Probability and Estimated Risk of SARS-CoV-2 Transmission in the Air Travel System

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Abstract

This paper estimates the probability of an infectious index passenger in the air travel system transmitting the SARS-CoV-2 virus to a fellow passenger during air travel. The analysis is based upon available data from several peer-reviewed and governmental sources. Variation and error in estimates due to structural variability in testing, reporting, and tracing for infected individuals in the air travel system are considered. Based upon a conservative view of the potential errors, the global risk of infection during air travel is calculated to be 1:1.7 million. Uncertainty in the number of asymptomatic persons and underreporting of SARS-CoV-2 cases indicate the transmission risk could range from 1 case for every 712,000 travelers to 1 case for every 8 million travelers.

Introduction

In late 2019, an outbreak of a novel coronavirus disease, now known to be caused by the SARS-CoV-2 virus and named Corona Virus Disease 2019 (COVID-19), was first documented in Wuhan, China.[1] By January 2020, the disease was confirmed to have spread to other parts of Asia,[2] and by February 2020 cases were being seen around the globe.[3] The World Health Organization (WHO) declared the global outbreak a pandemic on March 11, 2020.[1] As the pandemic continued, the air travel industry was severely impacted with a nearly 95% drop from 2019 passenger levels in a matter of weeks.[4] With segments of the global population continuing to travel, however, questions emerged regarding the risk of disease transmission in the air travel system, and specifically in the aircraft cabin. Although the risk of COVID-19 transmission is perceived to be high among the flying public, a data-driven approach is required to determine the actual range of risk.

This paper estimates the risk of COVID-19 transmission during air travel by estimating the risk of transmission in the air travel system from data collected during the pandemic and currently available from multiple sources. Acknowledging that COVID-19 testing and reporting requirements vary by locality and can be difficult to trace to air travel, uncertainties are included in these risk calculations to more conservatively estimate risk. This paper is limited to publically available literature which primarily considers infectious passengers and related transmissions during air travel; transmission risk among airport personnel such as TSA agents or crew-to-crew transmission are not addressed.

Research on disease transmission in flight from other viruses such as from SARS-CoV-1,[5] Influenza,[6] and Tuberculosis[7] has shown that the risk of any communicable disease being transmitted aboard aircraft is low.[8] Generally, investigations have found low COVID-19 transmission rates, such as was the case for the well-documented Milan-South Korea repatriation flights in March (one secondary case on each flight) where passengers wore masks and participated in mandatory screening and quarantine[9] and the Singapore-Hangzhou flight in early January with fifteen index passengers but only one potential secondary case.[10] A notable exception is the VN54 flight between London and Hanoi on March 1st-2nd in which fifteen secondary cases were presumed to be related to one index passenger.[11] However, the VN54 flight study's non-quantitative analysis and the large number of days between flight and COVID-19 test brings into question if each of these fifteen COVID-19 cases was the result of transmission in the airplane cabin or exposures after the flight from other social interactions.

Methods

I. Estimated Risk of Transmission in the Air Travel System

A literature review was performed to identify index and transmission COVID-19 cases related to the air travel system. Index passengers are those who tested positive for COVID-19 upon arrival at their destination. They therefore, with a high degree of confidence due to the known incubation period of the disease, were infected prior to entering the air travel system. Secondary cases are persons who travelled on a flight with an index passenger, test positive for COVID-19 after the flight, and are identified through contact tracing to have most likely been infected via transmission from the index passenger. Conservatively, all probable secondary cases identified in the literature are included in risk calculations.

i. Calculation of Estimated Risk of Transmission

The number of infected index persons in the referenced transmission events were determined through either mandatory screening or self-reporting, and it is likely that this count of infected persons is much lower than the true number of persons who have flown while infected. A number of caveats must be considered for potential error in the risk calculation. The first is the number of people who are infected, but are asymptomatic. Per the CDC, asymptomatic infections are nominally estimated to be 40% of the total infections and asymptomatic individuals are estimated to be 75% as infectious as a symptomatic individual.[12] This indicates a factor of 1.3x if assuming asymptomatic passengers are not counted as a secondary case in the data. The second issue is the number of unreported COVID-19 cases, both index and secondary, in relation to air travel which includes:

- Symptomatic passengers who seek medical attention for symptoms, but do not inform medical personnel of their travel;
- Symptomatic passengers who seek medical attention for symptoms, but medical personnel fail to report travel; and
- Symptomatic passengers who do not seek medical attention.

To account for underreported air travel cases, the number of unreported COVID-19 cases in the general global population is assumed to apply. Recent estimates indicate global under-reporting to be a 10-fold,[13,14] 23-fold[15] and 54-fold[16] multiplier of the current reported cases.

