Introduction to Helicopter Aerodynamics and Dynamics

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Today, what we will do is, we will show the actual helicopter model and the various functions of the controls.

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Now, see this is actually the engine. Engine gives the power through a centrifugal clutch; that means, only after certain rpm, the clutch will engage. Now, the reason for that is, suppose in case of engine failure, engine will disengage completely, but the rotor will not stop. Rotor will continue to rotate and then, you still can fly. That particular maneuver thing is called autorotation, because helicopter would not lose. It is not that, suddenly engine fails, the helicopter does not drop, but then the engine is disengaged. Then, from this, there is a gearing mechanism, because there is a reduction in the rpm. And, through this gear… This is the rotor shaft you can see; and then, the main rotor is rotated. But, there is no separate engine for tail rotor; please understand. Essentially, the same engine drives the tail rotor. Through this gear mechanism, you can see it has a double gear. So, when this rotates, the double gear inside also is rotating. As a result, you can say the main rotor drives the tail rotor. So, in case of failure, engine only will disengage, but both the rotors will be operating.

Now, you need to control the pitch angle of the blade from the non-rotating frame to the rotating frame. And, this is the swash plate mechanism. You can see there are control rods here – 1, 2 and this side, and here also. These control rods are attached to some of the servo actuator system, which we will show after that one by one. We have basically, four servos. One, we call it collective servo in which this particular unit will go up and down. When you make it up, the pitch angle of the blade changes, but it changes irrespective of whether the blade is here or there or any position; the angle is always the same. This is the collective.

Similarly, you can do the longitudinal. I call it longitudinal cyclic, which means this is the tilting of the swash plate about an axis this side perpendicular to that; (Refer Slide Time: 03:38) and, it tilts in the longitudinal plain. But, when it tilts, if you see that, as I vary the azimuth of the blade, the pitch angle of the blade will change once in a revolution. Similarly, bring it to neutral; you have the lateral. And then, the forth control is basically to the tail rotor; he will change the pitch angle. So, the tail rotor pitch angle will change if he moves the pedal. So, you now know there are four control angles: three for main rotor; one for the tail rotor in the conventional helicopter system. Conventional means single rotor single tail. But, there are some interesting points – here is – let us look at the main rotor blade. Main rotor blade – you see it is attached now here through a bolt.

Now, I want to you to think what kind of a rotor system is this, because this is held. So, I cannot do, because this is not that; this is attached to that blade. It is not a seesaw configuration. This blade is independent of that blade even in flopping motion; there is no hinge here (Refer Slide Time: 05:27). This is independent; that is independent. But, in the lead lag because it is little tight, it cannot move, but sometime it can go. And, the pitch bearing is right here. So, by moving the lever… I will say this lever – you basically move up and down; as a result, the pitch angle. You move the collective; you see the lever moves – see here. So, the pitch angle changes, but you see the blade is here, but the control rod is here. The location of the control rod is not straight below the blade. That is essential, because later you will see the importance of this. The control rod is at – possibly, in this case, it is 90 degrees; that means, when I tilt the swash plate like this, pitch angle here is changing; not when the blade comes in this location. That is why that is called the control rigging. You will learn when we study the dynamics; then, you will say what is that control rigging, which we are talking about. So, the control rod location – because of the physical geometrical, because there is also certain mathematical thing – how the system responds because of the control input. That is very important for flying of the vehicle from the pilot's point of view.

And, in this system, (Refer Slide Time: 07:20) this is – actually, you can say pretty much like a real big helicopter. That is why I thought I will bring you here and show you. Almost from the functionality point of view, this helicopter behaves like a real big helicopter in terms of all the controls, but now you see – engine throttle is here. That is also controlled by a servo. But, the difference between radio control models and the actual helicopter is here. In the radio unit, you may have some lever, which you move; throttle will increase. But, in the actual helicopter, rotor rpm is fixed; it does not vary too much; pilot has no control; he has little control, but for all practical purposes, we say the rotor rpm is a fixed quantity. Here what we did was we actually designed a closed loop such that we maintain the rotor rpm to a fixed value. That fixed value you can vary. Actually, we designed the closed loop controlled system. So, this is the sensor. It is a magnetic pick up. There is a magnetic caller here. That will keep rotating. There are tiny magnets. When it crosses, a pulse comes; then, we calculate what the rotor rpm is; and, from the reference rpm to the actual rpm, then we give a feedback control.

