Transmission of SARS-CoV-2 on Aircraft

Summary

- There are 8 case reports of in-flight transmission events, with varying levels of evidence.
- It is often difficult to determine whether transmission occurred during a flight, or pre- or post-boarding and whether transmission was direct (aerosol/droplet) or indirect (fomite)
- Factors including proximity to index patients, stage of illness, ventilation, density of passengers on board and duration of the flight all make a considerable difference to attributable risk.
- There are interventions that can be used to reduce the risk of in-flight transmission, however no one solution that negates risk completely

Air travel for both business and leisure has become increasingly convenient, available and affordable [1] and led to a large increase in global mobility. Subsequently, the transmission of infectious diseases during travel are an important public health issue [2]. Although infrequently reported and often difficult to evidence respiratory pathogens, like SARS-CoV-2 may be directly or indirectly transmitted from one passenger to another during a flight (inflight transmission). This is because of factors including limited ventilation, a high density of passengers and long exposure (flight duration, 1 to ~17 hours) [3]. The transmission of infectious agents on aircraft is not a novel discovery and previously a wide range of agents including SARS-CoV-1, tuberculosis and influenza have been evidenced to be transmitted during a flight [4-6].

SARS-CoV-2 can be spread through droplets and aerosols [7], therefore in an aircraft it is possible that the virus may be spread by either indirect or direct transmission. Given that flights are still flying globally between multiple COVID-19-affected countries and that border screening is inefficient [8], it is essential to determine if, and how, in-flight transmission of SARS-CoV-2 can occur.

It is difficult to ascertain the exact moment of viral transmission due to multiple confounding variables. Therefore proving beyond reasonable doubt that transmission occurred in-flight can be difficult. However, there is peer-reviewed evidence of inflight transmission (of SARS-CoV-2) either where it is highly likely that transmission occurred inflight and or where it is probable.

Case Reports of In-flight SARS-CoV-2 Transmission

To-date, there are 8 reports of in-flight transmission with varying levels of evidence. Below is a summary of each case report including contextual details. Table 1 shows a basic comparison of the below information.

Bae *et al* (2020) – direct evidence

Bae *et al* provides evidence from a cohort study of asymptomatic transmission of SARS-CoV-2 on an aircraft [9]. In March 2020, 310 passengers boarded an 11-hour evacuation flight from Milan, Italy to South Korea. The flight was under strict IPC measures recommended by the Korean Centre for Disease Control and Prevention (KCDC) and the WHO. Upon arrival in Milan airport physical examinations, medical interviews, and body temperature checks were conducted resulting in 11 symptomatic individuals being prevented from boarding. N95 respirators were provided for passengers and the 2m

social distancing guideline was maintained prior to boarding and during the flight. Most passengers wore the N95 respirators except when eating/drinking or using the toilet. Upon arrival the 299 asymptomatic passengers were placed in a government quarantine facility for 14 days and all passengers were kept apart. They were assessed twice daily for an increased temperature or other symptoms, RT-PCR tests were also conducted on day 1 and day 14 of quarantine. Six/229 passengers tested positive on day 1 and were transferred immediately to hospital, none of the six individuals went on to develop symptoms and were therefore asymptomatic. On the day 14 test a 28-year old previously healthy woman tested positive. During the flight she wore an N95 respirator except when using the toilet, the toilet was also used by other passengers including one of the asymptomatic individuals, who during the flight was seated 3 rows away from her. As the woman self-isolated for 3-weeks prior to the flight in her home and did not use public transport to get to the airport it is highly likely that her infection was transmitted in the flight, via indirect contact with an asymptomatic patient [9].

Choi *et al* (2020) – direct evidence of infection

Choi *et al* (2020), on behalf of the CDC provides strong evidence for inflight transmission of SARS-CoV-2 to at least two individuals [10]. From public records and data from the centre for health protection Hong Kong (CHP) the researchers identified a cluster of four cases (patients A-D) associated with a commercial flight that departed from Boston, USA, on March 9 and arrived in Hong Kong on March 10, 2020. The flight was 15 hours long and carried a maximum of 294 passengers. The cluster was made up of two passengers and two crew members, they did not fulfil the criteria for SARS-CoV-2 testing upon arrival, results of RT-PCR conducted in local healthcare settings within 5–11 days of arrival were positive. Patients A and B were a married couple and they both developed symptoms the day of arrival in Hong Kong. Patient C was an asymptomatic 25-year-old male identified through contact tracing as a close contact of patients A and B; and patient D was a 51-year-old female Hong Kong–based flight attendant on the same flight. To provide evidence of transmission between the four individuals the viral genomes were sequenced - the near full-length viral genomes from all 4 patients were 100% identical and phylogenetically grouped. Other than these 4, none of the 189 viral sequences collected from samples in Hong Kong (January 21–May 12) belong to this phylogenetic group. Given the epidemiological information and sequencing results, it is most likely that one or both of passengers A and B contracted SARS-CoV-2 in North America and transmitted the virus to flight attendants C and D during the flight as the only location where all 4 persons were in close proximity for an extended period was inside the airplane [10].

