AirSpace Season Four Episode One: Cool It Now

Emily: Look at you laying out the science knowledge. Sublimation?

Nick: They asked me to prep for that.

Music in and under

Matt: Welcome to season four of AirSpace, from the Smithsonian's National Air and Space Museum. I'm Matt.

Nick: I'm Nick.

Emily: And I'm Emily.

Nick: Right this very moment, there are doses of the COVID-19 vaccines on airplanes, making their way from manufacturing facilities to clinics, hospitals, and ultimately into your arm.

Emily: There've been global efforts to distribute vaccinations before, but as with everything to do with the current pandemic, the speed, logistics and infrastructure needed to distribute these vaccines is unprecedented.

Matt: Air travel is a critical component to this supply chain. On today's episode, we'll explore the history of flying temperature-sensitive products, and we'll break down the logistics and considerations required to get those vaccines in the air. That's just ahead on AirSpace.

Music up then out

Nick: At the time of this recording, there are two vaccines approved for use on an emergency basis by the FDA in the United States. One is from Moderna and the other is from Pfizer BioNTech. So what do we know about those two vaccines, to start off with?

Matt: We know that they were both developed using a new mRNA, messenger RNA, technology, which has never been used for a human vaccine before, but has helped them to accelerate the process of making these vaccines, but also makes them incredibly delicate and have to be stored at very cold temperatures.

Emily: Because of all this mRNA, which is super fragile, it's got this, it's got this thin coating of fat on it, and you need to keep that fat at just the right temperature so it doesn't, I don't know, sort of dissolve. I don't know how to describe this. I think of soup. But if you pull cold, homemade chicken soup out of the refrigerator, the broth is kind of jiggly and you got this layer of kind of like, gross looking white stuff on the top, all of that are different combinations of fat. And as soon as you start to heat that up, your broth gets liquidy and the weird looking gross white stuff at the top, which is your chicken fat, that all dissolves into your soup and makes it actually super delicious. In the case of this mRNA type vaccine, you've got to keep that layer of fat solid enough at the right temperatures to protect all the yumminess on the inside until it can get into your body.

Matt: Right. I mean, think about what a vaccine, a traditionally produced vaccine, is; it's usually an attenuated version of the virus, a sort of weakened version or a dead version of what you're trying to vaccinate against. This is different. This is actually a vaccine that carries instructions for how the cells within your body can produce the protein that your immune system needs to be able to recognize to fight COVID. And because of that, it is just made of mRNA, which is not very stable outside of your body at any temperature other than very cold temperatures.

Emily: And because of the way this vaccine was developed, I mean, normally it takes years or more for a vaccine to get developed. And in this case, it was ready in months, which is, to use the word again, unprecedented.

Nick: And because of the way that they were manufactured and because of the way that these vaccines were designed, distributing them is similarly challenging. And we'll get into that in a second. But obviously because of the urgent need for these vaccines, that's something else that, like the design and manufacturer of the vaccines themselves, we're hoping to get done worldwide in a matter of months instead of years and years, right?

Emily: Yeah, right. So not only is this vaccine completely different than any other vaccine folks have normally encountered in their lifetime, even if you've never considered how a vaccine actually works, this is different than any vaccine you've ever gotten. And it turns out that while we need additional infrastructure to help distribute this vaccination, it's using an infrastructure called the cold chain, which I've never heard of before, but is an infrastructure that, to a degree, exists in this world.

Matt: Right. If you think about a lot of the conveniences that you know right now in your daily life as an American, a lot of it actually comes from the cold chain. Being able to buy frozen vegetables, frozen meats from around the world at any grocery store on pretty much any corner in this country is thanks to that cold chain existing.

Emily: And so the cold chain is essentially the infrastructure that allows something to be frozen, at its manufacturing plant, or maybe seafood is a good way to explain it. Seafood has to stay super fresh. It's flash frozen at the source, but it has to stay frozen all the way to your freezer. You don't want to buy something that's been thawed and refrozen a couple of times. And so the cold chain is the name of this thing that allows you to go from, well as a geologist we'd say, source to sink, but essentially it goes from source to your kitchen.

