PHILIP GREENSPUN: We're going to talk about meteorology. So as pilots, we're just trying to understand the basics. And in terms of passing the exam, you don't need to be a physicist. You just mostly are trying to learn stuff that will help you fly within the VFR weather minimums and predict when those minimums aren't likely to be met or when there's going to be really serious hazards, such as thunderstorms. All right, this will be on the test.

You have to memorize all of this. Well, you kind of do. Anyways, they want you-- you will have to learn some of this stuff for the exam. In reality around here, almost all airspace is at least class echo.

That's controlled airspace. It means controllers could give you a clearance to fly on instruments and separate you from other aircraft. So they want you to be well separated from clouds, 1,000 feet above, 500 feet underneath, 2,000 horizontally. That way, if an aircraft under IFR comes out of the clouds, there'll be some time for the two of you to see and avoid each other.

You can see the weather minimums are different in class Golf airspace. And, actually, in uncontrolled airspace like up in Alaska, if you're flying on instruments, you don't have a clearance. So you'll say, well, how is that possible? You can be instrument rated, have an instrument capable airplane, and fly from airport to airport in the clouds.

But the air traffic controllers, they can't give you a clearance and guarantee you separation from other aircraft because they don't have radar. They don't even have the authority. It's not controlled airspace. I've done some flying up there in little airplanes, and you have to be very patient.

Another interesting thing to notice about this-- we'll talk about it more again later-- is notice how class Bravo airspace has lower minimums than ordinary class Echo airspace. So we have to be 1,000 feet from the clouds here. Here we just have to be clear of the clouds. Why are the minimums reduced right around Logan Airport and JFK and LAX than they are--

AUDIENCE: Because everyone's in contact with the tower so the tower knows where everyone is.

PHILIP GREENSPUN: Yeah, great answer. So her answer is that air traffic control is in contact with everybody in class Bravo airspace and knows where they are. And in fact, they're on clearances in class

Bravo airspace, so they're being told what to do. Fly this heading. Fly that heading. Maintain this altitude.

Great answer. All right, so how do we know if the weather minimums are going to be maintained? Let's talk about weather theory. So raise your hand if you're a science major here as opposed to engineering? Where are the smart scientists?

All right, Francis. So the science approach to this task would be to say if we could just assume that humans are only 4 inches tall, then we could build some really great aircraft. And we'll get into that in a moment. Just think about that. If you're a scientist, how much flexibility can you have compared to being an engineer?

All right, so let's look at the atmosphere that we do have. Mostly, the troposphere tops out around 40,000 feet according to this chart. And that's where most of the water vapor is and, therefore, most of the weather, also the higher temperatures. You can see it actually does get warm again way up high in the thermosphere. This is in kilometers on the left.

So you can see that part of the earth that we're flying through is really just, I don't know, probably around 20 kilometers and down. What did I say? Said he could go up to 65,000 feet in this F-22.

So that's what? That's a little over 10 miles. Yeah, it's about 20 kilometers, somewhere in that neighborhood. Anyway, so not too many people are going higher than just the bottom 0 through 20 on this chart.

All right, who's concerned about global inequality? Raise your hand. Awesome. Well, you'll be pleased to know that so is the FAA. And this figure here shows you why it's warmer at the equator than up at the North Pole. There's the same amount-- we're missing a little bit of tilt here, but that's OK.

There's the same amount of incoming solar radiation, but it gets spread out over a larger portion of the earth up near the poles. All right, so this is where guys like Francis have it easy. If you want to understand something, you just say, well, you know, I've got an earth, and it's pretty much the same as the existing earth. It just doesn't have any water on it.

And it doesn't rotate, and it's not tilted with respect to the sun. So now I'll do my analysis. And I'll publish my paper. And I'll get tenure, and your problem is solved.

Let's see. What would happen here? In a non-rotating, non-tilted waterless earth, it would get hotter at the equator, and the air would rise up from the heat. So we can see that here. So we would have low pressure right there at the equator.

And then the air would circulate up, and we would have high pressure up at the polls. Does that makes sense to everybody? All right, great, problem solved. We can go home. Unfortunately, as engineers, we have to deal with the real world a little bit more.

So if we're spinning around the Earth, We're going to end up with these three cells and in each hemisphere. And in this case, you end up still with a low pressure at the equator. But then you get a high pressure with all the air sinking down here. And you get still low pressure-- you still get high pressure up at the polls and low pressure down here.

