Aero Elasticity
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Lecture – 1

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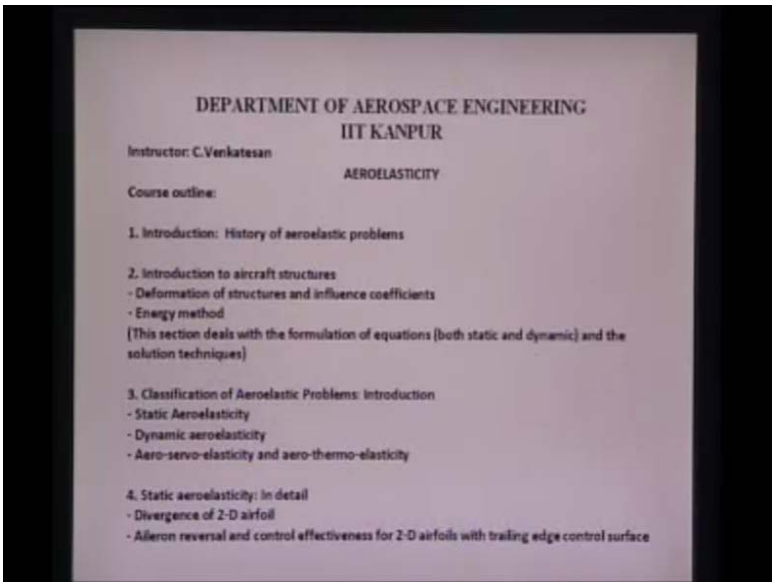

I have given you the outline of the course, which is the shown here? We will have first the introduction to aero elasticity that is what is aero elasticity? You learn that we will come to that, but here we need to have some background in the aircraft structures. So, that part I will cover in the after introducing to what is aero elasticity? And the then what are the various type of problems aero elastic problem, we encounter and that is again in detail, we have static aero elasticity.

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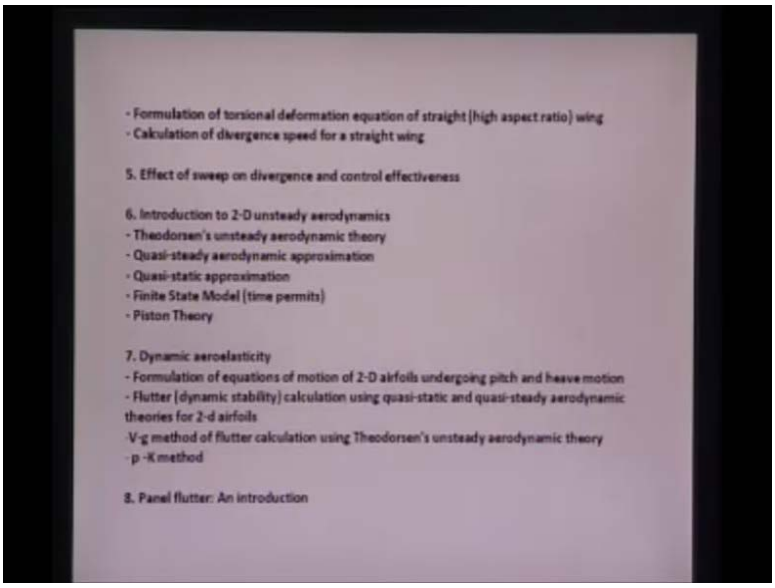

And then we have the dynamic aero elasticity, but in between we need to have again aero dynamic, which is the unsteady aero dynamic. So, I will cover some part of the unsteady aero dynamic and last this a panel method, which is again in aero elastic problem I will give a brief introduction. So, this is how the course is arranged.

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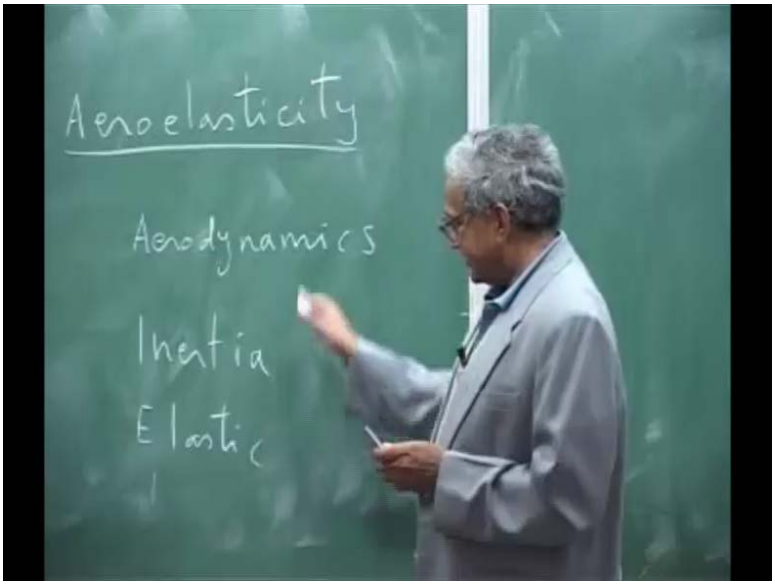

So, you have the course out line, now we will see, what is aero elasticity? Because we have it is essentially a study of the interaction of aero dynamic, aero dynamic inertia and elastic. These three the interaction of these three how they affect the alpha dynamic? And

then the last is how they influence the design itself that is very important. Suppose if the air craft is rigid or any of flying vehicle is rigid then this field is not existing at all there is no aero elasticity, but we have highly flexible or deformable structure that is why aero elastic problem becomes very important.

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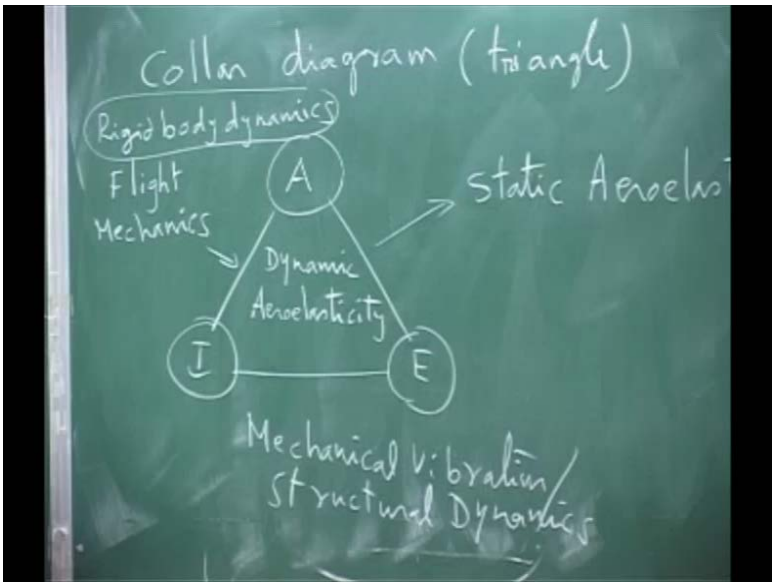

Now, this particular interaction is described by something called the collar diagram or a triangle or collar triangle, you can we can take this is aero dynamic inertia and elastic. Aero dynamics and elastic without inertia this particular interaction is called static aero elastic. That is this part if you take elastic and inertia this is basically your mechanical vibration. So, you can say this is mechanical vibration or structural dynamic anything you can call it mechanical vibration or structural dynamic. Aero dynamic and inertia that is basically your flight mechanics, because there you do not consider the air craft as a flexible body you treat it as a rigid body therefore, all the dynamic problem basically your flight mechanic problems are the interact of this. So, I will put it as essentially flight mechanics, but you do not treat the sometime they call dynamic stability rigid body dynamic you may call it even I if you want you call it this is rigid body dynamic.

