NOC: Introduction to Airplane Performance
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Lecture - 09
Measuring Instruments: Altimeter, Airspeed Indicator

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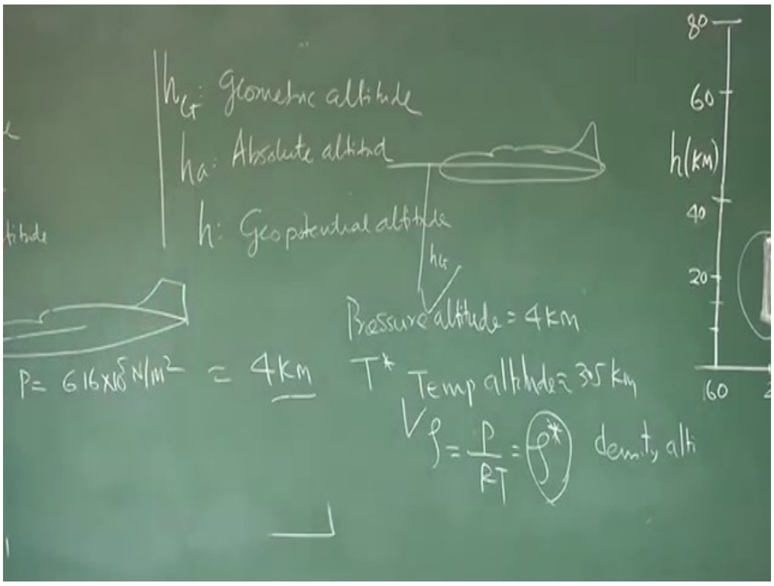

So, we have just completed hg (h_g), which is geometric altitude. We have talked about ha (h_a), which is measured from the center of the earth which is called absolute altitude. I have also defined something h which is fictitious altitude, it is also called geopotential altitude and we have seen that hg and h are not much of a different. If height is within 60 kilometres, but also we have seen even at 65 kilometre, the error will come which is around one percent. So, these are three types of altitudes are used in defining the atmosphere, atmospheric description, ok.

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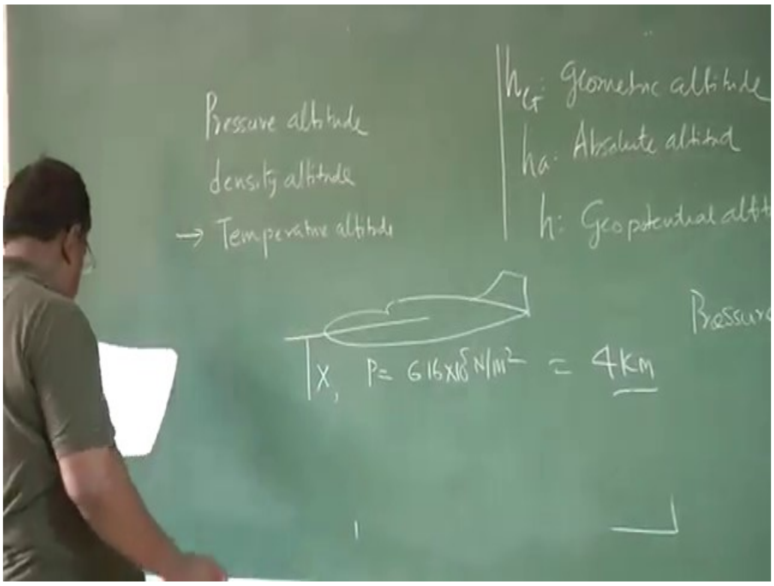

There are other important altitudes you will find, which we need to know one is pressure altitude, density altitude, then temperature altitude. What are these? And the principle of altimeter is, it senses the static pressure locally at that altitude and that pressure is calibrated and some number is recorded, right, either through an analogue or through a digital, right. But, that is not the pressure altitude.

Suppose for example, an airplane is flying at some altitude x and it is sensing pressure, static pressure let us say around 6.16 into 10 to the power 5 Newton per meter square ($P = 6.16\, X\, 10^5\, N/m^2$). Now, what is the pressure altitude? Pressure altitude is, now you go back to the standard atmosphere and see, what is that altitude at which the pressure is 6.16 into 10 to the power 5 Newton per metre square. So, that becomes the pressure altitude and that you will find is roughly equal to 4 kilometres. Are you clear about pressure altitude? Let me repeat.