See if I got that right. High. I should be high. It says high pressure at 30 degrees North. Oh yeah, high, high, that's good. And, yes, and low and low.

All right, we got that right. It gets more confusing as you see. OK, so the circulation-- one thing that the FAA wants you to know is that it's heat exchange that drives the weather. So the weather is basically a function of the sun heating up the earth. And then it's not uniform, so the heat gets pushed from one part of the earth to another. And all of this unequal heating is responsible for the altimeter varying, for wind blowing around.

Pretty much every phenomenon that is of interest to pilots is caused by heat trying to move from the hotter parts of the earth to the colder parts of the earth. We'll talk a little bit more about these. But notice there's parts of the earth that are windier than others. Unfortunately, we're in one of the windier parts.

OK, so you also have to know as a pilot just what an isobar is. That's a line of equal pressure. And that tells you-- that gives you an idea of how the wind is going to move. We'll see that in a minute. The tighter the isobars, the more dramatic the pressure change in a region.

And it's the pressure gradient force that's causing the wind to flow from the high to the low pressure. So you might think on this chart, for example, that wherever you see an L and an H that you would just draw a vector of wind from one place to the other, right? That kind of makes sense. However, there is Coriolis force. This is for Francis, the science major. Francis, what course are you?

AUDIENCE: I'm course 9, so [INAUDIBLE].

PHILIP GREENSPUN: Oh. All right, so scientists wear lab coats.

[LAUGHTER]

Coriolis force is a fake news force formerly known as fictitious. So you can see they're throwing the ball straight. But because they're on a rotating platform, it's apparently curving.

So camera is mounted to the ground, and we'll see the ball going straight. They're going to draw you a little dash line at one point so you can see the path is actually straight. So the ball has an inertia. Basically, once it's launched, it wants to keep doing whatever it was doing. And this guy's white lab coated colleague just moves away from where the ball was going. Whoa.

All right, everybody's got that? That's Coriolis force for you. What happens when we do this on the earth? So think about it. You have a parcel of air that's moving with the earth at the equator.

If you displace it up to a higher latitude, it still has that velocity. But now the Earth isn't spinning as fast. So it ends up essentially moving a little bit to the right. That is the fundamental insight just as you saw in that video. You'll have to go home and think about that a little bit. But, basically, I think the most effective way to think about it is just that a parcel of air that was the equator wants to keep moving as if it were still at the equator, but it's not there anymore, so it moves relative to the underlying earth.

If you combine the Coriolis force and the pressure gradient, then you get the actual wind direction. And the trend as seen here-- eventually, there's so much Coriolis force over so much time that the wind actually moves exactly 90 degrees to where you think it should move. It flows along the isobars instead of perpendicular across them. So there you have a couple pressure systems and you see that the wind is circulating around these lows and highs rather than flowing directly from one to the other as you'd expect.

All right, who would like to become a helicopter test pilot? Raise your hand if that sounds like a fun job. OK, so when you're developing the manual for your Sikorsky helicopter, you've got to go somewhere where the wind is calm. Where would you all suggest going now that you've seen this chart? What's your name, sir? Sorry.

AUDIENCE: Jeremy.

PHILIP GREENSPUN: Jeremy, where do you want to go? You're going to take your Sikorsky helicopter and you're going to write the POH.

AUDIENCE: [INAUDIBLE] Florida.

PHILIP GREENSPUN: Florida. Sikorsky, which is headquartered in Connecticut, they have a big flight test facility. I believe it's in Palm Beach. So there you have it. They thought just along the same lines as you, and they'll be in the horse latitudes.

There's a whole bunch of-- nobody really knows why it's called the horse latitudes. One idea is that the ships-- since there's no wind in those latitudes, they have to find a current, and then they get pulled along by the current as if they were on a horse. All right, surface friction is a little bit complicated. It tends to drag down the wind. You'll have to study this vector diagram on your own.

But, really, from the FAA's point of view, they just want you to know mostly that the wind 2,000 or 3,000 feet up is going to be different from the wind on the surface. Because of surface friction, it will be less intense and in a slightly different direction. OK, vertical circulation of the air. I think you're going to be OK if you just remember that warmer air is lighter than colder air. That's all that you pretty much need to know.

