Introduction to Helicopter Aerodynamics and Dynamics

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Lecture No. # 01

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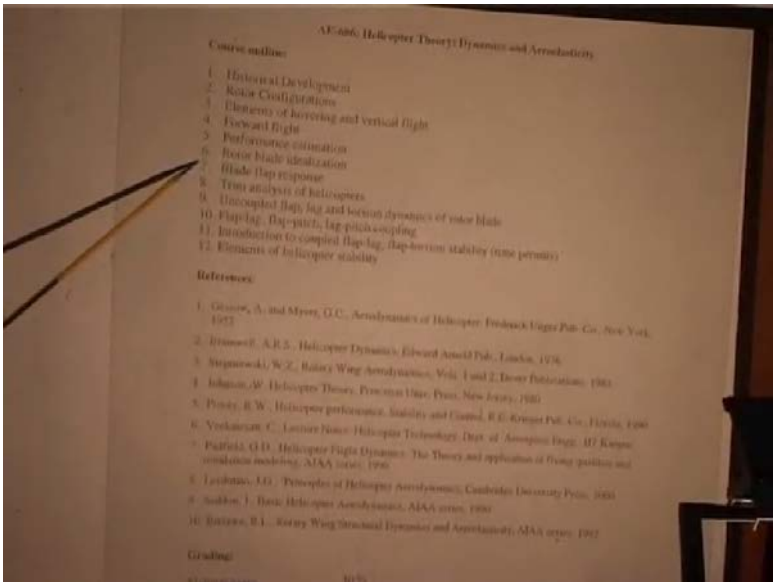

See, this is the course outline, tenderly, I have listed out 12 topics starting from historical development, then rotor configuration, elements of hovering and forward flight, sorry, vertical flight, then forward flight, performance, rotor blade idealization, flap response, trim and coupled flap lag torsion dynamics and then, introduction to certain stability problems. So, these are vast number of topics are covered, but we will go slowly because it is a very ambitious thing to cover everything.

But towards the end, if time permits, I will just give a brief introduction about some of the issues, which one has to tackle because unless you understand this basic stuff, you cannot directly go on, then solve that. You can address those problems; they are from map, practical point of view, what are the real issues, that is why the topic is given as helicopter theory dynamics and aeroelasticity. Please note that dynamics is very, very important for this course, that is rigid body dynamics I am talking about, later comes

flexibility, structural dynamics, that is important, but at this level, rigid body dynamics is essential. So, you can brush up of a rotating system that is essential.

And I have given the list of references, about listed 10 books, I will go through one by one. The 1st book is Gessow and Myers, aerodynamics of helicopter, which is a 1952, but it is available one copy in the library and it is out of print, but it is a good book; basically, very, very, in the, for a beginner it is good to read that.

The 2nd book is Bramwell, which is a 1976, it was published in London. Of course, another copy has come, but it is no more it is difficult to follow that book, but it has lot of information, lot of information, but difficult. Here, in the beginning it is ok, towards the end, you sometime, you will not know how those things are obtained, how the various expressions are obtained. Then, there is a Stepniewski, rotary wing aerodynamics, this is a Dover publication. This also has a lot of information, but it is difficult to read that book.

Then, Wien Johnson, this is about 1000 pages, they are also helicopter theory; this is a good book. See, all these books, later I would say, if you know helicopters, you can understand the book, you cannot say, that I will start reading the book and then understand. That is where the problem starts because the dynamics is really important. Of course, I have my lecture notes copies, which are there in the library, I do not know how many copies are there, there is sufficient number and there I have given all my derivation, starting from first principles, starting from basics. And please note, in this course I cannot derive the equations in the class because if I derive, then I will spend enormous time only in deriving and then, at the end, what I require is the result, but the most of the time is spent on just algebra.

So, I will be using power point, but the in between steps you have to read, understand, how they are obtained and Padfield, this is a, Prouty is about performance mainly and then Padfield is about flight dynamics. So, you will find, that the focus of each book is slightly different; you will find certain book will refer some topics, but some other book you would not see that.

And you will get to know only at the end of the course, oh, this is what I have mentioned in the first lecture, what I have told you. Then, Leishman, this is about helicopter

aerodynamics and then Seddon, this is, I do not have that book, but it is a basic helicopter. Then Bielawa, which is structural, this is from an industry, but slightly different.

So, you will find, that I follow my notes, but I have all these books, all the books I have pretty much, except this (( )) because I find it is a little low level, so I did not buy. These are kind of books, which you require for a helicopter theory. There is other class of books, which are like a pilot flying, how do you fly, that is from the pilot point of view. They will also called helicopter aerodynamics, something like that, but it is like a flight manual, lot of pictures, but you do not see any equation and only words, it is very difficult to follow. But because when a person who is not flying, he does not know what that means, but the person who is flying, for him equations are not important, he is more worried about how the vehicle behaves or flies or what happens. So, there is a difference between the kind of books, which are this and the books, which are pilot manuals. Then, of course, you can have the maintenance manual and etcetera, etcetera. We will not get into the maintenance part.

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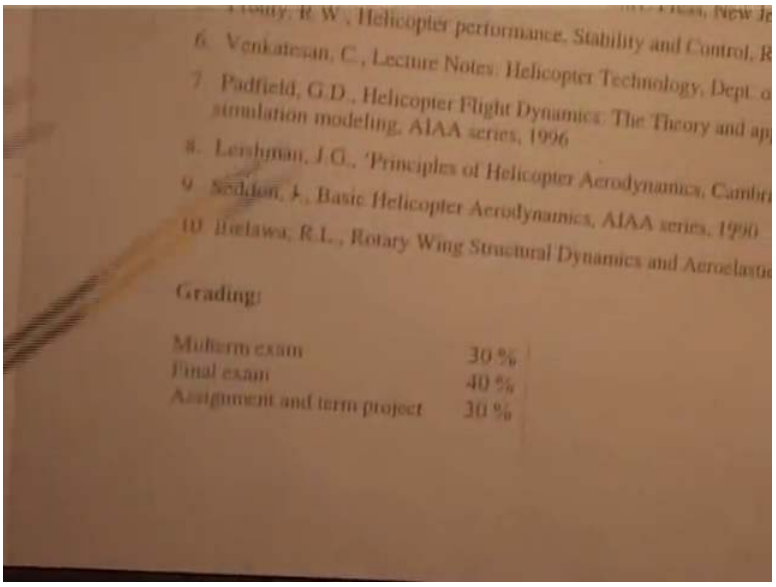

And of course, the grading, like I said, you have a midterm final and the assignment term paper. Term paper you have to, everyone, I will give one topic, that depends on your interest plus it is relevant to helicopters because I want to know, how many have really registered, because I find the 15, then 7 added, then 2 deleted. So, I have to fix how

many you want, the list comes, I will list out the topics, I will say each one is going to do one topic and that is about 30 percent weightage. And assignments I will give, but I do not, I will give the problems, you have to work it out. If you have doubt you can ask me, but I am not really asking everyday you submit this assignments, but certain thing I will ask you to submit. And that is about the overall picture of the, I would say, the course outline. I will try to make it like a story, the whole course.

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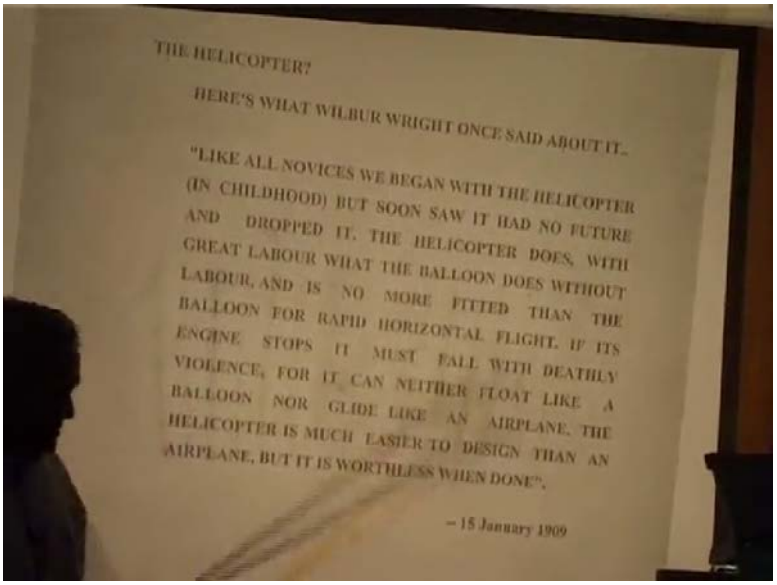

Now, we start the course. Let us see what the, helicopter, this is what 15th January 1909, what Wilbur Wright, Wright brothers, he said about it.

So, he says, like all novices we began with the helicopter in childhood, but soon saw it had no future and dropped it. The helicopter does, with great labour what the balloon does without labour, and is no more fitted than the balloon for rapid horizontal flight. If its engine stops, it must fall with deathly violence, for it can neither float like a balloon nor glide like an airplane the helicopter is much easier to design than an airplane, but it is worthless when done. So, this is what the helicopter.

