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Summer 2020, COVID-19, Flying: Yes or No? Caution: Health Risk and Unclear Legal Situation!

(Hamburg, 01.07.20) The sun is shining. The popular beaches in southern Europe are still empty. Airline tickets to the holiday destinations are already on offer and the German Federal Foreign Office[1] is considering the lifting of the global travel warning for COVID-19. The temptation to break out of everyday corona life is great. But beware. There is a real danger of getting infected with SARS-CoV-2 in an airplane, because in hardly any other place are people so close together as in an airplane. Do not cough at the airport; this could prevent you from entering the aircraft. Before the return flight, the body temperature may be measured - with an uncertain outcome. Freshly rescued airlines insist that there is no risk of infection on the plane. The air in the plane would be as good as in an operating room. The truth is not followed strictly with such statements, because it is about a lot of money. Those responsible turn a blind eye to such behavior, after all, a Lufthansa cannot be rescued every quarter. Here is a detailed description of the background from an engineering perspective.

How the Social Distance Requirements on a Plane were Politically Prevented

One of the basic health protection measures in the corona pandemic is to keep people apart. The distance should be at least 1.5 m (https://perma.cc/UC6T-GWWC). Anyone who does not abide by this can be fined. Business owners in Hamburg, Germany then pay between € 500 and € 1,000 (https://perma.cc/FK3M-6MKH). If a bus operator in Bremen, Germany takes a tourist trip on his bus, fines would be between € 500 and € 2500 (https://perma.cc/HWK4-WHFZ). Only in the airplane it is and should continue to be different. The passengers sit there in close seating. You could now leave one seat free, possibly every other row. It is not like that in Germany at the moment and it will not happen in summer 2020 either. Passengers will sit tightly in full aircraft as always. The lobbyists have long since threaded this in. First there were talks in the German Ministry of Transport

[1] This text was first published on 2020-06-05 in German as a press release. Download is available as https://purl.org/corona/PR2020-06-05 (PDF, 24 pages, 1.6 MB) from http://PR.ProfScholz.de and describes the situation from a German perspective. The press release caused much interest and media activities in TV, radio, online and print. The results of all this are listed on http://corona.ProfScholz.de.

(BMVI). There, the German industry representatives had already agreed that airlines were allowed to sell all seats (https://perma.cc/4GSP-9S6S). The regulation between Lufthansa / Eurowings and the BMVI (https://perma.cc/95BS-8GS2) specifying that seats should be blocked on some flights, expired on April 19, 2020 (https://perma.cc/MN8R-7AP7). The European Aviation Safety Agency (EASA) also became active. The "COVID-19 Aviation Health Safety Protocol" was published on May 20th, 2020. They are "guidelines to assure health safety in air travel despite COVID-19". In the entire document, no information is binding for the airlines. On the other hand, there are new procedures for the passengers to adhere to. EU Transport Commissioner Adina Vălean praised: "The protocol released today will assure passengers that they can fly safely, thereby helping the industry to recover from the [financial] impact of this pandemic." (https://perma.cc/7NHJ-VHAX) The main message of the protocol is: "If a physical distance cannot be guaranteed due to the passenger load ... passengers should ... adhere to ... other preventive measures ... and ... wear a face mask." (https://perma.cc/MR7X-Y73R). Talks were then led by the International Civil Aviation Organization (ICAO). The head of the International Air Transport Association (IATA), Alexandre de Juniac, is delighted. Whatever ICAO demands (https://perma.cc/J5ZX-4JRP), must be transposed into national law by the member states worldwide. A country like Pakistan could then no longer demand "free space from at least one neighboring seat" (https://perma.cc/JCF9-PYUC). On June 1st, 2020, the ICAO's Council Aviation Recovery Taskforce (CART) presented its "Recommendations and Guidelines", the "CART Take-off Guidance". In the "Aircraft Module - Passenger and Crew - General" it says: "Airlines should allow separate seating arrangements if the occupancy permits" (https://perma.cc/X447-UEU2). In plain language: Every seat can be occupied.

Safety distance at Hamburg Airport, May 22, 2020 – a theoretical value.

How We Will Fly in the Future

Report Mainz showed a foretaste of what will come on May 26, 2020 (almost a week after publication of the EASA "protocol") using the example of a flight to Portugal (https://perma.cc/CV2K-8F24). It is as crowded as ever. Almost every middle seat is occupied. Lufthansa requires mouth-nose protection (https://perma.cc/LSS9-6RRW), which is naturally removed when eating. There are no indications of orderly boarding and deboarding from the aircraft, which would prevent close encounters of passengers. As always, the passengers stand closely together for a few minutes when getting out.

Pictures of a flight from Germany to Portugal and back; end of May 2020. Almost every seat is occupied. The chaos of getting in and out is the same as always. The "COVID-19 Aviation Health Safety Protocol" published by EASA could have been observed. (Report Mainz, https://purl.org/cabinair/ard-report-corona)

How Financial Constraints Influenced Decision Making about the Minimum Social Distance

A press conference of the International Air Transport Association (IATA), the umbrella organization of airlines, took place on May 5, 2020. Brian Pearce, chief economist at IATA presents the numbers (https://perma.cc/4A7U-V97W). After that, weak demand from passengers is expected for summer 2020. However, the range of transport services will increase rapidly because of the many aircraft that are now parked and stored (https://perma.cc/9CYL-HVQX) have to go back into action because the invested capital has to generate income. There will then be a large supply of flights with only moderate demand. Accordingly, the prices for the plane tickets will be rather low. Ryanair boss Michael O'Leary expects a price war and swears: "Wherever there is a sale under costs, we will price under the sales below cost" (https://perma.cc/7GMJ-DTYM). The airlines saved with billions of Euros and now again liquid can start the price war. Worldwide, it is about $ 123 billion in support for airlines (https://perma.cc/JE57-WYWK). Ryanair calculates that its European competitors will receive "€ 30 billion in illegal state aid" that "violates EU state aid and competition rules" (https://perma.cc/94A5-M4ZW). Ryanair itself also receives £ 600m (https://perma.cc/28X8-QJCC). The current low fuel price helps somewhat on the cost side. However, fuel costs only make up around 10% on short and medium-haul routes. Overall, it will be economically difficult for the airlines. The planes must therefore be as full as possible. The percentage of seats sold is called the load factor and averages 85%. A healthy airline starts to make a profit at around 70% load factor. This percentage is called the break-even load factor. Of course, it is best - economically speaking - if every seat is occupied.

