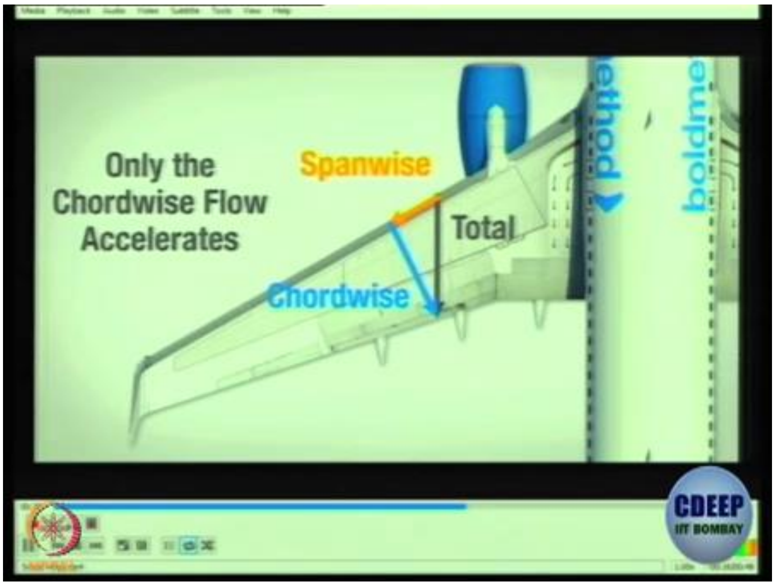
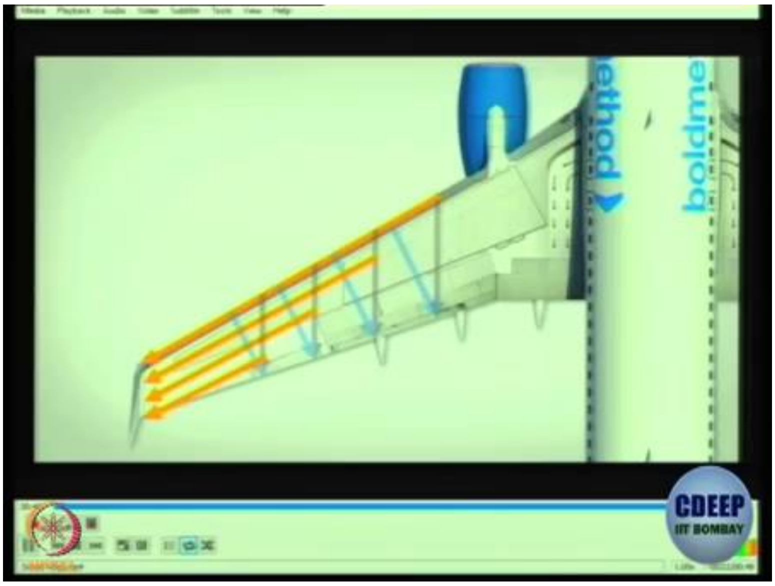
Introduction to Flight
Professor Rajkumar S. Pant
Department of Aerospace Engineering,
Indian Institute of Technology, Bombay
Lecture number 06.3
Swept Wings

So, let us see this video works

(Refer Slide Time: 00:33)





Video: By sweeping a wing we actually delay the supersonic flown ways to critical mach number. By tricking the wing make it feel like it swings slower than really is. We do this by creating two different components of air flow. The Chordwise component travels perpendicular with leading edge along the chord line.

That is the only component that accelerates and since it is less in total main flow only accelerating part of the air which means we can flight faster before we have supersonic flow. However, will also creating a Spanwise component to flow which moves parallel to the leading edge from the root to the wing tip. And as you move out to wing tip that Spanwise component stacks up making the wing tip feel like it flying slower than it actually is.

(Refer Slide Time: 1:08)

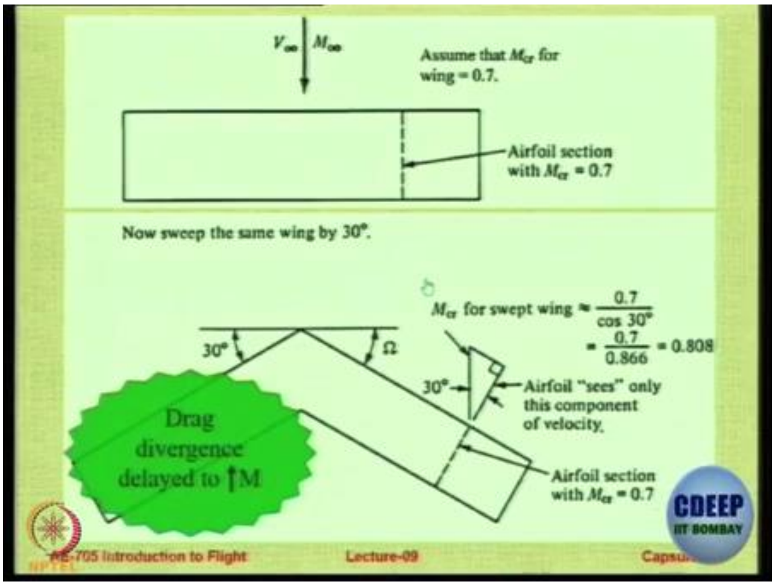
Professor: Ok, so remember one thing that you may have swept the wing and created a normal component lower than free stream. But by the Spanwise component of flow, you actually create problems because, the ailerons, the control surfaces etc. ok. There are flaps also there. But flaps will not be diployed at such high speeds. But you might deploy ailerons and these control surfaces which are mounted towards the tip, now get sideward flow.

So their effectiveness is also increasing. Sorry, decreasing. So their effectiveness is also decreasing, which is not desirable. So sweeping back has its own problems, in fact, if you talk to an aircraft design specialist, you will get this particular answer 'Never provide sweep unless it is essential from the aerodynamic considerations.' Because everything else about sweep is bad, nothing else is good.

It makes the wings more flexible, it makes the wings heavier; it creates control surfaces less effective, ok. Everything else is bad about sweep back. Even sweep forward. Ok. The only problem is that when you want to fly fast then ability to fly fast and hence, have a lower wave drag is the primary consideration and other things are going to take a back seat.

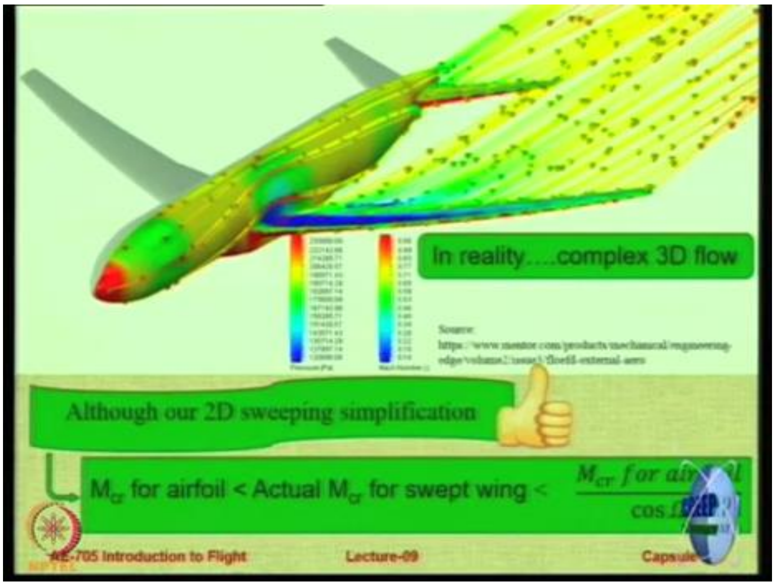
So, even in transport aircraft where weight of the wing is very important where control ability is very important. Since the benefits of sweep back in delaying critical mach number are so high. You are forced to provide sweep back. So, the moment you have to fly beyond mach number 0.7, 0.75, etc. you grudgingly provide sweep, grudgingly, because unfortunately other solutions are not as elegant as sweep.

