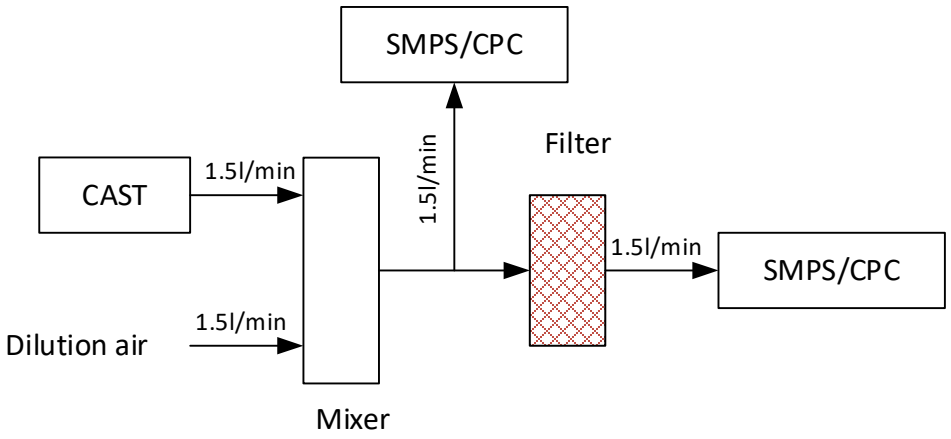

Figure 5: Measurement setup. Since only one SMPS is available, 3 measurements were made, the first with SMPS upstream and CPC downstream the filter, the second reversed, the third like the first.

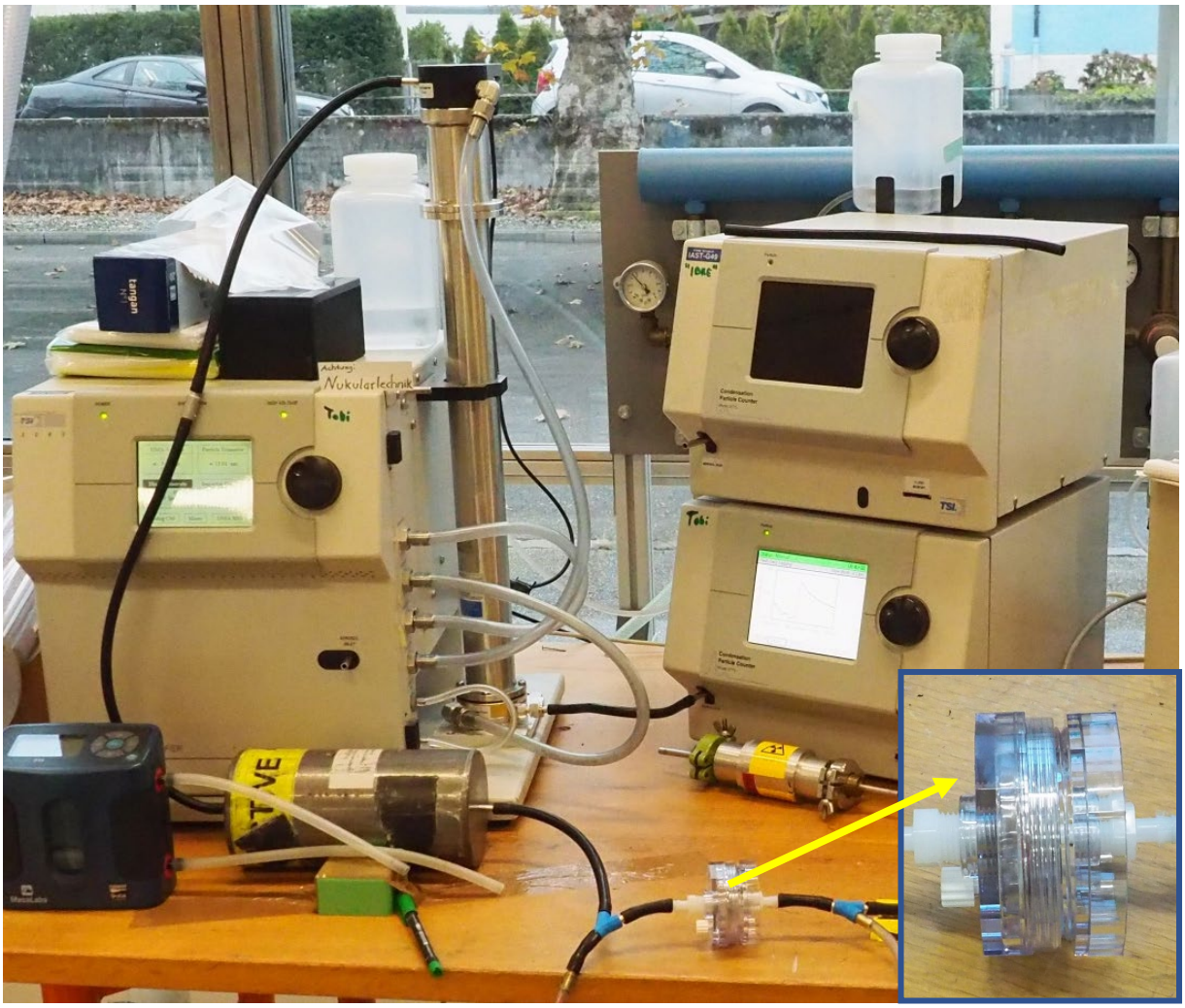

Figure 6: Picture oft the measurement setup.
left: SPMS, right: CPC, insert: filter holder with sample of the filter

3 Results of aerosol measurements

Figure 7 shows an example of the measured size distributions. The initial concentrations are some 10^6 cm^{-3}

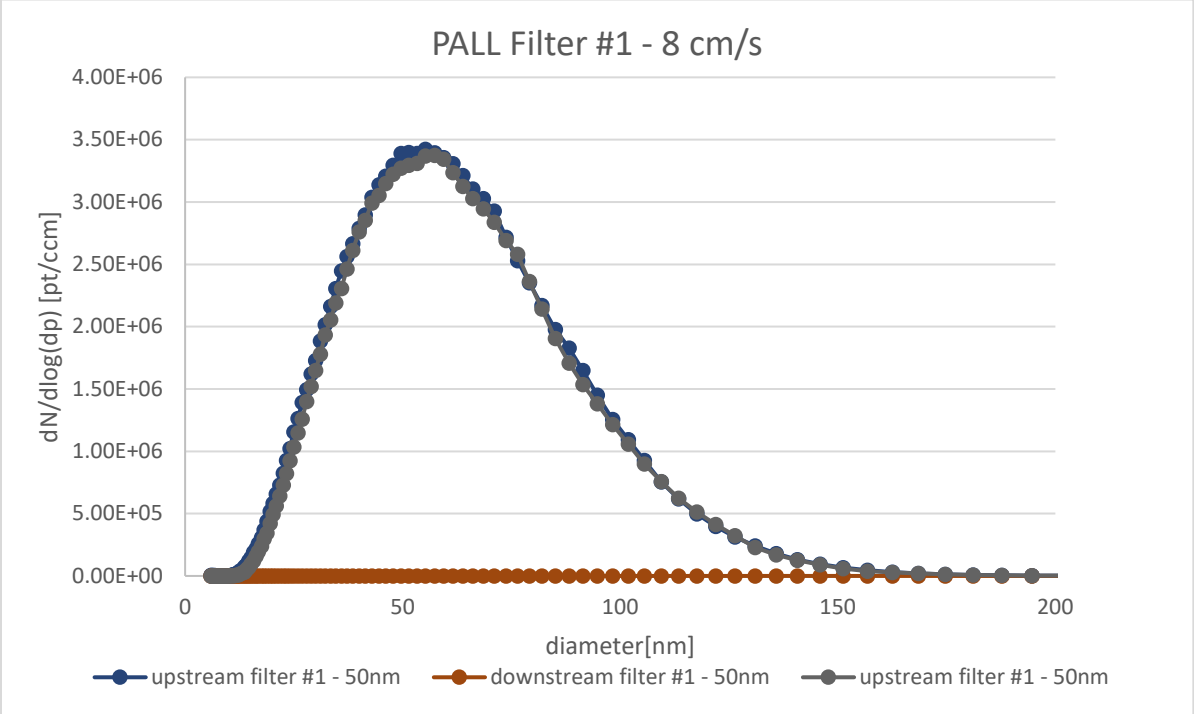

Figure 7: Example of a size distribution with CAST setting 50nm mean diameter. First measurement upstream the filter, 2nd measurement downstream the filter, 3rd measurement again upstream the filter

