

[CLICKING]

PHILIP All right, folks. Tina is going to tell you more. We had a little bit of weight and balance before
GREENSPUN: that flight planning example, but Tina is now going to give you the real story.

TINA So are guys all ready to go out and get your drone license? Good. I'm really glad.

SRIVASTAVA:

PHILIP [INAUDIBLE]

GREENSPUN:

TINA All right. Weight and balance So we talked a little bit. We've actually had quite a few
SRIVASTAVA: discussions throughout about stability, about where the center of G is, how that affects your controllability of the aircraft. So weight and balance is not only an important thing to know, but it's a required thing that you have to do before you go flying each time.

And one thing that's also relevant is to understand the center of gravity, and you want to make sure that center of gravity is within the limits for your given aircraft. So we talked about-- yesterday, when we were talking about aerodynamic flight, that certain aircraft have to be reinforced to do certain operations. So again, it really has to do with that. And by the way, from yesterday, mark left behind some of his aerodynamic procedure diagrams. So if you want to take a look at that, those are up front.

Well, one thing that really you have to keep in mind in terms of what the aircraft can handle is just what is the max gross weight. So what can this airframe sustain, in terms of stresses on its body. We also talked this morning about performance and discussed certain things like the distance-- the length of the runway and the distance you need to take off are affected by how the airplane is weighted. So we're going to talk about those things specifically, and then one thing I have on here is if you go over your gross weight, then you get into test pilot territory, and right after this-- we'll grab lunch and come back-- we'll hear from [INAUDIBLE], a test pilot who's going to tell you some really cool things as well.

All right, so it's just some basic terms to get started off. So when you're thinking about an aircraft, one piece of information is its standard empty weight. So that's the weight of the airplane, and there's also some fuel in the tank that sometimes it's hard to drain, and when

you refill, that fuel sits at the bottom and can't be used by the aircraft, so that's the unusable fuel, and then there's some different fluids and fuel oil inside the aircraft. So all those count in the calculation of the standard empty weight.

There's also the basic empty weight, where you have some optional equipment inside, and we'll go to a aircraft's POH to look into what it actually reports about what it contains. There's also a good rule of thumb to know about what weight you're going to associate with the per gallon of fuel. So it's generally a good number is six pounds. For the fuel that you'll be using, it's slightly more for different types of fuel.

So right at the beginning of the class, we talked about weight, which is the force pulling the aircraft down, which has to oppose the lift pulling it up. So the weight actually becomes less as you burn fuel. So when you take off, you have all the fuel on the aircraft. As you've been flying for a while, that fuel is used in the aircraft has less weight.

So there's a fully loaded aircraft. Has something called the maximum ramp weight. So that has fuel that will be expended even when it's just taxiing over to the runway, and so you make certain assumptions about how much fuel you'll actually burn off just taxiing up to the runway and then before you take off. And so when you're calculating the weight of the airplane when it takes off, it'll be slightly different than how you fueled it when it was sitting parking on the ramp.

OK, some of the biggest things that you would keep in mind that you change every time you get into the airplane. So there's the weight of the passengers, the baggage you take with you, and then how much fuel you fill the plane with before you take off. So the payload in this case is the passengers and the cargo. So whatever baggage and the weight of those bags that you take with you.

So one thing to keep in mind in addition to just the weight, we have to figure out where that vector, that force vector, acts on the aircraft. If all of the weight is really at the front, you might have a center of gravity at the front, which will create a moment on the airplane. So it'll cause it to bend in a particular direction. And if all that weight was acting at the back of the plane, you had a lot of really heavy bricks at your tail, which is not a good idea, it would cause that force vector to act over here and create a moment. So that's all related to torque, which we talked about before.

So it's also important, not just to calculate what the weight is of the airplane once everybody

and everything is inside, but also how that weight is distributed in the airplane and how it affects the airplane's center of gravity. All right, so I think that many of you have already-- It looks like most folks in the rooms were either MIT undergrad or grad student, which means you already understand some of these basic physics terms about torque and moment, so we'll discover them very briefly.

The moment is the weight times the arm. So basically where the weight is times how far away it is from a particular location that you're calculating it from. So we're going to do a couple basic examples. So we have a seesaw here. So in this case, whenever you're calculating your moment, you have to pick a reference point and make sure you're consistent as you use it.

So in this case, they have a-- their data point is at that triangle at that fulcrum in the middle, and so they have a moment on the right and a moment on the left. So you see various rectangles that represent different objects or different weight, and then they calculate it. So that blue box that's five pounds is 10 inches away. So to figure out what the moment is that it applies, you just calculate the weight times how far away is.