Why It Is Not Economically Feasible to Keep Social Distance in the Aviation Competition

If a seat should remain free next to each occupied seat, the number of available seats is reduced. In the case of the well known narrow-body aircraft (e.g. Airbus A320, Boeing 737) with 6 seats in a row, it looks like this: **P X P _ P X P**. P stands for passenger and X for an empty seat. In the middle the aisle is indicated. The number of available seats then drops to 2/3 = 67%. These remaining seats will also not be able to be filled completely for reasons of logistics. If the old typical load factor of 85% was transferred to the new situation with the free middle seat, the load factor would be reduced to 57%. Ticket prices would have to increase by a factor of 100/67 = 85/57 = 1.5 if the airlines wanted to generate the same turnover. The percentages and price factors depend on the arrangement of the seats in the aircraft. Here is a list of some common seating options:

1 aisle, 4 seats:	**P X _ X P**	seats: 50 %, load factor: 43 %, price factor: 2.0
1 aisle, 6 seats:	**P X P _ P X P**	seats: 67 %, load factor: 57 %, price factor: 1.5
2 aisles, 8 seats:	**P X _ P X X P _ X P**	seats: 50 %, load factor: 43 %, price factor: 2.0
2 aisles, 10 seats:	**P X P _ P X X P _ P X P**	seats: 60 %, load factor: 51 %, price factor: 1.7
2 aisles, 12 seats:	**P X P _ P X P X P X _ P X P**	seats: 58 %, load factor: 50 %, price factor: 1.7

From these values, IATA determined an average value for the available seats of the various cabin configurations of 62% with the frequency of the respective seat configurations (https://perma.cc/4A7U-V97W), which would give an average load factor of 53%. Even if the available seats were all filled, only 4 of the 122 airlines could make a profit, explains Brian Pearce. It is also unfavorable that more expensive tickets would reduce demand.

How the Aerospace Industry Argues to Go below the Minimum Social Distance

There is a contradiction that has to be resolved somehow argumentatively. On the one hand, the minimum distance cannot be maintained for economic reasons; on the other hand, the epidemiological requirements for the minimum social distance of 1.5 m are clearly formulated and indisputable. The argumentative solution:

1.) Staying on board an airplane is safer than in other places in public space (https://perma.cc/K5Q4-NV8Z).

2.) Consistent implementation of the hygiene measures (https://perma.cc/K5Q4-NV8Z).

3.) Other transport systems do not keep the minimum social distance either.

Point 1 is among other things about the ventilation system in passenger aircraft. Airbus provides information on this. Airbus Executive Vice President Engineering, Jean-Brice Dumont is quoted (https://perma.cc/8HW8-86CY):

Argument 1: The air in the cabin is (fully) renewed every two to three minutes.

Argument 2: The air in the cabin has the quality of a hospital because it is led through high-performance filters.

Argument 3: The air in the cabin flows down from the ceiling and is extracted again from the floor. So there is no horizontal air flow either sideways or lengthways.

These are the three arguments that the aviation industry presents in this or similar form in a mantra-like manner. "Hospital" can be increased by "operating room" (https://perma.cc/CCY3-8KT4). High-performance filters are the particulate filters or HEPA filters. The following is added in this way or similar:

Argument 4: David Powell, IATA: "Nobody has shown that an empty middle seat reduces the likelihood of passing COVID-19 from one person to another." (https://perma.cc/J5ZX-4JRP)

Argument 5: The passengers look forward and have little facial contact. (https://perma.cc/S2P6-S363)

Argument 6: The seats provide a barrier to forward and backward transmission in the cabin. (https://perma.cc/S2P6-S363)

Argument 7: So far, not a single case has become known in Europe in which an infection with Covid-19 has occurred on board an aircraft. (https://perma.cc/CKA2-E7VF)

Argument 8: The risk of getting infected with the virus during a flight is extremely low. (https://perma.cc/CKA2-E7VF)

But it is also admitted:

- "The only real health risk is person-to-person contact. Sneezing or coughing causes the infection to spread over short distances through droplets." "No ventilation system is able to prevent this type of transmission." (Airbus: https://perma.cc/2R93-GAAC)
- "An infection by coughing or direct contact is also possible on the plane - especially when people are sitting close together." (Airbus via DPA: https://perma.cc/8HW8-86CY)
- "The problem is the direct spreading of droplets from one passenger to another." (David Powell, Medical Advisor, IATA: https://perma.cc/J5ZX-4JRP)

In the following sections, the arguments of the aviation industry listed here are discussed in detail.

Why the Air in the Cabin Can Contain Viruses despite the Ventilation

The aircraft cabin must be ventilated. For this purpose, the certification regulations (CS 25.831) stipulate at least a volume flow of 5 l / s per passenger (converted units). With 200 passengers that would be a volume flow, Q of 1 m³ / s of fresh air. 3600 m³ of fresh air would then be required per hour. An airplane for 200 passengers has a volume of approximately 400 m³. This means that the air in the cabin is changed 9 times an hour. The value 9 1 / h is called the air change rate and results in an air change every 6 to 7 minutes with 60 min / 9 = 6.7 min. For reasons of comfort, a higher volume flow (8 l / s) is selected for new aircraft models, which leads to an air change every 4 minutes. The air is of course not completely renewed (as in an air pump where the piston ensures complete emptying). Mixing occurs; the 4 minutes are therefore only a theoretical value. Office buildings are also ventilated with 5 l / s or even 10 l / s. The air change rate is high on the plane, but not because the ventilation per person is exceptional, but because the cabin volume per passenger is with around 2 m³ so small compared to residential buildings or even churches. The important variable is and remains the volume flow per passenger.

So much for argument 1.

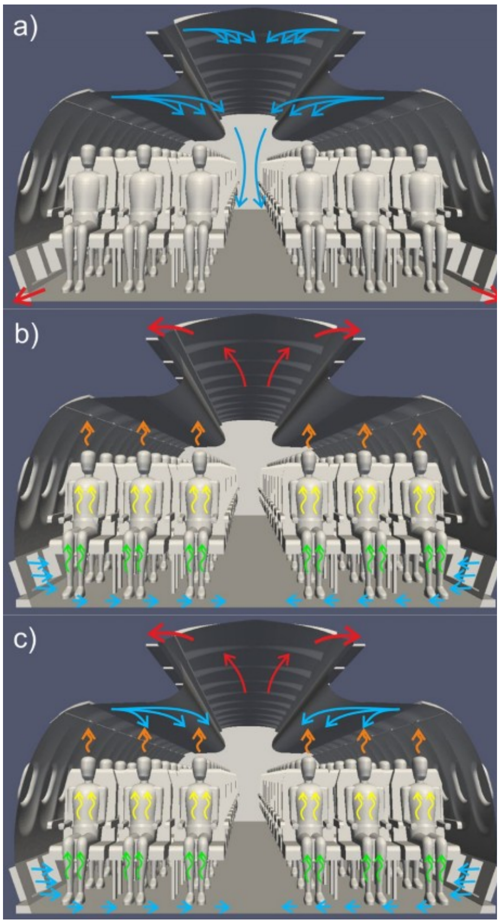
About half of the air that enters the cabin is recirculated air. This is air that was removed from the cabin and passed through a particulate filter (HEPA = High Efficiency Particulate Air Filter). HEPA filters are able to filter viruses and are also used in operating rooms. Instead of taking recirculated air, really fresh air could have be taken from outside. The highly purified air takes the place of the outside air and helps to save energy because the recirculated air does not need to be compressed, like the outside air, which is only available at low pressure at cruising altitude.