And now, if you have any questions, I will leave you to ask me, so that I will explain one by one what is being done here in the helicopter system (Refer Slide Time: 09:18). But, the first thing will come is what is this? This is there only for two-bladed helicopters. It is called the bell stabilizer bar. It is called the stabilizer bar mechanism. What is the use of this mechanism? This also looks like – there is a small aerofile type of a surface and attached to a long rod. And, when this rotates, that is also rotating. And, if I move this up or down, see the pitch angle of the blade is also changing; that means, the dynamic response of this (Refer Slide Time: 10:08) influence the pitch. But, I can give pitch through this also – from the swash plate; please understand.

Now, you see – you get pitch input to the blade from two sources: one is from the swash plate, which pilot gives; another one from the response of this. Now, (Refer Slide Time: 10:32) this is a stabilizer bar; they call it bell stabilizer bar mechanism. It is always hinged at the center. You see – here it is like – if I move this, if I bring it down, the other one goes up. This is teetering; whereas, this is not teetering; please understand. This particular mechanism up is actually used for control purposes; it aids; suppose if there is a disturbance because of wind – because later, when you study aerodynamic, then you… Disturbance means what? Either the wind is stationary; the helicopter moves. So, the relative wind. The moment there is the relative wind, the lift is going to change. When the lift changes, this will change its orientation, because one side will get more; other side will get less. As a result, this will tilt (Refer Slide Time: 11:29) in a way that it will reduce the disturbance to the main rotor. So, this is essentially a passive control mechanism, which is already built into the system. It improves. You may ask that if I remove it, can I not fly? You can, but it will be more difficult to fly. It aids in little bit of control; this is there only for two-blader rotor system; not for three, four; nothing. So, please note that this is little bit different from conventional – rest of the helicopter systems.

And then, we have put… These are all our electrical thing, which comes from that place and then we drive the servo that the electrical pulse we generate from our computer or data acquisition system; and then, it is like both uplink, downlink; both are there. And, this is a gyroscope (Refer Slide Time: 12:42) – single axis gyroscope. That is meant for measuring the yaw rate. It is highly sensitive to any disturbance, because even if some side wind, it will start moving. And, it is difficult to control the helicopter; whereas, this aids – you immediately sense what is the yaw rate that gives a feedback; through some feedback mechanism, an input to the tail. And, there are much more intricate things here; in the sense, we have – this is one servo; this is a servo; this is a servo; tail rotor servo is this, which is slightly our different characteristics, because servo means you want to activate some motion. How fast you can activate? That is very important, because you give an input. Suppose it moves very slowly, then that is not good; but, if it moves very fast also, you will find it difficult to control. So, there are certain things where you need to know what rate you must give the input; how the vehicle will respond.

Everything plays an important role in the selection of each one of the subsystem. That is very essential. That is why in all these things, one can learn lot of practical things in how you select a servo. And, all these control lever length – by changing it, you will pitch angle also. So, the control rod length is very important, because if you elongate one of the rods, you will find that the base angle itself is changed. But, those things are not done. Initially, there is something called… When the blades are attached, you want to make sure that the pitch angle of both the blades are identical in the neutral position, because you do not know. One blade may have a slide at a different angle of the track. So, they do something called the tracking and balancing; you may call it tuning, because there are two things. Any system, which is… because this is lifting surface; it has a mass and mass distribution. We say that both blades must be identical, but it is very difficult to have identical value. So, there can be a slight change in the mass, because you can never make.

Now, the tolerance – how much you give is a question. So, what they will do is, they will put it; they will rotate it. One is you measure the mass; physically, you can measure it. Then, you say some few 100 grams difference; then, you have to add that. So, they usually have some boxes here; not in this model, but usually they will have some boxes in the blade. What they will do? They will go and add weight; they open the box; put the weight inside – some 200 grams, 300 grams – some small pallets kind of a thing. They put it and lock it; that means, you make the blade almost equal mass distribution. See mass, center of mass and then mass moment of inertia – all must be equal; then only, it is dynamically equal. Then, the next question comes – aerodynamically are they identical? So, that is also equally important.