Chen *et al* (2020) – highly probable transmission

A flight in January 2020 departed Singapore Changi Airport and landed at Hangzhou Xiaoshan Airport in China [3]. There were 335 passengers and 11 crew members on board with a total seat occupancy of 89%. Those on board were categorised into group A - individuals who had originally departed from Wuhan; and group B - those with no travel history to Wuhan. Before departing the aircraft, all passengers were required to have a temperature check and following departure, all passengers were interviewed (face-to-face or by telephone) using a standardized questionnaire. As there was a large number of travellers from Wuhan, and two individuals presented with a fever and upper respiratory infection symptoms, all passengers were regarded as close contacts and had to undergo isolation and medical observation for 14 days. Passengers with symptoms were sent immediately to hospital, and group A and B were both sent to separate hotels. Initially the 10 crew members were transferred to hotel B for two days and then flown home, none of them contracted SARS-CoV-2. A total of 16

passengers, 10 symptomatic and 6 asymptomatic were diagnosed, an overall attack rate of 4.8% (16/335). Two of these were infected before taking the flight because they were symptomatic before departure. Epidemiological analysis of the other 14 positive cases showed that only one, case 16, was likely to have caught SARS-CoV-2 inflight. This is because he had no history of travel to Wuhan, sat in close proximity to cases 7, 8, 11 and 12 and wore his mask loosened below his nose. However, as no genomic analysis was done, and no swabs or air samples were taken onboard there is no direct evidence [3]. Therefore the research presents one case of highly probably inflight transmission.

Khanh *et al* (2020) – highly probable transmission

Another report published by the CDC investigated a cluster of cases among passengers on a 10-hour commercial flight from London, UK, to Hanoi, Vietnam, on March 2nd. They traced 217 passengers/crew and interviewed, tested, and quarantined them. In total there were 16 persons who tested positive for SARS-CoV-2. Twelve/16 (75%) were passengers seated in business class along with the only symptomatic person (attack rate 62%). Seating proximity was strongly associated with increased infection risk (risk ratio 7.3, 95% CI 1.2–46.2). Epidemiological investigation found no strong evidence supporting potential SARS-CoV-2 exposure either before or after the flight for any of the additional persons with flight-associated cases other than having travelled on the same flight as case 1 [11]. Further to this, until the departure date, only 23 COVID-19 cases had been recorded in the UK and community transmission in the UK was not yet widely established, making the presence of multiple persons on board incubating the illness unlikely. The main limitations of this research are the absence of genomic analysis and the incomplete information of passenger movements and behaviours whilst on board. However, the study provides evidence that the risk of in-flight transmission of SARS-CoV-2 during long flights is real and could potentially cause large clusters even in business class–like settings with spacious seating arrangements [11]

Yang *et al* (2020) - probable transmission

Upon arrival in China, from Singapore, on January 23rd, all passengers were screened for COVID-19 symptoms. One male (case 1), with no fever or respiratory symptoms at departure screening presented with a fever of 38.1 ^{o}C upon arrival and received a positive SARS-CoV-2 result 5 hours later, he did not wear a mask throughout the 5-hour flight. Subsequently the crew and rest of the passengers were placed under isolation and routine medical check for 14 days at local hotel(s). A total of 11 passengers tested positive, two of which were not interviewed, the remaining 313 passengers and all staff did not test positive and were released from isolation. To give a crude estimation of the risk of in-flight transmission the researchers calculated the numbers of persons diagnosed with COVID-19 divided by the total number of persons on this flight, the result is 3.69% (12/325). However, the true risk is likely much higher due to the presence of undetected asymptomatic individuals [12].