The aerospace industry argues much too brief: Airplanes and operating theaters have HEPA filters, so the air quality is equally good. Response: a) If HEPA filters are to filter viruses (recirculation), then the viruses must be present in the cabin air beforehand. b) Conclusion: the quality of the air in the operating room is comparable to that in the plane when 200 people stand and watch around the operating table.

The cabin air is contaminated because:

- Many passengers sit in a confined space and can infect each other before the air has been changed by the air conditioning system. Evidence of this is a) the simulation shown below, including the simple preliminary considerations and b) the evaluation of medical studies. That is the topic here and will be discussed further in the next sections.
- The air is supplied to the cabin via the engines. Engine oil escapes there in small quantities, which lubricates the bearings of the drive shafts because the shaft seals do not seal completely, are worn out or are faulty. This is another topic (http://CabinAir.ProfScholz.de).

So much for argument 2.



Three variants of air routing in the aircraft cabin:

a) Mixed Ventilation (MV) – presently used
b) Cabin Displacement Ventilation (CDV)
c) Hybrid Ventilation (HV)
(https://perma.cc/YW7R-ESYY)

How the Air Is Routed in the Cabin

There are various options for air routing in the aircraft cabin. Employees from the German Aerospace Center (DLR) and Airbus have presented and evaluated these options in a

publication (https://perma.cc/YW7R-ESYY). There are three different versions (see picture). Mixed air ventilation (MV) is used for Airbus aircraft. The air exits above and below the luggage compartments, is led down mostly in the aisle and then runs laterally above the cabin floor to the wall, where the air is directed into the cargo hold. It can be assumed that the flow in the area of the window seat is slowly directed upwards, thus creating two air circulations that ventilates all the seats. New options for airflow are: b) Cabin Displacement Ventilation (CDV) and c) Hybrid Ventilation (HV). The flow direction is reversed in both new variants. The air rises in the aisle. Pure CDV ensures low air speeds, low turbulence and high heat dissipation efficiency. In the hybrid system, 30% of the total volume flow is provided through the side outlets below the luggage compartments. HV enables even more comfortable flow rates and good heat dissipation efficiency, improves temperature stratification and cooling and heating rates on the cabin surfaces. Chen has examined the systems for virus contamination (https://perma.cc/7UDQ-KHWH). The body heat of the passengers lets the air rise. Going with this current instead of fighting against it reduced the turbulence and ensures that the viruses are washed out faster. Chen found that such ventilation systems could halve the infection rate. From the point of view of the aircraft system engineer, one thing is clear: the new variants would require a greater overall length of the pipe system. This would make the system heavier and more expensive.
So much for argument 3.

Why the Likelihood of Infection Increases Significantly by Reducing the Distance According to the "Volume Model"

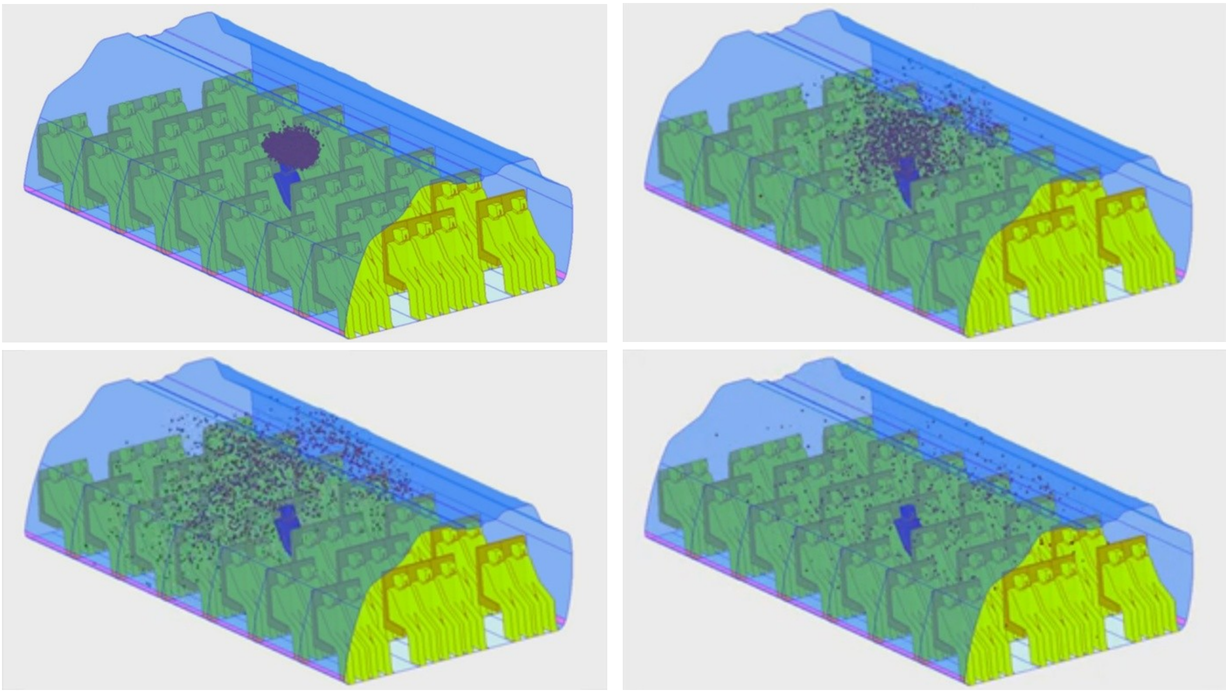
The greater the distance between two people, the less likely it is for the two people that one of them infects the other with the corona virus. The requirements for a minimum distance are not uniform. The World Health Organization (**WHO**) advises to keep a distance of at least 1 m from other people (https://perma.cc/Z5DV-68GA). Often 1.5 m are mentioned (https://perma.cc/UC6T-GWWC), but also 2.0 m. Dr. David Nabarro, one of WHO's Special Representatives for COVID-19, explains: "WHO and others have stated that the best distance to stay away from people if you want to avoid inhaling a drop is 2 meters. That's because that you are safe 99% of the time, but you can significantly reduce the risk even at 1 m, since 70% of the droplets stay within 1 m." "It's a decision that needs to be made based on personal circumstances. If you really want to reduce the risk of infection, stay at least 2 meters away." (https://perma.cc/TJ2S-FVQX)

The influence of the distance can be better quantified with a simple calculation based on a model. I call the model "**volume model**". We assume that a certain amount of droplets, all of which are loaded with viruses, spread in one volume from the person's mouth when sneezing or coughing once. This volume could e.g. be a cone with a certain opening angle, a sphere or a hemisphere. We assume that the volume is evenly filled with droplets. The droplets spread, but there are always some that remain near the patient. Simulations confirm that this assumption is justified. When the cloud of droplets spreads, it hits another person at a certain distance, *d*. At that moment the cloud has a certain volume. The greater the distance, the greater the volume and the lower the density of the droplets at this moment, ρ (rho). It is already intuition that it makes a difference whether I am coughed at by someone from a short distance or whether I am only exposed to diluted viruses at the other end of the aircraft cabin after the viruses have spread all over the cabin. It is now possible to relate the size of the volume and thus the respective density of the droplets to one another depending on different distances *d*. Regardless of the assumed shape of the volume (cone, sphere, ...) it always applies $\rho_1/\rho_2 = (d_2/d_1)^3$. If you double the distance from 1 m to 2 m, the density decreases by the factor due to the volume effect ("length times height times width") $2^3 = 2 * 2 * 2 = 8$.