There are two controls. There will be one trailing edge tab in the rotor blade. Trailing edge – here (Refer Slide Time: 16:54) not the full thing; some more here and through pitch control mechanism. So, they can adjust here of a blade. Suppose during rotation, if one blade is going up, means they will actually look at the – track the blade; please understand – track – if the blade is going up; that means, it is at higher pitch angle. So, they mark the blades; some color code. So, you know which is going up; which is down. Then, they adjust it. Once it comes to some level, then they use the tab. That aerodynamic tab – here it is not there; not in this; you can change it. It is like slightly changing the camber of the blade. But, it is set locked; that is it. But, you can never make the rotor blade track in one plane; please understand. That is the practical difficulty.

Theoretically, we assume that yes, all are identical; everything is going around beautiful. But, then they give a tolerance; maybe 1 inch. Something like that; if it goes up and down, it is OK. These are real life problems. But, when we treat mathematically, we assume that all the blades are identical; all the blades have the same characteristic. So, we say it is a rotor plane of rotation. When I say, this is the plane of rotation – you may say. This is the rotor disk plane (Refer Slide Time: 18:27). But, when it flaps up, the blade will go like this; during operation, it may go. Then, you would draw that; that is again the tip path plane. Now, you understand – you draw a plane; all the blades are going. That is the tip path plane. Now, you change the tip path plane by changing this. That is what we do. If you change that, you move longitudinal; give only longitudinal. See if you give longitudinal, now, the pitch angle is changed. You see – when I rotate it – I think I will keep this, you will find the pitch angle will change once in a revolution. So, the lift folds at some region is more than the lift in some other region. As a result, because of that, increase the lift, decrease the lift; the blade has to go up and down. But, this is dynamics.

Now, you see this is like (Refer Slide Time: 19:39) you have learnt the basic vibration – spring mass damper system with external loading. External loading is actually aerodynamics. Damping also may come from aerodynamics; please understand. Now, you solve that simple equation and you see how the blade will respond to a given variation in the pitch. That is a dynamic equation. That is what you call it flap dynamics. So, now, you know flap dynamics of the rotor blade is very important for you to fly, because that is the one which tilts the rotor plane of rotation – you may call it – like this; like this; you can turn it any way. Now, there are several planes – please understand – defined, because you need to have reference coordinate system. One is – you say hub plane. Hub plane is – this is the hub; that is it. Even if the helicopter tilts, the hub plane is like this, (Refer Slide Time: 21:01) because it is perpendicular to the shaft. Then, you can have tip path plane, which is the blade response thing. Then, you can have one more plane, which is like swash plate plane; that is, you can call it control plane, because control plane may move like this. So, I am referring everything to that plane.

And later, we will say there is some no feathering plane; couple of thing. Then, you see what will be the reference plane, because each reference plane has certain advantages, but usually, for clarity, most of the formulations use one reference plane, which is the hub plane even though it is complicated, because it becomes easy. So, we always use hub plane. So, I am saying later, as we go along the course, you will see that what will be the reference axis system, because this is a rotating axis. Please understand – it is rotating and the helicopter is flying; then, what happens? Helicopter can do this; that is a rigid body like aircraft. Whatever you study – aircraft flight mechanics, you study pitch, role, yaw and maneuver – any of these motions; that is, as far as the fuselage is concerned. But, the blade – that is also rotating; that means, when you do all these things, the blade axis of rotation keeps changing. And then, the blade in addition, this does – flapping, pitch angle – everything is changing. So, what reference plane I use for a systematic formulation; otherwise, it becomes you will lose track. That is why when you develop the equation of motion, which we will start next week, you will define very clearly – this is my axis system; so, basic dynamics. So, they are just kinematics and kinetics. This is my axis system; (Refer Slide Time: 23:24) and then, this is the rotating axis system; I define my motion of the blade in that system. So, we will develop it in a very systematic way of describing the motion of the blade, because pitch angle is in the rotating frame; please understand. Flap is in the rotating frame.

Now, the question is – are you solving the dynamics in the rotating frame or you are outside? When the rotor is rotating, you do not see any blade. You will only see a disk spinning. So, you see there is a difference between a person who is sitting on this; he is going with the blade; that means, he sees that blade. He does not bother about the rest of the blades – how this blade behaves; that is one. That person sits in the rotating coordinate system. Somebody is sitting outside; that is a pilot. Pilot is not in the rotating frame; he is in the fixed frame. Now, what he will see? He will see only disk spinning. So, for him, how the disk moves; he does not care what blade does, but there is a relationship between the disk motion and the blade motion. These are all through certain transformations people do. So, you will find all these complexities, because I am just introducing because we are here in the analysis of helicopter dynamics. Then, you will have certain special type of equations themselves, which you do not normally come across in aircraft, some periodic coefficients, because the time varying coefficient equations. So, you will find classes of problems are different and then you need to have to technique to solve those classes of problems. So, we will develop one by one and then we will say you will understand; if you have any doubt, then you can come here; you see how the system is; and then, how the response will look like; maybe we will rotate sometime; input/output – like that you will see. What we derive in the class; then, you will come and see. This is what is really happening in the actual helicopter.

This is as was as the rotor and the tail rotor. You see we have a small horizontal plate kind of a thing; it is a horizontal surface like in your aircraft like a tail, tail surface. Then, you see there is another one, which is a like a vertical tail. Why do we have? Because you say the rotor is there; this is there; is it necessary to have this? There can be several reasons; I am just indicating. Disk maybe to protect; suppose if it comes and hits the ground or anything, you do not want the blade to get damaged. That is why it is projected down; plus in forward flight, this can get a side force. It can relieve the load required on the tail rotor. And, similarly, it can give a lift; that means, for pitch moment control, you may require. But, these are all fixed surfaces; you cannot vary them.

Now, I will give you something. If you look at this; since I have told you, you look at different configurations of just one main rotor; one tail rotor. If it is a small helicopter, you may find it may not be there; it may be only on one side. And, you see as the weight is increasing, you will start seeing these things will be there; (Refer Slide Time: 27:37) or, you will find that when ALH, you will have side plate also – end plate. So, you will start seeing certainly some control surface type thing attached. That is because if you do not have that, you may not be able to fly the helicopter; trim the helicopter. We will learn what trim is; you cannot reach some speed, because if you do not have this surface, moment balance cannot be obtained at some speed. And, if you want to have, then you better put that and that is kept at a fixed angle.

And, another thing I would like to say – you see the tail rotor is outside this (Refer Slide Time: 28:19). It is not within this; it is kept away, because the rotor downwash at least in hover. This is a model; it does not; it should not be affecting the tail performance. Suppose if I put it here, you really do not know what kind of a flow situation the tail rotor is operating on. Even now, it is difficult in the real life situation. If you look at the literature, you will find a very few literally on tail rotors, because everything is companies' experience. They will use that and then whatever they get, they put it, because the study involved is more complex; because if the main rotor flies forward; if the wave comes and hits, you really do not know what kind of a flow condition it is in.

Now, you see the flow also, because this flow can come and then hit the fuselage. And, when you fly forward, there is a dragger on the helicopter; I can put a shroud around that nicely, because here we opened it up; you can put a nice aerodynamic shape. That is what most of the helicopter fuselages have a nice shape, but that is for aerodynamic shaping purely. But, the rotor is exposed, because that you cannot do much about it. And, they give lot of drag force. As you fly at high speed, the drag from fuselage when we say, even though we may add the hub as a part of the fuselage; but, that is projecting out and it will have lot of drag force. And, these are all the restricting factors, because it is not that I can fly any speed, because drag will increase. As a result, when you see the power, which the engine supplies may not be sufficient; and then, the rotor blade – no various other effects; undesirable effects will start coming up. Any other questions? Feel free to ask anything.

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This is the outer sleeve, which you see here; and, the inner one – this is this. So, it comes and sits inside. You see the slot. When this one is rotating, it is a very thin support you see. So, it will try to open up. This is like a spring technically. And, when this opens up, we have a surface here. That is a special type of surface; not a metal, but we have to put a… Basically, this is an interesting story. We need to get this material, which rarely gives a good friction. And then, this will engage the outer sleeve. Once it engages, that will rotate. The moment this is attached to the engine – please understand – this is attached to the engine; the moment engine fails, what will happen? This will come inside, but this will continue to spin, because there would not (( )) This will continue to rotate. So, engine is disengaged from the rotor, because that is important; otherwise, if it is not engaged, engine stops; rotor will stop. We do not want the rotor to stop. If the rotor stops, that is all; then, it is like a stone. That is why always in helicopter engines, it will immediately disengage.

Now, there is a question of what is the rpm of the rotor? How do you decide the rpm of the rotor? Because that is the one of the important parameter in flying even though it may be a fixed number. So, the deciding factor – what are the undesirable effects of aerodynamics? Let us look at it one by one. One is the tip speed, because when it rotates, tip is the one which is having the maximum speed; maximum velocity; you may call it maximum speed. Now, if the tip speed is in the… As you increase the tip speed, you are actually going from subsonic incompressible to subsonic compressible to transonic. What will happen? As you keep going, you look at the drag on the blade. What will happen? Drag will start; after some mark number, drag will increase. That is called drag divergence mark number of an aerofile.

Now, if the drag increases, what is the effect? The drag on the blade is increasing. Therefore, you have to give a higher power from the engine. Now, this is in hover; you look at it; hover condition. Now, you fly forward; the rpm is fixed. In the advancing side, which I was mentioning, the relative velocity is actually higher; that means, when the tip, the relative velocity is higher; that means, you will definitely go into the transonic zone. So, you will have increased track. So, they will look at the drag divergence, mark number as (( )); does not mean you will not cross; you will cross. That is one. Usually, this is a primary number; tip speed – please note that tip speed of a helicopter main rotor, even tail rotor – that will be almost same. It is around 210, 200 meter per second, which is about 0.6 mark and less than 0.6 in the C level. And, you take any helicopter – now, you look at the James Alward various; look at the rotor blade radius; look at the rpm. So, rpm is only a parameter; even the rotor radius is important, because if the blade radius is increased, you basically reduce the rpm. Then, you may ask I can reduce the rpm low; blade can be longer; but, then the drag on the blade will also go on, because you are increasing. That you will study. What is that? There are certain rotor radius; how do you decide the rotor radius? This is another question. When we derive in the class, I will tell you. So, once you say this is the rotor radius, then I know what should be the tip speed. This is how they make. Tip speed is around 200 plus – 200, 210, 217; they do not go near 300. Then, you are actually entering into supersonic. So, that is why I said there is no supersonic thing; maybe at some point, it can go on the top surface; you may have some sonic. But, not that blades are designed not for the supersonic thing.

Now, the twist – whether rotor blades are twisted; here it is not a twisted blade; (Refer Slide Time: 37:04) it is a constant cross section going. In the propeller blade, you will find – it is not straight; you will find a large twist – in the sense, the tip is at lower angle of attack than the root. It goes like this (Refer Slide Time: 37:23). Here also, some of the blades – nowadays, everybody makes; there is a twist. That is called the pre-twist. Why do you give pre-twist? That is because you will get the inflow; inflow means the flow normal to the rotor disk; but, then when we actually derive in the class later, we use normal to the hub plane. And then, we will to the blade from there. That is the flow, which comes like this. This is the plane and the flow coming. And, you want that flow to be uniform everywhere. Everywhere means right from root to tip; how do you get that and why do you want to get a uniform inflow? Mathematically, you can show – if it is a uniform inflow, the induced power required is minimum. So, mathematically, you can show – if it is uniform, I will get minimum induced power. I used a new word – induced power; when we do next week, you will know what that induced power means. Mathematically, you have shown – if it is uniform, you get it. How do you get it uniform? That is the next question in reality; that is to do twist. Through twist, you get uniform. But, it is only near; you can never get like this. That is a variation. That is why the blades are twisted to get a uniform inflow; reasonably, uniform. When you do actual calculation, then you will see you can get only up to this; then, you will say all right this is enough.

How does the stabilizing mechanism work? How does it work means you will say this is a spin aerofile, very thin surface. When it moves, you get a lift; see one side goes up means another side goes down. But, when it goes up and down, what happens? which angel it is changing? That means the dynamics of this affects the pitch angle of the blade. But, what affects the dynamics of the stabilizer bar? You are not going to shake it; please understand – if I start rotating it, immediately this will become… (Refer Slide Time: 40:13) because the centrifugal force will pull this way; that side will pull; it will become perfect. To this particular shaft, it will be always normal to the shaft.

Now, suppose there is a disturbance, wind is blowing, one side aerodynamic load will go up; other side will decrease; that means, what? This will respond to the disturbance. It will respond, because when the wind blows, even they get affected; please understand. As a result, the helicopter will start moving. Helicopter is an unstable vehicle, because that only when you prove it, solve everything, then only, you will know helicopter is an unstable like a bicycle. But, bicycle – actually dynamically, you can make it stable. But, here you have to keep an eye. See there also you are doing; you are actually adjusting it. Keep on changing the front wheel without your knowledge. Here the pilot has to keep on adjusting; otherwise, you will not be able to fly. It is statically unstable, dynamically unstable, because there the control he gets essentially from the gyroscopic.

Suppose you lock the front wheel and ride the bicycle. If you have done it – no, I had done it, you usually, immediately, fall down; that is all; you have no control. So, you have to be always sitting there to control. And, that is where the pilot becomes very important; his work load is always there; he has to fly. To relieve his work load, this is added (Refer Slide Time: 42:05) such that if there is a disturbance, this will respond. This response will affect the pitch such a way whatever is unstable will come back, but it not that it will completely make it stable. It improves a little bit; that is all, because the dynamics relating this to that is more complex, because you have to have; the pitch angel – you have to understand how various pitch is really the mechanism; how it is implemented. Then, you have to convert it into mathematical formulation and then you have to solve the full stability problem. So, you will find here variety of problems like what you have in aircraft also. One is trim. Trim means I want to fly at this particular condition either hover; now, what should be the control input I should give; that is a trim. Then, you have to fly at some 100 meters; not 100 meters; maybe 100 noughts or 150 noughts. You take it; you have to fly.

What should be the control input you should give such that the helicopter will fly at that speed hover? Then, you say you want control; you want to maneuver. So, how much the pilot command should give such that the helicopter will behave the way you want it to behave? That is very important; that is the control part. In addition, you will have vibration problems; all the other problems you will have. So, helicopter vibration becomes a very important thing. And, noise – whenever it flies, it makes hell of noise; jet aircraft makes also noise; but, that goes very high; whereas, the helicopters do not go at that height. So, you find the noise. Noise is one area still lot of processes being done. I do not think it is fully understood and then we have solved every problem and thinks like that; vibration problem is also not solved, because of some various complexities. Then, you want you see the controller how it is implemented there. You can go there and then you can show how we are sending signal from the computer to this, (Refer Slide Time: 44:29) so that this is going to fly autonomous. In the sense, there is no pilot; pilot is not there to control. But, instead of pilot, the computer is there to control.

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That is the data acquisition system.

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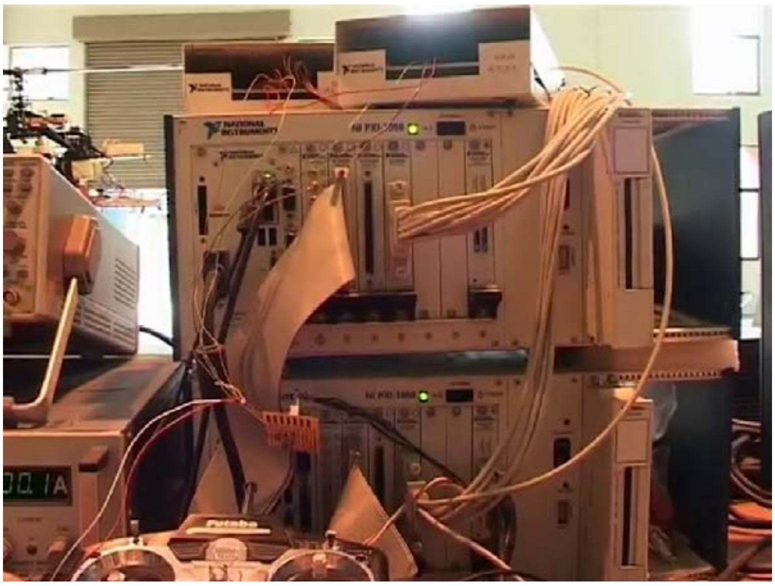

This is the national instruments – data acquisition system; as well as, we generate the controls from here – the electrical pulses. And, they are of some particular type; it is called pulse width modulation (PWM) signal. And, the signal goes through some circuit here; goes to the helicopter through wires and we can make it wireless (Refer Slide Time: 45:07). We have done some of them wireless through the wireless unit.

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Now, for ease of operation, he has created through virtual instrumentation, this type of a display. This is actually you write the display. Now, you see this particular unit – there is a small dial, which shows – there is a red needle and a blue needle. Blue needle tells what the reference rpm is; this is 900 set point; that means, set rpm is 900. So, it will be at blue. If it changes to 1000, that will go to 1000. Now, once the engine is started, the magnetic pulse – that is measured; that signal comes. So, we basically get two pulses or four/five pulses. Get the time duration for that pulse; calculate what is the rpm. And, that is denoted by this red. And, you will see once the engine is on, the red will start shaking as you increase the throttle of the engine; that means, you increase more power; so, the rotor rpm picks up. Then, this needle will start going. And, this is a close look (Refer Slide Time: 46:33). We actually show the display also; what is the engine actually. This is shown in dial; here it is a time signal.

How actually the rpm is varying with time? Actual signal we take it; we display here (Refer Slide Time: 46:51). Then, he has another one – auto working and manual working. Manual means manually if he moves this dial here, that is, he is changing throttle manual. So, he will move through the cursor he will go; or else, he will give the input here number wise. Then, it will automatically changes; see this will go either through entry or through mouse. But, once he goes and clicks auto mode, immediately, the closed loop control system takes over. And then, you will find this will go to that; and automatically, the auto mode – you will see the signal will keep changing; throttle will go to a particular value, where the set rpm and the actual rpm should be identical; but, you will find; then only, this is what the practical things.

If you get it plus minus some number; within that one, it is great. So, mathematically, you can always simulate in the computer nice curve. But, in reality, it will not, because this is actual vibrating environment of the signal comes. What fine tune you can give in pitch angle are the servo control angle; how much you can give; whether you can control 0.01 degree or 001? See if you see that kind of fine control; you cannot do it. If you give 0.3 degree in a rotor blade pitch angle, that is good; that means, 0.3, 0.1. Suppose if it demands, give it 0.01 degree, you cannot even measure number one with online. Then, you find the limitations of various censor mechanism, actuator mechanism and the mechanical system; then, you will say this is all you can achieve. And, if you achieve the best possible within that, then you say my system is wonderful. And, this is the reality. Reality is much complicated – I am telling you – even for a simple problem, rpm regulations. It is a tough thing. But, we have achieved the rpm regulation with our… Now, it is wonderful.

Then, this is only for that display (Refer Slide Time: 49:21). And, we also monitor when here he has created a little bit more – too many information, you will see collective role pitch yaw; that means, this are the four inputs. Here it is – what is it? Role pitch yaw angle. And, these are the inputs that go to that servo actuator. And, he can again auto or manual; and, he can manually change one by one if he wants, because the reason we have incorporated this is we wanted to study first open looped (Refer Slide Time: 50:09). Open looped means if I give this much, how the vehicle will be (( )) That is the basic characteristic of the vehicle. So, we said do it. After that, once we are confident, everything is wonderful, then we say auto; that means, it will automatically take over the flight. And, we have done that; that was the latest – just about couple of months. We achieved the flight pitch role yaw control and you will find the helicopter quite stable in that. But, translation we did not control. That will come later. That we are working on.

Now, here you will have lot of numbers – are displayed. These numbers basically corresponds to the (( )) in the close loop system (Refer Slide Time: 50:58). So, that is not important for you right now. So, this is how; but, this is entire unit and the data is constantly downloaded. So, that gets saved here in the system. So, after the experiment is over, we can go analyze how the vehicle is moving even though we keep and the rpm is also recorded. You will know whether the rpm is kept constant or whether it is fluctuating; what is happening. So, it is like monitoring the condition of the helicopter. That is the… And, this is through virtual instrumentation. So, it is like, actually, you will find this is like an instrument with all the dial. But, even create everything. It is very versatile and we can use it. But, there are limitations; it is not that it will do everything. There are limitations how much you can display, because if you put too many things, you yourself may not know what you want. Up to some information, you can display some; you have to save it. So, as we progress in the experiment, we know what to display, what to put back at the background, etcetera.

You have any questions on this? But, you have to know the cost; nobody has the cost of the helicopter. Cost of the helicopter is more than 2 lakhs – one helicopter. And, we…

Developed here or (( )) (Refer Slide Time: 52:37)

No.

(Refer Slide Time: 52:51)

Now, you are asking a different question. See very simple question I showed the gear. The gear fails in 10 runs, because you see the gear here; you can see here there is a gear; that gear is going; the drive shaft is going through that – the tail drive shaft. And, there is a coupler inside. That coupler basically transmits the power from here to the drive shaft; and, the coupler fails. So, when you are running, suddenly, tails stopped; you do not know what happened. Then, you go keep looking at it there; but, this you have to open it up. Then, you open; the coupler was gone. Then, you have to make the coupler also. So, the coupler was made; that means, you have to make the same drying, analysis, material selection – everything goes. So, this gear is our gear (Refer Slide Time: 53:41).

Then, there is a liner. In the centrifugal clutch, I said there is some material; there is a liner material. That went into quite a bit, because we did not know when are running an experiment, suddenly, what was working beautifully. One day, the rpm – we have good control of rpm. Suddenly, the rpm started going up and down. We have no clue why it is changing. Everything we taught that maybe fuel is… See how fuel is getting choked. So, look at that; clean the engine; put everything; you do nothing. Suddenly, one day, we keep looking at it. When you go in the evening, when you jog, when you do anything, you keep… That is in your mind always; please remember. Then, suddenly, either way open this. When we opened it, the liner was gone. The liner was actually wear and tear; and, getting the liner material.

Finally, now, we have everything. See the problems we faced and then the solutions. Sometimes you do not know why certain things are happening. That thing is challenging in one hand when you get the solution. If you do not have a solution, it is still a nightmare. But, once you get it, you will say this is so trivial. And, the trivial things are the ones, which make; that is where the experience is. So, we said that these are the critical issues, which nobody will tell you. You go through all the problems; and, if you make, then people will come to you. If you fly, then that means these are achieved; that means, they must have gone through problems.

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If somebody says see six component load cell; this one. Six component means it can give me thrust, which is the lift, side force, forward force; all up this way, that way, and then, three movements. It will give me all the loads. So, when I rotate the rotor, I will give different pitch input, but I have a calibrated thing, because I have calibrated; he gives an electrical signal; electrical signal to pitch angle; we have a curve – calibrated curve. And, we know what pitch angle will give; then, immediately, the load – if you increase, we increase the load. And, with load cell, we collect the data. And then, we will know how the data is. What is the variation of pitch with respect to steady state value? We can get transient also. We have a transient.

And now, I can give different cyclic inputs and I can measure how much forward force I am generating, how much pitch movement I generate. Essentially, I can get controlled derivatives in hover in the testing. We did some measurements; preliminary measurements we have done. They were quite successful. But, now, we want to improve some more tests. And, there are some problems, which we will address one by one and then see this. This is basically (Refer Slide Time: 57:13) load measurements on the… And, when we do the load measurement, the interesting thing is… I do not want the fuel tank to be part of the helicopter, because if I put the fuel tank as a part, as the fuel goes out, what will happen? CG is shifting. When the CG shifts, I will get a different movement on the load cell. So, what we did was…

[Not audible] (Refer Slide Time: 57:35)

That will be there. But, I want to see the characteristic of the rotor. See I want to know what the capability of rotor is. So, I kept the fuel tank outside. And then, I disconnected the tail rotor, because the tail rotor will give a force; I said I want to isolate. Now, you see I am only measuring the main rotor force and I can have a theoretical formulation. Then, match both; check how good we are; how bad we are in terms of theory experiment. Then, I can put the tail rotor later and I will see how much I generate the side force as well as the yaw. So, this can… One M.tech. student has completed the thesis. And now, we need to do some more work. This work will go on for a long time, because the actual load measurements is still… We cannot get anywhere in the outside. If we have our data, then it is very valuable data; highly valuable. Everybody will say they will immediately accept the publication also, because practical things always have value. So, this load test and the load cell – again, cost wise, because why we made this (( )) This looks (( )) because I want to keep the helicopter at different heights if I want to do. So, I can remove every stage; remove it. And then, I can bring down the helicopter and then keep the test in that; that means, the ground effect; effect of ground – I can study.

This is a very expensive load cell (Refer Slide Time: 59:23). It is 17 lakhs. And then, those computers are all… Both of them… That is more than 27 lakhs. So, now, you know that investment, that are gone on in this lab. It is substantial investment, because in terms of equipments, because… Otherwise, without this, you cannot do anything. Now, we can do any measurement, anything, any study. I have interest that you change the tip shape. What is the performance of the blade? Change the tip; that means you manufacture; we manufacture blades. You change; give different tip shapes; study the effect. But, these are all not available anywhere. But, these all are futuristic one can do. There is no end to the kind of very advanced research one can do; but, one has to struggle.