So, this is here now the interaction of all the three is the dynamic aero elasticity, now you see our entire aero elastic analyses has a subject requires input from inertia, input from structure, input from aero dynamic that mean you should have background in all this first, you study structure course, study the aero dynamic course, the study the vibration

course, and then you come to the aero elastic, you cannot start with aero elastic right at the beginning alright. Now this is the very basic level, now to this you have now hyper sonic flow, which is the high temperature effects are coming if you want to include thermal effects then the same subjects.

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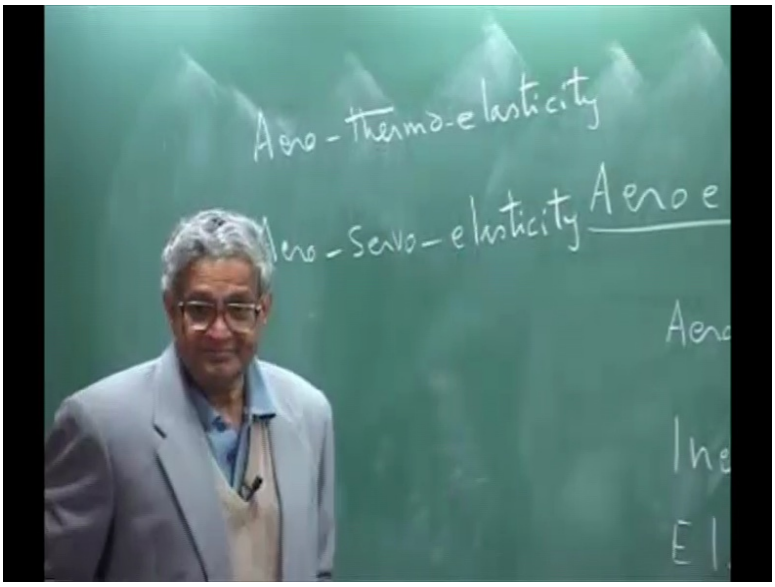

Become aero thermo elasticity these are all of shoot aero thermo elasticity. That is the effects of temperature on the structure, and also your flow everything and that is this subject. Similarly you can introduce control theory into the.., because you can have active flutter and various type of thinks are there related to aero elastic problem; that means, you are bringing in the control theory into that that is called aero servo elasticity, now you see how the field is changing expanding to include various aspects of either thermal, but if you want to include thermo, you must know the control theory and this is how the topic really develops. Now, if you look at the, I will briefly write what are the very specific problems or issues associated with static aero elasticity and dynamic aero elasticity very specific problem and actually this entire course deals with only those problem.

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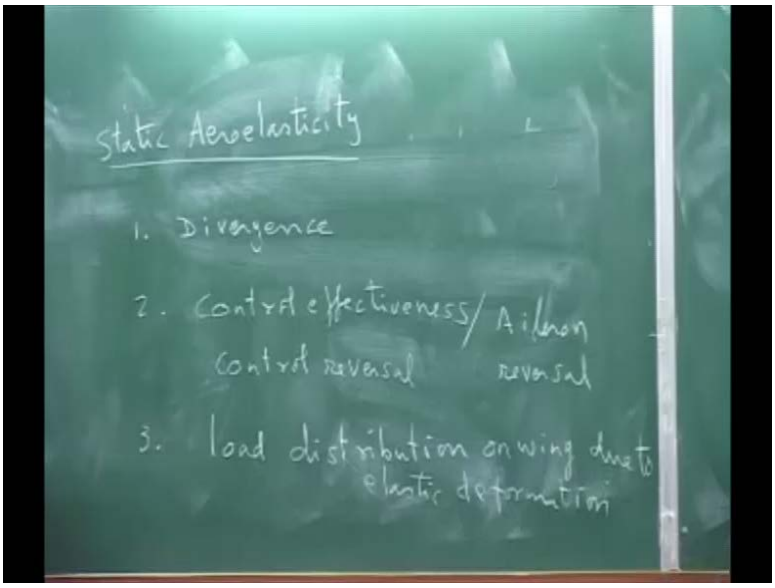

So, I erase this static aero elasticity under this we have one of the very important problem called divergences, but then you may ask diverges of what diverges of lifting surfaces, you may take it the divergence of wings aero elastic problem are always associated with lifting surface is under, but you may say what about fuse lights do you treat the aero elastic. If it is the panel if it gets into supersonic something then panel vibration, which may be a aero elastic problem otherwise, divergence next one is control effectiveness or control reversal. This is essentially when you say control with what you control their? You use the aileron or elevator any of those.

So, they are, but normally they put control reversal they sometime use aileron also aileron reversal or aileron effectiveness something like that, and another one is load redistribution, you may say load distribution on wing, due to deformation that is the key, due to elastic deformation that is all these are the problem what I will do is first write a list out, what are the key aspect? After that I will show few of the history about this whole subject, and then that time you think what these things mean.

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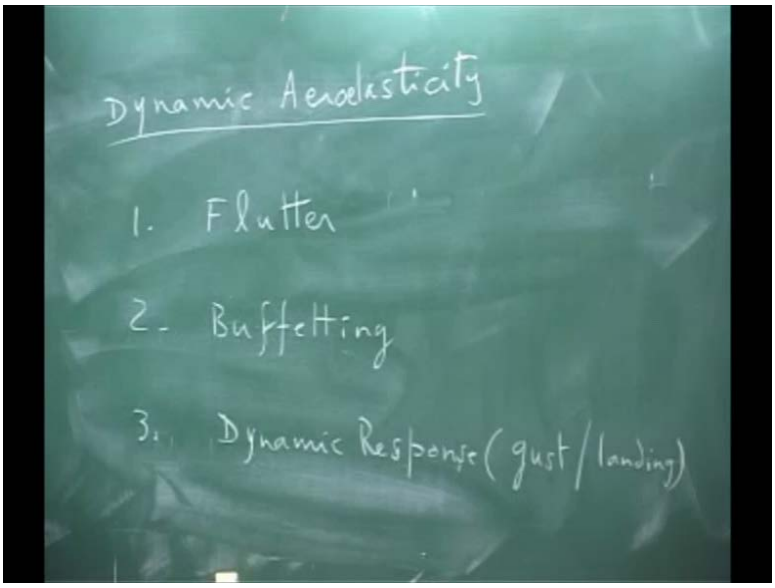

The next under dynamic aero elasticity, we have first is flutter then you call another one, which is called buffeting and third you call it due to dynamic response due to gust are landing any impact load. Suddenly applied load how the wing load that can be due to gust. So, this I will put it as dynamic response. These are due to gust or landing, now these are your major topics. That is all now you have this you may be wondering, we all know this problems. So, in aircraft design how they influence the design.