Now, we are discussing about pressure altitude. Suppose, I am flying at a geometric height hg and my instrument is sensing pressure equal to 6.16 into 10 to the power 5 Newton per metre square. The pressure altitude is defined in this way. What it said? Ok This is the pressure sensed by the instrument at a altitude hg, now you go back and look on the standard table, what is that altitude which corresponds to this pressure and that altitude, let say it is around 4 kilometre if you check.

So, this pressure altitude becomes 4 kilometre ((Refer Time: 03:42)), so pressure altitude is 4 kilometre, right? Now, come back to temperature altitude. When we are sensing a pressure of 6.16 into 10 to the power 5 Newton per meter square, you put it some instrument which can measure temperature and let see, that temperature is T* at that altitude. But, what will be the temperature altitude?

Now, from once you have noted down this T*, the temperature measured by the instrument at that altitude, come back to the standard atmosphere table and see, what is that corresponding altitude at which the temperature is T*, right, so that becomes temperature altitude. Roughly for this case, it may become 3.5 kilometres or any other numbers. Why I am writing differences? Please note that, although the airplane is flying at same geometric altitude, the pressure altitude and temperature altitude are different. Is this part clear?

Because, what is temperature altitude? Actually measure the temperature outside here and then, look back to the standard atmosphere table to get that temperature, what is the altitude the airplane should fly. So, that is not the 4 kilometre that could be something different than 4 kilometres. I am just putting a number 3.5 kilometres to trace this point, the temperature altitude and pressure altitude may not have the same number.

And now, if I ask what is the density altitude we all understand rho equal to p by R T.

$$\rho = \frac{p}{RT} = \rho^*$$

So, you know what is the pressure you are sensing, actual pressure; you know, what is the temperature actually you are sensing; you find what is the density by using this relationship. Let us say, it is rho*, now to get the density altitude I have to again go back to the standard atmosphere and see, this rho star corresponds to what altitude and that is called density altitude.

Again that may not be 3.5 or either 4 that could be anything other than this. So, what is the point I am stressing? Even if you are flying at same geometric altitude, the pressure altitude, the temperature altitude and density altitude will not be same.

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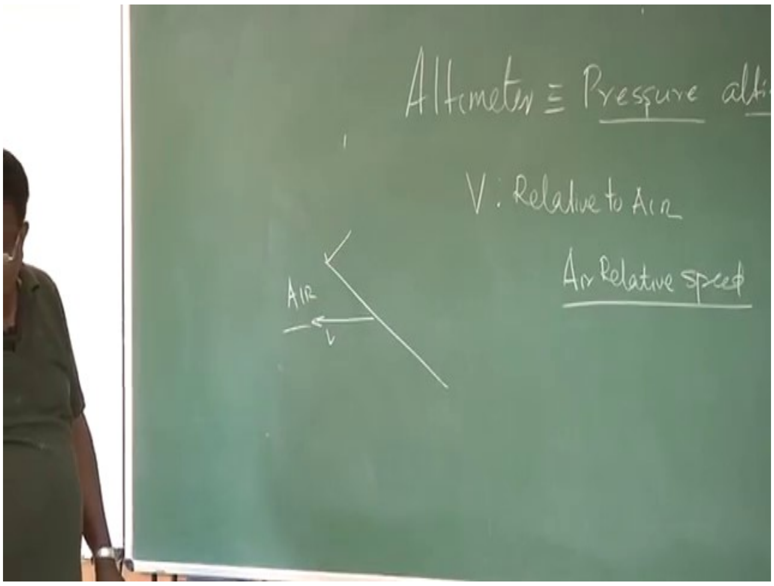

And that altimeter you will see some video on this, altimeter actually gives us the pressure altitude. They are calibrated like that, ok.

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Altimeter is the instrument which tells us the height above the sea level. So, here you can see this is an altimeter which is, this gauge is calibrated in feets and this is calibrated up to 20,000 feet. This just takes of the static pressure like the airspeed indicator and as I just told you, it takes both pitot and static pressure whereas; altimeter just takes a static pressure.

