Flight Dynamics – II (Stability)

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Module No. # 13
Introduction to Aircraft Control Systems
Lecture No. # 41
Autopilots, Automatic Landing System

In this class we will talk about, or give you an overview of automatic flight control systems. They are of three different categories, one is called Stability Augmentation Systems.

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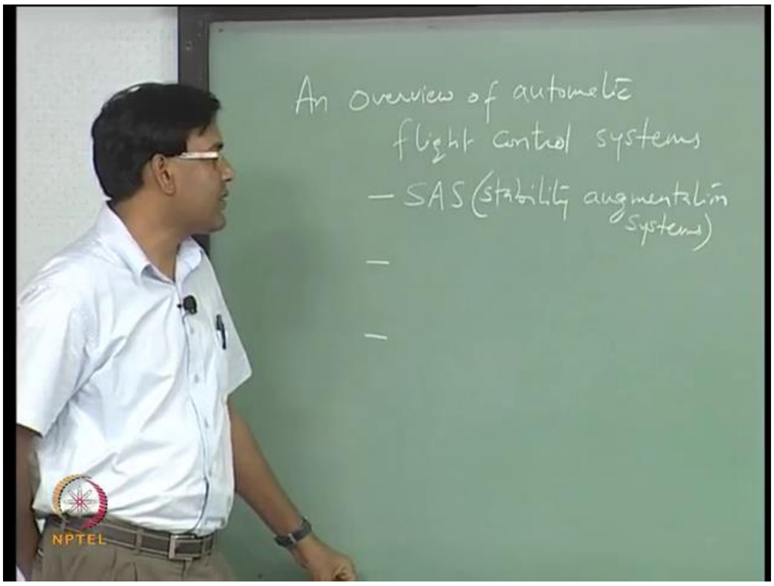
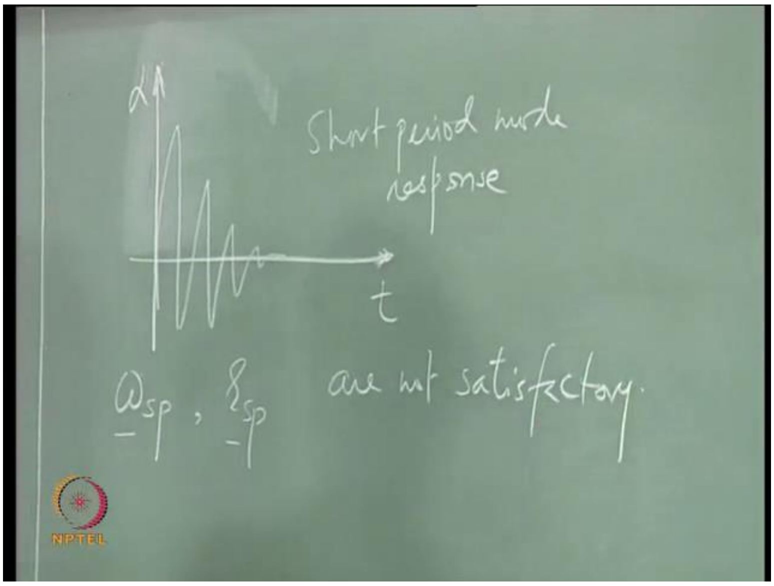


So, in case your aircraft does not possess the required stability characteristic as per the requirements of flying and handling qualities then, you have to artificially augment the stability of the aircraft using what is a stability augmentation system.

What you are trying to do here is, you are trying to use a feedback control mechanism wherein the objective is to try to change the dynamic characteristics of aircraft. For example, let us say you have a short period response. A short period response in angle of attack looks something like this (Refer Slide Time: 02:10). From here we can read what is the frequency of the response, and the damping. These are natural responses of the aircraft you know without control systems, where design results in giving us these number (ω_{SP}, ζ_{SP}). Let us say, these numbers are not satisfactory. In such a case, we can use this stability augmentation system to change the frequency and the damping characteristics of the aircraft using a feedback mechanism. The other type is called control augmentation system.