(Refer Slide Time: 03:47)



So this is what it is just a repetition. You have an Airfoil which is at M, mach number of 0.7. So, you have no sweep. Therefore, the two sweeps are same. The moment you sweep it, then you have a component and that component (come along) normally is going to reduce. Ok. So, effectively the mach number, the free stream mach number which was 0.7 was critical mach number earlier. It will become 0.808 by a simple approximation. This is only for indication.

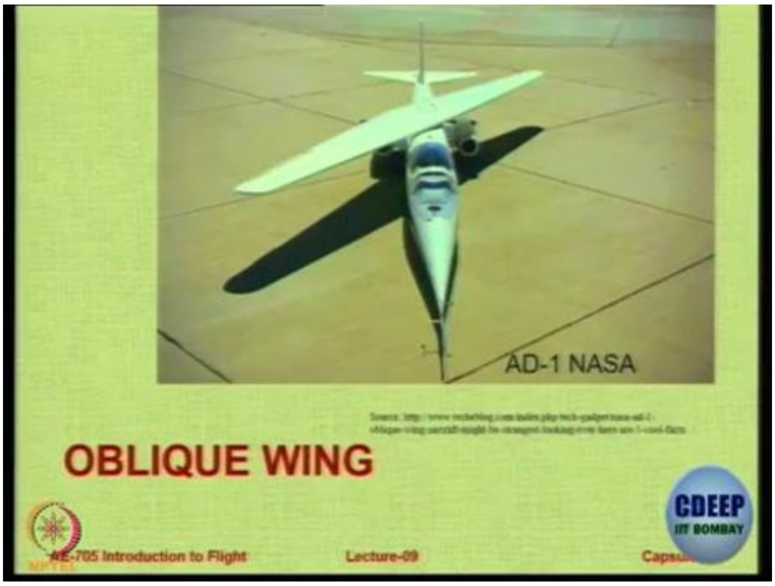
(Refer Slide Time: 03:49)



Actual story is very complicated. So, actually when you provide sweep back, you get a large amount of complexity. You get lot of 3D flow. But our assumption, ok, is a sweeping assumption. It is ok. But still it works. So, whatever we discussed in the class saying that, when you sweep the wing behind you have such reduction that is the very simplistic explanation. In reality you may not get exactly that much improvement

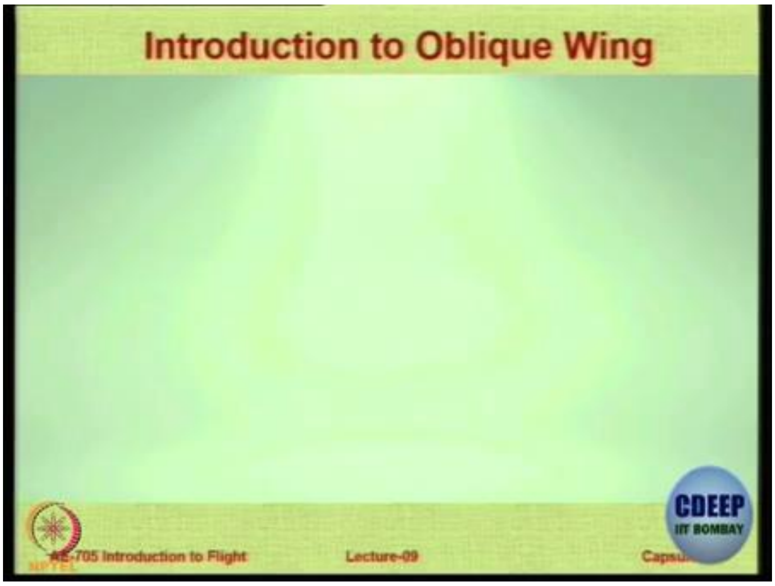
Because the moment you sweep, you bring in Spanwise component and the Spanwise component is going to create a very complex 3D aerodynamic pattern and hence, the benefits of the sweep back may not be as pronounced as the simplistic explanation. So, do not say that always if the free stream mach number is M infinity for un-swept wing, it will be M infinity upon cos theta for swept wing. That is just a simple approximation, just an indication but not the total story. The actual M critical is actually a function of many many many many things.

(Refer Slide Time: 04:55)



So now, there are other solutions which have been given. But we do not see them very often. Ok. It is actually very weird and that is why we do not see it. But it is highly beneficial. Ok.

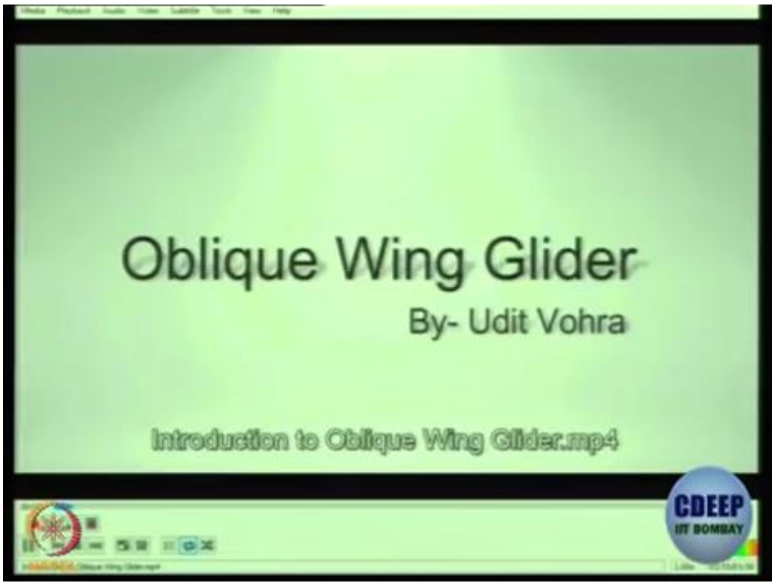
(Refer Slide Time: 5:17)

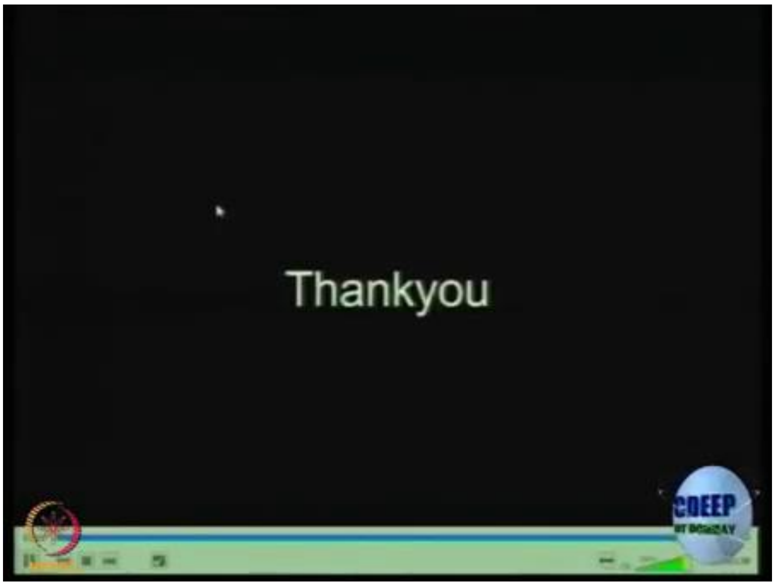


Let us have a look. So, one intern who came and worked with me during the summer and his content will come after mid-sem because he worked mostly on performance. So, I will introduce to him later. But right now I will show you a small video. So, this a small video that introduces a concept of ‘Oblique Wings’.

