Evidence brief on the risk of COVID-19 transmission in flight: update 3

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Introduction

What is the evidence on in-flight transmission of COVID-19, assessments of risk, and mitigation strategies related to air travel?

Many changes have been implemented by airlines and national government during the pandemic to reduce the risk of SARS-CoV-2 transmission during air travel. This evidence brief summarizes the literature on in-flight transmission of SARS-CoV-2, the characteristics of these events, and the strategies implemented or proposed to mitigate transmission in an airplane or during boarding and disembarkation. This is the third update and includes studies up to November 25, 2021. The first and second update of this review contained literature published up to October 28, 2020 and April 26, 2021, respectively.

What's new

Highlights from the current literature include:

- Twenty-five additional studies were added in this update; twelve flight investigations (Table 1), five reviews, one passenger/crew survey on infection and prevention measures, two risk assessments (Table 2), and five simulation studies on reduction of respiratory virus spread and the relative impact of mitigation strategies during air travel (Table 3). These new studies bring the total number of studies included in this review to 84.
- Overall, attack rates (AR) were low (0-10%) except for two new reports of super-spreading events caused by variants of concern (VOCs) or former variants of interest (VOIs) (AR: 16-40%).
- The findings from the new studies further substantiate results from the previous updates.

Key points

From a total of 37 flight investigations of transmission events during air travel, 13 reported no evidence of in-flight transmission (eight on repatriation and five on commercial flights) and 24 reported likely transmission from in-flight exposure. Whole genome sequencing results from eight investigations aided in linking cases to an on-flight single exposure [1, 2, 3, 4, 5, 6, 7, 8]. Emerging VOCs were reported in two of the studies [4, 5].

- Overall, most studies reported attack rates between 0-10%; the two studies with the highest attack rates, 16% and 40%, coincided with exponential growth of SARS-CoV-2 in their respective countries of departure (South Africa, Jun 2021 and India, Apr 2021) and reported transmission of VOCs onboard, with large clusters of Delta and Kappa [4, 5].
- Multiple reports of in-flight transmission events involved flights without mandatory face masks [1, 2, 7, 9, 10, 11, 12, 13]. There were several studies, with transmission events occurring early in the pandemic Jan-Mar 2020, that did not mention mask usage on board [8, 14, 15, 16, 17, 18, 19, 20]. There were also instances where transmission events occurred even though face masks were mandatory [3, 4, 5, 21, 22, 23, 24]; however, studies have indicated some instances of low-compliance with mask wearing/incorrect mask use (e.g., not covering the nose) [4, 22], the removal of masks for eating/drinking [4, 21, 22], as well as cases involving children who were likely exempt from masking requirements [5, 6]. One study found that wearing a face-mask is protective against SARS-CoV-2 on flights (odds ratio=0.21) [7].
- Symptom and temperature checks prior to boarding were reported by some studies [5, 11, 21, 25, 26]. Failure of passengers to report symptoms led to transmission on at least one flight [11].
- Proximity to an index case (two-row radius) was a risk factor in investigations where seating charts were available (odds ratio: 4.8; risk ratio: 7.3; attack rate 3.8-30.9%) [4, 7, 9, 10, 11, 12, 19, 24].
- Most reports of in-flight transmission events occurred prior to widespread vaccination roll-out. One study found that vaccinated passengers were 74% less likely to be infected compared with those who were not vaccinated [4].
- The most commonly implemented public health measures were in-flight physical distancing, enhanced cleaning, mandatory face masks, hand hygiene, physical distancing during boarding and disembarking, designated crew only areas, and quarantine areas for unwell passengers [3, 4, 5, 21, 22, 25, 26, 27, 28, 29, 30, 31, 32]. One survey of passengers and crew indicated that both the passengers and crew felt safer after implementation of enhanced safety measures to curb transmission and felt that most measures were feasible to implement, apart from physical distancing of 1.5-2m while in-flight [33].

The risk of SARS-CoV-2 transmission during air travel was addressed directly in 22 reviews, reports, and risk assessments (Table 2), and indirectly in 26 reviews, predictive models, simulation experiments, environmental monitoring studies, and *in silico* studies (Table 3).

- The key finding of the SARS-CoV-2 literature on transmission during flights is that multiple interventions are needed to maximally reduce the risk of transmission (Table 2); this is summarized well in the Appendix 1 figure from the Aviation Public Health Initiative report led by Harvard [34].
    - Across reviews, the risk of infection during a flight is low [35, 36, 37, 38, 39]. A meta-analysis found that from January–June 2020, the risk of being infected with SARS-CoV-2 in an airplane cabin was estimated to be 1 case for every 1.7 million travelers [35].
    - The longer the duration of the flight, the higher the infection risk [40]. On average, the attack rate increased from 0.7% (95% CI: 0.5% - 1.0%) to 1.2% (95% CI: 0.4% - 3.3%) when the travel time increased from 2.0 to 3.3 hours [40]. Removing masks for meal service led to increased risk [41].
    - Public health measures such as maintaining physical distancing during boarding, disembarkation, and in-flight, enhanced cleaning, hand hygiene, and universal mask use for duration of flight implemented in a layered approach significantly reduce the risk of transmission [34, 37, 38, 39, 42, 43].
    - Airplane ventilation systems are designed to quickly refresh cabin air and this level of ventilation substantially reduces the time particles remain in the cabin compared to other indoor environments and thus reduces the opportunity for transmission, particularly when coupled with other public health measures (Table 2 & Table 3).
    - Adherence to public health measures by passengers and crew are a critical factor to the impact of these measures to reduce the risk of transmission, such as symptom screening guidelines and on-board procedures [33].
- Indirect studies on risk assessment and mitigation strategies used aerodynamics of droplets and aerosols to characterize high risk situations, or simulated boarding and in-flight movements to suggest strategies for minimizing interaction of people and maximizing the distance between people in flight (Table 3).
    - In-flight particle numbers in the air in airplanes are lower than that of retail/grocery stores, restaurants, office spaces, homes, and other forms of transport [44].
    - Passengers who sneeze or cough while standing or moving about the cabin spread their respiratory droplets considerably further than those seated [45].

- Wearing a face mask significantly decreased the spread of respiratory aerosols (>90%). N95/FFP2 masks were more effective at reducing infections compared to cloth masks [46, 47].
- Boarding an airplane by groups of related individuals, those seated in back of plane and window seats first as well as other more complicated algorithms such as the reverse pyramid scheme were shown to reduce the interaction with other people [48, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57]. Decreasing the amount of carry-on luggage was also found to reduce interactions on-board. Although some strategies such as increasing the number of boarding groups or social distancing may sacrifice efficiency (i.e., longer total boarding/disembarkation time), they can significantly reduce the risk of infection.
- Grouping families and strategically spacing passengers on flights that are not at capacity improves physical distance between passengers. Algorithms developed by researchers were presented to maximize this concept and demonstrated the potential performance of these algorithms compared to middle seat empty or aisle seat empty strategies [40, 46, 58, 59]. Across all of these strategies, their effectiveness decreased on fuller airplanes [40, 46, 58, 59].

Overview of the evidence

The in-flight transmission events recorded across studies were investigated through contact tracing investigations and cohorts. The cluster/outbreak investigations are at high risk of bias due to their retrospective and descriptive nature. Cohorts were available for repatriation flights and are at lower risk of bias because the passengers and crew were followed-up in a uniform manner for a specific time period.

Review literature ranged from good quality systematic reviews to narrative literature reviews. There was good agreement in the information and recommendations across the different review literature.

Quantitative risk assessments, predictive models, simulation experiments, and other *in silico* studies were highly variable in their objectives and approaches. No attempt to assess the validity of these studies was conducted. These studies aim to mimic a real world scenario usually to explore options for different interventions. Their results should be interpreted with caution as they may not reflect what would happen in a field setting.

There were only a small number of flights for which epidemiological investigations of possible transmission events had been undertaken. These events are likely under-reported and/or under-investigated due to the logistics and available resources for contact tracing. It is also difficult to classify instances of in-flight transmission as acquisition of SARS-CoV-2 may occur prior to departure, at various points during travel, or during quarantine/upon arrival. Whole genome sequencing may help in linking cases to an on-flight single exposure. Future investigations, risk assessments, and predictive models should also address whether optimal public health measures are the same for small aircrafts, the implication that current VOCs, and emerging SARS-CoV-2 variants and their attributes (e.g., increased transmissibility) may have on in-flight transmission risk, as well as the impact of vaccination status of both travellers and airline staff in mitigating risk.

Investigations of in-flight transmission events

The full extent of COVID-19 exposure associated with airplanes is not known. Thirty-seven studies (13 are new since the last review update) were identified where the possibility of in-flight SARS-CoV-2 transmission was investigated. Twenty-four studies report transmission occurred and 13 report no transmission occurred during the flights. Transmission was primarily passenger to passenger, although six studies reported transmission event(s) from passenger to crew [7, 8, 11, 17, 19, 20]. Several studies of repatriation flights where many precautions were taken report no transmission to the crew [27, 28, 29, 30, 31, 32]. Overall, in-flight transmission attack rates ranged from 0-40%, but flights varied by a number of factors including public health measures implemented, capacity, presence of VOCs, and flight-time length. High level points are listed below and details on individual studies can be found in Table 1.

Public health measures enhanced during in-flight travel included a combination of physical distancing, enhanced cleaning, mandatory face masks, hand hygiene, physical distancing during boarding and disembarking, designated crew only areas, and quarantine areas for unwell passengers [3, 4, 5, 21, 22, 25, 26, 27, 28, 29, 30, 31, 32].

- Symptom and temperature screening at the airport were mentioned in a few investigations [5, 11, 21, 25, 26]. The failure of individuals to adhere to the screening guidelines and report symptoms demonstrate that screening was not an effective control measure on its own and it needs to be used in conjunction with other precautions [11].
- Many of the larger transmission events occurred before the mandatory use of face masks on flights [1, 2, 7, 9, 10, 11, 12, 13] or other risk reduction strategies had been implemented. There were several studies, with transmission events occurring early in the pandemic Jan-Mar 2020, that did not specify mask usage on board [8, 14, 15, 16, 17, 18, 19, 20].

- There are also instances where transmission events occurred despite mandatory face mask requirements [3, 4, 5, 21, 22, 23, 24]. One study found that wearing a mask inappropriately (OR 2.46, 95% CI: 0.75-8.09) or not at all (OR 4.6, 95% CI: 1.28-16.6) were associated with SARS-CoV-2 positivity [7]. Incorrect use of the mask (e.g., not covering the nose) was considered an important factor of transmission in at least one other study [22]. Three studies noted that masks were removed during the flight to eat or drink [4, 21, 22]. Two cluster investigations reported positive cases detected in children, who were likely exempt from masking requirements [5, 6].

Seating arrangements and proximity to an infected case were important risk factors for in-flight transmission.

- Cluster investigations that had access to seating charts showed those seated within two to three rows of the index case were at higher risk of acquiring COVID-19 compared to those sitting further away (odds ratio: 4.8; risk ratio: 7.3; attack rate 3.8-30.9%) [4, 7, 9, 10, 11, 12, 19, 24]. One study found that passengers seated in the two rows ahead a confirmed case were at a slightly higher risk of being infected compared to passengers in the same row or two rows behind [24].
- However, there were several cases across the cluster investigations that were seated much further away and the mode or circumstance of transmission was not obvious (could have been from movement in cabin, shared restrooms, or fomite transmission) and could not be confirmed [1, 6, 11, 18]. One investigation of three international flights to China found that the majority of confirmed cases were seated in the middle of the economy section or near restrooms and galleys [24]. It is not clear whether any particular seats are associated with a higher risk of contracting infection. While some studies suggest that sitting in the middle seat may be the most risky due to contacts on both sides, the prevalence of COVID-19 was not found to differ significantly between passengers sitting in window, aisle, or middle seats [10, 24].
- Across cluster investigations it was frequently postulated that the window seat should be a safer seat as there are fewer contacts with other people compared to the aisle seats, however one investigation found that being in a window seat was a higher risk than the aisle seat [1]. This was an unexpected finding that the authors could not explain. Table 3 describes modelling and simulation studies that look at the potential differences in risk of sitting in different areas and seats on an airplane.

Length of flight time was an outcome of an investigation into transmission on domestic flights in China early in the pandemic (January 2020) that reported increased risk with longer travel time [10]. The estimated attack rate (upper-bound estimate) increased from 0.7% (95% CI: 0.5%-1.0%) to 1.2% (95% CI: 0.4%-3.3%) when travel time increased from 2 hours to 3.3 hours [10].

Impact of vaccination was estimated to reduce the likelihood of a passenger being infected by 74% in one study [4]. The impact of vaccine mandates on risk of in-flight transmission was not reported or estimated in any study and most of the research included in the review occurred prior to widespread vaccination roll-out.

Variants of concern (VOCs) were implicated in two studies that identified multiple VOCs or VOIs present on-board including Delta, Alpha, Beta, and Kappa.