An aircraft seat has a width of approximately 0.5 m. Two passengers are therefore 0.5 m from nose to nose. Compared to the recommended distance of 1.5 m, this is a factor of 3 for the distance and a factor for the density (and the "risk") of $3^3 = 27$. If you left the middle seat free, then a distance from nose to nose would be 1 m and thus a factor of 1.5 for the distance, which gives a factor of $1.5^3 = 3.375$ in terms of density. If we compare the two results, we get 27 / 3.375 = 8. If the middle seat remained free, the ratios would improve by a factor of 8.

The conditions of the virus spread can be seen more precisely in a **flow simulation**. Prof. Qingyan Chen, Purdue University, simulated the spread of cough droplets in an aircraft cabin and published the results (https://doi.org/10.1111/j.1600-0668.2012.00773.x) – see picture. After a sick person coughs, the droplets spread out in the cabin. The air droplets when sneezing or coughing tend to propel the droplets forward. If someone has put on a mask, the air pressure from the lungs causes the viruses to flow to the side and up or down between the mask and face, rather than through the filter material (https://perma.cc/KS6R-XSZ4). A concentrated cloud of droplets spreads, as assumed in the volume model. First of all (and with high droplet density) the immediate neighbors are hit. If more distant neighbors are reached, the droplet density is already lower. The aircraft air conditioning system creates a two-dimensional flow in a fuselage cross section. How the air ducts are designed depends on the type of aircraft. In any case, the droplets with the cabin flow are initially distributed more strongly within a row of seats. The droplets are then distributed to the front and back through turbulence and diffusion over the rows of seats. At the same time, the droplets are washed out by the ventilation of the air conditioning system. According to Chen, after 4 minutes, only 12% of the droplets remained in the cabin. But the danger is not over because the same or another infected person coughs again. The flow simulation could now run again, with the only difference that when the simulation that now follows, starts with a cabin already loaded with an evenly distributed virus density. The new cough is added.

After many such cycles, the virus density, ρ becomes steady. The virus density depends on the strength of the virus source *S*. The virus source is the sick person who emits a certain number of viruses per unit of time. There is also a dependence on the volume flow of the ventilation of the cabin, *Q*. In the steady state, $\rho = S / Q$. The strength of the virus source is hardly known. However, it is important to recognize that two sick people generate twice the virus density in the cabin as one sick person alone. This "**stationary model**" is based on the simplified idea that the viruses are continuously emitted from a source and are immediately distributed evenly in the aircraft cabin.



CFD simulation (FLUENT) of the distribution of particles of a coughing passenger in the cabin of a Boeing 767 in a period of about 4 minutes. (Qingyan Chen, Purdue University, School of Mechanical Engineering, https://engineering.purdue.edu/~yanchen/infection.html)

There are other findings that were not considered in the flow simulation. When the air vents are open, turbulence increases and the spread of viruses is accelerated. Therefore, the air vents should be closed. The spread in the longitudinal direction is also increased by people who move in the aisle. Therefore, passengers should remain as quiet as possible in the seat. The flight attendants should also move as little as possible. Even if such thoughts are correct, the spread of the droplets laden with viruses cannot be prevented, as the simulation shows.

There is also a model that could be called a "**feather model**". The idea is that the viruses are thrown out horizontally and behave like the feathers of a bird. The horizontal speed is quickly reduced and the feather falls to the ground. When the feather is in downward air - like in the aisle of an aircraft cabin - it falls to the ground faster. This is the model that the aerospace industry is trying to convey.

Against this background, what can be learned from the explanation of Dr. Nabarro of the WHO (https://perma.cc/TJ2S-FVQX): "You can significantly reduce the risk even at 1 m, since 70% of the droplets remain within 1 m."? That is of course not true. A static view is made. However, the reality is dynamic, i.e. time-dependent. The droplets and viruses do not remain in a (small) closed volume.

The "risk" mentioned by the WHO could rather be associated with the density. If a person is hit by a cloud at a distance of 1 m, the density (in arbitrary units) is 100 - 70 = 30. However, if the cloud only hits someone at a distance of 2 m, the density is 100 - 99 = 1. According to the WHO, the distance has a great influence. The factor is then 30. The simple volume model underestimates the importance of the distance compared to the WHO statement and does not make an exaggerated statement in comparison.

We make simplified models to understand more complicated issues. Some of these simple models perform well under certain conditions, others less well. The "volume model" can be used shortly after coughing or sneezing and reflects the conditions of the neighbors. The "stationary model" applies more to small floating droplets after they have already been distributed and can be used for an overall cabin analysis. The "feather model" applies to large droplets.

Boeing launched the "Confident Travel Initiative" on May 14, 2020 (https://perma.cc/3PL3-FK7R). Head is Michael P. Delaney, Vice President, Digital Transformation (https://perma.cc/BLE6-RPSH). In this context, Boeing also wants to simulate the cabin flow (https://perma.cc/78T6-LQ22), but is late in doing so. Boeing intends to model the potential spread of corona viruses in aircraft to investigate the risk of infection on board and to assure passengers weary of the pandemic that air travel is safe. "We use science as opposed to anecdotes ... [and] emotionally motivated reactions," says Delaney (https://perma.cc/78T6-LQ22). But be careful: you can have a working hypothesis in science, but under no circumstances should the result be anticipated. However, this is exactly what Boeing is doing. Boeing places the result already in the title of the project "Confident Travel Initiative". The whole thing is probably more of an advertising campaign, which is certainly of extreme importance for the aviation industry, because all lobbying is in vain if passengers do not want to get into the plane. The great importance of the advertising campaign is also evident from the good financial standing of the project. Delaney explains that Boeing's executives said to him, "Whatever you need, ask for it. You'll get it."

So much for arguments 4, 5 and 6.