Video Presentation:

(Refer Slide Time: 05:34)





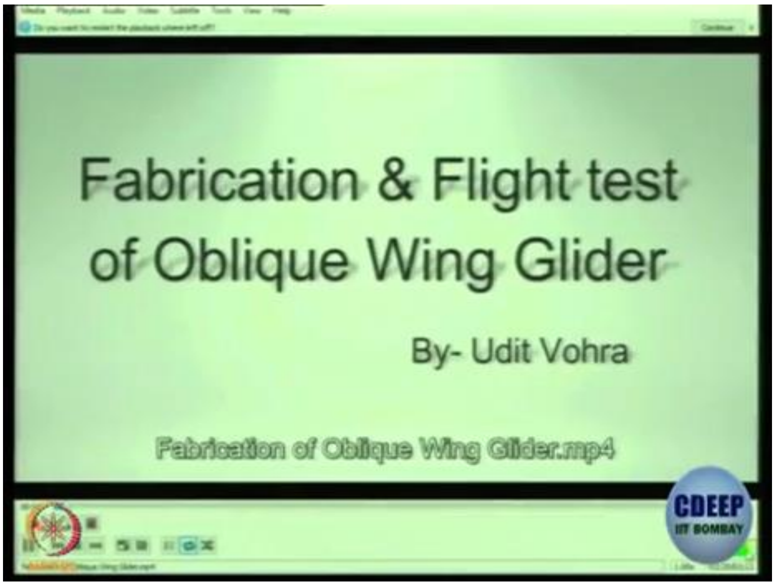
In 1958 R. T. Jones suggested that the aircraft with asymmetrically swept wings which we call as the Oblique Wing will offer high advantage at high transformic speed and low supersonic speed. You can see the oblique wing in this aircraft. This is a small glider model which have made on using balsa wood. The Spanwise length of this glider is eight and half inches whereas its width is only one inch.

So, why do we prefer Oblique Wing instead of a normal swept wing. The answer is clear that, the minimum lift dependent wave drag actually will be achieved when the lift is elliptically distributed along the span length on the wing. And it has been seen in a supersonic flight that the lift gets distributed over twice the length. Which means, which is the effective length becomes twice which actually help in reduction of minimum lift , wave drag by a factor of four.

Having on to it a single rivet in Oblique Wing will provide structural advantage over the two rivets which carrying a manning load in a variable international sweep aircraft. So, there were some challenges such as the significant variation in rolling moment with changing the angle of attack and the unusual inertial coupling and aero elastic characteristics which were which made the dynamics of such an aircraft complicated as well as those are the problem with the propulsion integration of such an aircraft.

How was it solved? With the help of modern competition methods and modern flight control the system technology which now makes a strongly coupled and more stable feasible aircraft system.

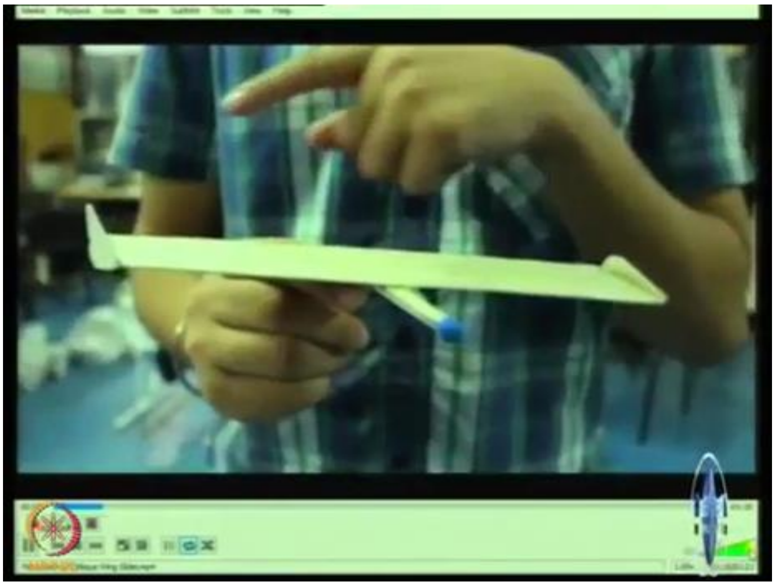
(Refer Slide Time: 07:33)



Professor: Ok so, this is just video we just gave us some ‘gyan’ about what this is. Let us look at his experiment. So what he did is, he actually fabricated a small oblique wing aircraft. Just to see how it performs.

Video presentation:

(Refer Slide Time: 07:38)



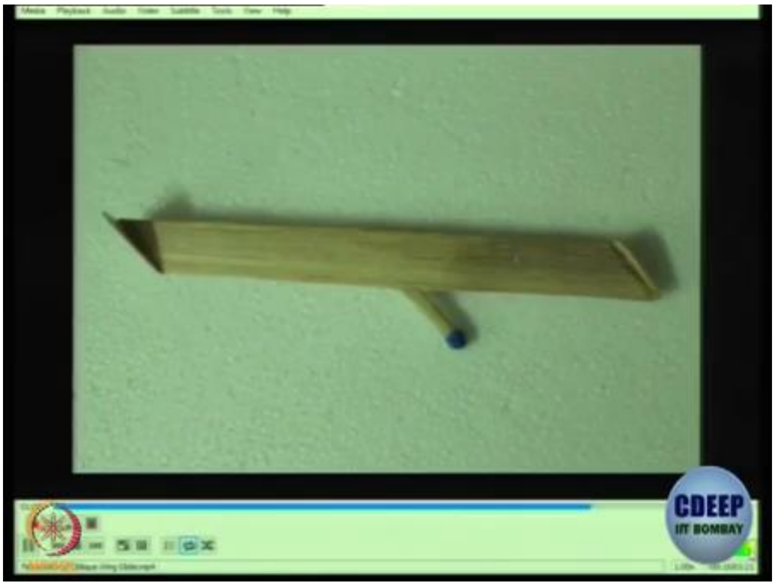
So now, here I have a Oblique Wing glider which is made out of balsa wood and as you can see the Spanwise length of this Oblique Wing glider is eight and half inches whereas its width is one inch. With the help of sand paper the edges has been made curved upwards and using water we have just bended this upwards because the slight bending will actually help in smooth gliding.