OK, so in order to figure out what the center of gravity is, you might want to consider where you're doing that reference point. So rather than doing the reference point from right in the middle of the aircraft, in this case, they're starting at the end. So where that yellow line is where it says datum is where they're starting, and then they're using the length from that same reference point. So now you have a purple box of five pounds that's 10 inches from that datum, and then three pounds then a green weight that's further, and the red box that's the farthest away.

So here they've listed all those different boxes and the weight of each of those boxes times how far it is. You multiply that to get the moment that it applies. And use that to calculate the location of the center of gravity. And just in terms of if you've been on a seesaw before, who has been on a seesaw before? All right, good. I'm glad.

So as you know that that fulcrum or where that triangle is, if you put that triangle at the center of gravity. So all the kids sitting on one side of the seesaw weigh the same as the kids sitting on the other side of the seesaw at the appropriate lengths away, so they're applying the same moment. Then the fulcrum balances. So if we determined what the center of gravity of this airplane was and I put my finger there, then it would balance and it wouldn't tilt one way or the other. So that's the whole idea.

So for a given aircraft, there is not only the center of gravity, but in the testing process, they understand what is that approved range of where that center of gravity can be such that the aircraft is still stable. So if you're thinking about putting a lot of weight at the front of the aircraft and less weight at the back of the aircraft, then the center of gravity moves forward, and there's a limit to how far forward that center of gravity can be that allows the plane still to be stable. So that's the forward CG limit, and then you see the same thing at the back. Aft just means back, so how far back the center of gravity can be.

All right, so we've already discussed some of the performance things, but just to just to remind you, what are some of the things that can happen if your air plane is overloaded? You want to just a shout out some things that you would experience if you have a very, very heavy airplane.

AUDIENCE: Longer take off.

TINA SRIVASTAVA: Yes, very good. Just to repeat it, longer to take off. So we have takeoff and landing distances increase. So if you have a very heavy airplane, you may not be able to take off from a short field runway. And then of course it was talking about if your aircraft gets outside the approved envelope, it will talk about what we mean by envelope, then it hasn't been tested to be stable at those areas, and so now you've become a test pilot, which you may not want to do.

Again, we're going to hear from a test pilot very soon. OK, so what happens if-- not just that it's overloaded, maybe it's still within the envelope for the total amount of weight, but what if the center of gravity has moved too far forward and pass that forward CG limit. So your plane naturally wants to be nose down. So what is the impact of that?

Well, it'd be harder to climb, right? It's harder to climb because your nose keeps pulling it down, for example. What does it mean to have a stall speed increased? Is that a good thing?

AUDIENCE: No.

TINA SRIVASTAVA: And why not? Why is it not a good thing?

AUDIENCE: [INAUDIBLE]

TINA SRIVASTAVA: Yeah, so basically, if your stall speed has increased, that means you're likely to stall at a higher speed. So if traditionally can fly at 60 knots without stalling but that stall speed has

increased from say 40 knots up to 60 knots, that means that when you traditionally have been able to fly safely at 60 knots, you could actually stall at 60 knots. So an increased stall speed is bad.

And what about an aft CG? Having the weight too far to the back. What is the impact there?

AUDIENCE: They pitch up.

TINA
SRIVASTAVA: They tend to pitch up. Right. And so one thing that they are talking about here is flare. So this is when you're coming into land, you go down, but then you flare up, and it could actually over flare, and that can cause some really strange things when you're trying to land, such as bouncing, and you definitely don't want to do that. But all of these things you might actually just notice when you're feeling the airplane. It acts differently than you want it to act.

So here's just basically a cross section. If you took off the wings and the top of the fuselage and you were looking at the plane, it shows you the pilot sitting in the left seat, a passenger in the right seat, two passengers in the back. This one actually has a third row of passengers, and then two baggage compartments. So this is just showing-- traditionally, when you're loading up an airplane, they payload again is your passengers and your baggage, where do they sit?

So now I'm going to go over to this document viewer and talk about specific airplane. The plane I like to fly, a Cessna 172. OK, so this book is talking about a particular aircraft, a Skyhawk, so it's a Cessna 172. This is a plane that many of you guys might use as a flying aircraft. We've also talked about for example a Piper, which is a low wing airplane that you might use.

So this is what a Cessna looks like, and it has a tricycle gear at the bottom. Whatever plane you are using for training, I would get very familiar with this book, and in particular, remember what the table of contents is. Because when you get your oral exam on your FAA examination, it's OK if you don't remember everything. What's really great is if you know how to find information, and you can say, hey, if I didn't remember this, I would go look at my POH, and I would go look at the weight and balance section, section 6 of my book, and I'd be able to flip and find this information very quickly.

