

# Covid-19 Risk Among Airline Passengers: Should the Middle Seat Stay Empty?

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Recent research results and data generate the approximation that, when all coach seats are full on a US jet aircraft, the risk of contracting Covid-19 from a nearby passenger is about 1 in 4,300 as of early July 2020. Under the “middle seat empty” policy, that risk falls to about 1 in 7,700. These estimates imply Covid-19 mortality risks to uninfected air travelers are considerably higher than those associated with plane crashes but probably less than one in 500,000.

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## *Introduction*

As of 7/1/20, the US air carriers American, Spirit, and United Airlines are filling all seats on their flights when demand warrants, but Delta, jetBlue, and Southwest Airlines will keep middle seats empty. While Delta Airlines plans to continue its policy well beyond September 2020, United Airlines CEO Scott Kirby stated that there is no such thing as social distancing on a plane, implying that limited distancing confers no real benefit compared to none. What does the evidence suggest about the wisdom of a “middle seat” policy as a safety measure?

Answering that question entails major complications and uncertainties, which can easily lead one to throw up one’s hands. But even a rough approximation of the risks at issue seems preferable to clashes of unsubstantiated conjectures. This paper strives for such an approximation, with an emphasis on the word “rough.”

To estimate the risk to an uninfected passenger from a passenger experiencing Covid-19, it is necessary to consider three questions:

- What is the probability that a given passenger on board is contagious with Covid-19?
- What is the probability that universal masking can prevent a contagious passenger from spreading the disease?
- How does the risk of infection depend on the locations on the aircraft of both the contagious and uninfected passenger?

The general formula for combining the answers to these questions is:

$$P = Q * Q_M * Q_L \quad (I)$$

where P= the probability that a particular uninfected passenger contracts Covid-19 during the flight

Q = the probability that a given passenger on the flight has covid-19

(It is assumed the Q is small enough that having two or more contagious passengers near the uninfected one is a remote risk.)

$Q_M$  = the probability that universal mask-wearing on aircraft *fails to prevent* transmission of Covid-19

$Q_L$  = the conditional probability that a contagious passenger transmits Covid-19 to the uninfected one *if the mask fails*

$Q_L$  and thus P can depend on whether the operating policy is “fill all seats” or “middle seat empty”

### *The Estimation of Q*

For a given passenger from a particular American state, the risk of contagiousness is estimated in several steps:

- First, one finds  $N_7$ , the number of confirmed new Covid-19 infections in that state over the last seven days (1) Seven days is chosen because that is the approximate length of the contagiousness period for someone experiencing Covid-19. (The average such period is a bit below seven days in asymptomatic cases and higher than seven in symptomatic ones; see (2,3).)
- Then, in accordance with recent findings from the US Centers for Disease Control (4) , one multiplies  $N_7$  by *ten* to approximate the actual number of new infections in the state over the previous week.
- Then one recognizes that people with Covid-19 who board airplanes are presumably either asymptomatic, pre-symptomatic, or mildly symptomatic. (Those with severe symptoms are unlikely to be flying.) Because of evidence that asymptomatic Covid-19 carriers are only about half as contagious as others (3), one multiplies the prior product by a factor of  $\frac{3}{4}$ .

(This factor of  $\frac{3}{4}$  arises if one assumes that asymptomatic Covid-19 passengers constitute about half of those Covid-19 passengers who board a flight, while the other half have the usual level of contagiousness.)

- Then one multiplies by a factor of  $\frac{1}{2}$  as an approximate reflection of the premise that passengers who fly are generally more affluent (and less likely to encounter Covid-19 risks) than the citizenry at large.
- Finally, one divides by  $N_{POP}$ , the state's estimated population in 2020, to obtain  $N_7/N_{POP}$  as the state's per capita rate of new *confirmed cases* over the last week.

The estimate of  $Q$  consistent with these specifications is:

$$Q \approx (N_7 * (10) * \left(\frac{3}{4}\right) * \left(\frac{1}{2}\right)) / N_{POP} = 3.75N_7 / N_{POP}$$

For Texas, which has a high number of recent Covid-19 cases,  $N_7$  as of 6/30/20 was 42,254, while  $N_{POP}$  was 29.1 million. With those numbers,  $Q \approx \frac{1}{184}$ . In New York, which is well past the peak of its epidemic, the corresponding numbers are  $N_7 = 5,200$  and  $N_{POP} = 19.5$  million, yielding  $Q \approx \frac{1}{1000}$ .

