Introduction to Flight

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Air Speed Corrections
Lecture 04.5

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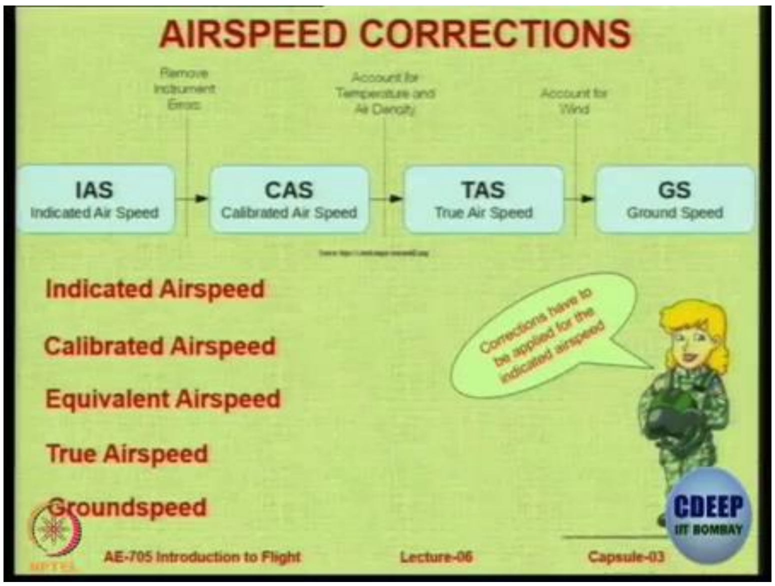

Let us see the corrections first. So, there is something called as a indicated air speed. The indicated air speed is what the pilot sees in the instrument, it could be zero it could be infinity. Suppose the tube is broken, suppose the needle is jammed, the needle which is supposed to move, there is a breakage. And now the needle has fallen to zero, now whatever speed you fly it will show zero. Correct, if the instrument is faulty, if the instrumentation has got some mechanical or electrical disconnection, it will show zero. Because, it is not sensing anything, it is not working basically. So, the indicated air speed is what the pilot sees. But that is not the actual aircraft speed, because this instrument has been calibrated based on pressure on the ground.

So, there are some errors in the instrument. For example, the dial has got some friction. So, under some pressure it should move to 38 degrees. But it is moving only 30 degrees, because there is a friction or there is some error or there is some permanent elongation. So, these are called as instrument errors, including breakage of the link. So, on ground when you do the maintenance of the instrument you say let us give it a dynamic pressure and see what it shows. So, in every aircraft there is a small pluck card which shows, if the instrument says 300 read 290, if it shows 350 read 320, if it shows this, read this. Because and that card is changed by the maintenance people every time. That is a simple calibration of the instrumentation. This is what you do in experiments also.

Before any experiment that you do you should do calibration, same thing we do in the instrument. So, let us assume that now that we remove the instrument errors. So, then the speed which the instrument shows is called as the calibrated air speed that means a perfectly working air speed indicator should show this particular speed when so much dynamic pressure is acting on the system that means so much now, the instrumentation basically does not worry about what is the static, total pressure, what is the static pressure. It works only on the given difference. Because on one side you put static pressure on one side you put total pressure, the difference is what moves it. For now we come to a speed called as the calibrated air speed. So, can I say now that a calibrated air speed is the speed that an error free instrument should show?

Clear, is very important because when we do aircraft performance in the post mid semester portion, you will have to understand and correct the values otherwise you will be getting wrong answers. I am warning you right now. Many people will simply take the numbers and start punching them, without processing it. And I am going to give you a very interesting assignment where you need to know how to convert these things. So, in the Calibrated air speed is what an error free instrument should show. Any doubt on that? Ok. So now let us assume a theoretical scenario that the errors in the instrument are zero. So what you see is what you should have got, which is the Calibrated air speed. But is that the true speed? It is not. For that we have to understand the working. So the working is very simple.

The dynamic pressure in an incompressible flow is can be shown as to be $\frac{1}{2}\rho V^2$.

So, $P_{Total} = \frac{1}{2}\rho V^2 + P_{Static}$.

So, if you subtract P_{Static}, then you get $\frac{1}{2}\rho V^2$. So, half is the constant. But, ρ is the density, density of what, of the air. And as we know the density of the air does not remain constant as we go from one altitude to the other. So, what does it depend on? What does density of air depend on?

