PHILIP GREENSPUN: Quick introduction. I know hardly anybody says they care about helicopters. But as God is my witness, I'm going to change that. If I can reach one of you airplane obsessed folks, I will do my best. So what is cool about a helicopter? Here, it's the view. So let's start, first and foremost, it's a view.

So these are some pictures that I snapped on a trip from the Robinson factory in Los Angeles back to Boston. Who recognizes the city in the middle? Ooh, some Midwesterners here, Chicago indeed. Of course this is the Stata Center where we'll be tomorrow, remember that, 32 141.

What are the parts of the helicopter? If you're between ages 3 and 5, it's acceptable to call it the thing on the top the propeller but older than that, it's better to say main rotor system. Tail rotor is in the back-- we'll talk about why we need that in a minute. You got to have transmissions.

In helicopters, the speed of the engine is never the speed that you want, I don't think. And landing gear is kind of nice. Although for record-setting flights, sometimes people have taken them off to try to get a little higher a little faster, and then they just land very gently.

So your typical helicopter drive train will have transmissions for both the main rotor, and they'll have another transmission to adjust the speed of the tail, maybe gear it back up a little bit. This unfortunately does introduce another source of unreliability.

So in the airplane, you've got your engine, it's bolted to the propeller. As long as the engine's turning, it's hard to have a problem. The propellers don't generally just come apart in flight. But here with the helicopter, you might have a working engine and working main rotor and the transmission, all the oil might come out and the gears seize up. There's a couple of warning lights in there for when you're having a transmission problem.

This is the rubber belt system that's used in some piston helicopters. I think this is probably a drawing off of a Robinson. But basically, you have pulleys on the engine side and on the drive change side, and you have these rubber belts connecting them. So you can start your engine with the belts loose and then tighten them up when you want the engine to begin driving the rotor system, that way you don't have to have the little starter motor actually turn all the rotors and stuff.

How does it work? So Tina is a hard act to follow with my cave person computer programmers understanding of lift. But if you assume that the lift is a combination of Newton's third law and the Bernoulli principle, the sped up air has more kinetic energy, therefore for conservation of energy, it has to have less of something else, it's going to have lower static pressure.

So here's one of the FAs diagrams here. We have velocity and pressure that are equal. They go into the Venturi. The velocity is higher, the pressure is lower, so the energy of the air is still the same. And it comes out again at the same velocity and pressure.

So you're getting lift from the wing from both Newton's third law just pushing air down makes the wing go up and the Bernoulli principle of generating some low pressure. This is the same drawing you saw earlier of how when you exceed a certain critical angle of attack, depending on the air foil, your lift party comes to a quick end. It doesn't go away completely, but it's a sudden drop.

Angle of attack, so remember there's your cord line, there's your relative wind, 4 degree angle of attack and a reasonable amount of forward speed. Remember the lift varies is the speed squared will have you going. And if you want to fly slowly, you just go to higher and higher angles of attack.

So why not hover in your Cessna 172 and save yourself the trouble of getting a helicopter rating? It's because you know off the right end of this chart you quickly get to the stalling angle of attack and the plane doesn't fly anymore.

So there's an FA drawing I think from the pilots handbook where the airflow becomes turbulent somewhere between 12 and 16 degrees angle of attack, depending on the air foil. And that's why the Cessna can't be used for hovering operations.

What if you saw the wing off the Cessna and spin it around? So if you do that, the wing will always have airspeed even if the fuselage is not moving. And that was an idea that was first reduced to practice in 1907. So only four years after the Wright brothers flew, a couple of guys in France were actually hovering a little bit in the helicopter.

The first helicopters that could be flown and controlled and actually operated as a practical aircraft I think mid 30s in Germany. And then Sikorsky is famous for being the first mass producer of helicopters with the Sikorsky R-4. It was used for a few computational purposes in

World War II, search and rescue type stuff. But really, the Korean War was the first time that helicopters were widely used by the military.

Let's talk about a very simple qualitative physics here. We're spending on the ramp. So we spin the rotor system up to 400 RPM. But we're still on the ramp. So does anybody have a brilliant idea for how do we get up into the air where we want to be?

AUDIENCE: [INAUDIBLE] were negative, because there [INAUDIBLE] of the main rotor system.

PHILIP GREENSPUN: OK, excellent. So-- what's your name? Sorry.

AUDIENCE: Aziz.