Nick: To Emily's point about seafood, we also owe a lot of this to hamburgers, right?

Emily: And bull semen. Matt, do you want to tell us more about bull semen?

Matt: Yeah, sure. Right, so we actually owe a lot of this infrastructure to the ranching industry, to cattle farms and to farmers who wanted to be able to send bull semen across the country and have it still be viable by the time it got to where it was going so that it could assist with breeding bigger and better beef cattle. But it was also from that commercial desire to get that meat around the country as quickly as possible and as coldly as possible so that it could be consumed by Americans at affordable prices, no matter where that happened to be. So yes, we do owe cattle breeders and cattle ranchers a big debt of gratitude for developing this technology.

Nick: So even though the original cold chain was designed using liquid nitrogen, the favor at the bottom of your box of frozen Cracker Jacks these days is much more likely to be dry ice, which is the solid form of CO_2. And that's really commonly used in situations where you've got to keep things extraordinarily cold. I remember years and years ago, you used to be able to order semi-industrial quantities of Dippin' Dots, and it would come packed with these giant slabs of dry ice. So we did that one 4th of July and it felt really wicked and futuristic to pull the lid off of this individual disposable container and have all of the smoke billowing out and inside is Dippin' Dots. And the consumer mindset had been informed that Dippin' Dots were these extraordinary, difficult to control things. And it turns out all you really needed to do was replenish it with dry ice from the grocery store every other day or so. And for anyone wondering it at home, it takes three days to get sick of Dippin' Dots.

Matt: But it is great. I mean, you can really get whatever it is, your favorite food from anywhere practically, and the cold chain will help you do that, right?

Nick: Yeah. And it is incredible. And dry ice, it turns out, is a lot more appropriate for the purposes of vaccine distribution than liquid nitrogen is. But there are still risks. In my case, you know, at a 4th of July party, the risk was don't stick your hand into the cooler without looking and touch the dry ice because you'll burn yourself. But it turns out that CO2 presents some additional challenges and risks that have to be taken into account for these necessary purposes, such as vaccine distribution.

Ben Supko: Yeah. Some of the keys behind you are obviously, you know, you can't touch it, it'll burn your fingers.

Nick: We asked Ben Supko about this. He's the Director of the FAA's Office of Hazardous Materials Safety.

Ben Supko: You have to be careful with the packaging that it doesn't create an overpressure, potential explosion, and packages are designed to alleviate the release of the gas. The key for aircraft transport is the quantity of dry ice you have and the volume of carbon dioxide gas that's coming out of the package or a number of packages, where you can get the level of carbon dioxide within the aircraft into an unsafe range. And that unsafe range would be where you would be affecting the breathing abilities of the pilots and the crew. And it can also lead to potential asphyxiation.

Matt: Yeah, if you've ever seen those headlines about pool parties where they threw a bunch of dry ice into the pool, and then a whole bunch of the partiers had to be treated for basically asphyxiation, that's the danger is that the gas is heavy and it takes the space of the oxygen that you really want to be breathing. I know I want to breathe it.

Nick: So, Matt, what you're talking about is if you throw a giant chunk of dry ice into a swimming pool, the carbon dioxide that's led off sits above the surface of the water and the swimmers don't realize that they're not getting any oxygen, even though they're breathing normally?

Matt: Right, exactly. And you don't even realize that you're being asphyxiated, exactly like you say, because you're still breathing in that gas and it's not hurting you. I mean, it is, but not painfully hurting you.

Nick: And as another Hollywood example of how dangerous CO2 can be in a completely enclosed environment, this was one of the more perilous things that happened to the crew of Apollo 13 on their way back from the moon.

Apollo 13 Engineer 1: Gene, we have a situation brewing with the carbon dioxide.

Apollo 13 Engineer 2: We had a CO2 filter problem on the lunar module.

Apollo 13 Engineer 1: Five filters on the LEM.

Apollo 13 Engineer 2: Which were meant for two guys for a day and a half. So I told the doc-

Apollo 13 Flight Surgeon: They're already up to eight on the gauges. Anything over 15 and you get impaired judgment, blackouts, the beginnings of brain asphyxia.