Professor: Yeah, Sohrab you can speak. What is it? What does it depend upon? Yeah.

Student: It depends on temperature, humidity.

Professor: Humidity, temperature,

Student: And the altitude from the ground.

Professor: Altitude from the ground. Anything else? Anything else will affect the density of the ambient air? Perhaps these are the only things. Something new? Yes?

Student: Speed of air.

Professor: Right, even the Mach number. Even the Mach number, there is a relationship between the density and the Mach number also.

So, whatever it is, it is not the same at all altitudes. So, when you calibrate the instrument on the ground, see I cannot do the calibration of the instrument at various altitudes, I will calibrate only on ground. So, what do I do on the ground is, I apply some pressure into the, I apply some pressure into the total port and I open the static port to atmosphere on the ground. The instruments reads the differential pressure. So, that is equal to $\frac{1}{2}\rho V^2$. But which rho is it? That ρ is actually ρ_0, or rho at the test condition.

So, if I test at Mumbai it will be rho at Mumbai. And that too rho at Mumbai will not be the same in summer, winter, there will be minor changes. So, assume a condition when you are calibrating the instrument under perfect ISA sea level conditions. Density of the air is going to be 1.2256 kg per meter square that is the ideal sea level value. So, you tell, you do the calibration so that if there is so much pressure which is being put into the instrument that pressure is equal to $\frac{1}{2}\rho V^2$, so that v it should show.

Let us say it is 180 knots, then you change the pressure and you make the instrument such that it shows that one. So, remember that rho is constant at sea level or in testing conditions. So, it is v square versus pressure. So, you keep on adding more pressure and it should show velocity as a function of square. And then you seal the instrument. So, when the pilot is flying this aircraft, now in New York at a height of 2 kilometers under a very cold condition. The air which is coming in the instrument is not at the same density as the air which came when the instrument was calibrated. The instrument was calibrated at Mumbai at sea level.. But so much pressure equal to so much velocity. Now the same pressure if it is occurring in New York at 2 kilometer altitude at much more speed because that half rho v square is equal to this half rho v square. What will the instrument show?

No, not different, see understand. I gave some pressure to the instrument at Mumbai at sea level, I have removed the instrument errors. It shows 180. The same pressure is exerted by an aircraft flying in New York at 2 kilometer altitude at some speed. If the pressure that is coming in is same as what was here, the instrument will show again 180. Correct? But the speed is not 180. The speed corresponds to 180 only under that density. The density there is not the same. So just imagine a situation, forget about New York and the other things, Let us say Mumbai only, you fly the aircraft at 2 kilometer altitude.. Will your density be lower or higher? Are you sure? Density will be lower? Are you sure?

Student: Maybe, sir.

Professor: Ok. Density of air at 2 kilometers in Mumbai, is it lower or higher than the density at sea level?

Student: Lower

Professor: 100 percent sure? Positive? Do not worry. You say yes. It is lower. It will be lower, obviously. I just meant to scare, sorry. It is lower.

Okay. So, if the pressure which is acting on the instrument at 2 kilometer, tell me I asked you another question now. Assume, that the instrument is showing 180 knots, the instrument calibrated at Mumbai at sea level is now flown at 2 kilometers, it shows 180 knots. So, what is the pressure acting in the instrument? The pressure acting in the instrument is the same which was acting at the same instrument at sea level when it showed 180.

So, that pressure is half into rho 2 kilometers into v 2 kilometers square and this pressure was half rho zero into v zero square. V zero was 180, so this 180 will not be the same because rho 2 kilometers is not same as rho zero. So since rho 2 kilometers is going to be lower, the velocity will be higher. In other words, whatever this is how you remember it. You get confused sometimes, So, basically you always tell yourself the pilot always sees the velocity which is lower or equal to the actual. The pilot always sees the velocity which is lower or equal to the actual because the density of the air at any altitude is going to be definitely lower than density at sea level under ISA conditions. Correct?

So, therefore, the true air speed that means at 2 kilometer I was flying at 190 knots, but the pressure that was created, half into rho at 2 kilometers which is lower than rho zero into 190 square is equal to half rho zero into 180 square. Instrument only measures pressure, so when I, when I tell students about working of the working of the calibrated air speed, I always say the calibrated, listen to my words ok, the calibrated air speed is the reading that an instrument will show when the pressure acting on the instrument will be same as the pressure acting on the instrument will be seen as the pressure acted on the instrument when at that reading it was at sea level. Is it clear?