So, that is the key one, you have to know this problem and the next one is you make sure that they do not affect your performs of the aircraft. Today, you say whether there are approach whether, we can tailor our properties or the wing by suitable design. Can we take the advantage of this problem, which we call it has problem whether we can take the advantage of this among this that is how the study is very, very important particularly when the air craft become more and more flexible. They assume a very, very prominent role now. I thought I will give you brief historical background how this started whether the Wright brother really knew about this problem this is a question see in the beginning Wright brother, you all know successful that is the first flight, which has happed, but before him there if another person who flew the air craft.

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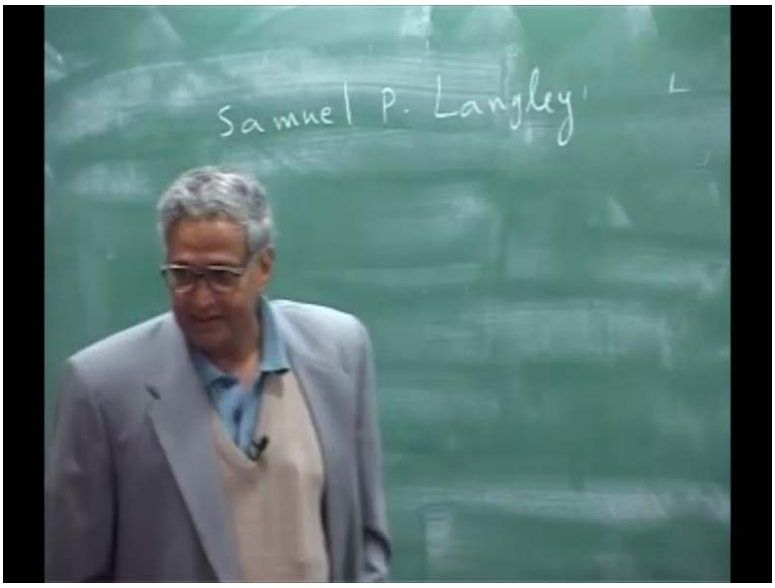

But his name is Samnel P Langley, he flew the air craft on a small scale that I will show in the next these are the book, we will come to the books later.

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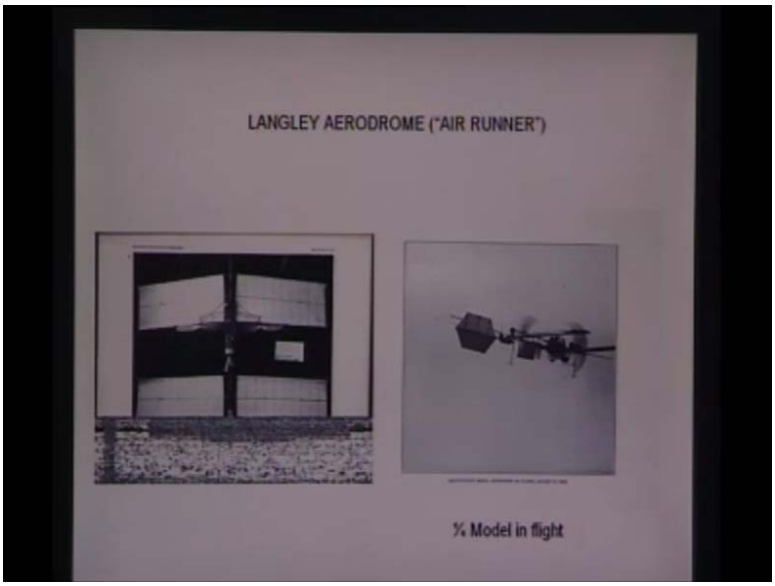

This is the air craft model which was developed by Langley. This is a mono plane mono plane means only one meaning were as the by plane you will have like this..Mono plane are today's air craft they have only mono plane.

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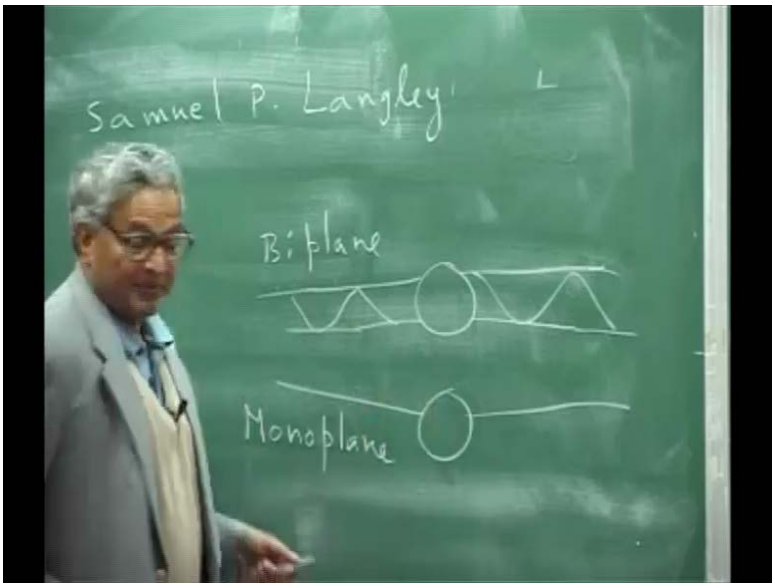

So, this is by plane right and this is mono plane right, he made this and this is a quarter size model, which he flew that was in 1896 he was a he flew it was successful and you see the popular is here, but then he got a grand he was acutely the director of Panasonian institute, then he got a grant to built a man vehicle man vehicle he built it.

