PROFESSOR: So when we start considering short-range effects of respiratory jets and plumes, it raises the interesting question of what is the role of social distancing, which is our primary means for fighting the pandemic at the moment.

So as we've discussed, this is especially important when masks or face shields are not worn, so that the jets and plumes that come from breathing and speaking and singing and other respiratory activities are not blocked, in the sense that the momentum is not blocked.

And furthermore, there's no filtering going on.

So then we have our long-range airborne risk coming from respiratory aerosols that have become well mixed into the background air.

But we have a new term that comes from short-range transmission.

And in a worst case scenario, we can imagine that as a wedge-like or cone-like plume, which we have just described.

In reality, there is going to be some background flows in the room, which will sweep that jet in different directions and break it up.

There'll be motion of people, turning of heads.

So it'll never be this simple.

But the worst case scenario is really a well-formed respiratory jet and somebody essentially standing right in it at a certain distance, X bar, which is our sort of average social distance.

As we've discussed, we can also take the ratio of these two terms and speak of fs, which we define here as the short-range risk enhancement factor.

So that comes down to two new parameters which we've been discussing-- P jet, the probability that a susceptible person is in the respiratory jet of an infected person, and X bar, the typical distance over which that occurs.

Xc is this transition distance, where the respiratory jet concentration starts to match that of the background ambient air, which we substitute and form this expression shown here.

So there are a number of situations we can think of to estimate what would be these parameters.

So the first would be just to consider random occupant placement.

So in this situation, if we view from above, we have, let's say, a person.

This is now viewing from above.

And they have a respiratory jet, which is going off like this in one direction.

And then at any given distance, we can imagine there's sort of a typical social distance here.

Now, I'm kind of exaggerating how far that is compared to the size of the head.

But if this distance here is X bar, then at that distance, we'd like to say, what is the probability that the susceptible person is in the jet?

And that would simply be formed by taking the angle of the jet relative to the full circle.

So we could imagine, what is the probability of putting a person right here versus over here or over here where they're not going to be in the jet?

So in that situation, we could write that P jet is approximately the inverse tangent of alpha.

So alpha, remember, is the ratio-- is the entrainment factor.

And it's sort of the slope of this line defining the cone of the respiratory jet.

And then we can divide that by pi.

So that basically tells us the probability of being in this yellow region versus somewhere else at a given distance.

And then, now, if we think about the distance factor-- if it's completely random, then if we just imagine lots of people scattered throughout a room-- imagine a busy space, for example, in a bar or a nightclub, a place where it's somewhat crowded but people are kind of moving around.

Then we might have an average social distance, which is the area of the room divided by N.

So that's the area per person.

And then take a square root.

That's an estimate of the distance.

And the square root of area is the length L of the room.

So it's divided by square root of N.

And so with these two assumptions, we would then find that this short-range risk enhancement factor-- well, what does it look like?

It then is this factor P jet times Xc over L times-- and then we have this N minus 1 factor.

So if N is larger than 1, we could just estimate that as a square root of N. So what that shows is as more and more people pack into the room, we have an increase in the importance of long-range versus short-range transmission.

And this pre-factor here is something which typically will be much less than 1, because the probability of being in a jet-- if alpha is around 0.1, 0.15, this turns out to be around 3%.

OK, so that's-- it's not quite as wide as I've sketched here.

The jet is a little bit more narrow.

And we've already discussed that Xc-- the distance where the concentration in the jet starts to match that of the ambient-- it does depend on the conditions of the room and the ventilation and other factors.

But roughly speaking, Xc is typically smaller than the size of the room.

And so this factor here is quite a bit less than 1.

So you see that in a random situation, the short-range transmission starts to become important only when the number of people becomes large.

And it grows like square root of N.

And there's a certain point, which might be at N equals 20 or N equals 50 or N equals 100, depending on the space, where the short-range risk is larger than the risk of the background airborne transmission.

And that's, again, just coming from random placement.

So on the other hand, the random placement situation is not quite the best case scenario.

But it's sort of a fairly optimistic scenario.

The best case scenario is if people are always kind of having their backs to each other, never breathing on each other.

That never really happens.

In fact, it's more typical in human interactions for people to face each other.