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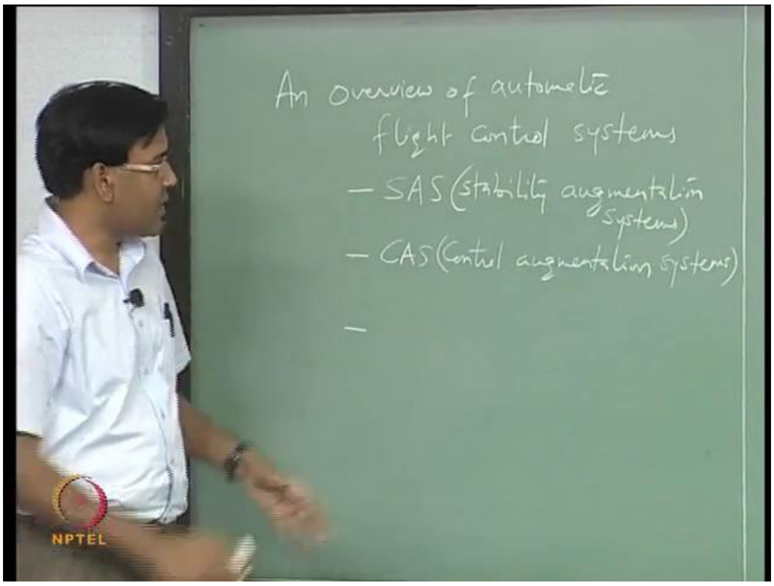

So, in case you are still not able to (meet other desired features in a response), you know that the stability augmentation system is only (going) to change the dynamic response of the aircraft (via stability characteristics). Control augmentation system is basically to either enhance the dynamic response beyond what is possible by using stability augmentation system, OR, you could have some control objectives that need to be satisfied and there you want to design the control system which can meet the objectives, some other control objectives.

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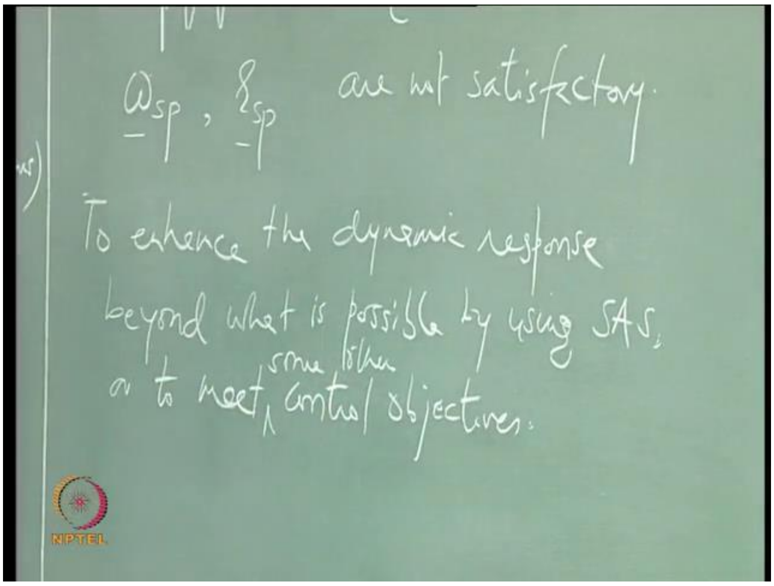

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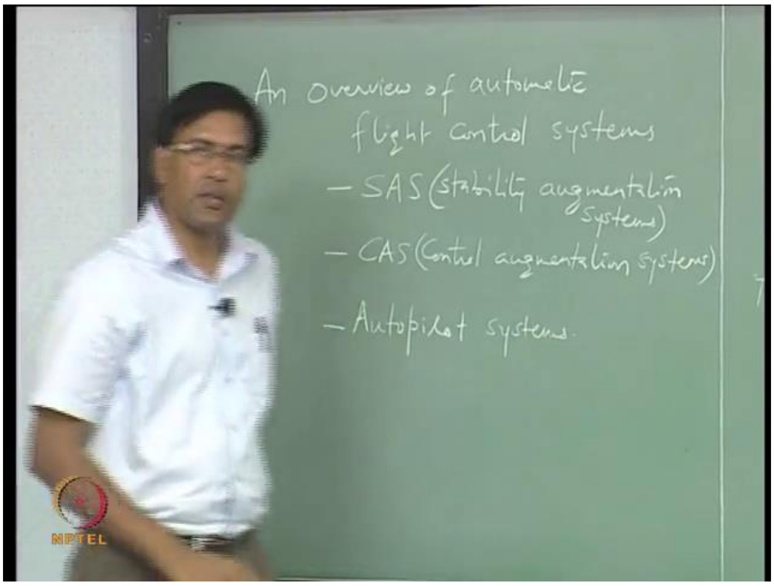

The third one is what we will talk a little more in detail is autopilot (control) systems.

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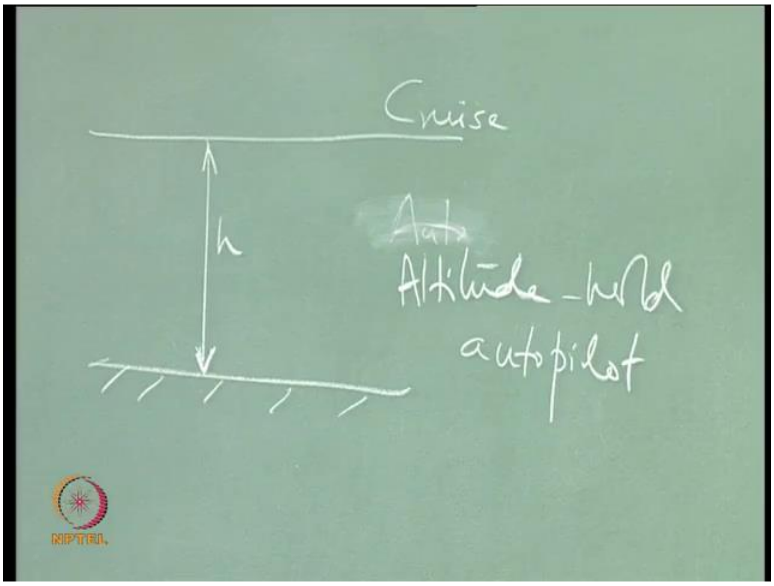

Autopilot systems are mainly used to keep the aircraft on a prescribed path or attitude. What you want to do here is, design a control system such that, for example, you know this height (Refer to the sketch) is maintained throughout constant in flight; as in cruise.

So, here the autopilot engaged with this constant altitude (objective) condition is called altitude-hold autopilot. The idea is to design a control system which will meet these objectives, but not really bothering about how the dynamic response is looking like. Of course, a control system that we have to engage to maintain the altitude should not result in unwanted situation; unwanted transient response. These autopilots are also including some features which will try to control the dynamic response.

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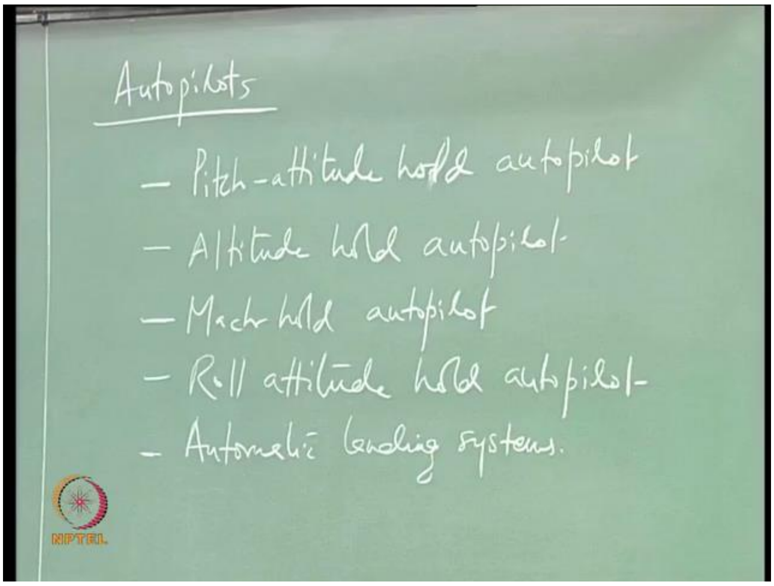

So, let us look at some of the autopilots that are normally seen on an aircraft: pitch-attitude hold autopilot, altitude hold autopilot, Mach hold autopilot, roll-attitude hold autopilot: these are some of the autopilots that an aircraft has onboard, and automatic landing systems.

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So, what we are trying to do here is (via autopilot systems), we are trying to give some comfort to the pilot. Pilot does not have to keep holding the stick to maintain, for example, the altitude in case of a cruise level flight or a bank angle in case of a sustained steady level turn. We will (now) look at each one of them in some detail; not exactly giving the complete detail.

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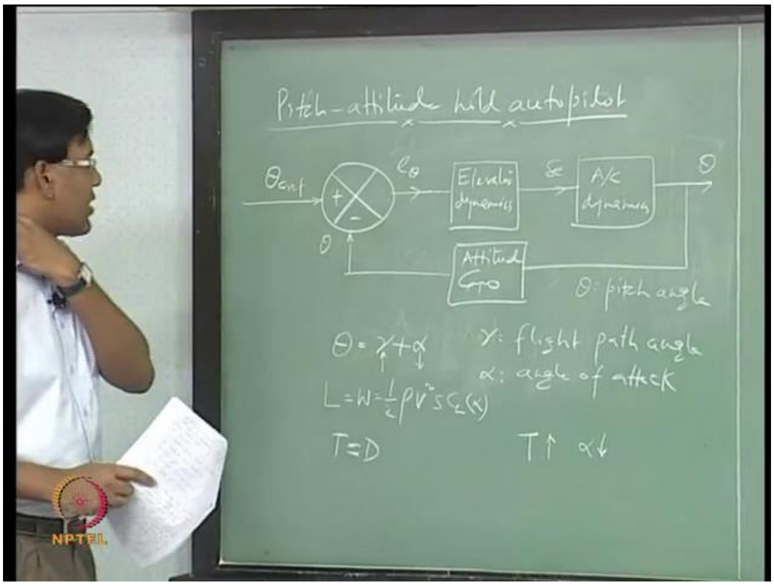

The idea actually can be represented using this schematic, which is also called block diagram. So, this is about controlling the pitch angle, theta (θ) is the pitch angle here (Refer Slide Time: 10:30). This is the reference theta (θ_{ref}) at which we want to keep the aircraft at all times, even in the presence of disturbances.

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What is happening here is, as soon as there is a change in pitch angle from this reference condition, the attitude gyro which is fixed at this condition will be reading an error in change in pitch angle and that error is going to actuate elevator in such a fashion that this theta reference minus theta is minimized.

So, this theta is being read using this attitude gyro and this is being fed here (Refer Slide Time: 12:29), it is comparing the theta with this theta reference and, if it is not 0, then there is an error which is being introduced here. This error, proportional to the error, this elevator is being deflected, that in turn, is giving theta which will try to minimize this error in pitch angle.

Pitch angle actually is: $\theta = \gamma + \alpha$. When we talk about controlling the pitch angle, we are actually not controlling the flight path angle or the angle of attack independently. Gamma here is flight path angle and alpha is angle of attack. So, let us say we are flying a level condition, actually this autopilot is engaged in a wing level condition. If we look at the equation of motion of equilibrium; lift is equal to weight. Whenever there is a change in throttle that changes the velocity, and if this change is to increase throttle somehow (resulting in corresponding increasing in speed) then the alpha goes down to balance this equilibrium (via Lift = Weight relation). And when alpha goes down, what happens is, gamma has to go ~~up~~ down. Because we are trying to maintain the pitch at the reference condition, such a thing can happen. Even when we are flying a climb flight, it may so happen that finally, if we are just using this controller autopilot, finally the aircraft may just level out. So, this is not a very popular autopilot, but it is used within another autopilot, for example, this altitude hold autopilot. And the other disadvantage of this is that if we just look at this kind of feedback mechanism it is not really controlling the dynamic response. A better pitch attitude hold autopilot will look like (Refer to sketch on screen)

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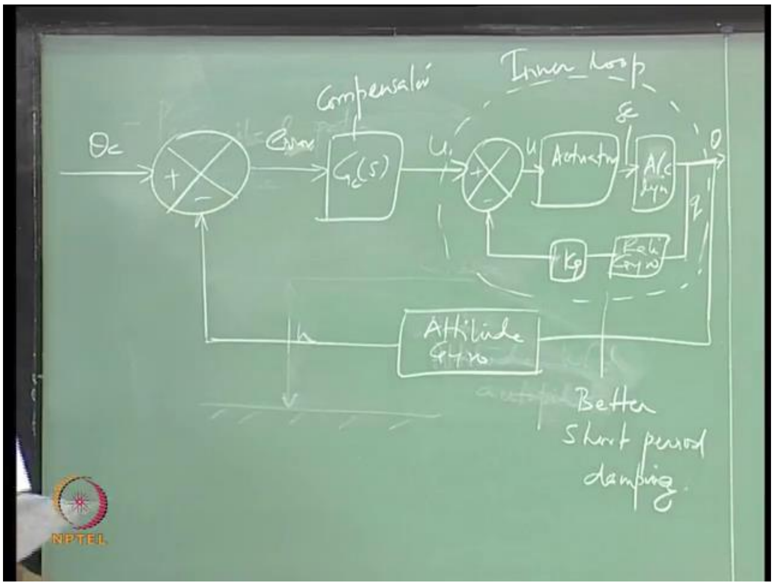

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This is a compensator. This is what we are talking about, compensator is used for augmenting the control power of the aircraft almost acting like a control augmentation system. So, there is an inner loop which tries to change the dynamic response or damping actually, in such an autopilot. This kind of arrangement not only meets the criteria of keeping the pitch angle constant, but also tries to change the dynamic response using this inner loop. This is the inner loop which is using the pitch rate feedback through this rate gyro and this results in a better short period damping.

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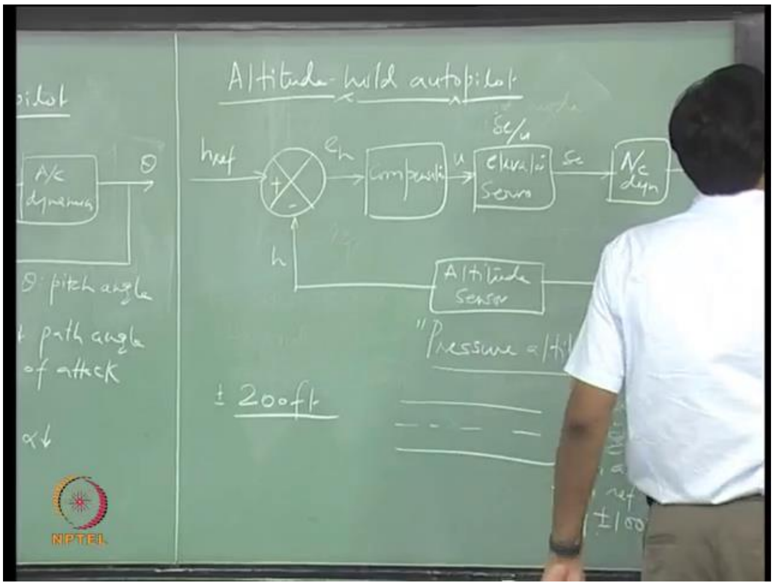

Clearly as the name suggests the main function of this autopilot - altitude hold autopilot is to maintain an altitude, a prescribed altitude, which is called h reference (h_{ref}) here. Idea is same. You have to read the actual altitude, compare it with the reference altitude and proportional to the error that is introduced in the altitude, deflect controls so that you can reduce this error. Typical elements of the altitude hold autopilot controls systems are these.

This delta e (δe) is the modified delta e (δe) which is going into the aircraft dynamic equations and thus, that is outputting this h. As soon as this h becomes h reference (h_{ref}), this control system may stop functioning. The altitude sensor is based on pressure reading, the altitude that we are measuring here is the pressure altitude.

An altitude hold autopilot actually holds aircraft within 200 feet of the h, which is reference h, reference altitude. It keeps the aircraft within this plus minus 200 feet and actually, it starts signaling, starts giving the warning signal as soon as altitude from reference changes by plus minus 100 feet. So, you can clearly see that 200 feet is actually not a small number, but typical altitude autopilot can be engaged to give this kind of performance.

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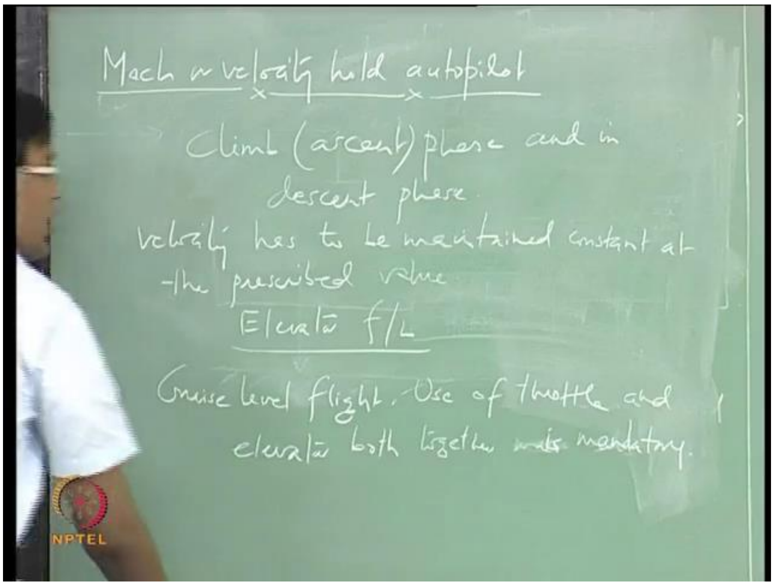

Main function of Mach or velocity hold autopilot is to keep the velocity or Mach at constant value in climb for ascent phase and in descent phase. So, velocity has to be maintained constant at the prescribed value. This again uses as an elevator feedback. So, we feed the variable which is Mach number here or the velocity to the elevator and elevator has to act appropriately to keep the velocity constant. But if we are flying a cruise level flight, in order to maintain speed in this particular flight, you also need to use throttle. So, use of throttle and elevator, both together is mandatory.

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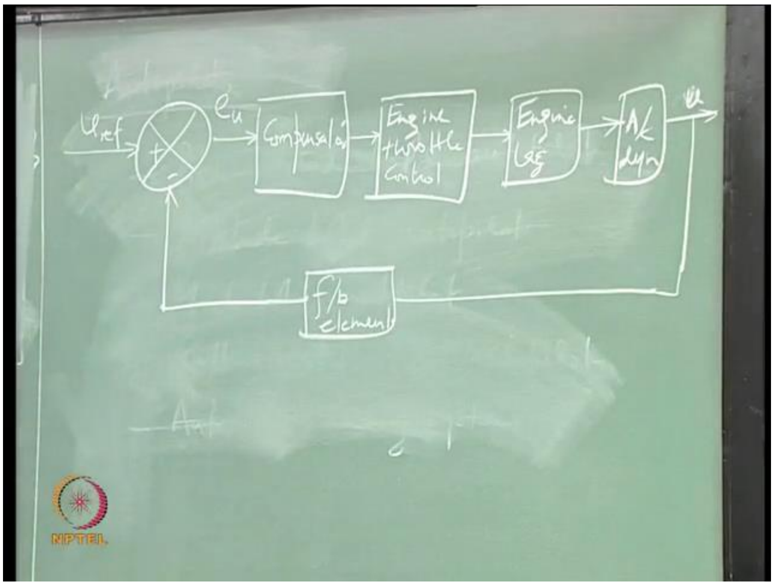

So, let us look at the block diagram of a Mach hold autopilot. It is similar to what we have drawn earlier.

You have to remember that each of these autopilots are for specific purposes. If you are trying to hold the velocity here, it can only hold velocity and it is not going to do anything else. If you want to do something else also, for example, you know controlling the dynamic response then, we can have something within the loop of this control system. The main outer loop will try to control the Mach number or the speed and the inner loop can be used to change the dynamic response.

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This one here is using throttle to keep the velocity constant. A feedback element can be, for example, a sensor which can read the actual speed. In general, basic feature of any control system using feedback will look something like this (Refer Slide Time: 28:09).

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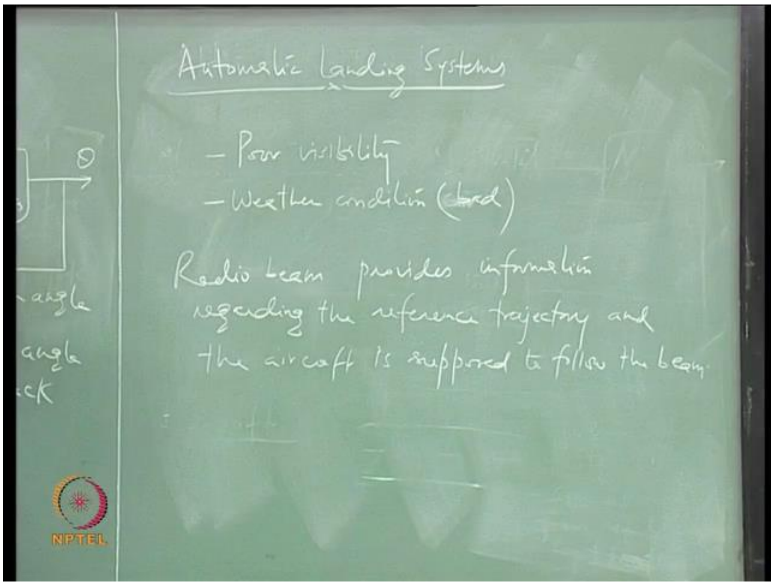

Automatic landing systems: Landing is usually a difficult maneuver because many times the visibility near the ground may be poor or the weather condition can be bad.

What may just happen is, when an aircraft is approaching the runway or it is about to go on to landing approach, it may just find itself slightly disoriented from the center line of the runway. And there could be presence of wind also which can move it laterally. So, the aircraft, if it is not having an autopilot landing system, in such a case, aircraft is guided by a beam. Beam provides, beam which is radio-beam, this beam provides information regarding the reference trajectory and the aircraft is supposed to follow the beam. So, the mechanism, this instrument, equipment which radiates this beam is right at the touchdown point.

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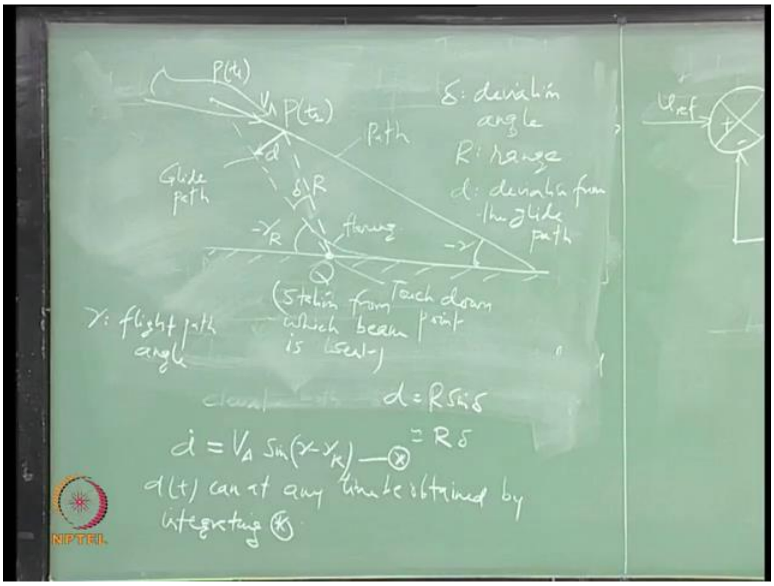

This equipment or the station from where the beam is thrown, is this. An aircraft which may be following let us say this glide path. Let us say, this aircraft is following this path; not really in a glide path and it is supposed to follow this beam. This (the dashed line) is actually the glide path and this station is at touchdown point, and after which the aircraft has to flare out and then move on the runway for some distance before it stops. This (curved path) is called flaring.

So, automatic landing system will consist of guiding the aircraft to this glide path and to flare when it is coming closer to the touchdown point, so that it can land safely. This angle is a reference flight path angle; gamma is the flight path angle. So, let us say this is the point where aircraft is at any time t_1 and afterwards after time t_2, it has moved to this point. But it is supposed to touchdown here. The amount by which it is deviating from its required glide path can be denoted by these angles.

This delta is the deviation angle, R is the distance which is called range, and this (d) is the lateral correction. So, this d is the deviation from the glide-path. An aircraft is having some velocity V_A on approach. Clearly both these angles are negative because we are trying to land the aircraft.

Glide path deviation, this (distance) d, is given by R into sin delta ($R \sin \delta$). This angle (δ) is usually small even though (in) this picture is looking big here. This angle is small so that this d (may be approximated as) is R into delta ($R\delta$). d dot ($\dot{d}$), in order to correct the glide path, this one on approach path actual, and this is what it should; this is the reference glide path and this is the actual glide path. So, correction has to be done for changing this d. So, d dot is V_A sine of (gamma – gamma R) ($\dot{d} = V_A \sin(\gamma - \gamma_R)$). $d(t)$ at any time can be obtained by integrating this equation. With this background (Refer Slide Time: 37:28), let us look at how actually an automatic landing system looks like. Here we are again looking at the autopilot for automatic landing.

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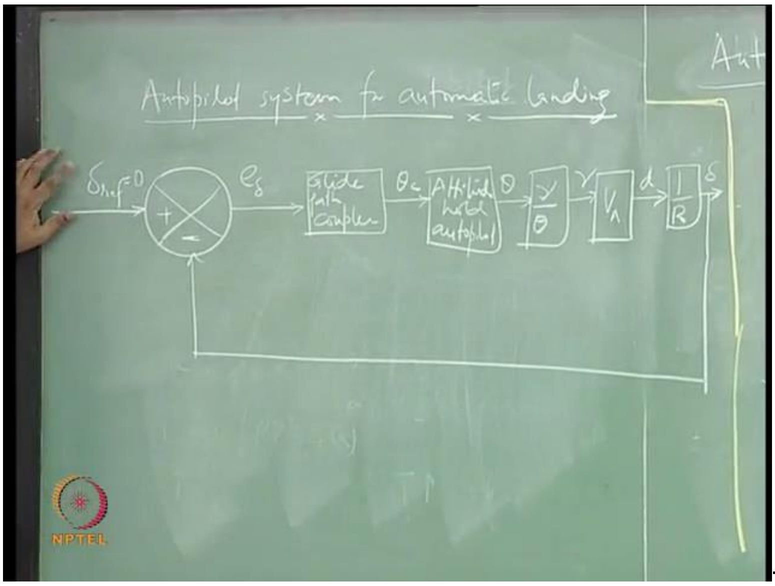

The reference variable here is the deviation angle which has to be 0. Error in delta (δ), the deviation angle is fed to what is called glide path coupler which is trying to change the attitude of the aircraft, so that it is following the glide path. And here, an altitude hold autopilot is engaged because (so that) theta can be maintained at the prescribed value. This will change the flight path angle according to this dynamics. This gives gamma (γ).

V_A into gamma ($V_A\gamma$) is actually resulting in the altitude. So if you look at the altitude, rate of change of altitude is V_A sine gamma ($V_A\gamma$). Rate of, it is also called rate of climb or rate of descent. This gives, this deviation from the glide path, which multiplied by 1 over R gives delta, actual delta ($\delta = d / R$). And this will be fed back to compare it with the reference condition.-The objective of this is to control this deviation angle.

The flare control is, having another control block in place along with it. So that, when aircraft is coming closer to this touchdown point, it has to flare out and roll out.

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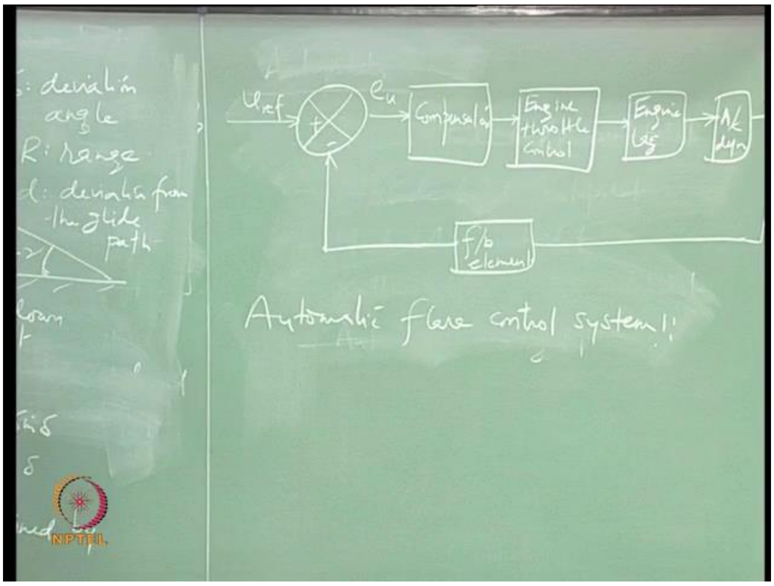

There is a separate control system which gives automatic flare. So, with this we conclude our lectures on flight dynamics.