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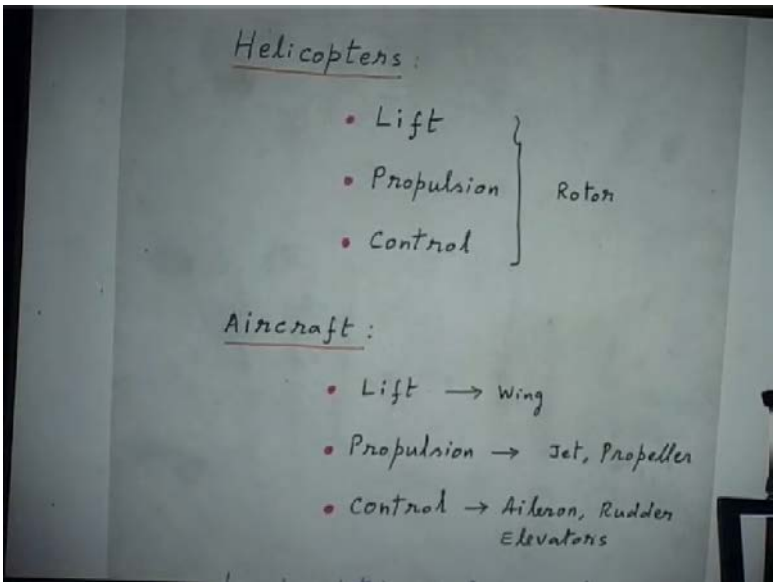

Now, that is a statement, later you will have a counter statement that I will give at the end of course. So, what is a helicopter? We will go slowly, one by one; very simple. We will start with the key, key difference between an aircraft and helicopter. Of course, all flying vehicles, we need to have to lift to support the weight and you need propulsion for moving forward because you need to lift, you need to have propulsion, but then, once it is up in the air, you need control. So, basically, you need to have lift, propulsion, control. These are the three main things, or of course, structure (( )) comes later, that is all part of it, I am just saying key.

But in the helicopter, all these three, please note that all the three lift, propulsion and control, they are all done by the rotor only. The rotor system has to do all three functions and you will find some of the terminologies, which are used in helicopters, they may contradict what is used in aircraft. So, that is why, those things will be introduced as we go along because what you called thrust in an aircraft, it is for propulsion, but in the helicopter, the word thrust is for lifting. So, there are differences, which we will introduce, you have to get used to that.

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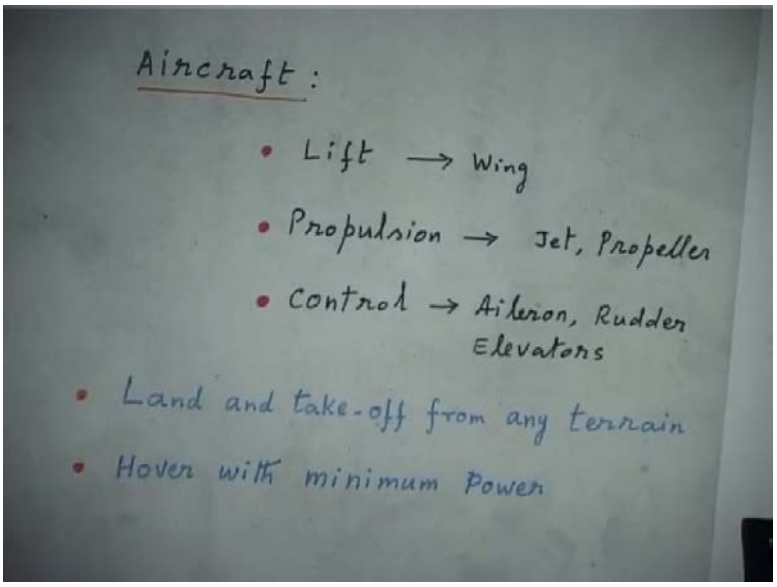

But if you look at an aircraft, you have wing to take care of the lift; propulsion, you have separately jet or a propeller or any of these units; then, control you basically do with aileron, rudder, elevators, etcetera. It is a traditional aircraft, but the key difference after this is, helicopter can land and take off from any terrain, that is the, you do not need a runway, you can land in a roof top, you can land in a (( )), even of course, you need some clearance, so whereas, aircraft cannot do that. So, it is like a vertical take-off and landing, you may call it VTOL, but this is the advantage of the helicopters.

And another, this you will learn as we go along because this is you need to calculate, it can hover with minimum power because you may say, hovering capability you can have in different types of vehicles, but the power required to hover for each class of vehicle may be different. So, helicopters have the advantage of having minimum power to hover for the same weight; you have to take a weight as the baseline.

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Now, let us look at the, I will go for the historical development knowing the key difference between the helicopters and the aircraft. What are the key differences you learned? Difficulties, when they were building helicopters, please understand, and then I will go through historical development, these are very common.

For aircraft, structural weight should be minimum. That means, you must choose a proper material to design your structure. Then, for the rotor you need to have a strong light structure for blade and hub because the kind of force, just for idea you know, in typical blade, which is (( )), the Indian blade, I will take Indian rotor helicopter, which is the advance like helicopter, the blade masses about 64 kg, around 64 and it rotates about 300 plus rpm. Now, this at the (( )), the force you get, the centrifugal force is of the order of few 100,000 Newton. So, it is a tremendous amount of force, it comes at the root where you attach. So, you need to have strong structure for blade, hub, everything, otherwise you will simply (( )).

And of course, control including torque because you are something rotating. So, if you do not have a compensating, there is anti-torque device, it will also start (( )) rotating. So, how do you balance the torque? These are the problems; these are all there right at the beginning.

So, how different people, different people in the sense, these are all not government supported projects or anything like that; it is like a purely personal enthusiasm, that is all. They just want to fly, they designed the different aircraft, different thing, tested it, but it is because of the development of all these individuals in various places. Finally, it came to the today, what we call it is a helicopter. As a history if you go, suppose I will give, first is, I have just brought because this is very interesting thing.

So, I showed Chinese top B.C., which is actually before 400, this is what the Chinese top, you all know, that is all. This is a helicopter, very first, but it is a toy, now no more. But nature also has certain things, very nice, because this I have picked up my trip from somewhere, this is actually two blade. If you drop it, see, so I do not know, whether you can see, you can capture this, but may be from height, maybe I will throw it and then, so this is a two blade. Another one is a maple leaf, which is a single blade, but this I founded very interesting. So, even if you see, but if you have high speed camera you can really look at how it really turns, then it starts descending. This is, I call it nature, this is man-made, this is nature; this is one because I found two-bladed it is nice. So, I picked up couple of them and brought it. I do not know the name because if you want to know where I picked up, when I went to Andaman, I saw in some place in the Andaman, this one. So, I picked a lot. So, I went home, I brought all this because the single one maple (( )), that is there. But this is a very nice interesting thing and it can float also, there is a seed like thing, it floats in water, it can go. So, it is very nice, I thought this is a nature rotor.

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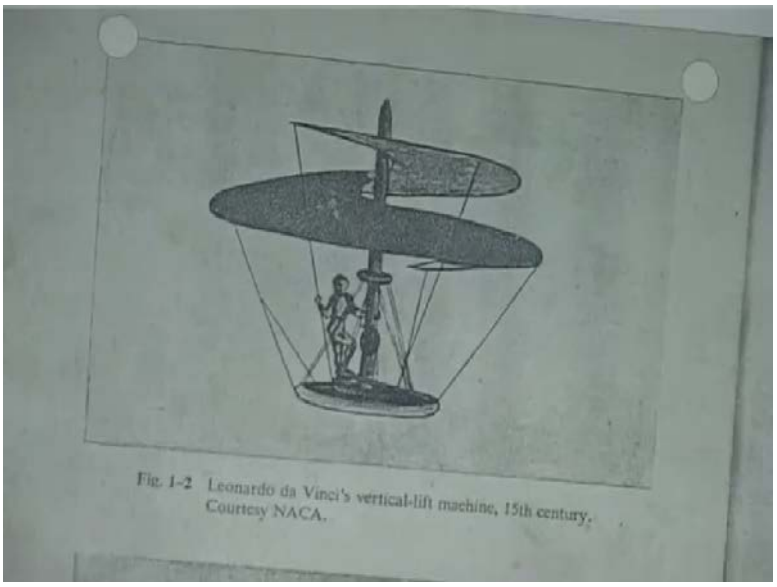

Then, you have 15 century Leonardo da Vinci, I will show, that, which, that picture, which is actually, Leonardo da Vinci's picture is this, this is the, we called it air screw. That means, air is a medium, you just screw through that and you go up, that is all, it is a nice concept.

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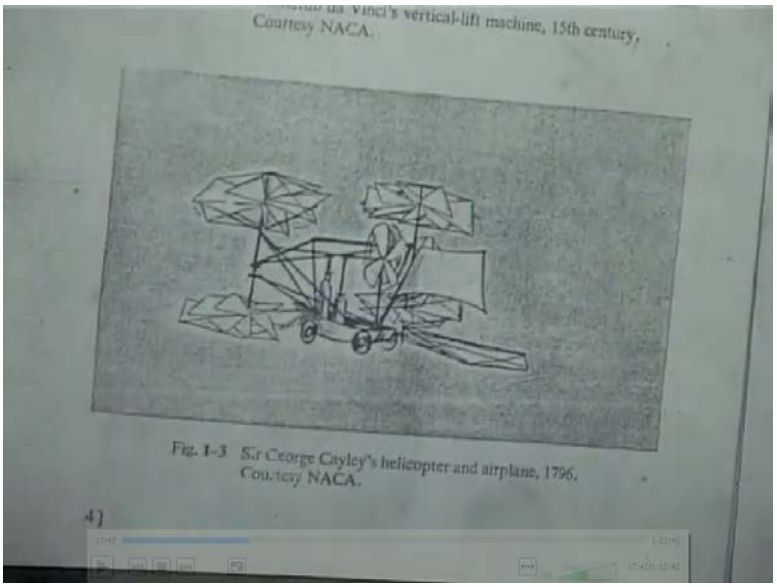

And this is a famous picture they always show. Then, of course, (( )) this is the 18th century, you say, George Cayley, he made some and there are other people also, I would say, he made some models basically with rubberband and rotor, just rubberbands, that is,

all these are all toys. You may see one rotor, rotor, rotor and another one horizontal something, but all these things and it is a nice concept, that you can go, you can climb, but it has no bearing, unreal big helicopters, till the time people were thinking how to fly, how to go, that is all. But then, if you really want to know, the development of helicopters started with the 19th century, I would say it was realized first, I will give some details about that.