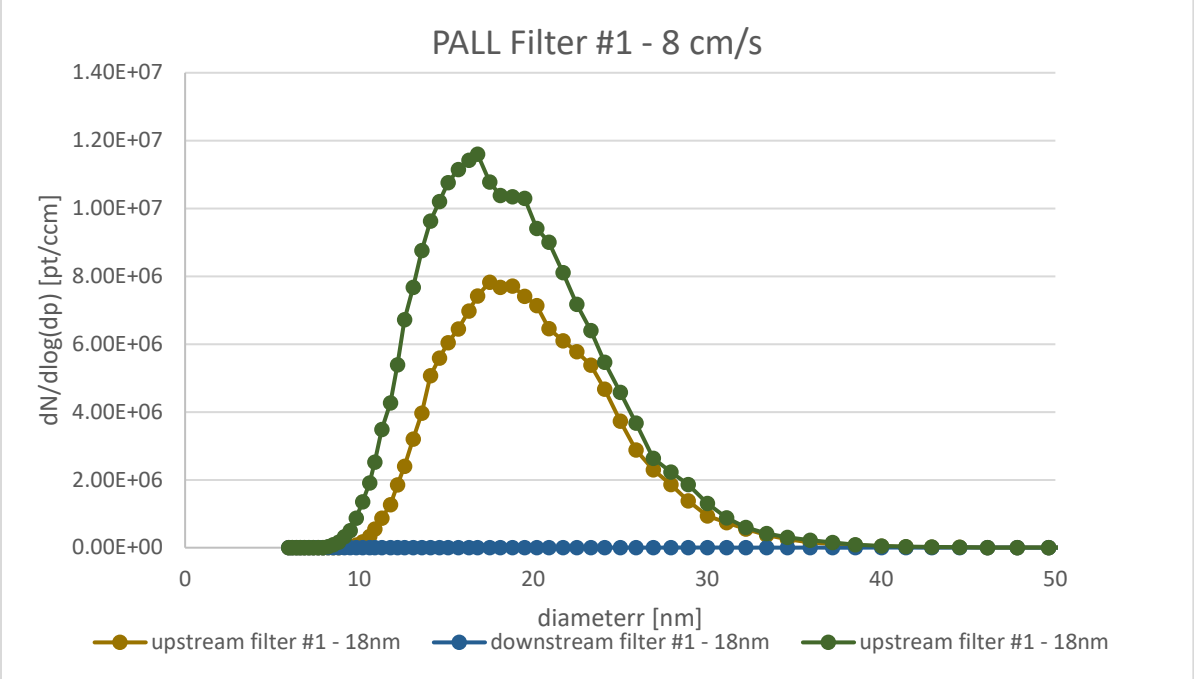

Figure 8: like Figure 7, but with CAST setting 18 nm mean diameter. With this setting, the CAST is less stable, which is reflected in the slightly different concentrations of the two measurements in upstream the filter.

3 filter samples were measured:

- Filter 1 was first coated until the pressure drop approximately doubled,
- Filter 2 is an unused filter, but with a fold in the examined area,
- Filter 3 is an unoccupied filter with no fold.

Filter 1 was measured at 2 CAST settings (18nm and 50nm mean diameter), the other two only at 50nm

Pressure drop (at v = 8cm / s)

- Filter 1: 975 Pa
- Filter 2: 403 Pa
- Filter 3: 413 Pa

Figure 9 to Figure 11 show the measured filter efficiencies. In all cases the efficiency is so high that the concentration downstream the filter is close to the detection limit, although very high input concentrations (>$10^6 cm^{-3}$) are used.