The Importance of the Masks

EASA writes in its "Protocol" (https://perma.cc/MR7X-Y73R): "The wearing of medical face masks (hereinafter 'face masks') should be recommended to all passengers. ... The use of face masks should only be regarded as a supplementary measure and not as a substitute for established preventive measures such as physical distance, ..." EASA defines: "A medical face mask (also known as a surgical mask ...) is a medical device that covers the mouth, nose and chin, that is, a barrier that limits the passage of an infectious agent between hospital staff and the patient. They are used ... to reduce the spread of large breath droplets from the person wearing the face mask. Medical masks meet the requirements defined in the European Standard EN 14683 (Medical Face Masks – Requirements and Test Methods) Accordingly, it is a Mouth-Nose Protection (MNP) for the protection of others, which only helps to a limited extent because the mask does not fit tightly to the face.

An effective protection of yourself and of others is only reached with FFP (filtering facepiece) masks (also called respiratory protection mask or simply respirator). It is a type of protective mask certified by the European Union that serves to protect against particulates such as dust particles. Filtering facepiece masks (FFP1, FFP2 und FFP3) according to EN 149 (https://perma.cc/F8SG-YRBN) without exhalation valve are required. At least an FFP2 mask should be used (minimum protection 95%). Possible would also be a respirator (e.g. Dräger-X-plore-3300, Dräger X-plore 6300) as half face mask or full face mask with particle filter (labeled P). The particle filter can retain dust, bacteria and viruses. There are filter classes 1, 2 and 3. It would also be possible to use a combination filter against organic, inorganic gases and vapors ("fume event") and against particles (viruses) (https://perma.cc/AM7C-ALCE). What is important for all masks is that they fit tightly on the head.

There are a number of contradictions here. EASA recommends medical face masks according to EN 14683 – so called Mouth and Nose Protection (MNP) because, given the small distance between the seats, it is impossible to argue that a simple Mouth and Nose Cover (MNC) also called "community mask" would be sufficient. However, the MNC is also not sufficient. An FFP2 mask would be required. Furthermore, the recommendation "MNC" is in conflict with practice, because MNC are largely sold out and can probably not be procured by passengers. The German Robert Koch Institute (RKI) has therefore announced: "Multi-layer medical (surgical) mouth and nose protection (MNP) and medical respiratory masks, e.g. FFP masks, must be reserved for medical and nursing staff. The protection of specialist staff is of great interest to society as a whole" (https://perma.cc/V87Y-H8NX). The use of high-quality masks in the field of aviation would therefore be anti-social.

The airlines are free to choose how they want to implement EASA's recommendations. Lufthansa writes: "Please wear a face mask [?] during the entire flight to provide additional protection to yourself and others." (https://perma.cc/HCT4-ZSFM) or in German: "Bitte tragen Sie zum Schutz aller während des gesamten Fluges einen Mund-Nasen-Schutz" (https://perma.cc/AE5U-3NK7). According to the definition, this would be a EN 14683 mask. However, this is not explained (possibly on purpose), so that it can be assumed that passengers with Mouth and Nose Cover (MNC), so-called "everyday masks" or "community mask", will continue to board the aircraft also in the future. As such, Lufthansa adheres formally to EASA's recommendation and hands the problem of compliance or non-compliance over to the passengers. (In the mean time it has become evident that Lufthansa allows people with community masks on board.)

If the masks are removed while eating, there is no protection and the argument for an allegedly safe reduction of the distance of 1.5 m loses its the last justification. David Powell, medical advisor to IATA, answered a question about wearing the mask while eating on an airplane: "Ideally, two neighboring people should not remove the mask at the same time" (https://perma.cc/J5ZX-4JRP). This appears as a helpless attempt by IATA to explain something that cannot be implemented in practice.

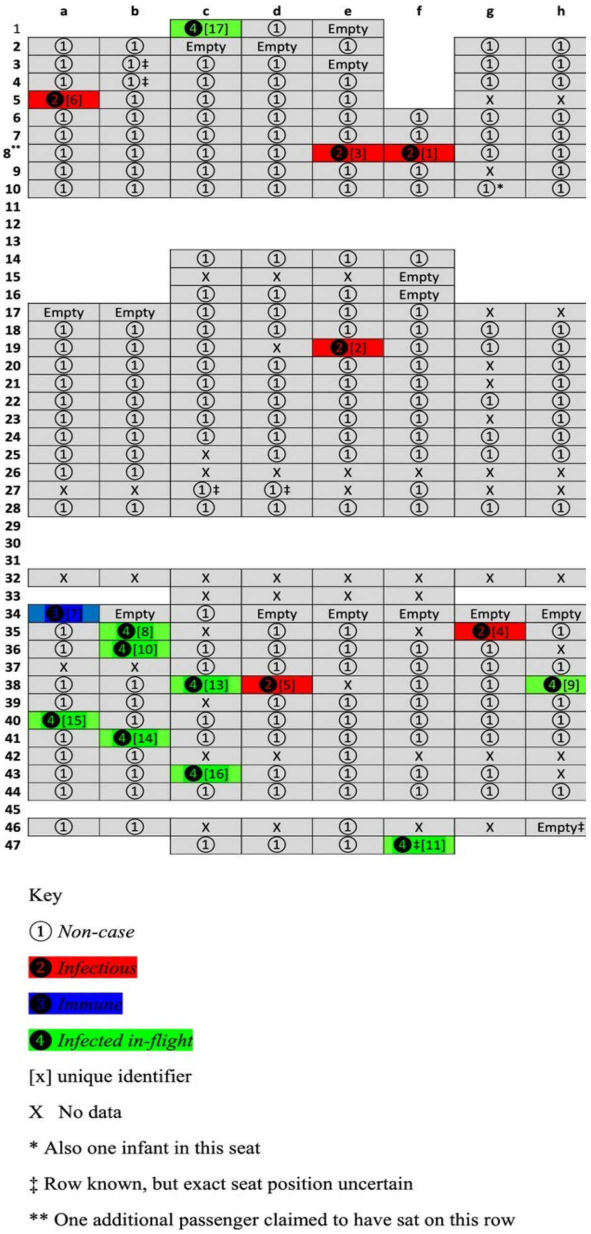
Conclusion: FFP2 masks would be necessary given the short distance in the airplane. However, EASA only recommends medical face masks (EN 14683), the MNP. The airlines are free to choose how to implement the recommendations. Both with the information on the Internet and with the application in practice it is already clear that even the already inadequate EASA recommendations are further watered down. In the end, the passenger is identified as the culprit if the MNP (EN 14683) is not purchased and used.

What Knowledge There Is about Infections in the Aircraft

The WHO made a recommendation on what to do if a person with Influenza A (H1N1) was found on board. In this case, the WHO considers every person at risk who was in the same row as the sick person, 2 rows ahead or two rows behind, to be at risk (https://perma.cc/6KBW-5KCL). An infected person then affects 5 seat rows.