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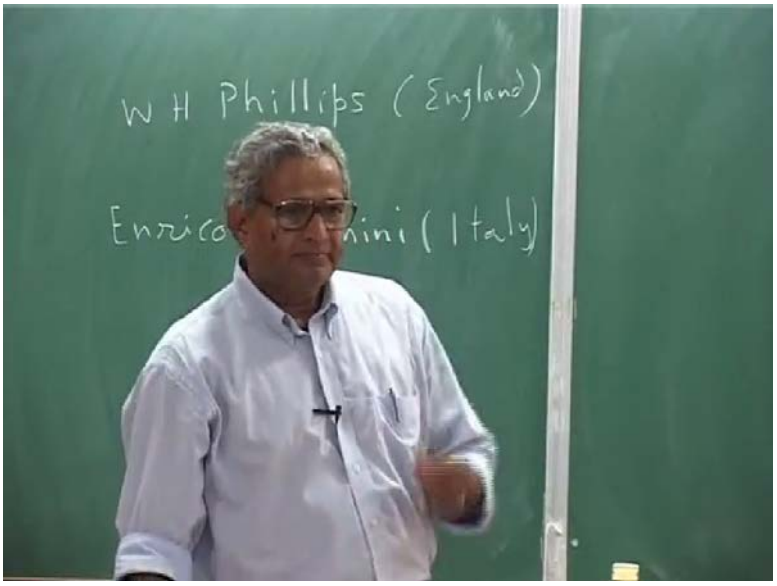

We got steam engine, so steam powered models were made small couple of kgs, that is all, and they were able to fly. It was demonstrated to various, what we call, academies, science academies I would call it, science academies. I give you the 19th century first half, I will write the name, that is, because these are, because if you understand history, you will appreciate.

This is in England, this is in 19th century and then, Enrico Forlanini, this is Italian, they built steam powered engines and about this was 3.5 kgs, worked with rotor. They showed models, but then Edison, that is a very interesting thing, they said lack of reliable light engine that means, power, if you want to go up, you need to put some power. So, the first thing, that came up was power.

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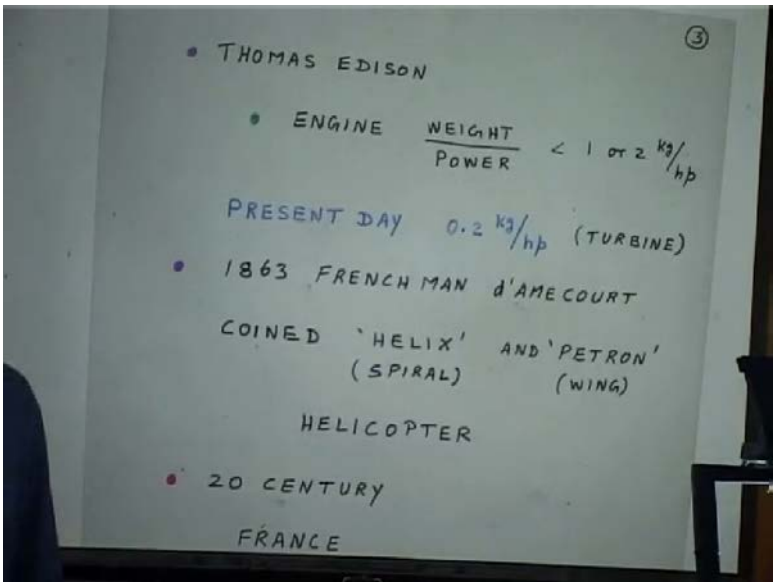

Now, that power requirement, Thomas Edison, you will be surprised he said that thing. Unless you have an engine weight to power, this is an engine, do not bother about rest of the things, that the engine, if it is less than 1 or 2 kg per hp, unless you achieve that, you just cannot fly.

Now, I can give relating background story. Present day turbo shaft, 0.2 kg per hp, that is, of that order engine because we also did some… See, in the 1980, in, when I was a student in IISc Bangalore, there was a project to design a rotor. So, the engine chosen was a scooter engine, Bajaj scooter engine, and of course, we four of us, because that time we were just beginning in helicopter, 80s, so we designed a big rotor, rotor diameter more than, what I think, 13 to 14 feet and then we put that, we were able to rotate the rotor, was fine, it was rotating, no problem. And then, we had a big platform on which the rotor was mounted, the engine was mounted. Then, when if wanted to lift, of course, when he said it was not even lifting because the power later was removed, the engine keep it outside. So, the engine was removed from the structure itself, then from that you give a shaft with the universal coupling and then engine was removed. This was able to lift and with that we closed the project. We said, I think Professor closed it he said, we demonstrated lifting. The reason why I am saying is, we did not know at the time, I did not know honestly, because I started learning about helicopter only after my PhD.

Then, today you remember lot of people say, I want flying car. Please understand, yes you can make a car fly because we should go up, but please understand, whether your rotor and the power and the weight, whether it is sufficient because I remember few years back, somebody came, he said, that I will put four fans and then I lift it. How? You just put something means, it will not, nothing will be lift. You have to see whether the engine has the capability to lift your weight; unless you have that basic thing you will not be able to lift a helicopter. So, that, that is the reason I said, that this is very, very important. If you are going to design a helicopter aircraft you have a wing because wing lifts. Here, actually the rotor has to lift the engine weight, that is the problem, it is like, lifting it like this vertically aircraft, you need to give only propulsive and you need to overcome only the track and if you see the aerofoil, lift it to drag. Drag is very, very small, one-hundredth, but one-hundredth of the power. You give, you can lift it to weight, whereas here, you have to use all that; that is the key difference in helicopters.

Now, how the word helicopter came? Actually, this was coined by 1963 by French man d'Amecourt, it is called helix and petron, that is, a spiral wing. Then, it became the helicopter, of the general word for this class of rotating wing. Now, people call it rotary wing vehicles, you may call it helicopter because sometimes people use the word rotary wheel and these two are used, you know, commonly in publications. Some people use rotary wings, some people use helicopter, that does not matter. But the real development of helicopters as a vehicle, you will see, started in 20th century, 1903, aircraft flew December, that is, Wright brothers, but most of the developments in terms of building a machine.

Now, I will show a few of the samples pictures of how people built various machines, you will have a idea how the development was going on in building this helicopter. This is, I will show, this is the 20th century.

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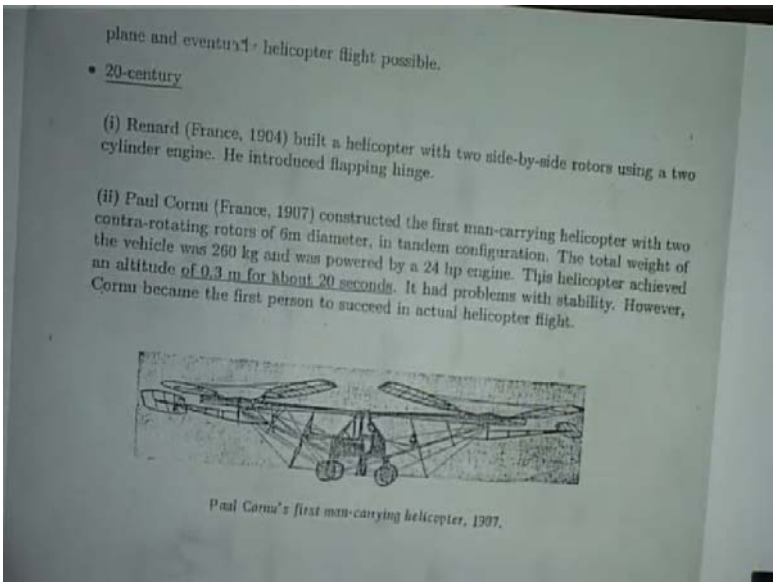

plane and eventually helicopter flight possible.

- 20-century

(i) Renard (France, 1904) built a helicopter with two side-by-side rotors using a two cylinder engine. He introduced flapping hinge.

(ii) Paul Cornu (France, 1907) constructed the first man-carrying helicopter with two contra-rotating rotors of 6m diameter, in tandem configuration. The total weight of the vehicle was 260 kg and was powered by a 24 hp engine. This helicopter achieved an altitude of 0.3 m for about 20 seconds. It had problems with stability. However, Cornu became the first person to succeed in actual helicopter flight.

Paul Cornu's first man-carrying helicopter, 1907.

This is in my notes, it is there, lot of pictures; I have also CD where I put my notes. 1904, Renard, France; then Paul Cornu, 1907. Please have remember, aircraft flew 1903, I will just give some, this is the one of the interesting way constructed. The first man carrying helicopter with 2 contra rotating rotors of 6 meter diameter in tandem, that is, one behind other, the total weight of the vehicle was 260 k g and was powered by 24 hp engine.

This helicopter achieved an altitude of 0.3 meters for about 20 seconds and it had problems with stability. However, Cornu became the first person to succeed in actual helicopter flight, 0.3 meters, 20 seconds. This are the (( )). Please as you go along you will see really how people were struggling to build.