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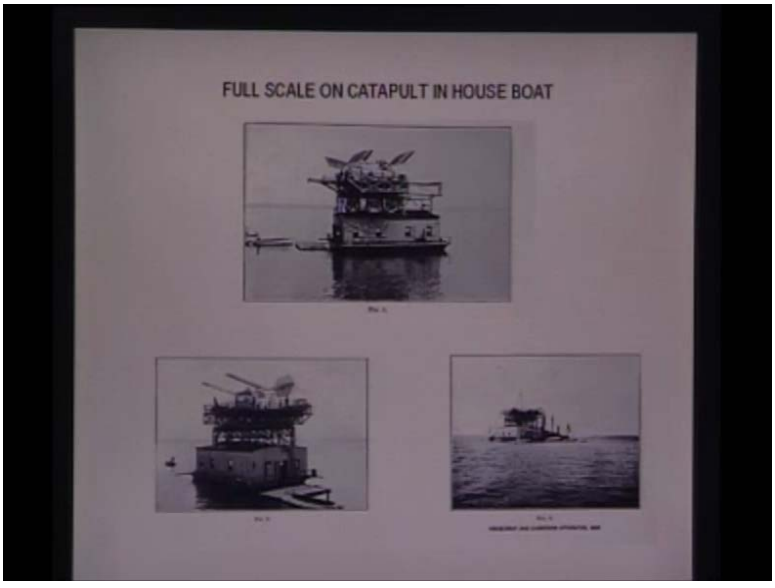

And he it was a catapulted. It was a they call it a house board on the top of it this is mountered and the pilot will be sitting in it they will just pull it, and then and what happen was? This is a full scale in the sense manned planed this is before Wright brother

flew in 1903 that was one on. October 7 and another one was December 8 just it is few I think what is that December 17 was Wright brother flight this was December 8, but this as soon as he took off it just fell into the water it was not successful.

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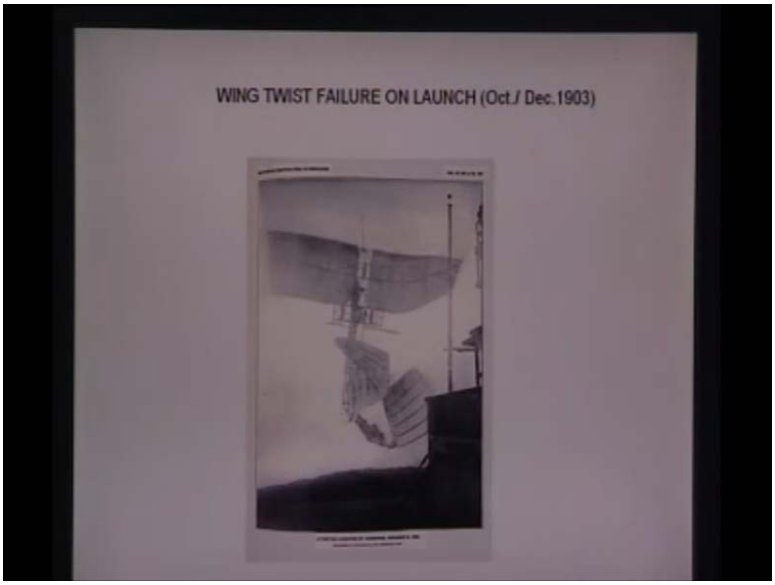

Now, this is the wing twist failure October December 1903 had he been successful, he may be in the history of course, he is in the history today, but like Wright brothers he would have been in the history also, but he was building mono plane why Wright brother successful his flight fail? This initially there was some question why this fail that is because the Wright brother made the by plane which was partially twist. So, they were successful that is why in the beginning of aviation the failure of this the success of this let to design all the preliminary air craft which was built in the beginning they are all by plane I will show someone.

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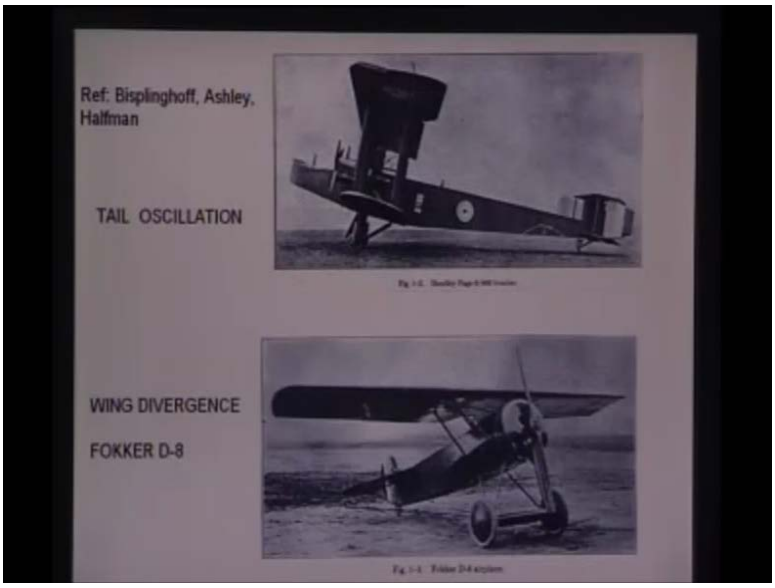

These are all these are taken from the book this wing of Ashley is up, now this is all old now what is the problem? Which aero elastic problem the by planes normally face was that tail osculation the fuse large tail combination osculate.

So, you basically increase the Torsional, but the later even during world war one Europe they were building the mono plane mono plane means this is the mono plane, and this particular thing this is Fokker D 8. Suppose to be high performance air craft to be deliver through the air it was delivered, but whenever the wing the air craft goes into drive the wing will fail, now it is a very interesting history the users blame the designers, but designers say there is something, because nobody knew what was the problem, but when army tested the wing, because it is designed for 6 time the load of air craft 6 g they put that 6 g load its fine.

It is not breaking then became a problem what is that really happened? Then it came back to the company and then they tested it suddenly a I think Anthony Fokker came to it. That is why the Fokker company? Is there what was observed was that when the wring was deforming suddenly, he found that the twist was happening that was Torsional deformation, which means my angle of attack changes; that means, my load is changing. So, this was the first absorbed phenomena that this is what wing divergence that only, let them to think I have to take care of some problem, which is due to the elastic deformation and subsequently of course, during the 90 20s 30s mainly raising.

So, they put high performance powerful engine more faster etcetera only after those they understood in 1930 onwards only the monoplanes successful mono plane were made nineteen thirties around that now the problem with mono planes, you start having again now; however, I have listed out all this problems are there in all, because today you find everything in a monoplane.

So, you have to analyses all these out related to, because they are all anti liver wings. So, they go through this wing divergence is one problem, then you have a lot of problem. This is static aero elastic problem another one is the dynamic aero elastic problem, you need to take care of both this problem, now I will show in the static problem itself there is a due to deformation .The wing load gets re distributed.