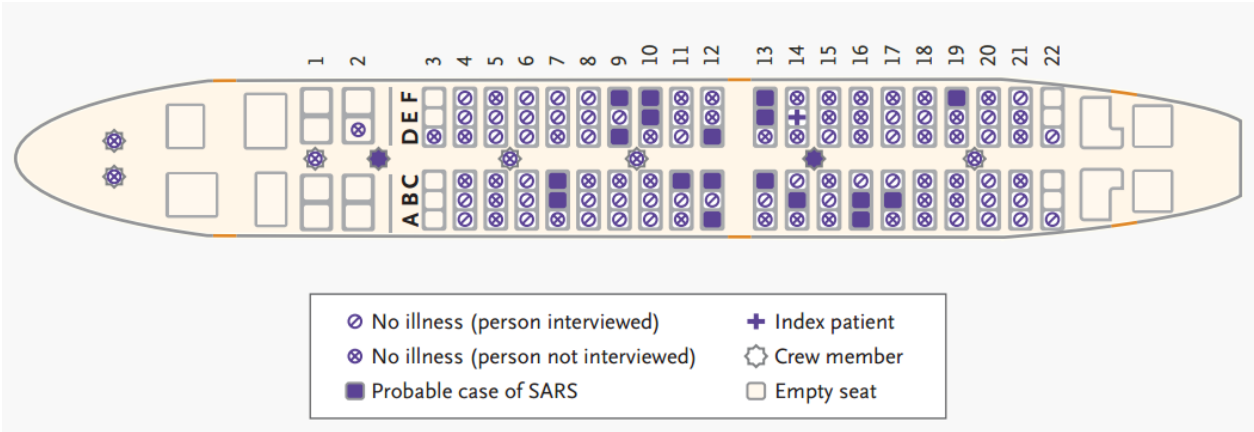
Young et al. shows in a study (https://doi.org/10.1111/irv.12181), that there is no significance for the 5 rows of seats of the WHO. A flight on April 27, 2009 from Mexico to the United Kingdom was evaluated with a Boeing 767 over 9.5 hours. A group of 238 people on board the flight was identified (86% of the passengers). Out of 6 sick people, 10 people in the group were infected with the influenza A (H1N1) virus. An infection rate, a can be calculated from the numbers with a = 0.00074 1 / h, i.e. per flight hour and per sick person present on the plane. The infected people sat all over the plane. There is no connection between the place of the sick and the place of the infected person (see picture).

Olsen et al. describes a flight from Hong Kong to Beijing on March 15, 2003 (https://doi.org/10.1056/NEJMoa031349). It was a 3 hour flight with a Boeing 737-300. 120 people were on board. A person who had SARS-CoV infected 20 people on the flight (a = 0.056 1 / h). Two infected people sat 7 rows of seats in front of the sick person, one infected person sat 5 rows of seats behind the sick person (see picture).



Boeing 767 on the flight from Mexico to the United Kingdom over 9.5 hours. Another infected person is not shown in the seating plan.

(https://doi.org/10.1111/irv.12181)



Boeing 737-300 on the flight from Hong Kong to Beijing over 3 hours. "Index patient" is the sick person at seat 14E (https://doi.org/10.1056/NEJMoa031349).

Yan et al. (https://doi.org/10.1101/2020.03.28.20040097) writes about a flight from Singapore to Hangzhou on January 23, 2020. A sick person with COVID-19 infected 12 passengers on the flight with 325 passengers and crew members over 5 hours (a = 0.0074 1 / h).

Eldin et al. (https://doi.org/10.1016/j.tmaid.2020.101643) reports an infection with SARS-CoV-2 on an Air France (AF775) flight from Paris to Yaoundé with a stop in Bangui, (Central African Republic) on February 24, 2020. It could only be worked out here that on this flight one person infected another person with SARS-CoV-2. Other possible infections are unknown.

At this point it is not the goal of submitting a complete research on the topic. Cases of COVID-19 infection in aircraft have been found. Infections with other viruses are also reported in the literature. This disproves the view of the aviation industry, which wants to persuade passengers that virus infections on board are not possible. These observations are important here: a) The **argument 7** "There has not been a single case known across Europe ..." from the BDL is selective and obscures the facts. It may actually be the case that no flight with COVID-19 infection was found in the internal BDL research within Europe. But then the BDL has (as can be seen from the wording and this short research), swept all other cases under the rug. Research by IATA is of a similarly low scientific level (https://perma.cc/4MMS-KX5J). b) It should be noted that shortly after the appearance of COVID-19, air traffic was largely discontinued and is only now slowly starting up again. Due to the circumstances and also because of the delays in the scientific publication process, it is extremely unlikely to find scientific articles on the topic at this point. Only the future after the start of aviation will make the facts visible and even that is unlikely, because usually it is unknown if sick people are on board and without any evidence and with limited staff, national health organizations will not start a time and labor intensive investigation.

In this context, another contradiction can be pointed out. In the recommendations of EASA and ICAO, a distinction is made between a) the distance between passengers (from whom one or more passengers may have a certain (low) probability for COVID-19 and b) the distance between a proven sick or symptomatic person on board and other passengers. In case a) no minimum distance is required. In case b), a distance is considered necessary (despite an air conditioning system on board, which allegedly has the virus problem under control). The recommendations of the ICAO are: "Separate the sick person from the other passengers by a distance of at least 1 meter (usually about two free spaces in all directions, depending on the cabin design)" (https://perma.cc/KS8L-FE9S). EASA's recommendation is similar: "An isolation area should be defined in which, if possible, two (2) rows of seats remain free in every direction around the suspect passenger" (https://perma.cc/7NHJ-VHAX).

As always, such considerations are ultimately a question of probability and financial circumstances. If the person sitting next to you is only likely to be ill and the airlines would run into financial difficulties if a minimum distance would be demanded, then a requirement for minimum distance is waved. Alexandre de Juniac, IATA: "The point is to see what the [financial] damage is and that it [the free middle seat] does not bring an improvement in safety" (https://perma.cc/J5ZX-4JRP).

So much for argument 7.

Flying Is Safe! Why This Doesn't Apply Holistically in Times of the Corona Pandemic

If someone says: "Flying is safe even in Corona times", then this statement has the level of "The pensions are safe". There are no published calculations or estimates of the health hazards posed by SARS-CoV-2 when flying. For that reason, an attempt of such health hazard assessment is made below.

Flying during the pandemic can lead to a second wave of infection (https://perma.cc/4VBE-Q6AJ) and the infections would spread quickly all over the world (https://doi.org/10.1016/j.jmii.2020.03.026), like in the beginning of the pandemic. The global dimension may not matter to the individual traveler. But the traveler is also endangering himself/herself. Let's first see why flying is safe and how the calculations for such a statement works. From this it can be derived how to proceed with a corresponding assessment of COVID-19 when flying.