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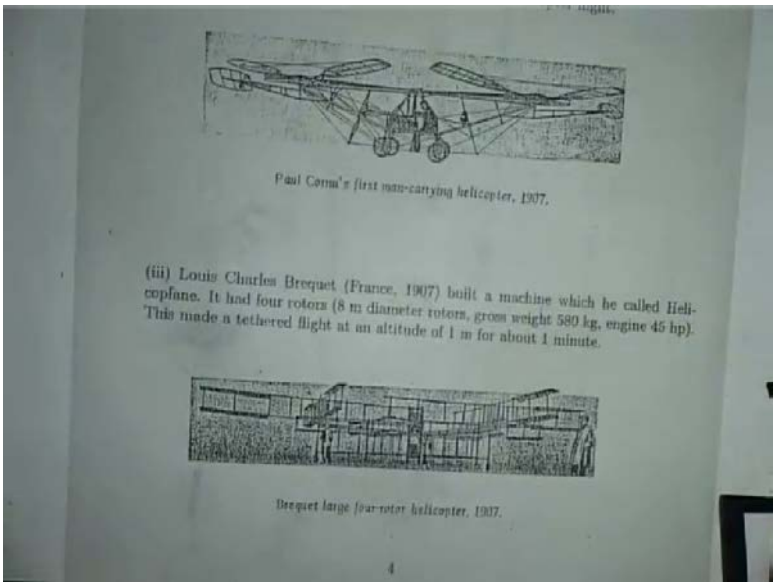

Then, of course, this is again 1907, this has 4 rotor helicopter. So, you see, you have to have 1st engine, that was the first it was realized. Steam engine was built, but then they made only models, then came the IC engine, internal combustion engine. Now, with the internal combustion engine only the development started going on in the helicopter field. And this is another, Louis Charles Brequet, he built a machine, which he called helicoplane. It had four rotors, 8 meter diameter rotors, gross weight 580, engine 45 hp. This made a tethered flight at an altitude of 1 meter for about 1 minute; this is in 1907.

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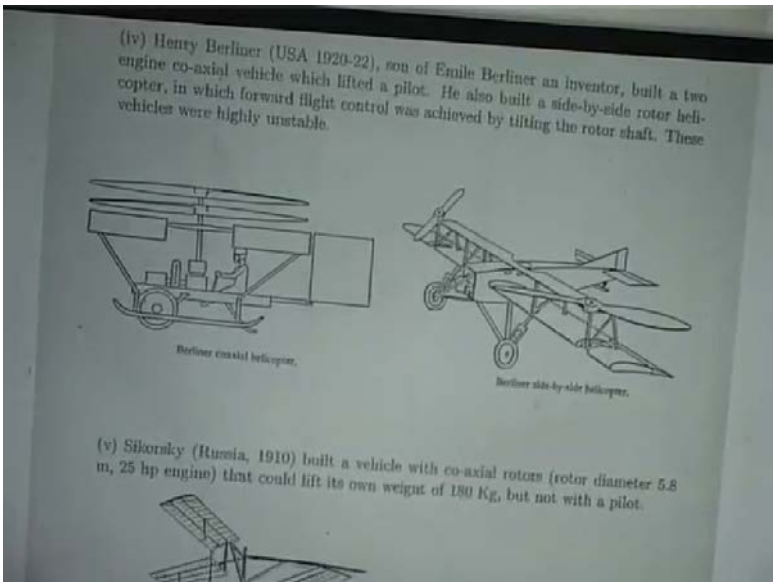

Then, I will give some group in US, is a father-son combination. In 1922 Emile Berliner and Henry Berliner, the father-son combination, they built a two engine co-axial vehicle, please understand. Now, you see, there are two types of how different, different geometries are there, that is why, I want to indicate you, each group was trying different configurations. This is a one below other, same thing he also made, another one side by side; the earlier one is tandem and other group at four in a crush berth. He built a side by side helicopter in which forward flight control was achieved by tilting the rotor shaft, these vehicles were highly unstable.

So, first you want to lift the vehicle, after lifting, the problem comes on stability. For lifting, the engine requirement; when you go to stability, you have to understand the vehicle dynamics. So, without that you cannot achieve stability. You may lift, but you not have any control for the vehicle. You see, how the development really went about in building a vehicle.

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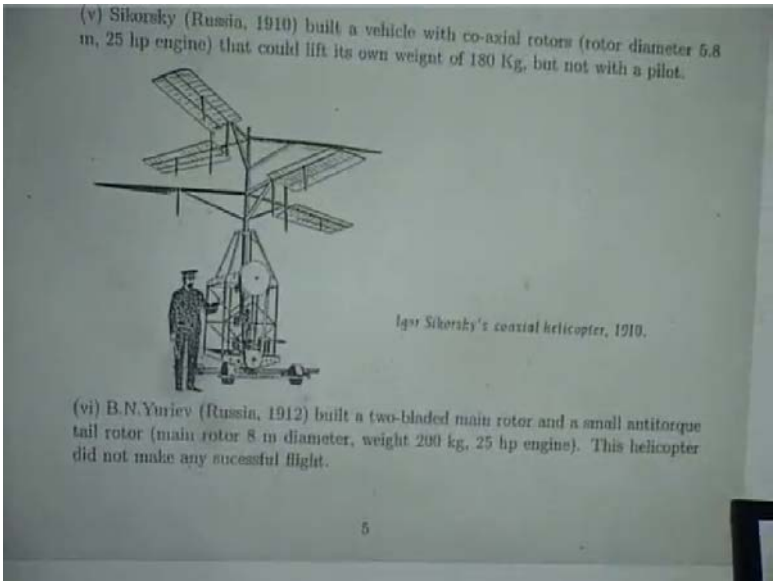

And of course, you may know there are lots of things. Sikorsky, he was in Russia earlier, he is a Russian, 1910, he built a vehicle with co-axial rotors. It could lift its own weight, but not with a pilot, that is all, nobody concerned.

But later he moved to US, initially he was in Russia. In Russia he was trying to build a co-axial, but there is another Russian, in 1912, he built a, Yuriev, two bladed main rotor, small anti-torque tail rotor. This helicopter did not make any successful flight.

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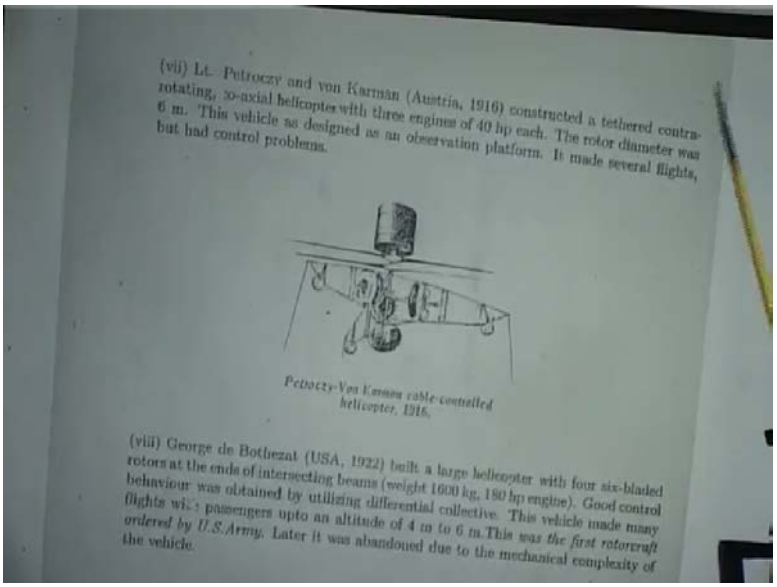
(vii) Lt. Petroczy and von Karman (Austria, 1916) constructed a tethered contra-rotating, co-axial helicopter with three engines of 40 hp each. The rotor diameter was 6 m. This vehicle as designed as an observation platform. It made several flights, but had control problems.

Petroczy-Von Karman cable-controlled helicopter, 1916.

(viii) George de Bothezat (USA, 1922) built a large helicopter with four six-bladed rotors at the ends of intersecting beams (weight 1600 kg, 180 hp engine). Good control behaviour was obtained by utilizing differential collective. This vehicle made many flights with passengers upto an altitude of 4 m to 6 m. This *was the first rotorcraft ordered by U.S.Army.* Later it was abandoned due to the mechanical complexity of the vehicle.

Now, I will give, there are lot of pictures, different groups of people and this is in Austria. Lieutenant Petroczy and von Karman constructed a tethered contra rotating co-axial helicopter with three engines of 60 hp each, the rotor diameter was 6 meters. Vehicle was designed as a platform, observation platform. Even now people talk about observation platforms, but it made several flights, but had control problems.

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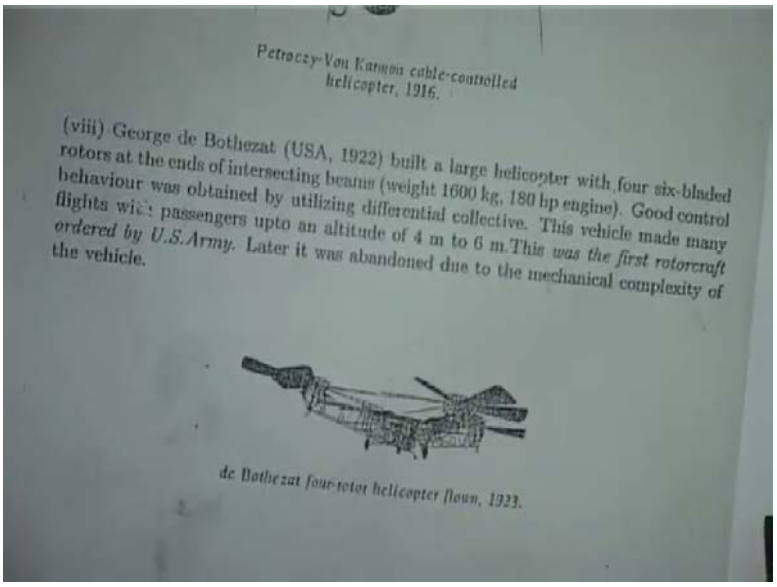

Another, because they were able to lift, this is an interesting vehicle George de Bothezat, it is in USA, in 1922 he built a large helicopter with four six-bladed rotors at the ends of intersecting beams. Now, you know, (( )) everybody building intersecting beams. Good control behavior was obtained by utilizing differential collective; we will learn about collective, what it means, later. This vehicle made several flights with passengers up to an altitude of 4 meters to 6 meters. This was the first successful rotor craft, which was ordered by US Army, but later it was abandoned due to mechanical complexity of the vehicle because you have 4 rotors, each one has to be controlled with different rpm, etcetera.