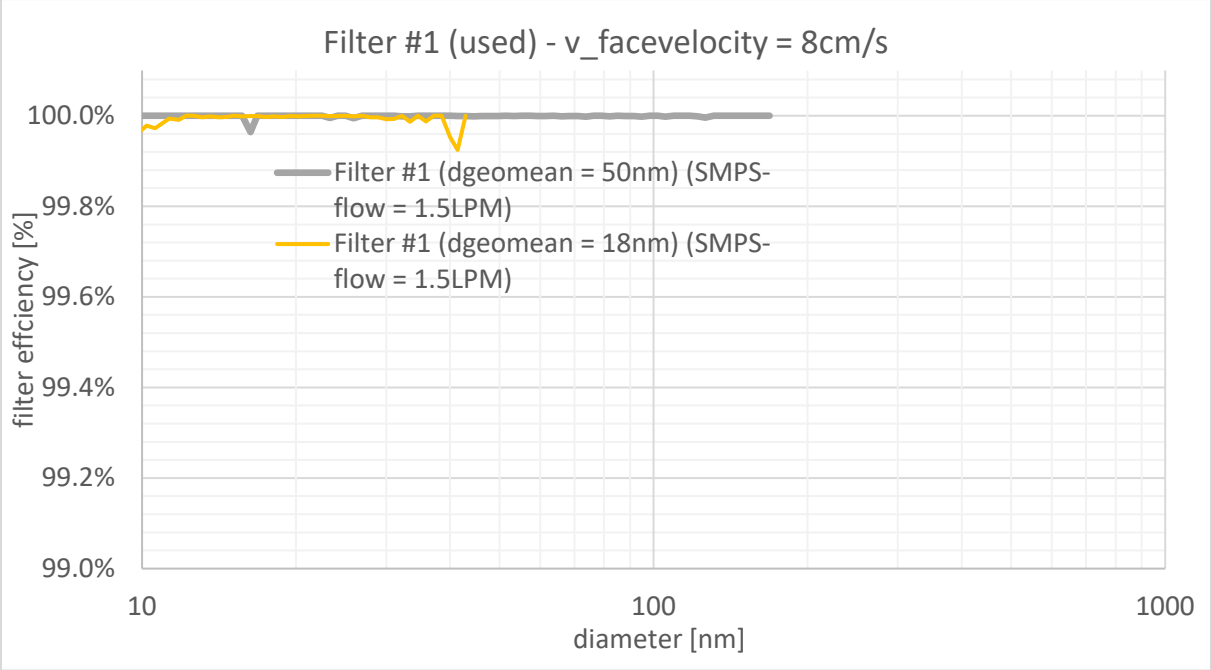

Figure 9: Filter efficiency, filter 1

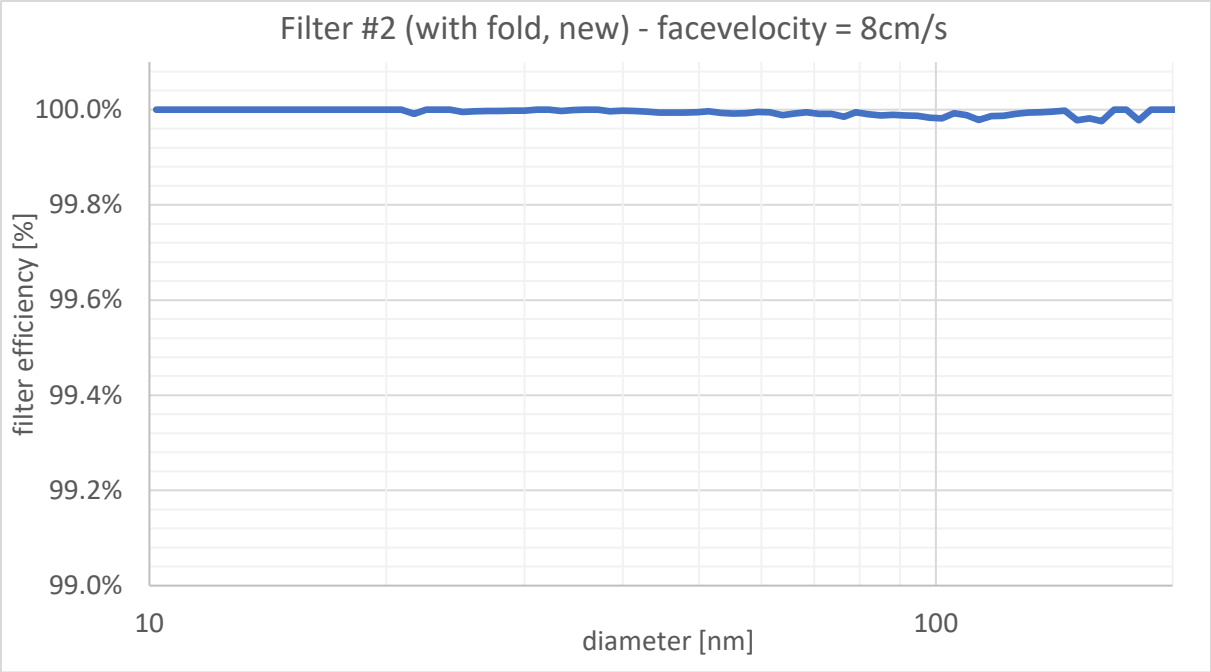

Figure 10: Filter efficiency, filter 2

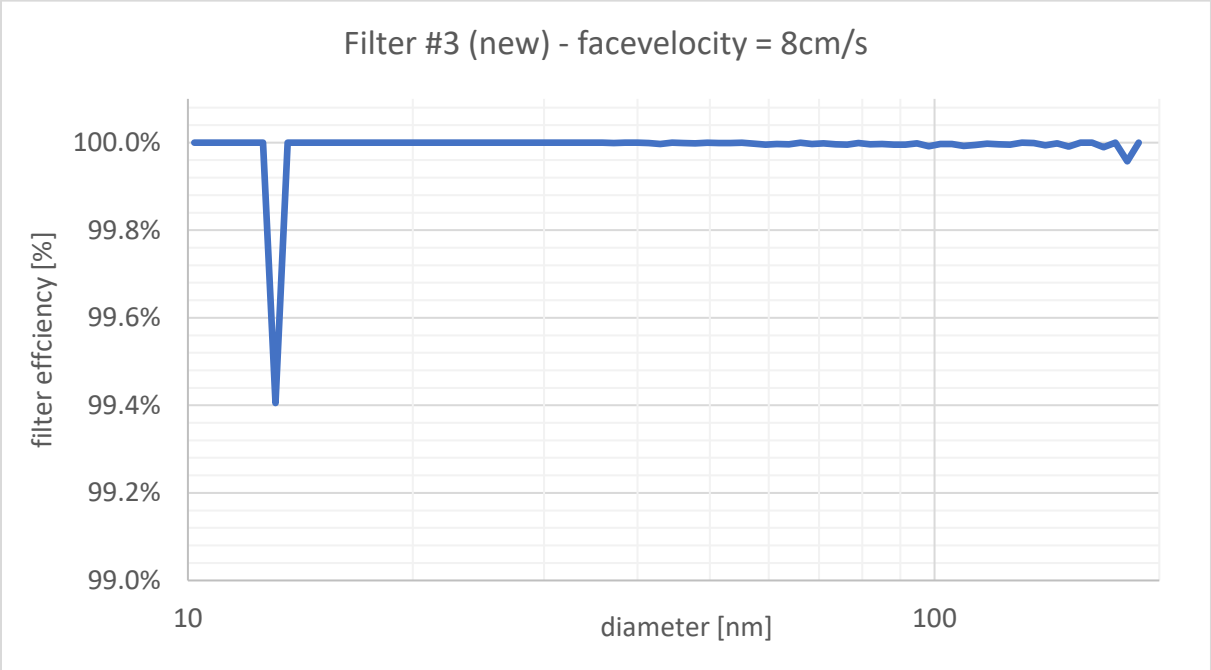

Figure 11: Filter efficiency, filter 3

In all cases the efficiency is close to 100%. In the measurements at 27 cm/s, an efficiency of about 99.9% was measured. In real use the flow velocity is maximum 4.8 cm/s, so the efficiency will be even better.

Tests with 5 samples from the filter, taken from different locations showed the same result.

The measurements were performed at the FHNW/ISE by Tobias Rüggeberg.

October 2020 H. Burtscher

4 Filter efficiency of model viruses (Bacteriophages MS2)

4.1 Background

The Airbus filter with updated test bench system has been delivered by FHNW collborators to the Adolphe Merkle Institute (AMI) on 30 November, 2020. The updated Filter test bench for Airbus filter was used to test the filter efficiency for viral particles.

To assess the filter efficiency for viral particles (virions) removal, the bacteriophage MS2, also called Escherichia virus MS2, was used. Bacteriophage MS2 infects and replicates only in Escherichia coli F^+ K12 bacteria, a subclass of Escherichia coli which is a safety class 1 laboratory stain, making it hence a bacteriophage which is safe for human handling. Furthermore, bacteriophages MS2 are significantly smaller than other known human viruses and hence are particularly interesting to assess filtration cut-off for various filter purification systems. Electron microscopy of the corona virus SARS-Cov-2 (also named 2019-nCoV) showed their spherical shape and size between 60 nm and 140 nm in diameter, averaging about 125 nm (Zhu et al., 2020). On the other hand, the size of bacteriophage MS2 is around 30 nm (Figure 12). Additionally, bacteriophages MS2 proved to be a good model system for corona viruses studies as both are negatively charged and hence expected to have similar behaviour when interacting with the filter surface (Diaz, 2008; Sen et al., 2020).

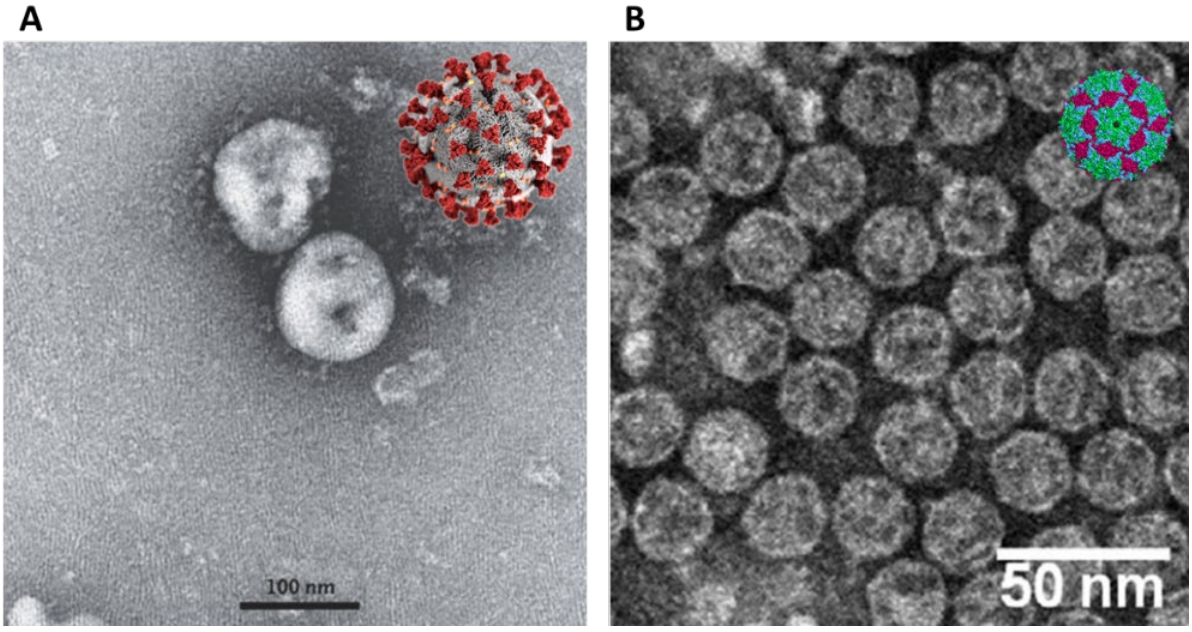

Figure 12. Electron microscopy micrograph and a structure model of A) SARS-Cov-2 virus (https://www.pharmaceutical-business-review.com/news/gsk-cepi-coronavirus/; Zhu et al., 2020) B) bacteriophages MS2 (https://de.wikipedia.org/wiki/Enterobakteriophage_MS2; Nguyen et al., 2011)

4.2 Methodology

To assess for the presence and activity of bacteriophages MS2, the plaque assay was used. The assay was performed according to the protocol given in Miller, Jeffrey H. Experiments in molecular genetics (Miller et al., 1972) where bacteriophages MS2 and bacterial host (*E.coli*) were preincubated together for 10 min at 37° C before the soft agar was added to facilitate the bacteriophage attachment to the host.

The *Escherichia coli* bacteriophage MS2 (ATCC® 15597B1™) and the *Escherichia coli* (*E.coli*) (ATCC® 15597™) host cultures were purchased from ATCC and cultured in 271 media according to the supplier instructions.

Briefly, one day prior to the experiment, 10 µL of *E. coli* culture was added to 10 mL of 271 media and incubated at 37°C overnight at 160 rpm in a shaking incubator. The following morning overnight culture was kept at the room temperature until further use.

The bacteriophages MS2 were kept at 4 °C until use. On the day of the experiment 100 µL of the original stock solution was added to 5 mL of warm 271 medium which should result in 10^8 PFU/mL. Once prepared, this stock solution was nebulized in the test system for 15 min using the commercially available Emser nebulizer under the flow and environmental air stream (Figure 2).

The time needed for all liquid to be nebulised was 12 min and the experiment was run for additional 3 min to make sure that all nebulized bacteriophages could reach the sample collection 1 (before the Airbus particle filter) and sample collection 2 (after the Airbus particle filter) (Figure 13). The average temperature during nebulisation was 21° C and humidity 40-50%.