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The static port of altimeter can be seen, this is the static port. It is just, this planking is removed and this is the static line from where the static pressure goes in. ((Refer Time: 07:31)) Three needles which can be seen on the gauge, the smallest one the intermediate and the longest one are there for indicating the altitude and different, in different thousands of feet.

Like the smallest needle gives the reading in tens of thousands of feet, the intermediate one gives a reading in thousands of feet whereas, the longest needle gives the reading in hundreds of feet and the Kollsman window that is used to set the barometric pressure by the knob to, so that the pressure can be related to the atmospheric pressure when the aircraft is flying. As the aircraft goes up, the pressure decreases, which shows up by the increase in altitude in the gauge.

We have another important parameter variable, we should know before we interact with the atmosphere and that is the speed or velocity, which is relative to the air, right. The air or we say air relative speed of the airplane. Because, we have understood that if I want to lift as per George Cayley's explanation, I need to move this in such a way it there is a relative speed between the wing or the plate and the air or the atmosphere. So, aerodynamic force says they will depend upon the relative airspeed.

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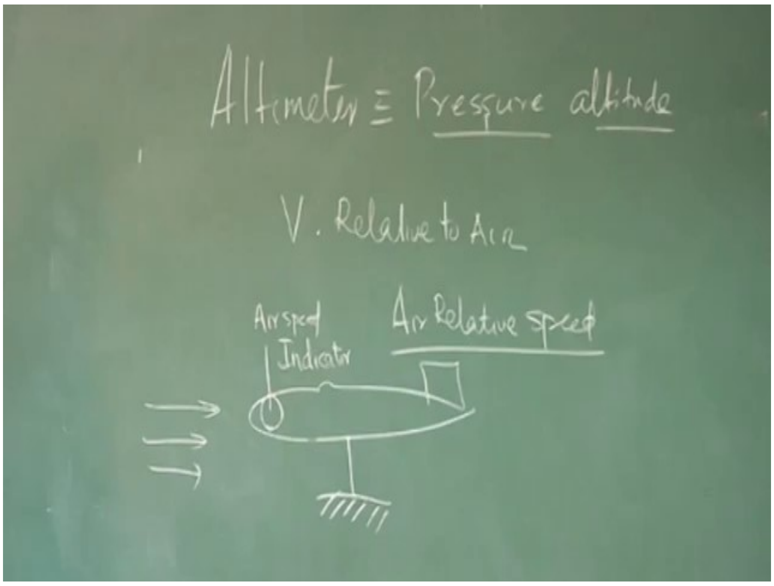

Just to explain you, if this machine is grounded and moved on the ground and if there is an air speed indicator and if there are no winds blowing, this airspeed indicator will give a zero reading. But, if suddenly a wind starts blowing, even if this airplane is not moving, the airspeed indicator will give some finite value of the speed, which will be the wind speed. So, let us understand how airspeed is sensed or measured in an aircraft, when it is in motion or when it is in ground.

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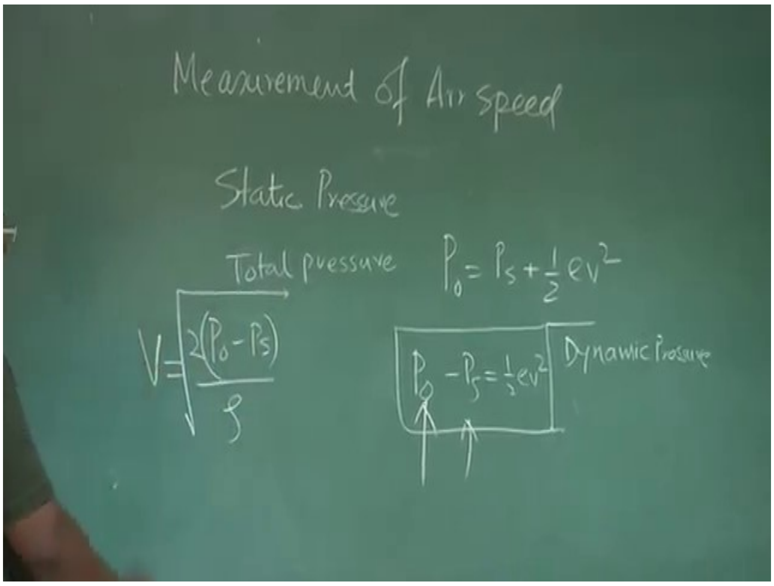

So, I will give a title measurement of air speed. When I say airspeed, keep back of your mind, for flying we are interested in the air relative speed of the airplane. Before we understand this, let us revise something which is very important one is static pressure, another is total pressure. The static pressure is primarily because of random motion of the molecule, which impinges on your body and there is a momentum transfer and that can gets converted into pressure, which is static pressure.