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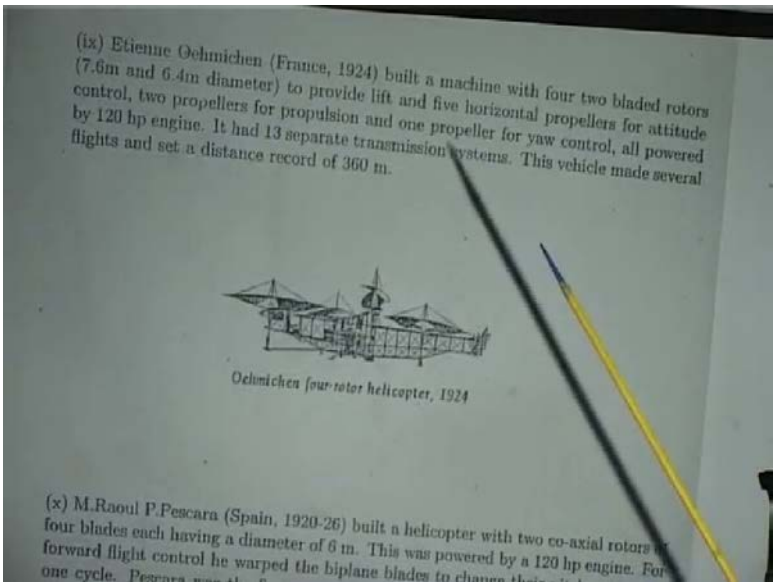

Then, this is another very interesting configuration, this is in France again. Etienne, I do not know how do you pronounce, Oehmichen built a machine with four two-bladed rotors to provide lift. Five horizontal propellers, horizontal propeller means propeller like this, plane of rotation is this for attitude control, that means, pitch roll, etcetera. Two propellers for propulsion, one propeller for yaw control. So, how many rotors have this vehicle? All powered by 120 hp engine, it had thirteen separate transmission systems. The vehicle made several flights and set a distance record of 360 meters.

Now, why I am bringing this kind of various configurations is, today there is a lot of interest among students to build, I do not know, micro-vehicle, flying vehicle. They will say, I will put six rotors, I will put ten rotors, I will put this, I will put one more for forward flight, I will make this, it is good. But one should also know if you try, similar thing long time back and what are the problems they faced. It is important one should understand the history because history teaches a lot of things even in aviation. It is not, writing equations later is all fine, but please understand, all these people built, I do not think the level of mathematical knowledge, what we have today they had. It is for sure because I do not think they had, but they tried, they built, but it is with conviction, it like discipline, they try to make, each person tries because let me try this vehicle, let me try this vehicle and that is how the development started.

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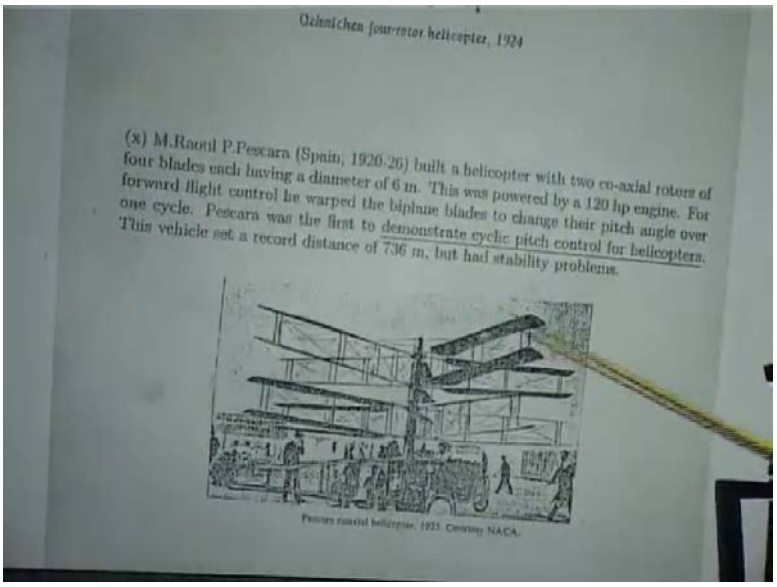

Now, this is another configuration, you look at it, this look like Wright brothers, now Biklin, but he has, it is in Spain 20-26, Raoul Pescara built a helicopter with two co-axial rotors of four blades having a diameter 6, this was powered by 120 hp engine for forward flight control. He warped the biplanes to change their pitch angle; how you warped, I do not know the technical details, but he was twisting, you will learn later. So, he was the first to demonstrate, please note, cyclic pitch control. Earlier, I used the word collective, now there is another word, cyclic.

So, these are key terminologies in the helicopter flight. This vehicle set a distance of 736 meters, again stability problems.

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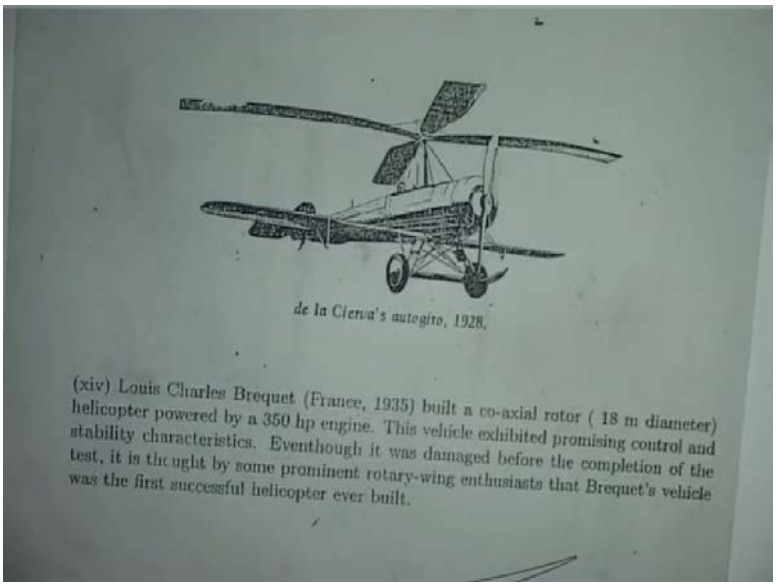

Now, a little deviation will go and that is the autogyro. I will give a brief history on the autogyro; this is Cierva in Spain. What happened was, see, he wanted to build an aircraft, he build an aircraft, but then the low speed the aircraft stopped he said that I want to fly at very low speed that was his (( )). So, he was the first one to design something called autogyro.

What it means is, there is a propeller, you see, is like an aircraft and of course, is a small wing is there. This rotor is a freewheeling rotor like a wind mill, what it does is, the rotor will be kept at this angle, once it said, like what we showed from the seed, which when it is coming down, wind is going up, so it is rotating and then it will slows down. That means, wind is going through the rotor and because of that, rotor start rotating like your wind mill and then, when it rotates and some angle, it lifts because the cross-section of every blade is an aerofoil. So, you get the lift and he does not need any antitank because it is freewheeling and you can fly very low speed; that is what he built that vehicle.

But what happened was, but you need to go forward speed, you cannot just hover because you need a forward speed for the vehicle, like you see kids, when they run with that small fan type in the paper, they are, when wind blows it starts rotating, same thing, you run, instead of that you move aircraft little slowly, it start spinning and then it lifts.

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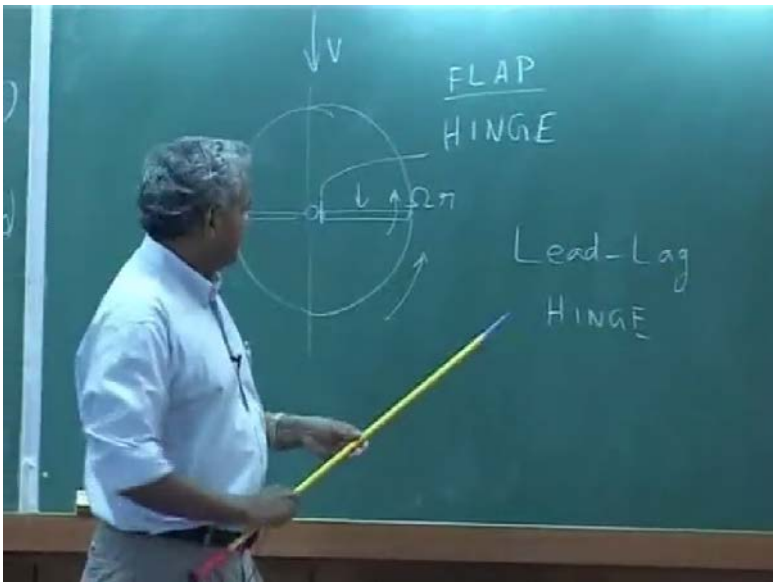

But what he found was, the problem he faced, because why he is listed in, you consider this as a rotor disk and this is rotating, this is wind is coming this way.

So, when it is rotating, you will find here, you will have a, because this is omega times some smaller velocity, then this is forward velocity, the relative wind is additive. Then, you have a large relative wind, but once will go this side, the relative wind subtracts. So, he found, on one side I am getting increased lifts, other side reduced lift. So, as the result, the moment the vehicle takes up, it was rolling. So, what he did, that was his why he regarded is his ingenuity he said, that because there is a rolling movement that is generated on the vehicle when it starts. So, I am going to, if you do not want rolling movement, I will put a hinge (( )) like a door because it is rotating, centrifugal force pull, lift force will go and the movement transfer to the fuselage is minimized. So, he was, this is a great engineering solution and it was successful. He built 500 autogyros, he formed a company, he sold, it was a very successful vehicle; this (( )) 19, 25, 27, that is Cierva, this is 28.