So oftentimes, you'll get questions in that oral exam where they would ask how you would go about finding information. We discussed that a lot with regard to weather data. What are the

sources of weather data, so with regard to weight and balance, the information about your airplane is found with a book made about your particular airplane. And if you're at a particular flight school, and we'll show you that in an example, they might have a-- they most likely have all of this weight and balance information listed in a spreadsheet, sometimes it's accessible online so you know for your exact airplane what its gross weight is.

So if we flip to that section 6, it has a fair amount of information, including the picture we just showed you. So it talks about-- in this case, there are only two rows of seats. So that the pilot and passenger, one row of seats, so it seats four people, and then it has a baggage area. But what's really important to understand is that even though the Cessna can fit four people, it will show you that if you put four 200 pound people in there with a bunch of bags, you'll actually exceed the allotment.

So just because there are four seats, doesn't mean you can take four large people on a flight. Some of it is something we'll keep in mind, and maybe you can reduce bags and reduce fuel such that you can make that weight workout. So we talked about envelopes. So the envelope is basically a line on this graph that shows where the center of gravity can be, and the envelope is where is it safe to be. So if you're inside the envelope, so inside this line, if your calculations result in a center of gravity inside, then you're within the envelope.

If you're outside of it, then you're not. You can see a little pencil mark towards the top where I took a flight recently, and I was trying to calculate whether or not I was inside and in fact I was. And it's OK that I'm right at the edge of the envelope. As long as you're inside, you're still with inside the tested limits. Now, there are two different categories or two different lines here. There's a bigger line that says normal category, and then there's a smaller line-- smaller envelope-- that's talking about utility category.

Does anyone know what the difference is between normal and utility?

AUDIENCE: G limits.

TINA SRIVASTAVA: G limits. Is that what you're going to say? So there's different restrictions. One question you might get asked is, how do you find out where the answer is? And it's right in here. Right where you think it is. And I'm actually going to show you real examples, so we're going to go through an example of loading up an airplane.

Don't want to embarrass anyone, but we might ask some of you what your weight is. So

beware. So every time you have to calculate your weight and balance, you can do it by hand, or you can use a computer to do it, and I would just caution that you have to double check all the information. So here's a great link that tells you for a particular Cessna 172, a weight and balance calculator.

So here, you can actually type in the empty weight. Now, there's a big Warning here, use your own AC data. What is that saying? What is AC?

AUDIENCE: Aircraft.

TINA SRIVASTAVA: Aircraft. Use your own aircraft's data. So look at your actual information from your school to figure out for the plane that you're renting what those pieces of information are. So here is a link from east coast aero club just as an example, and they have provided for every aircraft that they have a bunch of information.

So for each aircraft, they have provided the empty weight and the CG, the moment, gross weight, useful load, and then they also talk about two different settings for fuel. So you can have full fuel or fuel to tabs. So that is something you'll hear pretty frequently. Fill the fuel to tabs.

So if you want to have extra mass, extra weight in your plane, you have some heavier folks flying with you, you might only want the fuel to tabs. But if it's just you or you and your instructor and you want to fly a cross-country flight, you might want to fuel full. So these are all things you can change.

This calculator has some restrictions, which is that the weight is identified here in terms of-- so they have the oil. So you might want to check what is the oil level inside your engine. For a Cessna 172, six quarts is a really good number to have, but you check it every time and during your pre-flight. It could be five quarts, it could be seven quarts, so you want to double check that.

And of course, if you see that it's low, four quarts, you really want to ask someone to fill that up before you go flying. But the other thing here is you actually list the weight of the people that are sitting in the front and the back. So I talked about embarrassing folks. Well, let's not let's not embarrass folks right now.

So let's say the pilot and let's say you're doing some great resource management. You have another pilot sitting next to you, so your co-pilot is there, and you also have some big folks

sitting in the back, both the left and the right side. And you want to take a bunch of pictures and stuff, but you want to get as low as you want, so you put in some bags. So this-- it's actually hard to see because there's too much weight. This red little plus sign is showing where your center of gravity fell and whether it's within that utility or normal category.

So in this case, we have three people. Front two are 200 pounds each, one person in the rear with 200, and bags there weighing about 10 pounds. Is this safe to fly? No, so you're a little red dot went outside the limits. If you have a much smaller person sitting in the back seat, you cross over that line, and now you're back into the normal categories so you can fly. Again, another thing you can alter is, of course, you fill the fuel to tabs.