OK, local wind patterns. If you heat up the shore line, the air will rise off the shore and pull in air from the ocean during the daytime so you get that sea breeze. And then at nighttime, the opposite happens, so you get a land breeze. So there are some of these predictable local weather patterns.

The bigger ones have to do with atmospheric stability. If you have a stable atmosphere, meaning that a displaced parcel of air tends to get pushed back down to wherever it was, then you get these weather characteristics where you're not going to be bumped around in your aircraft. You're going to have trouble seeing, and you're going to see clouds that are basically flat, these stratiform clouds here that you see on the right. If it rains, it's just going to rain all day. It's going to be a typical miserable New England day where it rains all the time, or Seattle, I guess, is like that as well.

Well, what about if the air once displaced tends to want to keep being displaced? If it rises up a little bit, it keeps rising. Then you have these clouds with vertical development. And the good news is you can see really well.

You're not going to have an obstruction to visibility unless you're in heavy rain. And the rain won't be all day, every day. It'll be showery, but it'll be very turbulent if you get into that cloud or maybe right underneath that cloud.

OK, what about the profile of the atmosphere? Let's have a look at this. So on the right-- I wonder if this is actually my newest version of the presentation. We'll see. I corrected an error.

On the right, you can see that for every 1,000 feet you go up. So we go from 0 to 1,000 feet up. The temperature is gone from 18 Celsius to 15, so it's lapsed by 3 degrees. And the dew point has gone down by half a degree. Does that makes sense?

The air goes up, it's lower pressure. This is called an adiabatic process. I was not a chemistry major, but I think that means that we're not adding or taking away heat from the air. We're just moving it. So the temperature and dew point spread, actually does get narrower.

You can see as we rise up to 5,000 feet that the spread has gone down to 2 and 1/2 degrees because the dew point is not falling nearly as fast as the overall temperature. Does that make sense? So I think this conceivably could be an FAA test question that the dry adiabatic lapse rate is 3 degrees.

OK, then the moist air is lapsing only at 2 degrees. So this figure shows you going from 0 to 1,000 feet, and from 1 to 2,000 feet, we were dropping 3 degrees per thousand feet. After that, we're dropping only 2 degrees per thousand feet. And once the temperature dew point spread goes to 0, that's when a cloud happens. So the air can't hold anymore water vapor. And when the temperature and dew point meet, the water vapor turns into water, and now you've got a cloud.

All right, so you might ask yourself, well, why is this air moving at all? Why does it start moving? One thing that can start it moving is a mountain range. So the air gets pushed by a wind coming from the left side of the slide up the top of the mountain. And at that point, it will condense into a cloud. Just let you absorb that cloud here for a minute.

Notice also that relative humidity is just another way of stating the temperature dew point spread. So here temperature and dew point are pretty close, 10 and 15 or 15 and 10. So we've got relative humidity of 80%. Over here, they're quite far apart. The temperature is 23, and the dew point is minus 2. So the relative humidity is low.

OK, you've heard that there's a cold front coming in and we have all these thunderstorms. Well, this is why. The cold air is denser than the warm air. So it pushes the warm air up. And at that point, you get clouds forming, and you get thunderstorms all along the line of the cold front.

OK, so what if you have stable air? Let's have a look at this. You end up-- Let's see. We've gone from 0, to 1, to 2, and we're only dropping-- actually, we're not dropping at all. And then we're back up. This is an inversion.

OK, so, basically, the air temperature is pretty constant as we go up. So if a parcel of air rises up into the atmosphere, it's not going to be warmer than the surrounding air, so it doesn't want to keep rising. OK, what if it's unstable? So look at this by contrast.

The environmental air temperature is lapsing at a higher than standard rate. It's going down 4 degrees Celsius per thousand feet. And this parcel of air that was in equilibrium down at sea level is still warmer than the surrounding air, and, therefore, it wants to keep rising. Does that make sense?

So, basically, if it goes up and it wants to keep going up, that's unstable and a perfect situation for forming thunderstorms, which we'll talk about shortly. Temperature inversion like we saw on that earlier slide where it was actually a little bit warmer here, that tends to keep air where it is, and, therefore, you end up with poor visibility and haze because all the stuff that's obscuring your visibility is just staying underneath the inversion. It's kind of a common phenomenon I think in some of these basins like Los Angeles. Talk about an inversion, and ordinary people think about that, and hear that term, and worry about it.