So, therefore the true air speed is always going to be either equal to or lower than unless you have a rare situation in which the density of the air at 2 kilometers is more than sea level density. Can it happen? Is it possible? Is it possible that density of air at 2 kilometers at any place in the world is more than density at sea level? Where is it possible? Yes? So, is there a place on earth where the mean sea level is 2 kilometers or 2.5 kilometers? Unlikely right, you cannot have a place which have, I can understand 100 meters, 200 meters difference. But to find place where that 2, sea is at 2 kilometer altitude from sea at Mumbai is not generally possible.

But let us not talk about all these things. We are saying that in general, the indicated air speed is going to be always more than or less than the true air speed. So, then you have true air speed, you account for the changes in temperature and density, then you get the true air speed. Now this true air speed is what actually the pilot wants to know because the pilot the aircraft will not stall or will not misbehave or will not do anything based on the indicated air speed. For all you know, instrument is blocked, IAS could be zero or infinity, it does not matter. Aircraft works on physics, not on instrumentation.

So, therefore for all phenomena where you need to know the actual speed, you need to have a correction between the IAS and the TAS. So, from IAS you get CAS, removing instrument errors. From CAS to TAS you get the true air speed. Now we forgot one small thing here, which is called as the position error that is the error in the readings because of the location of the pitot static tube that could come also under the IAS to CAS conversion. So, when I say instrument error you can say instrument error because of the mechanical instrument and because of the location.

Remember all discussion is applicable right now, only in subsonic flow where the other effects are not yet modeled. When we go further we will look at modeling of. Now the other thing is ground speed, so now come to your point. You are flying at 100 knots and the wind is coming at 100 knots opposing direction. So now what is going to happen is you are actually flying at 100 knots physically, but two are observer on the ground you are stationary, because for the observer there is no relative motion now. So the ground speed is the speed of the aircraft with respect to the ground and remember the ground speed can be negative also. If the oncoming wind is at 20 knots and you have a small UAV which is flying at 5 knots, then yours ground speed could be minus 15 knots. It is possible.

So ground speed is used for what purpose? What is the advantage of ground speed? Who will need ground speed? Yes.

Student: Hello, my name is Dinesh.

Professor: Yes.

Student: It is air traffic control, airport they use the ground speed.

Professor: Why?

Student: For landing purposes and for takeoff purpose.

Professor: In what way? You mean to say no, they tell the pilot that the head wind is so much, cross wind is so much, tail wind is so much. That I understand. But why will the air traffic controller, what will he do with the ground speed? I do not think it is the ATC. ATC is not concerned about ground speed. Somebody else. Yes, now let me, let us see if you have the answer. Who wants to worry about the ground speed?

Student: Sir, the pilots.

Professor: Why?

Student: Because, they will require to know that what is their speed with respect to the ground.

Professor: Why do they want…

Student: They should know that how much fuel they have so that like they will calculate their if there is if I am going to land at a distance of 10 kilometers, the airport is 10 kilometers away, so like they will need to know that how much time it will take for them..

Professor: No, honestly speaking pilots are not concerned about how much time it, because they are flying the aircraft because when they reach their aircraft, the ATCO is may say go for one circle. Then one more circle, 10 circles, pilot cannot do anything so it is the airline who is interested, not the pilots. It is the relatives of the people who are coming in to receive you, to pick you up. So for example, just as a theoretical example, if the aircraft is flying at 100 knots, and the wind speed is 100 knots head wind, you can tell the relatives, just wait for infinity. Because this plane will never come to you all, it cannot na, relative speed is matching so the aircraft is virtually stationary.

On the other hand, I will talk about this when I come to range and endurance, I will give you a very beautiful example in which the presence of head wind and tail wind can create a time difference of 2 hours in flying, between Mumbai and New York, 2 hours and it can save 12 tons of fuel for the airline. Then I will talk about this. Right now, we will go ahead so you have to apply the corrections, and this is the sequence in which the conditions are applied.