They may be talking to each other, looking at each other.

And so hence, we tend to find ourselves more typically in the way of breathing.

And so it might be better to think about this estimate in other ways.

So a second way that we can think about it is by using a social distance guideline, or a social distancing rule, let's just say.

So let's say that instead of a random situation where people are keeping sort of the average distance between each other, that no matter how many people in the room up to a certain maximum occupancy, they're not going to come within, let's say, a 6-foot radius or a 3-foot radius, 1-meter radius.

Depending on what the social distancing guideline is in that region, there's going to be a certain sort of minimum X.

And let's just think of that as the worst case scenario.

For the people that are that close to each other, that's the distance we'll choose.

And so this might be something like 6 feet, 1 meter.

You can pick.

And in that case, the fs is P jet over N minus 1 times Xc over X. And we've already estimated that at 6 feet, Xc over X, it does depend on the ventilation and the size of the room and other factors.

But we've already said that this factor here might be something like 6 to 600 for a certain set of examples that we've just considered.

So when we put all this together, if we take into account also that P jet is around, let's say, 3%-- if we imagine having random placement of people but at a fixed distance, minimum distance, of 6 feet, then what we'll find is this ends up being something like 0.2 over N ranging up to, let's say, 20 over N. And again, this is just very rough.

So this is with random angle.

So in other words, we're still thinking now of just this kind of random orientation of somebody's head, not necessarily facing one person all the time.

And so you can see here that if N is-- if we're in the situation of the 20, which is-- by the way, that's the case where this is getting large.

So that would be a case of a large room.

Or it would be of low breathing rates, et cetera.

Then we-- you can see that when N gets-- if N is small, then this number can actually be quite large.

So in other words, if we just have a few people in the room, and they can get this close to each other-- like one minimum social distance, like 6 feet-- then the primary risk is coming from airborne transmission, especially if the room is very big.

If two people are by themselves in an enormous room, then the risk from background airborne transmission is minimal compared to the risk of direct short-range transmission.

So that kind of makes sense, right?

On the other hand, notice the effect of N.

If you have more and more people in the room, then even though most of those people are a lot farther away, there's so many of them that are potentially going to get infected that it becomes worse, even in the case of 20 here, which is sort of the more conser-- the case where short-range is more important.

It starts to switch to where the long-range transmission becomes more important when N is larger than 20 in this particular example.

So basically, so significant for small N and basically large V. So basically, low-occupant densities-- if people are to come close to each other, then it makes sense short-range is important.

In fact, a limit that we haven't talked about yet is, what if we're outside?

What if we don't even have-- what if the V goes to infinity or V is very large, so effectively it's infinity?

What this is telling us is that we have to stop worrying about the long-range background well-mixed concentration of infectious aerosols.

And instead, we have to focus on the short range.

Just whenever people are coming close to each other, make sure they're not breathing directly on each other for long periods of time.

That's the key.

Now, the last thing we can think of, which is really kind of like a worst case scenario-- that would be where a person is at the closest distance that's allowed or expected-- let's say, 6 feet, maybe even 3 feet, 1 meter.

And also, they're not randomly placed and angled.

But they're really just constantly in the jet of the other person.

So let's say, for example, P jet is 90%.

That's a pretty high number, keeping in mind that there's also turbulent and chaotic flows in the room, such that even if you're facing somebody all the time, the stable respiratory jet and puff train is going to be swept away by other currents.

And so it's really not as though the other person is constantly going to be in-- fully exposed.

But let's just say, we pick a number like 90%, which is kind of like a worst case scenario.

And we're always facing each other.

So let's, again, pick-- X bar is, let's just say, 6 feet.

Let's just say, maybe we're sitting across a table at a distance which is sort of an acceptable social distance according to the 6-foot rule.

Then we're going to find that this enhancement factor is around 6 over N to 600 over N. So we can see that the short-range effect can be a lot larger.

So notice, even if N gets to be really large, like a lot of people in the room-- let's say, it's a restaurant with 100 people in the room-- still, it's 6 times worse to be in a single person's respiratory jet 90% of the time at 6-foot distance.