With these caveats, the equation for estimated risk of transmission is as follows:

$$estimated\ risk\ of\ transmission = \frac{n_t}{n_p} \times f_a \times f_c \qquad \textit{Equation 1}$$

where n_t is the number of secondary cases due to air travel transmission, n_p is the total passenger population, f_a is the factor to account for number of and infectiousness of asymptomatic cases, and f_c is the factor to account for number of unreported cases.

Results

I. Estimated Risk of Transmission in the Air Travel System

During the pandemic it has been estimated that, even with a significant decline in air travel, approximately 1.4 billion passengers traveled by air between January and September 2020.[17] As of August 2020, there were at least 2866 index passengers documented to have passed through the air travel system (Table 1). Due to the widespread prevalence of the disease and presence of pre-symptomatic, asymptomatic, and mildly symptomatic cases in the population, it is known that there necessarily have been additional COVID-19 infectious passengers entering the travel system, beyond the identified index cases. Nonetheless, review of publicly available data reveals fewer than 50 documented potential secondary cases associated with air travel during the pandemic. Mask use on reviewed flights ranged from use unknown to mandatory N95 use.

Table 1 documents the index and secondary cases for passengers who have flown during the pandemic. IATA and CDC data are included for thoroughness with the acknowledgement that limited details are known about the data methods and sources and that case counts may be duplicates of other reported cases.

Table 1. Flight, passenger and reference list for index persons and secondary cases due to transmission.

Flight Information		Affected Persons		Author
Date	Country/City Pair	Index	Secondary (due to Transmission)	
General IATA Data		1100	3	IATA[18]
General CDC Data		1600	0	Duncan[19]
1/22/2020	China-Toronto	1	0	Schwartz et al.[20]
1/24/2020	Singapore-Hangzhou	15	1	Chen et al.[10]
2/20/2020	Tokyo-Tel Aviv	2	0	Freedman and Wilder-Smith[21]
2/24/2020	Bangui (CAR)-Paris	1	1	Eldin et al.[22]
2/26/2020	Multiple-Greece	21	5	Pavli et al.[23]
3/2/2020	London-Hanoi	1	15	Khanh et al.[11]
3/9/2020	Tel Aviv-Frankfurt	7	2	Hoehl et al.[24]
3/10/2020	Boston-Hong Kong	2	2	Choi et al.[25]
3/11/2020	New York City-Taipei	11	0	Freedman and Wilder-Smith
3/19/2020	Sydney-Perth	11	11	Speake et al.[26]
3/31/2020	Milan-South Korea	6	1	Bae et al.[9]
4/3/2020	Milan-South Korea	3	1	Bae et al.
6/20/2020	Dubai-Hong Kong	85	2	Freedman and Wilder-Smith; IATA[27]
	Total	2866	44	

For the purpose of this study, transmission from the index passenger was conservatively assumed to have occurred inside the aircraft cabin in each of these documented cases, although transmission could have occurred elsewhere, such as in the airport. For example, the 15 secondary cases associated with the London-Hanoi flight on March 2, 2020 may not all be the result of in-flight transmission. All of these 15 passengers had either hotel, cruise ship, secondary transportation, travel to a second country, and known contact with other infectious persons not from the flight, or combinations thereof, after the flight from London to Hanoi and prior to testing.[11] Based on the arrival date of the flight (March 2) and the earliest date of the following reverse transcriptase polymerase chain reaction (RT-PCR) tests (March 6), it is possible that the potential secondary cases were infected post-flight since a positive test via PCR can occur on average 2 to 5 days after infection.[28] The testing of the London to Hanoi passengers did not include genomic analysis of the virus and therefore it was not possible to demonstrate that all of the secondary cases were of the same origin point. For these reasons, the causal connection between the London to Hanoi flight and the eventual positive test results for the 15 cases is in question.

i. Epidemiological Study of SARS-CoV-2 in Flight

An epidemiological study of the January 24, 2020 flight from Singapore to Hangzhou, China with a number of confirmed COVID-19 cases on board (Figure 1) was recently completed.[10] This flight, which lasted approximately five hours, was loaded at 89% capacity. Upon arrival at the destination, all passengers and crew were quarantined and tested as necessary. The study determined that of the 16 passengers who ultimately tested positive for COVID-19, 15 of the passengers were index cases on the flight due to the timing of symptom onset; if they had been infected on the flight, they would not have had symptoms immediately after the flight. The index cases had membership in one of three tour groups with other passengers who also tested positive for COVID-19 and originated in Wuhan. Only one passenger was identified to be a potential secondary case of SARS-CoV-2 in flight due to a different city of origin (Hangzhou), membership in a different tour group with no recorded cases of COVID-19, and reported activity of temporarily moving to an unassigned seat surrounded by infectious and symptomatic passengers during the flight as indicated in Figure 1. All 16 passengers wore masks during air travel, but removed their masks during meal time and to drink water; the mask of the secondary case was not worn tightly and did not cover their nose when sitting in the unassigned seat.