Most frequently-- you're going to I think see this on a test maybe-- is phenomena having to do with the ground radiating back heat into the atmosphere or into space at night. Tends to make the ground cold and the air right next to the ground cold, whereas the air just slightly higher than that, a couple thousand feet up, hasn't changed the temperature too much. So the terrestrial radiation on a clear still night can cause a temperature inversion. We talked about this earlier when the temperature and dew point meet, and that's when the water vapor will condense.

Frost. When the dew point is below freezing and you have a surface that's cold, then you will get-- maybe it's cold because it radiated its heat back out into space at night, for example.

That's when you get frost forming. And you want to definitely clear that off your aircraft before you go anywhere because it messes with the smooth flow of the air, so the wing becomes much less efficient even if the shape hasn't changed that much.

All right, let's look at the kinds of clouds. You've got basically-- the prefix to the cloud tells you what height it is. And then the second part of the word tells you kind of the shape of the cloud.

So I'll just let you absorb this a little bit. If it says nimbo, yeah, cumulonimbus or nimbostratus, that means it's raining. Towering cumulus is bad if they talk about that. And cumulonimbus is the worst. That's just another fancier way of saying thunderstorm.

OK, so here's your Latin lesson for today. Unfortunately, I didn't study Latin. It would have been nice when I went to Peru to be able to communicate with the locals in Latin America. OK, that wasn't funny I guess.

[LAUGHTER]

If you have low clouds, the main hazard to worry about is the icing. If the water is supercooled, that's the worst. You can usually get a forecast of that. You'll get AIRMETs for icing, and they might talk about supercooled water is a hazard. I guess this might be an exam question.

Stratus clouds form when moist, stable air flows upslope. But just remember stable usually means the flat clouds, stratiform clouds. And unstable is where you get the cumuliform clouds.

So same deal. Those altocumulus are going to be much more turbulent and probably more severe icing potential. The high clouds-- it's so cold in the high atmosphere that the maximum amount of water that can be stored is pretty low, and, therefore, you don't tend to get ice when it's below say minus 15 degrees Celsius. There just isn't a whole lot of moisture to begin with.

OK, so this is what as a GA pilot you're more likely to have to worry about. You're probably not going to be up at 25,000 feet in your Piper Warrior. But you could be underneath a cumulus cloud. I will tell you that if you have passengers and there is low cumulus clouds, you desperately want to get above those.

So let's say there's a bunch of cumulus clouds at 4,000 or 5,000 feet. You can climb probably to 8,000 or 10,000 feet in a light airplane, and that'll be much, much smoother. So as soon as you get above the cumulus clouds, that's where the air tends to smooth out, and it'll be much more comfortable. But if it's a towering cumulus cloud, they may go up to as high as 60,000 feet down in Texas. And you really can't get over them in anything short of an SR-71 or maybe last as F-22. Even the latest Gulfstreams only go to 51,000, I believe.

OK, so thunderstorms are the worst hazard. Even the airliners get in trouble and thunderstorms with hail smashing into the windshield and turbulence that can bend stuff. So how do you predict if you're flying along-- well, if you're preparing to go on a flight, how do you predict where the clouds are likely to be? One thing you do is look at the temperature dew point spread. The FAA tells you to use a lapse rate of 2.5 degrees Celsius to figure out where the clouds will be.

So if there is a 10 degree temperature dew point spread, then you should expect the clouds to have a base at about 4,000 feet. There's a typo in the slide. Sorry about that. I thought we had the new version in the Dropbox. The temperature lapses at 3 for the dry adiabatic air. You remember that?

And the dew point's at 0.5. So if we go back to that figure-- I think it was our-- yeah. Yeah, if we go back here, you remember this? We went from 18, to 15, to 12. And the dew point, meanwhile, is falling from 3, to 2 and 1/2, to 2. So that's why.

It's 2.5 as a rule of thumb. That's not great, but you can actually-- Just look at METARs around the country, and I think you will see because they give you the basis of the clouds and the ceilings. I think you usually will see that it's reasonably close to this formula but almost never spot on.

OK, this is worth studying. I'm not going to cover it completely here. But some of these are exam questions. Advection fog-- I think I remember they like to ask about that, when the warm moist air moves over a cool surface along coastlines. So I think that makes sense.