Later, this is called way, please note, I will use the word flap. Flap means, this is again a new word for rotor blade going up and down, that is out of plane of rotation, that is called flap, but it is rotating, but it is going up and down. Now, he introduced a flap hinge, the first and that is how he is successful and he is credited for that engineering solution.

Then, of course, subsequently there is the other problems happened. When it was going up and down, you know, that centrifugal force is pulling this way, lift force is doing this way, but you will start getting because one, it moves your center of gravity of the blade, is coming, moving back and forth from the access of rotation, then you will create Coriolis. The coriolis will be in the plane that means, if you move your blade like this, you are going to get a force in this plane, and if it is not strong enough you will break it, so there was a crash. Then, he said, oh this is another problem, go and put one more hinge in the plane normal to that; that is called lead-lag, lead-lag hinge, so he put that lead-lag. So, you see, from dynamics now I can go back, but there are certain failures happened. I learned, name anything, see certain interesting thing you put up there are certain absorbers, which are put in rotors, not all rotor.

If you want to reduce the vibration, there is something called a vibration observer system, pendulum observers. And I am just giving you story initially, they put a pendulum with 2 kg weight, which was fine, it is reducing the vibration. But then, they put 4 kg with the same attachment, but then one wing flied, it flew off because the attachment, whatever you have, because if you have 4 kg then plane coriolis force is tremendous, you are just increasing it and as a result, that whole thing broken.

So, you have to see from dynamic points of view, whenever you have, anything, system, which is rotating, which is moving, flapping up and down and which also moves back and forth. You need to evaluate the dynamic force precisely, that is why, the dynamics becomes very important in the rotor bullet. Please understand this rotor bullet, like I said 6 meters, that is just for sample, the blade radius normally around 6 meters, you can say, there are blades, which are 13 meters long, the diameter is more than 100 feet, there are helicopters.

So, please imagine, that is a very long blade, it is highly flexible, that is why, when the helicopter is parked, we find the blades are down. So, you are now dealing with a system, a beam you can say, a very long beam, a beam, which is like, can do this and you are rotating. So, you have to be careful about the dynamics of that. So, that is why, structural dynamics is very, very important in the rotor.

And he gave an engineering solution, now it is used I, in this form or in some other form. So, as we go along in the course, you will see, oh flap hinges by Cierva. That is why, he

given, even though this is not a real helicopter, he did not build a helicopter because it cannot hover.

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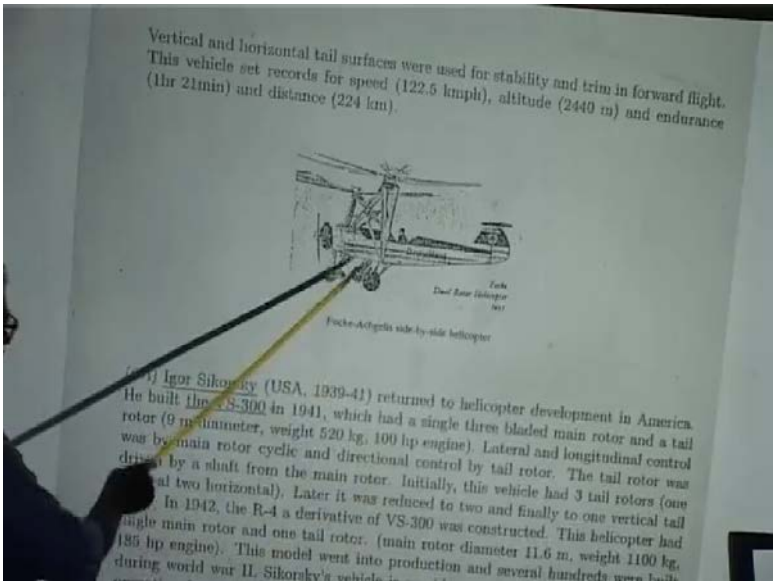

Then, this is another vehicle, which was Henry Frock, this is in, I think it is in Germany, he built a helicopter with two rotors side by side, but you see, a small propeller like thing, actually that is not propeller, that is a cooling. This is a rotor to cool the engine, just like in your car your radiator, you have some small fan, it is like that, it is not propulsive thing and he built this.

This rotor had articulated hub, articulated means, you put a hinge, later I will explain what is articulated, and he has directional control and vertical. Of course, he had to put a tail, it also has a shape of an aircraft, but wings are not there, the rotors are the wings. This vehicle set records for speed 122 kilometers per hour, altitude more than 2 kilometers and endurance 1 hour 20 minutes and set a distance record of 224 kilometers. This was one of the successful vehicles.

But then, you go to Igor Sikorsky in US in 1939-41, first he built because he moved from Russia to US, VS, it called VS-300, 1941, which had a single three-bladed main rotor, a tail rotor.

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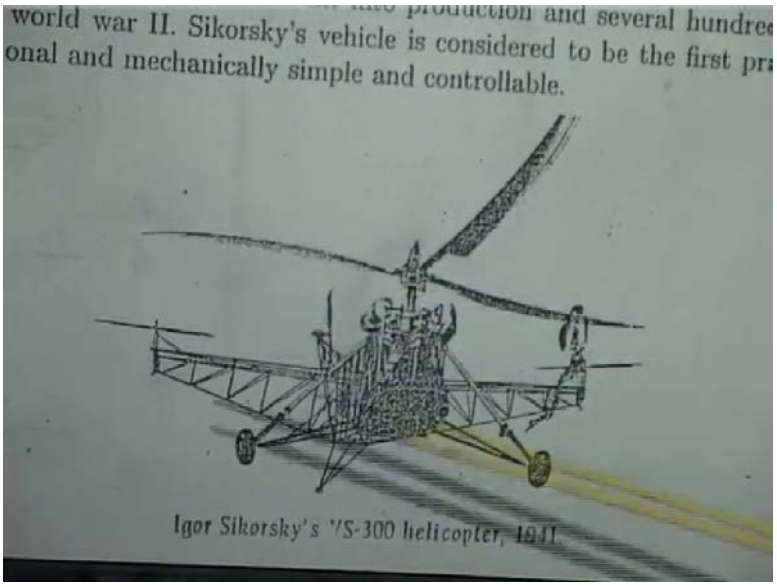

See, here in this picture you will see, there is one rotor here, one rotor here, there is one rotor here and then one main. These are two horizontal thing, initially this model had this, later he removed these two horizontal rotors, put them in the middle as one rotor, later that also he removed.

That one was R-4, a derivative of VS there was constructed, that is why it was reduced to two and finally to one vertical tail rotor, 1942, R-4, a derivative of VS-300 was contracted. This helicopter had single main rotor and one tail rotor; main rotor diameter 11.6 meters. So, you see what, and then, weight 1100 kg 185 hp engine. This model went into production and several hundred were built during World War 2, basically for medical evolution. So, the helicopters first used in military was for evacuation and please note, Sikorsky vehicle is considered to be the first practical, truly operational, mechanically simple and controllable, that is all.

So, till this, it was all helicopter development, development, development. Once you have a successful vehicle, successful in the sense, a vehicle, which can fly. Of course, it has problem, problems will always there, even today problems are there, but this is a successful vehicle, practically operational.

Now, after you build the helicopter, then you will say, now I have built a helicopter, now what is going on, what is that I have to do because helicopters are built, they are flying.

So, you start thinking about what next is actually improving (( )) in the, like you said performance, which goes the technology because the developments, now mainly in the field of improving the capability of the vehicle with increased, with further technology improvement. You will also have improvement in the vehicle.

So, today, now you would say, you are going to build a helicopter, you can build a helicopter, it is, everybody knows what you are going to do because already people have build it. Then, you say what technology you are going to use and what is the configuration you are going to choose? How? So, the focus, that is, 1942 please remember. Now, I think I will show you, of course, I will give some pictures here, the type of configurations.

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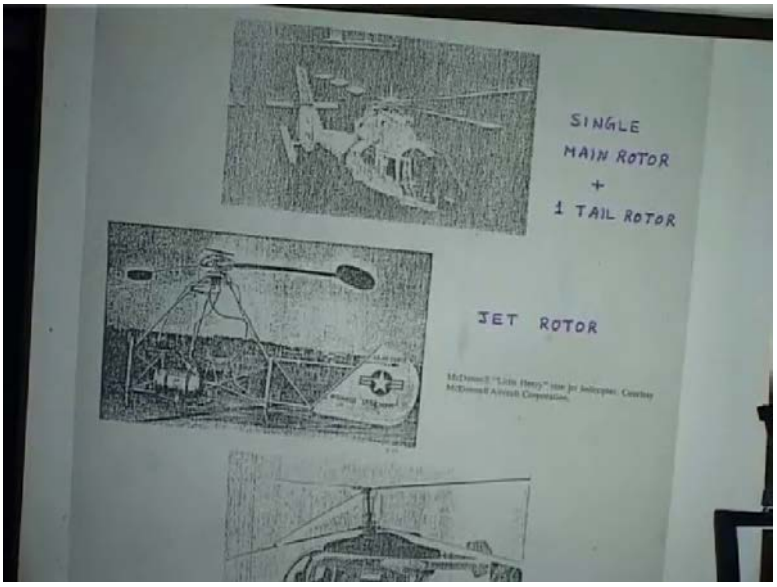

You all know what are the various configurations of helicopter (( )), you have a single main rotor, one tail rotor. Of course, this tail rotor here, it is a fan-in-fin, it is called fenestron because open tail you can have; another one, the same tail rotor put inside a shrouder. This is few companies make, only recently.

Then, there is another scheme, which was start, you do not need a tail rotor, but you have a jet rotor, of course it was abandoned, it is just for picture I am showing. So, you have a jet at the two ends and it keeps spinning. So, you have a jet rotor that means, it can lift,

no problem. Well, of course dynamic, various other, other issues will come, but you do not need a tail because this, if torque transfer is not, there is a freewheeling.