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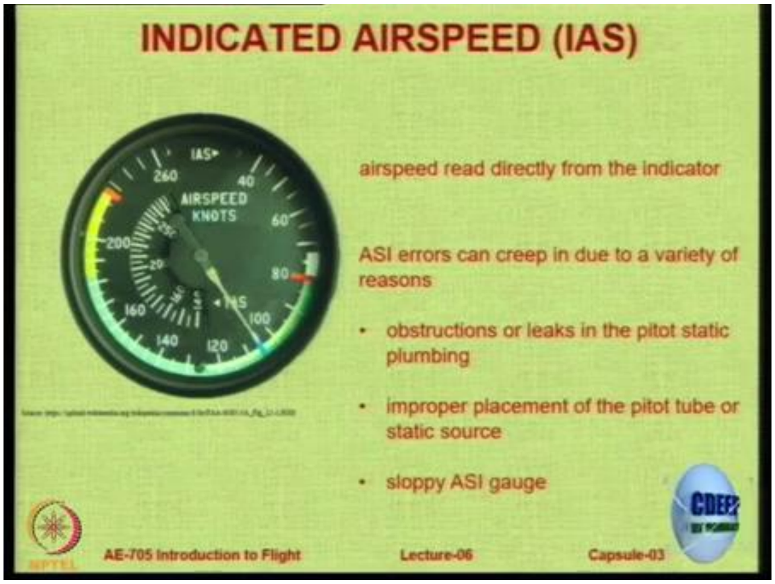

Ok. Yes?

Student: What does the pilot read on this meter?

Professor: Indicated air speed and true air speed. So, you can see this is the instrument that the pilot gets and that shows it just shows IAS.

Professor: No no I never said that the indicated air speed is zero, if the relative wind is zero, I never said that. I said the ground speed is zero. There is a difference. The, if the aircraft is flying, whatever be the head wind, there will be a pressure acting on the instrument and that pressure will be react as a speed. So, the indicated air speed is the speed of the aircraft. Whether it is flying in head wind, or tail wind is not important. So, the, what you are asking is the ground speed. So, the indicated air speed could be 100, ground speed could be zero.

Student: I have another way round like the there is ground speed but then there is no air speed.

Professor: That means you are…

Student: It is the same reaction as the plane is starting with the same velocity.

Professor: No, that is a tail wind.

Student: Yeah.

Professor: So, at that time what will happen see because the aircraft is flying the instrument attached to it will face some oncoming wind. Now because it is flying, now air from the back is coming and pushing does not matter, that is not really going to affect the instrumentation. The pressure will be right. The ground speed will change based on head wind or tail wind, presence or absence.

Professor: Not necessary, see do not mix up indicated air speed with the ground speed. Do not mix indicated air speed with the relative wind. The IAS is not reading relative wind, the IAS is reading the wind, the IAS is reading the speed of the aircraft based on the pressure that the aircraft is facing because of the oncoming wind.

Ok. So, the IAS or the indicated air speed is what the pilot will actually see. But it is dangerous for the pilot not to know the true air speed. So, therefore there is also a small scale inside you can see in the same picture called as TAS. It is hidden by the needle. So in this example the true air speed is approximately 140 but the indicated air speed is only 105. Yeah. 5, 10, 15, 20 so this is 105 indicated speed; true air speed is actually 140. So as you can see the true air speed is more than. So, how is it more? How is it more? Is it going to be more? Then what is the problem here? Ok. So, the air speed that the pilot reads is directly and there could be errors, so these could be the errors.

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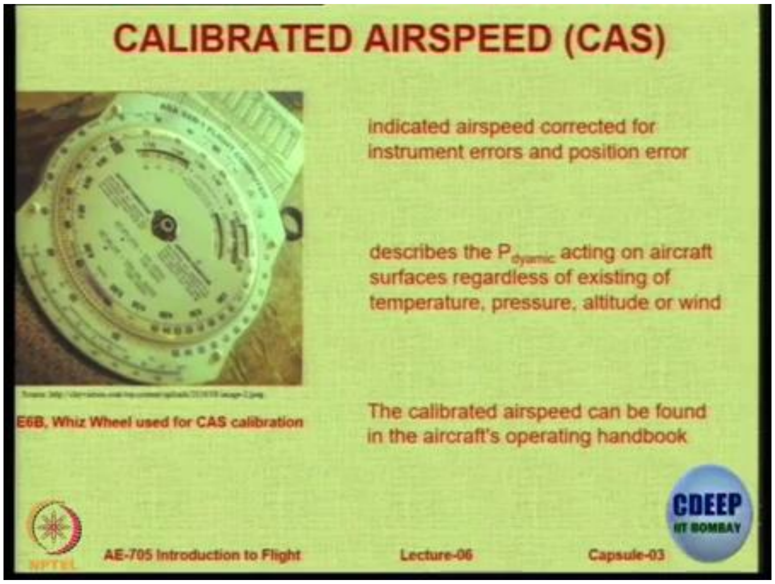