Hoehl *et al* (2020) – weak evidence of in-flight transmission

A case series study assessing a commercial flight from Tel Aviv, Israel to Frankfurt, Germany on March 9th 2020 documents 102 passengers, of which 24 were members of a tourist group [13]. No member of the group had received a diagnosis of COVID-19 before the flight, and no measures to prevent transmission (e.g., wearing of masks) had been applied. The flight duration was 4 hours 40 minutes. Due to a known contact 7 days previously, the 24 members were tested upon arrival: 7 tested positive for SARS-CoV-2 RNA in a throat swab sample on arrival. Of these 4/7 were symptomatic during the

flight, 2/7 presymptomatic, and 1 remained asymptomatic. A total of 71 of the other 78 passengers (91%) who had been exposed to the group on the flight completed an interview and serum samples were obtained from 13/71. From the epidemiological and serological analysis they discovered two likely SARS-CoV-2 transmissions on this flight, with 7 index cases. However, the evidence for in-flight transmission is weak and the transmission may have also occurred before or after the flight [13].

Pavli *et al* (2020) – probable transmission

Pavli *et al* (2020) analysed international passengers arriving to or departing from Greece from February 26 through March 9, 2020 [14]. If an index case had travelled within 4 days of symptom onset or whilst being symptomatic, they underwent contact tracing. The contact tracing focused on 'close contacts' e.g. passengers sat <2m ?from a case >15minutes, including all passengers seated within two seats (all directions) and all crew members or personnel who has close contact. Contact tracing was carried out for 18 international flights within the time period, in these flights there were 21 index cases and a subsequent 891 close contacts traced. Of the 891 contact traced cases, 4 passengers and 1 crew member developed laboratory-confirmed infection (3 with COVID-19 and 2 with asymptomatic infection); they travelled on the same flight with two COVID-19 cases. These five cases demonstrate probable in-flight SARS-CoV-2 transmission [14].

Eldin *et al* (2020)- ?highly probable transmission

Eldin *et al* (2020) reports a case of COVID-19 most likely acquired during a flight from Bangui, Central African Republic to Paris, France [15]. A male in his 50s travelled to the Central Africa Republic (CAR) from February 13th to February 25th for business and he gave presentations for 6 days, to a public of about 30 resource directors of several CAR ministries. Upon his return to France, he consulted his general practitioner, in the Marseille area on March 6th, 2020, because of fever, headache and cough evolving since February 29th. Given the average incubation time range of COVID-19, the researchers excluded that the patient acquired COVID-19 in France before leaving to CAR. Furthermore, only 15 documented cases were identified in France before the patient travelled to CAR none of which was documented in Marseille where the patient lives. Transmission in France on return, between February 25th and 27th, with a short incubation time was considered possible, but unlikely given that no local circulation was documented in Marseille area. The most probable place of exposure was therefore suspected to be in CAR, but epidemiological investigation showed none of his contacts in CAR developed any symptoms. Furthermore, the first confirmed case of COVID-19 in CAR was identified on March 8th only after the patient returned to France. In contrast, the patient (which patient) was on the same flight from Paris to Yaoundé with a stopover in Bangui with an individual who was later diagnosed with SARS-CoV-2. Therefore, the patient likely caught SARS-CoV-2 whilst on the plane [15].

Table 1: Summary table of the 8 case reports described above.

Author	Flight Duration and Route	Flight Size	Number of Index Cases	Number of Secondary Transmissions	Level of Evidence (e.g. direct, probable, highly likely)	Contextual Details
Bae *et al* (2020)	11 hours, Italy – South Korea	299 boarded. Originally 310 passengers - 11 symptomatic individuals were prevented from boarding	Six passengers tested positive on day 1 of quarantine	One passenger tested positive on day 14 of quarantine	Direct evidence – the passenger self-isolated for 3-weeks prior to the flight and did not use public transport	N95 respirators provided 2m social distancing
Choi *et al* (2020)	15 hours, Boston, USA – Hong Kong	Maximum 294	Two passengers developed symptoms upon arrival	Two, one passenger and one flight attendant	Direct evidence - near full-length viral genomes from all 4 patients were 100% identical and phylogenetically grouped	The only location where all 4 persons were in close proximity for an extended period was inside the aeroplane
Chen *et al* (2020)	~9 hours, Singapore – China	335 passengers, seat occupancy 89%	Sixteen passengers, 10 symptomatic and 6 asymptomatic	One	Highly Probable	No history of travel to Wuhan, sat in close proximity to cases 7, 8, 11 and 12. Mask worn loosened below the nose. No genomic analysis, swabs or air samples were taken