Maybe that's what they're having in California a lot of the time. They have the fog over the coastal areas. And radiation fog-- also, in the Western deserts, oftentimes, there's fog in the morning. So I think you're advection fog would be a coastal phenomenon. And the radiation fog, something they can have in a place like Arizona or Palm Springs.

OK, the FAA loves this. If you see ice pellets, you probably shouldn't be flying. But they want you to know that if you do see ice pellets, how did they arrive? Well, they had to be freezing rain up higher. So don't climb in hopes of getting out of the ice pellets because then you'll have freezing rain on your airplane which is probably the worst kind of icing-related hazard.

OK, airmasses. You can just have a look here. If you hear that there's a polar airmass coming in, it's going to be cold, not too exciting. Might be a question.

Fronts, they do want you to see-- be able to read one of these maps. They may occasionally asked you a question. So one thing to remember is the cold front has the pointy spikes like icicles. So if you can remember that, you'll be pretty good. There's a cold front. Again, you can just read this and study it at your leisure.

I guess they might want you to remember that the front is the boundary between two air masses. OK. Here's a typical drawing where they'll show you the cold fronts and the warm fronts. When there is a front, how do you know when the front has gone through? Well, the temperature's changed and the wind's changed, simple as that.

Here's a little explanation of what you can expect when a cold front goes through. Everybody is happy with that? OK. When a warm front goes through, it gets warmer afterwards. Yeah, so the warm front produces, as you can see, light to moderate rain, drizzle, visibility is bad. That's actually the important thing here. The visibility gets poor. And then it becomes fair and haze, whereas the visibility becomes really good after a cold front comes through.

Occluded fronts-- same deal, bad visibility. All right. Let's talk about hazards. This is more important. So this is a summary of where heat is released into the atmosphere versus absorbed by water. So as the water goes, for example, from vapor to liquid, it releases heat. So that's exactly what's happening when it's raining in a thunderstorm. And that's not a good thing.

All right. So here's the FAA's chart of a cumulus cloud forming. So you can see the lapse rate over here in the ambient atmosphere. It's going from 28 to 24 down to 21. So it is, at least initially, higher than standard lapse rate. So this warm air-- it starts at 28. And then it drops only to 25. So it's still warmer than the surrounding air. So it goes into becoming this big, nasty cloud.

There's this-- you can see-- if you don't want to look at the summaries of weather forecasts, you can look at these shards of lifted index. Here, it shows the difference between minus 18 and minus 11, minus 7. That gives you a measure of the thunderstorm potential. There are charts of that.

But as pilots, this is more what we deal with on our practical day-to-day basis. We just look at the next rad data from the radar stations that are strewn around the country. And if it's red, we try to find a path around it, because there's just not much else you can do in a little aircraft. It's possible that you could get over this entire front if you were in a jet that could climb up to 40,000 feet or higher. But in a Piper or Cessna or Cirrus, you're just not going to be able to do that.

OK. The thunderstorm lifecycle-- this is, I think, my favorite test question. How do you know that the thunderstorm has reached its mature stage? Well, it's raining, simple as that. If it's raining, it's mature. If it's dissipating, you're going to get these downdrafts. If it's building, you get updrafts.

So everything comes up, and then it all comes down. OK. Look at that nasty thunderstorm. You're going to get turbulence right on top of it. If you can clear that thunderstorm by 5,000 feet, it'll probably nice and smooth. So this is your good argument for a plane that can go to 51 [INAUDIBLE] or 510. Airliners don't go that high. The latest these jets go much higher than airliners.

All right. The hazard-- we're going to hear more about this tomorrow from [? Dojo, ?] from the Brazilian Air Force. But there is this chart here that shows you how much load factor-- that's in g's. If you're going pretty fast, you can pretty quickly get into the structural damage range. So that's why they tell you-- this these lines here are basically-- this is how many g's you can get on the aircraft with either extreme movements on the controls or extreme movements that are imposed on you by a thunderstorm or something. So the takeaway from this diagram is slow down if you get into heavy turbulence, because then the airplane will stall before it bends. And stalling can be corrected by pushing the nose down.

OK. So these are all of the hazards from thunderstorms. Again, it's a lot better-- in this day and age, there's so much information out there and datalink available in the cockpit that going through thunderstorms is just much less common than it used to be. And therefore, don't really have to remember too much, other than don't fly through a thunderstorm.

Microburst-- however, if you're trying to land and beat the thunderstorm, you can actually get into a little bit of trouble, because the wind right before a thunderstorm or right after can be pretty squirrelly and cause you some difficulties here. Let's see. What do we have?

So here, this airplane is getting a performance boost from a strong headwind. Now, not much is happening, except that it's getting pushed down, maybe faster than the airplane can climb. And at this point, you're getting a performance reduction from this big tailwind. So that's reducing-- you might think, well, that's great. I'm getting pushed along with a tailwind. But if it's suddenly taking away your airspeed, then that's not a performance boost.

All right. So the thunderstorm emergency procedures are, again, probably a little bit less relevant now that we're living in this world of constant datalink and NEXRAD data. 2006, there was a famous accident with a former test pilot, Scott Crossfield, who maybe didn't get the best advice from air traffic control. And I don't think he had datalink in his cockpit.

The Boeing B 29 bomber crews, they would fly, I think, seven or eight hours from an island in the Pacific over to Japan. And during those eight hours, they had satellite data, no data from a ground station. So they just had no idea what they were going through. And they didn't go as high as the designers thought that airplane was designed to go, super high.

But they were so loaded up with fuel and bombs, they couldn't practically climb all that high. So they were going at 10-15,000 feet over the ocean. And at those altitudes, you can't really see-- you may get into an embedded thunderstorm. Today's airliners, they go so high that you really are never in a position where you blunder into stuff, or almost never, because you're in the clear, and you can just see the towering cumulus and not fly there. You just back yourself around them.

So I guess-- yeah, the final statement there is, get-there-itis hasn't been cured. So as a pilot, the safest thing you can do is really fight that tendency to want to complete the mission as planned and overcommit to your plan of action. All right. There are three other categories of turbulence to worry about.

Probably the worst is due to terrain, like mountains. This low level turbulence from thermals is not crazy. But as I said, if you get above the clouds, that plane on top is going to be in a nice, smooth air. Wake turbulence [INAUDIBLE] is also another thing to consider. Let's look at that.

So if you're taking off behind an airplane, so look at that-- heavy, slow and in clean configuration. So airplanes will tend to retract their flaps, and therefore be in a clean configuration shortly after takeoff, whereas, if they're landing, the flaps are down. They're not generating quite as much wake turbulence. Although, still if you land behind a Boeing, in your little Cessna, you will notice that.

The solution here-- and I think this is a test question-- is you land or take off beyond the touchdown point of a large aircraft. So if the large aircraft-- let's say the large aircraft landed right here in front of the laptop on the runway. You just fly a little bit higher. And you land maybe in the middle of the runway. And that way, you can't possibly get into wake turbulence, because it will have sunk below that big aircraft's flight path.

Controllers at a towered airport, they'll also separate you by the necessary number of minutes. They have a bunch of regulations about how much separation they have to have between aircraft. And then similarly, for liftoff point-- so if the big airplane-- again, this is not really that much of a practical problem, because so little runway is used by light airplanes.

But if the big airplane rotated and took off and started climbing here, well, then you take off and start climbing earlier. Of course, the climb rate of the big airplane is probably a lot better than you are. So you've got to think about which way the wind is going and maybe try to turn away from it. I've only really been stuck in weight turbulence once that I can think about. It was at Hanscom Field. And there was a heavy helicopter that was cleared to land on the runway, and then transitioned sideways.

And I was in the Cirrus. And I think the controllers didn't really think about, well, how much wake turbulence can a helicopter generate. So I was trying to land. And maybe about 200 feet above the ground, there was a sharp wing dip that I-- the good news is you don't have to be heroic to correct it, because, if your airplane is banked, the natural tendency is to want to take the bank out. So whenever your natural tendency is to do the safe thing, that's usually not much of a problem.

Oh yeah. So anyway, here's the FAA question. Who wants to give an answer? Shout it out. A, B, or C?

AUDIENCE: A.

PHILIP GREENSPUN: Yay. All right. So this is a practical issue, especially for anybody who wants to fly out west. You have the Sierra Mountains. You have the Rocky Mountains. And you have to be very careful when crossing these mountain ranges. If the wind aloft forecast is more than about 30 knots for the time that you're planning on crossing, you can expect this kind of turbulence on the lee side or the eastern side of those mountain ranges.