Apollo 13 Gene: What about the scrubbers on the command module?

Apollo 13 Engineer 1: They take square cartridges.

Apollo 13 Engineer 2: The ones on the LEM are round.

Apollo 13 Gene: *scoffs...clip fades*

Emily: But if you do this in a really safe environment, dry ice is really fun to play with. You just have to be really careful. But this is that danger that Ben is talking about in transporting things on dry ice, because you can have this material go from it's solid, icy looking form to a gaseous form. And because it's colorless, odorless, and a little denser than air, you can be breathing, feeling like you're getting full breaths, but you're getting a lot of carbon dioxide in there instead of pure oxygen. And so you're not getting as much oxygen as your body needs, and that's where it can be slowly dangerous because you don't know it's happening.

Nick: Yeah. And the word for that is sublimation. You'll hear that a couple of times today. Sublimation is when something turns directly from a solid into a gas. It's effectively like evaporation, but that's when something goes from a liquid into a gas. But CO_2 as it, umm, well melt is the wrong word, it sublimates. And that's when it goes from being a chunk of dry ice that's keeping your vaccine or your Dippin' Dots cold and turns into invisible, odorless carbon dioxide, that if you are in a closed environment, or to Matt's point, at a raging pool party, things can get pretty hairy pretty quickly.

Musical transition

Nick: Because dry ice and a unexpected quantity of CO_2 in a closed environment can be really dangerous, the FAA regulates how much dry ice cargo planes can carry at any given time. The thing that we love about the FAA is how much thought they put into all of these different regulations. And it turns out that, like all of them, this one's there for a really good reason. But when historic circumstances come to grip the globe and we need to do things like rush vaccines to everyone everywhere, those regulations can be taken into account and possibly adjusted in order to get things where they need to go as safely as possible.

Matt: Right. And you have to also consider that these regulations have to take into account something going wrong with some other part of the airplane system, right? Like perhaps the air circulation system shutting down, either because it has to be shut down during, say, normal deicing of the exterior of the plane, or if it shuts down for some other reason during flight, that crew still has to be able to not only do its job, but survive, having all of that dry ice on board.

Emily: So as the FAA has done research about how much dry ice you can safely transport, keeping in mind crew safety especially, a lot of the engineers putting together the packaging for the transport of the COVID vaccine have taken those regulations into consideration in how they've constructed those containers to increase the amount of CO_2 that can be safely transported on each individual airplane.

Ben Supko: Under the COVID-19 vaccines, we also saw some packaging enhancements. So as the vaccine need rose, so did the technology used to develop the packaging. The packaging can sublimate at a lower rate now, much lower than the 1.5-2% rate of previous standard packaging. So what you would see is air carriers assessing that rate, using information from the aircraft manufacturers on how much is safe within the aircraft. And then you could raise the volume of packages you could take. So if your sublimation rate is, say, 0.5, you can take four times the amount that you could have taken previously.

Emily: Right, so the packaging is not only tighter to keep the gases in, but it's also heavily insulated to keep that dry ice at a more regular temperature. So because you have less sublimation or less solid going into a gaseous phase, you have less danger of that CO_2 creeping out of the packaging into the plane and endangering the crew that you have working on that airplane.

Musical transition

Emily: So there's a challenge in transporting the vaccine at the right temperatures, but the transportation itself right now during a pandemic is an added challenge, and not the challenge you would necessarily expect because we've got great airplane infrastructure and great air infrastructure across the globe. But not right now.

Matt: Yeah, I mean, normally a lot of the cargo that that gets transported around this country actually flies with you when you're flying on a passenger airplane. And since there are fewer passenger airplanes flying due to fewer people flying around the country, a lot of the cargo space in cargo planes has actually been taken up by your Amazon packages and other things that you've been shipping across the country during the pandemic.

Nick: As hard as it is to believe from when you fly in an airplane, there's a lot more cargo room on that aircraft than the overhead bin above your seat. It's where all the luggage goes and everything like that. But there's a whole lot more that is contracted out for actual cargo purposes.