Khanh *et al* (2020)	10 hours, London – Vietnam	217 (incl 16 crew)	One	Fifteen	Highly Probable	12/16 (75%) were passengers seated in business class along with the only symptomatic person. Epidemiological analysis found no other likely exposure.
Yang *et al* (2020)	5 hours, Singapore – China	324	One, fever upon arrival and tested positive, did not wear a mask	Eleven	Probable	The clustering of illness onset around 3 days in these patients is consistent with the expected incubation period of COVID-19. There was no recognized exposure history within 14 days before travel
Hoehl *et al* (2020)	5 hours Tel Aviv, Israel - Franfurt, Germany	102	Seven, 4/7 symptomatic, 2/7 resystematise, 1/7 asymptomatic	Two	Probable	No masks worn. Due to a known contact 7 days prior the 24 members were tested upon arrival. From the epidemiological and serological analysis they discovered 2 likely SARS-CoV-2 transmissions on this flight
Pavli *et al* (2020)	N/A, international	18 International Flights	Twenty-one	Five, 4 passengers and 1 crew member	Probable	

	passengers arriving to or departing Greece over a 14 day period			(Of the 891 contacts traced cases).		
Eldin *et al* (2020)	Bangui, Central African Republic to Paris, France	N/A	One	One	Probable	Epidemiological investigation ruled out likely exposure before/after the flight. One leg of the flight they were onboard with an individual whom later tested positive.

Reducing the Probability of Inflight Transmission

Masks and Face Coverings

From March 1 to March 31, 2020, a total of 130,000 passengers arrived at Beijing International Capital Airport on ~830 international flights, an average of 156 passengers per flight. Zhang *et al* (2020) screened 4492 (3.4%) passengers and crew with suspected COVID-19 infection arriving in Beijing airport and found 161 laboratory-confirmed cases of SARS-CoV-2 [1]. Of these, during the flights 121 patients were symptomatic and 40 asymptomatic. Of 830 international flights, 94 (11·2%) carried confirmed cases and the number of cases per flight ranged from 2 to 11. Epidemiological investigation found that all but two confirmed cases had no known exposure to a suspected or confirmed case prior to boarding the respective flights. Assuming that these two patients were infected while in the aircraft, the overall attributable risk for SARS-CoV-2 on aircraft would be 0·14%. Furthermore, there were no laboratory-confirmed secondary cases, interviews suggest that the universal use of face masks on the flight, together with the airplane's ventilation system, likely prevented all secondary cases of COVID-19 [1].

After disembarking the Diamond Princess cruise ship and receiving at least one negative SARS-CoV-2 RT-PCR test) 11 passengers boarded a small repatriation flight from Japan to Israel [16], see figure 1. Four days after disembarking two individuals tested positive for SARS-CoV-2 meaning they acquired the virus before boarding and were likely infective during flight however, both of them remained asymptomatic. All passengers on board were told to wear surgical masks and to replace them every 3 hours, a few were using FFP2 masks instead. During the 13.5 hours flight, the passengers were allowed to take off masks for eating and drinking and move freely throughout the cabin.

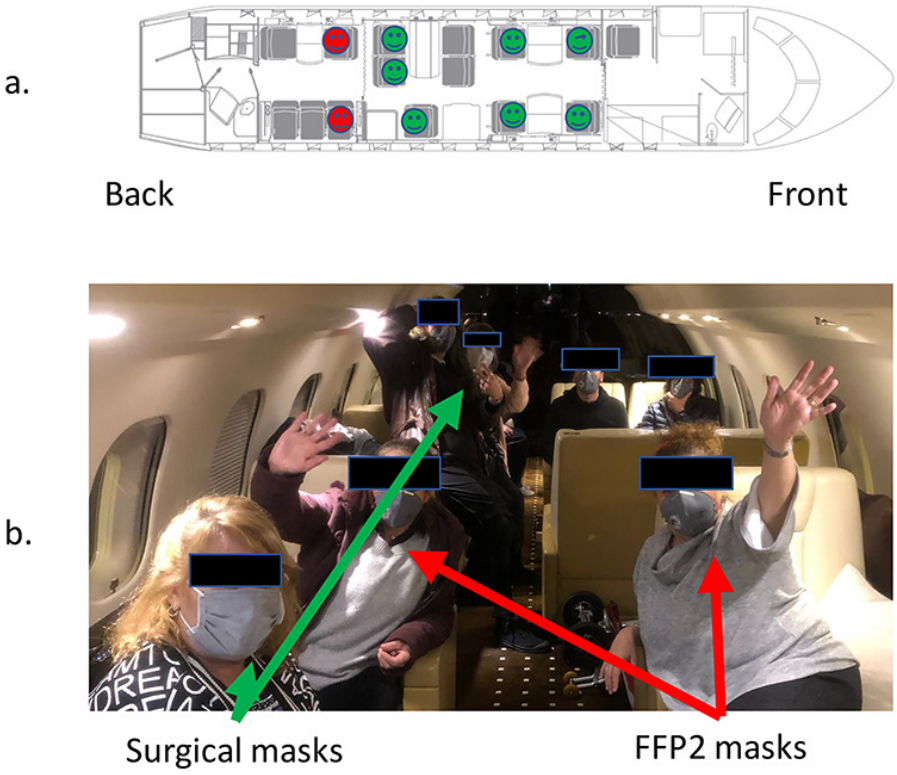

Figure 1 (a) Interior of aircraft and sitting of passengers. The positive (red) passengers were in the back part of the aircraft wearing FFP2 masks. Negative are marked with green and crew with yellow. (b) Surgical masks used by passengers are demonstrated by green arrows, and red arrows shows FFP2 masks [16].

The research by Zhang *et al* (2020) and Nir-Paz *et al* (2020) suggests that the risk of inflight SARS-CoV-2 transmission is low, especially when wearing face coverings or high standard masks e.g. N95. However it is important to consider the practicality of ensuring all passengers wear masks, especially ones of higher quality and cost. As most commercial flights are a minimum of one hour, individuals will need to remove their masks to eat and drink and further to this many individuals report finding masks uncomfortable and subsequently do not wear them properly e.g. under the nose. Even if the assumption is made that all individuals wear their mask correctly there is still a proportion of people who are exempt from wearing a mask for e.g. children (<6) or adults with medical conditions. Therefore, masks are not a viable solution on their own.

Cabin Ventilation

Most commercial aircrafts recirculate 50% of the air pumped into the passenger cabin for improved control of cabin circulation, humidity, and fuel efficiency [2]. It is favourable that the air circulation within a cabin is laminar and therefore this can help prevent disease transmission [1]. There have been multiple studies that demonstrate improved ventilation systems for aircrafts. You *et al* (2018) suggests that using personalised ventilation systems can help mitigate infection risk by supplying clean air, at a lower temperature than the cabin air, from individual supply units under the seat in front. The buoyancy force from the passenger's body would generate a thermal plume that can bring the clean air from to the breathing zone of the passenger and move the contaminated air breathed out by the passenger to the upper part of the where it could be extracted at the ceiling level [17]. However, the research and engineering of such systems do not provide a cheap or timely way to reduce risk and

increase air travel during the pandemic and the risk of transmission when the passenger is out of their seat or boarding/departing the plane is not reduced.

Social Distancing

Social distancing is an effective way of reducing the risk of SARS-CoV-2 transmission in multiple settings [18]. Some airlines have adopted a 'middle seat free' seating plan to improve this but there is no legislation to ensure this. In addition, social distancing does not negate the risk of indirect transmission of SARS-CoV-2. Currently, the CDC recommend contact tracing 2 rows in front and behind any symptomatic cases However, for both SARS-CoV-1 and influenza, approximately 50% of airplane transmission occurred beyond these rows [19].

Fomites and Environmental Cleaning

The role of fomites on aircrafts surfaces such as tray tables and toilets remain unknown. However, as previously discussed, on a 10-hour commercial flight from London, UK, to Hanoi, Vietnam it is highly probable that 15 passengers onboard contracted SARS-CoV-2 from one symptomatic individual [11]. Three of these patients were sat in economy, away from the symptomatic individuals who was seated in business. As cabin crew travel throughout classes during the flight it is possible that they acted as a vector for the indirect transmission of fomites. On a practical level, many budget airlines keep prices low by implementing minimal time and cleaning between fights <1 hour. As SARS-CoV-2 has shown to be viable on plastic/stainless steel surfaces for up to 72-hours [20] many airlines would have to drastically change their usual cleaning procedures to ensure the aircraft was completely disinfected after disembarking.

Conclusion

Although it is often difficult to ascertain evidence that transmission directly occurred in flight, the same could be said about numerous settings e.g. restaurants, gyms and buses. However, it is important to recognise that there are numerous case reports of direct, highly likely and probable in-flight transmission events. Factors including proximity to index patients, stage of illness, ventilation, density of passengers on board and duration of the flight will all make a considerable difference to attributable risk [11, 12, 16]. It is essential that airlines and policy makers ensure that the risks associated with air travel during the pandemic are minimised and mitigated. Unfortunately, there is no one solution to reducing the risk of inflight transmission and the outcomes are often a result of multiple factors. Therefore the mitigation strategies mentioned above need to be further researched, evidenced and importantly legislated to ensure standards across global aviation.