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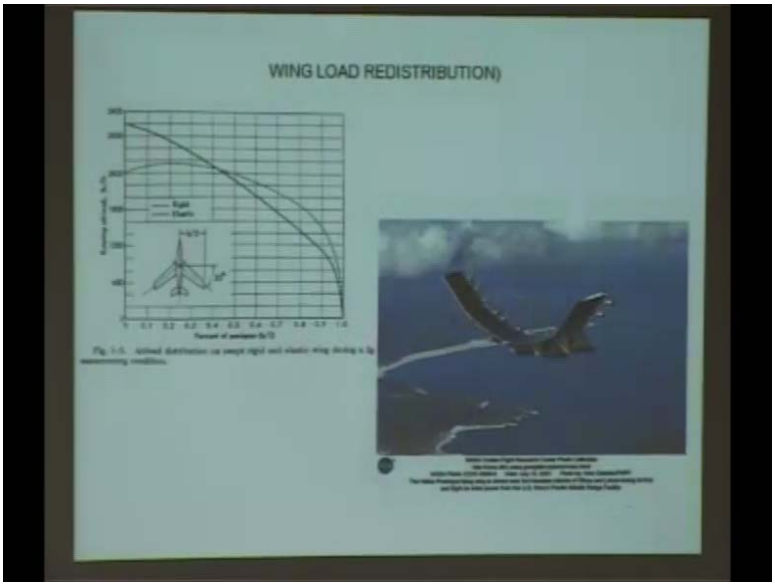

So, you see this is a very recent I think 2000 or something like that is a high altitude long endurance starter, which has solar anal every think, you see the kind of deformation the air craft is having. It is just to show you that how flexible the wing for this particular one this left diagram shows this is for a suffering air craft see the continuous line, and the dash line that dash line represent the rigid wing, suppose you feed the wing as rigid then you directly put the internal test aero dynamic load, you can get the distribution, but if the wing is deforming because of the deformation. The load is now gets redistributed this is the centre of pressure moves in board, but because of the re distribution your structure

as to be manipulated, because the loading bending movement air force rational movement everything will change.

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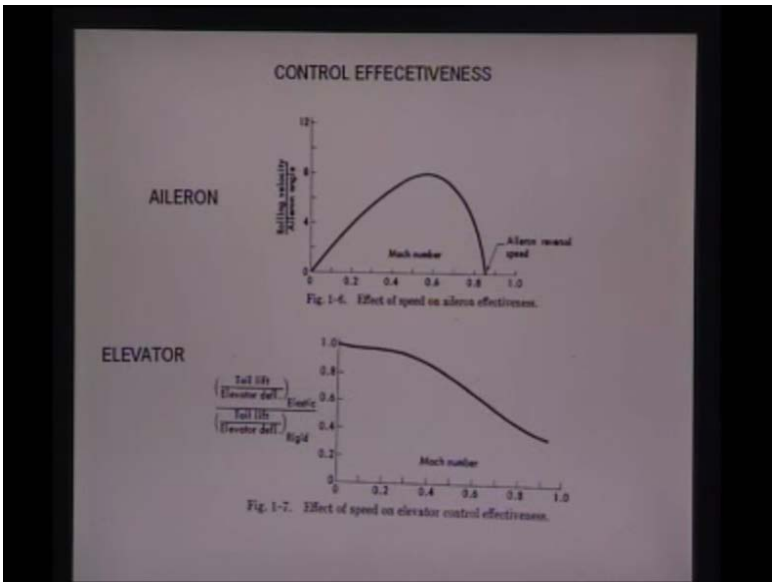

So, the redistribution plays the important role and another one is that control effectiveness are another one this called the aileron reversal. What happens is? If the wing is rigid, and you deflect the aileron what are we doing? When you deflect the aileron, you are essentially changing the chamber when you change the chamber you increase your lift, but at the same time you also change your pitching movement. Pitching movement flows down what happens it is going to reduce the angle of attack of the wing right, now I increase my lift by deflecting this, but the movement is trying to reduce my angle of attack, which will reduce my lift.

So, the combined effect of this initial speeds is fine that is why this is the mark number that is shown here it is essentially written as rolling velocity by aileron angel deflection; that means, as the mark number increases it is fine, but beyond some point start rolling velocity by deflection this that decreasing, which means it make it a point, where it is zero; that means, it is in a fix at that speed whatever you do nothing will happen beyond that speed what you do you will do the opposite? That is if you want to turn left actually the air craft will turn right this is the control reversal. So, the control reversal speed is one control effectiveness is this if it is the rigid air craft you will get one if it is the flexible air craft you get some thong else.

So, this thing has to be analyzed and then this is for the elevator. If the elevator problem is more complicated, because the wing the fuse large itself can bend fuse large the deformation and the attachment of the tail with respect to the fuse a large everything plays a role and that is why here also with mark number. If it is an elastic analyses to a rigid analyses as a ratio, you see it start decreasing the effectiveness of the elevator any control surface, which speed these are all within the flight envelop please understand not that they are beyond the flight envelope.

So, these problem have to be tackled when you are doing a aero elastic analyses and this is something, which I thought you all know plant from does it affect a my aero elastic plant form in the sense wings swipe, yes it has an effect on divergence, usually if you swipe the wing back the divergent speed is clear, but aileron decreases, but if you swipe forward divergent speed will be decreases only one air craft just air craft that is why you do not find any air craft flying with the forward swept?

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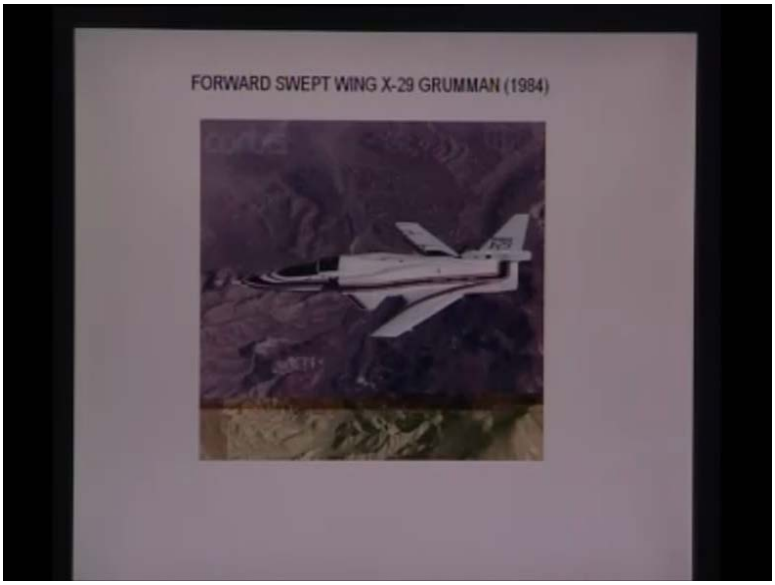

This is just to show you there is one X 29 GURMMAN 1984, because this is aero elastic failure in composite material composite material was used this was the test diagram and… So, you have seen the distribution this problem how this were really 1926 was the first I will write there.