You can say "flying is safe" because there is a basis for this statement. We have safety when the actual risk is less than the risk that we are willing to take. The risk results from a comparison of the expected effects (death, injury, ...) and the respective probability of these effects occurring. Less dramatic effects are more likely to occur. Such a (generally recognized) comparison of effects due to technical (!) failure and the probability of occurrence is contained in the certification regulations for aircraft. Their verification is part of the aircraft certification. According to this, an aircraft system may not fail more often than once in a billion flight hours (10^{-9} 1 / h) for technical reasons. The calculation assumes that there are 100 aircraft systems on board (which is insignificant for certification). Hence, due to the design of the aircraft, it must be expected that aircraft will crash every 10 million flight hours for technical reasons. Before Corona we had about 25,000 larger passenger planes in service worldwide, which are in the air about 30% of the day. If these planes fly for a year and two planes crash for technical reasons, we would get 33 million flight hours per crash. In this scenario, passenger aviation would still be 3 times better than required. Theory and practice fit together here. See also: http://handbuch.ProfScholz.de, Section 1.5.

What about your own risk of getting COVID-19 from a flight and dying from it? The different "effects" (illness or death) would have to be considered individually. Death presupposes the disease and is linked to it via lethality. We start with the medical basics.

How COVID-19 Risks of Flying Can Be Estimated and Compared

A certain minimum number of viruses that have to be inhaled are required to become infected. This is the so-called threshold dose, n_S. "The influenza virus appears to require several hundred copies of the virus, with the threshold dose being subject to large individual variations." "Coronavirus is also likely to have an individual threshold dose, but precise data on this is still lacking. There is also data that relates the viral load to the severity of the disease." (https://perma.cc/KS6R-XSZ4).

With every breath we inhale 0.5 l of air when we are at rest. This volume is called the tidal volume, V_T. At a respiratory rate, f of 15 breaths per minute, this is a volume of 7.5 l per minute. This volume together with the density of the viruses in the air yields the number of viruses inhaled per minute. For the density I choose (likewise as above) the designation ρ (rho). It is the number of viruses per cubic meter. The number of inhaled viruses per minute multiplied by the duration of the flight, t gives the number of inhaled viruses: $n = V_T * f * \rho * t$. The number n of inhaled viruses is therefore a measure of the health risk. The health risk can be understood as the likelihood of infection combined with the severity of the disease. Let us take two scenarios 1 and 2. For the comparison of the scenarios only the ratio of the inhaled viruses, n is important: $n_1 / n_2 = (\rho_1 / \rho_2) * (t_1 / t_2)$. The tidal volume, V_T and the respiratory rate, f do not enter as long as the respiratory breathing is involved in both scenarios. The risk to health increases with the duration of the flight and the virus density. The ratio of virus density has already been estimated with the volume model and can be used in the equation. The equation is then $n_1 / n_2 = (d_2 / d_1)^3 * (t_1 / t_2)$. The equation says e.g. that you can fly 8 times as long with the same health hazard if the distance is doubled.

A second approach can be made based on the concept of the "stationary model". However, the values for the calculation are not obtained from the flow simulation, but from publications on flights on which passengers were infected - as shown in the text above. Infection rates of a = 0.00074 1 / h, a = 0.0074 1 / h (10 times more) and a = 0.056 1 / h (76 times more than the first value) were found there. In order not to cause panic, the lowest contagion rate found of a = 0.00074 1 / h is used. This may also account for two other facts: a) an occasional flight with a COVID-19 person on board without anyone getting infected and b) the reduced infection rate due to community masks.

The next step is to determine the probability that a person with COVID-19 is sitting on the plane. The number of diseased people in a country, *D* is the sum of all cases, *C* subtracted by those who have already recovered, *R* and subtracted by those who passed away, *P*. $D = C - R - P$. The data are disseminated on the Internet and in the news (Germany, in May/ June 2020: $D = 17000$). The real rate of diseased people in a country, *d*, due to underreporting, *U* greater by a factor of $U = 16$ (https://perma.cc/LW7M-KX3P). *I* is the number of inhabitants (Germany: $P = 83$ million). So $d = D * U / I = 0.0033$. So 0.33% of Germans were suffering from COVID-19. Screening is used to ensure that no diseased person comes on board the aircraft. This is only possible to a limited extent. About 30% of the sufferers have no symptoms (manifestation index: 70%, https://perma.cc/LW7M-KX3P) and fall directly through the safety net and are on board. On the outward flight, half of the people with symptoms may not want to travel, and half of those willing to travel may be stopped by deterrence or discovery. On the return flight, many sick people (presumably: 90%) will find ways and means (antipyretic medication, cough suppressant, ...) to get back home with the already booked plane. Based on these figures, a small calculation shows that, in the end, 70% of those who wanted to take a flight will travel despite and with COVID-19. This security gap, *s* arises because of a lack of manifestation, desire to travel, failure of the safety net and / or the need to return.

The probability that a person with COVID-19 is on board is $b = d * s * n_{PAX}$. n_{PAX} is the number of passengers on board (typically: 200). With 200 passengers on board, the probability is $b = 46\%$. It can therefore be assumed that a person with COVID-19 will be present on an aircraft with 430 passengers on board. The probability that you will sit in the WHO danger zone (5 rows of seats) together with a COVID-19 person is about 7% for narrow-body aircraft

($n_{PAX,\text{WHO}}$ = 5 * 6 = 30). In the event that you have two neighbors (in the seats left and right) (you are in the middle seat) on your flight, the probability is 0.46% that you have a COVID-19 neighbor.

The probability per flight hour that a person ("me") on board is getting infected with SARS-CoV-2 is $i = d * s * n_{PAX} * a$. With the numbers given here, i = 0.00034 1 / h = 1/3000 1 / h. In the case of a 10-hour flight (t = 10 h), the probability of infection with SARS-CoV-2 would then be $i * t$ = 1/300. Depending on the still very little known infection rate, the probability could also be significantly higher.

The probability per flight hour that a person ("me") gets infected with SARS-CoV-2 on board and subsequently dies from it, m depends on the real lethality, L of COVID-19. The lethality calculated from the case fatality rate (which is slightly underestimating) is according to the German Robert Koch Institut, L_{RKI} = 0.047 (https://perma.cc/LW7M-KX3P) and is divided by the underreporting: $L = L_{RKI} / U$ = 0.00294. The probability per flight hour is $m = i * L$ = 1/1000000 1 / h or 1 in a million.

Thus, both the probability of getting infected with COVID-19 from a flight, i per flight hour, and death, m are more likely by a factor of 10 than injury or death due to technical failure of the aircraft. If it were about technology instead of COVID-19, the planes shouldn't fly! Nevertheless enough passengers will probably take off because they are ready to take the risk or have been manipulated by the misinformation of the aviation industry in their decision making.
So much for argument 8.