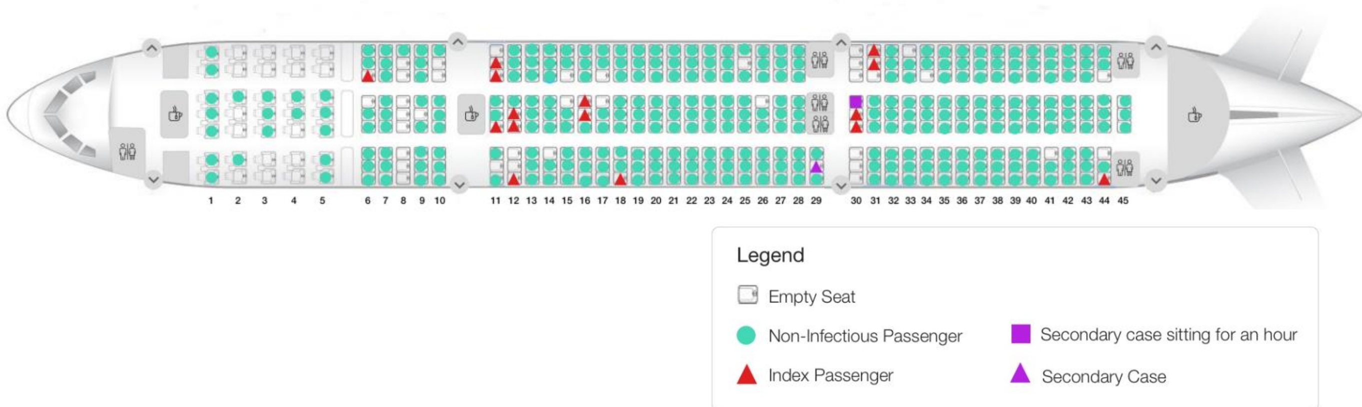

Figure 1: Seat map of flight with 15 index passengers and one possible secondary case.

ii. Estimated Risk of Transmission

The secondary cases listed in Table 1 are for over 10 flights that occurred March 2020 or earlier, while flight traffic was still high, in areas like Europe and the United States. To take a conservative position on risk, transmission risk was calculated for three time periods of interest: (1) January–June 2020 during which the transmission events all occurred, (2) the month of March 2020 due to the global spread of COVID-19, and (3) April–September 2020 to account for the sharp drop in worldwide air travel and increased use of COVID-19 testing. For a slightly more conservative risk calculation, the 3 secondary cases recorded by IATA were included in the multi-month risk calculations (January-June 2020, April-September 2020) based on the assumption that March was a well-documented month, so it is unlikely that these cases are duplicates of the transmission events in that month. Passenger counts were derived from ICAO monthly reporting of actual passenger totals.[17] Table 2 lists the estimated risk of COVID-19 transmission in the air travel system for the global public as calculated with Equation 1.

Table 2. Estimated risk of transmission in the air travel system for the global public in 2020.

Dates	n_t	n_p (million)	f_a	f_c	Risk	
					Numerical	1 in X
January-June 2020	44	965	1.3	10	5.927x10^-7^	1,687,063
				23	1.363 x10^-6^	733,506
				54	3.201 x10^-6^	312,419
March 2020	31	171.3	1.3	10	2.353 x10^-6^	425,062
				23	5.411 x10^-6^	184,810
				54	1.270 x10^-5^	78,715
April-September 2020	6	552	1.3	10	1.413 x10^-7^	7,076,923
				23	3.250 x10^-7^	3,076,923
				54	7.630 x10^-7^	1,310,541

For 44 secondary cases from January–June 2020 with 1.3-fold factor for asymptomatic persons (f_a) and a 10-fold factor for underreporting (f_c) against a population of 968 million travelers, the risk of being infected with COVID-19 in an airplane cabin is 5.927×10^{-7} or 1:1.7 million. A 54-fold multiplier of current reported cases gives a risk of 3.201×10^{-6} or a 1:312,419 chance of being infected with COVID-19 in the airplane cabin.