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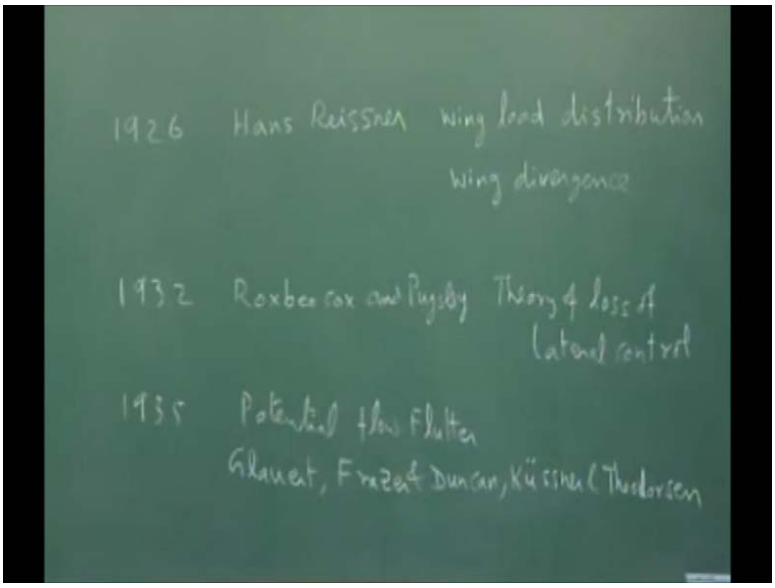

Who you know the credit has been given to the people who contributed 1926 Han Reissner, he represented wing load distribution wing load distribution, and wing divergent and then of course, 1930 in 1932 Rox Ber and Pugsley gave theory of loss of lateral control and in 1935, we have the potential flow flutter was potential flow, but actually it is very interesting at the time these are all mathematician and designers were reluctant to believe theoretician particularly in all this areas, but now what is that in aero elastic?

You know the problem today the field of aero elasticity is what is that we are doing is for every air craft, you have to analyses number one and number two is you are using composite material different structural forms of design therefore, the aero elastic problem assumed greater significant particularly, if the air craft is highly flexible like that we need to have to analyses this type of problem. Now, I will also go little away from the only aircraft that is all only aero craft problem are necessary that may be one question, which may arrive actually the aero elastic problems are important in several areas and those are I will just list them out for your basic understanding.

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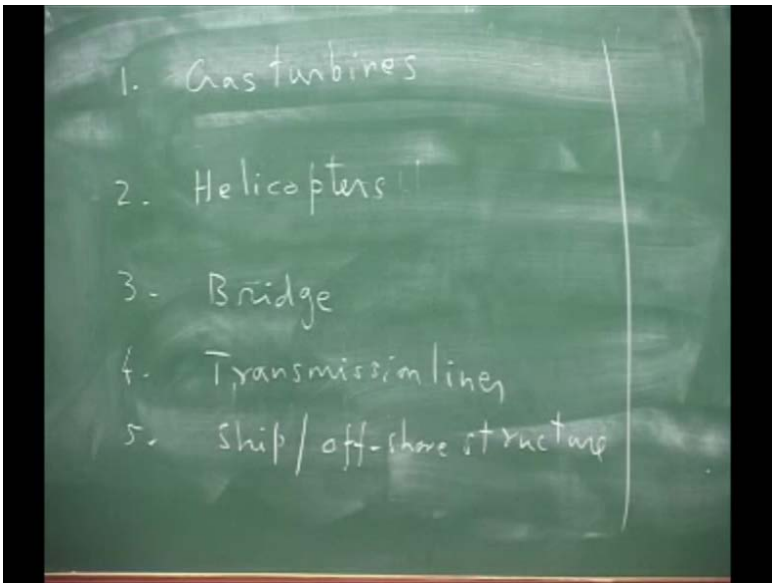

But, we will not be covering those things. That is you can have in a gas turbine then of course, row triving or helicopter these are related to and then you can have bridge, then you can have transmission line and ship off shore structure.

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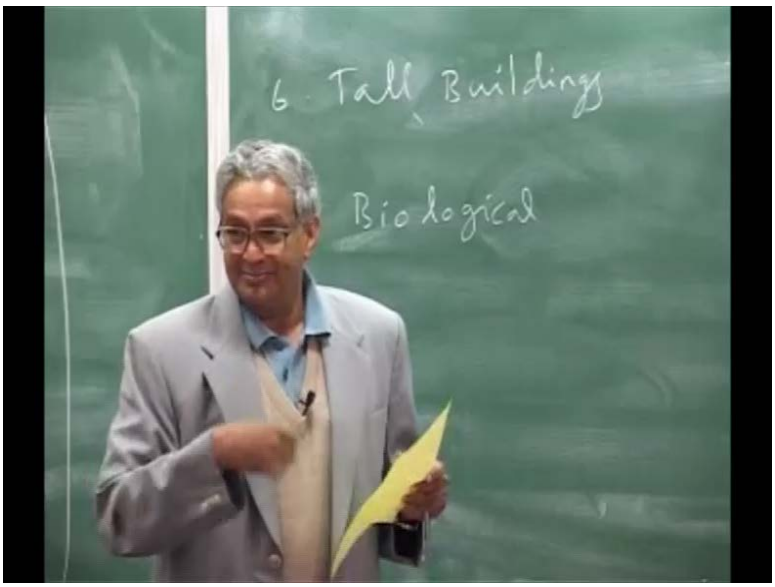

And may be tall building even a biological thing biological here basically, blood flow through various blood vessels, so biological application. So, all this are related to the broad field of fluid structure interaction, but we call it aero elasticity, and then we say we focus on problems related to this any flying vehicles flying vehicles we are not bothered

about these things, but they are also related to aero elastic problem we may call it fluid structural in Torsional problem, but we restrict our selves here again. I would like to say aero elastic problems are very peculiar for the type of air craft. If you deal with gas turbine that is the specialization, if you deal with helicopter that is another specialization if you deal with this it is another specialization. So, it is not that one person can handle everything, because it depends on what is its research interest? And how to continuous this field, but in this course what we will cover a fixed? It because has why they are different is essentially the flow is different.

In the case of gas turbine you have stator rotor everything is there, and the flow go through that actual flow, but then the situation is different in the case of wing it is different flow pattern and you have subsonic fan sonic supersonic all types of designs in the case of helicopter, then it is a rotating wing and its has its own peculiarity of the flow pattern that is why the problem also different type; however, aero elastic. So, it is very essential to understand which field you are focusing on, and then you are perusing that area you may not find the similar type of problem what I listed out here in helicopters similar, but they have the own aero elastic problem. So, in this course we will cover only the problems related to fixed wing type and I thought I will show few video and also some of the reference material.

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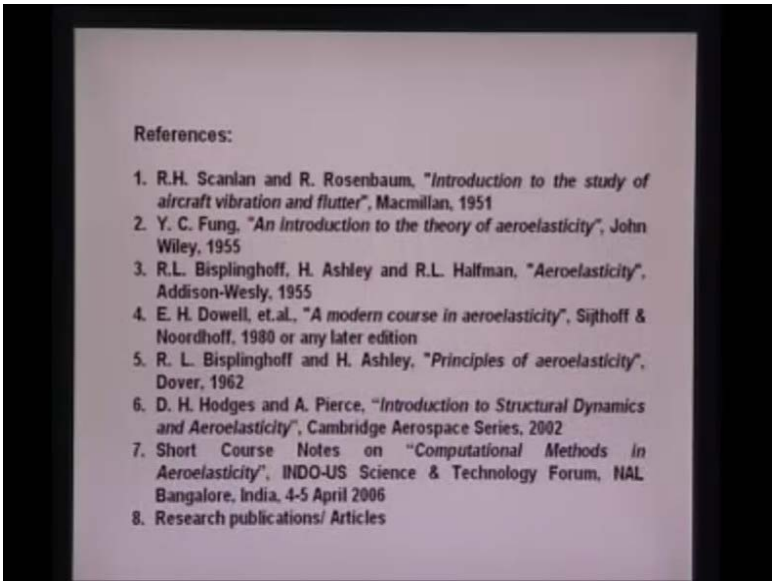

So, first we will go to the reference material.