The bacteriophage MS2 samples were collected on the gelatine filters:

- Gelatine filter 1 (**before the Airbus particle filter - BF**)
- Gelatine filter 2 (after the Airbus particle filter- AF)

The gelatine filters were then dissolved in 5 mL of 271 media, and 10-fold serial dilutions of bacteriophage MS2 were prepared (10^{-1} – 10^{-6}) by always transferring 20 µL of bacteriophage MS2 sample to a consecutive well containing 180 µL of 271 media. Once the samples were prepared, 100 µL of *E.coli* bacterial culture was pipetted in individual tubes and the 100 µL of bacteriophage sample were added. The aliquots were incubated for 10 min at 37° C before 5 mL of the soft top agar was added, and transferred onto the pre-heated solid agar plates and incubated overnight. On the following day the plaques were counted.

The data was only used when there were no plaques visible on the plates marked ‘’control-*E.coli* only’’ which were prepared to eliminate the possibility of viral contamination. The plaques were counted and indicated with a pen. Only the plates which had up to 300-350 plaques were counted.

Only the plates which had up to 300-350 plaques were counted as above that number single plaques could not be distinguished anymore. When analysing plates only the ones with 15 and more plaques were considered due to statistical relevance.

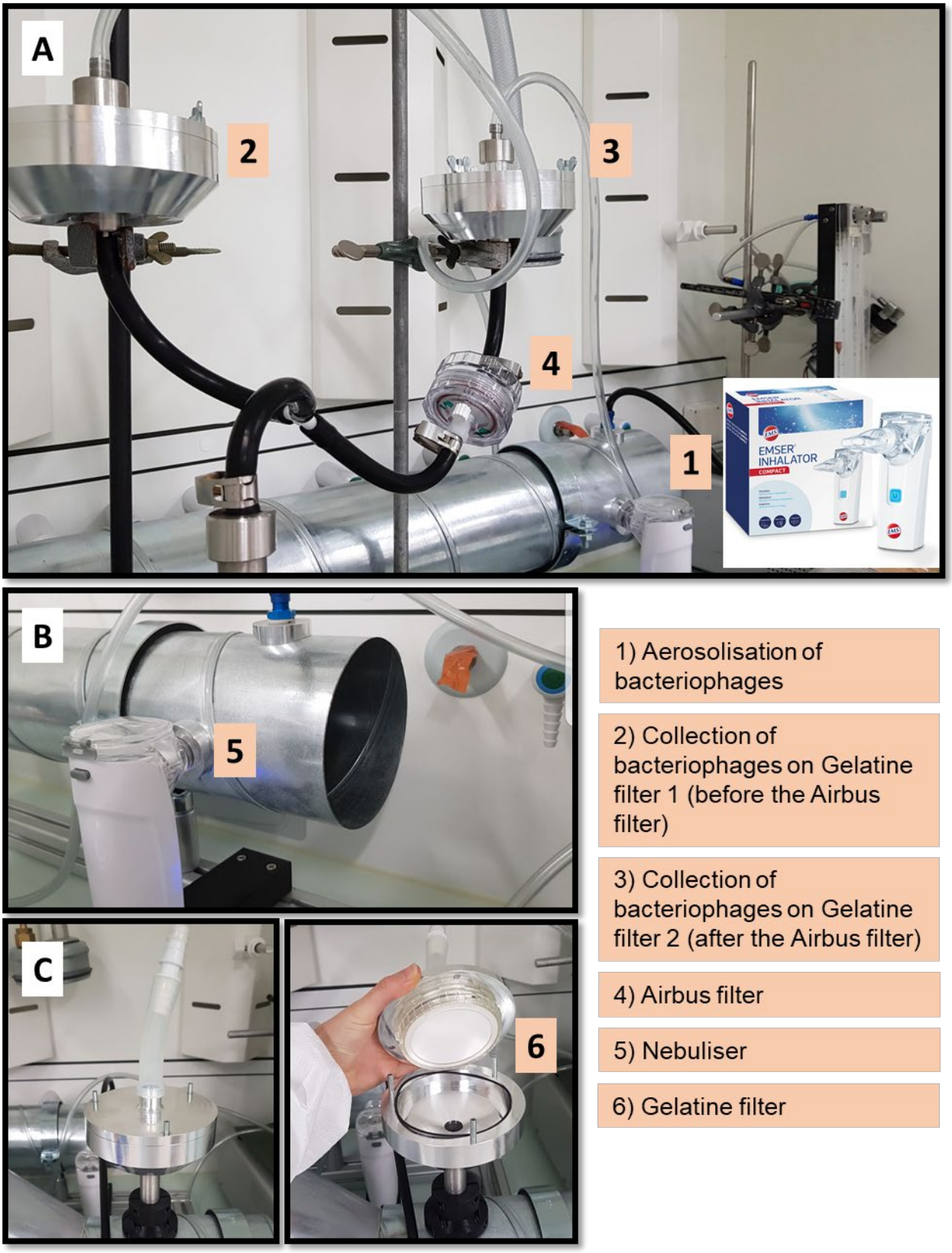

Figure 13. Airbus filter test bench system. A) Test bench system overview; B) Nebulisation point with the commercial nebuliser; C) Collection points and gelatine filters.

4.2.1 Calculating plaque forming units (PFU) and filter efficiency

The number of counted plaques was divided by the dilution factor (10^{-1} – 10^{-6}). To obtain PFU/mL we multiplied the obtained value by dilution factor of 10, since only 100 µL of the sample was plated.

To calculate the filter efficiency (%) the following formula was used:

> Filter efficiency (%) = 100 - ((PFU/mL sampled after the NanoCleanAir® particle filter * 100)/ PFU/mL sampled before the NanoCleanAir® particle filter)

4.2.2 Control experiments

In parallel to the bacteriophage MS2 samples plated on agar plate we always included a plate with *E.coli* only. When no plaques were visible on the plates marked with ‘’control- *E.coli* only’’ we could eliminate the possibility of viral contamination during the plate preparation.

Furthermore, for the experiments described for the optimized methods on gelatine filter was kept on the bench in the hood throughout the experiment and it served as the environmental control to assess potential bacteriophage MS2 contamination in the air. The samples from the bacteriophage MS2 stock solution were also prepared to serve as a positive control.

4.3 Preliminary results

The nebulization experiment in the test system was repeated two times and the results are summarized below. The initial results show that even at the lowest dilution plaque forming units are absent in the sample collected after Airbus filter (gelatine filter 2). However as both repetitions had to be conducted on the same day due to the time constraints, second repetition shows significant signs of the contamination.

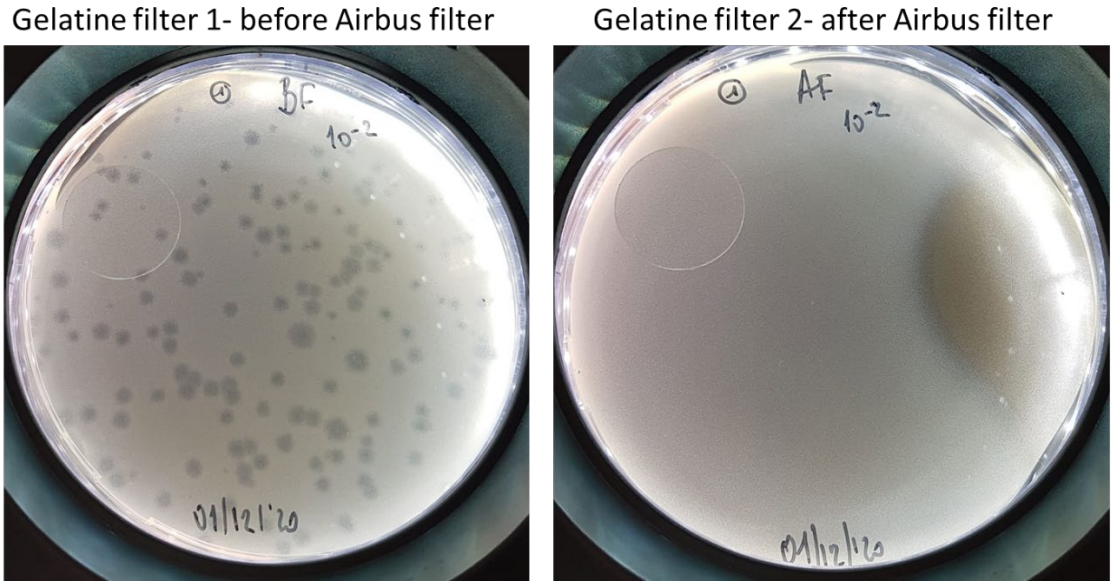

Figure 14. The figure shows the representative photographic images of the agar plates from which the number of plaques was counted before and after the filter. On the AF plate, the air bubble can be observed.