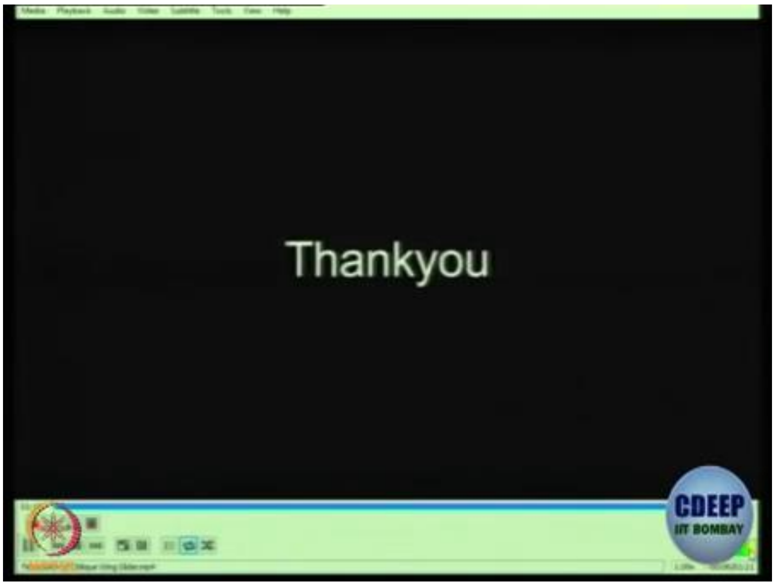
Only things that need to be taken care of is that excessive standing do not just remove the extra part of this glider, as well as node bending can result in stalling off in aircraft rather than the smooth gliding of this aircraft. Another major issue that I have been facing on this aircraft is the CG balance of this glider. This angle is 135 degree.

(Refer Slide Time: 08:25)

(Refer Slide Time: 08:27)

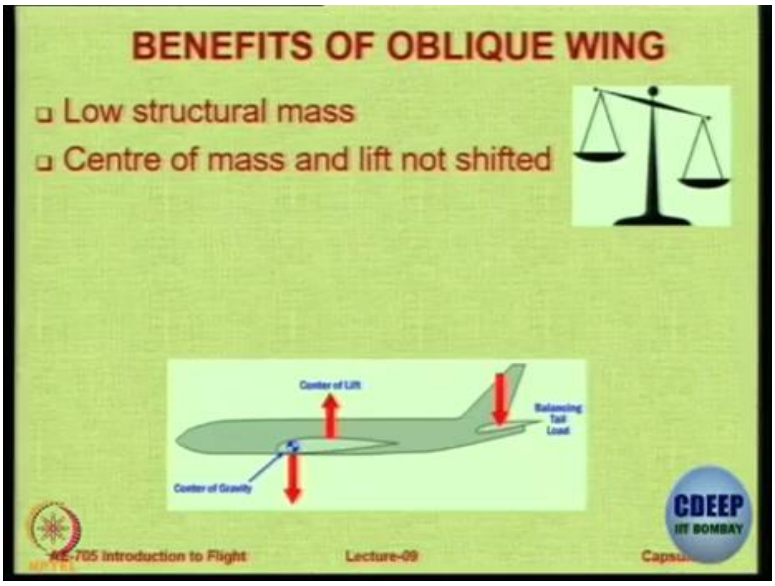
(Refer Slide Time: 08:34)





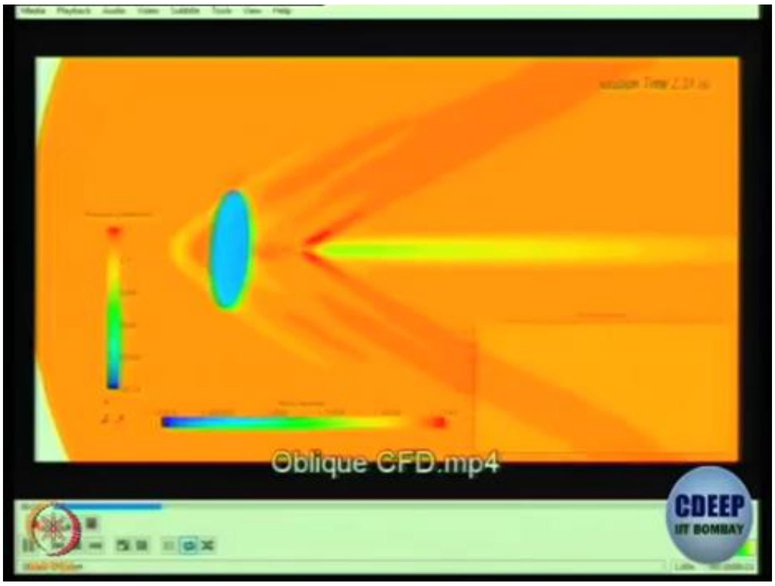
Professor: You can see there are rolling moments introduced and that is what he was saying. And that is a problem with Oblique Wings. It is very difficult to create Oblique Wings which have a perfectly balanced rolling moment. Ok. So, that is a reason for so, we we did an experiment and it was successful. We were able to fly this we were able to fly this reasonable distance. But it is not really very common.

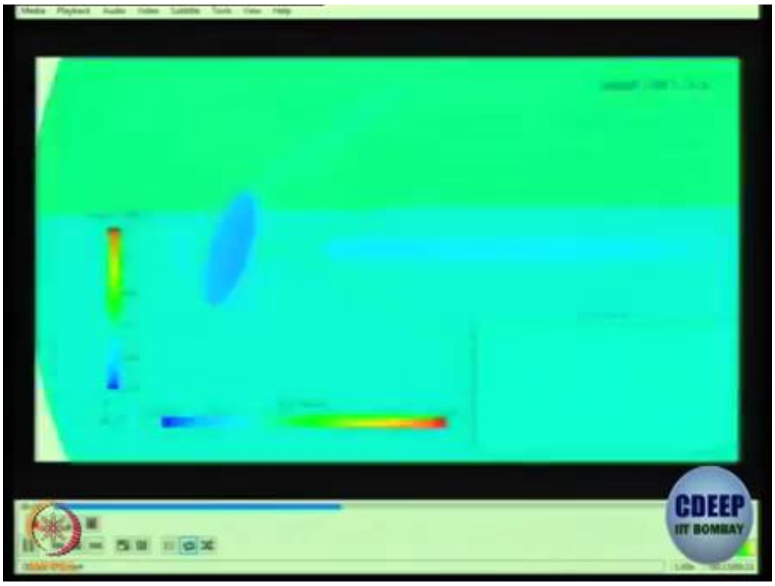
(Refer Slide Time: 09:05)

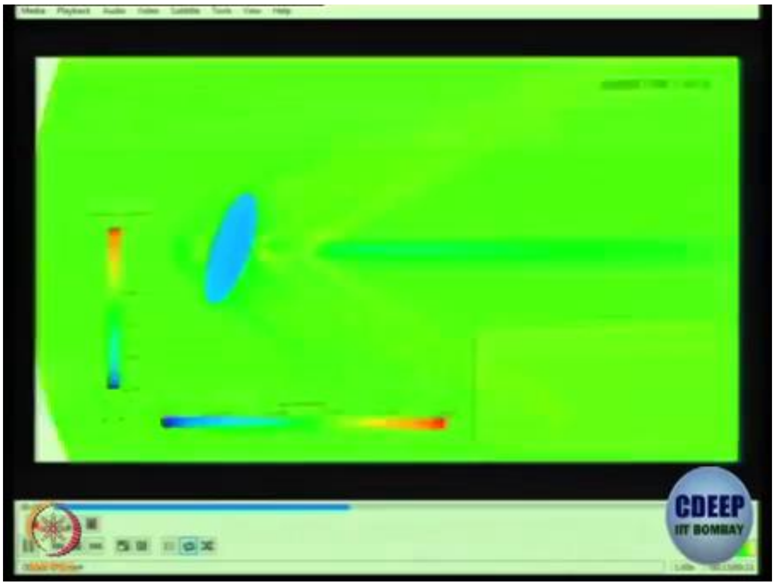


So, there are some benefits, there is a lower structural mass. The center of mass and lift is not shifted. Because on one side it is swept forward, on one side it is swept back. As against either sweep back or sweep forward, the center of gravity is completely shifted ahead. Here it is not shifted. There is a lower wave drag. Let us see, if our video works let us see, how a wave drag is lower?