So, first we will go to the reference material, which you require this are I have listed out the various references, actually Scanlan these are all old book 1951 again 55 that third book Bisplingh off Ashley and half man of aero elasticity that is also same. It is very good book it is there. In the library and of course, I think it is not different now and the forth one is a model course, and they have lot of print this book is also good forth one fifth is some section are handle and of course, this is the latest book hedgers and pierce is the introduction to structural dynamics and aero elastic.

And I also have short course, which was given by under indo U.S science technology. It is computational method in aero elasticity, but this is not available I if you want to have a look it can also have a look at it and then of course, research publication. So, these are our reference books, but I will cover the syllabus in the pretty much I follow 3 and 4, now I listed out the various speech, which is just for indication very know. It is only some kind of a pictorial representation how the critical speech, because we said there is a divergence that is the control reversal or irrelevant reversal and then there is the flutter.

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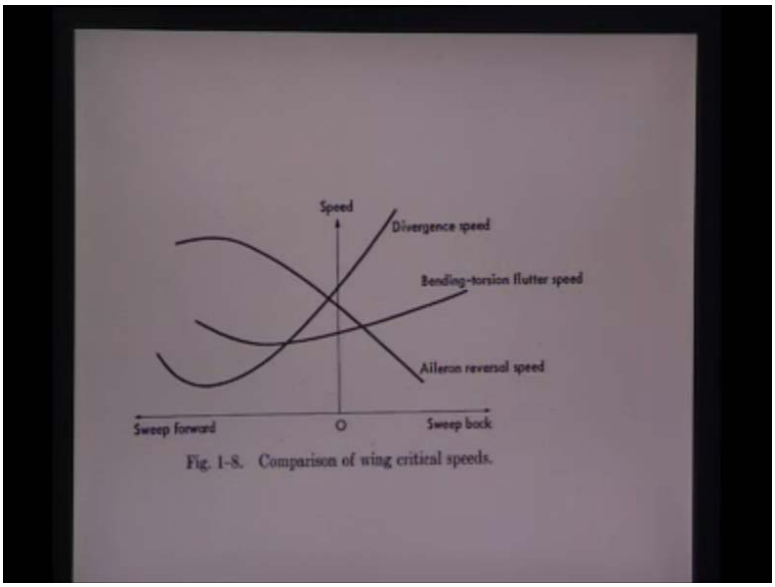

Fig. 1-8. Comparison of wing critical speeds.

Now how they vary with sweep of the wing, if you see sweep back that is what you see normally in all the air craft divergence speed is high, flutter speed is here, but aileron reversal is slow. So, aileron reversal become critical of course, all are critical I am just saying were as when you go to the sweep forward aileron reversal is fine, but divergence is critical and flutter speed is almost like this the sweep, but divergence is the major

problem that is why you do not find? Swept forward aircraft expect for that experimental one X 29, which was I just wanted to show that this is this thing, now I will show some videos of acutely the dynamic aero elasticity, because under dynamic aero elasticity, we had three one is flutter another one buffeting and then third one dynamic flow now what are these problem? I just want to show some of the civil thing first. I start I will hope. It will play see this is the galloping of the transmission line.

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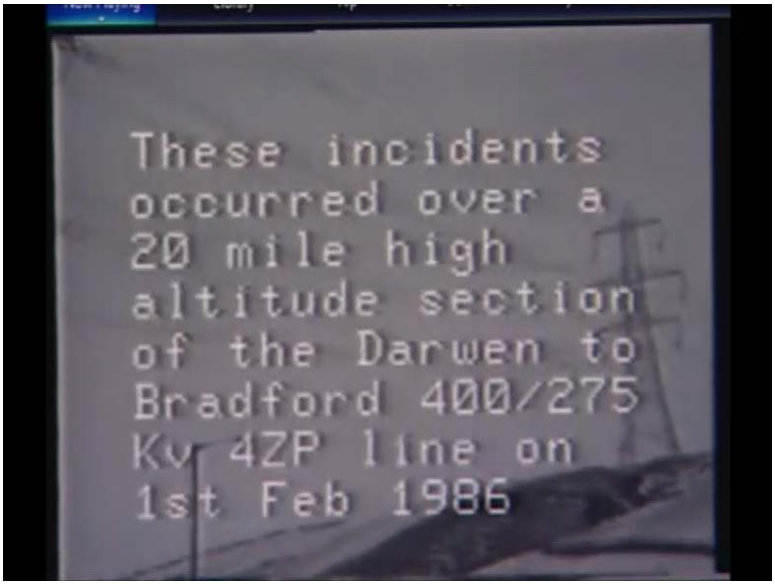

I do not know whether you are able to see this is transmission line, which is vibrating in the craft wing and they will snap just to show how they vibrate the transmission line. Even though this is aero we are not going to deal with that this is for you to know that well this thing happen. And then the going seven four seven all are video this is and another civil structure I will show this is about the bridge.

This is always shown at the Tacoma narrows whenever they want to say any aero elastic problem this bridge open and within the short. It collapsed say one day it started and collapsed collapse 1942 or something like that, but for the wing I will show few of them videos this is how the this is the vent anal how wing start vibration, you do not do anything it is just the natural flow that makes this, and similarly here there is a tail part tail stabilizer this is also in vent anal and this is another one, which we have mounted we created a small flutter model you see the kind of vibration it happen it is an aero foil supported on four actually this is the spring mechanism.

Mounted it, and then we allowed it to in the low speed tunnel, and you say at particular speed that really very violent isolation. It has I do not know. It is clear or not and this is another one, which I thought I will show you this is the tail see tails, then controls it. So, these are actually the real issues, which one has to analyze. It now the question is how do we analyses what do we do that? Is what entire course is about even develop the background material how do we formulate the equation of motion, and then what is the method of solution? And how do we predict various phenomena? And that is what we will cover in this course, but now I would like to go little into just a introduction today.