So that's actually fairly alarming if you think about situations such as restaurants or office meetings or any other normal activity where people are facing each other and breathing on each other continuously without wearing masks or face shields.

So this would be-- I'll just mention here, short-range dominates in this situation.

So then, how do we mitigate against this short-range transmission risk, which is going to be worse, again, when we have people that are not wearing masks or face shields and are in close proximity and facing each other for long periods of time, and especially in a larger room and a lower occupant density where the N is maybe not so big, and we don't have to worry as much about long-range transmission?

Well, one way to proceed is to continue using the universal guideline that we've derived right here for long range, and simply choose a small epsilon, much less than 1.

And you can see here, it doesn't have to be that tiny.

From this simple estimate here, maybe an epsilon of 0.01 might not be so bad because, see, this number 600 is there.

And if N is maybe 5 or 10 in the room, then that might be already helping you.

So remember, we use the guideline with a fudge factor, or a tolerance, epsilon.

And some of the uncertainties in different modes of transmission are already kind of included in there.

But certainly, if we're not wearing masks, the risk is pretty high.

And so that may not be enough.

And that's why social distancing can help.

But I want to emphasize from our discussion of these respiratory plumes, there's nothing really that special about 6 feet.

There's unfortunately today a feeling in the general public that if you're closer than 6 feet, you're at extremely high risk.

You've penetrated somebody's bubble.

But when you're a little bit more than 6 feet, you can breathe easy, because you're safe.

And you can see that's really not true.

If you are not wearing masks, these respiratory jets and plumes can travel very long distances.

Of course, airborne transmission is everywhere in the room at any distance.

But even the elevated risk of short-range transmission can extend further than 6 feet.

On the other hand, when people are turning their heads, and there's sort of convection in the room and thermal convection as we've been discussing, in fact, 6 feet might be overkill.

Maybe being even a little bit closer might be OK.

But the important thing is that distance is not so special.

And also, the details matter.

So as you can see here, we can get very different estimates based on where the occupants are placed, how they're facing each other, what kind of activities they're engaging in, what kind of movements.

So there's really no universal guideline.

It makes more sense to start from a universal guideline for long-range transmission and then enforce mask use in situations where we are worried about transmission, rather than trying to guess how people are going to behave and what kind of distance they're going to keep not wearing masks.

So the safest thing is, if you're worried about coronavirus transmission, just wear a mask, indoors especially.

So that brings us now to thinking about summarizing this entire chapter, going beyond the well-mixed room, where we've been discussing the fluid mechanics of indoor spaces and of human occupants and respiration within those spaces.

So I think I'd like to leave you with the picture of people who are smoking in the room.

So we're all familiar with the situation where you have a room-- let's say, could be a restaurant or some other space where there is, let's say, a table or a few tables, where there's maybe 5 or 10 people in the room.

And there's one person or two people that are smoking.

Now, we know that when the person who's smoking breathes in on the cigarette and exhales, there's a very dense plume of smoke that comes out.

It gets carried by thermal currents and rises.

And you know that if you stand right in that space, it will be a very significant amount of smoke you're going to have to breathe.

In fact, it's courteous for the person who's smoking to [EXHALES] breathe away and not breathe directly in other people's faces.

That would be sort of rude.

And maybe, as we're thinking about respiratory transmission of viral disease, we should think in the same way.

Each person should be worried about, am I really breathing directly on another person?

If I'm not wearing a mask, why don't I breathe somewhere else?

But we also know from our experience with smoke-filled rooms that there may only be one or two people smoking.

And you can occasionally see these puffs or burst of smoke when they're exhaling after drawing on a cigarette.

But if you look around the rest of the time, the smoke is kind of swirling around.

It's a little more concentrated in some places.

But you can see very quickly, it's uniformly spread throughout the room.

And somebody who is on the far side of the room is at essentially the same risk as somebody who's very close-- even 6 feet or 3 feet away, whatever that special distance may be-- because the air is typically well mixed.

And those smoke particles end up throughout the room.

And you're just as much risk at 60 feet as you are at 6 feet under those circumstances.

And so that's really the main message of this course, while we also keep in mind that there are these sort of details of short-range transmission that I'd like you to be aware of when applying the guideline for long-range aerosol transmission.