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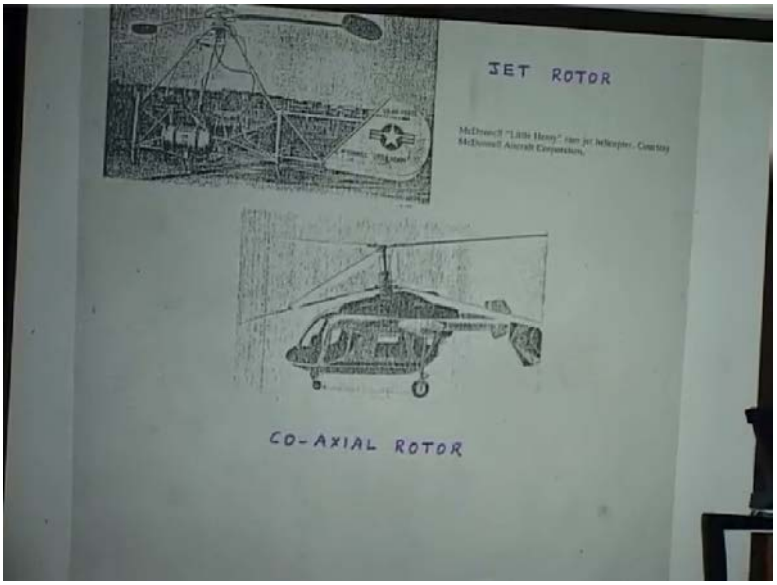

Then, you have another configuration, which is the co-axial on below the other, but today, this type of configuration is built only by Russians, that is a Cornu helicopter because they have specialized, they make these helicopters. Then, what is the use? One of the uses is because it is a compact you do not know the tail, which is long hanging there.

There are advantages, disadvantages. The disadvantage is, tail requires power, that means, you actually spend power not for lifting, but for just having (( )) control. That is, here, both the rotors here I am using, one is in one direction, another one another direction and the vehicle is compact, but then controls more complex.

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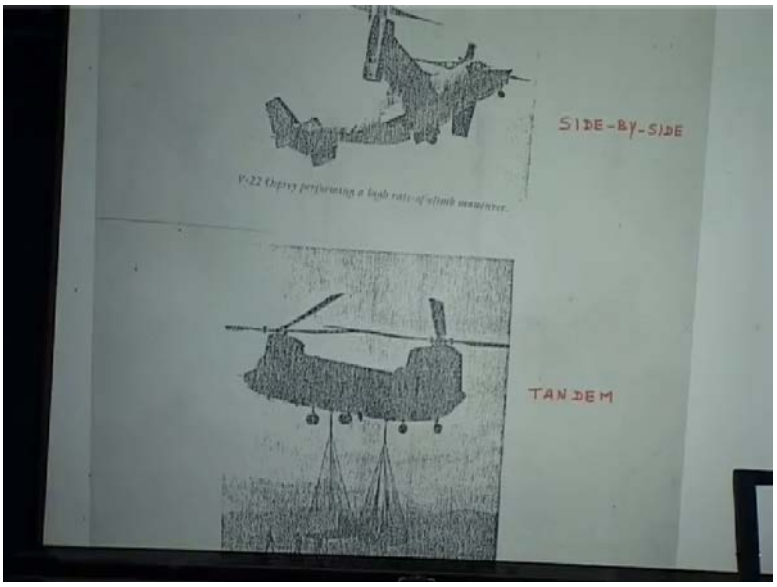

Then, you have the configuration of this side-by-side, of course this is, I showed the picture, this was a project, V-22 Chprey. See, it went on for more than 50 years, 40, 50 years; US navy was pumping money to build this side-by-side rotor. You, it is the tilt rotor configuration, others are only, of course, pure helicopter more, this is the tandem.

Advantage in tandem, please understand, you can shift your CG to a large, the CG travel is more, whereas in conventional helicopter, the CG travel is highly limited. Please understand, it may be less than, may be 20, 30 centimeters in the longitudinal direction, you cannot put wherever you want. So, there are restrictions where the CG should be because otherwise, you just cannot fly the vehicle.

So, but this is for heavy lift, you cannot do the same kind of a very highly memorable things. So, every vehicle has its pluses and minuses. Of course, the transmission system is complex and you see, the tail rotor, this rotor is slightly above this rotor because the wake or whatever disturbance from this, should not hit it. If it hits, then it have its own problem. So, you have, these are the basic configurations.

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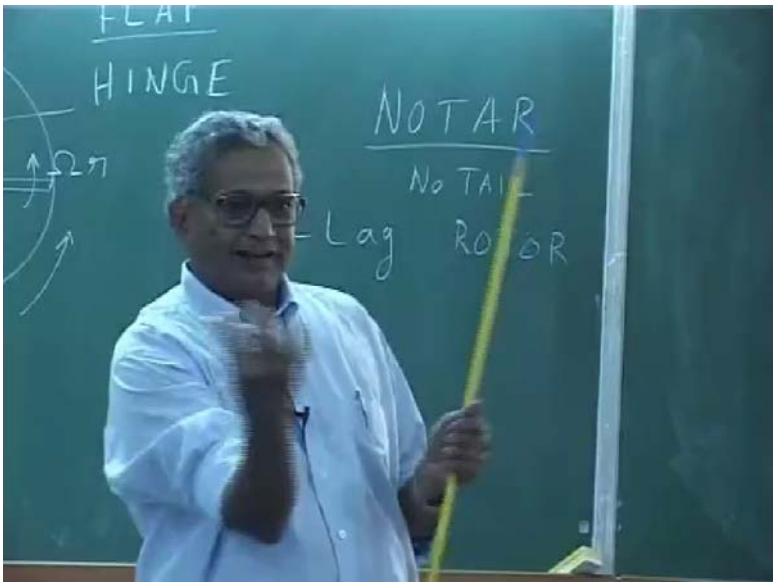

And of course, there is another configuration, which is called the notar, that is, no tail rotor; that is, no tail rotor. This is the name they gave, but it does not mean, that there is no tail rotor. What they do? They have a jet and they have coanda effect, gives the side force. It is like, I will draw the picture, it will come and then the flow comes out like this and the rotor downwards comes. So, one side you get a side, this is the rotor and this is the tail cross section.

So, you somehow have to generate a side force to balance. So, they call it the coanda effect, you blow the air through a small slit and then there is also a jet at the end. That means, there is fan inside the tail, that blows the air through the tail and the air comes out and that gives the reaction force and then balance, this is called a notar configuration. But it is only for one arc, one helicopter, that was built actually, that is here. This picture, there is no tail rotor here, but there is a fan inside, so and that is blowing air through this. Now, these are the configurations, these are the last statement.

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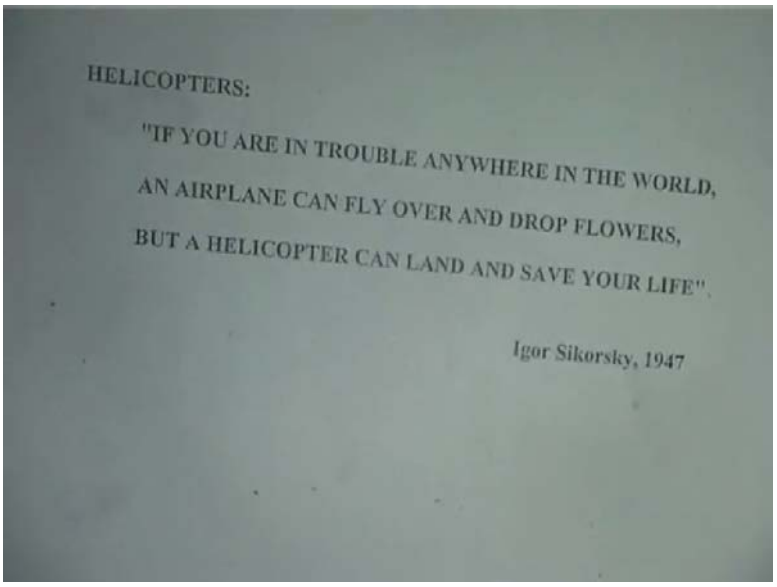

What are helicopter? We started with Wilber Wright, now you say, if you are in trouble anywhere in the world, an airplane can fly over and drop flowers, but a helicopter can land and save you; that is it. So, this was by Igor Sikorsky in 47.

Now, with this, pretty much the history is over. So, this is all the history, wherein of course, more information, colorful pictures, they all there in my other notes, but this is the key why I gave this, spent an hour. And giving a history is to know, that lot of people have struggled to build a vehicle, to be a successful vehicle has come out today, it may be Sikorsky built, but then several people have contributed towards, that is why it is with a day. It is not that they were doing it for name or fame or anything like that, it is just interest to build that, that is, it to fly.

Some preliminaries, today with that we will close today's lecture, control requirements for a helicopter because any vehicle we said, that for lifting we need power, engine selection is a must. So, you should have a sufficient power to lift, number one. Once you have lifted, then comes control. Now, basically you need to control what position and orientation, so it is a six degree of rigid body, three positions, three orientations.