So this is also talking about-- so most of the time in the POH book, so the section 6 is about weight and balance. So although the one example I just showed you was for a Cessna 172, the Piper Warrior also has that consistent, so really recommend just memorizing the table of contents for your POH. So the way that you go about calculating it is the same way we entered it into their little calculator.

So first you have to determine the basic empty weight of the aircraft and then the moment. Section 6 almost always also has a place for you to do that calculation, and so they have a place right there where you can enter in your airplane, the moment, and it does the same steps that we just saw on the slide. So you start with that basic empty weight, then you focus on the fuel, and it gives you the 6 pounds per gallon is what you're going to most likely be using.

What is the max number of gallons? What is the amount for tabs? You want to actually look this up for your airplane. The weight of the pilot in the front passenger, rear passengers, and the baggage area, and then you get this ramp weight.

And as I talked about, you can actually have your plane be a little heavier than the envelope right when it's fueled on the ramp because there's some allowance for the fuel that you'll burn off during a taxi, and so that's right here. So fuel allowance for engine start, taxi, and run up. So they took off about eight pounds over there, and then you can calculate it.

And once you locate the point, then you go to that diagram right here. So you go to the weight and the moment, and you figure out whether or not you're in the safe-- whether or not you're in the envelope for that normal category of aircraft. So what we just went through is the same

procedure that's listed right here.

And so here is it just doing that same example for a particular Piper Warrior. So they have the basic empty weight of the aircraft. Just as a hint, if it's something round like 1,500, then you probably didn't get the exact accurate amount. So again, if you look at the real thing, you're getting it down to some very specific accurate numbers. So 1,196.63. That means you got a real number.

Here's our Piper Warrior. And so they have the basic empty weight, the passengers in the front and the rear. They don't have any bags here right now, and they basically multiplied the weight times the arm. The arm is really indicated in the book and in these calculators as to where the location is of the chair. Now, of course, the seats slide forward and back, but they usually don't-- they don't get into that many specifics, and then you can calculate here the moment.

So next, we do the ramp condition. So ramp condition is basically, what's the weight and loading of your airplane once it's fueled up and sitting on the ramp? Then you, in this case, they took off seven pounds for that taxi, and run up and then you're takeoff condition, in this case, is 2,440 pounds, and it has a moment here as calculated.

So you basically do the same thing we just showed. So you you look at the weight on the left, and the CG location as the vertical line, and you see where those two lines intersect and you see whether or not it's inside the envelope. You can also check the landing condition. In general, you will have burned fuel during your flight, and so your landing condition will be lower, but you might have heard big jets, and you've heard that sometimes they have to do a fuel dump.

Why did they have to do a fuel dump? Well, maybe they calculated their landing based on having flown across the country, but their flight across the country was canceled because of weather or whatever, and so they had to dump their fuel in order to land, which you don't like to hear is once they've dumped their fuel then you have another delay in the air, and you're like, hey, what happened? I thought we dumped all of our fuel.

But of course, as a small little airplane, dumping fuel is not really a procedure you're going to be doing, so it might be a good idea to just calculate the landing and the runway lengths with the full fuel in case you have to make it landing right then and there before you've flown all the distance you thought you were going to get to fly. So in general, as you can see that where we

were beforehand was higher and the weight goes down, so your landing condition is almost always going to stay within the envelope. There's some places, where if you're CG is too far aft or too far forward, where actually that reduction in weight could cause you to come outside the envelope.

All right, so there are also a lot of spreadsheets available. You can make your own spreadsheet pretty quickly in Excel using the data from the particular aircraft that you're renting or buying. All right, and these are just some snapshots from the book that we just looked at and the show pictures of where the seats are in the airplane in order for you to calculate that. You could also calculate the moment left to right. It's pretty easy to think about, though, that in that tiny little airplane, if you're sitting on the front in the left and no one's sitting on your right and you have someone sitting in the back on the left, then you're going to be tilted over. It's very easy to fix that problem, just make sure you have someone sitting on the other side.

I have noticed some of these effects before. I'm a little bit of a smaller person, and there was a very, very large instructor sitting next to me, and I actually could tell as I was flying that it was a little bit tilted. And so with the future flights, we put some more bags on my side, and it was a little bit more evened out. Usually, you won't run into that too much as an issue. In some of the small puddle jumper aircraft and so a commercial aircraft, they have sometimes a situation where there's only one row of seats on one side and then there's the aisle and then two seats on the other side. Have you guys seen that configuration?

I'm getting a lot of head nods. So in that situation, they might enforce that you have to sit in the seat that was assigned to you. And when people try to move from the side that only had one seat in the row to the side that has two seats because they just want more space to spread out, they might say, hey, for weight and balance reasons, you have to sit in the seat that was assigned for takeoff and so that's what they're talking about. There any questions about weight and balance?