As previously mentioned, due to potentially easy contamination of the surrounding air with the bacteriophages, apart from the standard negative control used to assess bacteriophage contamination in bacterial culture, an additional control to check for the contamination in surrounding air has been performed.

An opened gelatine filter was placed on the bench during nebulisation and served as an environmental control (Figure 15) to monitor the contamination in the air. While no plaques were observed in the first repetition, plaques can be found in negative and environmental control and after filter in the second repetition (Figure 16). This is an indication that plaques appear after filter only in case of the contamination but as contaminated samples cannot be taken into consideration, these experiments will have to be repeated.

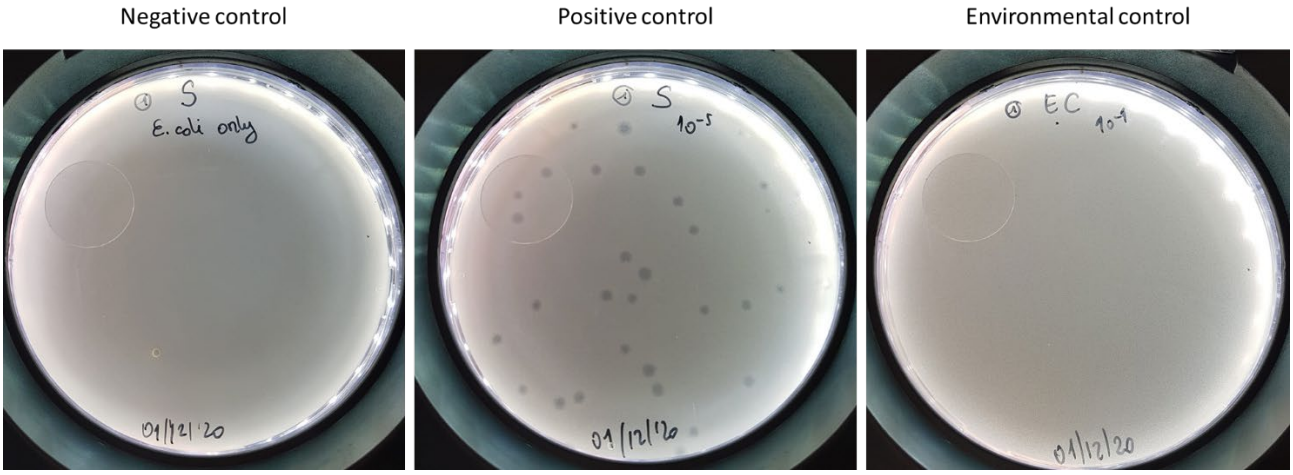

Figure 15. The figure shows the representative photographic images of the agar plates from the first repetition which served as the control: negative control (bacterial host only), MS2 (bacteriophage stock solution incubated with the host) and environmental control (EC) which served to monitor the air during the experiment execution.

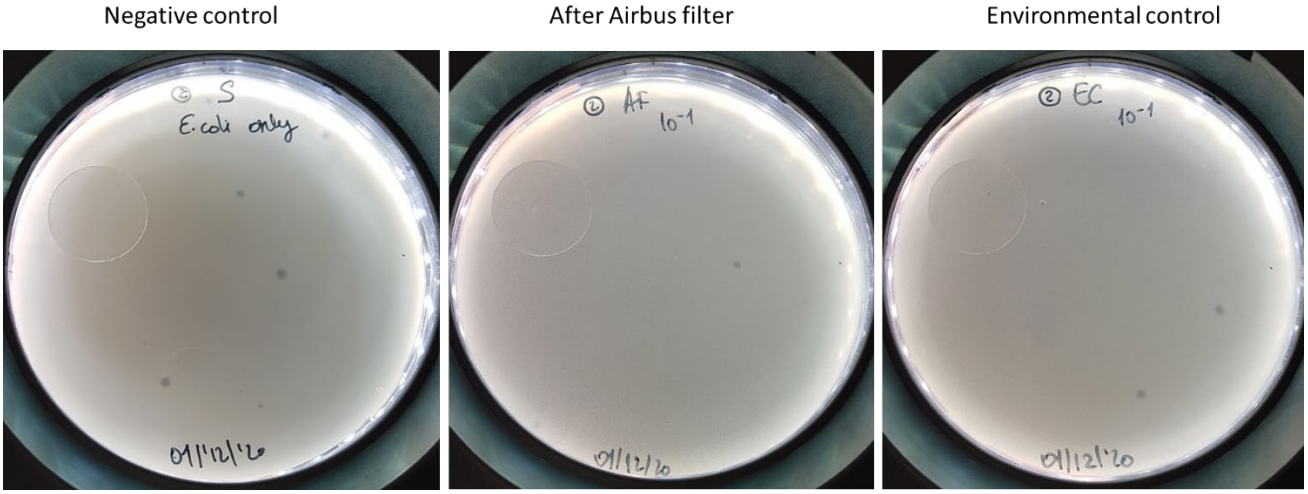

Figure 16. The figure shows the representative photographic images of the agar plates from the first repetition which served as the control: negative control (bacterial host only), MS2 (bacteriophage stock solution incubated with the host) and environmental control (EC) which served to monitor the air during the experiment execution.

From the number of plaques in the first repetition there is an indication that the efficiency of bacteriophage elimination by Airbus filter is > 99% (Figures 16 and 17). However, in the second repetition, plaques were detected after the filter which can be potentially be contributed to contamination as plaques were detected in both negative and environmental control. The contamination which was present in the second repetition also impacted the number of detected plaques in the samples obtained before the filter. Namely, the PFU/mL increased in the second repetition (Figure 16).

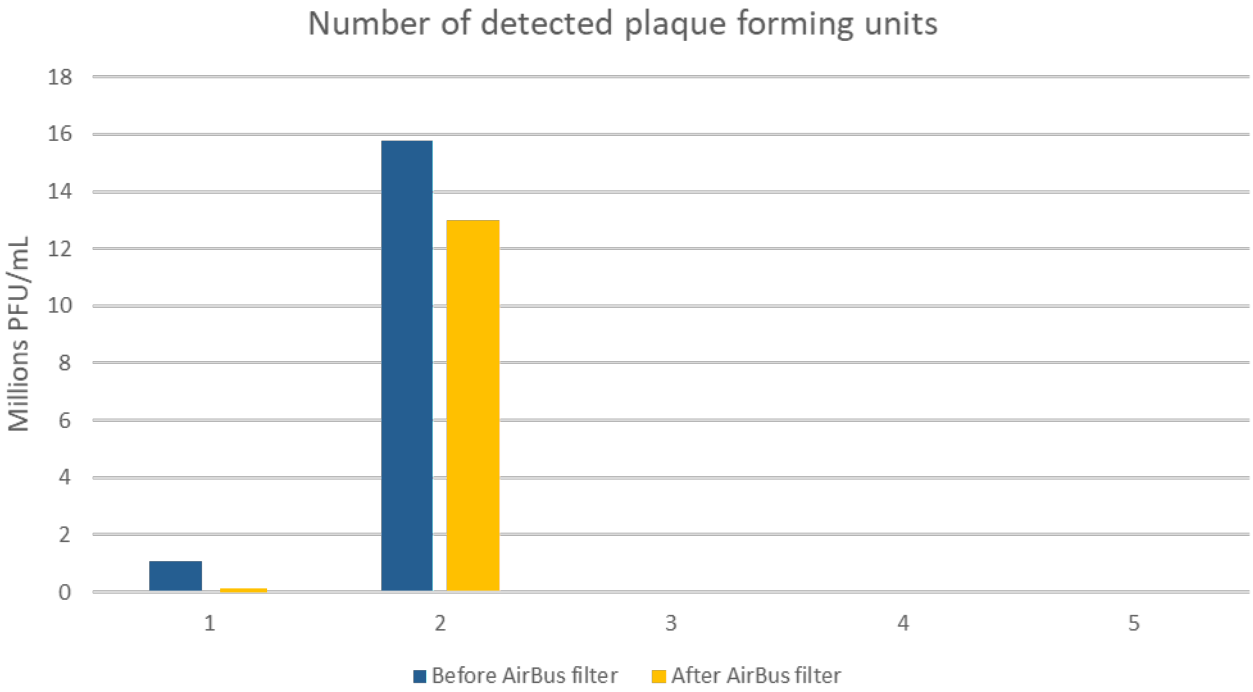

Figure 16. Number of detected plaque forming units before the Airbus filter (Gelatine filter 1, blue bars) and after (Gelatine filter 2, yellow bars). Contamination was observed in the second repetition.