### *The Estimation of $Q_M$*

Here we assume that all passengers wear masks. For  $Q_M$ , a meta-analysis in *The Lancet* (5) estimated that mask wearing cuts transmission risk given contagiousness from 17.4% to 3.1%, a reduction of 82%. Ignoring the possibility that the masks under study were more effective than those worn by airline passengers, one can estimate  $Q_M$  as  $1 - .82 = .18$ .

### *The Estimation of $Q_L$*

This quantity depends on the airline's seating policy, as well as the

duration of the flight. Chu et al (6) estimated that transmission risk given contagion is about 13% assuming direct physical contact and drops by  $\frac{1}{2}$  for each meter further apart. Under this pattern of exponential decay, transmission risk  $R_T$  can be modeled by the equation:

$$R_T \approx 0.13 * e^{-.69d} \quad (\text{II})$$

Where  $d$  = distance between contagious and uninfected person

$e= 2.718$ , the base of the natural logarithms

This formula assumes no barriers between the infected and uninfected persons. If there were (say) a layer of plexiglass between the two, then transmission risk would essentially drop to zero.

In this exercise, we focus on the coach sections of the two widely-used jet planes, the Airbus 320 and Boeing 737. There are six seats in each coach row, consisting two sets of three seats separated a center aisle. The individual seats are approximately 18 inches wide, while the aisle width is about 30 inches. If the seats are labeled A/B/C and D/E/F, where A and F are the window seats, B and E the center seats, and C and D the aisle seats then, under the “fill all seats” policy on a flight that is full, all six seats will be occupied. Under “no middle seats,” A/C and D/F will be occupied on a full flight but not B/E.

We first consider the transmission risk to an uninfected passenger in the window seat A, under each policy *and full flights*. In doing so, we first assume that the primary source of risk to uninfected passengers are other passengers seated *in the same row*. While imperfect, this assumption could be plausible because (i) the air in the aircraft cabin is constantly refreshed, so the cabin does not constitute a closed indoor space (ii) the seatbacks in Row 16 can somewhat

block infectious emissions from contagious passengers in Rows 17 and behind, while the opposite happens for rows ahead of Row 16.

The transmission risk for a A-seat passenger because of others in the same row is obtained by adding the risks related to those other passengers:

$$Q_L(A \text{ same row}) \approx \begin{cases} R_T(A, C) + R_T(A, D) + R_T(A, F) & \text{under middle seat open} \\ R_T(A, B) + R_T(A, C) + R_T(A, D) + R_T(A, E) + R_T(A, F) & \text{under "fill all seats"} \end{cases} \quad (\text{III})$$

where  $R_T(A, X)$  = transmission probability *absent masks* given a contagious passenger in seat X of a given row and an uninfected passenger in seat A of that row (treating multiple contagious passengers in the same row as a remote possibility)

$$R_T(A, X) \text{ is approximated by } R_T(A, X) \approx .13e^{-.69d(A, X)} \quad (\text{IV})$$

where  $d(A, X)$  = distance from a person's head in the *middle* of seat A to another person's in the middle of seat X. In inches, this distance is 18 inches for seat B,  $18+18=36$  inches for seat C,  $36+9+30+9=84$  inches for seat D,  $84+18=102$  inches for seat E, and  $102+18=120$  inches for seat F. Because a meter is 39.37 inches,  $d(A, B)$  in meters is  $18/39.37 = .457$ . Similarly,  $d(A, C) = .914$ ,  $d(A, D) = 2.13$ ,  $d(A, E) = 2.59$ , and  $d(A, F) = 3.05$ .