When you try to understand about total pressure, imagine a stream of fluid is flowing and you want to stop this fluid motion very slowly and then, what sort of pressure you will feel is, what is total pressure. In an aeronautical term or aerodynamics term we said, you bring that fluid motion into rest isentropically, that is there are no losses, total momentum is transferred into force through pressure.

So, and if you recall I can always write p total is equal to p static plus half rho v square, which is the dynamic pressure.

$$P_{total} or\ P_0 = P_{static} + \frac{1}{2}\rho V^2$$

Let us see what is the difference between static pressure and total pressure, this is nothing but, half rho v square. So, the difference between total pressure and static pressure is nothing but, dynamic pressure, I am referring to low speed incompressible flow. So, whatever now we will be using, keep that back of your mind.

$$P_0 - P_s = \frac{1}{2}\rho V^2$$

I repeat again here total pressure is static plus dynamic pressure, so difference between total and static is nothing but, dynamic pressure. If I want to find the speed, I know if somehow I can get, if somehow I can get this difference between total and static and density at that point, I can get what is the speed that is the basic concept. Let us see, what is the problem here and how this concept can be utilised.

$$V = \sqrt{\frac{2(P_0 - P_s)}{\rho}}$$

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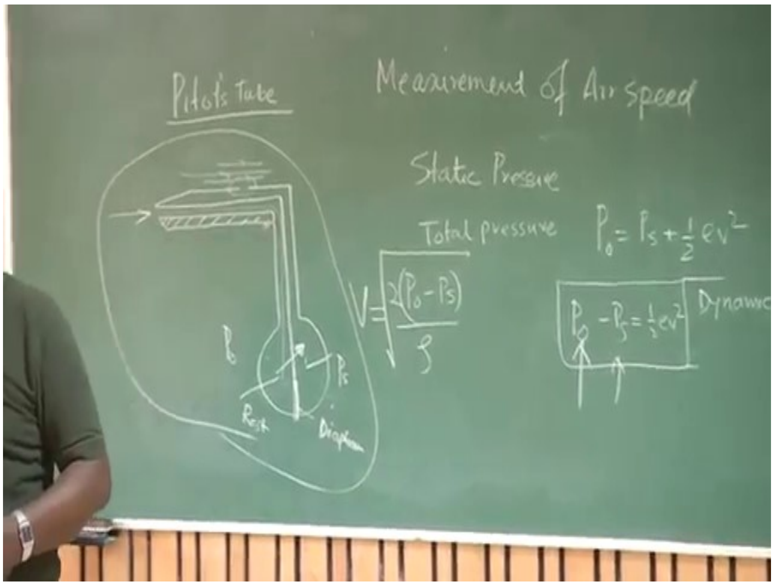

Very popular instrument that is used pitot’s tube, where the principle is very simple. Watch out here, there is a opening, so the fluid particles are moving like this. So, what will happen? This point will sense the static pressure and this input goes to the chamber. Let us say here I am sensing static pressure and now, what is happening here the fluids which are going inside like this, they come to rest here.

So, this part will be sensing total pressure that is, I told you total pressure the whole fluid is brought to rest isentropically. So, they are brought to rest here, so this is total pressure. So, what is the difference between these two? The difference is nothing but, dynamic pressure half rho v square and let us say, this is a diaphragm and which is sensitive to the pressure difference and I schematically, I put a pointer.

And if I calibrate that pointer for difference in total and static pressure, then I can measure this p0 minus ps. So, this is the concept that is used to measure or instrument the difference p0 minus ps. But, the problem is on rho. At every altitude, I cannot find out the rho, so easily. So, what is done is, when I calibrate this airspeed indicator, we make an assumption.