(Refer Slide Time: 09:39)

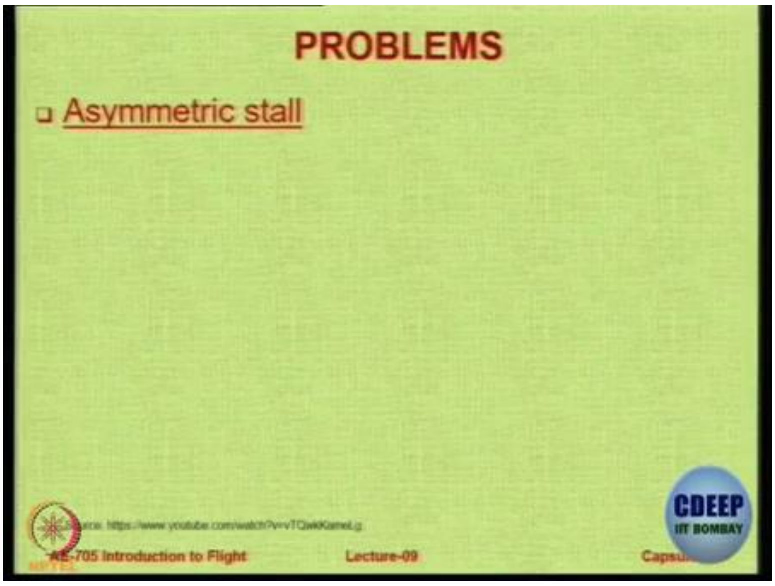






So, this is the CFD analysis, real time CFD analysis of an of a wing at various angles. So, the colours you can see the solution time is increasing in seconds. So it is 7, 8, 7 seconds, 8 seconds. And the colour coding is such that when you go towards the blue you have higher values and when you go towards the red you have lower values for the pressure coefficient as well as for the mach number. So, you see the graph that you see on the bottom figure. It shows you, how as a function of time a value of Cd is changing. Ok.

(Refer Slide Time: 10:34)



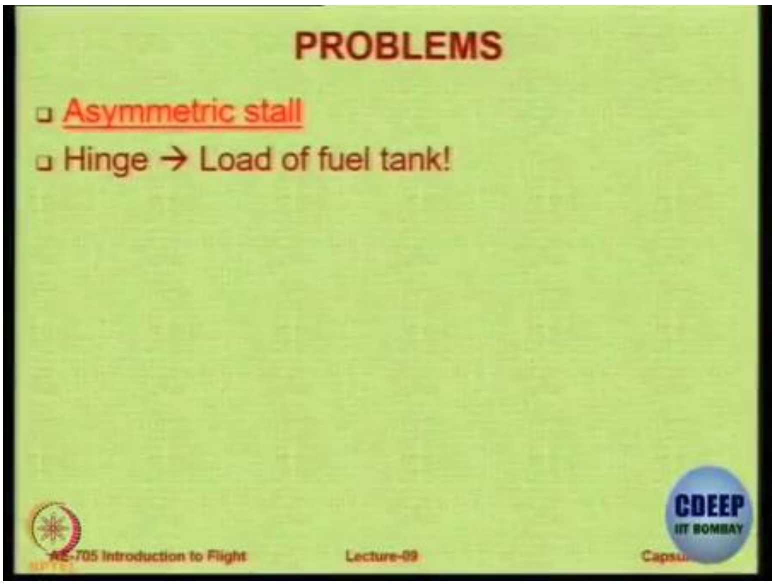
So, this I will, but there are some problems. One problem I have already showed you in the flight, when it was flown by Udit you realized, there is asymmetric stall.

(Refer Slide Time: 10:44)

(Refer Slide Time: 10:55)

Ok, so, when the aircraft stalls you do not have both the wings stalling at the same time. That would be easy for the pilot to handle. What sometimes happens is that only one wing will stall before the other. So, then you have this kind of a problem. Now, to recover the aircraft from this kind of a motion as you saw in this video is not very easy. And if you have one wing swept forward and one wing swept backward there is a very good chance that there will be an asymmetric stall whenever stall happens. So, that is why oblique wings are dangerous. Ok.

(Refer Slide Time: 11:45)



Then the whole wing is going to hinge at one particular point. So, there will be a lot of load on that point. So, that point will be heavily loaded and the place where you are going to, so you imagine you have a wing which carries fuel and then you are moving the whole thing along the hinge. So that is a serious problem. Then we have something called as ‘inertia coupling’. Now, I would like to cover this it is a flight dynamics problem. But it I found this very nice animation of inertia coupling.

(Refer Slide Time: 12:16)

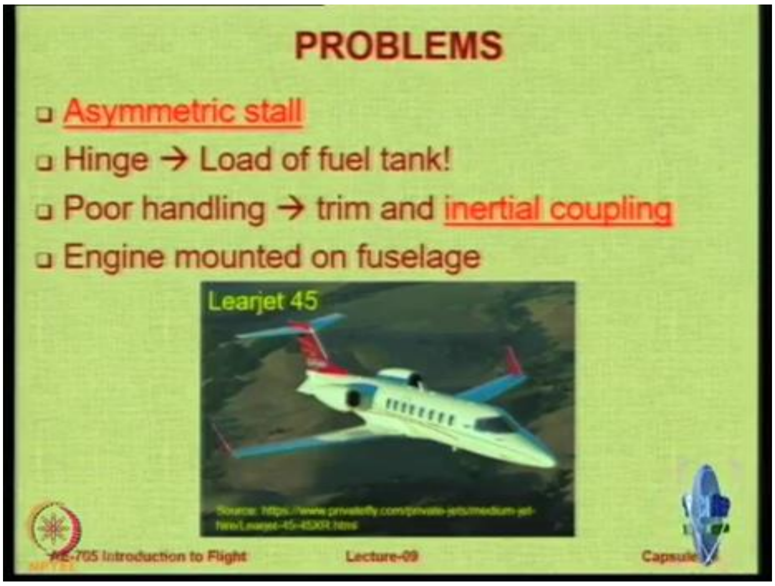

CDEEP
IIT BOMBAY

CDEEP
IIT BOMBAY

CDEEP
IIT BOMBAY

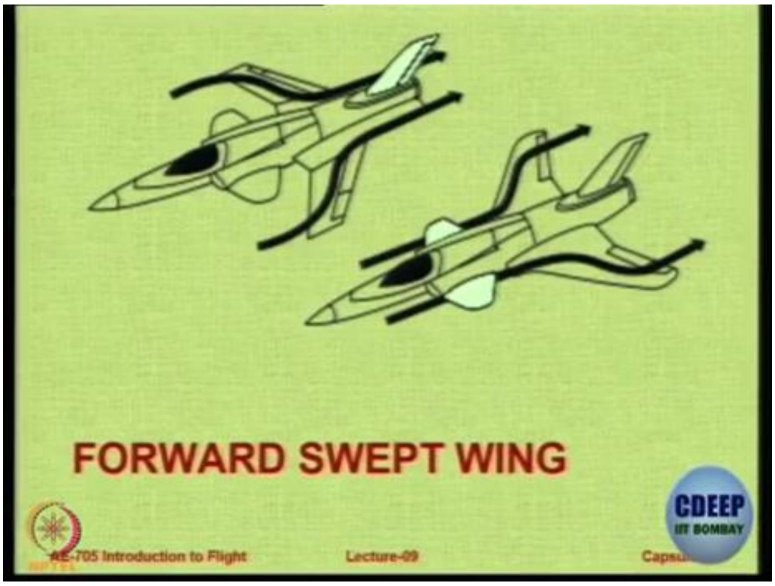
So, inertia coupling happens when two modes of the aircraft start getting coupled and then one of them causes the other to accentuate. And then it becomes completely uncontrollable.