So, this is a small wheel, which the pilots use, is a old instrumentation where the dial type thing so we can use the calculator. So you remove it for the position and the instrument errors.. And this is in the aircraft operating hand book because they are designed for standard conditions.

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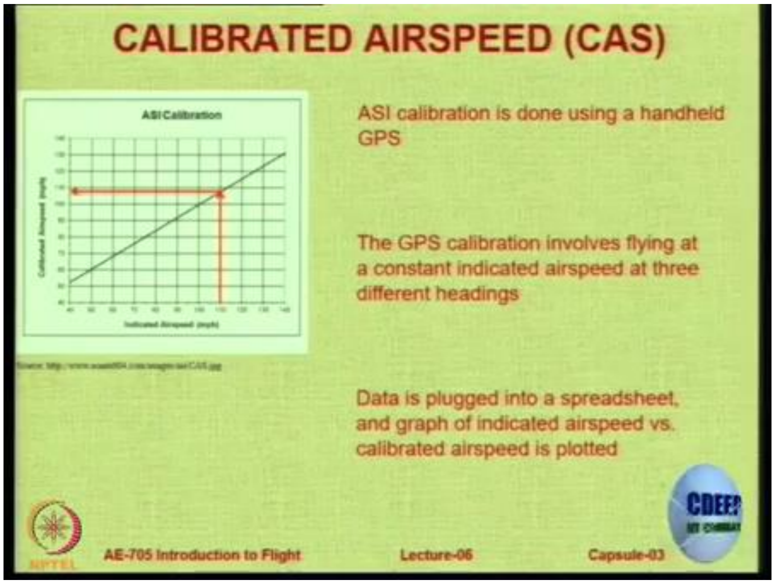

So you can get chart like this, Calibration chart. If the speed shows 110, actual value is little bit less or little bit more so if this line is 45 degree that means it is correct instrument if there is a slope more slope less that shows the error in the instrumentation. So, we normally do it with a hand held GPS because GPS will give you the actual location and you can have time and GPS, time from a clock and the GPS location, you can use that to do the calibration.

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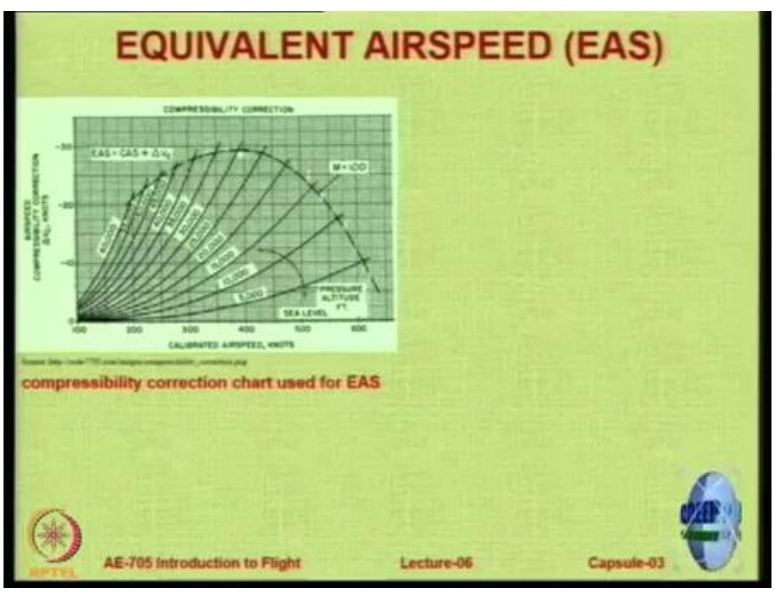

This and then this is the detail which we will skip right now.