Matt: Yeah, so we asked Glyn Hughes of the International Air Transport Association about the problem that's been created by there being essentially more competition for cargo space in cargo dedicated planes due to fewer passenger planes flying.

Glyn Hughes: It has been a major influence because historically air cargo moves about 50% through passenger aircraft. So by the grounding of those passenger aircraft, it's actually removed nearly half of the global capacity that aviation traditionally relies upon. And when you consider the passenger network has really connects the planet with about 22,000 connected city pairs, it really left a very, very huge dent or a large dent on the air cargo landscape. So as the demand for PPE and other things happened during the COVID crisis, it actually put additional pressure on the air cargo networks, considering that reduction of passenger available capacity.

Emily: Right. So not only is commercial air traffic, right, us on airplanes, down over 90% from last year, you also have this issue of, "Can you put this specialized cold storage infrastructure onto commercial aircraft with a bunch of passengers and crews?" That's where the real confluence of keeping everything at the right temperature and also keeping crew and people safe, and also doing it at the scale that is needed to distribute enough vaccine to everybody in the United States and the globe.

Matt: Right, well, we also talked to Glyn about how you might convert space on passenger planes to carry more cargo. And this was especially important in the beginning of the pandemic when they needed to move a lot of PPE, personal protective equipment, around the country.

Glyn Hughes: If you actually wanted to put cargo on the seats, or in some cases actually remove the seats and create, as it were, a reconfigured passenger aircraft, airlines would then need to submit those aircraft for additional safety certifications by their civil aviation authority. And during this crisis, there were about 2,500 passenger aircraft that were deployed for cargo only operations. Of that, there were several hundred who actually had their seats removed. And we have to say that the civil aviation authorities responded incredibly quickly to ensure that these aircraft were being able to be operated in a safe environment. And it also enabled the industry to respond to what was a human based safety issue and health concern.

Nick: So even though there have been some headlines about vaccines being transported on United aircraft or Delta airplanes, that's by and large not how the bulk of vaccine doses are going to make their way around the country and around the globe.

Matt: Right. They're actually mainly going to be flown around the globe through dedicated cargo planes by some of the big cargo shipping companies. The big three are FedEx, UPS, and DHL. And that's not to say that no vaccines are going to be carried by commercial planes and carriers, just that most are going to be on these dedicated cargo planes.

Emily: Right. And the advantage here is that companies like DHL and FedEx and UPS already have more experience carrying temperature-controlled, sensitive medical items instead of people like commercial planes. In fact, on December 10th, representatives Richard Smith for FedEx and Wesley Wheeler for UPS testified before the Senate Commerce Committee about preparations and logistics for vaccine distribution.

Wesley Wheeler: Good morning, Chairwoman Fischer, Ranking Member Duckworth, and members of the subcommittee. While UPS is known primarily for its brown trucks, members of the subcommittee may not be aware that UPS is also a longstanding provider of supply chain services for the many healthcare companies around the world. UPS has been on the front lines of COVID-19, as FedEx has...*clip fades under*

Nick: So because of the fragile nature of the vaccine themselves, and because of the temporary nature of the manner in which you can store them for transport, that is kind of informing an unprecedented level of cooperation and communication between all of the different stakeholders from the commercial cargo carriers themselves to federal authorities and airports and air traffic controllers are all working as one to make sure that the vaccine shipments take precedent and the maximum number of vaccine doses reaches the maximum number of people in the shortest possible period of time.

Richard Smith: Well, we've said throughout this, that there will be no higher priority shipments in our network than these vaccine shipments. So they will have the highest priority of anything we carry in all of our FedEx networks, but certainly in the FedEx Express system that'll be carrying them.

Nick: In addition to the industry prioritizing vaccines, Ben Supko at FAA says government entities are working to priorities these shipments as well

Ben Supko: We're also working with stakeholders to determine additional needs for air navigation support. This includes prioritization of the flights and that's the flights carrying COVID-19 vaccines. And obviously, ATO, the Air Traffic Organization is providing around the clock air services to keep the cargo moving seamlessly.