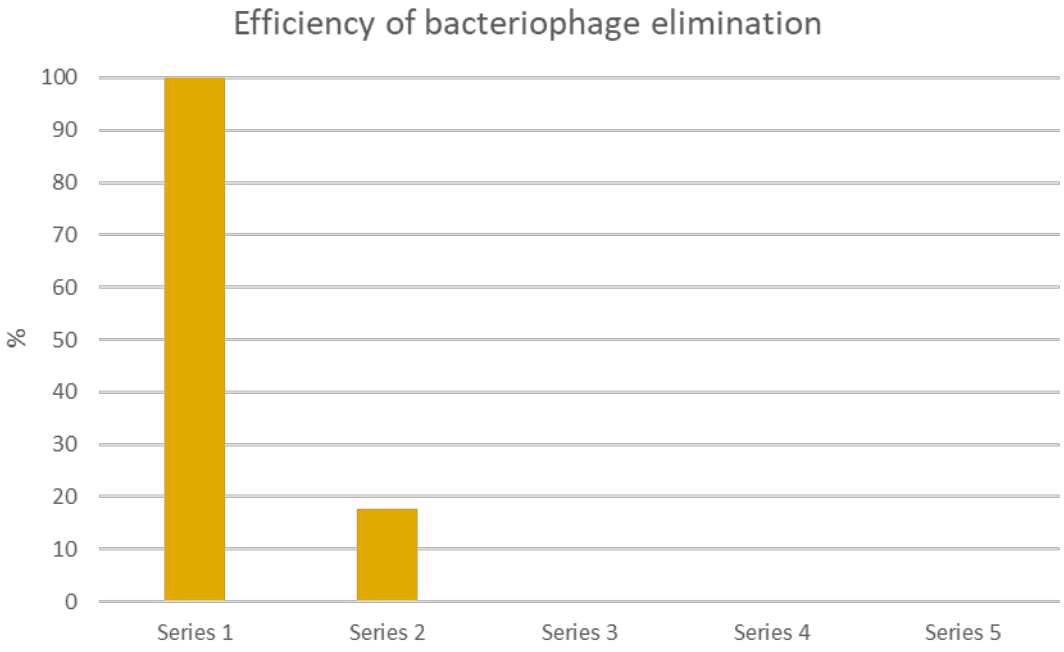

Figure 17. Efficiency of bacteriophage elimination over 2 repetitions.

4.4 Conclusions

We have shown that the adapted test system designed by FHNW can be used to nebulize the virus model particle, i.e. bacteriophages MS2, into the air stream. The collection of the bacteriophages MS2 on gelatine filters, which are sampled before and after the Airbus filter (i.e. gelatine filter 1 and gelatine filter 2), allows to determine the filter efficiency.

Although we previously introduced efficient cleaning strategy with nebulisation and cleaning with 70% ethanol, such strategy is insufficient when 2 repetitions are run consecutively. Hence, additional cleaning steps have to be introduced.

As second repetition showed signs of contamination, experiment has to be repeated.

4.5 Bibliography

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The Aerodynamic Mechanism of Virus Infection in Aircraft Cabins and the imperative Conclusion to reverse the Direction of Ventilation

1. The usual airflow in large passenger aircraft

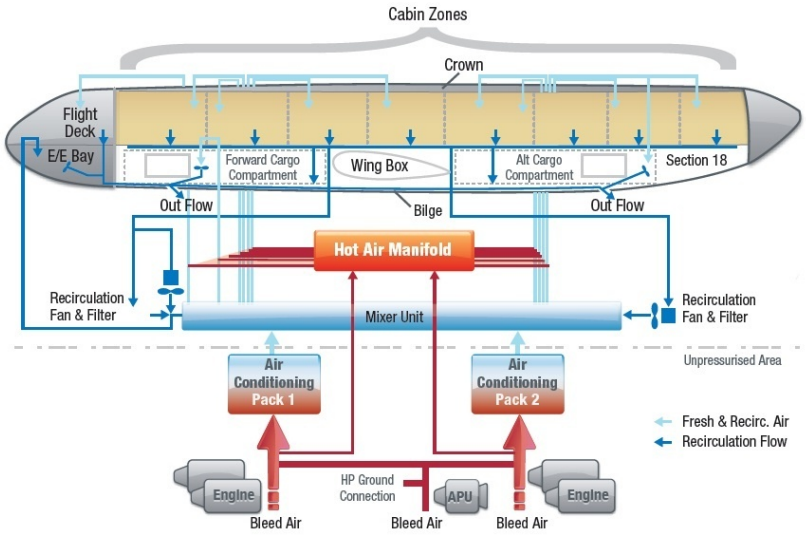

Fig 1: Ventilation diagram of the Airbus 320 as an example of the standard solution [1].

The cabin is usually ventilated in cross-flow. The fresh air comes from a connecting pipe in the cabin ceiling and flows from top to bottom. The inlet nozzles, whose settings can usually be adjusted by the passengers themselves to suit their needs, are located directly above the head of each passenger. The air is taken up again through extraction openings in the footwell and fed by a blower through a filter to a mixing chamber, from where it is recirculated into the cabin. Although there are standards for these filters and HEPA13 filters are often used [2], there are apparently no internationally binding regulations. In the mixing chamber, "fresh air" is added to this air flow, which comes from the engine and is cooled but not filtered on its way to the mixing chamber. To regulate the cabin pressure, part of the air is released back into the atmosphere.

2. Cleaning the cabin air from particles, viruses and other germs

If, as described above, the air extracted from the cabin is passed through a filter, then the quality of this filter only partly determines the quality of the air supplied to the passengers and crew, because the actual "fresh air" is not filtered, but is supplied to the cabin air after the filter. It is probably assumed that pollutants mainly come from the cabin itself, not from the ambient air or the engine, which is not necessarily true under all operating conditions. As far as viruses are concerned, it may be true that there are some reservations about bacteria, as bacteria can form colonies, a major problem known from hospitals. The HEPA filter from an Airbus 320 examined in this study has excellent filtration properties, even for nanoaerosols in the size range of viruses. It can therefore be assumed that there is no significant penetration of viruses coming from the passenger compartment. The question of the possible formation of bacterial colonies that could colonise the filter and penetrate the filtration medium should be further investigated. Especially since the replacement intervals of such filters are very long - in the case of the Airbus, according to SWISS: 5000 operating hours!

3. Risk 1: insufficient filtration of the recirculated cabin air

Given the nature of the disease, an infected passenger is likely to release viruses throughout the flight. Since one million new viruses can be reproduced in a single virus-infected cell within a few hours [3], which are released when breathing out or even coughing or sneezing, the viral load of the recirculated air transferred from the breathing area of this passenger cabin into the cabin air is mixed with the other air including the fresh air and since the viruses remain in the aerosol state as suspended particles for many hours, the entire air will be homogeneously enriched with viruses after a few recirculation cycles, i.e. after one hour at the latest. This means that every passenger and every crew member must inhale virus-contaminated air and this during the entire flight. Even the cleaning staff is still exposed to this risk, unless the cabin is purged specifically. This is the general problem of recirculation in ventilation systems, which has recently led to massive waves of infection in many large slaughterhouses and restaurants.
Filters with a weaker effect than HEPA13 therefore represent a great danger and, for longer flights, are equivalent to the unfiltered state, which is apparently still common for many airlines or aircraft types. We do not consider the EASA recommendation [4] to increase the proportion of fresh air to be sensible, as this only achieves a slightly higher dilution, which is irrelevant for the risk assessment (see section 7). Whether such an approach is justifiable for energy reasons and whether it can be implemented in existing aircraft at all remains to be questioned.

4. Risk 2: pollutants from the ambient air

When discussing pollutants in flight operations which could be highly toxic to humans, the quality of the ambient air should not be disregarded. Investigations carried out by the authors on small turboprop aircraft in July 2019 have shown that very high concentrations of gas turbine combustion particles can be found in aircraft cabins when the aircraft is stationary, with engines running, in taxi operations and up to a certain altitude. In the DAHER TBM aircraft, concentrations of up to 800,000 P/cm3 were measured in the pilot's breathing air in the size range around 30 nm, which must be classified as dangerous to humans (carcinogen risk class 1 according to WHO 2012). These combustion particles may come from the engine itself or from engines of other aircraft in the vicinity or simply from the air in the airfield area. Such particles can enter the cabin directly from outside via leaks or via the air taken from the compressor ("bleed-air").

5. Risk 3: pollutants from the engine or conditioning system

Whether the engine and/or the conditioning system must also be regarded as a source of pollutants depends on the design, the materials used and the operating temperatures in each individual case. There are known cases where components of the lubricating oil have leaked into the cabin air ("fume-events") and others where substances from plastics have been released, as there seems to be no requirement for this in aircraft in contrast to road vehicles.