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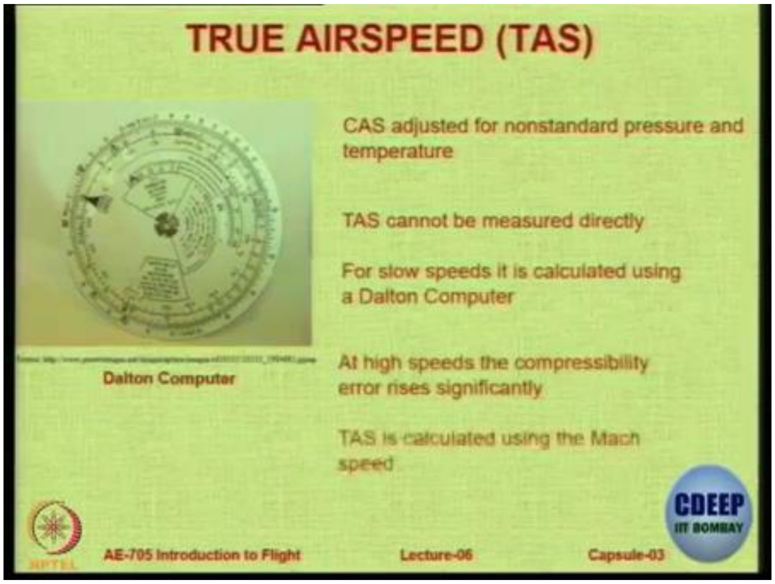

So these are again instruments. I want to keep it for you for self-reading.

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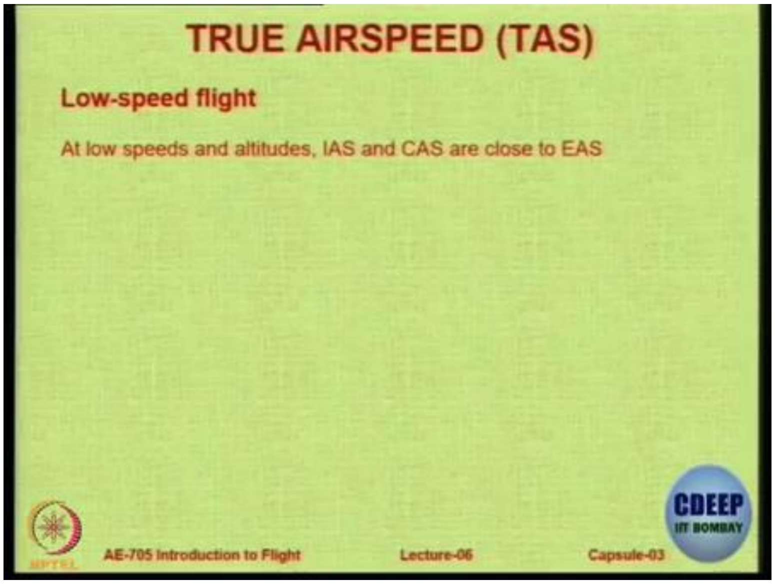

Student: Sir.

Professor: Yeah.

Student: What is the need to show both the airspeeds?

Professor: Because, so now I want to ask you another interesting question which is what he has raised. Do you think the pilot is happy only to know the true air speed? Or the, what is the advantage of indicated air speed for the pilot? That is the question that you are raising right? So, now can someone tell me if we as engineers or instrumentation experts can do the corrections and tell the pilot that this is your true air speed. The job is over, then why should we tell the pilot what is your indicated air speed.

Because the pilot has to apply the corrections to that to get the calculated air speed. So, why why is it needed for the pilot to know the indicated air speed? This is the question I do not want to answer. I would like this to be answered by you on Moodle. So there must be some advantage. In today's technological world do not tell me that you cannot do the corrections and tell the pilot because you are giving pilot both. You saw the dial.

The dial showed that the true air speed was 140, indicated was 110. So, do not tell me that it is not possible. But then why not show him only the 140, only the true air speed. Why show him the indicated him/her. So now that is the question which I want you to answer. Ok. So at low speeds and low altitudes.. yeah you want to answer the question? Ok. You have another question. That is good.

Student: So, true air speed should always be higher than the fly airspeed, right?

Professor: What do you think?

Student: It should be higher.

Professor: Always? Ok. Why should it be higher?

Student: Yeah, so as you said that density decreases as we go up.

Professor: Go up, ok.

Student: So why was there an error in the picture you showed?

Professor: Which error?

Student: It was higher in center, there was an error.