Emily: So Nick, you were talking a little bit about the prioritization and it's not just about kicking passengers off planes to make more cargo space. That's not what we're talking about prioritization, because that's not what's happening. It's about giving right of way and/or priority air traffic lanes to cargo planes that are delivering vaccine. Is that more accurate?

Nick: Yeah, it's the air traffic control version of you hear a siren and you see the flashing lights, "Please pull over to the side while this vehicle passes you. They've got very important, urgent business to take care of."

Emily: See, I would've thought it was the air traffic equivalent of the HOV lane.

Nick: Oh, that's a good one too. Can ambulances take the HOV lane?

Matt: Yeah, I think so. I think emergency vehicles get that perk. If it's a perk.

Nick: Yeah.

Musical transition

Nick: Once, at the end of this very long road, we are on the other side of all of this, let's let's think for a second what we'll come out of this with in relation to the cold chain. So the cold chain started out with liquid nitrogen and liquid other things to get cattle genes across the country from farm to farm. And we ended up with a supply chain that enables us to get fresh hamburgers, fresh fruit, a lot of things that require refrigeration, basically anywhere in the United States and in many places around the world. That was a unintended offshoot of a very specific need from a very specific industry. So once we have come together as a country and as the world to solve the cold chain supply challenge for the COVID vaccine, we will still have all of these lines of communication. We'll still have all of this technology. So this capability is going to be with us a lot longer than the vaccine distribution challenge itself. And I wonder what kinds of things will be available to us in the future.

Emily: So there's still a long way to go here. I don't think I expected vaccinations to start being administered in 2020, but I also think there's still a really long road that we have yet to travel. Even once folks start getting that vaccination, they have to remember, there's a second dose that needs to occur so that that vaccine can be at its full force. And so in the meantime, while folks are getting vaccinated, there's still a lot of mask wearing and social distancing ahead of us.

Matt: Yeah and also that road is long, not just because of the time it will take to get that first and second dose, but also to get that first and second dose to enough people that we actually can have herd immunity, which means essentially that that virus won't be being passed from person to person. And even those few folks who are left who haven't been immunized will be protected.

Emily: Nick, you mentioned the unprecedented, sort of, infrastructure and innovation that's occurred between all these different channels that are not accustomed to working together in quite as close contact. But I think as a scientist, one of the things that's the most inspiring to me is what happens when all the companies and all the scientists in a particular field come together to solve a problem and the ability to solve that problem in a short amount of time with the right amount of resources and a lot of support. And I think this is a really wonderful example of the scientific community coming together and trying to solve a problem. And I'm really excited about what future administrations and future countries coming together can achieve when they focus on a single problem.

Matt: As someone whose first degree was in biology, the thing that I think I'm most impressed with, and I think that going to have a huge impact on our lives moving forward, is this new mRNA vaccine technology, which really did produce a vaccine at an unprecedented rate. And with these really high efficacy numbers that we're seeing for this COVID vaccine could potentially be a game changer in fighting other viruses, including ones that we've been struggling with for years like the flu and the common cold.

Nick: In the scenario that you're outlining, Matt, where we're able to apply this mRNA technology to fighting other diseases, having an understanding of how to get a super chilled vaccine serum from place to place and maintain its efficacy is going to be absolutely key.

Matt: Yeah, absolutely. And, I mean, you'll still require that cold chain. You might not require it on the same level, because we hopefully won't be fighting those other viruses on pandemic scale, but you'll absolutely need that same technology to keep those mRNA vaccines viable throughout their shipping across the world.

Emily: Well, and I think with anything, this rapid innovation and the rapid increase in technology and push in scientific information and understanding, I think is going to lead to more innovation and more scientific discoveries that we certainly didn't anticipate.

Music in and under

Emily: That's it for this episode of AirSpace. AirSpace is produced by Katie Moyer and Jennifer Weingart. Mixed by Tarek Fouda. You can follow AirSpace on Instagram and Twitter @airspacepod. Distributed by PRX.

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