- Phylogenetic analysis of genome sequence from 30 cases linked to a flight from South Africa to China in June 2021 found that 27 were caused by Delta and 3 were caused by Alpha, Beta and C.1.2 [4]. A single index case on that flight was associated with secondary transmission to 33 passengers.
- WGS conducted on 46 cases linked to a single flight from New Delhi to Hong Kong in April 2021, reported likely transmission of three variants on-board, with Kappa causing the largest cluster (37 cases), onward transmission of Alpha occurring from 1 of 3 primary cases to 2 others onboard, and at least one onboard transmission of Delta [5].

Whole genome sequencing (WGS) was undertaken in eight investigations. In all cases it helped to identify cases linked to the same source and added a layer of information that the epidemiological investigation would have missed [1, 2, 3, 4, 5, 6, 7, 8].

Several limitations are observed across these investigations mainly related to limitations in the data obtained. For example, pre/post flight contacts between index case and secondary contacts could not be excluded [1, 11, 12, 14, 15, 16, 17, 18, 22], and for some investigations, seating location was not known [11, 21].

Risk of SARS-CoV-2 transmission on airplanes

Twenty-two citations provide evidence on the transmission risk of SARS-CoV-2 on airplanes (Table 2). These are a mixed group of review literature (n=10), reports (n=2), passenger/crew surveys (n=2), and quantitative risk assessments (n=8) that examine the risk of SARS-CoV-2 transmission while flying. High level points are listed below and details on individual studies can be found in Table 2.

- **Reviews and reports** had similar conclusions and recommendations [37, 38, 39, 42, 43]. The report released by the Aviation Public Health Initiative (APHI) on October 27, 2020 remains the most comprehensive risk assessment of SARS-CoV-2 transmission from gate-to-gate [34]. It evaluated the available evidence and considered expert opinion and simulation results in its evaluation of reducing risk transmission of SARS-CoV-2 on flights [34]. They outline why a layered risk mitigation strategy is necessary and the importance of compliance from passengers and the airlines, which was also suggested in the other reviews.

- In agreement with findings from Table 1, three systematic reviews and two literature reviews concluded that the risk of infection during a flight is low but may be highest for individuals seated within two rows of the index cases [35, 36, 37, 38, 39].
- A meta-analysis of studies from January–June 2020 found the risk of being infected with SARS-CoV-2 in an airplane cabin was estimated to be 1 case for every 1.7 million travelers (95% CI: 712,000 to 8 million) [35]. The risk was substantially decreased with implemented mitigation measures where the risk in March 2020 was 1:425,062 and from April-September 2020, the risk was 1:7.1 million. Quantitative risk assessments outlined in Table 2 also provide risk estimates of SARS-CoV-2 on airplanes and in many cases they estimate the risk of transmission is higher than the meta-analysis. While we know in-flight transmission has been under-reported, the risk of in-flight transmission varies depending on many factors, including the parameters used in the models and the variation in the analysis across studies.

Passenger and crew surveys examined the impact and perception of enhanced safety measures to reduce the risk of SARS-CoV-2 transmission gate-to-gate [33] and infection and prevention performance and awareness [60].

- In April 2020, passengers and crew from a flight from Auckland to Bangkok reported positive feedback about implemented changes such as crew only restrooms, frequent cleaning of restrooms, designated quarantine areas on the plane, masking everyone, use of face shields, frequent hand hygiene, and symptom and temperature checks [33]. Passengers reported physical distancing of 1.5-2m could be maintained at check-in, pre-boarding and boarding, but not in-flight [33].
- Using a five-point Likert scale, the average infection prevention score among cabin crew in South Korea was good with a mean score (SD) of 4.56 (± 0.44) on a five point scale, this was lower than their awareness scores 4.75 (± 0.28) [60]. The difference between awareness and performance was only significant for hand hygiene and not mask wearing or handling COVID-19 cases [60]. Infection prevention performance was significantly associated with awareness ($p < 0.05$) and simulation-based personal protective equipment (PPE) training experience ($p < 0.05$) [60].

Risk assessments explored the impact of different public health measures and implementation of a variety of strategies on the risk of transmission during a flight.

- The combination of masks, social distancing among passengers, and improved ventilation can reduce infection risk to <1% [61, 62, 63].
- One study reported the risk of per-person infection during a 13 hour air travel in economy class where the majority of passengers were masked was 0.56% (95% CI: 0.41%–0.72%), equivalent to 0.17 infected individuals [23]. If all the passengers were not masked, the estimated number of infections increased to 17 for a 13 hour flight [23]. Another study reported that infection probabilities for a 2 hour flight without face masks was comparable to a 12 hour flight where all passengers wore high efficiency facemasks [41]. This study also found that removing mask for meal service increased risk [41].
- The longer the duration of the flight, the higher the SARS-CoV-2 infection risk [40]. On average, the attack rate increased from 0.7% (95% CI: 0.5% - 1.0%) to 1.2% (95% CI: 0.4% - 3.3%) when the travel time increased from 2.0 to 3.3 hours [40].
- Removing roughly one-third of the passengers by keeping the middle seats empty and increasing social distancing while boarding significantly reduced the infection risk (by 35-50%) compared to a full airplane [64, 65]. One risk assessment, based on data from late Sep 2020, estimated that a traveller on a flight in the US had a risk of contracting SARS-CoV-2 of 1/3900 on a full flight and 1/6400 if the middle seat empty policy was in place (these numbers depend on the disease activity in the population) [66].

Indirect analyses of SARS-CoV-2 infection transmission risk and mitigation strategies on airplanes

Several simulation and *in silico* models have been developed to explore ways to minimize the risk of transmitting an infectious disease on an airplane or during embarkation and disembarkation. There were eleven studies on boarding/disembarking an airplane, six on optimal seating patterns to minimize in-flight transmission, one that analyzed both boarding/disembarking an airplane, masking, and optimal seating patterns, and seven on the aerodynamics of respiratory aerosols in an airplane when coughing and sneezing. A single review of these aerodynamic studies up to June 2020 was also identified. These studies looked at strategies for boarding to minimize passenger interactions and seating plans to maximize distance and minimize interaction with other people. The studies that look at ventilation on the airplane and how coughing or sneezing impacts airflow describe the distance and range of droplets and aerosols from various seats (e.g., window, middle, aisle) and when standing or walking about the cabin. High level summary points are listed below and details on each individual study can be found in Table 3.

Public health measures such as the impact of masking and physical distancing on minimizing the risk of inhaling respiratory aerosols from other passengers were examined.

- When surgical masks were used in simulations, there was a >90% reduction in droplets released during the cough simulation compared to no mask [46].
- A predictive model demonstrated that N95/FFP2 masks were more effective at reducing infections compared to cloth masks (95-100% vs 40-80%, respectively) [47].
- Physical distancing can be improved by grouping families and strategically spacing passengers on flights that are not at capacity [52, 67].

Boarding/disembarking an airplane strategies to minimize contact while maintaining some level of efficiency were explored in several simulations.

- Increasing the number of boarding groups, decreasing carry-on luggage, and avoiding interaction with other passengers (i.e., boarding back of plane and window seats first) was found to decrease risk of infection significantly, albeit with a sacrifice in overall efficiency (i.e., lengthier boarding/disembarkation time) in some scenarios [48, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57].
- One predictive model estimated that the boarding/deplaning process contributed more to infection risk than inflight movement (total secondary infections: 4.4 vs 0.7) [47].
- Two predictive models demonstrated the reverse pyramid boarding scheme, where passengers are divided into boarding groups depending on their seats' positions and boarded in a diagonal fashion, was effective in reducing infection risk [55, 56]. Back to front boarding of the plane was also shown to decrease risk in another predictive model [53].

Optimal seating arrangements to minimize the risk of in-flight exposure was conflicting across simulations.

- The seats immediately adjacent to the index cases have the highest infection risk, followed by the row directly behind and in front [40, 46, 58, 59]. There is conflicting evidence on what seats (aisle, middle, or window) have a higher infection risk [46, 68, 69]. Differences in risk between different airplanes as well as business and economy seats are also discussed in two studies [68, 70].

- Vacant middle seat occupancy was shown to reduce infection risk in two studies [47, 65].

Studies of in-flight respiratory aerosol dynamics were demonstrated in several simulations and experiments to show both the superior ventilation within an airplane and activities that may be higher risk than others.

- The travel distance of cough particles is heavily influenced by the direction and type of cough [69, 71]. Standing or walking about the cabin can lead to much further spread of respiratory droplets and aerosols [45].
- In-flight particle concentrations in the air in airplanes are lower than that of retail/grocery stores, restaurants, office spaces, homes, and other forms of transport [44, 46]. Further, simulation experiments of in-flight aerosol transmission and surface contamination find that air in the cabin is rapidly renewed [58].

Methods

A daily scan of the literature (published and pre-published) is conducted by the Emerging Sciences Group, PHAC. The scan has compiled COVID-19 literature since the beginning of the outbreak and is updated daily. Searches to retrieve relevant COVID-19 literature are conducted in Pubmed, Scopus, BioRxiv, MedRxiv, ArXiv, SSRN, Research Square and cross-referenced with the COVID-19 information centers run by Lancet, BMJ, Elsevier, Nature and Wiley. The daily summary and full scan results are maintained in a refworks database and an excel list that can be searched. Targeted keyword searching is conducted within these databases to identify relevant citations on COVID-19 and SARS-COV-2. Search terms used included: flight, airplane, aircraft, plane, airline travel, and air travel. The search netted 849 citations (507 from initial search up to October 28, 2020, 147 from second search conducted April 26, 2021, and 195 from updated search conducted on November 25, 2021), which were screened for relevance to the review. Additional references to relevant synthesis research not related to SARS-CoV-2 or the current pandemic were identified through citations in articles on the current pandemic and an additional google search was executed May 4, 2021 to identify any new non-indexed reports using (COVID-19 or SARS-CoV-2) AND (flight OR plane). Potentially relevant citations were examined to confirm it had relevant data and relevant data is extracted into the review. This review contains research published up to November 25, 2021.

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Evidence tables

Table 1: Investigations of in-flight transmission events (n=37)

Study	Method	Key Outcomes
Flights with secondary cases identified (n=24)		
Lv (2021) [4] new Cohort study China Jun 2021	This study investigates a flight of 203 passengers which took off from South Africa on June 9, 2021 and arrived at Shenzhen, China, on June 10, 2021. All passengers had negative PCR and IgM assays within 48 h before boarding. It was mandatory for inbound passengers to wear masks throughout the entire flight and on the way to the quarantine hotel. An online questionnaire survey was conducted among all passengers. Upon landing, passengers underwent a 14-day quarantine period. Multivariate logistic regression was conducted to identify risk factors for infection.	● During the quarantine period, 39 passengers tested positive for SARS-CoV-2. Phylogenetic analysis of genome sequences from 30 cases found that 27 were caused by Delta and 3 were caused by Alpha, Beta and C.1.2. ● Six PCR-positive cases were identified to be the primary cases, who were likely to be infected in South Africa. ● Transmission to secondary cases was linked to 1 index case. ● 197 passengers were considered exposed to the index case, and 33 flight-associated cases were reported during the quarantine. ● Passengers sitting within three rows of the index case had a higher attack rate (30.9%, 17/55), compared with that of those located three rows away from the index case (11.3%, 16/142) (RR 4.22, 95% CI: 1.55–11.50). ● Use of hand sanitizer showed significant protection (RR 0.24, 95% CI: 0.09–0.66). ● Vaccinated passengers were 74% less likely to be infected compared with those without vaccination (RR 0.33, 95% CI: 0.08–1.43) but this was not statistically significant. ● 87.3% (172/197) of travellers reported having taken off their masks during the flight (reason and length of time not reported).
Blomquist (2021) [9] Cohort study UK Dec 2020	Identified infections among passengers 18 England-bound flights with infectious cases using national case management datasets. Passengers were considered to be infectious during the flight if lab results were positive 7 days before or 2 days after the flight. Note: whole genome sequencing could not be applied as this data was not available for index and secondary cases from the same flight.	● The investigation determined 5 cases to be linked to potential aircraft transmission, 55 infectious passengers and 2313 co-passengers, with 2221 flight-only contacts. The overall SARS-CoV-2 transmission on short to medium-haul flights was estimated to be low. ● The following attack rates were estimated: ○ 0.2% (95% CI 0.1-0.5) among all flight-only contacts. ○ 3.8% (95% CI 1.3-10.6) among contact-traced flight-only contacts who sat within a two-seat radius. ○ 13.0% (95% CI 7.6%-21.4%) among co-travellers with multiple non-flight exposures to infectious cases.

		● Passengers were likely not wearing masks during the flight as it was still early in the pandemic before mask wearing was widespread/mandatory.
Zhang (2021) [23] new Cohort study China March-Aug 2020	Enrolled all passengers and crew suspected of being infected with SARS-CoV-2 that were on international flights bound for Beijing on international flights in March 2020. They provided the characteristics of all confirmed cases of COVID-19 infection and utilised Wells-Riley equation to estimate the infectivity of COVID-19 during air travel. The infectivity is quantified with infectious quanta released by one source case per hour. Passengers were screened upon arrival. Health passengers underwent 14 days of isolation for medical evaluation and those suspected of having COVID-19 were transferred to hospital. Clinical outcomes were followed up until August 1, 2020.	● Of 4492 passengers and crew with suspected COVID-19 infection, 161 cases were confirmed during quarantine. ● The number of confirmed cases on the 30 flights investigated ranged from 2 to 11 per flight. After investigation, only 2 (1.2%) confirmed cases were suspected of being infected during flight. ● Taking masking and ventilation into account, the effective infectivity was estimated to be only 4 quanta/h (range 2–5). This value was used to calculate risk of per-person infection. The risk of per-person infection during a 13 h air travel in economy class where the majority of passengers were masked was 0.56% (95% CI 0.41%–0.72%), or 0.17 infections. ● If all the passengers were not masked, the number of infected individuals could be roughly 6 for a 5 h flight, and 17 for a 13 h flight in economy class. ● The per-person risk of individuals in first class was ~4 times higher than travel in the economy class.
Toyokawa (2021) [7] new Cohort study Japan Mar-Apr 2020	This study investigated passengers and flight attendants exposed to COVID-19 on March 23, 2020, on board a 2-hour flight (Boeing 737-800) in Japan. Whole-genome sequencing of SARS-CoV-2 was used to identify the infectious linkage between confirmed cases. The association between confirmed COVID-19 and proximity of passengers' seats to the index case and/or the use of face masks was estimated using logistic regression.	● There were 148 passengers: the index patient, 141 other passengers (seat occupancy: 80.2%), four flight attendants, and two pilots. The authors were able to interview/follow-up on 126 passengers. ● Of the 146 passengers (excluding the pilots), there were 14 confirmed cases and 6 probable (symptomatic but did not undergo RT-PCR testing) identified. The secondary attack rate was 9.7% for confirmed cases only and 13.8% if probable cases were included. ● The genome sequence of the virus in 12 of the 14 confirmed cases were all either identical or differed only by 1 nucleotide to that of the index case. ● 92 passengers wore a mask at all times, 20 most of the time, and 11 did not wear a mask at all. Wearing a mask inappropriately (OR 2.46, 95% CI 0.75-8.09) or not at all (OR 4.6, 95% CI 1.28-16.6) were associated with SARS-CoV-2 positivity. ● Passengers seated within two rows of the index patient were at higher risk of infection (OR 4.8, 95% CI 1.46-15.8).
Bae (2020) [21] Cohort study	299 passengers were on an evacuation flight from Milan, Italy to South Korea (duration 11 h) March 31, 2020. Medical checks	● Based on RT-PCR testing and no development of symptoms, 6 evacuees had asymptomatic COVID-19.

South Korea Mar 2020	were conducted before the flight, everyone wore N95 respirators except when eating and social distancing was observed on embarkation and disembarkation. All evacuees were under medical observation during a 14 day quarantine with RT-PCR testing on day 1 and day 14.	• One evacuee, who self quarantined for 3 weeks before the flight and then 2 weeks after the flight, had an RT-PCR positive test on day 14 of quarantine in South Korea. The authors suggest her exposure must have been on the flight where she was 3 rows from an asymptomatic case and they shared the same washroom.
Guo (2021) [24] preprint new Surveillance study China Jun-Aug 2020	Obtained data on all international flights to Lanzhou, China, from June 1 to August 1, 2020, through the Gansu Province National Health Information Platform and the official website of the Gansu Provincial Center for Disease Control and Prevention. They calculated the period prevalence rate of COVID-19 among the passengers of all flights during the 14-day period following the flight, and stratified the prevalence by the seat positions. Passengers were required to wear masks during the flight.	• There were three international flights during the study period, from Riyadh (MU7792), Jeddah (MU7790), and Moscow (CA608). The flights had a total of 700 passengers, of which 27 (3.9%) passengers were confirmed to have COVID-19. • Flight 1: Prevalence of COVID-19 was 7.9%. The prevalence rates were 4.8% (95% CI 0.7-10.3%) among passengers seated on the window seats, 15.5% (5.9-25.1%) on the middle seats, and 5.6% (1.5-9.8%) on the aisle seats (P=0.054). The prevalence rates were 16.7% (9.5-27.2%) in the two rows ahead of each confirmed case, 14.0% (5.8-28.6%) in the same row with a confirmed case, and 10.7% (6.0-17.9%) in the two rows behind each confirmed case (P=0.465). • Flight 2: Prevalence was 1.6%. The prevalence for the window seats was 0%, for the middle seats was 3.4% (1.4-8.1%), and for the aisle seats was 1.6% (0.6-3.8%) (P=0.268). In the two rows ahead of each confirmed case, the prevalence was 4.5% (0.2-24.9%)], in the same row 0%, and in the two rows behind 4.2% (0.2-23.1%) (P=1.000). • Flight 3: Prevalence was 1.6%. The prevalence rates were 2.3% (2.3-6.9%) in the window seats, 1.6% (1.6-4.8%) in the middle group, and 1.1% (1.1- 3.4%) in the aisle group (P=1.000). There were no other confirmed cases around the seats of the confirmed cases. • Conclusions: The majority of confirmed cases were seated in the middle rows of the economy class, or near restrooms and galleys. The prevalence of COVID-19 did not differ between passengers sitting on window, aisle or middle seats. Passengers seated in the two rows ahead of a confirmed case were at a slightly higher risk of being infected compared to passengers in the same row or two rows behind.
Dhanasekaran (2021) [5] new Cluster investigation	This study reports on a large cluster (n=59 cases) linked to a single flight with 146 passengers from New Delhi to Hong Kong in April 2021. The airline used thermal screening and social	• The attack rate of passengers was 40%, 12/59 cases were symptomatic. • WGS, conducted for 46 cases, identified infections on board were caused by three different variants: Alpha (n = 5/46, 10.9%), Delta (n = 2/46, 4.3%) and Kappa (n = 39/46, 84.8%).

China Feb-Apr 2021	distancing during check-in and boarding. Passengers were tested at arrival and during a 21-day quarantine period. Epidemiological information was collected from passengers of the flight. Whole genome sequencing was conducted to compare sequences from this flight.	● 37 of the Kappa sequences clustered together very closely suggesting a single transmission cluster (i.e., a superspreading event onboard). ● Onward transmission of Alpha likely occurred from 1 of 3 primary cases to 2 others onboard. ● Evidence was suggestive that there was at least one onboard transmission of Delta. ● 8 of the positive cases were detected in children under the age of two, who were likely exempt from masking requirements. ● Using the time from arrival-to-detection as a proxy for SARS-CoV-2 incubation, they estimated that at least 7 individual cases were likely infected prior to travel and 41 were infected during transit. 11 cases were detected >14 days after arrival. ● Limitations of this study were that not all cases could be sequenced and possible confounding due to lack of detailed information on passenger movements during airport check-in, pre-flight boarding, onboard the flight and during ground transportation to designated quarantine hotels.
Hu (2021) [10] new Cluster investigation China Jan 2021	Used the itinerary and epidemiological data of COVID-19 cases and close contacts on domestic airplanes departing from Wuhan city in China between Jan 4- January 23, 2020, to estimate transmission risk of COVID-19 among travellers. Data from the National Health Commission of China was used to identify cases who had a travel history of domestic flight during illness or within 14 days before symptom onset. Passenger lists who seated within three rows to the confirmed cases were supplied by airlines. A passenger was defined as an index cases if they had confirmed infection after the travel, had symptom onset within 14 days before travel or within 2 days after, and had the earliest date of symptom onset among other cases within 3 rows. Passengers were considered close contacts when they were within 3 rows of an index case. Secondary cases were defined as close contacts who had symptom onset later than the index case and within 2-14 days after travel. The attack rate (AR) of a	● A total of 5,797 airline passengers on 177 planes were included in this study. 209 airline travellers were confirmed to have COVID-19. ● 175 individuals were identified as index cases. The attack rates of a seat were 0.3% (lower-bound estimate, 18/5400, 95% CI 0.2-0.5%) to 0.6% (upper-bound estimate, 34/5622, 95% CI 0.4-0.8%). Each index case infected 0.2 (SD 0.5) to 0.1 (SD 0.3) individuals. ● The seats immediately adjacent to the index case had an AR of 9.2% (95% CI 5.7-14.4%) and a relative risk of 27.8 (95% CI 14.4-53.7) compared to other seats. ● The middle seat had the highest AR (0.7%, 95% CI 0.4-1.2%). The window and aisle seats had the same AR (0.6%, 95% CI 0.3-1.0%). ● There was no significant difference in AR between airplanes (Boeing vs. Airbus). ● Risk increased with longer travel time. The upper-bound AR increased from 0.7% (95% CI 0.5%-1.0%) to 1.2% (95% CI 0.4%-3.3%) when the co-travel time increased from 2 hours to 3.3 hours. ● There was a lack of detailed information on passenger movements during airport check-in, pre-flight boarding, and onboard the flight. Further, asymptomatic cases would not have been included in the analysis. ● Note: This study took place before the implementation of stringent public health

	seat= the number of confirmed cases/the total number of close contacts that used the same seat location apart from index cases.	measures in China. Masks would not have been mandatory during the flight.
Swadi (2021) [2] Cluster investigation New Zealand Sep 2020	A comprehensive investigation into the potential source of COVID-19 infections among 7 travelers that were on a flight from Dubai, UAB on Sept 29th 2020, with a stop in Kuala Lumpur, Malaysia, and landed in Auckland, New Zealand (18 hour duration). These 7 passengers had been seated within 4 rows of each other. The lineage of the genomes obtained from the 7 passengers was determined. Mask use was not mandatory. Post aircraft transportation to quarantine facilities was physically distanced where possible, and mask use was mandated.	● During the required 14-day managed isolation and quarantine period, 7 passengers who had traveled on the flight received positive SARS-CoV-2 test results. ● The 7 passengers had begun their journeys from 5 different countries before a layover in Dubai; pre-departure SARS-CoV-2 test results prior to boarding were negative for 5. None of the passengers reported close contact at the Dubai airport. ● Among the 7 passengers, 2 were probably index case-patients infected before the flight, 4 were probably infected during the flight, and the remaining passenger was probably infected while in isolation. ● 5/7 cases wore masks and gloves while on the flight, including the two index cases, while the other two cases did not. ● Genomic analysis found that the sequences obtained from all 7 cases were assigned to lineage B.1 and were genetically identical.
Eichler (2021) [3] Cluster investigation New Zealand Aug 2020	Investigated the origin of multiple COVID-19 cases identified after 14 days in post travel quarantine.	● Genomic sequence and epidemiological analysis identified a multi-branched chain of transmission that included international and domestic air travel and probable aerosol transmission in the quarantine hotel (not summarized below). ● The index case was identified to be a repatriated citizen returning to New Zealand from India. ● Three secondary cases from the index case's 18 hour (35% occupancy) international flight on a Boeing 747 were identified by whole genome analysis. All three cases sat within 2 rows from each other, and were required to wear facemasks. ● In-flight infection transmission also occurred from one of the secondary cases, who was unknowingly exposed during quarantine and released from quarantine before they were positive, to three passengers during an 85 minute domestic flight (50% capacity) on a Boeing 737. The three cases sat near one another (in front of each other) while the infectious case sat at a distance. ● Note: All flight passengers wore masks during the flights.
Murphy (2020) [6] Cluster investigation	An outbreak investigation into COVID-19 cases linked to an international flight into Ireland in the summer, 2020.	● 13 cases were linked to a single international flight (duration 7.5h). The cases had come from three different continents. ● Only 49 passengers and 12 crew were on the flight. No data on the crew or 11 passengers.

Ireland Jun-Aug 2020	Masks were worn by 9 cases, not worn by 1 child case and was unknown for 3.	● Whole genome sequencing showed 5 strains from passengers matched suggesting a single point source of infection. The index case(s) was not identified through the epidemiological investigation, but plausible theories suggest a proportion of cases acquired COVID-19 in-flight. ● 4 of the flight cases were not seated near a positive case, had no contact in transit, wore face masks in-flight and would not have been considered a close contact. ● A social network is shown to demonstrate how the flight cases spread SARS-CoV-2 to 46 secondary contacts in the community.
Speake (2020) [1] Cluster investigation Australia Mar 2020	The flight, an Airbus A330-200, on Mar 19, 2020 from New South Wales to Perth (duration 5h) had 28 business class and 213 economy passengers. An epidemiologic and whole-genome sequencing investigation were undertaken. Mask use was rare on this flight and inconsistent.	● 29 passengers on the flight had SARS-CoV-2, and an additional 35 had compatible symptoms by tested negative. 18 from cruise ships and 10 domestic/international travellers. ● Based on WGS 18 cases were considered primary: 13 Ruby Princess, 4 Ovation of the Seas and 1 traveller from the US. ● 11 secondary cases, 3 did not have WGS and were classified as possible, 8 are considered to have occurred in-flight. The 8 did not know each other, 4 from US and 4 Australians. ● Among the 11 secondary cases, 8 were within 2 rows of an infected case and 3 were more distant. All secondary cases were from the mid section despite 5 infectious cases in the aft cabin. ● 64% in were in a window seat, risk ratio 5.2 (95% CI 1.6-15.4). ● WGS allowed proper attribution of cases to in-flight transmission.
Khanh (2020) [11] Cluster investigation Vietnam Mar 2020	Flight from London, UK to Hanoi, Vietnam on March 2, 2020 (duration 10h). All successfully traced passengers and crew were interviewed, tested and quarantined. At arrival, there were temperature checks and symptom screening and some countries (not UK) had to undergo SARS-CoV-2 testing. Facemasks were not mandatory on airplanes.	● There were 16 crew and 201 passengers. The index case started to experience symptoms the day before the flight, she was seated in business class. ● 14 passengers and 1 crew were identified as positive during the contact tracing investigation. ● 12 were in business class and 92% were seated within 2 meters of the index case and 1 was more than 2 meters, risk ratio 7.3 (95% CI 1.2-46.2). ● Three other contacts (2 passengers and 1 flight attendant) did not have a close encounter with the index case as they were in economy class.
Choi (2020) [8] Cluster investigation Hong Kong Mar 2020	A study examining confirmed COVID-19 cases in Hong Kong and travel history identified 4 people that shared a flight from Boston, US to Hong Kong, China March 9, 2020. The airplane was a Boeing 700-300ER (duration >15h), with 294 passengers.	● The cluster included 2 passengers (a married couple) in business class and 2 crew. ● The couple both had symptom onset on March 10, so they were already infected during travel. ● The flight attendants developed symptoms March 16 and 18. One of 2 flight attendants spent 5 days in Boston, the other could not be confirmed.

	Not all passengers were tested. No mandatory quarantine or airport screening was in place. Use of facemasks was not mentioned.	● Their viral sequences all matched 100% and were not sequences that had been seen in Hong Kong. However, close matches were identified from Toronto, New York and Boston. ● Based on this analysis the authors conclude it is likely that the couple transmitted SARS-CoV-2 to the flight attendants during the flight.
Hoehl (2020) [12] Cluster investigation Germany Mar 2020	102 passengers of a flight from Tel Aviv, Israel to Frankfurt, Germany March 9, 2020. 24 members were from a tourist group that unknowingly at the time had had contact with an infected hotel manager 7 days prior. No preventative measures were taken on the flight. Crew were not followed-up. Antibody tests were offered, however many passengers did not get tested, so additional transmission events may not have been detected.	● The tourist group was tested for SARS-CoV-2 on arrival, 7 of 24 were positive. On the flight the 7 positive from the tourist group were symptomatic (n=4), presymptomatic (n=2) and asymptomatic (n=1). ● 1 of 71 other passengers with follow-up data reported having a positive RT-PCR test 4 days after the flight. 7 of 71 reported symptoms of COVID-19 within 14 days of the flight; one was confirmed with IgG serology and PRNT test. ● Both confirmed cases are considered likely on-board transmission events, they were sitting within 2 rows of an index case.
Quach (2021) [20] new Cluster investigation Vietnam Mar 2020	This is an in-depth analysis of the epidemiological characteristics of a flight-associated COVID-19 outbreak and subsequent contact tracing, systematic testing, and strict quarantine to prevent further transmission. Flight VN54 (10hr) consisted of 16 crew members and 201 passengers.	● 183 primary, 1000 secondary, and 311 third generation contacts all of which were tested and quarantined. ● In addition to the index case, 15/183 primary contacts tested positive for COVID-19, of which 14 were passengers and 1 was a crew member. ● 5 secondary cases emerged among secondary contacts of 4 primary cases. ● The attack rate among secondary contacts was 0.3%. ● Public health measures were not mentioned.
Pavli (2020) [19] Cluster investigation Greece Feb-Mar 2020	Contact tracing activities of international passengers arriving or departing from Greece Feb 26- Mar 9, 2020. No public health measures were noted.	● 18 flights with 21 index cases and 891 passengers and 90 crew were traced. ● Of the 21 index cases, 6 were symptomatic, 12 were pre-symptomatic and 2 developed symptoms 5-7 days after the flight. ● 5 secondary cases were identified that many have been in-flight transmission from one flight (Israel to Greece, duration 2h) with two COVID-19 cases. The secondary cases were seated within 2 seats of an index case.
Wang (2021) [18] Cluster investigation China Feb 2020	Contact tracing activities of a family cluster of COVID-19. The reported cluster involved 3 confirmed cases, 2 asymptomatic infections, and a total of 34 close contacts within the family, of which 8 were visiting relatives from other provinces, and 1 was on the same flight as a confirmed case.	● The source of infection in this cluster was a family member's girlfriend who travelled via plane from Guizhou province. This case had close contact with a confirmed case on the plane while waiting in line for the bathroom as well as getting on and off the plane.

Yang (2020) [13] Cluster investigation China Jan-Feb 2020	A flight from Singapore to Hangzhou (duration 5h) carrying 325 people on January 23, 2020. Seat assignments were not obtained, so physical proximity of the index and other cases is not known. Masks were worn by flight attendants, but not by most passengers.	● The index case developed a fever on the flight and did not wear a mask, he was identified during disembarkation and tested positive. All passengers were quarantined for 14 days. 11 other passengers developed symptoms and tested positive for an AR=3.4%.
Chen (2020) [22] Cluster investigation China Jan-Feb 2020	A flight from Singapore to Hangzhou (duration 5h) carrying 335 people on January 24, 2020. The flight was strictly managed because 100 people on the flight were from Wuhan. All passengers were quarantined for 14 days. Facemasks were worn on the flight except when eating and drinking.	● 16/335 COVID-19 cases were diagnosed among passengers, attack rate 4.8%. None of the crew were infected. ● Only one passenger did not have a plausible epidemiological history of exposure prior to the flight. On the flight, he was seated near 4 infected passengers from Wuhan for approximately 1 hour and did not wear his facemask properly (not tight and nose not covered).
Zhang (2020) [16] new Cluster investigation China Jan 2020	Reported two case clusters of COVID-19 who were identified through inbound screening when returning to China from Singapore/Malaysia.	● Public health investigation and contact tracing led to the identification of 12 confirmed cases of PCR-confirmed SARS-CoV-2 infection related to 2 tour groups. For the majority of cases, the exact route of transmission was unclear as the cases could have gotten SARS-CoV-2 infection in Wuhan/Hubei before travel, or from each other during their 5-day tour in Singapore/Malaysia, or during the 5-h flight. However, one of the documented cases was not actually part of the tours, but had close contact with the other COVID-19 patients on one of the flights. Considering the incubation period of SARS-CoV-2, the most likely exposure for this case was the flight.
Kong (2020) [15] Cluster investigation China Jan 2020	This paper details the travel and potential transmission of SARS-CoV-2 from an index case in tour group A to 3 other tour groups that were in Europe Jan 16-28. Shared flights and lodging were considered in the epidemiological investigation. Face mask use or other precautions were not mentioned.	● Transmission within the tour group (group A) resulted in 13 confirmed or suspected infections and could have occurred on flights, bus or during tours. The first case was hospitalized Jan 22, and others in the group fell ill starting Jan 26. ● It seems unlikely that transmission from Group A to Group B tour group occurred on a January 16 flight as the 3 cases in Group B were not identified until January 29. ● It is plausible that transmission from Group A to two others and a tour guide from group C and- an independent traveller,-occurred on a Jan 28 flight. ● It is also plausible that transmission from Group A to 3 people in Group D occurred at lodging shared by both groups Jan 22.
Mun (2021) [17] Case series	This case series describes two flight attendants diagnosed with COVID-19 who shared the crew's	● The first case became ill on Feb 21, 2020 and was diagnosed on Feb 25, 2020. Thorough epidemiologic investigations suggested in-flight

South Korea Feb-Mar 2020	resting area and ground transportation, and discusses the risks experienced by flight attendants.	disease transmission as the source of infection as the flight attendant had worked during a flight on February 15th, 2020 which had on-board 39 Korean Catholic pilgrims coming from Tel Aviv, Israel. Soon after their return to South Korea, 30 pilgrims were diagnosed with COVID-19. There were no other identified sources for this case. After the flight, she continued to work between February 19 and February 22, 2020. ● After the first flight attendant was diagnosed with COVID-19, a 2-week self-quarantine period was imposed on all crew members (n=30). Only one crew member was diagnosed with COVID-19 during this quarantine on Mar 6, 2020. While the two flight attendants worked on different decks of the plane, they had shared the crew's resting area and ground transportation after the first flight attendant had developed symptoms.
Eldin (2020) [14] Case report France Feb 2020	A case investigation of a French national who developed COVID-19 shortly after returning to France. He had left France February 13 for Bangui, Central African Republic and returned to Marseille, France with his partner on February 24th via Yaoundé, Cameroon.	● This investigation suggests that transmission occurred on the flight from Bangui to Yaoundé where French nationals were on the same plane as the first case of COVID-19 diagnosed in Cameroon after the February 24th flight. ● The case developed symptoms shortly after returning to Marseille France. The flight is the most plausible point of exposure.
Flights with no secondary cases identified (n=13)		
Lee (2020) [25] new Cohort study Taiwan Mar 2020	Describes a repatriation flight from China to Taiwan. All the medical staff were equipped with personal protective gear (protective coveralls, face shield, N95 mask, gloves) and these remained donned throughout the mission. At Wuhan airport before boarding the passengers underwent temperature screening. People boarded based on colored labels. Green: free of fever and respiratory symptoms for the preceding 14 days; Red: well on examination but had declared that they had fever or respiratory symptoms in the past 14 days; Black: afebrile but experienced any kind of respiratory symptoms at the point of examination). Two seats were left vacant between each passenger. Passengers were asked not to talk to each other during the flight, not to consume Food/drinks, and to avoid going to the toilet. All evacuees underwent	● No cases of COVID-19 were detected among the evacuees.

	14 day quarantine upon arrival and RT-PCR testing.	
Kim (2020) [27] Cohort study South Korea Mar 2020	Describes a repatriation flight of 80 Koreans from Iran to Korea, with a direct transfer of passengers between airplanes in Dubai. Strict infection prevention precautions were implemented (i.e., vinyl curtains to separate clean and contaminated zones, PPE, face masks, and social distancing). Passengers with symptoms in the last two weeks were designated as 'patients under investigation' (PUI). Everyone aboard the flight was screened for SARS-CoV-2 upon arrival into Korea and completed a mandatory 14-day medical quarantine.	● One passenger was identified as a PUI during the first leg of the flight but tested negative upon arrival and one additional passenger was categorized as a PUI during the second leg of the flight upon developing a fever tested positive upon arrival. No additional passengers, aircrew, medical staff, or others involved in the evacuation, developed signs of infection during the 14-day observation period.
Suzuki (2021) [28] Cohort study Japan Feb-Mar 2020	Measured serum antibody titers for SARS-CoV-2 in 10 healthcare workers who were engaged in the operation of charter flights for the evacuation of Japanese residents from Hubei Province. All participants wore PPE. Blood samples were collected at enrollment (after February 14^{th}) and at every 2 weeks after enrollment until 4 weeks after the final participation in the evacuation operation.	● Median compliance with PPE was 90% (range 70-100%, n=8). ● The number of positive cases on each of the five flights was 3, 2, 2, 1, and 0, respectively. ● All samples from all healthcare workers were seronegative, indicating that PPE was effective in protecting staff during repatriation flights.
Nir-Paz (2020) [29] Cohort study Israel Feb 2020	This article describes the repatriation of 11 citizens from the Diamond Princess cruise ship. Before boarding a 13.5 hour flight Feb 20, 2020 all 11 citizens had a negative SARS-CoV-2 RT-PCR test result. Precautions were taken, everyone wore surgical or FFP2 masks and crew had minimal interaction with passengers.	● Two of the repatriated citizens (a couple), were SARS-CoV-2 positive upon arrival. Thus, it is assumed that they were infectious on the airplane. ● No secondary cases were identified among the other repatriated citizens or 4 crew members. ● Everyone on the flight were observed to wear their facemask except for eating and drinking.
Ng (2020) [26] new Cohort study Singapore Jan 2020	Followed up on 94 persons who boarded an evacuation flight from Wuhan to Singapore. Temperature checks were conducted at check-in. Surgical masks were provided to passengers. At arrival they underwent temperature screening again and then underwent 14 day quarantine, where they were checked for symptoms 3 times	● Two passengers tested positive for COVID-19 on arrival. The son of one of these cases also tested positive during day 3 of quarantine. ● Although individuals on-board tested positive, it was not confirmed whether any cases occurred in-flight.

	daily. Any persons reporting symptoms underwent RT-PCR testing.	
Jia (2021) [72] new Cluster investigation China Mar-Apr 2020	During a second outbreak in Guangzhou, China in Mar-Apr 2020, near real-time genomic surveillance was conducted on 109 confirmed imported cases to elucidate the source and spread of SARS-CoV-2. The cases were from travelers returning from 25 different countries in Asia (n = 26), Africa (n = 28), Europe (n = 36), and North and South America (n = 19). The phylogenetic analyses aimed to determine how the virus was transmitted among passengers on the same flights and among family members.	• Travelers on the same flight carried different viral variants whereas travelers who lived together shared the same viral variants. • Flight ET606 departing from Ethiopia had 12 infected passengers from 6 different African countries. Viral genomes were obtained for 10 of them, and the viral variants were assigned to 4 different haplotypes. • Flight TG668 departing from Thailand included 6 infected passengers from Pakistan who were previously unacquainted but were traveling together on a tour. Viral genomes were obtained for 5 of them and 4 viral haplotypes were identified. • The findings suggest that SARS-CoV-2 was not transmitted during air travel, and the travelers were likely infected before the flight.
Draper (2020) [73] Cluster investigation Australia Mar-Apr 2020	Two flights with an infected crew member were identified in Northern Territory, Australia. All 555 passengers were considered close contacts necessitating contact tracing and quarantining activities. There were 28 cases and 527 close contacts over the two months. 94% follow-up rate was achieved. No public health measures or mask wearing noted.	• Due to a delay in getting manifests, it was almost a week before the flight passengers were notified (n=195 people to quarantine). • 326 air passengers from other flights were also monitored with 131 quarantined for being in the same row or within 2 rows of an infected case. • No secondary cases (0%, 95% CI 0-1.1%) from flights were identified.
Qian (2020) [74] Cluster investigation China Jan 2020	12 cases had taken a flight Ningbo to Zhejiang, China following a super spreading event at a temple in Ningbo. No public health measures or mask wearing noted.	• Eleven of these cases were linked to the temple; the exposure of one case was unknown, but not considered to have occurred on the flight. No secondary cases are known to have occurred from the flight. • The results of contact-tracing investigations identified 88 cases of COVID-19 admitted to five hospitals in Zhejiang province, China.
Ruonan (2021) [75] Surveillance analysis China Jan-Apr 2020	Analyzed Guangzhou imported case data from The National Information Management System for Infectious Diseases Reports of the China Disease Control and Prevention Information System.	• Out of 34 flights, 10 (29.4%) had more than 3 cases on-board. There is no clear evidence of the spread of COVID-19 on any of the flights.
Chen (2020) [32] new Descriptive study China Jul 2020 (est)	Describes repatriation of people back to China. Does not provide any details on number of flights investigated. The cabin area was divided various zones (a clean area, buffer zone, passenger sitting area and quarantine area). Each	• Flight personnel were tested three times, no COVID-19 cases were identified.

	passenger was provided with two N95 masks and could take them off only to eat/drink during meal times. Crew members and medical staff could choose to wear medical disposable caps, gloves, goggles, protective suits, or gowns. All flight attendants performed hand hygiene frequently.	
Karim (2020) [30] Descriptive study Malaysia Feb-Apr 2020	This article summarizes the repatriation of Malaysian citizens using chartered commercial aircraft. The mission objectives were to repatriate as many citizens based on aircraft capacity and prevent onboard transmission of the disease to flight personnel. All flight team personnel underwent briefing on in-flight safety procedures and use of personal protective equipment (PPE). All repatriates were required to wear face masks and sanitise their hands upon boarding the flight.	● There were 82 positive cases detected among the repatriated citizens. Secondary transmission among repatriated citizens during the flight was not investigated. ● There was a single positive case of a healthcare worker involved in the mission, based on the sample taken on arrival of the flight. This worker was asymptomatic and did not test positive again upon repeat testing (potential false positive or sampling error). No investigation into how the worker may have acquired infection was described. There were no infections involving flight team members who worked with the case.
Cornelius (2020) [31] Descriptive study US Jan-Mar 2020	This article summarizes the repatriation of US citizens by US Department of health and human services air medical evacuation crews.	● The study included 39 flights with > 2000 individuals. ● The article describes in depth the precautions taken to transport many potentially infected individuals. Best practices for IPC during air transport are described in the paper. No cases were identified of emergency workers acquiring COVID-19 during evacuation flights.
Schwartz (2020) [76] Case reports Canada Jan 2020	Reports on the index case who arrived in Toronto on Jan 22, after taking a 15hr flight from China with 350 people onboard. No public health measures or mask wearing noted.	● No secondary COVID-19 cases were identified despite public health follow-up.

Abbreviations: AR, attack rate; Est, Date the study took place is estimated from the publication date or the country the study was conducted was based on author affiliations

Table 2: Reviews, reports, passengers surveys, and risk assessments related to SARS-CoV-2 transmission on airplanes (n=22)

Study	Method	Key Outcomes
Reviews (n=10)		
Moon (2021) [77] new Systematic review Korea (est) Nov 2021 (est)	This systematic review and meta-analyzes aimed to analyze different transmission risks of respiratory infectious diseases (including SARS-CoV-2) according to the type of confined space (e.g., home, residential space, school, work, airplane etc.). The systematic review is high quality and includes studies up to Dec 2020.	● Of the 147 included studies, 14 were on SARS-CoV-2. These included risk of transmission in the following confined spaces: airplane (n=1), home (n=7), hospital (n=3), restaurant/bar (n=2), and navy ship (n=1). ● In the sub-group analysis for SARS-CoV-2, residential space (combined RR 8:30, 95% CI: 3.30-20.90) and airplanes were the riskiest spaces for transmission (RR 7.30, 95% CI: 1.15–46.20).
Pang (2021) [35] Systematic review US (est) Apr 2021 (est)	Systematic review of COVID-19 cases related to air travel up to Sept 2020. The review was limited to flights with passenger index cases and did not include transmissions amongst air crew, ground crews, or airport staff. A quantitative approach was used to estimate the risk of air travel transmission. Correction factors were used in risk estimates for asymptomatic transmission and underreporting. Transmission risk was calculated for three time periods of interest: (1) January–June 2020 the period covered by the literature, (2) the month of March 2020 when the global spread of COVID-19 was occurring, and (3) April–September 2020 to account for the sharp drop in worldwide air travel and increased use of COVID-19 testing.	● As of August 2020, there were at least 2866 index cases that were documented air passengers. ● Fewer than 50 documented potential secondary cases associated with air travel during the pandemic were reported. ● Mask use on reviewed flights ranged from use unknown to mandatory N95 use. ● From January–June 2020, the risk of being infected with SARS-CoV-2 in an airplane cabin is estimated to be 5.927×10^{-7} or 1:1.7 million. Uncertainty in the correction factors and a 95% CI indicate risk ranges from 1 case for every 712,000 travelers to 1 case for every 8 million travelers. ● For the month of March 2020, the risk is estimated to be 2.353×10^{-6} or 1:425,062. ● From April-September 2020, the risk is estimated to be 1.413×10^{-7} or 1:7.1 million.
Arora (2021) [78] new Narrative review Apr 2021 (est) Germany (est)	This review was based on articles that have studied or analyzed the impact of international travel by air or sea. A search was carried out in PubMed with the terms "coronavirus, COVID19, international travel, transmission, screening, airports, aircrafts, maritime, ship."	● Factors that affect the transmission risk on flights include duration of the flight, number of infected persons (passengers) on board and their stage of illness, size of the aircraft, and type of air-ventilation system used.
Rosca (2021) [36] new Systematic review	Four electronic databases were searched for studies published 1 February 2020–27 January 2021 on SARS-CoV-2 transmission aboard	● 18 studies on in-flight SARS-CoV-2 transmission (130 unique flights) and 2 studies on wastewater from aircraft were included.

Romania (est) Feb 2020-Jan 2021	aircraft. Assessed study quality (QUADAS-2) and reported important findings.	● The quality of evidence from most published studies was low. ● The proportion of contacts traced ranged from 0.68 to 100% across studies. ● In total, 273 index cases were reported, with 64 secondary cases. Secondary attack rate among studies that followed up on >80% of passengers and crew (n=10 flights) varied between 0 and 8.2%. ● Genomic evidence was used to investigate on-board transmission on 4 flights. ● Conclusions: SARS-CoV-2 can be transmitted during aircraft travel, but is relatively rare. Risk of infection could be highest for individuals seated within two rows of the index cases. The heterogeneity in design and methodology restricts the comparison of results across studies.
Khatib (2021) [38] new Literature review Canada[1] Jan 2020-May 2021	Narrative review of the literature assessing safety of air travel relating to coronavirus disease 2019 (COVID-19) transmission from January 2020 to May 2021.	● In-flight transmission risk is low, but a layered multipronged approach (onboard masking, distancing during boarding and deplaning, disinfection protocols and preflight screening and testing measures) is necessary to reduce the risk and establish a threshold for safety.
Sun (2021) [79] Literature review China (est) Apr 2021 (est)	Narrative review of publications related to the COVID-19 pandemic and air transportation published in 2020.	● A summary of literature on airport screening operations and boarding strategies. ● Summarizes the existing (2020) literature regarding in-flight operations in the presence of COVID-19 and in-flight transmission events. ● Conclude that widely available, robust data for whether there are transmission occurs despite proper mask use on airplanes would yield more valuable insights.
Bielecki (2021) [37] Literature review Switzerland (est) Feb 2021 (est)	Narrative review of topics related to air-travel in the pandemic period. Topics included traveller numbers, peri-flight prevention, and testing recommendations and in-flight SARS-CoV-2 transmission, photo-epidemiology of mask use, the pausing of air travel to mass gathering events, and quarantine measures and their effectiveness.	● Air travel numbers have significantly declined (51.6% decrease compared to 2019). ● Infection risk during flights is low: 1 infection per 54 h of flight and zero infections during a 12-h flight. ● Flying will be safer by optimizing screening procedures, minimizing the risk of allowing pre- or asymptomatic cases to board (i.e., testing), and implementation of/adherence to simple hygiene measures and physical distancing that prevent the spread of diseases. Passenger screening is inadequate to detect all infectious cases. ● Models predict minimal risk of in-flight transmission but these do not consider human behavior and variations between airline procedures. ● High airflow and use of HEPA filters onboard planes make it unlikely to catch the virus from

		someone who is not seated close by. There is some evidence that passengers within two rows of an index case are at higher risk.
Khatib (2020) [42] Literature review Canada (est) Dec 2020 (est)	Narrative review of literature on SARS-CoV-2 transmission risks and infection prevention strategies used by commercial air travel. Authors provide recommendations and propose strategies to mitigate the spread of COVID-19.	• Air quality aboard modern aircraft is very safe (HEPA filters are 99.97% effective in removing particles between 0.1 and 0.3 µm in diameter and 100% of larger particles). • Further study is needed to examine the interaction between airflow and resulting particle dispersion, but authors recommend turning on the personal airflow (gasper) above each passenger to improve travel comfort, air quality and reduce person-to-person transmission of exhaled contaminants. • Risk is highest during boarding and disembarkation. • A window seat is thought to be the safest option-though recent real-world outbreak studies are questioning this. • Recommendations included: masks should be used, frequent hand sanitization promoted and physical distancing ensured when feasible from boarding to disembarkation. High-frequency touchpoints should be disinfected between flights and in-flight. Pre-screening and pre-testing measures should be used in addition to the preventive measures enforced onboard. The implementation of a standardized digital health pass for COVID-19 and more robust contact tracing may be key factors to allow for a gradual safe return to air travel.
Kelly (2021) [39] new Literature review Ireland (est) Jan-Dec 2020	A literature review was conducted on in-flight transmission of SARS-CoV-2. Articles published January 1 to December 1, 2020 were included.	• Captured 11 studies that reported possible evidence of in-flight transmission of SARS-CoV-2, with attack rates ranging from 0-6.9% among the exposed passenger and cabin crew. • Flights with the highest attack rates did not have mandatory masking.
Freedman (2020) [43] Literature review US (est) Sep 2020 (est)	Narrative review of all publications of possible in-flight SARS-CoV-2 up to Sep 21, 2020. This review summarized transmission events by attributes such as mask wearing on the flight in an attempt to describe and quantify the risk under different scenarios and considerations such as differing incidence rates of SARS-Co-V-2 at origin and destination, intensity of viral load in index cases, flight duration, masking practices onboard, pre-flight screening and passenger spacing.	• Describe 4 well documented flights, three included in Table 1 [1, 8, 11] and the forth is an online inventory of flights to Hong Kong that reported transmission to 2 passengers, 1 seated with 5 index cases, masks were used on-board (duration 8 h). • 3 single transmission events have been reported, 2 were published [12, 22]. • 6 high risk flights with no transmission are listed, 1 is published [76]. The inventory of flights from Hong Kong lists many flights with positive passengers and no secondary transmission attributable to the flight. • 5 evacuation flights of which 3 are published [21, 29] are listed with one possible transmission event. The review states >1.7 million passengers

	There were not enough data points to quantify the risk.	were repatriated by their government or a cruise ship company during the pandemic, few have been documented in the literature. ● Flights lists with known COVID-19 cases were identified from Canada and Australia. These lists are for other passengers to self identify and isolate. US CDC is also collecting data, but has not published any findings. ● Clear clustering of cases was identified where seat plans were available, but some transmission occurred to people > 2 rows from the index case. The flights with large transmission clusters occurred before face masks were mandated on flights and several high-risk flights with no transmission had mandatory masks.
Reports (n=2)		
Marcus (2020) [34] Aviation Public Health Initiative Report from the Harvard TH Chan School of Public Health Risk assessment US (est) Sep 2020 (est)	This excellent quality APHI Report includes data up to September 28, 2020. This research-led guidance report reflects a mixture of literature review, in silico models and expert engagement to assess the following question: "In the midst of this complex, novel coronavirus crisis, how can aviation leaders advance an independent evidence-based program to reduce the risks of SARS-CoV-2 disease transmission and with that, enhance the safety and confidence of its workforce and passengers?"	● Layered non-pharmaceutical interventions (NPIs) significantly reduce the risk of disease transmission and includes: optimal ventilation, disinfection of surfaces, wearing face masks, procedures to encourage social distancing particularly during embarkation and disembarkation, but also during flight (e.g. no queuing for the restrooms or walking about the plane and minimizing interaction with crew.) ● Airplane ventilation is highly sophisticated and delivers high amounts of clean air to the cabin which rapidly disperses exhaled air. ● Crew and Passenger Behavior: Public safety on board and airplane depends a lot on individual behaviours: first health attestations and screening pre-boarding, mandatory facemasks, social distancing and orderly conduct to avoid congestion combined with hand washing and cleaning. This is encouraged via the penalty of being on a "no-fly" list for non-compliance. ● Overall, there is limited data on in-flight transmission, however it appears that a very low number of infections could be attributed to in-flight transmission and there is evidence that NPIs, particularly mask use, resulted in no transmission despite infectious passengers onboard. They describe 13 manuscripts (also included in Table 1) of studying in-flight transmission. Of note, no crew from repatriation flights acquired SARS-Cov-2, a demonstration that adherence to NPIs is effective. ● Layered risk mitigation strategies can significantly reduce the risk of transmission, but require compliance from passengers and the airlines.
Shaimoldina (2020) [80]	A public dataset of international flight infection information was	● Flight infections have decreased and air travel has been significantly reduced.

Surveillance data analysis and literature review Kazakhstan (est) Dec 2020(est)	used to analyze the trend in flight traffic and infections during the pandemic. Based on existing literature, the authors then describe challenges of prevention of SARS-CoV-2 infected individuals from boarding flights and solutions for flight resumption.	● Preventing SARS-CoV-2 infected individuals from boarding flights is challenging due to testing accuracy, asymptomatic cases and many other factors including the inability to maintain physical distance and density of passengers on a plane. ● Solutions may include hotel quarantine for arriving passengers, mandatory PPE, airport diagnosis, and rapid imaging/biomarker diagnosis by advanced high-technology.
Passenger and crew surveys (n=2)		
Pongpirul (2020) [33] Cross-sectional study Thailand Apr 2020	This study targeted passengers and crew of two repatriation flights operated by Thai Airways (TG476 from Sydney 9.25h and TG492 from Auckland to Bangkok 11.5h), total 335 passengers and 35 crew. An online questionnaire was administered to get individual feedback about social distancing, mask wearing, and other procedures put in place to reduce the risk of SARS-CoV-2 transmission. In depth interviews were conducted with crew.	● Response rate for the online questionnaire was low: 22.5% ● Several risk reduction measures were implemented and well received. These included crew only restrooms, frequent cleaning of restrooms, designated quarantine areas on the plane, masking everyone, use of face shields, frequent hand hygiene (alcohol gel provided to all passengers), symptom and temp checks. ● Physical distancing of 1.5-2m could be maintained at checking, pre-boarding and boarding, but not in-flight. ● Crew found that handing passengers surgical masks, face shields and alcohol gel prior to the flight was impractical as passengers often had their hands full already with multiple pieces of carry-on luggage.
Ryu (2021) [60] new Cross-sectional study South Korea Aug-Sep 2020	An online survey was conducted to assess the level of infection prevention (IP) and factors affecting IP performance among aircraft cabin crew (n=177) during the COVID-19 pandemic. Infection prevention (IP) performance and IP awareness was evaluated using a five-point Likert scale. Mean and SD are provided as outcomes. Simulation-based personal protective equipment (PPE) training experience and organizational culture was also evaluated.	● The level of IP performance (4.56 ± 0.44) was significantly lower ($p < 0.05$) than that of IP awareness (4.75 ± 0.28), however the difference was not significant for wearing a mask or handling confirmed or suspected COVID-19 passengers. Hand hygiene had significantly lower performance (4.47 ± 0.56) compared to awareness (4.61 ± 0.08). ● IP performance was significantly associated with IP awareness ($p < 0.05$) and simulation-based PPE training experience ($p < 0.05$).
Risk assessments (n=8)		
Horstman (2021) [61] Risk assessment US (est) Mar 2021 (est)	Applied computer fluid dynamic results of virus transport and concentration, past data on Influenza transmission in airplanes, and the Wells Riley quanta estimation, to estimate infections risk of an arbitrary airborne viral infection on Boeing 737-600	● In a 3-hour flight, infection risk of an airborne infection influenza was approximately 50% for passengers sitting in the vicinity (i.e., a single row) of infected cases (positioned at the 12th row aisle seats), estimated as 2-3 infections per 131 passengers. ● When the analysis was compared to field data where 4 symptomatic infected cases led to 2

	airplanes. The parameters and data in the analysis were then compared to field data on SARS-CoV-2 on an airplane. Note: Field data based on the transmission event described by Hoehl (2020) in Table 1. Investigators assumed the virus emission rate was $1.6 \pm 1.2 \times 10^5$ genome copies/m^3h that corresponded to 1267 viruses/minute released, and an Influenza human 50% infectious dose (HID_{50}) of 2554 copies/quanta.	secondary infections, SARS-CoV-2 was found to be less infectious and lie mid-range of the applied Influenza infectious dose data. ● Masks, social distancing among passengers by 2.9 feet, vacant middle seat at 66% capacity, reduced the risk of transmission by more than 48%. The use of N95 masks and surgical masks (ASTM 3) reduced the number of secondary infections to 0.
Wilson (2021) [63] new Risk assessment New Zealand May 2021 (est)	Using a stochastic SEIR model, the study aimed to model the risk of COVID-19 outbreaks associated with international air travel from Australia to New Zealand, along with the likely impact of various control measures that could be used to minimise the risk of such outbreaks. In-flight transmission risk was a parameter used in the model. Using previously published literature, the authors estimated the number of hours of exposure to infected cases for a flight with mandatory mask use (number of infected people on the flights x flight hours).	● Although this study was mainly about importation risk, the authors provided an estimate of infection risk in their methods as a parameter for the larger model. ● Estimated 2 in-flight infections arising from 933 exposure-hours, giving an estimated risk of transmission per hour of flying in a plane containing an infectious person of 0.00214.
Wang (2021) [41] Quantitative risk assessment UK (est) Feb 2021(est)	Estimate inflight SARS-CoV-2 infection probability for a range of scenarios using experimental aerosol dispersion data and a modified Wells-Riley equation. Scenarios were varied based on quanta generation rates and face mask efficiencies, and specified for a B777-200 aircraft.	● Infection probabilities for a 2 hour flight without face masks were comparable to a 12 hour flight where all passengers wore high efficiency facemasks. Overall, infection probabilities were higher in the economy class cabins (MID-AFT) compared to the business class (FWD) sections. ● Individual infection probabilities during a 2 hour unmasked flight ranged from 4.5%-60.2%. The average infection probabilities based on the number of infected passengers on the flight ranged from 0.1%-2.5% in the same scenario. For a 12 hour unmasked flight individual infection probabilities ranged from 24.1%-99.6%, average infection probability 0.8%-10.8%. ● The use of high/low efficiency masks by passengers during a 12 hour flight except during 1 hour meal service increased average infection probabilities by ~59% to ~8%, compared to when masks were worn for the entire flight.

McCarthy (2021) [64] Quantitative risk assessment NA (est) Jan 2021 (est)	This mechanistic transmission model assumes that the probability of SARS-CoV-2 infection is additive over sub-activities. Sub-activities that together make up the air travel activity include boarding the plane, moving to and entering one's seat, sitting on the plane for the duration of the flight, and finally leaving ones seat and disembarking the plane. The model also assumes a three-hour long flight and that there is no direct physical contact between participants and that all surfaces are disinfected. It also assumes that all passengers are compliant with the boarding and masking policies. This is a risk-cost-benefit decision analysis framework that can be applied to many settings, including airplanes. The analysis can produce relative risks.	● The relative benefits of different mitigation strategies on the airplane can be explored: ○ Time spent seated was the most important factor in total risk score. ○ Mask-wearing, making masks mandatory, given what we currently know, could be a (cost-) effective strategy for risk reduction. ○ Keeping the middle seat vacant unless there is a party of three travelling together at least halves the risk, under a very wide range of decay assumptions. ○ Managing boarding is less costly than leaving seats empty, but the analysis found that the total impact will be lower.
Dai (2021) [62] new Risk assessment China (est) Aug 2020 (est)	Estimated the association between the infection probability and ventilation rates with the Wells-Riley equation, where the quantum generation rate (q) by a COVID-19 infector was obtained using a reproductive number-based fitting approach. The model was applied to multiple confined space scenarios (offices, classrooms, buses, and aircraft cabins).	● If people wear masks in an aircraft cabin, then natural ventilation or normal mechanical ventilation can provide a sufficient ventilation rate to ensure that the infection probability is less than 1%.
Zhang (2021) [23] new Risk assessment China March-Aug 2020	Enrolled all passengers and crew suspected of being infected with SARS-CoV-2 that were on international flights bound for Beijing on international flights in March 2020. They provided the characteristics of all confirmed cases of COVID-19 infection and utilised Wells-Riley equation to estimate the infectivity of COVID-19 during air travel. The infectivity is quantified with infectious quanta released by one source case per hour. Passengers were screened upon arrival. Health passengers underwent 14 days of isolation for medical evaluation and those suspected of having COVID-19 were transferred to hospital.	● Of 4492 passengers and crew with suspected COVID-19 infection, 161 were confirmed during quarantine. ● The number of confirmed cases on the 30 flights investigated ranged from 2 to 11 per flight. After investigation, only 2 (1.2%) confirmed cases were suspected of being infected during flight. ● Taking masking and ventilation into account, the effective infectivity was estimated to be only 4 quanta/h (range 2–5). This value was used to calculate risk of per-person infection. The risk of per-person infection during a 13 h air travel in economy class where the majority of passengers were masked was 0.56% (95% CI 0.41%–0.72%), or 0.17 infections. ● If all the passengers were not masked, the number of infected individuals could be roughly

	Clinical outcomes were followed up until August 1, 2020.	6 for a 5 h flight, and 17 for a 13 h flight in economy class. ● The per-person risk of individuals in first class was ~4 times higher than travel in the economy class.
Hu (2020) [40] Quantitative risk assessment China Dec 2019- Mar 2020	This risk assessment applies epidemiological data from airplane passengers (n= 9,265 passengers and 175 index cases, on 291 airplanes) and close contacts to estimated attack rates (AR) and reproduction number (R_0) prior to the lockdown in Wuhan. Relative risk among seats by proximity to the index case was also estimated. AR upper bound was estimated, based on the assumption 34 and 69 close contacts were infected on the flight departing Wuhan.	● The overall risk of SARS-CoV-2 transmission on planes with high efficiency air filtration devices was reported to be relatively low. The estimated AR upper bound was 0.60% (95% CI: 0.43%-0.84%), and R0 ranged from 0.12 to 0.19. ● Transmission risk was variable by seat distance from infected case(s) and duration of the trip. ● The seats immediately adjacent to the index cases were the highest risk, AR of 9.2% (95% CI: 5.7% - 14.4%), relative risk (RR) of these seats compared to others seats on the airplane was 27.8 (95% CI: 14.4 - 53.7). The middle seats had the highest AR (0.7%, 95% CI 0.4% - 1.2%), followed by the window seats (0.6%, 95% CI 0.3% - 1.0%) and the aisle seats (0.6%, 95% CI 0.3% - 1.0%). ● Lower bounds of AR estimates linked to air travel increased from 0.0% (95% CI 0.0% - 0.6%) to 0.4% (95% CI 0.02% - 2.2%), and upper bounds from 0.7% (95% CI 0.5%-1.0%) to 1.2% (95% CI 0.4% 3.3%) when trip duration increased from 1.5 hours to 3.3 hours. However these results were not significant due to limited data on secondary cases based on flight times.
Barnett (2020) [66] Preprint Quantitative risk assessment US Sep 2020	This risk assessment calculates the risk of SARS-CoV-2 infection resulting from exposure on an airplane using data from late September 2020 and earlier research findings. It did not account for loading/unloading, going to the bathroom, length of the flight, and made some assumptions about the "protection" afforded by the seat backs as a barrier between rows. It is based on economy class in airplanes with 6 seats in a row.	● Based on the assumptions, the risk of contracting COVID-19 from a nearby passenger on a flight in the US was about 1 in 3,900 on a full flight. ● Under the "middle seat empty" policy, that risk falls to in 6,400, a factor of 1.64 lower. ● The point estimate for death risk was approximately one death per 800,000 passengers. ● Transmission risk was lowest when the contagious passenger is in a window seat and highest when in an aisle seat.