Professor: No you think about it, the density is the density of the air at high altitude is lower, so the total sorry, the pressure at which the instrument shows 110 the same pressure is acting when the density is lesser, so the speed tends to be higher. So I only said that the indicated air speed is always lower than that of the true air speed. There is no error in the instrument. It is working correctly. The true air speed is more than the indicated air speed which is typically the case.

So at low speeds and low altitudes, the three speeds oh now we have one more speed called as the equivalent air speed. So, now we are into a soup. We have somehow skipped this. Why did we skip this?

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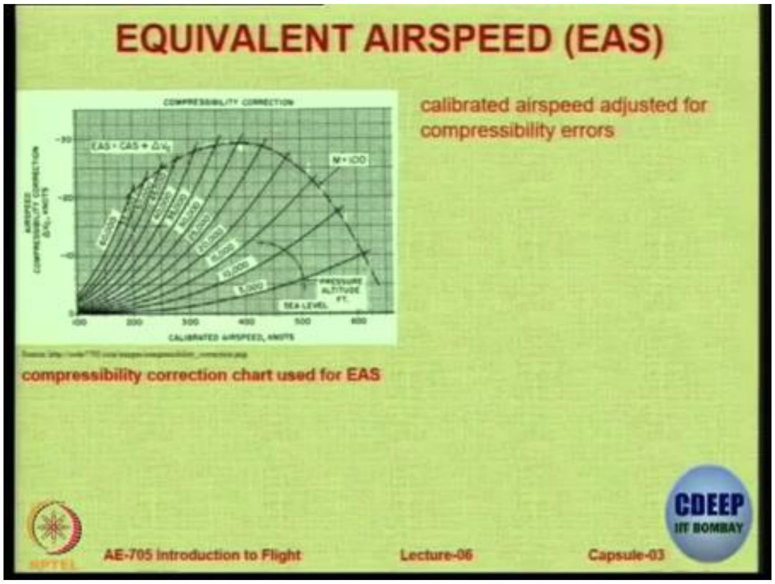

Ok. So equivalent air speed sorry I, it is my mistake I thought I can skip, but it is important. The equivalent air speed is the air speed when you remove the compressibility errors. Especially at high altitudes, because the density change happens due to static, due to altitude and also because of speed as my friend rightly mentioned that there will be a change in density because of altitude and because of speed, that correction is the compressibility correction.

And that correction when you do it, you can get what is called as the equivalent air speed which is the air speed that should have been shown on the instrument without, so this is for very important because the equivalent air speed is actually the one that is the dynamic pressure acting on the aircraft, so from the loads point of view, from stalling, etcetera, that is it, so it is a function of dynamic pressure so EAS is basically is equal to 2q by rho zero, remember I am not using rho altitude here. Ok so suppose I replace rho zero by rho altitude, q is half rho v square, the q is half rho v square which is the rho at the altitude. But I am saying root of 2q divide by Q knot , rho knot, so rho knot is the standard density 1.2256 kg per meter per meter cube, so that is why it is equivalent air speed. This is the speed that gives the same pressure with the compressibility effects removed.

So since the value of, so you will get some more indication there.

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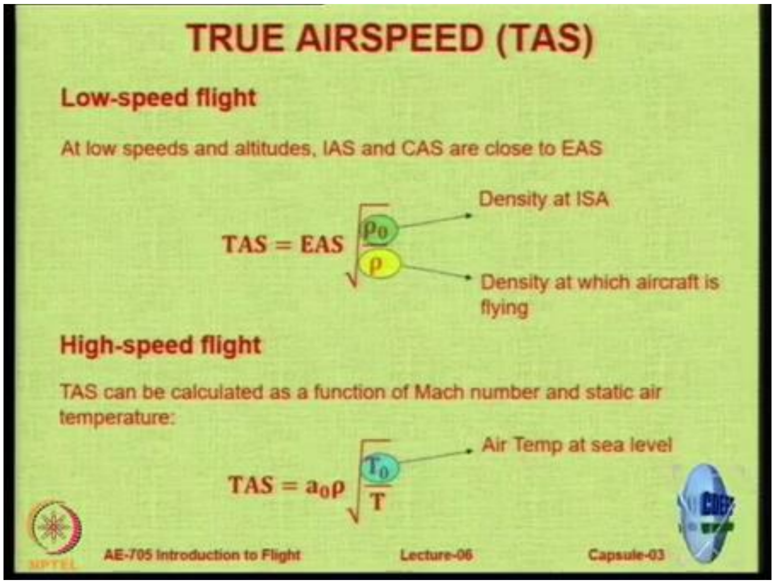

