Introduction to Flight
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Lecture 04.3 – Pressure Measurement

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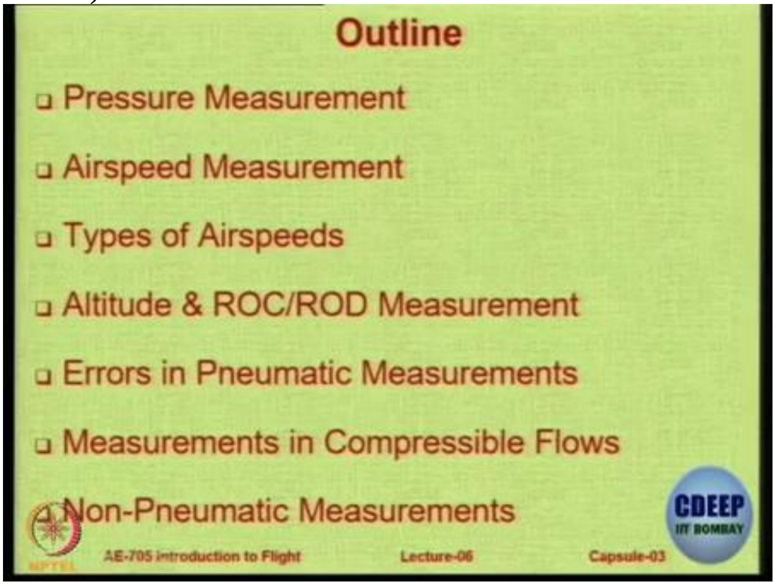

Welcome to the second lecture of capsule number three or the 6th lecture in this particular course. Today, we are going to look at measurement, pressure and airspeed. So the outline of today's presentation is going to be, we will start first with pressure measurements, then we move onto measurement of airspeed. And, once we study about airspeed measurement, we also need to know that there are different types of airspeeds. So we look at the differences between those speeds. We will also look at two measurements, one of altitude and the other of the rate of climb and descent. And then we will move onto errors in the pneumatic measurements because most of the instrumentation in the aircraft so far has been based on pneumatics.

We then look at how there are errors in compressible flows and what kind of compensations are provided. And finally we look at the future about usage of non-pneumatic instruments for measuring pressure as well as speed as well as other parameters like angle of attack.

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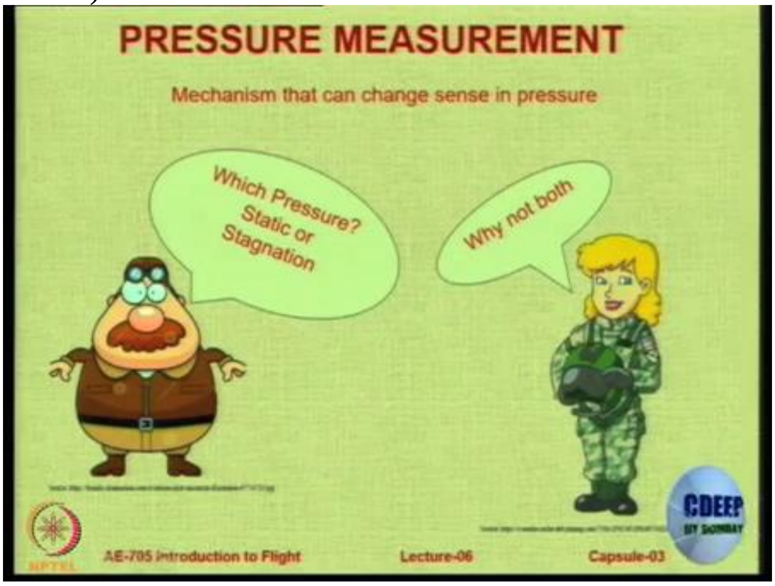

Okay, so let us start with pressure measurement. Essentially what we need is a mechanism or a system on the aircraft that can sense changes in pressure. But the question that immediately beholds us is which pressure are we measuring? Is it the stagnation pressure or the pressure when the fluid is brought to rest isotopically or is it the static pressure or dynamic pressure? So the question can be answered by saying let us measure both of them because both of them are of some use to us. We will see very soon.

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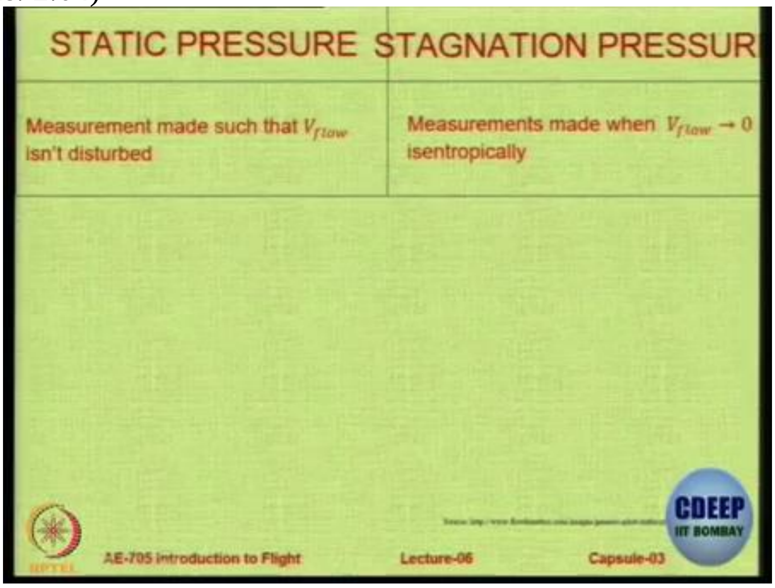

So the measurements made such that the flow is not disturbed is called as the static pressure measurement and in static pressure measurement we have to be passive. The in both the cases, of course one should not disturb the flow field as far as possible to get a true reading. In static pressure measurement we are not interested in changing the parameters of the flow. In stagnation pressure measurement we need, we want to measure it when you bring the flow to rest, but bringing the fluid to rest has to be done isentropically. So what is isentropically? Do you remember? We discussed this in one of our previous lectures, so can somebody help me? What is meant by bringing flow to rest isentropically? So what happens in isentropic flow or what does not happen in isentropic flow?

Student: No heat is exchanged.

Professor: No, heat is exchanged. No heat is lost or gained. Okay. Would you like to add something? Take the mic, mention your name first.

Student: My name is Satyam Rai. And in isentropic process entropy should be 0.

Professor: Entropy should not change. So in real life can we have an isentropic process? No. It is very difficult to have a physical process which is perfectly isentropic but if the losses are minimized, if the heat gain and loss is almost negligible, if the entropy changes almost negligible, then we can say that it is isentropic. So why is it required to do isentropically? Yes. If you have some interesting point you can discuss in the class. As I mentioned in my first lecture, I prefer discussion and interaction.

Student: What is the difference between isentropic and adiabatic to answer this?

Professor: So I would like you to elaborate that, it is a very, very valid point. So you elaborate. What you are seeing is the process that they have described is not isentropic but adiabatic. Okay.

Student: That is the, basically what the difference between in adiabatic…

Professor: Okay, So can somebody answer? Yes, please take a mic. There is a mic somewhere there in the middle.

Student: Sir, my name is Kavita. Adiabatic flow is the one in which heat exchange is taking place. Whereas isentropic flow is the one which is irreversible.

Professor: Reversible, not irreversible, reversible. But then what about entropy change? Is entropy change permitted in adiabatic flow? What about isentropic flow?

Student: Isentropic is both

Professor: A reversible adiabatic flow is isentropic, can we say that? Okay. So we just go ahead. Basically we want to bring it to adiabatically. So in the static pressure measurement, what we normally do is there is a flow and you see there is one L shaped pipe, but that is not our concern right now.

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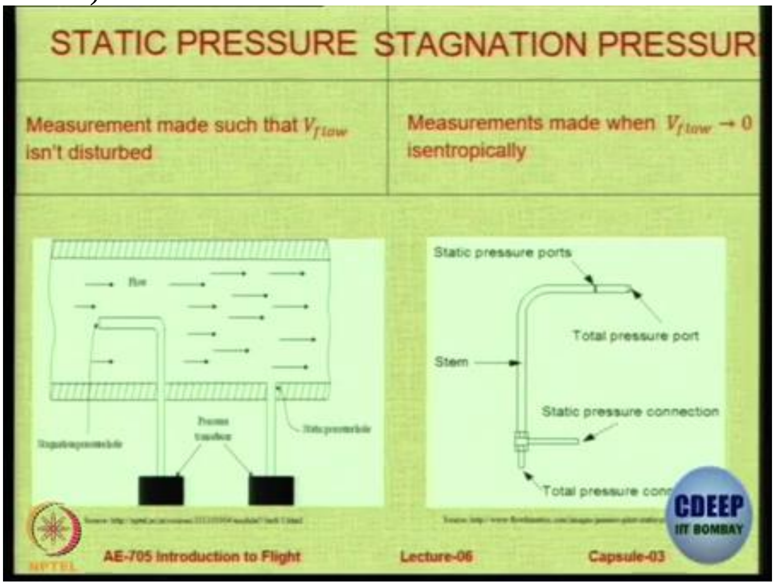

In the static pressure measurement we have another pipe or a probe, but that is flushed with the inner edge of the tube. So therefore it is not protruding inside and the pressure that it will measure is called as static pressure. The one on your left is a tube which is going to probe inside, which is going to disturb the flow and that is going to measure the total pressure. Similarly on the right hand side we see a similar thing. You have a total pressure connection and then on the side you have a static pressure connection.

And on the top you have a bent stem which has a static pressure port on the sides and in the front it takes the incoming flow head-on. We have the total pressure port.

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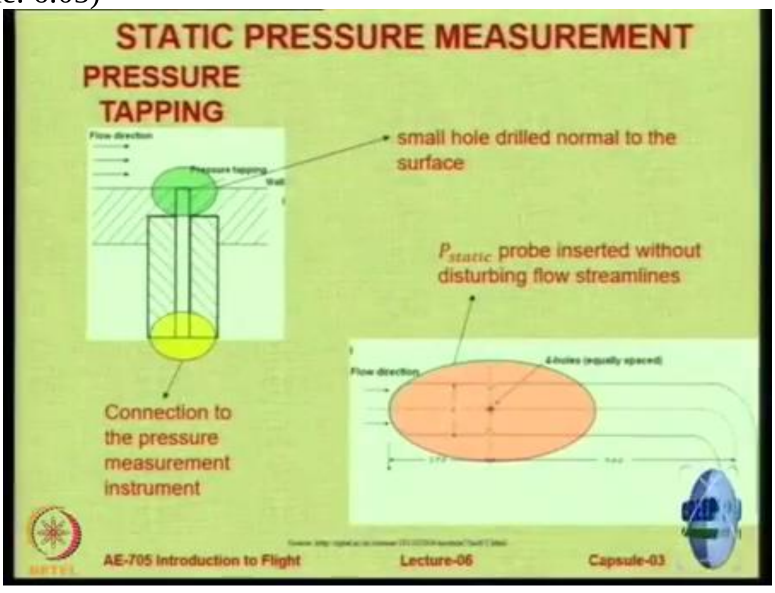

So both these pressures are important to us and we need to measure both of them. Okay, so let us see how the pressure tapping is done. This is just a close-up of the same figure. It shows you that the tube that is used can be integrated to the pipe partially but the probe where you do the measurement has to be absolutely flushed with the pipe. Even a very small projection can lead to losses and errors and that is going to be a problem. So this is a small hole which is drilled normal to the surface.

And on the bottom one is connected to the pressure measurement instrument. If you want to do it in free flow, that means external flow. That one was internal flow, in external flow you create these holes equally spaced if possible on all along the periphery of the tube which is projecting into the flow direction. Notice that the front of the tube could be closed or open. For static pressure measurement we do not want to worry about the air coming in the front, but in most cases as we will see very soon we couple these two together. So P static probe is inserted without disturbing the flow streamlines.

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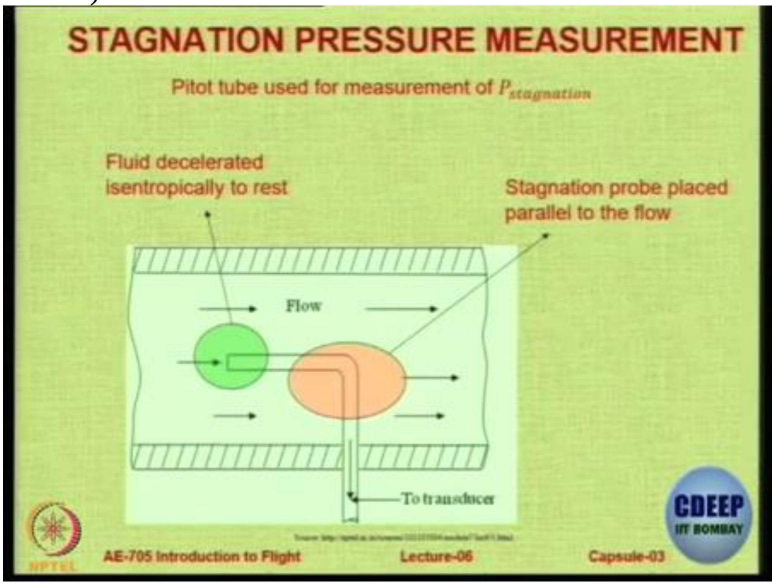

And if you look at stagnation pressure measurement, the most commonly used instrument is called as a pitot static tube. The last t is silent. It is called as the pitot static tube and this actually is used for measurement of both. And sorry, we are talking about pitot tube right now, so pitot tube does not have any static port, it is just a pitot tube. Pi tot tube basically is to measure total or stagnation pressure, is very simple. Just take a tube, round the edges in the front so that it does not create any sharp, discontinuities and bend it perpendicular to the stem, you get a tube which can be aligned to the flow and it measures total pressure.

So the fluid is, this is rated isentropically to rest. Now, how do you confirm that the fluid is brought to rest isentropically in such a tube? Why are the isentropic requirements or how are the isentropic requirements met? How can you be so sure that this particular method of bringing to rest is isentropic in nature? Can someone ponder over it and tell? Suppose we challenge and say, no, this is not isentropic. Then how will you justify? Because if we do not stop it isentropically, then we are not making a true measurement.

So one requirement is it has to be perfectly parallel to the flow. So this is something I will leave it to you for Moodle homework. People are very active in Moodle in this class, I am very happy, they are posting things on Moodle. But from now on we have to look at posting quality material. So when you post material on Moodle, remember, we are not playing a game of Fastest Finger First on Kaun Banega Crorepati. That you simply go, Google the term whatever first link you get, copy and paste it. That is not the intention.

I do not want to check how soon you can do a simple Google search. That is not the intention; the intention of asking you to go on Moodle is a self-study aspect of this course. I would like you to ponder before you post, you can post YouTube videos because that improves clarity even you see, I also use lot of YouTube videos to improve the clarity. That is not a problem, but the problem is like there was a post about rivets and I have given my comments on that on the Moodle page. Similarly, do not simply put something because it has to be put. The quality of the posts that you put is going to be evaluated, not the number.

We want to see how much processing you do. Are you able to get some interesting material which is not hither to available? Something simply from a textbook unless it is mentioned that, okay, I want derivation of something to be shown then it is okay, you can go to a textbook, you can copy, just give the reference and paste it. But merely putting something just for number game is not our intention. So now we have a very valid question.

We have to now convince ourselves by arguments and by some kind of explanation, why a pitot tube which consists of a simple bent tube 90 degree bent tube immersed in flow provided it is kept perfectly aligned to the flow direction? Why is it and how is it sure that the flow is brought to rest isentropically? Okay, are you out in a technical manner? And then we will learn.

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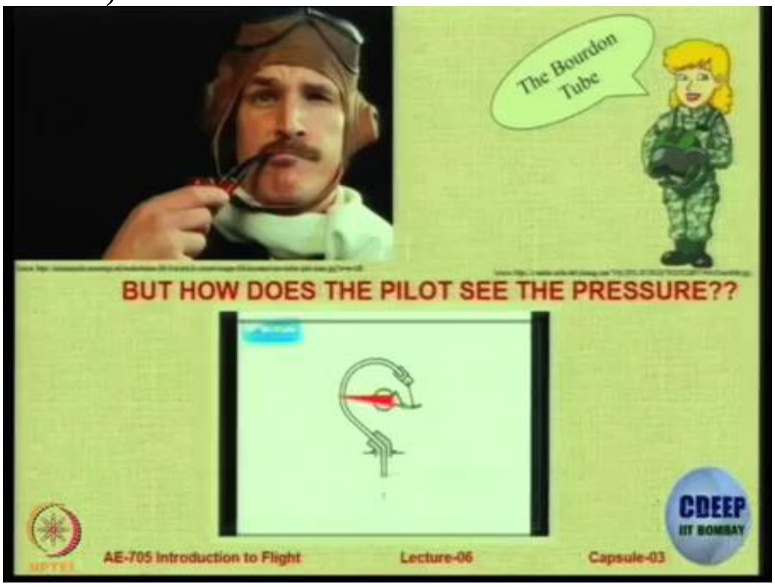

The question that I want to now talk about is the instruments are for the people who work on instrumentation, et cetera, but the pilot is the one who actually sees on board. So the question is, how does the pilot see the pressure? The pilot sees the pressure basically by an instrument. In the olden times they used to be dials where needles used to move such as the one that we are seeing. This is a bourdon tube but there could be other ways of also showing it to the pilot. You can show it digitally also, you can create the same display using electronics.

So what we have nowadays is called as a glass cockpit. By glass cockpit, we mean that the instrumentation or the displays that you see on the aircraft are not physical or mechanical instruments. These are computer simulations of instruments. So these are basically, most aircraft nowadays have what is called as a multifunctional display, MFDs.

They will be four of them typically, and any of them can be made anything by programming. So if there is a pilot and co-pilot and there is a problem with the co-pilot, again, I am just saying the whole instrumentation can be shifted to the left hand side and vice versa. So these kinds of facilities are available. In a combat aircraft for example, you may have a person sitting behind. Many combat aircrafts have 2 member crew. So typically the person sitting behind will be doing the navigation, mission planning, weapon release, etcetera and the one in the front is going to do basic airmanship or flying.

Suppose the person on the backseat has a problem, suppose that person faints. The display can be transferred to the front so that the pilot can do all the actions. It is not that now I cannot do anything because I cannot see. So that is a beauty of multifunction displays.

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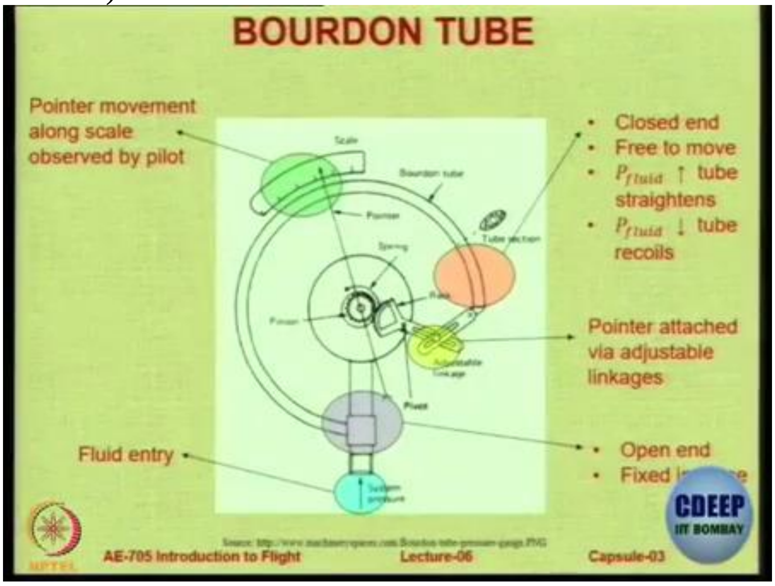

But let us first go into what is currently available, the physical instrumentation system. This is a very typical Bourdon tube, which has got this Bourdon tube which deflects based on the pressure which is coming. I will soon show you a video. So the fluid, it could be water, it could be air, in aircraft normally we use air measurements, so the air will enter from there. And that is going to basically lead to, so this is the open end on the bottom and the open end is fixed in place. It is held inside the instrumentation.

The other end is a closed end to which we connect some kind of bell cranks and leavers. So this is free to move. So the pressure of the fluid enters and the tube under reaction to that starts to straighten. As it straightens, then the tube will recoil. And as the tube recoils, the pointer there is going to move the screen. And this pointer movement will be seen by the pilot in the display. So this is the most basic instrument and it has to be calibrated on ground based on the pressure expected at a particular condition should be replicated.

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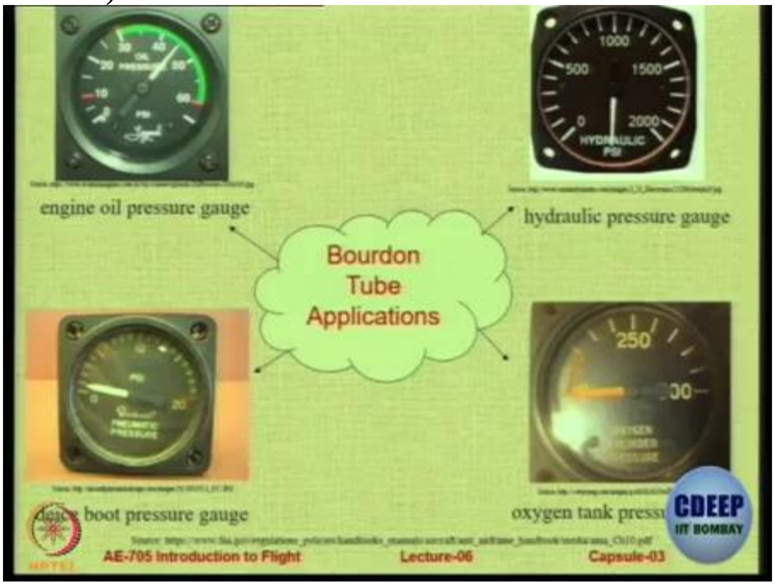

Okay, so one application would be engine oil pressure gauge. The other application could be hydraulic pressure gauge. The next one could be de-icing boot pressure gauge, and the fourth one could be oxygen tank. So any place where fluids are used in aircraft under pressure, you can use the fluid pressure itself to communicate to the pilot what is the magnitude of the pressure by moving the screen. So what is meant by deice? Anybody knows? What is meant by de-icing? And what is meant by de-icing boot? There are two questions here.

Student: My name is Vinay.

Professor: Yes, Vinay.

Student: At higher altitudes where the temperatures are lower, there is a formation of high for the cockpit. So there is a device called de-icing system,

Professor: Just a small correction. One need not have to go to high altitude for de-icing. Even at sea level at very cold conditions in many countries you can have icing. Icing basically takes place when there is presence of ice. Okay. So yeah, mostly when aircrafts are flying at high altitudes, temperature drops, so the icing builds up. But you can have icing even at ground level at the airport before take-off. So whenever there is collection of ice, we need to have a system which is meant to remove it called as de-icing system.

So what is meant by deice boot? Any one? Yes, mic can go there. So de-icing we know, but what is meant by de-icing boot?

Student: From the wing when the ice formation is there, then there are lot of pads which play that are called as de-icing.

Professor: That is right, thank you. So there are many ways of de-icing. One of the method is called as a pneumatic de-icing, you could do electrical de-icing by sending a heat element some current and that melts the ice. But one very simple way is the mechanical method or the pneumatic method where there are certain rubber based contraptions, typically near the quarter chord of the wing, upper and lower areas. So they start vibrating or they inflate and deflate which breaks the ice. So the inflation and deflation of that will require some fluid and that fluid will have some pressure. And this tells the pilot. So if the deice boot pressure gauge shows 0, it means that the de-icing system is not working. Okay.

There is something called as the minimum equipment list or MEL when you fly an aircraft. So if you do not expect icing conditions during the flight, you might be allowed to fly without the de-icing system working. Okay? It is not that every system on the aircraft has to always work in every flight. But if you are slicing in what is called as a known icing conditions, then you will not be allowed to fly if the de-icing boot because it will be in the minimum equipment list. So when the pilot does a pre-flight check and sees de-icing boot pressure is 0, he or she checks, is it permitted to operate? If it is okay, known, we fly.

Similarly, oxygen tank pressure, why do we need oxygen in the aircraft? Oxygen system is required because when you go to higher altitude for passengers as well as for the pilot, you need oxygen in the case of a situation where there is a complete loss of pressure and ambient air will not be breathable. Similarly hydraulic pressure, similarly engine oil pressure. So these fluids, they exert pressure and that is used in the Bourdon tube.

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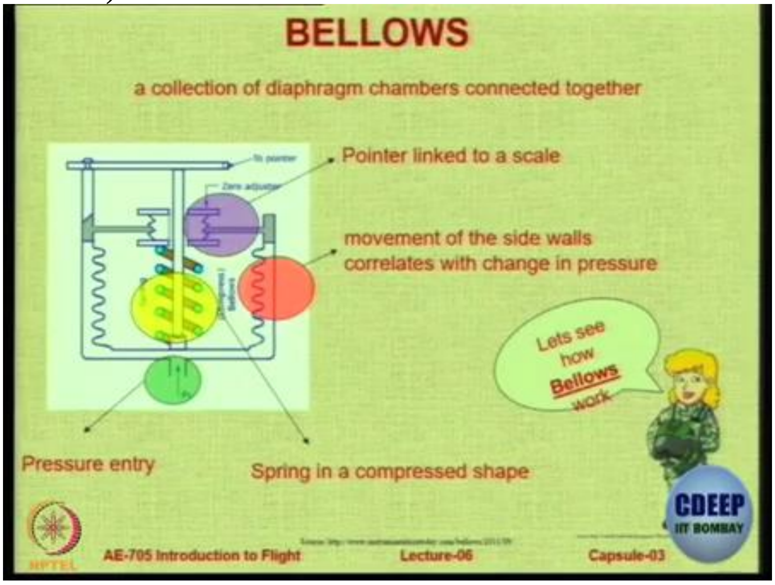

Then there is another system called as bellows. So bellows basically are a collection of diaphragm chambers which are joined together. Something like the spring. The, you can see, you can see there is a diagram of the bellows. So the pressure enters from the bottom, the spring is basically going to hold the bellows together when there is no pressure. When the pressure acts the pressure forces against the spring. So the pressure force is acting on the spring and it is expanding the spring. It is a constraint spring. Okay, so it is a compressed shape spring which will expand because of the acting of the pressure and the movement of the sidewalls that is a bellows they are correlated with the change in the pressure.

And at the end you have a pointer linked to a scale. So as the bellows move you will be able to get a reading. There is a short video showing how the bellows work.

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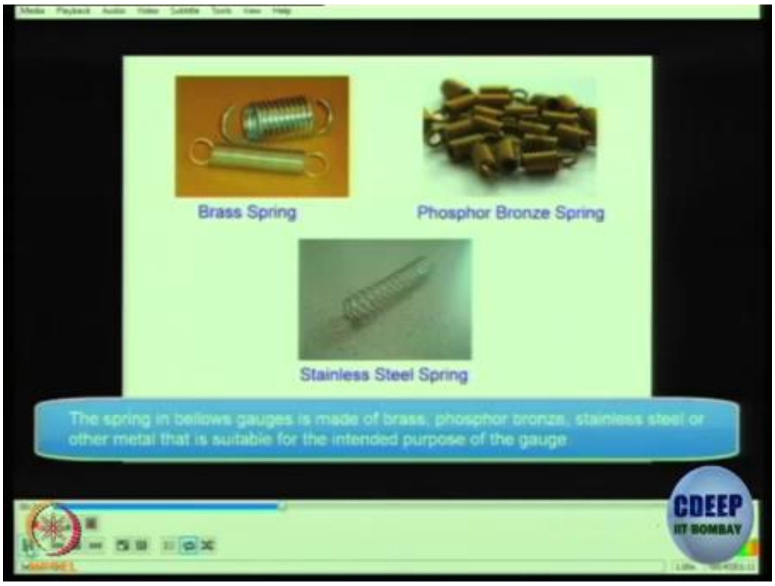

Obviously depending on the amount of pressure you are expecting and the size limitations in the instrumentation, you have to choose an appropriate material for the spring and the material of the spring should be such that it can come back. It does not have any hysteresis so that when you extend it contract it thousand times it does not have any permanent deformation. So that is why we have to go very carefully about the material.

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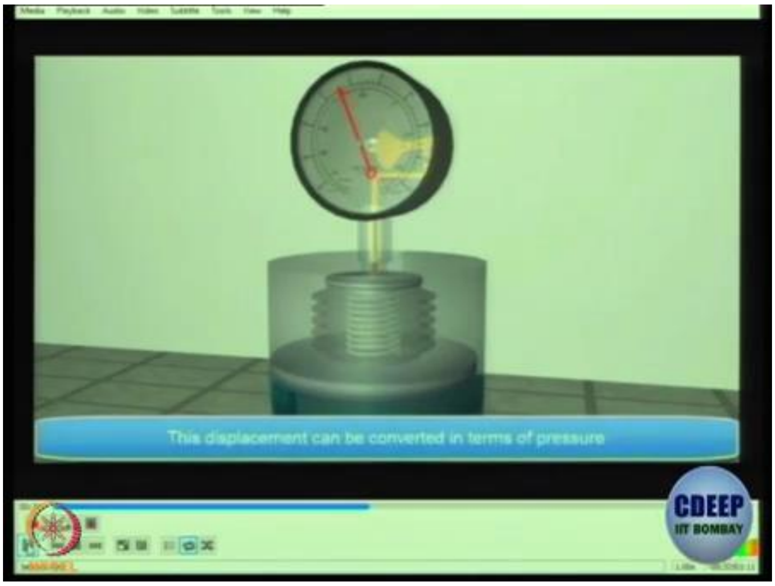
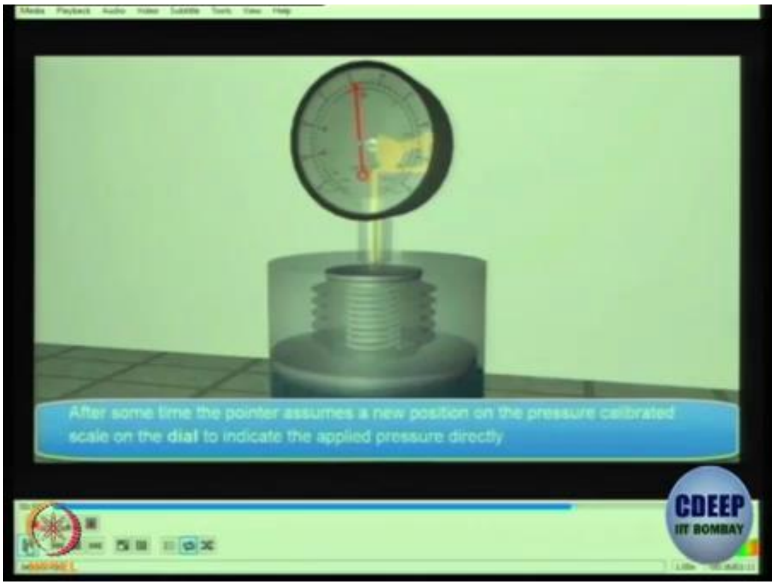
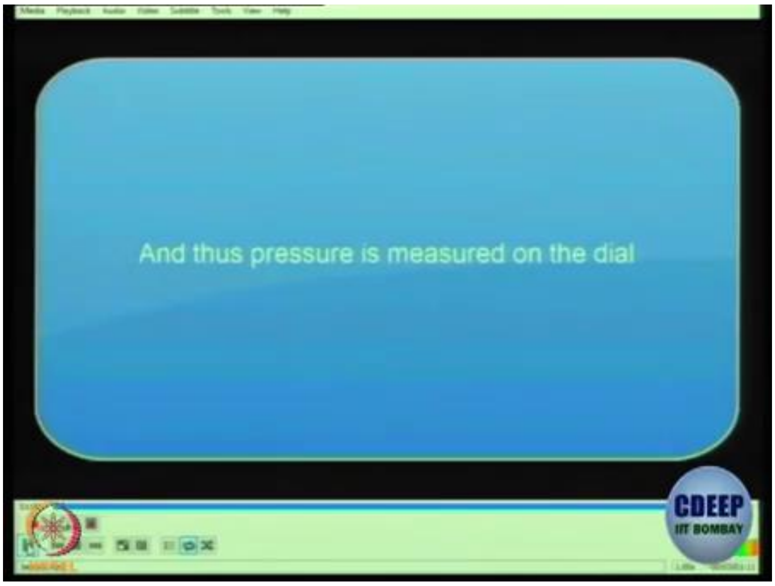

This displacement can be converted in terms of pressure
CDEEP
IIT BOMBAY


As flow of pressure increases, a pointer starts rotating on the dial which indicates the pressure of the flow and to make this measurement precise the scale of the dial is divided in many sectors
CDEEP
IIT BOMBAY


After some time the pointer assumes a new position on the pressure calibrated scale on the dial to indicate the applied pressure directly
CDEEP
IIT BOMBAY



Okay. So this is very simple. In fact, this instrument is much simpler than even the Bourdon gauge because for the Bourdon gauge, you have to have provision for the displacement of the gauge. Here, there is no displacement. It is only the spring which is getting compressed or extended. Okay, so this is the information regarding pressure measurement.