From the research presented it is clear that one infected passenger will not infect every other individual onboard, however if this individual does infect a small number of people these individuals may go on to seed infections in their respective destinations, as seen during the SARS-CoV-1 epidemic [21]. For an air-traveller, the increased risk of exposure and transmission is present not only in-flight but for the entire 'door-to-door' journey, including – taking pubic transport to/from the airport, waiting in the departure lounge and collecting baggage - therefore it is important to consider more than just the risk for the duration of the flight but from multiple aspects. Social distancing, ventilation and mask wearing will mitigate a proportion of the risk, but it is impossible to negate all risk when taking any public transport including planes.

References

1. Zhang, J., et al., *Transmission of SARS-CoV-2 on Aircraft.* SSRN, 2020.
2. Mangili, A. and M.A. Gendreau, *Transmission of infectious diseases during commercial air travel.* Lancet, 2005. **365**(9463): p. 989-96.
3. Chen, J., et al., *Potential transmission of SARS-CoV-2 on a flight from Singapore to Hangzhou, China: An epidemiological investigation.* Travel Medicine & Infectious Disease, 2020. **36**: p. 101816.
4. Olsen, S.J., et al., *Transmission of the severe acute respiratory syndrome on aircraft.* N Engl J Med, 2003. **349**(25): p. 2416-22.
5. An der Heiden, M., et al., *Contact investigation after a fatal case of extensively drug-resistant tuberculosis (XDR-TB) in an aircraft, Germany, July 2013.* Euro Surveill, 2017. **22**(12).
6. Lei, H., J.W. Tang, and Y. Li, *Transmission routes of influenza A(H1N1)pdm09: analyses of inflight outbreaks.* Epidemiol Infect, 2018. **146**(13): p. 1731-1739.
7. World Health Organization. *Transmission of SARS-CoV-2: implications for infection prevention precautions*. 2020 9 July 2020 27/09/2020]; Available from: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions.
8. Quilty, B.J., et al., *Effectiveness of airport screening at detecting travellers infected with novel coronavirus (2019-nCoV).* Euro Surveill, 2020. **25**(5).
9. Bae, S.H., et al., *Asymptomatic Transmission of SARS-CoV-2 on Evacuation Flight.* Emerging infectious diseases, 2020. **26**(11).
10. Choi, E.M., et al., *In-Flight Transmission of Severe Acute Respiratory Syndrome Coronavirus 2.* Emerging Infectious Diseases, 2020. **26**(11): p. 18.
11. Khanh, N.C., et al., *Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 During Long Flight.* Emerging Infectious Diseases, 2020. **26**(11): p. 18.
12. Yang, N., et al., *In-flight transmission cluster of COVID-19: a retrospective case series.* Infectious Diseases., 2020.
13. Hoehl, S., et al., *Assessment of SARS-CoV-2 Transmission on an International Flight and Among a Tourist Group.* JAMA network open, 2020. **3**(8): p. e2018044.
14. Pavli, A., et al., *In-flight transmission of COVID-19 on flights to Greece: An epidemiological analysis.* Travel Medicine and Infectious Disease, 2020. **38**: p. 101882-101882.
15. Eldin, C., et al., *Probable aircraft transmission of Covid-19 in-flight from the Central African Republic to France.* Travel Medicine and Infectious Disease, 2020. **35 (no pagination)**(101643).
16. Nir-Paz, R., et al., *Absence of in-flight transmission of SARS-CoV-2 likely due to use of face masks on board.* Journal of travel medicine., 2020. **14**.
17. You, R., et al., *An innovative personalized displacement ventilation system for airliner cabins.* Build Environ, 2018. **137**: p. 41-50.
18. Newbold, S.C., et al., *Effects of Physical Distancing to Control COVID-19 on Public Health, the Economy, and the Environment.* Environ Resour Econ (Dordr), 2020: p. 1-25.
19. Schwartz, K.L., et al., *Lack of COVID-19 transmission on an international flight.* Cmaj, 2020. **192**(15): p. E410.
20. van Doremalen, N., et al., *Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1.* N Engl J Med, 2020. **382**(16): p. 1564-1567.
21. Shen, Z., et al., *Superspreading SARS events, Beijing, 2003.* Emerg Infect Dis, 2004. **10**(2): p. 256-60.