(Refer Slide Time: 12:38)



This is on a simulator; this is on a simulator, so you can see. Ok.

(Refer Slide Time: 12:42)



Now, let us look at forward swept wings. Forward swept wings are better than rear swept wings actually speaking because as you can see the Spanwise component is along the, along the root. So therefore, actually the flow is being gathered by the wing on the root and you can make it flow over a controlled surface and make it very-very effective. But there is a problem, there is a problem regarding forward sweep and that problem was encountered by during flight testing.

That problem is called as Torsional Divergence. So what happens is, let us say this is, let us first have look at some videos of forward swept wings.

(Refer Slide Time: 13:30)

So, here is an example of a forward swept wing.

(Refer Slide Time: 13:51)

Professor: So the initial…

Video: Through the use of the X29 is a test vehicle. Engineers will be able to explore the forward swept wing's unique mixture of speed, agility and slow flying qualities.

(Refer Slide Time: 14:05)

They will also explore the interaction of the wings with the forwarded canards and rear step flaps.

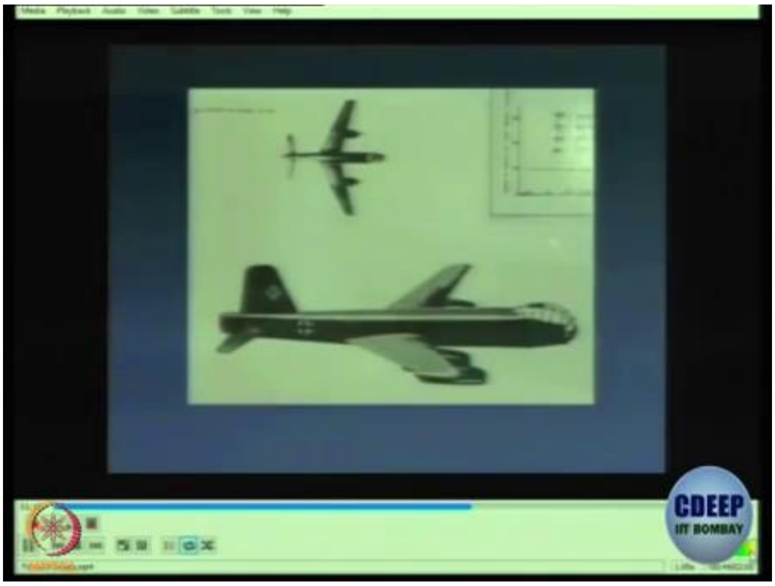
(Refer Slide Time: 14:10)

In this design all control surfaces are linked together by computer.

(Refer Slide Time: 14:16)

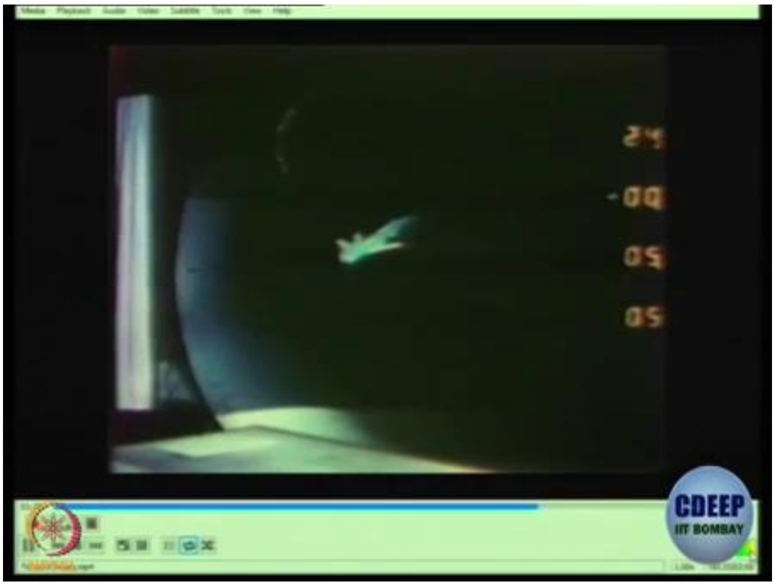
Roger Stack, NASA’s program manager got the X29. All three of these surfaces are tied into a digital computer and air deflection or movement in flight is optimized by the flight control computers. In a, pilot makes a stick in fit to the airplane, these three surfaces all will react simultaneously to get the optimum response of the airplane to minimize drag and maximize performance.

(Refer Slide Time: 14:43)



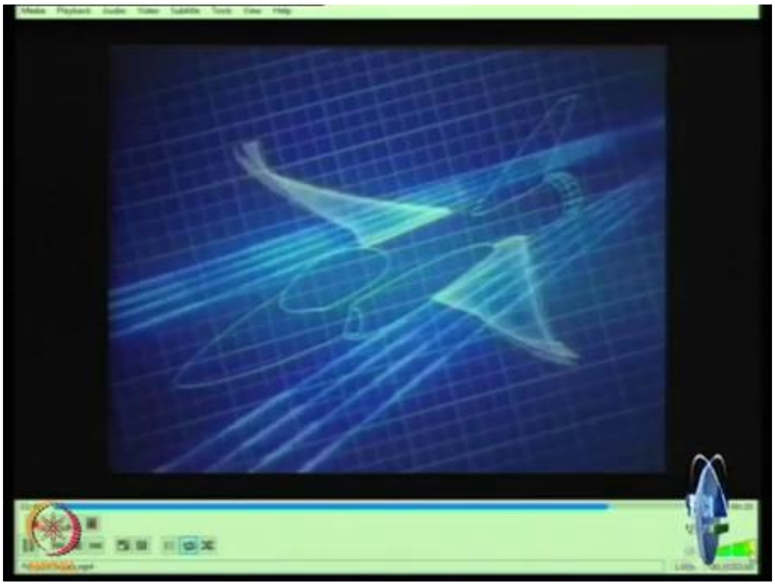
The forward swept wing concept was first explored during World War 2, when the Germans built a test bomber with 15 degree forward swept wings.

(Refer Slide Time: 14:54)



The bomber had a limitation which is in inherent to all forward swept wings. It is called Structural Divergence and is illustrated here.

(Refer Slide Time: 15:00)



As soon as higher speeds are realized the wing tips experienced tremendous twisting loads which flex the wings and can relatively tear them off.

(Refer Slide Time: 15:20)

The X29's wing is crisscrossed with 750 composite tapes of such material as carbon, Kevlar and glass. The materials are oven in a way to contract the twisting poses encountered by the wing at transonic and subsonic speed.

Professor: So, this torsional divergence one has to understand. Since, the wing is located ahead of the center of gravity. As the angle of attack increases the loads on the wing will increase and the increase of the load will be such that the tips are deflected upwards more than the root. Why? Because the wing is flexible and the distribution of load is ahead of center of gravity so as alpha increases load increases.

So, something increases ahead of the center of gravity so the wing will deflect upwards. When wind deflects upwards its angle of attack increases. When angle of attack increases the load increases. When load increases the wing flexes upward. So, very soon you have what is called as a Torsional Divergence and there are the examples in which the wings have been torn off during flight. So, this concept was started, experimented and then people says this is very dangerous because the wings are breaking away during flight.