Abbreviation: Est, Date the study took place is estimated from the publication date or the country the study was conducted was based on author affiliations.

Table 3: Studies and reviews that examined the aerodynamics of respiratory droplets on airplanes and mitigation strategies for respiratory infections on planes (n=26)

Study	Method	Key Outcomes
Boarding/Disembarkation (n=11)		
Milne (2021) [56] new Predictive model Romania (est) Aug 2021 (est)	Used an agent-based model to determine the number of passengers to include in each boarding group when using the Reverse Pyramid method. They investigated the effect of carry-on luggage, the social distance maintained between passengers walking down the aisle, and the number of boarding groups. The model assumed a 30 row single-aisle airplane with three seats on each side of the aisle, with each middle seat empty (due to seat social distancing), for a total of 120 passengers boarding the airplane.	● The reverse pyramid boarding method divides passengers into boarding groups depending on their seats' positions, using a 'diagonal loading' scheme. ● Health risks decrease as the number of Reverse Pyramid boarding groups increase. ● In a scenario with the most carry-on luggage and 1m aisle social distance, using 6 boarding groups vs. 3 groups reduced the average risk to aisle and window seat passengers by 58% and 81% respectively while increasing the average boarding time by 1.2%. ● In a scenario with no carry-on luggage, using 6 boarding groups vs. 3 groups reduced the risk to aisle and window seat passengers by 62% and 96% respectively while increasing boarding time by 3.2%. ● Changing the aisle social distance from 1m to 2m brings provided negligible health value to seated passengers.
Islam (2021) [57] new Predictive model US (est) Apr 2021 (est)	Simulated new boarding processes enacted by airlines in response to COVID-19 using pedestrian dynamic models to determine whether they lead to an increased or decreased risk of infection spread compared to alternatives.	● Back-to-front boarding doubled the infection exposure compared with random boarding and increased exposure by around 50% compared to a typical boarding process prior to the outbreak of COVID-19. Increased exposure arises from the proximity between passengers moving in the aisle and while seated. Prohibiting the use of overhead bins to stow luggage and boarding the window seat before the aisle seat can ameliorate this increase in exposure risk. ● Keeping middle seats empty also resulted in a substantial reduction in exposure.
Cotfas (2021) [54] Predictive model Romania (est) Mar 2021 (est)	Use an agent-based model and stochastic simulation approach to investigate the impacts of the Reverse Pyramid method on average boarding time and health risk to aisle and window seat passengers. Assessments were based on social distancing by maintaining distances of 1-2 meters	● When minimizing the health risk to passengers was the primary objective the optimal solution was to assign an equal number of window seat passengers to 1 and 2 boarding groups, and an equal number of aisle seat passengers to boarding groups 2 and 3. This option was robust to changes in luggage

	between passengers when walking down the aisle, keeping the middle seat empty, and different carry on luggage policies.	volume and aisle social distance. The option reduced health risk among aisle seat passengers by 22.76%-35.31%, when compared to other simulations which minimized boarding time. ● Scenarios that reduce boarding time, and health risks to a lesser degree, are also discussed.
Milne (2021) [49] Predictive model US (est) Feb 2021 (est)	In these stochastic simulation experiments and agent-based models, the authors assess six boarding methods and compare their performance with that of the two best boarding methods used to date with social distancing according to four performance metrics. Three of the metrics are related to the risk of the virus spreading to passengers during boarding. The fourth metric is the time to complete boarding. The two "best" baseline boarding methods are back-to-front by row and modified reverse pyramid half zone (see figures for description). The back-to-front by row – WilMA method boards the passengers one row at a time starting from the rear of the airplane. The five other boarding methods are created by adjusting the back-to-front by row – WilMA method so that some of the window seat passengers board earlier. In particular, k rows of window seat passengers will board the airplane before any aisle seat passengers. In the five new methods, the value of k ranges between 2 and 6.	● Increased luggage = increased boarding time. ● In a scenario where there is 1 m aisle distancing, the back-to-front by row – WilMA method has shorter boarding times, fewer seat interferences, and less aisle seat risk than the baseline back-to-front method for each luggage scenario. The baseline back-to-front by row method has less window seat risk for the higher volumes of luggage scenarios. ● In a scenario where there is 2 m aisle distancing, the back-to-front by row – WilMA – offset 3 method is superior to the baseline modified reverse pyramid half zone method because its boarding time is about the same and it has less significantly less aisle seat risk and window seat risk. The back-to-front by row – WilMA method has the lowest window seat risk.
Xie (2021) [50] Predictive model China (est) Jan 2021 (est)	Quantitatively compare the disembarkation process of a Boeing 737-300 before and after adopting disembarkation management strategies. Two strategies are investigated: Strategy I: Where there is one infected passenger, ground crews first disinfect cabin aisles before the disembarkation process begins, then passengers in front of the infected patient disembark from the front door while passengers in the rear of the case disembark from the rear door. The patient and his or her "close contacts" disembark only after all passengers have left the cabin. Strategy II: Where there are multiple infected passengers, passengers are evacuated from the front door or rear	● The number of high-risk passengers decreased by 72% after adopting Strategy I. ● After adopting Strategy II, the number of high-risk passengers again decreased by 27%. ● Although both strategies sacrifice efficiency (i.e., longer total disembarkation time), they also significantly reduce the risk of infection.

	door from traversed columns that do not contain patients or close contacts. After the passengers have left the cabin, the cases and "close-contacts" leave from the front or back door without picking up their luggage. After the cases have left, the ground crews perform a second disinfection of the cabin. After disinfection, the remaining passengers leave through the front or rear door.	
Milne (2020) [48] Predictive model US (est) Nov 2020 (est)	In these stochastic simulation experiments and agent-based models, the authors adapt the Reverse Pyramid method for social distancing when an airplane is boarded using a jet bridge that connects the terminal the airplane's front door. They assess the impact of number of boarding groups (2 vs. 6) to show the resulting impact on four performance evaluation metrics. The first performance metric is the average boarding time. The second performance metric is the number of type-3 seat interferences during the boarding (i.e., switching seats, moving out into aisle to allow window passenger access to seat). The third and the fourth performance metrics pertain to seated passengers' health while later boarding passengers pass them.	● As the number of boarding groups increases from two to four, average boarding times decrease. ● When the number of boarding groups increases from 3 to 6, the aisle seat risk decreases significantly from 44% to 21%. ● As the volume of luggage carried aboard the airplane decreases, the risk duration decreases significantly. ● Doubling the aisle social distance from 1 m to 2 m increases the average boarding time and decreases both aisle and window seat risks.
Schwarzbach (2020) [81] Simulation experiment Germany (est) Oct 2020 (est)	Evaluate the applicability of technology-based social distancing methods while boarding in an aircraft cabin environment using a radio propagation simulation based on a three-dimensional aircraft model. They perform a ray tracing propagation simulation in a section of a modeled Airbus A321 aircraft cabin.	● The authors demonstrate that commonly utilized Receiver Signal Strength Indicator (RSSI) measurements can lead to false-positive and false-negative encounter classification, depending on the path-loss model tuning, lowering the reliability and user acceptance of technology-aided social distancing options. ● From an application point of view, a possible implementation of the proposed technological approaches could look at the following: Real-time proximity warning, Post-processing contact tracing, Boarding/deboarding scheduling.
Delcea (2021) [55] Predictive model Romania (est) May 2020 (est)	Estimate the number of passengers for each boarding group assuming reverse pyramid boarding with the middle seats unoccupied. Apply agent-based modeling and a stochastic simulation to evaluate impacts on boarding time and	● If the objective is to minimize health risk among passengers, then reverse pyramid boarding first group should be those with window seats in the rear half of the airplane, the third group should be passengers with aisle seats in the front half of the airplane, with the second

	health risk to passengers in each scenario.	boarding group being the remaining passengers. This arrangement was found to be the most ideal as it reduced health risk to aisle seat passengers by 25% and by 22% for window seat passengers, while increasing boarding time by 2%.
Milne (2020) [51] Predictive model US (est) Aug 2020 (est)	In these stochastic simulation experiments, the authors assess nine adaptations of boarding methods according to four performance metrics. Three of the metrics are related to the risk of the virus spreading to passengers during boarding. The fourth metric is the time to complete boarding of the two-door airplane when apron buses transport passengers to the airplane.	● Average boarding time is the comparable measurement between several scenarios. ● Increased social distance (1m to 2m) = increased boarding time. ● Increased proportion of people with luggage = increased boarding time. ● Seating the window seat passengers before aisle seat passengers decreases the risk of seat interference (where the aisle seat has to get up to let the window seat in). ● Aisle seat risk is higher when social distance is lower (1m), luggage is carried, when boarding is random. ● The author indicates that window seat risk is less than aisle seat risk during boarding, but does not estimate what the difference may be.
Schultz (2020) [52] Predictive model UK (est) Jul 2020 (est)	A cellular automata model that models the movement of passengers during the boarding process. They do not consider facemasks. They model distance to index case and contact time to estimate transmission risk.	● The model shows that compared to random boarding of people, boarding groups (e.g., families) together individually will result in the shortest boarding time 41% of the random scenario and least transmission risk 0.09 compared to 0.57-0.62 for any of the random scenarios when the plane is half-full. These boarding times were relatively stable at 75% and 100% capacity; however, transmission risk increased to 0.31 and 0.66 for the boarding in groups, individually scenario.
Cotfas (2020) [53] Predictive model Romania (est) May 2020 (est)	An agent-based model is used to simulate the passenger boarding process, mainly interactions with agents and other people. (used NetLogo platform). They model the length of time to board the plane under a number of scenarios and considering hand luggage storage times. The outcome is about length of time already seated passengers come into contact with other people either as they pass by down the aisle or due to having to get up to let a person into the window or middle seat.	● Back to Front boarding of the plane took the longest time, but had the lowest health risk in the simulation. ● The risk is similarly low if a 2-meter social distance is maintained when boarding. ● Boarding is more efficient and less risky when passengers do not have luggage to store.

In-flight transmission and seating (n=6)		
Dietrich (2021) [65] Environmental monitoring and predictive model study US (est) Apr 2021 (est)	Used bacteriophage MS2 virus dispersion data as a surrogate for SARS-CoV-2 and modeled the relationship between SARS-CoV-2 exposure and aircraft seating proximity. Both full occupancy and vacant middle seat occupancy scenarios were considered.	● Compared with exposures in full occupancy scenarios, relative exposure risk to an individual passenger in vacant middle seat scenarios was reduced by 23% to 57%. ● The 23% exposure reduction was observed for a single passenger who was in the same row and two seats away from the SARS-CoV-2 source, empty middle seat between. ● A 57% exposure reduction was observed in a scenario involving a three-row section that contained a mix of SARS-CoV-2 sources and other passengers. ● Overall exposure risk reduction in a full 120-passenger cabin with vacant middle seats ranged from 35.0% to 39.4%.
Saretzki (2021) [82] new Simulation experiment Germany (est) Oct 2021 (est)	This study investigated the distribution of exhaled air between crew members and passengers on a small aircraft (4-seater Morane Saulnier MS893E). An externally connected ventilation system was used to simulate the cockpit in-flight airflow. The airstream was marked with smoke for visualization and the airflow velocity was measured with a thermal anemometer.	● The visualized airstream in the cockpit demonstrated no crossflows, indicating no, or minimal, aerosol transport between the two pilots. ● There was negligible air flow towards the passengers who received ventilation from the additional nozzles just in front of their seats. ● In small planes, the air will leave the cockpit either via leakages of the side windows and doors, discharge valves or systems in the side windows or doors or discharge valves in the cockpit's floor. For this reason, individuals on board should be instructed to sneeze or cough towards the side wall of the cockpit or inside the crook of their arm. ● Conclusion: The risk of transmission from a strong ventilated airstream in a small plane is insignificant.
Zhang (2021) [83] new In silico study China (est) Sep 2021 (est)	A cabin model of a seven-row Airbus A320 aircraft is constructed for simulating the SARS-CoV-2 spread in the cabin with a virus carrier using the Computational Fluid Dynamics (CFD) modeling tool. The passengers' infection risk is also quantified with the susceptible exposure index (SEI) method. N_2O is used as a tracer gas to establish a continuous system, and Euler's method is applied in the CFD tool to simulate the SARS-CoV-2 concentration and distribution in this study. The virus distribution changes in the cabin under the carrier's normal	● The virus spreads to the ceiling of the cabin within 50 s of the infected passenger normal breathing. ● When the infected passenger breathes normally, the virus can spread to the seats in the front row, the same row and to the back two rows. ● When the infected passenger coughs, the virus can spread to the front three rows, the same row, and the two rows behind that an SEI>1, which indicated the risk for infection. ● While the high mass fraction areas stay on the same side of the aisle as the infected passenger.