One can use (III) and (IV) to obtain:

$$Q_L(A \text{ same row}) \approx \begin{cases} 0.115 & \text{under middle seat empty} \\ 0.232 & \text{under "fill all seats"} \end{cases}$$

Using similar reasoning, one can likewise determine that:

$$Q_L(B \text{ same row}) \approx .282 \text{ under "fill all seats"}$$

$$Q_L(C \text{ same row}) \approx \begin{cases} 0.155 & \text{under middle seat empty} \\ 0.291 & \text{under "fill all seats"} \end{cases}$$

$$Q_L(D \text{ same row}) = Q_L(C \text{ same row});$$

$$Q_L(E \text{ same row}) = Q_L(B \text{ same row});$$

$$Q_L(F \text{ same row}) = Q_L(A \text{ same row});$$

Averaging across all the passengers in a given row yields:

$$Q_L(\text{same row}) = \begin{cases} .268 & \text{under "fill all seats"} \\ .135 & \text{under middle seat empty} \end{cases}$$

Previous studies have indicated, however, that contagious air travelers can infect passengers seated in other rows. A study on SARS transmission in 2003 on a particular flight (7) noted that about half of those infected were within two rows of the traveler with SARS and the rest more than two rows away. But a more recent National Academy of Sciences (NAS) study with the same authors concluded that transmission risk was minimal more than one row away from the contagious person (8). (The later study suggested that those infected on the SARS flight may have become so in the boarding area rather than on the aircraft.). The NAS study concerned droplet-mediated respiratory diseases; a more recent article (9) stated that Covid-19 on airplanes was primarily spread through droplets.

The authors of (8) estimated that transmission was possible within one meter of the contagious person, affecting the same number of people in the row before or the row behind that

person as in the same row. They assigned equal probabilities of contagion to all three rows, though they noted that they did not consider the fact that seatbacks are barriers to transmission. Absent existing studies about the benefit conferred by seatbacks, we make the following approximations:

- When the flight is full, the six passengers one row ahead of the uninfected passenger pose  $\frac{1}{4}$  the transmission risk of the five passengers in the same row
- When the flight is full, the six passengers one row behind the uninfected passenger pose  $\frac{1}{4}$  the transmission risk of the five passengers in the same row
- When the flight follows “middle seats empty” but is otherwise full, the four passengers one row ahead of the uninfected passenger pose  $\frac{2}{3}$  the transmission risk of the six passengers in that row had the flight been full
- When the flight follows “middle seats empty” but is otherwise full, the four passengers one row behind the uninfected passenger pose  $\frac{2}{3}$  the transmission risk of the six passengers in that row had the flight been full

If the factor of  $\frac{1}{4}$  overstates the effectiveness of the seatbacks against contagion, then the estimate of  $Q_L$  advanced here could well be too low.

Under these approximations:

$$Q_L(\text{full flight}) = 1.5Q_L(\text{full flight, same row})$$

$$Q_L(\text{middle seat empty}) = Q_L(\text{middle seat empty, same row}) + \left(\frac{2}{3}\right) * \left(\frac{1}{2}\right) Q_L(\text{full flight same row})$$

Thus:

$$Q_L = \begin{cases} 1.5 * .268 = & .402 \text{ for full flight} \\ .135 + \left(\frac{2}{3}\right)\left(\frac{1}{2}\right) .268 = & .224 \text{ when middle seat empty} \end{cases}$$



One might expect that the risk of infection would vary with the duration of the flight, perhaps in proportion to the time spent with a contagious person (10). Unfortunately, it is unclear how to incorporate flight time into the risk analysis. The papers that Chu et. al. synthesized in their meta-analysis that led to (II) involve varying (and unreported) times of exposure, with an unknown relationship to the two-hour flight time for an average US domestic flight. Absent further information, the analysis here will not consider any differences between flight times and the exposure times in the studies synthesized by Chu et. al. Thus, the calculations will use the expressions for  $Q_L$  (A same row) and kindred quantities as estimated above. Readers uncomfortable with this assumption can linearly adjust the results presented, in a form of sensitivity analysis. If one believes, for example, that (2) is appropriate for one hour of exposure, then one might consider doubling the transmission-risk estimates used here.