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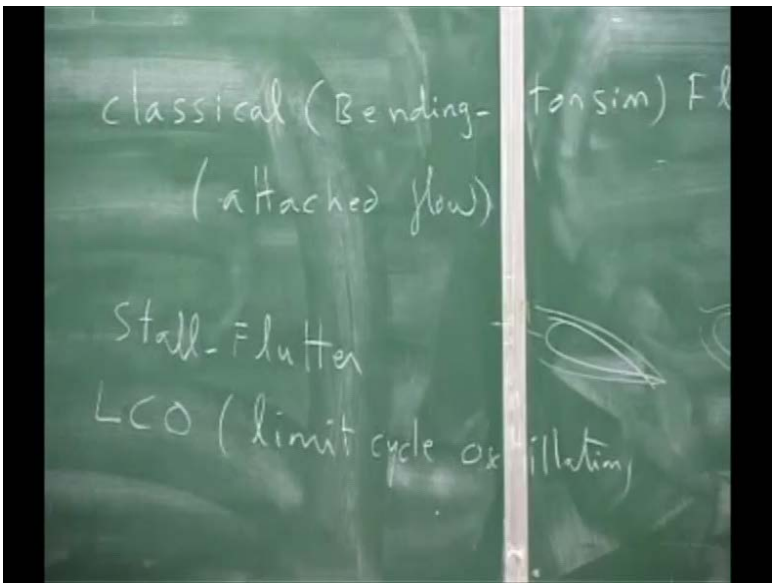

The flutter, what is flutter? What is buffeting? A dynamic response flutter normally, we refer any two or more degrees of the freedom of the structure. In case of wing two or more degree, please note that when they combine couple, and then get into some kind of osculation usually this is called the classical flutter. I will put it classical within bracket I will write bending torsion flutter; that means, the being motion and the torsion motion they couple to create a instability. That is what you saw that video? When it really went into violent oscillation, because violent structure oscillation will break, but is that all you have only this type of flutter, you have even see there can be even a single degree of freedom flutter, which can be there single degree only torsion that to in turbine blades the torsion flutter, which are because this is almost rigid.

So, you will have the torsion type of problem that is the single degree of freedom factor that can happen in turbine blade that is why I said? It is not the same problem, every were another aspect is non classical that we classical non classical; that means, you can have this is a classical when I mention it is under attach flow condition, we can take it as attach flow condition attach flow over the aero foil no problem suppose, but you have attach detach attach detach, then it is like a stall inducing a vibration. So, you can have stall flatter in this situation what happens your aero foil will be at one point flow is going like this, and in other point flow is separating it and again. It come attach this is different kind of a problem, because you need to know the detach flow also all the characteristics how the pressure.

Varies everything and that comes under stall flutter kind of problem. Now people also talked about this is not part of this they call it L C O limit cycle oscillation, now what is the limit cycle oscillation? See here, if you go beyond some speed the flutter stage it is going to violently break were has in this what happens after some times is it continuous to vibrate there is the continuous vibration happening. It is not a diverging vibration now here it will non-linear system can exhibit, because non-linearity you may have to come with the non-linearity this is analyses with linear system, you can solve thus our potential flow is linear theory. So, we are doing that linear theory were as here stall flutter is not a linear theory anymore, because you have attachment detachment everything happening and here the limit cycle can be non-linear. It could be structural non-linearity it could be aero dynamic non-linearity you follow.

So, these are the types of flatter problem. So, in this we deal with bending tertian, but in the case of helicopters there are of from different type, you also have stall problem, but not flatter we do not call it flatter that we have, because there helicopter blade. It will bend up out of plane it also will bend in plane. So, you have a flap lag instability, where as there is no lag motion in the case air crafting wing, you have only bending and tertian were as in helicopter blade, you have the out of plane bending in plane bending tertian everything the outer plane and in plane themselves can couple to give you plug in stability that is why I said? Each line flying vehicle has its own special characteristics problem.

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And then the buffeting part this is usually happens the disturbance in the flow causes the vibration that is suppose, if you are having the high C L match pull up of the air craft the wing, because there is the change in the loading everything on the wing and that creates a vortex behind it that disturbance goes and effects the tail, and the tail starts vibration under that circumstance you there is little different the disturbance of the flow is creating the vibration, now you say what is the difference between this bending and that problem here, please note it is one aero foil that is all the flow is please understand.

It is steady flow is steady this is there, but this is flexible through as you go now when this oscillate in a steady flow, where it creates lot of disturbance behind usually this type of problem is this is the classical flutter this we do not call it buffeting is when the flow itself is unsteady flow, because it is due to some other structure in front and that is that time variation of the flow is affecting my tail vibration, now only way to avoid that particular problem is you position your tail suitably, because that is more complicated problem, because you do not know how the flow get disturb, because of a high C L.

So, the positioning of the tail plays a major roles there and of course, the last one is the dynamic response is an air craft landing the landing loads immediately. It is a impulse type of loading very short duration, but heavy load and that will make the wing vibrate that is the dynamic response of the air craft under landing situation or even gust response again the atmospheric gust is always represented by some mathematical representation.

This is it statistically collected and then they represent like one minus cosine R S step gust, and see it if comes and hit how the air craft will vibrate? This is what they normally treat in the dynamic aero elastic problem, but for our case we will be studying the flutter problem and have dynamic aero elastic condition.

So, the entire course now I will the I have given you the background of the history and some of this, what are the aero elastic problems? Which you encounter, because what we do first is structural analyses, we will introduce, how do you model the air wing? We will restrict the whole study to wing and two d aero point this is what we are restricting our study to.

So, all the things related to that we will first modeling of a air craft for bending portion, because even though you have done the structure one course. It is very important that those details are required why, because in a what is that you have learnt in a aero foil what are the various point important 0.5 minutes? What are the important points are? One is aero dynamic centre, which you may say 25 percent card for I will call it a c sub sonic 25 percent supersonic subsonic will be half 25 percent card and structures, you take elastic or shear center or elastic. So, I will mark that elastic axis are shear center and then inertia you can have mass centre. I think now we can cut aero dynamic centre mass centre elastic axis now mass centre goes to towards, your structural design what material you have used? Now were put this stiffness etcetera aero dynamic center is purely shaped that is all nothing else were as elastic axis are the shear centre that again depends on your structural details.

So, now if you are given a aero foil section you have to know all this points why it is critical? If you take the static aero elastic problem first you know that your lift is going to integrate the value lift and movement act. The aero dynamic centre the vertical centre of the lift now the wing will twist about elastic axis not mass center that is dynamic case static case elastic axis, now you see if will start twisting. So, all these centre become very critical. So, modeling first learn, how do you model the structure? So, I would say you better learn how to get the elastic axis at the shear centre of in a small structure, which was start in your structure course, but you must know that because if I give you one problem were find out that you have to go then under calculate find out the location of the shear centre and then calculate the divergent speed wing you must know all this and then the distribution of it.

So, these are critical now in this course. I will not be going into everything all this, because I presume that I know it, but potential flow I will introduced, because unsteady aero dynamic theory is not in the regular course. So, I will introduce unsteady aero dynamic theory also how do you model a flexible wing in an approximate manner, and then how do you solve this problem that is what we will be studying in this course from next class we will start this.