	breathing and coughing are compared based on the simulation data.	● Simulations investigating the effects of mask wearing were not done.
Desai (2021) [68] In silico study US (est) Feb 2021 (est)	Modeled the airflow, transport of oral and nasal expired particles (e.g. CO_2 and coronavirus) at different seat positions inside Airbus Airbus 380 and Boeing B747 aircraft. Simulations considered First, Business and Economy class sections in each aircraft. Seat positions were ranked based on CO_2 mass fraction, temperature, and velocity corresponding to passenger nose positions at each seat location.	● Seat ranking across aircrafts were highly variable. ● In the first class section: The Airbus best ranked seat was warmer than the Boeing best ranked seat, but has worse circulation. ● In business class: Airbus best ranked seat was colder, but offered better circulation than the Boeing best ranked seat. The Airbus seat was located in the side bank of the seats on the aisle side and the Boeing seat was is located next to the window. ● In economy class: The best ranked seat for the Airbus was located next to the window while the best ranked seat for the Boeing was the middle seat in the side bank of the seats. The Airbus seat had a higher temperature, lower CO2 concentration, and lower air velocity, the trade-off for a warmer seat was worse circulation. ● Overall, airbus economy best ranked seat was both warm and with good circulation; the Boeing seat performed worse in all these areas.
Ghorbani (2020) [84] preprint In silico study US (est) Oct 2020 (est)	The model, Monte Carlo Simulations, optimizes the number of passengers and their arrangements under a social distancing measure for the airline industry for single aisle and double aisle scenarios.	● The figures in the paper depict optimal arrangement of passengers in an airplane. Key to safely increasing the number of passengers is to group families closely together.
Salari (2020) [67] In silico study Canada (est) Jun 2020 (est)	A mixed integer programming (MIP) model to properly assign passengers to seats on an airplane while effectively preserving two types of social distancing: keeping the passengers seated far enough away from each other and providing a safe distance between seat assignments and the aisle. They use an airbus A320 with 20 row, single aisle and three seats on each side. The MIP model ran a number of scenarios: ● Middle seat empty ● Social distance of 3.3 ft when seated ● Aisle seat empty ● Hybrid	● If social distance is completely adhered to, no aisle seat use and no one within 3.3ft, the max load is 20 passengers in a 120-seat plane. ● If passengers can sit in the aisle seat, this increases to 30 passengers socially distanced 3.3ft+. Sitting in the aisle should include strategies to limit movement / possible exposure of people moving around the plane. ● Middle seat blocking policy lead to less multiple people within 3.3.ft compared to the leave the aisle seat open policy. ● The more people on the plane, the more people were seated close to each other and thus considered to be in increasingly higher risk situations with 1, 2 or 3+

		people within 3.3.ft. See figures for illustration.
Boarding to disembarkation (n=1)		
Namilae (2021) [47] preprint new Predictive model US (est) Jun 2021 (est)	An infection spread model was developed using pedestrian dynamics to model the movement of passengers during boarding and deplaning and the passenger trajectories and seating arrangements. This model accounted for varying infection dose by distance to an infective person and then included a standard exponential dose-response relationship for infection risk. The model was then calibrated against a different super spreading event and modified to account for public health measures such as mask wearing. Data from three flights was to inform the model. Specifically, they used: 1) London to Hanoi on Mar 1, 2020, 201 passengers with 1 index passenger resulting in 13 secondary infections; 2) Singapore to China on Jan 24, 2020, 321 passengers with 2 index cases and 12-14 secondary infections; 3) Japan to Israel on Feb 20, 2020, 9 passengers with no secondary infections.	● Simulation results for secondary infection by passenger status during the London flight indicate that the boarding/deplaning processes contribute more to infection risk than inflight movement does (4.4 vs 0.7). ● Using the data from the Singapore flight as an example, the simulation demonstrated that if everyone had used FFP2 or N95 masks for the entire duration of the flight, there would be 2.3 secondary infections compared to 55 with no mask usage. ● Over 50 simulations revealed that the type of mask impacted secondary infections. With the middle seat vacant, the mean secondary infections were 29.75 with no masks, 5.72 with cloth masks, and 0.99 with N95/FFP2. This increased by all mask types when the middle seat was not vacant (55.03 no masks, 10.46 cloth masks, and 2.32 N95/FFP2 masks). ● Overall, N95/FFP2 and cloth mask usage would have reduced infections by 95-100% and 40-80%, respectively.
Aerosol studies in an airplane (n=7)		
Talaat (2021) [58] Simulation experiment US (est) Feb 2021 (est)	Studies in-flight aerosol transmission and surface contamination using a computational model of a cabin zone of a Boeing 737. The investigation aims to understand the effect of reducing passenger capacity (from 60 to 40) and to compare to alternative intervention measures such as using sneeze shields (sneeze guards) between passengers on a full capacity flight. The investigation considers a wide range of particle sizes (1–50 µm). This study does not take into account more than one infection on board, human behaviour e.g. talking, eating, drinking, adherence to mask wearing, or moving down the aisles.	● Particles take 2–3 min to deposit or leave the system as air in the cabin is rapidly renewed. ● Aerosol in the 1 µm–20 µm size range is concentrated within one row of the index patient, and virtually, no particles make it past two rows from the index patient. Larger particles such as 50 µm particles are only present in the row of the index patient. ● A relatively small fraction (21–26%) of exhaled particles are directly removed by the ventilation system. The majority of the particles deposit on surfaces in the cabin, with more 1 µm particles depositing on the walls than on the ground (10–14% vs 3%–6%). ● The most contaminated surfaces in the full capacity model (60 passengers) with no sneeze guards are the passengers (including the index patient) at 31% deposition fraction followed by the seats

		at 27%. In the reduced capacity model with no sneeze guards and the full capacity model with sneeze guards, total deposition on passengers is reduced to 21% and 15%, respectively. ● The total inhalable fraction is the lowest in the full capacity model with sneeze guards (0.5%) followed by the reduced passenger capacity model without sneeze guards (0.7%) and then the full capacity model without sneeze guards (1.7%). However, reduction in passenger capacity and use of sneeze guards eliminates the direct transmission of 50 µm particles. Although these particles deliver a much smaller inhalable fraction compared to 1 µm particles, they contain substantially more virions than 1 µm particles due to their volume.
Kinahan (2021) [59] Simulation experiment US (est) Jan 2021 (est)	Aerosol dispersion and deposition in two wide-body aircraft (Boeing 767-300 and Boeing 777-200 at 30,000 ft) was measured using fluorescent and DNA-tagged microspheres. Experimental data included over 300 releases from a simulated SARS-CoV-2-infected passenger in seats while in-flight. The tests were designed to measure the aerosol concentration within passenger breathing zones in neighboring seats and rows from the simulated infected passenger. The breathing releases included a mix of tests with the mannequin not wearing a mask and tests with a mask. This study does not take into account more than one infection on board, or human behaviour (e.g., talking, eating, drinking, or adherence to mask wearing).	● The maximum exposure, 0.0947-0.4614%, occurs in a seat next to a source, with the next highest risk of inhalation typically occurring in the seats in front and behind the simulated infected passenger. This maximum exposure risk equates to a minimum reduction of 99.54% of 1 µm aerosols from the index source to the breathing zone of a typical passenger seated directly next to the source. ● Less than 0.03% of tracer particles settle out on solid surfaces during testing, with the highest concentration on the surfaces closest to each release location. Notably horizontal surfaces, such as arm rests were typically higher than vertical surfaces such as seatbacks and inflight entertainment (IFE) systems. ● The average reduction with a mask in total particles counted was 15.6%.
Rivero-Rios (2021) [44] Biological monitoring study US July 2020	Particulate matter (PM) concentrations were measured in a variety of indoor spaces including 19 flights, retail/grocery stores, restaurants, office spaces, homes, and other transport (private cars, buses, trains). Flights were chosen to cover a range of flight durations/destinations and aircraft models and including the following stages of air travel: Terminal (departure), Boarding, Taxiing (out), Climbing, Cruising, Descending,	● In-flight particle concentration in the air in aircraft was lower than that of retail/grocery stores, restaurants, office spaces, homes, and other transport tested. ● Particles with diameters smaller than 1 µm dominate the total particle number concentrations (because they are the most difficult to remove by filtration). ● PM concentrations exhibited a V-shape pattern, with high levels at boarding and a continued decrease and stable minimum concentration during cruising.

	Taxiing (in), Disembarkation, and Terminal (arrival).	Slight increases in particle mass concentration during food service were observed. When the plane began descending, particle concentrations started increasing and an abrupt increase was typically observed once the cabin door was opened and the disembarkation process began. ● Air exchange rates in the cabin are rapid during flight, reducing the number of particles in the cabin significantly. Ambient air at altitude contains fewer particles than air at the surface, contributing to low cruising particle number and mass concentrations and also explains the decrease and increase observed during climbing and descending.
Kotb (2020) [45] In silico study Egypt (est) Sep 2020 (est)	In this computational fluid dynamic (CFD) modeling simulation to examine what happens to respiratory droplets when expelled by a sneeze or cough by a person moving around an airplane cabin.	● The airflow of coughing and sneezing droplets produced from the moving passengers could reach seated passengers several rows from the source compared to when standing still. Cough distance 1.1m, sneeze went further when standing still. ● Comparing the droplets spread range resulting from the moving passenger and stand-still one, the quicker the passenger moves, the further the droplets spread. ● Figures illustrate coughing/sneezing during standing and in motion in an economy class airplane cabin.
Silcott (2020) [46] Unpublished Simulation experiment US Aug 2020	The simulations used 767-300 and 777-200 aircrafts/models to study aerosol penetrations by an infected COVID-19 passenger into the area around them. 300 replications were conducted including terminal loading and unloading. Inflight simulations conducted in the hanger and at 35 000ft. This study does not take into account human behaviour e.g. talking, eating, drinking, adherence to mask wearing or other modes of transmission e.g. fomite.	● High air exchange rates 1.8 x 108 on aircraft. Cumulative particle exposure was 10x less on the airplane compared to a residential house. ● Particles were in the cabin less than 6 minutes (vs. 1.5h in a house). Air particulate removal was 15x faster than in a house and 5x faster than in a modern hospital isolation room. ● Surgical masks were used in simulations, there was a >90% reduction in droplets released during the cough simulation compared to no mask. ● Sharing a row with a COVID-19 case is the highest risk, the row behind and in front are the next highest risk. There was little practical difference in risk between seats. See figures in paper. ● The individual air nozzle did not make a difference to the risk.

		• During embarking and disembarking, keeping the air circulating, loading in small groups may reduce risk. There was low risk of jet wave exposure from an infected person already sitting on the plane.
Yan (2020) [71] Simulation experiment Australia (est) Aug 2020 (est)	This study developed a computational model to mimic a Boeing 737 economy section with three rows and 9 manikins.	• The cough flow was found to have a long and effective impact on contaminants transport, up to 4 s (or 8x longer than the cough). • A wide range of sizes of droplets was dispersed in the direction of the cough due to the strong jet-effects of coughing compared to what occurs with ventilated flow. (see figures in paper).
Yang (2018) [69] In silico study Australia (est) Dec 2017 (est)	Using computational fluid dynamics, this study investigated the effect of cough-jet on local airflow and containment transport in a typical airplane cabin. The particle dispersion from a cough in a three-seat airplane row was simulated.	• The travel distance of cough particles was heavily influenced by the direction and type of cough. The aisle seat person coughing resulted in longer particle travel distance than the middle and window seat. The middle seat was considered the most at risk of exposure seat.
Reviews (n=1)		
Jayaweera (2020) [85] Literature review Sri Lanka (est) Jun 2020 (est)	Literature Review on aerodynamics of SARS-CoV-2 in droplets and aerosols – in an Airplane Cabin (see Appendix 1). The section of the review that focuses on airplane cabins.	• They describe the flow of air in the cabin and reports a complete air exchange within 2-3 minutes, which should be good for quickly dissipating virus-laden droplets. They also indicate the air is passed through a HEPA filter, which can remove particles >0.3 µm. Cough-jet trajectories with no mask, surgical mask and N95 mask are described in the paper.

Abbreviation: Est, Country of study based on author affiliations and date of study based on publication date

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