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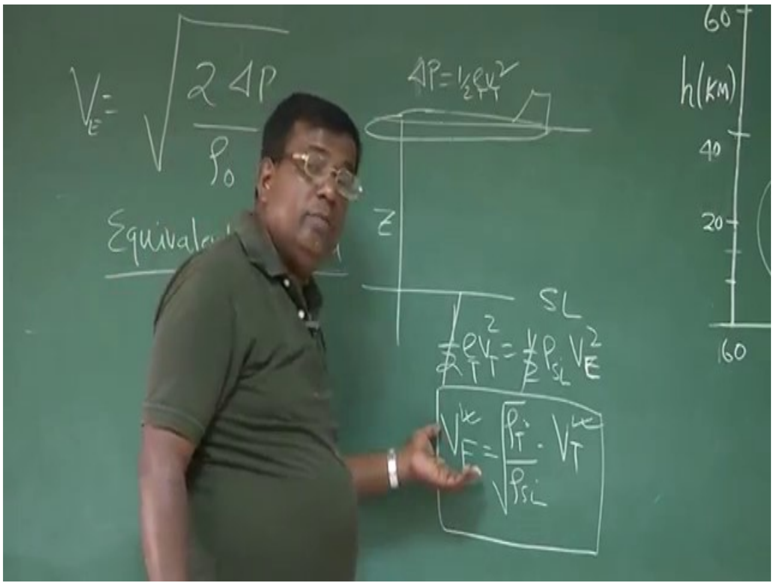

We use V as 2 delta p by rho0, that is sea level condition and we term it as V_E or equivalent airspeed.

$$V_E = \sqrt{\frac{2\Delta P}{\rho_0}}\ ; V_E: Equivalent\ Airspeed$$

What is the physical meaning of this equivalent airspeed? It is suppose an airplane is flying at this altitude, say some altitude z and it is sensing the differential pressure delta p possible, that is I am flying at altitude z and the instrument is sensing the differential pressure delta p which is nothing but, the dynamic pressure.

I am flying at this altitude ((Refer Time: 16:16)) and I am sensing the dynamic pressure at that altitude. What is equivalent airspeed here? If I fly at sea level, I am flying here now I fly at sea level and duplicate this dynamic pressure that is, I fly at sea level and duplicate this sea level and that speed is called equivalent speed or V_E by notation. So, what was this? This was rho true and v true, so I write rho true v true.

$$\Delta P = \frac{1}{2}\rho_T V_T^2$$

$$\frac{1}{2}\rho_T V_T^2 = \frac{1}{2}\rho_{SL} V_E^2$$

This is the actual dynamic pressure, which was sensed by the airplane at a given altitude. And when you were defining equivalent airspeed, we said or you ask a question to ourselves to duplicate this same dynamic pressure, if I fly at sea level what will be the equivalent airspeed. So, you could see now this equivalent airspeed will be this half, half goes cancel, so rho true by rho sea level under root into v true.

$$V_E = \sqrt{\frac{\rho_T}{\rho_{SL}}}\, V_T$$

So, the airspeed indicator will be giving us V equivalent. Whatever instrument they are installed in the aircraft cockpit, they actually give Vequivalent. Because, that is the speed which is we get through a airspeed indicator, where rho equal to rho0 has been used and the graduations are met. However, it is not difficult. If I know v through airspeed indicator, if I know true density at that altitude and sea level altitude or sea level density, then I can easily find out what is the true airspeed.

This relationship let us again see the airspeed indicator will give us equivalent airspeed. So, but if I want to find out what is true airspeed, I simply want to know what is the density of air at the altitude the airplane is flying and what is the density of air at sea level. With this ratio, I can find out true airspeed, once I know equivalent airspeed.

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Pitot static instrument is the primary instrument of the aircraft. Pitot static system comprises of the altimeter ASI and vertical speed indicator, which uses static pressure and pitot pressure to indicate the altitude, vertical speed and with respect to time and the airspeed of the aircraft. See you can see, this is the airspeed indicator. It takes two inputs, the pitot pressure and the static pressure.

The pitot and the static port, through this the air pressure goes inside and the difference of pressure is measured through this diaphragm by expanding or retracting it. And then, through the coupling element that is the gears, the mechanical linkages and the reading is given to the indicating element that is on the gauges. Airspeed gauge is calibrated in knots, the difference of pressure when the diaphragm moves is shown on this gauge.