So, it was kept in the cold storage. What was the advantage? The advantage was that Spanwise component coming towards the root is beneficial; you can use it to energize the control surfaces. On the other hand with sweep back you are making flow bad over the control surfaces. So then, when we develop expertise and composite material, we were able to provide flexural strength in the direction we want. So, it is called as 'Aero-elastic Tailoring'. Just like a tailor stiches a shirt or a suit matching with your dimensions, providing more material where needed and less material where not needed.

Similarly, using composite material, because you have lay ups and you have various orientations of flights available to you. You can actually strengthen the wing such that it is without heavy weight; it is strong in the flexural direction and not that strong in the direction where we do not expect the loads. So, with limited or with a lower weight of the structure, we were able to provide sufficient strength. So, when that technology was available, the forward swept wings have come back.

But as the testing of X29 shows, the net result of the forward swept wing experiment was that it is too complicated, requires very-very accurate and précised flight control system. It is prone to other problems of control ability and hence the technology is demonstrated and kept but it is not popular because the problems that are encountered are actually more than the benefits ok. So, all these are benefits. However, the problem was in the instabilities. So there is a phenomena called as a 'Dutch Roll'.

(Refer Slide Time: 18:36)

Video: Make it remember by the Dutch Roll. Firstly, there is a damping ratio which is have quickly the most important task. There is a frequency which…

Professor: So, this is the coupling between aerodynamics and structures. The structure of the aircraft provides damping to the oscillations and disturbances provide oscillation. So, there is a frequency at which the aircraft generates disturbances because of its aerodynamic configuration and the atmosphere. And depending on the structural configuration there is a frequency at which those are damped. Now, if they are not matching then you get a phenomena of Dutch Roll.

So, you can see now

(Refer Slide Time: 19:18)

Video: The speed of the motion itself and the Roll T or ratio which is measured, how much roll, how much bank angle, those are the three aspects which you have to assess and they are all important in the runway.

Professor: So, this is a Dutch Roll, when the aircraft starts oscillating in roll and yaw. Ok and this is a very common problem.

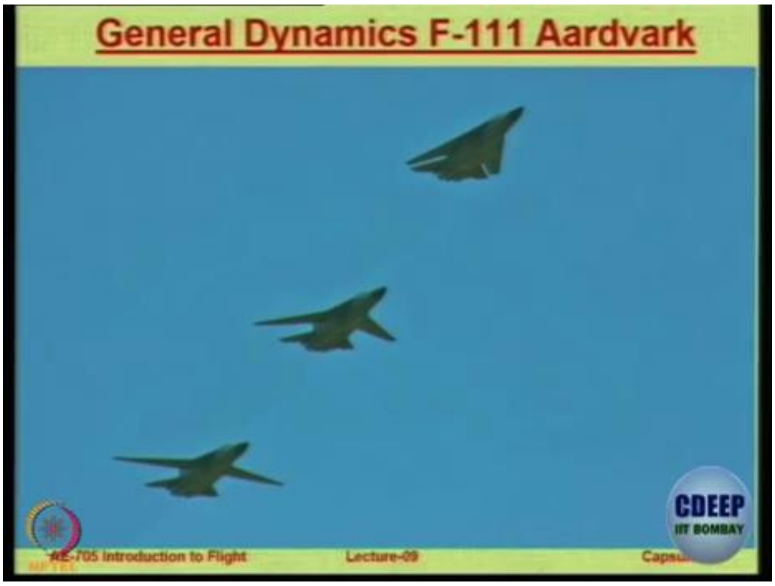
(Refer Slide Time: 19:48)

This problem is more pronounced in forward swept wings. I have already talked about torsional divergence. Ok.

(Refer Slide Time: 19:50)

So then the answer to that is variable sweep. Variable swept wings. Basically you provide whatever sweep is needed at whichever condition.

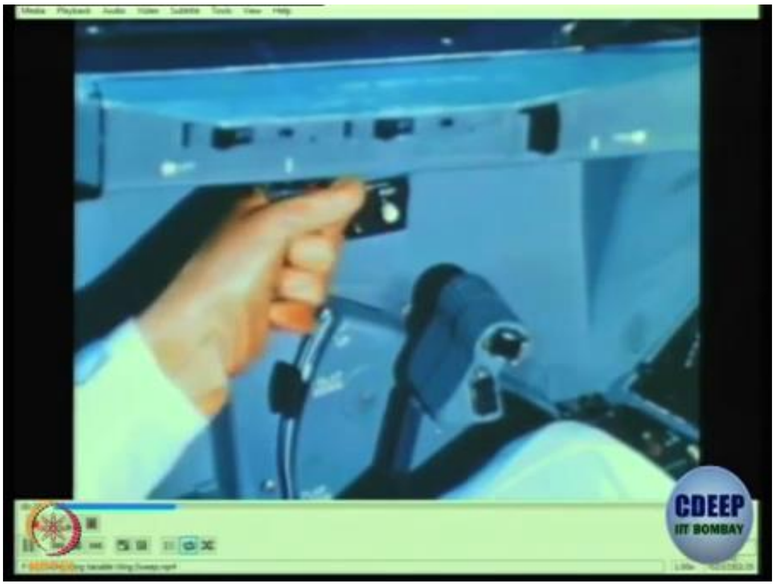
(Refer Slide Time: 20:01)



So, this is an example of an aircraft. The first aircraft to provide the ability to sweep the wing at whatever angle you want, at whatever speed you like is the F-111. So, let us see F-111 in action.

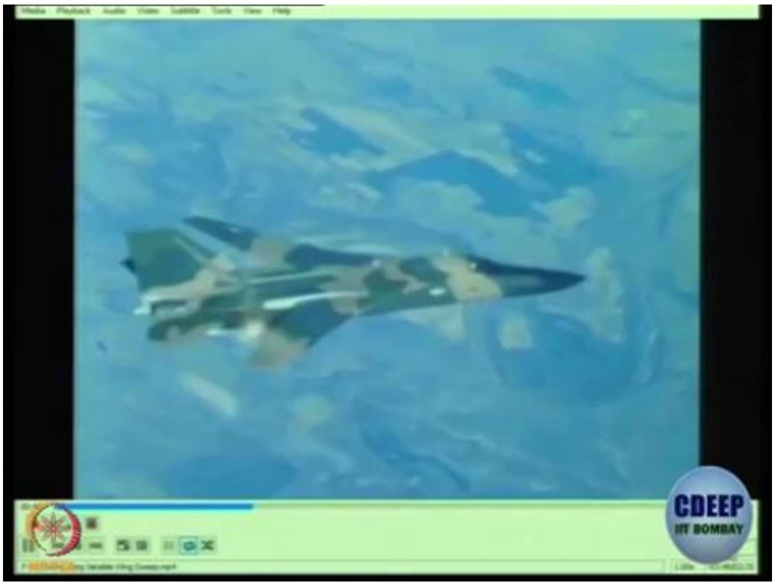
(Refer Slide Time: 20:22)