Why Travelers May Not Arrive at Their Destination Due to the Unclear Legal Situation

According to the new recommendations of EASA ("Protocol", Annex 2), air travelers must state their state of health. In order to do so, they must indicate:
O *I have been diagnosed with COVID-19 at any time during the 14 days prior to my flight.*
O *I have had any of the COVID-19 relevant symptoms (fever; newly developed cough; loss of taste or smell; shortness of breath) at any time during the 8 days prior to my flight*
O *I have been in close contact (e.g. less than 2 meters for more than 15 minutes) with a person who has COVID-19 in the 14 days prior to my flight.*
O *I am required by local or national regulations to be in quarantine for reasons related to COVID-19 for a period that includes the date of the fight.*

It can be assumed that the flight will be refused if one of the statements is made. However, if passengers give false information (e.g. fever or cough becomes apparent at the airport), then the flight will also be denied.

It is interesting that the contact is given here as "less than 2 meters for more than 15 minutes". What applies to passengers on the ground could also apply to the airline in the air. Furthermore, no information can generally be given on the third statement because many COVID-19 sufferers are not recognizable as such. A statement would only be possible about: "in close contact ... with a person about who I know he / she had COVID-19."

EASA also describes the possibility of temperature measurement for passengers, but also shows the inaccuracies and problems of temperature measurement. It can therefore be assumed that there will be no temperature measurement of air passengers in Germany. It could be different abroad. A passenger who then comes to the airport with fever (more than 38 °C) (no matter what the cause of the fever) could be denied the flight. It should be noted that the temperature measurement - like every measurement - is of course faulty. According to EASA ("Protocol", Annex 1) it must be expected that between 1% and 25% of the measurements indicate fever, even though there is no fever (false positives). It makes no sense to get angry because of the fact that you missed the flight. Passengers who do not follow the instructions are referred to as "Unruly Passenger" and are handed over to the security authorities at the airport.

How to Fly If You Have To

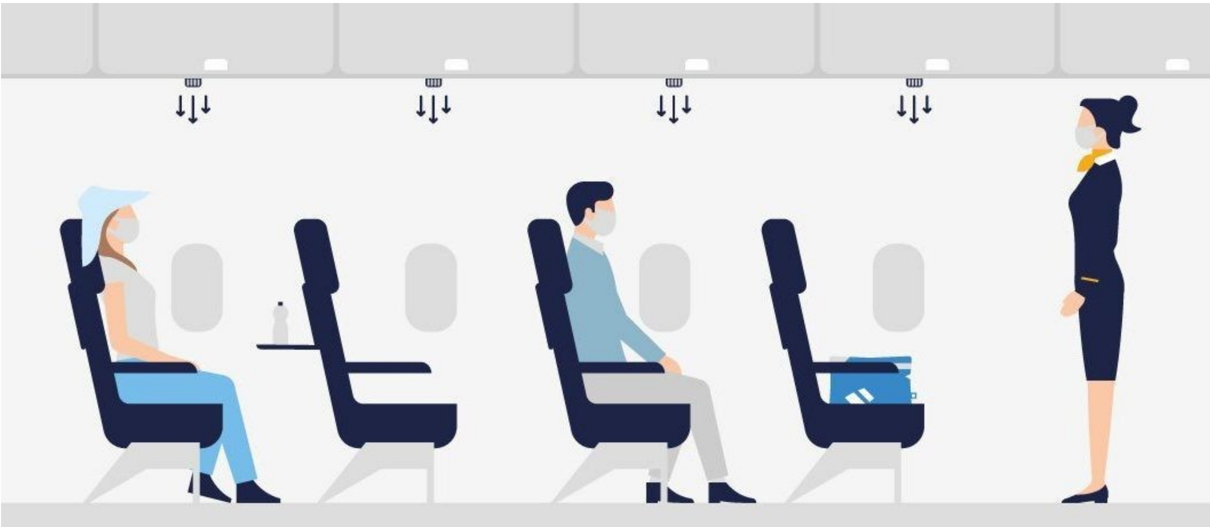
If you don't really want to fly, but you do have to, these tips could help:

- Book a seat in the last row by the window.
- Stay in the seat for the entire flight, do not walk around.
- Close air vents.
- If available, use an FFP2 mask or a respirator with at least a P filter.
- Much more likely than COVID-19 is that you get sick for some other reason while on vacation. Many travelers have a small first-aid kit with them or get the medication aboard. Symptoms can also be combated with medication.

Where the Ethical Problem Lies

It is the whole way of doing things that is not valid:

- Sharing the burden between passengers and airlines is not balanced. EASA and ICAO only made recommendations to airlines. Airlines can do whatever they want with these recommendations and decided to waive several or all recommendations. However, passengers are bound by the instructions of the airlines (e.g. to sit close to strangers) and have to face the danger to get infected according to the risk assigned to them by the airlines.
- Reasoning of the aviation industry is misleading. The "facts" are handpicked.
- Promotional videos show a situation beyond reality: almost empty airports and planes (examples are https://youtu.be/fSLQ0hj3eZg, https://youtu.be/D1rdX-24NrM). In the airplane it looks as if every second row is kept empty (see picture).
- Aviation organizations (EASA, ICAO) bow down to the aviation sector with its companies and lobby. Decisions are made in face of the financial pressure of the industry. Consumers are deceived because they perceive the information provided by official aviation organizations as objective, but in reality the information is anything but objective.
- Passengers decide about action (and spending money) in a way differently from what they would have decided based on better information.
- Health is our greatest asset. Those who deprive others of their health no longer operate in the field of ethics, but in the field of law.



Lufthansa advertises (https://perma.cc/UQ59-AZ3F) under the heading "#WeCare – so you can fly with no worries". It appears that every second row of seats is kept free (or at least only half of the cabin is occupied). Air flows out of the air vents. This is not in line with EASA's recommendation (https://perma.cc/MR7X-Y73R). Background: The aim is to keep the turbulence of the air in the cabin as low as possible in order to avoid the distribution of possible viruses over the length of the cabin as much as possible.

Which Means of Transport May Be Better

You have a clear advantage in your own car, on a bike or on foot in nature. However, this text is about public transport. If a connection by long-distance bus or train to your destination is offered at all, both are unfortunately not an alternative to an airplane. The required social distance is also clearly undercut in these modes of transport. Here, too, the operators have spoken out against leaving seats empty. Nevertheless, ground-based transportation has an advantage over flying: If the current situation becomes unbearable because the person next to you just does not stop coughing, you can get up on the train and go into another wagon. There is always another option in ground-based traffic: Just get off at the next stop! Even if you had a parachute with you, it would not be possible to use it in a passenger plane. In the passenger plane, you lose more of your autonomy than in other modes of transport.

Aircraft Design and Systems Group (AERO) is the research group for aircraft design and aircraft systems in the Department of Automotive and Aeronautical Engineering at Hamburg University of Applied Sciences. AERO's aim is to guide research assistants to cooperative dissertations and to conduct projects in research, development and teaching.

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