Do you guys think you could do weight and balance calculations? Yes? OK, I'm getting a lot of head nods, so everyone took physics. That's good. Good job. Yes?

AUDIENCE: So I assume that [INAUDIBLE] the helicopter has lateral elements in the chart. [INAUDIBLE].

TINA Helicopter question. I will actually defer to Philip, who flies helicopters quite frequently. So once

SRIVASTAVA: he's back, we'll ask him about helicopter CG limits. Good question. Anything else? Yes?

AUDIENCE: [INAUDIBLE]

TINA So the question is, when you're actually flying, do you do this calculation every single time, or

SRIVASTAVA: do you mostly only do it when you're really loading the aircraft? So it's actually required that you have the weight and balance done. The reason you don't do it every single time, though, is you frequently fly in the same configuration. So if you rent from a flight school, you might frequently rent you know a couple aircraft, and you might frequently fly just yourself, doing a solo flight, or fly with your instructor.

So you might just keep it stored that you have a couple of pieces of paper in your flight bag that are the weight and balance calculations for what you almost always fly and is almost always within the normal category envelope. But you definitely want to do those calculations if you're getting passengers in the back seat. Whenever we go on these MIT fly outs, we actually ask people for their weights, and it's actually a big restriction too.

So when we're trying to get passengers to sit down, just because I fly assessment with four seats, as we just saw from the example, I don't have four pass-- I don't have three passengers to offer. I often say, I have 220 pounds available, and so they then have to sort out, Sebastian and his team, as to who to assign to my plane versus another plane. And also, if people aren't being-- if you notice people aren't being overly forthcoming about their weight, you might want to increase the amount that they gave you.

PHILIP Yeah, let me add that-- obviously, have a lot more experience being over overweight than Tina

GREENSPUN: might have, but also-- actually, these pants are a good example. 20 years ago, some friends and I, we made a web front end to a Levi Strauss factory that could make custom cut khakis. So we asked people in the web form when they ordered what's your waist size, what's your inseam, what's your height and weight. And from that, we had software to try to infer their actual weight, their actual waist size, and then we make them-- you can't really see this, but these pants just say pair number 7. They don't say anything about what size it actually is.

They would get their pants-- this was in 1997. They would get their pants, if they didn't fit, they'd say, look, it needs to be a little looser in the waist. It needs to be a little shorter, and then a revised pair would be made and sent to them, but we never relied on their stated weight or their stated waist size, exactly.

TINA Philip, there was a question for you that I wasn't able to answer about helicopter CGs, and

SRIVASTAVA: really thinking it was the lateral CG. What was your question specifically?

AUDIENCE: [INAUDIBLE]

PHILIP It's very hard to get a-- the question is it's very hard to get a helicopter out of lateral CG, as

GREENSPUN: with an aircraft. If you have to have you people in the back and a light person in the front, it's easy to get out of front back CG, longitudinal CG, but--

TINA He's talking about, what we just discussed, it's frequently the case that you might have a

SRIVASTAVA: forward CG or an aft CG, but you don't usually have an issue with the CG on the left or the right, unless-- it's very visible in a four seat aircraft how to fix those types of problems.

PHILIP One issue with the Robinson is they put the main fuel tank on the left, so they're budgeting for-

GREENSPUN: - in a solo situation, a pilot of at least a certain minimum weight in the front right. So very lightweight, sometimes when teenagers are learning to fly helicopters, they have to add a little bit of ballast, let's say like a big heavy gym weight. A 50 pound gym weight in the front left footwell or something.

AUDIENCE: The other thing that could go wrong is-- so when you do your pre-flight, one of the things that you do is that if you're sitting in the pilot's seat, so on the left side, so to your right in the middle at the bottom, there's a little knob where you can say whether you want the fuel to be coming from the left tank, the right tank, or both. And pretty much, all the time, the checklist says that after you've parked the plane, you want to twist it to the left or the right, and the reason is you don't want-- while it's sitting there, fuel to be sloshing across the plane, and so you set it to left, for example.

Now, if you skipped that step, even though it comes up several times throughout your pre-flight and then your run up check, if you didn't put the fuel to draw from both tanks and it's only drawing from one tank, then you might experience that instability.

PHILIP All right, why don't we-- should we take a 15-minute break so people can run out, grab food,

GREENSPUN: bring it back, and then we'll hear from [INAUDIBLE] about--

TINA The test pilot and life potentially outside of the limits.

SRIVASTAVA: