Introduction to Flight
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Altitude and ROC/ROD Measurement
Lecture no. 04.6

Alright, Welcome to this third lecture of the third capsule.

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Basically, we are going to do the second part of the lecture on pressure and airspeed measurement which we could not do last time. So, the outline is that first we will look at measurement of rate of climb or rate of descent using an instrument. We then look at the typical errors that we see in pneumatic measurements and we will look at an example of an accident that took place, a famous accident.

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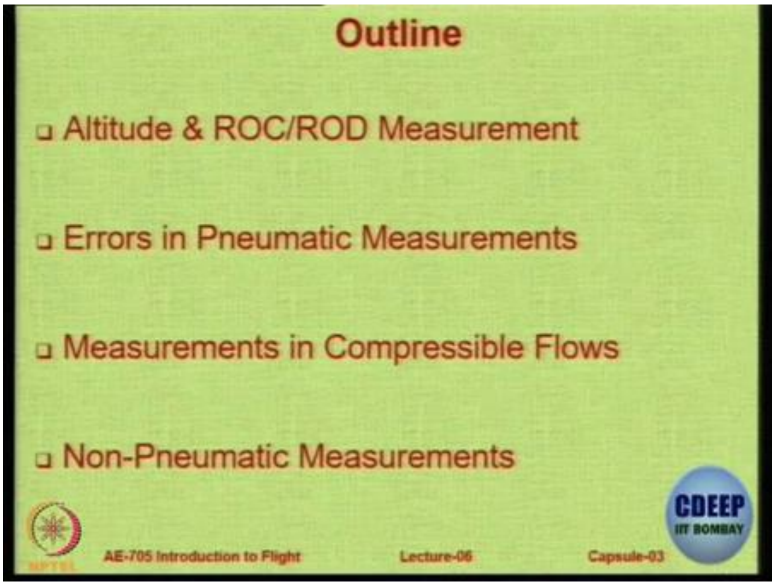

We move on to measurements in compressible flow, although we have not yet covered compressible flows in detail, I will kind of give you an overview and then we look at some modern instruments which are used for measuring both air speed and pressure especially, air speed without using any pneumatic measurements.

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Okay, so let us see how do we measure altitude using pneumatic instruments. There are also other ways of measuring altitude, for example you can have a radio altimeter which sends the signal from the aircraft and the signal bounces off from the ground and it is received back in the aircraft.

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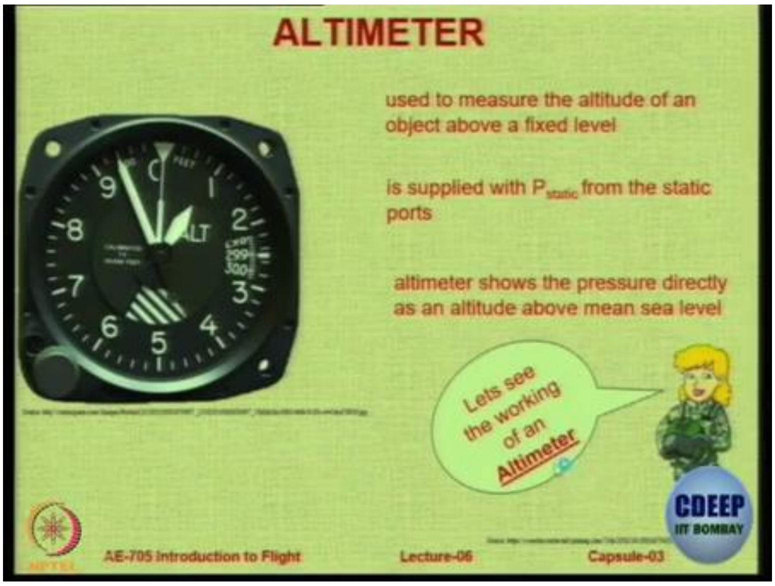

But we are talking today only about pneumatic instruments and the most common and the most prevalent equipment that you see is the altimeter. This is how it looks like. You can see that it has got three arms, just like the hour, minutes and second arm in a clock. Okay and there is also a small window which is showing some numbers 29.9, 30. 0, etcetera. And also on the bottom there is an area which has a hashed line so we will understand what these are.

Essentially, this instrument is used to measure the altitude of the aircraft above a fixed level, and since it is based on pneumatic or pressures, it is going to measure only the pressure altitude. So, this instrument is supplied with the static pressure from the static ports on to the system and the altimeter shows you the pressure directly as an altitude above the mean sea level.

So, therefore, remember when it is showing you above the mean sea level you will have to actually correct the location of the mean sea level at any specific location to get the geometric or true altitude. So, this is only going to give you a pressure altitude. Let us see how this instrument works. It is a very basic, very simple instrument.

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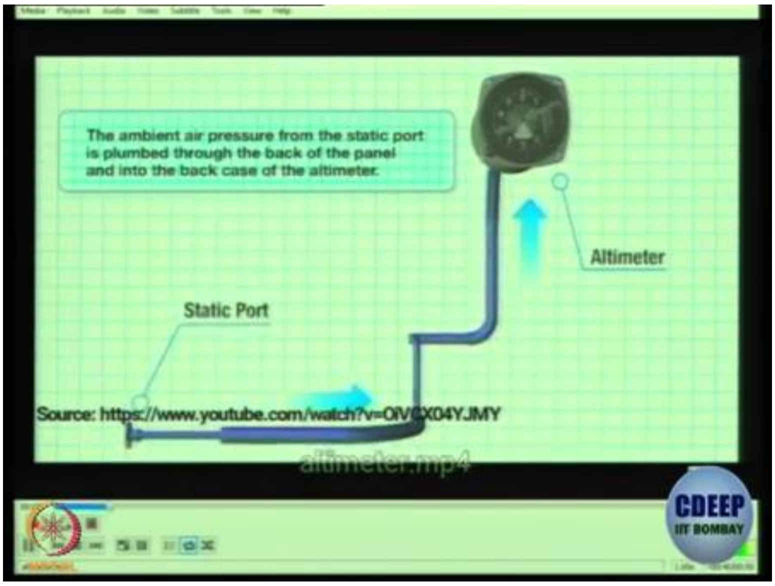

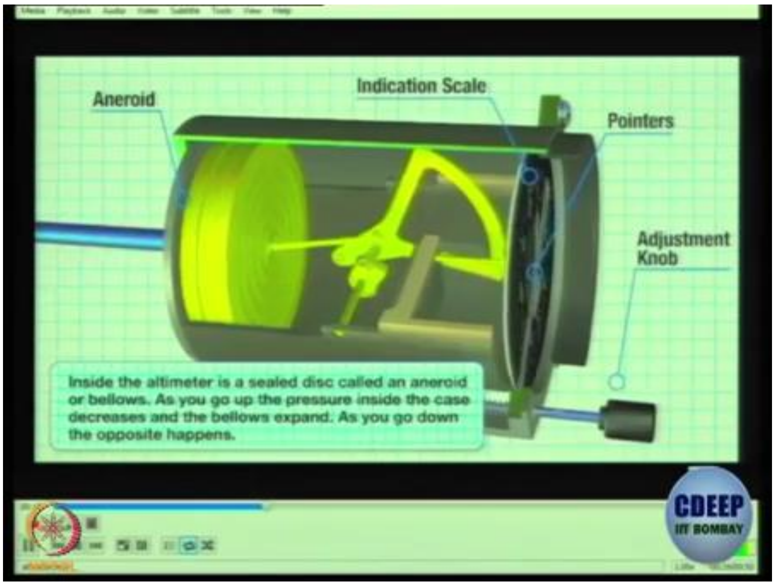

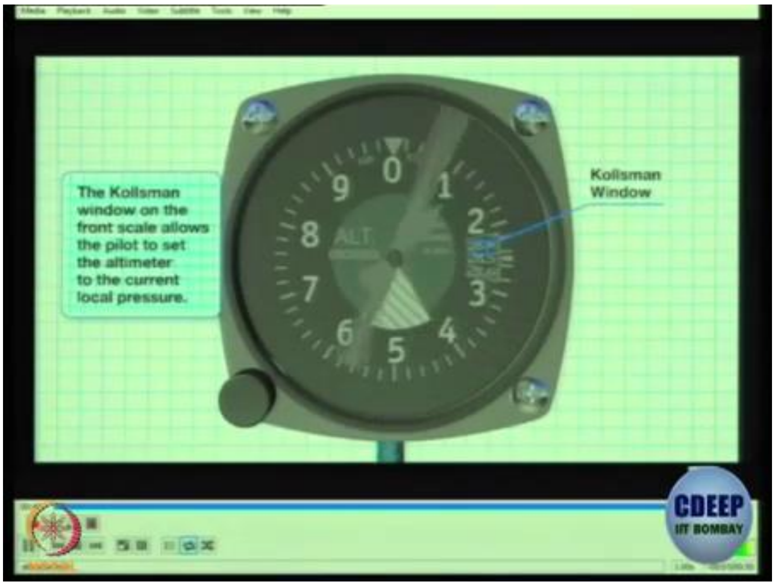

So, you can see that the static port is connected to this instrument from the back and what it simply does is that as the pressure increases, it is going to push this aneroid barometer type bellows and that motion is transmitted through links to the scale.

So, you can see there are two pointers moving, one the one which is short one is showing you the altitude in thousands and the next one is showing you the altitude in the break-up of thousand. So, it is a pure and simple mechanical instrument and there is window called as a Kollsman window which is used by the pilot to adjust the readings.

We will see this in little bit more detail, I will let it run for one more time. One of the most simple and basic instrument, it works both ways the same way – when the pressure decreases in the ambient condition at high altitude, the aneroid is moved towards the valve; when the pressure increases at low altitude, the pressure the bellows are moving in the opposite direction to show you the loss in the altitude and you can see there is knob which can be used by the pilots to adjust the window readings to suit the calibration.

This is not the calibration error. This particular adjustment is basically for a matching with the standard sea level ambient pressure reading.

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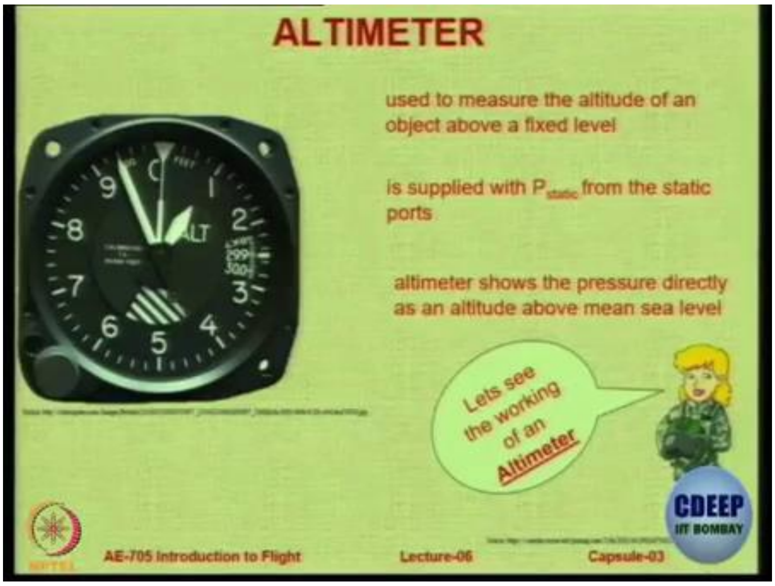

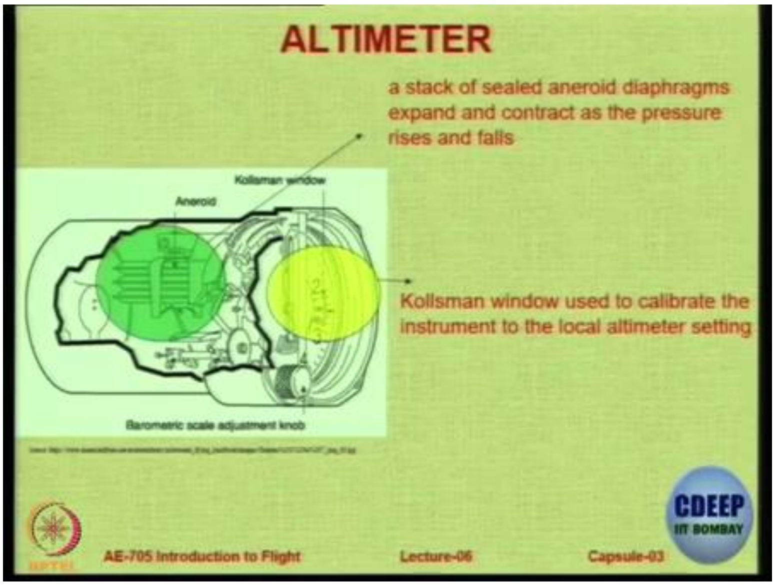

So here is how it is. If you cut open you will see that there will be an aneroid system which can be of different types, here it is mounted vertically. So, a stack of sealed aneroid diaphragms with the expand and contract based on the pressure rising and falling and this window, called as the Kollsman window it is used to calibrate the instrument.

So, the pilot will ask the air traffic controller or the ground support guy, what is the pressure at the altitude at which the airport is located and then you adjust the altimeter to that particular pressure. So, if you want to measure the standard number, you will make the sea level as 29 point 9 inches of mercury, or you will adjust it based on what the ATC tells you. So that, for that we have this one. And this pointer keeps on moving, giving us the reading. Simple instrument.

Now, the same thing can be used with slight modifications to measure the rate of change of altitude. Either positive or negative, because at any altitude, there is a particular pressure that you expect. So as the altitude changes, that pressure also will keep changing.

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So, the rate at which the pressure changes can also be measured and indicated to the pilot, that is called as a variometer, or the vertical speed indicator, VSI. So, how does a variometer work? Simple instrument again. You can see that it is giving you the values of the vertical speed in 1000 feet per minute. A unit which the pilots are tuned to read. And, there is a up area and a down area. Okay, so when it is moving in the up area, it means the aircraft is climbing or raising in altitude. When it is in the down area, the aircraft is sinking.

So, it is very simple. The way it works is also very straightforward. It just detects the loss or the change in the static pressure as the altitude changes. So, let us see how this instrument works. Now, here there is a small, a small modification, because it is a rate. Now, when you have rate of change, remember, the rate of change means, you need to, give it some time. So, to do that there is a very interesting system.

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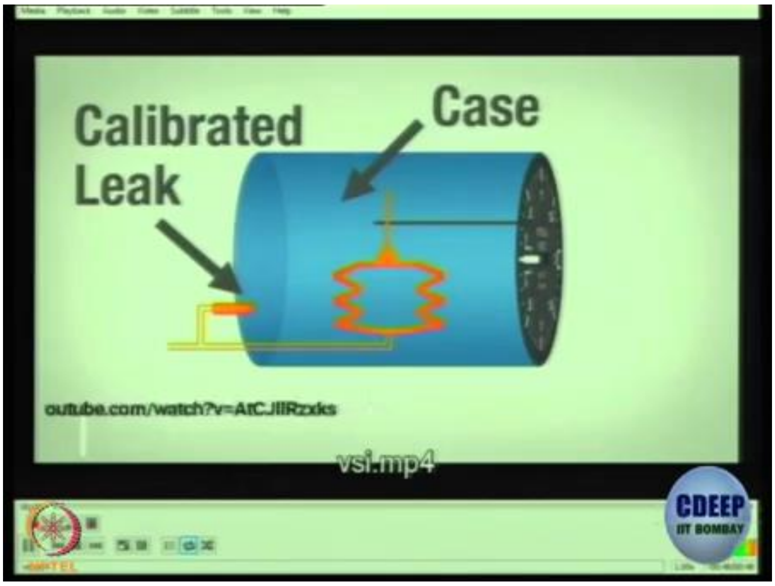

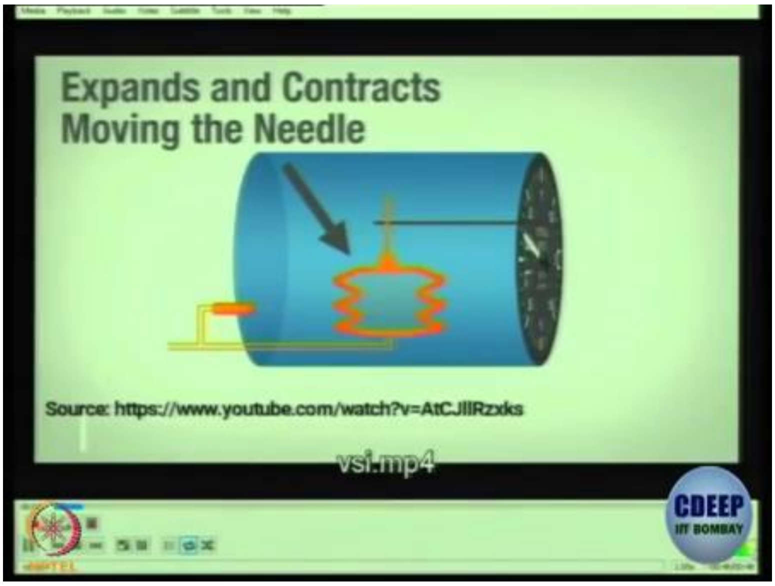

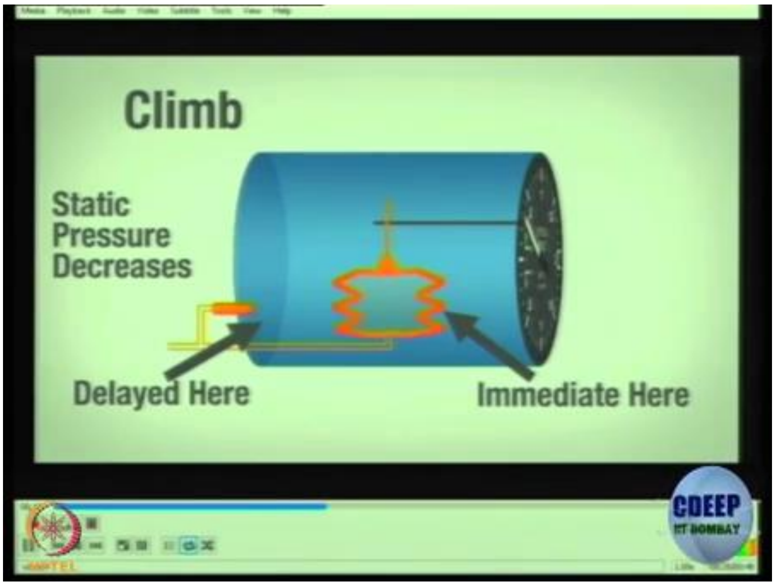

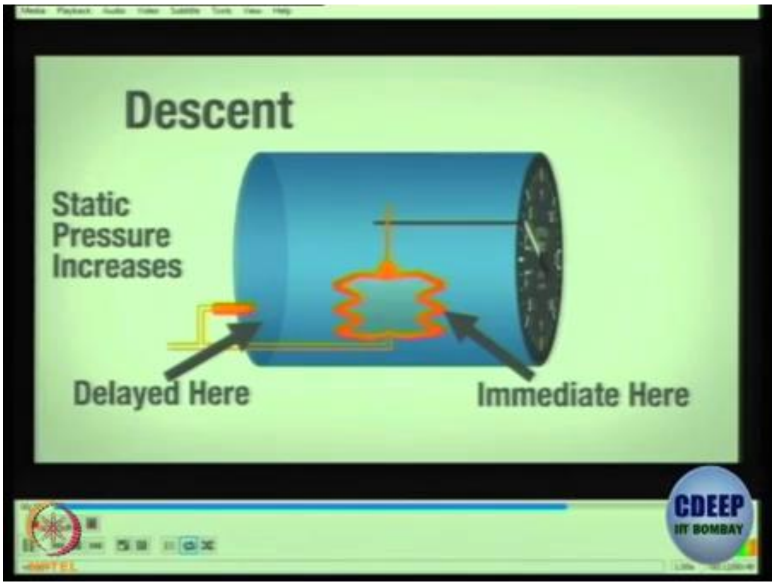

Presentation Audio: Diaphragm expands and contracts.

Professor: Can we have slightly more volume please?

Presentation Audio: Diaphragm expands and contracts. And as it moves, it turns some gears and some rods, which causes the needle on the front of the VSI to move up or down.

Professor: on that side please.

Presentation Audio: So, let us look at a scenario where you are climbing. As you climb, the outside air pressure starts to decrease. And that decrease happens immediately in the diaphragm. But, the calibrated leak in the case does not let the air escape right away. So, now the case is in a higher pressure than the diaphragm. That causes the diaphragm to squeeze. It gets smaller, causing the VSI's needle to move up.

Descent is the exact opposite. As you descend, the outside air pressure begins to increase. That increase happens immediately in the diaphragm. But the case does not let its air escape right away. So now, the case is at a lower pressure than the diaphragm, the diaphragm begins to expand. That causes the VSI's needle to swing down.

Diaphragm expands and contracts, and as it moves, it turns some gears and some rods, which causes the needle on the front of the VSI to move up or down. So, let us look at a scenario where you are climbing.

As you climb, the outside air pressure starts to decrease. And that decrease happens immediately in the diaphragm. But, the calibrated leak in the case doesn not let the air escape right away. So, now the case is in a higher pressure than the diaphragm. That causes the diaphragm to squeeze. It gets smaller, causing the VSI's needle to move up.

Descent is the exact opposite. As you descend, the outside air pressure begins to increase. That increase happens immediately in the diaphragm. But the case does not let its air escape right away. So now, the case is at a lower pressure than the diaphragm, the diaphragm begins to expand. That causes the VSI's needle to swing down.

Professor: So, we have seen it a couple of times. So, you have this calibrated leak, which is allowing you.

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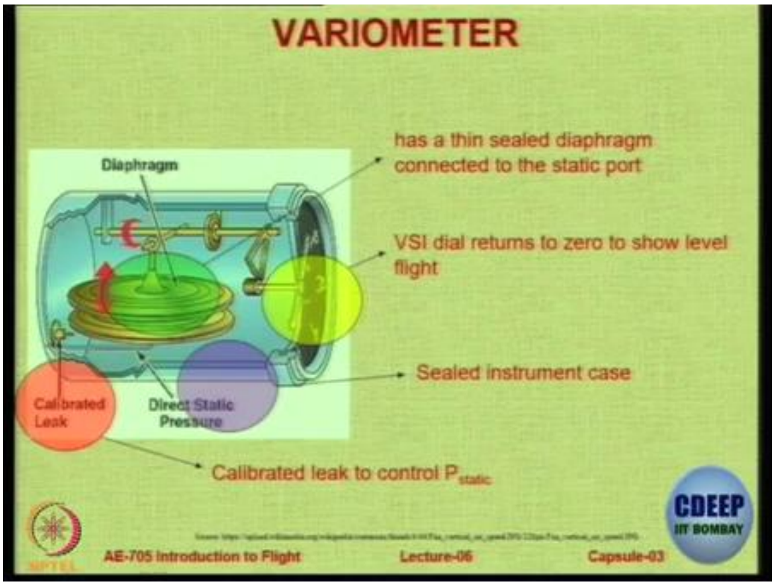

In this particular figure, the same instrument, but now in this case, the aneroid barometer is mounted vertically. That does not make any difference. So, what is happening here is, there is a sealed diaphragm connected to the static port. So, the pressure inside the diaphragm is going to be directly connected to the static port. But, the pressure outside is going to be connected or will be a function of the seal. So, therefore, there is a need for a calibrated leak, which allows us to know what is the rate at which it is changing.

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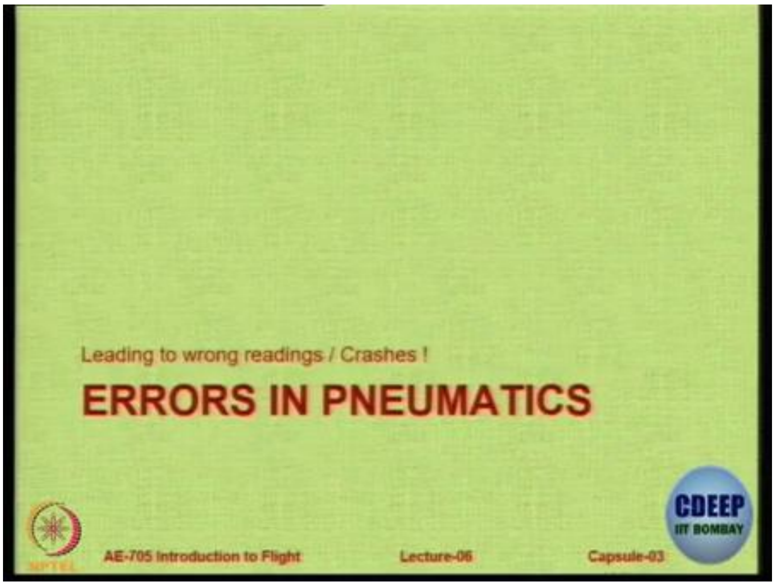

So, the VSI dial return turns to zero to show level flight and it shows up and down depending on whether you are climbing up or climbing down. So, we noticed that, for measurement of vertical speed and for measurement of altitude, we use only the static pressure. For measurement of speed, we use both static and? Static and? Static and total pressure because the difference of them is dynamic pressure. Half Rho V square. And that is used to show the reading on the instrumentation.

Now, pneumatics is dependent on how well-sealed the instrument is, how well-sealed the system is, how well the pressure is conveyed. And as I discussed with you in the last lecture, there could be wrong readings because of blockages. So, let us see what are the typical problems in the pitot-static systems.

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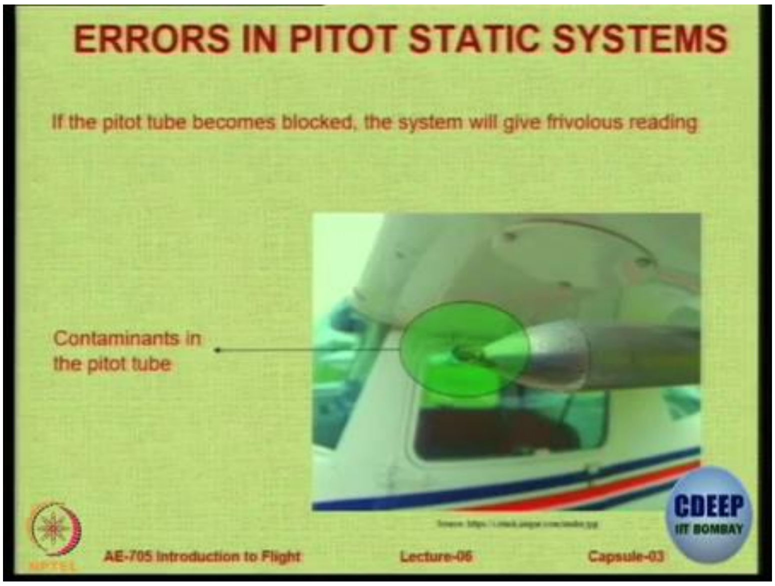

Obviously, if the tube becomes blocked at some place. It could be blocked right in the front, so the total pressure read is zero. Or it could be on the sides, where there are static ports, or it could be both. So, this is one example, a real-life example of a wasp getting sucked inside. Or getting stuck in the intake of the pitot-static tube. So, the, now the total pressure is blocked.

So, it could be contaminants because of ants, bees, wasps, etcetera. It could be because of some dirt or during maintenance of the aircraft, if the technicians are not very careful and they leave some oil or some other things which coagulates. Anything can cause a blockage.

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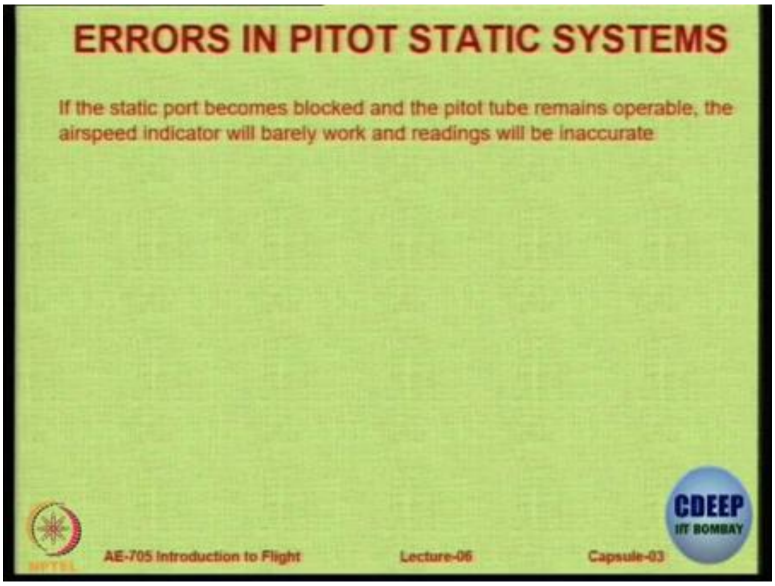

So then, if the static port becomes blocked, then what will happen, the pitot-static tube remains operational. Because the pitot-static tube system requires a difference of both of them. So, when static port is blocked, it means it will show that there is no pressure there. So, the altimeter will freeze in the place because altimeter needs static pressure and there is no static pressure. So, whatever is the reading in the altitude, it remains constant. Whatever height you are.

So, if the altimeter does not change when your altitude changes, it means the static port is blocked. Similarly, the vertical grid indicator will not also change because there is no difference in pressure now. Whatever pressure is recorded, it will read that only. So therefore, vertical speed also will not be changed, right. However, what will happen to the pitot-static system. I mean, this is an example of a blocked static port. So, if the pitot tube and the drain hole are blocked, then what will happen is the pitot-static, the airspeed indicator will act like an altimeter.

Because now both the things are blocked, the drain hole is the one, this is not a static hole, the drain hole is the one which allows us to drain out water or any other collectants inside that. So, if that is also blocked and the main thing is blocked, that means the static port is working. So, therefore, the pressure conveyed will be only static pressure. So, it will show, it will work like an altimeter, although the readings will be all frivolous. Because it will, it will show some speed, actually it is responding to the static pressure only.

So, how do we prevent these things? We prevent these things by using covers. That is all. Very simple. So, if you go to any aircraft which is parked, you will find that the pitot-static tubes or any other things which are projecting out of the aircraft and are needed to work, they normally put a plastic cover on that.

And to remind the pilot, they put a sticker there saying, ‘remove before flight’. Otherwise you may like to fly the aircraft without removing them. So, these are examples of the covers for the pitot-static tubes. So, obviously they have to be removed and they have to be kept in place when the aircraft is going to be parked for a long time. Now, this did not happen in one particular case. It is a very sad case. A very very silly thing has caused a major crash. And it is not a simple crash, it has led to the loss of life of 176 passengers and 13 crew members, all because of a blocked static port. All because of a blocked port.

So, let us see, this is a very important case study in crash investigation. So, what was the reasons for this crash? The reason for this crash was very strange. It was a wasp. It was a wasp. In fact, it was not only a wasp. It was cluster of houses or nests which are build by the wasps. I will show you the details. So, here is a close-up of a wasp nest.

So, the aircraft had three pitot tubes. And one of the tubes was actually blocked by a nest of the wasp like this. Now why was this nest allowed to be created?

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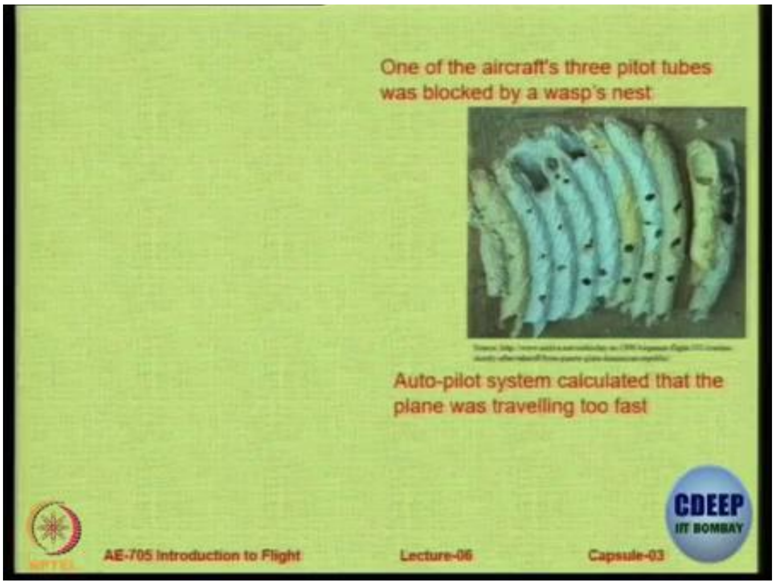

Because the static ports, and the pitot-static tubes were not covered with the pitot tube for many-many days and the location where the aircraft was parked, if I am not wrong it was kept for 23 days without usage, this aircraft at one particular place and during those 3 weeks or so, a colony of wasps had built their nest and they had covered the pitot-static, one of the pitot-static tubes like this.

This is not the actual picture of that, this is one, this is an example, because nobody has recovered those that nest after the crash, but this is a investigation. So, now the aircraft has a auto-pilot system which also gets inputs based on the data that the system is recording. So, now if the static port is blocked then the difference between static and dynamic pressure will be very large because although the aircraft is actually going reasonably slowly, the difference will be very high because it is blocked.

So, the auto-pilot in the aircraft when it was engaged, so, during take-off the pilots were on manual mode. So, they flew the aircraft. The co-pilot detected some error in the instrument and they said ok, we will ignore, we will see. But the moment the auto-pilot was engaged; the auto-pilot thought that the aircraft is flying very high. So, what should the auto pilot do? If an auto pilot detects that the aircraft is flying very high at very high speed – how do you reduce speed in the aircraft?

See, there is no question of putting speed brakes and air brakes when you are in the climbing flight. They are, do not even mention that, they are used only for? Only for?

Student: For landing.

Professor: For landing, that is all. For landing. Maybe in approach, at the end of the approach maybe to kill the lift. So, you will not kill the lift during flight. So, you would put throttle back, that is right. That is what the autopilot also did. Anything else you would do? Anything else that can brought bring the speed down of an aircraft that is flying. Yes, anybody else? Any other option? Anybody has any other option?

Yes, please take a mic, just behind you. One option is the throttle can be reduced what is the other option?

Professor: Right! Pitch up the aircraft. That means increase the nose of the aircraft. Because if you increase the aircraft nose, the drag will increase, the speed will reduce. That is exactly what the auto-pilot did. The auto-pilot raised the nose of the aircraft to slow it down. So, then the aircraft began flying at a very high angle.

Did not work because the port is blocked. So, therefore the auto-pilot thinks nothing is happening. So, then the next thing is engines to be throttled back to reduce the thrust. That is what that auto-pilot did, and this is what is the result. The result is the left engine or the port engine, first stalled and then the airliner to a full stall and crashed into the Caribbean Sea and as I mentioned to you so many people died.

So, let us see a small animation of exactly what happened. This is just an animation.

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So, take off is fine because pilots are in command. It is climbing into the, it is in the climb. Now we have the auto-pilot engaged, ok. It is trying to control the speed. Not working. So, now the engine is throttled back. You cannot see that but look at the flight of the aircraft So, it completely lost control, and very soon after take-off, it went into a complete spin and crashed.

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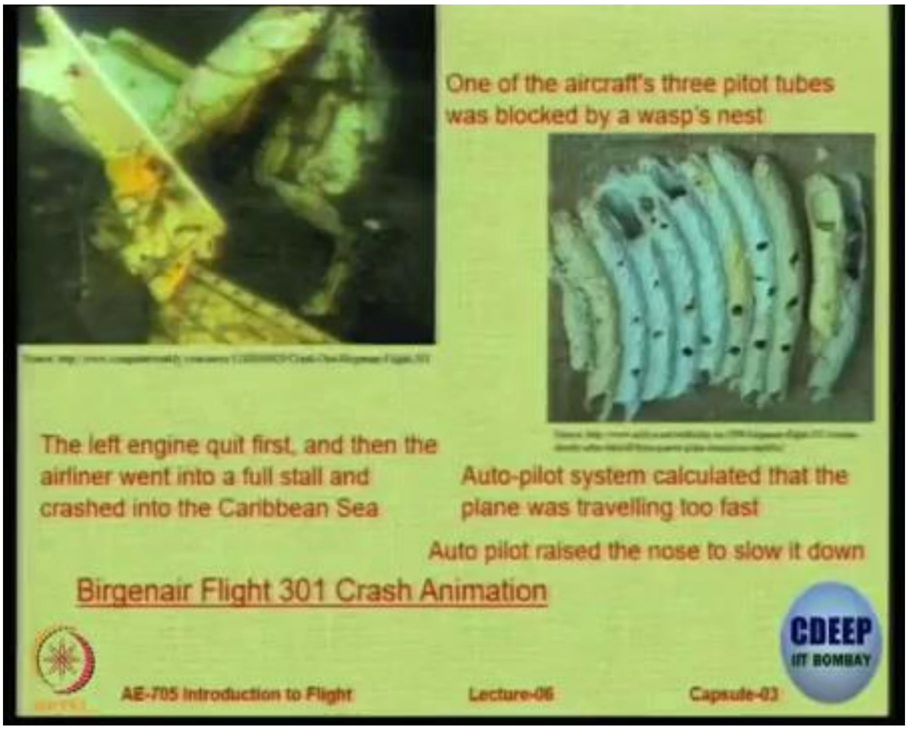

There are several videos available which also indicate, there is also a cockpit voice recorder audio available on how the pilot spoke to each other and although it is a very tragic incident, it is actually very interesting to see how the aircraft responded. And, after this people became very careful about the simple thing like covering a pitot-static tube after it is doing its job and the aircraft is being restricted.

So, sometimes very simple things like this can cause severe problems. Apart from this, a pneumatic pitot static tube system or a pneumatic system also has other problems – leakages.

The system has to be completely air tight and with time, with vibrations, with usage there could be some problems. So, there are several times when the maintenance engineers are breaking their head in trying to make the system work and to locate the leakage, plug it. Sometimes, flights get delayed. Many a times when you as a passenger go and you are told there are technical reasons for delay. Among many reasons one reason could be that the main air data system is not working because there are some errors, some problems, some leakages.