Due to developing availability and reliability of COVID-19 testing and localized variability in reporting since the start of the pandemic, statistics for asymptomatic persons, infectiousness, and underreporting carry a degree of uncertainty which affects the overall risk calculation. The CDC indicates that asymptomatic patients could range from 10–70% of the infected population and that asymptomatic infectiousness ranges from 0.25–1.00.[12] The Chow et al. study indicates a 95% credible interval for an estimated 10-fold underreporting factor ranges from 2.2–50.[14] For this paper's treatment of risk, uncertainty is established by first identifying the uncertainty in factors f_a and f_c in Equation 1, next fitting triangular distributions to each statistic with the peak at the baseline values stated above, then running 1 million simulations with a draw from each distribution to calculate risk, and finally selecting the 2.5% and 97.5% risk estimate from the 1 million simulations which set the bounds of the uncertainty interval. Using the above literature estimates of uncertainty in the parameters of f_a and f_c, uncertainty in the transmission risk is estimated to be from 1 case for every 712,000 travelers to 1 case for every 8 million travelers.

At the onset of the pandemic in March, the estimated risk of transmission was 2.353×10^{-6} or 1:425,062 (f_c=10). Estimated risk of being infected with COVID-19 could have been as high as 1:78,715 (1.27×10^{-5}, f_c=54). In comparison, estimated risk during the pandemic (April–September 2020) ranges from 1:1.3 million (f_c=54) to 1:7.1 million (f_c=10) with reduced passenger traffic and few documented secondary cases.

Discussion

The following section discusses the practical application of the risks described above for the air traveler.

Fewer than 50 passenger-related secondary cases have been recorded in the air travel system since the outbreak of COVID-19. There is documented evidence of flights with multiple infectious passengers but few or no secondary cases recorded.[9,21,23] Moreover, the majority of the documented secondary cases occurred on flights in March 2020 or earlier, when current common practices like wearing face masks and increased sanitization varied by region.[29] A notable finding of the Chen et al.[10] study discussed above is that only one possible secondary case was identified despite the large fraction of passengers on this flight, next to, in front of and behind index passengers. While physical distancing recommendations of many health organizations worldwide recommend 6 feet of separation to lower transmission risk,[30] the results of this study indicate the actual risk of transmission in an aircraft cabin is still very low. This finding warrants a detailed analysis of the aircraft cabin environment that could explain how such results are possible.[31]

The ICAO traveler population numbers, used in risk calculations presented herein, include global passengers, from regions such as Africa with less immediate outbreaks of COVID-19. Their inclusion could lower the ratio of infectious passengers to all passengers. Risk is also lowered by decreased worldwide air travel starting in March 2020 and limitation of air travelers to a small self-selecting subset of the global population, therefore a 10-fold change is assumed sufficient for a baseline estimated risk of transmission during air travel. Recognizing that studies could be ongoing to identify transmission events in the air travel system from this summer, the estimated transmission risk calculated for January–June 2020, 5.927×10^{-7} or 1:1.7 million (f_c=10), should be considered the baseline estimated risk of transmission. With uncertainty, this risk may range from 1 case for every 712,000 travelers to one case for every 8 million travelers.

While the risk of transmission in March was higher than current estimates, COVID-19 transmission aboard an airplane in March was still a low probability event. It should be noted that these calculations are based on limited testing of 2020 travelers and limited publically available data, and are subject to the forces of a shifting global pandemic. While the specific numbers will change as more flights are made, tests performed, and papers published, the reports to this date indicate a low risk of transmission aboard an aircraft.

Conclusion

Research has shown that the risk of any communicable disease being transmitted aboard aircraft is low.[8] This conclusion is consistent with studies on disease transmission in flight from other viruses such as from SARS-CoV-1,[5] Influenza,[6] and Tuberculosis.[7] Similarly, the risk of COVID-19 transmission on an aircraft is also low, approximately 1:1.7 million. Given the global spread of COVID-19, it is clear that infectious individuals, including asymptomatic individuals, have been traveling by air. However, there has not been the large number of secondary cases that might be expected. Analysis of the limited reporting on infections traced to the air travel environment during the current SARS-CoV-2 pandemic supports the conclusion that even with infectious persons onboard, the overall risk of contracting COVID-19 from such an index passenger is low.[9,10,20-27]

It is thought that the engineering controls on the aircraft, that are more effective than those in common commercial spaces that the public may experience, contribute to the low probability of infection in the air travel system. Specifically, the high airflow, high-efficiency particulate air (HEPA) filtration, and seat-height/passenger-positioning (passengers do not face one another for the majority of the flight) are thought to minimize air flow between rows and protect passengers from infectious particle transfer. Studies of the engineering controls on aircraft are currently being prepared for publication by these authors.

Finally, the improvement in safety provided by wearing masks is well established.[32,33,34] The outcomes presented in this paper in no way affects the recommendation that masks be worn properly at all times when in public spaces; they should be worn when in public to protect others and one's self.

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