So at low speed flight they are all same, so the true air speed will be the equivalent air speed into rho knot by rho, rho knot is the density at sea level conditions, rho is the density actual condition. So since rho is less than rho knot, therefore what is the, which is more, TAS or EAS? In high speed flight you have a function of Mach number also. So you have to have you have to put that Mach number function that is what our friend mentioned. This a knot rho is the effect of the density.

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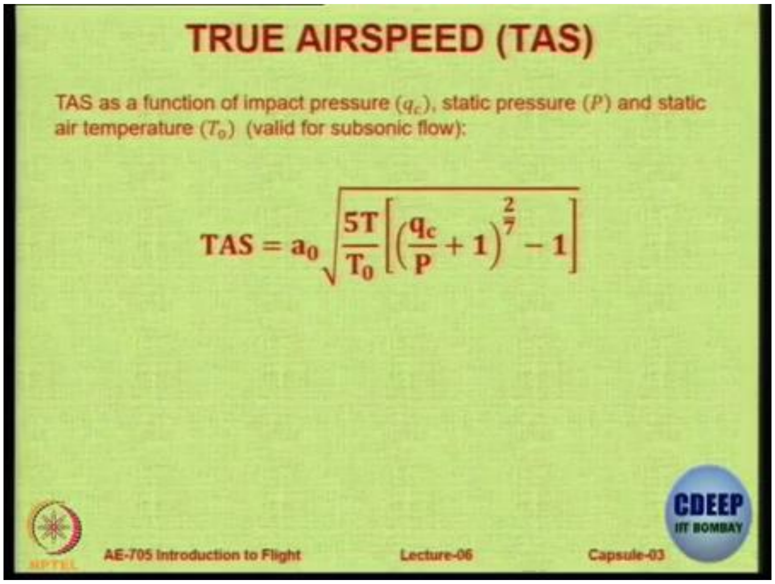

So this is the equation when you bring in temperature, so look we are not here to derive these expressions because in the introductory course of fluid mechanics or introduction to flight we are interested in just knowing what the relationships are.
So you do not have to really worry about, talking about, let us to ground speed. The actual speed of the aircraft over the ground, so you correct the true air speed for the wind effects, head wind or tail wind, so if you have a head wind it subtracts, head wind means coming from the head, tail wind coming from the tail. Which one is better? That is what you think? Takeoff distance would be less or more depending on the head wind or tail wind. So, we will talk about it.

So this is how you do it see there is a resultant ground speed, so suppose there is a wind coming at an angle then you have to take a vectorial addition and get the value of ground speed. Now let us look at the markings in the indicator, there are these regions, green region, yellow region and red region.

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So from pilot's safety point of view, so obviously the white arc depicts the normal flap operating conditions that means what is the speed at which the flaps can be operated because if you do not the flaps may break off. Flaps cannot take so much structural loading. They are only meant to be deployed in takeoff and landing and in military aircraft we also have combat flaps, but very small angle 5 degrees perhaps 15 degrees in some cases, so that is a different case. But in general, flaps are not to be deployed after you achieve the climb and before you come into land. So therefore there is a maximum speed at which flaps can be deflected so that is indicated.

The green arc represents the normal operating range on the airplane, and there is a cautionary range that is yellow color. For now if you are flying at the yellow color area and you have turbulent weather. It can become dangerous, because the loads will become very high. So the pilot is told, if you are expecting disturb weather conditions, take it to the green region. Do not go in the yellow region and then you have a maximum allowable speed with the red line that should be never exceeded. But can the pilot exceed that speed? Do you think it is possible for this pilot to fly beyond 230? How is it possible? What does the pilot have to do to fly at a speed more than the maximum permissible speed? Yes?

Student: Sir if engine is capable enough to go beyond that speed then after that the 230 or 240 the structural limit will be exceeded. As a happen in one air crash, when the aircraft just plunged down with the, with the speed more than the limiting speed and its flap and all the components were just teared off that.

Professor: Yeah, so the pilot can exceed this speed, either using the power of the engine if the engine can give that much power or you can go for a dive.