PHILIP GREENSPUN: Aziz has a correct observation that if you want to get the same lift out of a wing without changing the speed, we don't want to have this-- we don't want to speed up too much because the tips will go supersonic, and the neighbors will begin to complain. So we just twist the blades up a little bit. And as they're twisted up, they'll bite more air, generate more lift, and the helicopter will begin rising up.

What will happen to the speed? Let's hear from one of these aeroengineering heroes. As we generate more lift, what happens?

AUDIENCE: You now have more drag on the rotors, so the engine slows down.

PHILIP GREENSPUN: More lift, more drag, so without adding more power, the engine-- well, without adding more power, the blades will slow down. So you want a correlator. As you're lifting the collective control on a helicopter, the correlator is opening the throttle and adding more power automatically.

And there's also an electronic governors that will just touch that up a little bit by watching the RPM. Turbine helicopters all have governors. Most piston-- Robinsons have governors, as well.

All right, so what if we're parked on ice? Has anybody here seen my favorite movie, *Blades of Glory?* So when Will Ferrell and his partner, what if they're on the ice and they push each other? What happens?

Both go backwards, the pusher and the pushee. So keeping in mind *Blades of Glory,* an important physics work, what if we're parked on the ice? What happens to our helicopter after we start the engine and start the blades spinning?

AUDIENCE: [INAUDIBLE]

PHILIP GREENSPUN: Helicopter spins the other way, excellent. Yeah, so that's Newton's third law, once again. For every action, there's an equal and opposite reaction. You're not going to see that as dramatically if you're parked on pavement, because of the friction.

So what do we do? We add the tail rotor. So here are the forces up here.

There's the blade rotation. There's the torque. To counteract the torque, we've got the tail rotor thrust to blow the tail back into position.

And the only thing here that's not corrected, you'll notice, is the tail rotor thrust. So if you set everything up the way you would think obvious, like put the rotor mast straight up and put the tail rotor on it, the whole helicopter with the controls neutral would drift to the right from the tail rotor thrust. Because it's pushing the tail.

The helicopter wants to rotate that way. The tail rotor blows it back this way. And that would blow the whole machine off the side of the ramp if the pilot didn't hold a lot of left cyclic. So to counteract that, the helicopters are rigged with the mast at a slight left angle so that they don't have this tendency to go off to the right.

AUDIENCE: [INAUDIBLE] question, what does the governor do?

PHILIP GREENSPUN: The governor, yes, let me reinforce that. So yes, as you generate lift, you get more drag, which will cause the blades to slow down. So there's a mechanical correlation.

As you're raising the collective, the throttle's being opened just kind of blindly. And the governor is touching that up. The governor is watching and maybe twisting the throttle control slightly to fine-tune the throttle to keep the blades exactly at 400 RPM. Let's say that's the [INAUDIBLE].

For a pilot, pilots are-- you don't want to distract the pilot too much, so the gauge is just calibrated in percent. It's 100% RPM. That's good. That's all you need to know about your helicopter. I think in the Robinson, it works out to pretty close to 400 RPM.

All right, forward flight-- so we're hovering and we want to go forward. So it seems obvious that we want to tilt the fan. We want to push the fan down this way, and that way, we'll get some horizontal vector of thrust and we'll be going forward.

But where do we push it from? It's a spinning gyro, so it has a lot of stability. If we're really strong and we reach up from our pilot seat and try to nudge the rotor system, why wouldn't that just cause the helicopter fuselage to move underneath the fixed rotor system, instead of moving the rotor system?

There's nothing to fix unless we can call up an incredibly strong friend, and say, would you mind holding the helicopter in a fixed position? We don't have anything to push against in order to tilt the rotor. Does that make sense? You've got this gyro on top of you, and disturbing it is going to take a lot of power. And even if you had the strength, you don't have anywhere to stand rigidly and push.

So what do you think? Could the rotor just fly itself into a new position? And how would that work? How could you use the spinning wing itself to fly itself into a new tilted-down position? Anybody have any brilliant ideas?

AUDIENCE: You increase the angle of attack of the blades on one side [INAUDIBLE].

PHILIP GREENSPUN: What's your name, sorry?

AUDIENCE: John.

PHILIP GREENSPUN: John has a good idea. So John says, increase the angle of attack and decrease it as the blade moves around the disk. So if you can increase the lift on part of the disk compared to another part of the disk, it will naturally tilt itself.

So if you want to go forward-- let's ignore gyroscopic procession for a moment, because I think we've proven that nobody understands it. Let's just say that we could make the angle of attack higher on the back of the disk compared to the front. Then the back of the disk would have more lift. It would rise up and the front would go lower, and then you would see this flight path that you do see. That make sense?

So basically, you're basically flying the rotor system. You're not flying the helicopter. The helicopter's just hanging from the rotor system. That's a good mental model.

And all of the power is from the engine to the rotor system. So that's a natural place to do it, just by tweaking the blade angle as it rotates around. So the left hand is collective, moving the blade's angle regardless of where they are on the disk, and the cyclic, which is changing the pitch cyclically as you suggested.

All right, what's the magic? This design-- I'm not sure it's really changed at all since the very first helicopters. Maybe those brothers in Paris didn't have one in 1907, but I'm pretty sure that every helicopter since then has had this. There's a swashplate.

Watch this-- so the lower part of the swashplate here is fixed and connected to the flight controls. And then there's a bearing, and the upper swashplate rotates with the blades. Does that make sense?

So if you lift the lower swashplate up, that pushes the upper swashplate up, which pushes these rods that are connected to a corner of the blade. And that'll cause the blades to tilt. That make sense?

So you have this rotating swashplate that's connected to a corner of the blade. And if you push the whole thing up by yanking up on the collective, then you can see the blades actually twist. You can do that in the hangar and see the effect of this.

At the same time, in your right hand is the cyclic. And with the cyclic, you're tilting the swashplate. So with the tilted swashplate, that will just cause the blades to twist up and twist down as they rotate.

So it's a pretty elegant solution. This is not carrying much of the load of the helicopter. There's still a mast holding the whole thing up. This really just has to carry enough force to twist the blades up and down, up and down, up and down. So that's your engineering design.

Everybody appreciates that? Do we want to take off straight up like in a Hollywood movie? Well, if you have one or two people in a helicopter designed for four or five, you actually do have enough power to do that.

However, there is something over here on the right called the "height velocity diagram." And you can see it says, "avoid operation in shaded areas." So they're saying-- we'll talk about this maybe a little later if people are interested.

But if you are, let's say, up at 200 feet at zero airspeed, so you're just parked, hovering 200 feet above the ground, you don't have huge stores of forward speed, which is kinetic energy, or potential energy, because you're only up 200 feet. So it's going to be hard to do an auto-rotation that's perfect and doesn't bend anything, especially because the FAA says, if you're up high like that and the engine quits, in test pilot, you have to sit there with your arms folded for one second and do nothing, because that's what would probably happen in real life. You'd be surprised.

People can do auto-rotations from 200 feet and land perfectly, but they know it's coming. They chop the throttle themselves. They immediately put the collective down and they do the auto-rotation. So but basically, if you're a pilot of average skill and you don't do anything for about a second after the engine quits, then this is supposed to keep you safe, by you either fly 50 knots or faster, or you fly 400 feet or higher at sea level, and higher than that at high altitude.

So what we're actually recommended to do-- see this recommended takeoff profile-- is skim along the ground until we get up to about 45 knots and then let the helicopter climb. I think this is the curve for a Robinson R44. Why would you want to do that, aside from safety?

Another good reason to do that is you watch these drag versus speed curves, and you see that you reach kind of a minimum. This is some generic helicopter from an FAA book. It's actually 55 knots for the Robinson.

But if you can go 55 knots, you need less energy than any other airspeed. So the idea for a takeoff is you nudge the helicopter forward a little bit. If you can build up two knots of speed, that gives you excess power. You can use that excess power to climb up three inches or you can use that excess power to accelerate, maybe to three or four knots.

And if you just keep accelerating using your extra power to accelerate, the faster you go, the less power you need. So even if you've never touched the collective or drawn any more horsepower, as long as you have an open area in front of you, you will accelerate. And once you hit 45 or 55 knots, your hover power turns into significant excess power that you can use for a climb. So that's why you often see helicopters at airports taking off kind of like a short-field airplane, and also landing a bit like a short-field airplane.

Straight and level, it's very similar to an airplane. The performance is all a function of the attitude that the aircraft is in. Is it pitched up or down and how much power is being applied? And that's an indirect function of the collective position.

So as with an airplane, remember, your pitch controls your speed. And the amount of power-- throttle in the airplane, collective in the helicopter-- determines whether you're climbing or descending at that air speed. Your attitude indicator in a VFR helicopter is the horizon, so you're watching the horizon carefully.

The reason why people who are instrument-rated airplane pilots, they jump into the helicopter and they can fly it immediately, and people who've never flown have a tough time. It takes them 10 hours. And the reason is that people who are instrument-rated airplane pilots, they become very sensitive to watching for small changes in attitude.

The anti-torque pedals-- remember, we had that tail rotor, and we adjust it so that the tail doesn't spin around on the ground. In the air, we adjust it so that the helicopter is streamlined into the wind. We don't actually have to use them to make turns. There's no adverse yaw as in some airplanes, where it'll start skidding or-- there's none of that, or slipping.

All we do to make a turn is we put the helicopter, using the cyclic, into a little bit of a bank. And then we wait. So if we have, let's say, a 10-degree bank, the helicopter in one minute will make a 180-degree turn.

Landing with power-- so again, like an airplane, if you see the spot in the ground, you adjust the power so you don't overfly the spot or underfly the spot. If the spot's rising up in the windshield from your perspective, that means you're going to land short, so you add power, raise collective in the helicopter. If the spot is descending, then you're overflying the spot, so you have to reduce power.

It's a purely visual maneuver, except when you're landing on a pinnacle. And the reason for that is if you're landing on a pinnacle, you don't get a sensation of your forward speed from the ground rushing by. So the idea in the helicopter is to land, unlike with the airplane.

It's actually a little bit less unnerving than an airplane. Some people get a little bit ground-shy in the airplane. They're happy flying 80 knots in the pattern, but they're not that happy flying 70 knots 10 feet above the runway, which makes sense, because you don't want to slam into the ground going really fast.

The good news is in the helicopter, you never get to that phase where you're going fast close to the ground, because when you're landing, you just say in my peripheral vision, how fast is the ground rushing by? And you just kind of keep that constant. Whatever it was up at 500 feet above the ground, that's what you want when you're five feet above the ground.

And you'll very naturally slow down. You'll do the right-- your natural instinct to slow down as the ground begins rushing is a helpful one in the helicopter. So your peripheral vision is used for speed reference, and the spot moving up or down is used for a descent rate reference. And that's why you never have to look inside at the gauges, except when you're landing on top of an office building or something.

Can you land the helicopter without power? It turns out the answer is yes. You have these three buckets of energy that I alluded to earlier-- kinetic from your forward airspeed, potential from being up high, and then another form of kinetic, which we'll call "blade inertia" from the relatively heavy blades spinning.

So raise your hand if you think the forward airspeed is number one in terms of size. Let's rank these. What's the biggest-- airspeed, a heavy helicopter going 100 knots, potential energy, helicopter having been lifted up off the ground, or the blades whipping around near the speed of sound?

Who votes for one, forward airspeed? A few. Who votes for potential? A fair number. Who votes for blade inertia, the blades whipping around?

All right, good. We've got a good distribution. Let me give you-- I'll tell you about, I think it was a crazy French guy who got into what's now called a Eurocopter, an Alouette, went up to 40,000 feet to set an altitude record.

The record was set when the engines flamed out-- that's why it's 40,000 and change, not 41,000 and change-- and then auto-rotated all the way down to the ground. So whatever energy bucket that was there had to be sufficient to make it all the way the ground. So what does that tell you the biggest one is?

It's got to be something that scales up to 40,000 feet. Potential, yeah. So potential energy is a good candidate for the biggest, because again, you've got to keep the rotors spinning for longer if you're auto-rotating from 10,000 feet or 50,000 feet or wherever. I don't think that record's been broken, actually. It was set in the '70s.

So number two is the forward airspeed of the helicopter. The blade inertia isn't good for much except for cushioning your fall from five or 10 feet above the ground. So what you do in the helicopter if the engine were to fail-- number one reason is fuel starvation from failing to top it off.

Helicopters are often short on payload, so people will say, I want to take these seven people somewhere, and I'd be overweight if I fill the fuel tank. So I'll put in half an hour of fuel for this 15 minute trip. Actually, that would be illegal. 20 minutes is the minimum reserve.

So I'll put in half an hour of fuel for this 10 minute trip, and then there's a bit of a delay, and you run out of fuel. There is a warning light at 10 minutes. And the good news is you can land in a field, a baseball field, pretty easily.

So the engine quits for whatever reason. Let's say you run out of fuel. You want to get to 60 or 70 knots, some reasonable air speed.

And then the challenge is to hold that airspeed even as the ground is rushing up at you. You hold it right till you're at treetop height, about 40 feet above the ground. Then you begin to flare, just like in an airplane flaring for landing.

You scrub off that forward speed. And that reduces your descent rate. So you can reduce your descent rate to zero by bleeding off all of that energy from the forward airspeed.

And the kinetic energy, remember, is mv squared. So it's very important. There's twice as much energy at 70 knots compared to 50 knots.

So once you've scrubbed off all your descent rate and all your forward speed, you're like this. So your tail is going to be low. And now you're going to just fall to the ground and hit the tail first. So it's not going to be an FAA quality-- you're going to walk away, but it's not going to be an FAA-quality landing.

So what you can do is stick forward and settle by pulling up on the collective. So you stick forward to level the skids. And then when you're about five feet above the ground or maybe two feet above the ground, you start pulling up on the collective to cushion your fall that last few feet.

So you've used up potential energy keeping the blades windmilling. If you just flatten the collective, the blades will have a relatively normal angle of attack to the air that's now coming from below. You've kept up your forward speed, and you bleed that off at the end to reduce your vertical speed. And then finally, you go--

[VIDEO PLAYBACK]

The guy cheated.

[END PLAYBACK]

What's the cheat? And I'm telling you the cheat is you can hear it. You could hear the cheating going on. He landed with zero forward airspeed. Why?

What enabled that? And like I said, you could hear it.

AUDIENCE: [INAUDIBLE]

PHILIP GREENSPUN: It's not from the engine running. The engine was presumably at idle. So what was the cheat? Nobody heard?

AUDIENCE: The wind probably [INAUDIBLE].

PHILIP GREENSPUN: Wind, exactly, yes. What's your name?

AUDIENCE: Messen. Messen.

PHILIP GREENSPUN: Messen figured this out. So basically, he landed with probably-- it's very hard to kill all of your vertical speed and all of your forward speed. So if you go out and it's 15 knots down the runway, if you can just get down to 15 knots, and instead of sliding and going [MAKES NOISE] down the runway, which is common and not harmful to the helicopter, you'll have a perfect, what looks like a perfect landing.

It's very hard. In the big helicopters like a Huey or something, it's practical to do a zero/zero landing out of an auto all the time. In a Robinson, it can be tough, but the wind helps hugely. And like I said, the throttle was down at idle, so the engine is not really doing anything. Question?

AUDIENCE: The tail rotor was still spinning. Is auto-rotating [INAUDIBLE]?

PHILIP GREENSPUN: It is, yes. Great, great question. So there's a sprag clutch, which prevents the rotor system from trying to drive the engine, because that would introduce a lot more drag. But the main rotor and the tail rotor are yoked together, so you still have tail rotor control. Great question.

AUDIENCE: [INAUDIBLE] directional, because you don't really need the torque anymore, so--

PHILIP GREENSPUN: Yeah, you don't need much. I don't know. I'll have to think about why it's useful.

AUDIENCE: [INAUDIBLE]

PHILIP GREENSPUN: Yeah, it's not useful for much. That's for sure. One thing that is good about it is the hydraulic pump is also geared to the transmission. So you still have hydraulic boost even if you're auto-rotating from super high.

What can you do with a helicopter if you have a private? You can visit schools. I visited the Winchester Public Schools. I'm not sure you can give them all rides if you only have a private. There's some kind of-- like I said, there's those charity laws that-- regulations that we don't really worry about, because we have commercial certificate and a letter of authority from the [INAUDIBLE].

But here's one of the East Coast Aero Club helicopters. I flew to the public schools in Winchester. I gave all the kids rides. And when we flew over houses like this, I said, oh, that's just like the house where I grew up. If you do that with kids from Weston and Lincoln, they believe you. They don't parse that as an ironic statement.

Helicopter pilot careers, just in case any of you guys are thinking about leaving the desk where all the people work as a flight instructor, fly tours in the Grand Canyon or Alaska, and then they'll either go to offshore oil or Medevac after that. Usually offshore oil used to be easier to get. When oil prices are low, when oil catches a cold, the helicopter industry catches the flu. They shut down these oil rigs and there's a lot less need for helicopter transport.

Medevac is kind of considered the plum job. That's my friend, Marcus. He trained at East Coast Aero Club and now he does 12-hour shifts at a volunteer fire station. And he gets paid in North Carolina and goes hospital to hospital, or sometimes picks people up off of highways and stuff.

So what can you do? You can fly low and slow both legally and safely. You saw there was a carve-out for helicopters able to fly lower.

One problematic aspect of flying Piper Warriors and Cessnas is that people-- their expectations of what an aircraft is and what it can do has been set by their airline experience. And the first time you try to get up and use the bathroom in your Piper, you'll discover that JetBlue has some advantages in the aircraft department. And your passengers will notice this, too.

This is noisy. It's not climate controlled. There's no bathroom.

The helicopters are awesome, because people usually haven't even been in one, so it's a whole different experience. There's a different view. You can take them on a 10-minute ride from Hanscom Field and go back.

You don't have to say, oh, let's go have lunch in Martha's Vineyard. You just take them on a little tour and they say, wow, this is awesome. So when I actually want to show people what GA is like and what my world is like, I usually take them for a helicopter ride. I don't take them for a trip. The serious is for transportation, and the helicopter is really what I think of as the kind of aviation dream that people had in ancient Greece. They didn't dream of going to LA in six hours. They dreamed of soaring like a bird.

You can land off-airport. That's where a lot of the challenge comes from the helicopter. People think you're a pilot of heroic skill if you take off and land at Hanscom. That's not very challenging. It's not really that different. And in some ways, it's easier than taking off and landing in a Piper or a Cessna.

When you're off-airport, you have to exercise a lot of judgment, a lot of skill. And that's part of your training. But it's also where people get in trouble hitting obstacles and stuff.

If you do get all of your airplane skills, you can transfer them over to helicopters very easily. It's 30 hours minimum of additional training to add a helicopter rating. 40 is probably a good budget number.

All right. Are there helicopter questions?

AUDIENCE: [INAUDIBLE]. Can you just pick [INAUDIBLE]? OK, here it is. Or like, who's going to tell you [INAUDIBLE]?

PHILIP GREENSPUN: That is a great question. Is there any regulation about where you can land your helicopter? The answer is until about 5 or 10 years ago, there wasn't any. So it was just permission of the property owner and don't do anything careless or reckless. So basically, the whole world was open to helicopter pilots.

There is a little bit of a tweaking of the law. The FAA passed this-- they added this regulation that I think was intended for airplanes, but they forgot to carve it out. So they said if you make more than 10 takeoffs and landings in the same place in a year, then you have to get it approved as an airport with a huge amount of regulation.

I think it was intended for mining companies that would set up their own landing strip. It doesn't really make sense. For helicopters, like if you have a construction site that you want to regularly visit, now it's a bit of a hassle because that 11th landing, in theory, you need it to get approval as an airport. But as a first approximation, you can land anywhere that the property owner is happy to host you.

And towns, also. They're really aggressive about harassing people who try to have a helipad at their house now, just because they can. They get them under zoning laws, even though they're not really supposed to.

The FAA is supposed to have exclusive authority to regulate aviation. Because think about it-- there's all this-- there's so many levels of government in the US. If you let them all just forbid activities, eventually there would be nothing that was legal at all, because people in Concord and Lexington would say, we don't want airplanes flying over our head. So we'll just make it illegal to fly a Gulfstream in Concord.

AUDIENCE: [INAUDIBLE] from flying [INAUDIBLE]?

PHILIP GREENSPUN: I had that in an earlier slide on learning to fly. The marginal cost is about double. So it goes from 150 an hour to 225, or 100 an hour to 200, because so many rotating components get discarded after 2,200 hours-- so the transmissions, the blades, and so forth. So it is more expensive per hour.

However, like I also said, the flights tend to be a lot shorter. So I would say as a hobby overall, it's about the same cost, because you're not dragging people all the way to the Vineyard or Bar Harbor. You're just taking them into Boston and back out, which is about 20 minutes of flight time and 30 minutes of engine running time.

Whereas an intro airplane flight would be an all day thing. You'd probably fly a couple hours, two or three hours. So you actually probably spend more with the airplane.

That's a great question. All right, so I guess we should take a 10-minute restroom break. And after that, we're going to hear from Laz about the F-22.