So when I've crossed those mountains in light airplanes, I have usually done it first thing in the morning basically. So I arranged to shut down just short of the mountains the night before, and then cross early in the morning when the winds are typically calm. So you can look for these lenticular clouds. But again, if you saw the winds aloft forecast that it was going to be blowing 50 knots at 12,000 feet, you can be pretty sure that it's going to be turbulent.

All right. Structural icing-- you can get rime, clear or mixed. I'll just let you look through the conditions that lead to this. Clearing rime-- probably rime icing is more common. What happens? Everything gets worse about your aircraft. Especially if you're on autopilot, it's a challenge to recognize when icing is occurring. You can be in the air, fat, dumb, and happy while the airplane gets iced up.

So the worst part of it, I guess, is that you can't climb. Basically, when your airplane has all this performance reduction, you can summarize this all-- if it's only moderate icing, basically you have an aircraft that can't climb. All you can do is descend. So a good practical tip is, if you're-- well, first off all, the good news is, if you're a VFR pilot, like you guys are going to become, initially you shouldn't have to worry about icing, because it's a phenomenon that occurs when you're in a cloud. So you shouldn't be in a cloud if you're a VFR pilot to begin with. So how did you get ice?

The exception might be freezing rain, if you somehow drive through freezing rain. But if you are instrument-rated and you are going somewhere-- I'm planning on going to New York next week in the Cirrus. So if it's cloudy, even if there's no icing forecast, I know that there is a risk of getting ice on the wings. So in the wintertime, I just say, well look, I'm not going to go unless it's above freezing on the surface, because, if I get iced up, then inadvertently I need an escape route.

And if it's going to be above freezing at, say, 3,000 feet, well, that's fine. I know that I probably won't be able to climb if I get moderate icing, but I will be able to descend. Even a brick can descend. So descend down to 3,000 feet, and all the ice will melt off. That would be great. But if it's below freezing on the surface, then it's basically a no-go.

I've definitely had icing a few times. And it's pretty scary. I was out on a day when with an instrument student. And it seemed like a perfect day to go practice instrument flying. There was no turbulence. There was just clouds everywhere, about 800 feet of ceiling. So you could be in the clouds, do real approaches, get experience with actual IMC.

And halfway through the flight, I started criticizing this guy for using way too much power. The power settings were all off. What are you doing wrong? And then I looked out on the wings. And I saw they were all frosted. So we descended. We managed to complete an ILS approach into Lawrence and pulled the airplane into a warm hangar and got it warmed up. So actually, as we were as we were flying, the FAA issued an AIRMET for icing, but the controllers never told us about it.

All right. Requirements for icing formation-- near freezing temperatures, minus 10 to 0, is the worst. You have to have a surface on which the ice can form. And you have to be invisible moisture, basically. So again, if you're flying in the clear with your VFR pilot certificate, icing should not be a factor for you. Yeah. So as I said below, go through a cold cloud only if you have an escape route of warm air below.

AUDIENCE: [INAUDIBLE] for the engine [INAUDIBLE] as far as getting the icing in the carburetor [INAUDIBLE].

PHILIP GREENSPUN: Yeah. So the question is, what about icing in the engine? So you can get carb ice that we talked about. You can get carb ice when it's 50 degrees outside, as long as it's humid. So it's slightly unrelated. The main problem with engines is that you can get ice in the induction.

So if the intake for the engine where it's trying to breathe gets iced over, then there's an alternate-- again, they're relying on the hero pilot. Some airplanes actually, it'll just open automatically, the vacuum of trying to suck the air through the intake that's not working will cause some backup door to open. And a lot of-- most IFR-certified aircraft have an alternate air lever that you can pull and have air pulled from somewhere inside the-- it's a little more protected inside the airframe. Does that answer your question?

AUDIENCE: Yes. So I guess you're saying as long as the heat's working your [INAUDIBLE].

PHILIP GREENSPUN: As long as which heat?

AUDIENCE: [INAUDIBLE]

PHILIP GREENSPUN: You're not going to get carb icing and airframe icing at the same time probably. I think, at that point, it's probably too cold. I'm not I'm not sure. Well, the other issue is you're probably not going to fly a carburated airplane into the clouds, because the real IFR airplanes that people use to travel, like Cirruses and Bonanzas and stuff, in challenging conditions, those are almost all fuel injected. But you do have to worry about induction icing, like I said.