### *Overall Risk Calculations*

The various estimates can be combined via (I) to achieve an approximate probability of infection for coach passengers on full flights. Given a focus on US domestic jet flights, one might approximate  $Q$  by taking the average of the estimates for higher-infection-rate Texas and lower-rate New York, which yields  $Q \approx \frac{1}{310}$  around 6/30/20. Even on a flight from Dallas to New York City, there will be Texas natives, New York natives, and transfer passengers who originated elsewhere, so a mid-range estimate seems suitable. As noted,  $Q_M$  is estimated as 0.18, while .348 and .192 are treated as, respectively, the transmission probabilities absent masks under “fill every seat” and “middle seat empty.” In consequence, one reaches the following estimates for dates around 6/30/20:

$$P(\text{infection}) \approx \begin{cases} \frac{1}{4,300} & \text{on full US flights} & \text{under "fill all seats")} \\ \frac{1}{7,700} & \text{on full US flights under "middle seat empty"} \end{cases}$$

The first of these risk estimates is the average for passengers in the six filled seats in each row.

The second is the average for the four seats occupied under “middle seat empty.”

### *Discussion*

For a coach passenger who is infected on a full flight and has a 1% chance of dying from the virus, then the mortality risk based on the estimates above would be about 1 in 430,000 under “fill all seats” and about 1 in 770,000 million under “middle seat empty.” Both these estimates are considerably higher than the risk of perishing in a US air crash unrelated to Covid-19, which is about 1 in 34 million (11)). However, data from late June 2020 imply that approximately 1 in 120 Americans have Covid-19 on a given day (i.e., 40,000 confirmed cases per day x 10 x 7 days is about 1/120 of the US population of 330,000,000). Thus, it is not clear that the risk of getting infected during a flight is any higher than the risk associated with everyday activities during the pandemic.

Moreover, these calculations are contingent on a flight being as full as possible.

In 2019, the average passenger load factor on US flights was 85.1%. If one assumes that 85.1% of seats are taken on airlines that would fill all seats, then they could operate with roughly 55% of middle seats full and 45% empty. Then a 1% chance of dying from Covid-19 given infection would yield a death risk of 1 in 540,000. Airlines that keep middle seats empty could presumably fill nearly all of them, so their mortality risk would remain about 1 in 770,000.

The risk estimates presented above do not consider the possibility of infection during boarding and leaving the plane, from contagious passengers who walk down the aisle to the lavatory, or within the lavatory itself. The authors of (9) concluded that, because these risks involve short periods near a contagious person, they are far lower than the risks tied to seat proximity. Thus, despite reports of crowding on entering and exiting planes even during the pandemic,(e.g. (12)) we treat the risks they pose as second-order effects.

Beyond those stated earlier, there are reasons that Equation (II) that relates infection risk to distance need not literally apply to a passenger flight. The estimates in Chu. Et. al. (6) do not distinguish between people speaking to one another and people who are silent. On the aircraft, nearby passengers probably are largely silent, unless one is seated close to two travelers who spend much of the flight talking. For this reason, Equation (II) could overstate passenger risk. On the other hand, it is assumed here that the equation pertains to individuals not wearing masks, and that one should therefore reduce the risk estimate by 82% via  $Q_M$ . Yet some contagious people in the meta-analysis apparently were wearing masks (private correspondence from Dr. Chu), meaning that the equation does not literally reflect the risks without masks. That circumstance would suggest that the factor of 0.13 in Equation (II) is too low. It is possible that these two opposite effects largely cancel one another and leave Equation (II) unaffected, but that need not be the case. This analysis offers a baseline risk estimate using the Chu et al. results at face value, which is a reasonable starting point absent more detailed information about the nature and duration of the exposure to someone contagious.

Calculations like the ones here are highly approximate and, as has been evident during this pandemic, projections about it often fall far from the mark. It is therefore all the more

important that attempts be made to use actual passenger outcomes to estimate what fraction of travelers contracted Covid-19 on their flights. If, averaged over US carriers, the risk level per passenger is estimated as (say) 1 in 6,500, then approximately 90 cases of Covid-19 should emerge each day at a time (like early July 2020) when 600,000 US passengers are flying daily. Determining how many such cases actually arise will not be easy: travelers who get asymptomatic Covid-19 (especially younger ones) may never know it, while some passengers who subsequently get Covid-19 may have been infected elsewhere than the airplane. Collating records over widely-diverse localities would be challenging. But when safety is at stake, it is worth some effort to substantiate or refute projections that are tied to strong assumptions.

The calculations here, however rudimentary, do suggest a measurable reduction in Covid-19 risk when middle seats on aircraft are deliberately kept open. The question is whether relinquishing 1/3 of seating capacity is too high a price to pay for the added precaution.

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