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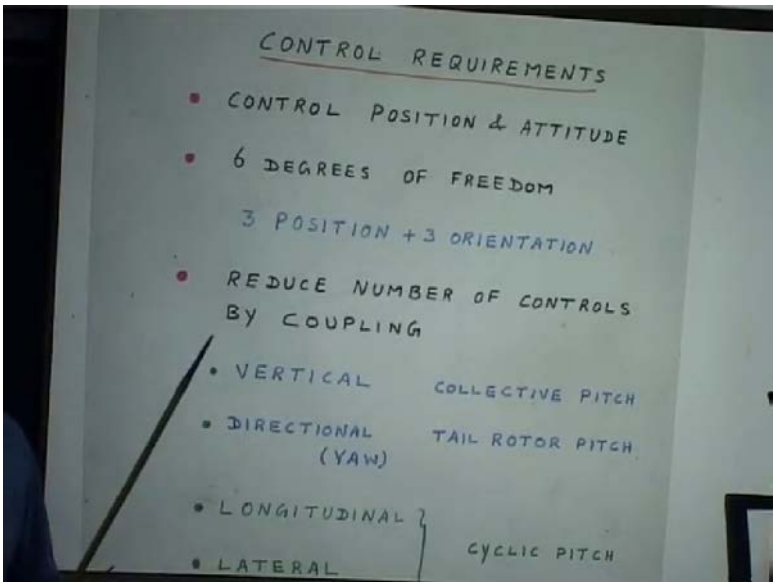

Now, that means, you can have six inputs, I will say, I will give this input it will control that. If I gave another input I will control that. Unfortunately, human beings, we are restricted with two hands, two legs. So, what happened is, we can give, only move these two and both legs, so the controls are also reduced, but how do you reduce? Mean, you reduce the number of controls by coupling that means, if you give one input, it will not do only one function, it will do something else, which may be undesirable, but it will do it.

So, in the helicopter what are the controls? I have used four main, lists down, one is the vertical that means, you want to go up and down, simple. That means, the helicopter's altitude is changed only by one control, that control is collective pitch. I have used the word collective pitch, you will slowly understand what is the meaning of collective pitch as we go along you will learn, but from pilot’s operation point of view, he will have a lever on his left hand. Please understand, that lever will, you will pull it up, pull it down, that is all. If you pull it up, is going up; if you push it down, is coming down. So, that is the collective lever; I will show a schematic.

Then, for directional control, because you need to know, which direction you are pointing, that is called the yaw, we know because we are all aerospace engineers. So, yaw control, that is, by tail rotor pitch angle because the tail rotor is there, you adjust the side push. So, if you increase, you will turn, you will go this way. So, the tail rotor,

which angle he controls by pedal. So, his two legs are engaged in controlling only the tail rotor. So, either you will move this way or you will move this way. So, now, we have basically kind of split the two functions, even the later you will understand all of them are coupled.

Then, comes longitudinal lateral, that means, you want to move forward or you want to move sidewards, but then, here when you want to move forward what happens is the vehicle also pitches, there is a nose down.

How you move a vehicle forward? See, how you move a vehicle go up is, you increase the lifting capability, that is, you increase the pitch angle of the blade, that is basically the angle of (( )). You all know the basic aerodynamics of an aerofoil, I change the angle of attack of the blade, I get increased lift, so I am going up. But here, I want to go forward, forward means, how do I (( )), I do not have a propeller to push me forward. So, what is done is, this is the difference between the aircraft and helicopter, the rotor disc, you say, you call it the disc, the vector, the force vector, we call it thrust vector, just for sample, thrust vector is perpendicular to the rotor. Now, I tilt the rotor disc forward. When I tilt the rotor disc forward, my thrust vector is also tilted forward, as a result I get a forward component of the force and a vertical component; vertical component will support the weight, forward component will push me forward.

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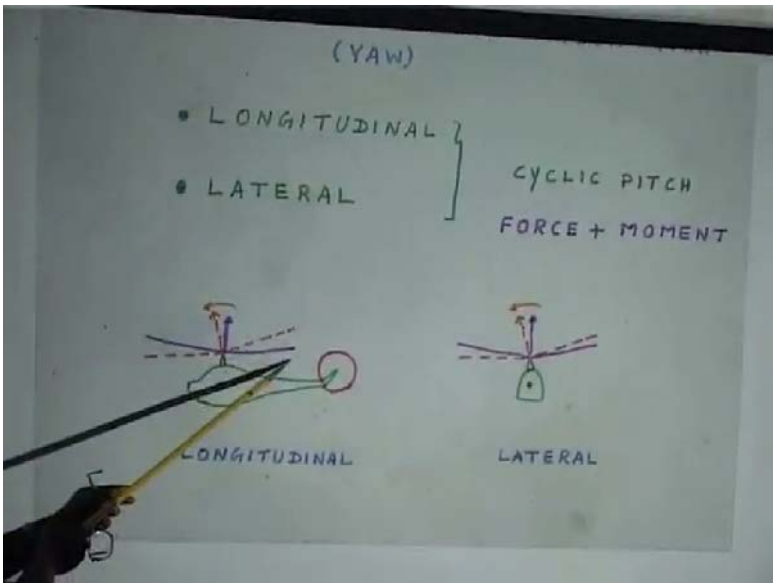

But the problem is when you tilt the rotor, this is the horizontal thing, I tilt it, so my thrust is here. Initially, the CG is right here, is coming down and holding it. Now, what happen because of the tilt? It has gone; I am going to get a moment about the CG. Now, the moment also it will come. Now, if you do not balance the moment properly, then you will have, you cannot control the rhythm. But how the moment is balanced in the helicopter?

You will see as we go long, we will see, this is a great design, yeah, that is why helicopters there are, you cannot fly it a very high speed. There are various reasons for you cannot fly, sometime you cannot trim the vehicle, that means, you cannot get an equilibrium, equilibrium of forces and moments you cannot achieve, that means, you cannot fly assuming everything is wonderful.

So, this is what you, when you want to go forward, you get a coupling of the pitching. Similarly, you can do the lateral that is why, the helicopter has an ability to go in because this is a disc, I can tilt it this way, I can tilt it this way, any orientation. That means, I can fly in any direction facing in one direction, it is not that I have to turn to the other direction and then fly, that is the advantage of helicopter, that is, I do not have to turn and then fly, I can just go back. Of course, these are requirements, which the user will demand.

I want to fly this much forward speed, this much sidewards, all these things I will give just a brief, why this is. See, this is I learnt when I was discussing with some defense people. See, today helicopters, I said that earlier, it was used for evacuation basically. Nowadays, they take the role of attack; they have become a force, earlier it was only for injured people, emergency evacuation in the military. The reason was first, you know, it is a very interesting political thing, Russians are very good (( )) because they have land. The US thought, initially the whole theater of war will be only in Europe and Russia is a land where I can come through with tanks. But US, if they have to come, they have to fly because they cannot bring all the tanks. So, they said we will have a flying tank. What is the flying tank, is an attack helicopter.

So, now, that is all the concept of attack helicopter themselves have come about because they say, that you can hide, you can be below the tree tower, they suddenly go up, fire and again you go down or you can go back. Now, the role of the helicopter is

completely, know the demands are met more and more because the services say, ok, this is good, we will use it for some other reason. And of course, today in India you find, that any floods, anything will only with helicopter going around and then picking people, coming because that is one of the major usage you, because they can go, hover and you saw even in the, what is, that terrorist attack in Bombay, how they landed on the roof top. Again, the helicopter, because you cannot take aircraft and then parachute down, so you do not know where they will go and sit, that slithering. So, the demands, you see, they are all different types, so they meet. That is why today helicopters have become an important flying vehicle. It is like aircraft, it has its own utility, which cannot be met by an aircraft, conventional aircraft. So, you can see, that development of helicopters and the demand for helicopters are started increasing tremendously.

Now, if you see, in the defense side army wants the helicopter. You will say army wants tanks and other things, why do they want to fly because now the majority of the helicopters are operated by army, because they want to use it as a flying tank type of thing. Of course, air force has its own utility. Then, navy, because they want ship based operation. Now, when I said contra rotating rotor, usually navy operates. The reason is it is compact, so they can keep it and store on a ship. So, the size is small, so demand for helicopter has gone. Of course, the defense has a tremendous demand.

In the civilian side, yes, the demand is there because if you, future, that is what. Now, air transportation, US normally says where the city traffic has gone too much, if you take two hours to reach your airport, means you fly five minutes, you go there, you land. But of course, you pay normal money because helicopter flying is not cheap. Commercial helicopter, if you say one hour of flight will cost fifty thousand rupees, of that order, but still lot of business. People use the helicopter because if they want to go, instead of going from Bombay, lots of people have because they do not want to go from Bombay to Pune or wherever their factory is. They hire a helicopter, morning they go, maybe couple of lacs, and they come back. So, utility is growing, of course, there are problem. Now, off shore, which is a civilian operation, you need to go and then put the personal only with helicopters or you have to send them by ship. So, that is why, the helicopter utility is growing, but it is a very complex vehicle.

At the end of the course today, you may not know what is the complexity, this is a, this is what one, one complexity is basic thing. You have a disc, you want to tilt it because I

said with words, hey this is the thrust, you just tilt the thrust, good how do you do it that is the next question?

Because you modify, tilt it, I will fly forward. Of course, it gives me a coupling of pitch and coupling of role also, but how do I tilt it, I cannot take the whole shaft. Please understand, there is, one way is propellers rotating, tilt the shaft, that is one way, this is what the tilt rotor, which use, I showed the tilt rotor, that means, you have a rotor, you shift, you actually rotate the shaft, this is one way. Another way is, I do not want to rotate the shaft, but the disc must do this in conventional helicopter that is what is done. The shaft is not rotated, please understand, shaft is kept in its orientation, but you tilt the plane of rotation of the rotor disc.

How it is achieved, that we will learn as we go along because these are all there dynamics, how it is. So, now, you know. Then, you have longitudinal lateral motion, the input that is called the cyclic pitch. So, we had a collective, collective pitch, tail rotor pitch, cyclic pitch. We will explain what cyclic everything is, but how cyclic pitch is given?

The pilot has a stick in front; he will move the stick forward. That means, if he moves forward you will go forward; if we moves lateral, he will go lateral; if he go this way, it will go this way; he will go this way, he will go back.

So, this stick he can move in any direction, 360 he can actually churn. So, left hand right hand leg all are engaged for the pilot to fly I think I will leave you now.