OK. Icing layers are usually pretty thin. So if you're in a jet, you just add power and climb up another few thousand feet and you're out of it. Again, one of the effects of icing is to dramatically reduce your climb performance. So this best approach of climbing out of it is not always available.

You will end up using more power on the final approach. And you'll add speed as well, because the stall speed may have gone up. And you can't really be sure, since it hasn't been quantified and tested. You probably won't use flaps. And you'll not make severe turns. So there's a good NASA video that I encourage you to watch, especially as you work on higher performance aircraft and IFR. NASA has this great video about icing.

OK. How do the transportation class airplanes handle this? One approach is to push antifreeze out onto the wings. That used to be called TKS. Now, it's called CAV. It's just a brand name. So if you go to a flight school and you see a modern Cirrus, like the SR22s, the leading edges of the wings will be metal. And they'll have little tiny holes in them. And that's for this antifreeze to come out.

If you have a very light jet or a turbo prop, you may have rubber boots on the wings and on the tail surfaces. And those inflate to crack the ice off. The jets are really the ultimate-- the bigger jets all have bleed air. Remember, the jets are compressing air so much that it becomes really hot even before it's burned. So you pull the bleed air off the compressor, and you run it out into the leading edges of the wings. And that just melts the ice off.

The transporter aircraft, they also heat the windshields. So you'll be able to see when you do-- if it's not above freezing at the airport, you'll have a clear windshield, so you can leave the runway. Even in very basic airplanes like a Cirrus, if they're IFR-certified, the pedo tube is going to be heated. There will be pedo heat.

OK. You can learn a whole bunch more about this. I think everything you know to pass the test is pretty much in the *Pilot's Handbook of Aeronautical Knowledge.* There's a little bit in the *AIM.* If you want to dig deeper and understand more of it, then I would encourage you to look at these FAA weather publications. One is about weather theory and one is about information that you can get from various sources.

There's also these videos that I would encourage you to look at. One of them is called "Ambushed by Ice" and "Into Deep--" these particular links, don't write those down, because I fixed them last night, but the Dropbox didn't update yet.

Do they have real-time weather data? So the question is, in your basic trainer airplane, do they have real-time weather data? So let's just talk about East Coast Aero Club is a typical higher end flight school. About maybe 10 years ago, almost all the aircraft had a Garmin IFR-certified GPS put in, a Garmin 430. So at that point, you had a really good GPS. But they did not have XM weather pulling data from satellites, which we'll talk about in a little bit, because it's a $500 a year subscription and a $10,000 box. So people didn't want to do it.

With ADS-B, the FAA is now providing some of the same data that XM was providing for free, as long as you have an ADS-B in transponder. And the East Coast Aero-- well, everybody has to upgrade to ADS-B by 2020. Not everybody has to have ADS-B in, but I think East Coast Aero Club's probably fairly typical of the better flight schools. They've put-- or they're gradually putting in a ADS-B in and out transponders in all their aircraft. It won't display in the cockpit. You'll have to have your phone, your iPad, or something. But you'll be able to see-- you'll be able to see NEXRAD radar picture. You'll be able to get METARs and TAFs. You'll get all of that. So I think--

TINA: But if you don't want to rely on someone else-- this is MIT. You can actually get that data yourself. So when we talk about weather data today, we're going to also talk about how you can do it yourself, build your own Stratux ADS-B receiver. And I've actually done this. It was really fun to do. It's very easy, actually. Basically, based on a Raspberry Pi with a couple of antennas, with a little cooling fan, you can build a little box that can receive that weather data. And it actually-- the software is open source. And it can sync with your other tools.

So I have it synced with my Foreflight app. So when I'm flying, I plug that in, I bring a backup battery for it. And it gives me weather data and some other traffic data. And we'll be talking about that in a couple hours.

PHILIP GREENSPUN: Yeah, I should have noticed. As Tina said, a lot of flight school customers for the last five years would bring little battery powered boxes and stick them to the windshield of whatever they're flying. And they would get a whole bunch of more modern services.

I personally don't love that. When I started out in my flying career, I had my big flight bag with all the stuff I was going to bring into the airplane. And now, I have the philosophy that I don't want to bring anything into the CIrrus other than a pencil. I want everything that I need to be in the panel. But yeah, I definitely think, in the older airplanes, it's become conventional for people to bring some sort of ADS-B receiver and get that data.