6. Risk 4: immediate danger of infection by exhaled toxic aerosols

Since the risk of infection in aircraft has long been suspected and in some cases of tuberculosis and influenza has been proven [5], this question has been investigated by numerous authors, now also for COVID-19 [6].
The ACER study of the National Air Transportation Center with the Harvard School of Public Health "Infectious Disease Transmission in Airliner Cabins" [7], which was published as early as 2012, is particularly significant. In this study, detailed flow calculations were carried out, which show the ventilation conditions in modern passenger aircraft and also the dispersion dynamics of virusses exhaled by individual passengers. Some illustrations from this study are reproduced below.
Since there is hardly any longitudinal flow in an aircraft with a flow pattern like the one shown below, the air movement is dominated by the body heat of the passengers without additional ventilation (thermals). So in the warmer areas a vertical flow forms, which reverses near the cold walls and thus drives two large vortex-tails, the air is constantly moving with speeds of up to about 0.4 m/s. This is a rather threatening idea, if one considers that viruses are locally released in this room, which are thus already in this state intensively turbulent distributed, i.e. this already starts when the aircraft is occupied and not yet flying.

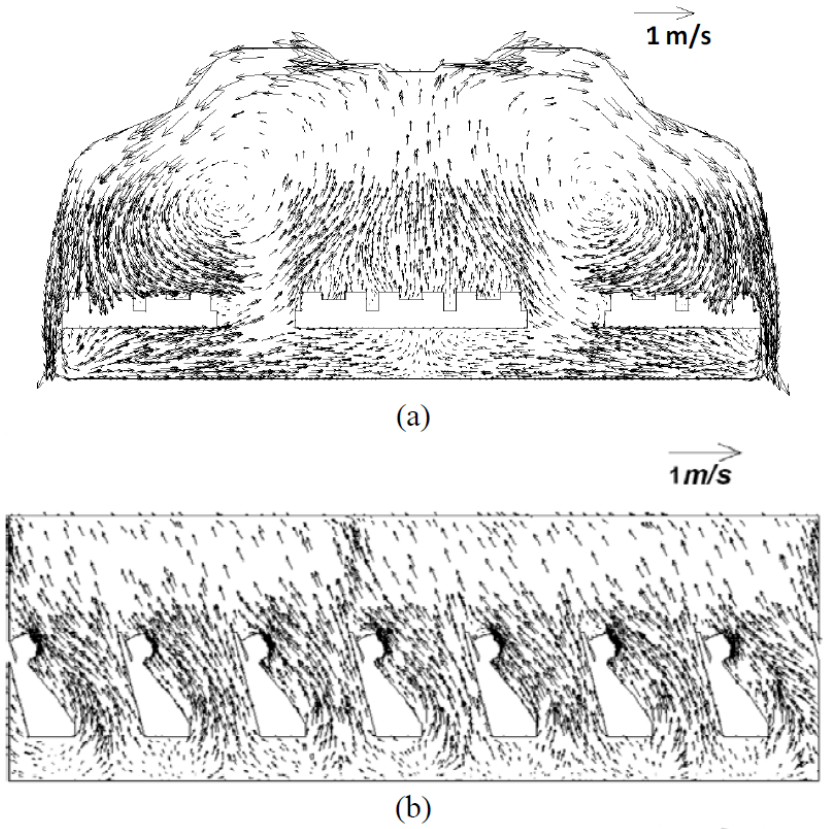

Fig. 2 Formation of the flow in an airliner due to thermal conditions (body heat)
(from the quoted ACER study 2012)

However, if forced ventilation from top to bottom then sets in, the direction is reversed and flow patterns such as the following occur. Here it is now clear how the flow normally proceeds, namely that the exhaled air is guided into the foot area where it can spread over several rows of seats within a very short time.

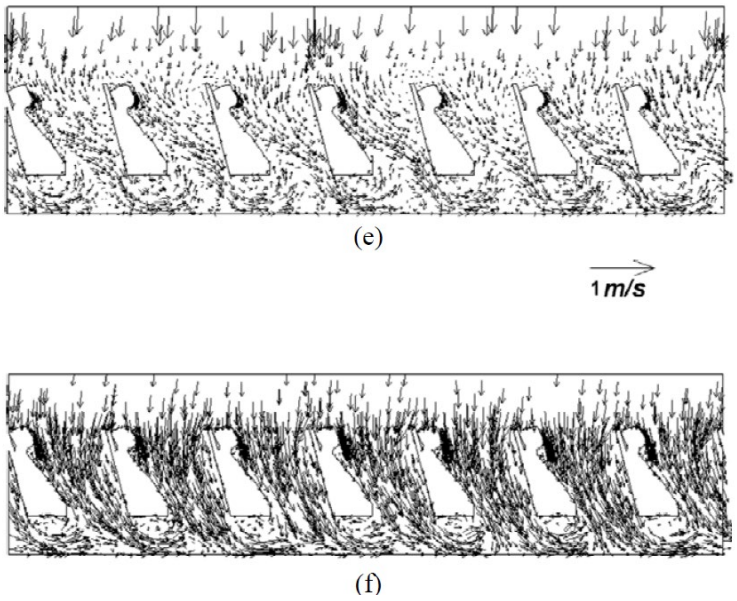

Fig 3 Formation of the flow in a fully occupied airliner with forced ventilation from above
(from the quoted ACER study 2012)

The thermal components and the diffusion are now superimposed on this flow pattern and thus a model of the spread of exhaled viruses was created in very complex calculations, whereby only a period of 4 minutes is considered here and the effect of recirculation was not included.

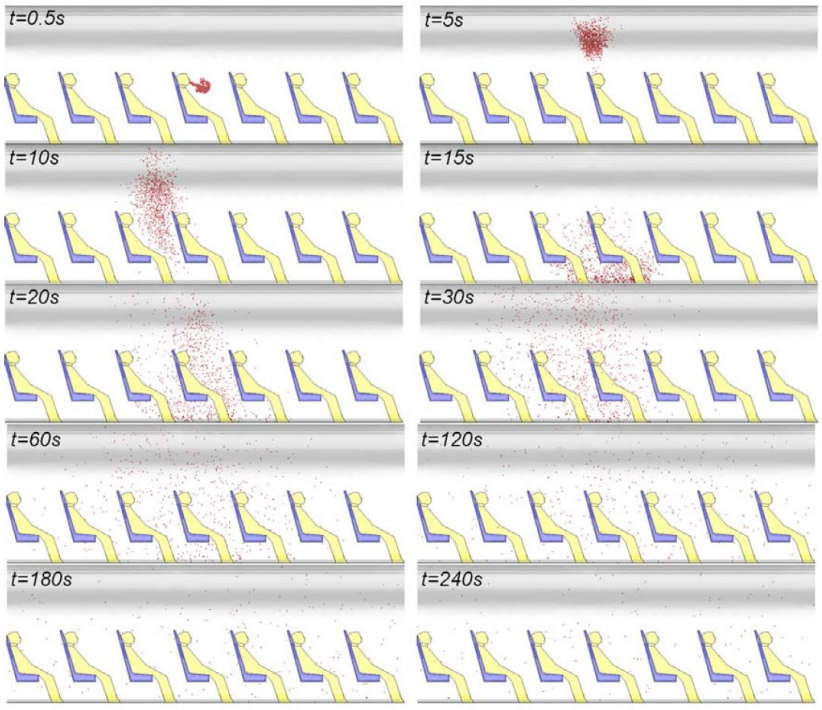

Fig. 4 Spread of viruses exhaled by a single infected passenger
(from the quoted ACER study 2012)

7. What is the real risk of infection during long flights?

Looking at these pictures, one is tempted to interpret the clearly visible dilution as a rapid reduction in the risk of infection. For this purpose, the following figures must be taken into account [3].

- A single cell that bursts in the throat of an infected person releases about 1 million viruses
- A concentration of 100 million/m3 can develop in the vicinity of an infected person
- The infection dose is 500 to 2000 viruses, which can be ingested in a single breath or consecutively.

It follows that a dilution below the infection threshold in the cabin of an aircraft is not achievable under any circumstances. On the contrary, the risk of infection is always present as long as the air breathed by infected passengers is allowed to spread in the cabin. In this case, mixing in the area of the immediately adjacent 10 passengers is quite sufficient. This will not change even with the best filtration in the recirculation loop as long as the flow is not changed in a fundamental and targeted way.

8. Despite the AHA-precautions and quick test, are further measures really necessary?

On this question the following current press release should be quoted:

> On an Emirates flight from Dubai to Auckland in New Zealand on 28 September 2020, a Swiss passenger infected seven other passengers with the corona virus.
> He was able to present a negative test.
> A study shows that all infected passengers sat a maximum of two rows in front or behind the Swiss passenger.
> 86 passengers were on board. After the 18-hour flight, seven of them tested positive for the corona virus [8].

This seemingly paradoxical situation is clearly illustrated by the presentation of the virus transmission probability for this insidious disease:
During the first 3.2 days between infection and the start of virus transmission, all tests will be negative, and in a further 2.3 days the infected person will not experience any symptoms, i.e. no fever or cough and the like. He will feel healthy and the test will confirm this in a period of more than 2 days when he is at the highest risk to his environment. This is, of course, a statistical means, so the times can vary widely in both directions.

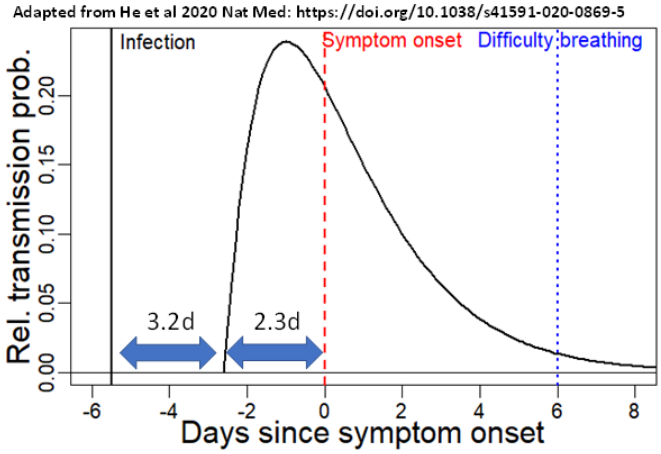

Fig. 5 Relative transmission probability after infection with the SARS-CoV-2 virus (FAQs on Protecting Yourself from COVID-19 Aerosol Transmission) [9].

It must be concluded that all the measures mentioned - including rapid tests for all passengers and crew - do not guarantee that no persons with a maximum risk of infection will come on board. The only really effective measure, namely to keep a distance from all persons or, even better, to avoid any accumulation of persons, is not applicable in air transport.

9. A simple, highly effective and universal solution: overhead extraction

Only one method remains, namely the capture and elimination of pollutants, in this case viruses, at the source, which is the general aim of emission technology. And of course all passengers must be considered as possible sources.
In doing so, we make use of the fact that not only the "dry" viruses with 30-150 nm are in the size range of aerosols, i.e. they behave almost like gas molecules, but also exhaled or coughed up aqueous droplets in the size range of 5-10 µm are dried in fractions of a second to their solid contents, i.e. viruses or virus clusters, and thus become suspended particles [10]. Some particularly large droplets may sediment, but this proportion, which was in the foreground at the beginning of the pandemic, is insignificant according to current knowledge.
Since such suspended particles follow the air carrier flow even at low air velocities in the range of 0.1 - 0.4 m/s without significant delay or deviation of the trajectories due to mass forces, a new design of the air flow in the head area of the passengers - all passengers - offers us a solution.
The technical solution, as shown in the following video clips, was presented within the framework of the FOEN-UTB project 636.15.20 "Virus filter" in a very complex flow simulation on the case of a lift car. This room, which is always too small, is known to be one of the most important sources of infection - the example of an infected resident who infected 70 flat mates in his house in less than a week, whom he never met personally, is well documented [11].
The distribution of the viruses exhaled by the man is shown in the left picture for the normal case, in which the movement of air is only caused by the body heat of the two persons. After 17 seconds the infection is, so to speak, already complete.

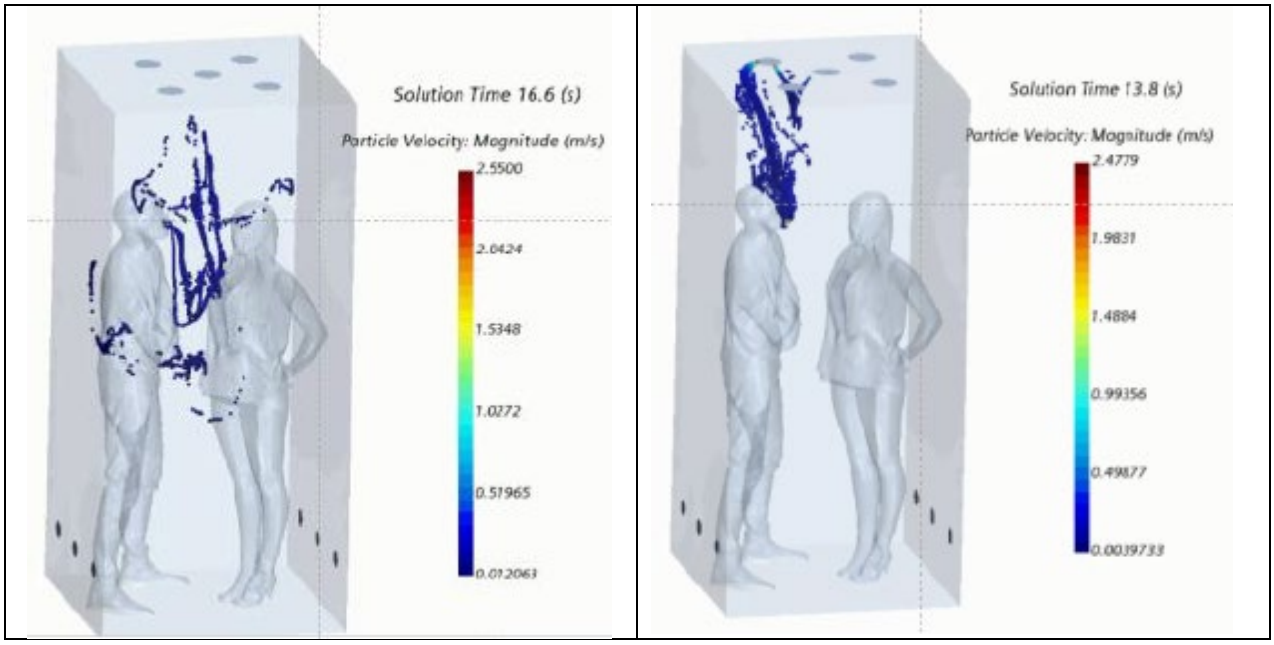

Fig. 6 Flow simulation in a lift car. Left without and right with vertical suction

In the right picture the air in the cabin is extracted through the ceiling, filtered there and returned through the ducts at the bottom of the cabin. The vertical velocity component is on average only 0.1 - 0.2 m/s. This slight, low-turbulence vertical drift is apparently perfectly sufficient to capture the viruses directly from the mouth of the man exhaling at approx. 0.2 - 0.4 m/s and to discharge them in such a way that there is no risk of infection for the woman.

In the cabins of airliners this possibility is already provided for, so to speak: Directly above the head of each passenger is the access opening to the cross-ventilation system - only the direction of flow is fatally "wrong" and thus the infection is intensified and accelerated by the forced vertical downward drift of the fresh air instead of reversing the direction of flow from bottom to top, reliably prevented by the natural thermal.

So do you only have to reverse the direction of the air flow, turn the fan?

10. Suggestions

It may be that aircraft cannot be converted, or that this involves considerable costs - so should they be left on the ground instead of at least trying?

NanoCleanAir has the proposed solutions and together with our partners we are able to examine the following approaches and prepare them step by step for implementation:

- Modelling of the flow processes by suction "overhead". Thus, design of the ventilation aerodynamics, duct and nozzle geometry and ventilation capacity.

- Experimental verification on a laboratory model on a reduced scale (1:4, produced by 3D printer), in which aerosols of corresponding sizes are realistically used and measured.

- Simplified installation in a decommissioned aircraft to demonstrate the extraction system with flow measurements and smoke demonstrations and to show the combination with a suitable recirculation filter.

- Practical testing of the new ventilation system with a partner (airline SWISS, aircraft manufacturer AIRBUS, aircraft ventilation manufacturer LIEBHERR) with a view to retrofitting options, which may be the only really remaining solution.

- Specification of the new ventilation philosophy with a view to standardisation

11. How the aircraft industry will react to these proposals:

Response to a test question to an insider in the USA:

While the science is compelling we don't expect this to be supported by passengers and industry. The passengers like the ability to direct a fresh airstream to their nose. Perceived odor of the person next to you, and some control over one's environment are difficult to give up. The next issue is that airlines have declared that aircraft are safe to fly as is. This change makes it obvious that there are possibly better solutions. So this is asking airlines to spend money to retrofit aircraft to make it then obvious that current conditions are not ideal. Alternatively airlines could say: if you are really concerned and/or have underlying health issues we provide proper N95 masks for free. If you need to change them consider going to the bathroom, wait for a while to ensure that the bathroom air is clean and then swap N95 masks in the bathroom.

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