CDEEP
IIT BOMBAY


CDEEP
IIT BOMBAY

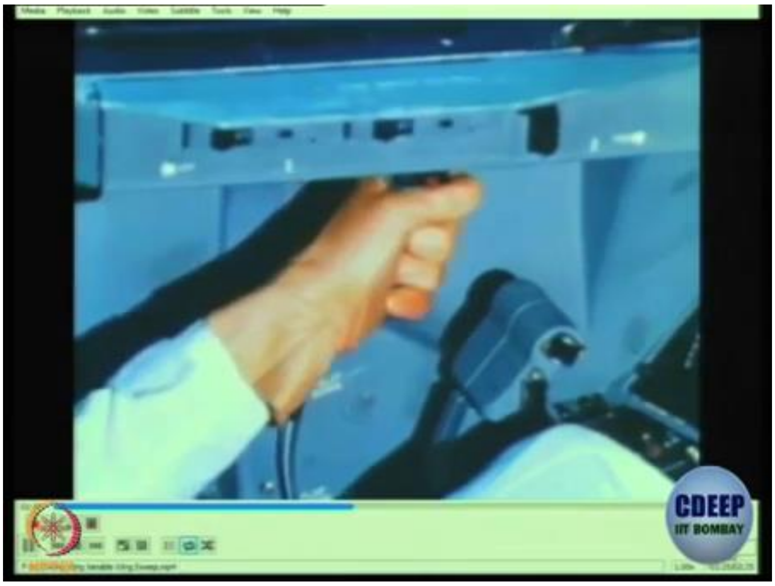
So, very old video because it is a very old aircraft. You will see a very interesting control on the left hand side of the pilot which is the control of the sweep. So, during takeoff and low speed flight, you have low sweep and that is a one.

(Refer Slide Time: 21:04)



So in this aircraft any location or any sweep position was possible. It is a truly variable swept aircraft. The pilot can actually lock the handle at any point. Right from the starting, starting to the end at any point.

(Refer Slide Time: 21:23)



And then you can take it forward also at location and lock it. Notice that, there is a chase aircraft which is salving this particular aircraft.

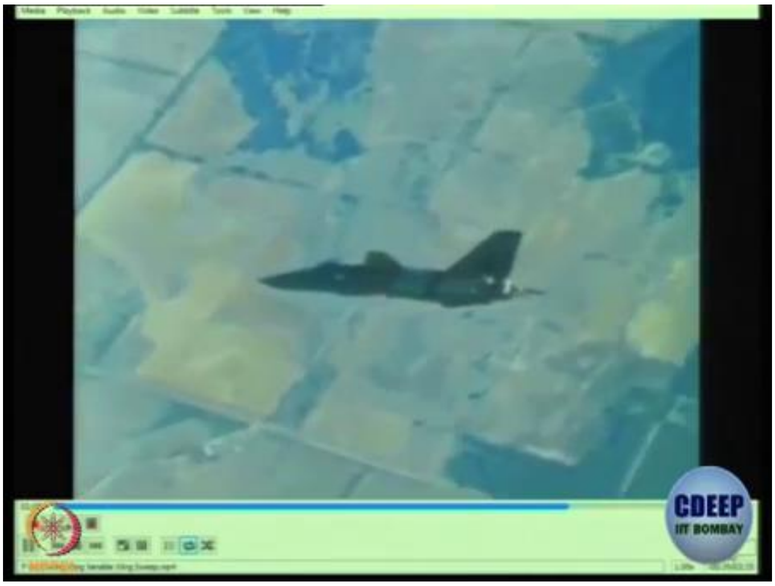
(Refer Slide Time: 21:48)


CDEEP
IIT BOMBAY


CDEEP
IIT BOMBAY

Notice that as the wing swept forward and backward, you do not have any great speed changes. So the idea is not to make a flight faster or slower but to present the aircraft in the best configuration at various speeds.

(Refer Slide Time: 22:12)



So, during low speed flight lower sweep is better, because you want a high aspect ratio. During high speed flight, it is better to have delta wing or a fully swept wing. So, you go into whatever position is appropriate for your flight profile.

(Refer Slide Time: 22:26)

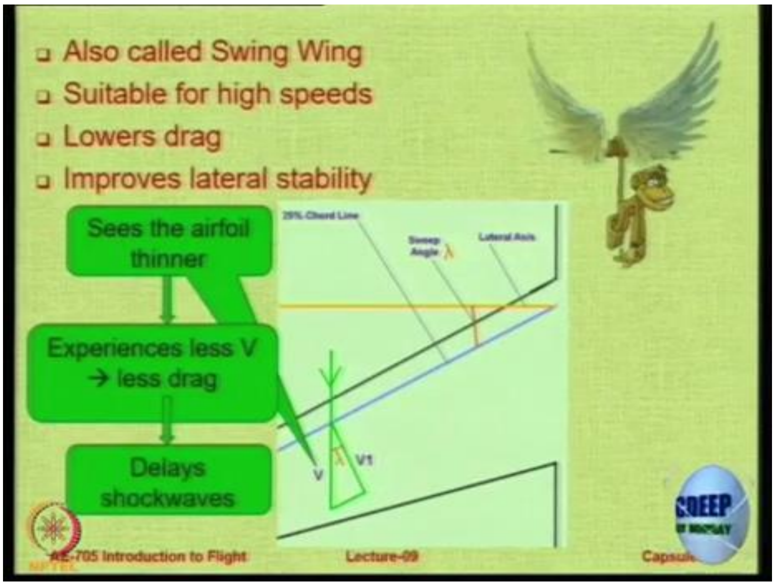
That is the airbrake, coming down during landing. So, during landing you will find the sweep will be always the lowest possible sweep. Ok.

(Refer Slide Time: 22:44)

In India also we have dealt with two aircraft. Now, I have worked on this aircraft for one and a half year so it is very close to my heart, The MiG 27M Bahadur. This particular aircraft had three sweep positions. It was not a continues sweep aircraft. The pilot had a choice of 16 degree, 45 degree and 72 degree. These are approximate numbers. Actually, it is 16 degree and 43 minutes and all that. So, three possible positions, the lowest sweep position was during takeoff, during landing and low speed flight.

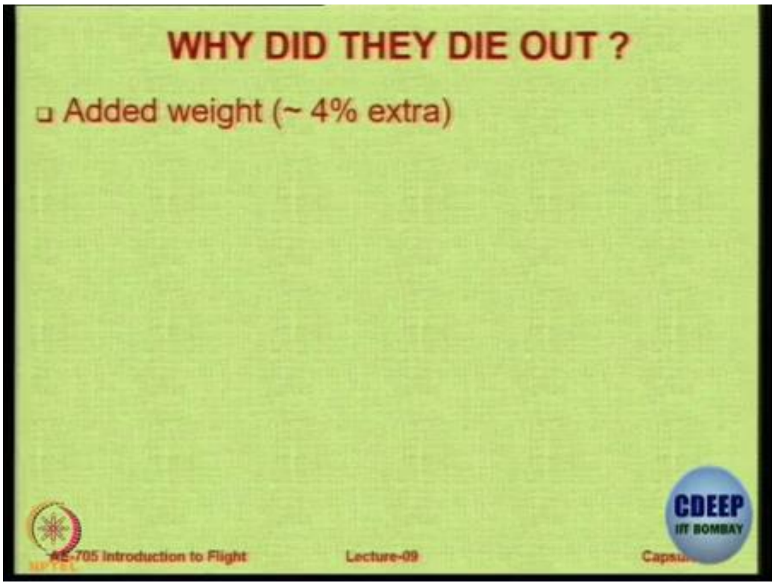
The 45 degree sweep is during transonic maneuvering during combat, at transonic speeds, because that is the most appropriate one and high speed flight when you are basically coming back home after doing the damage. This is a bomber aircraft, MiG 27M is a ground attack bomber. So, you go and do your work and then you simply run behind, run back to your safe territory. At that time high speed flight with no external stores attached you just move it to the maximum sweep and rush back home or dash back home. Ok.

(Refer Slide Time: 23:56)



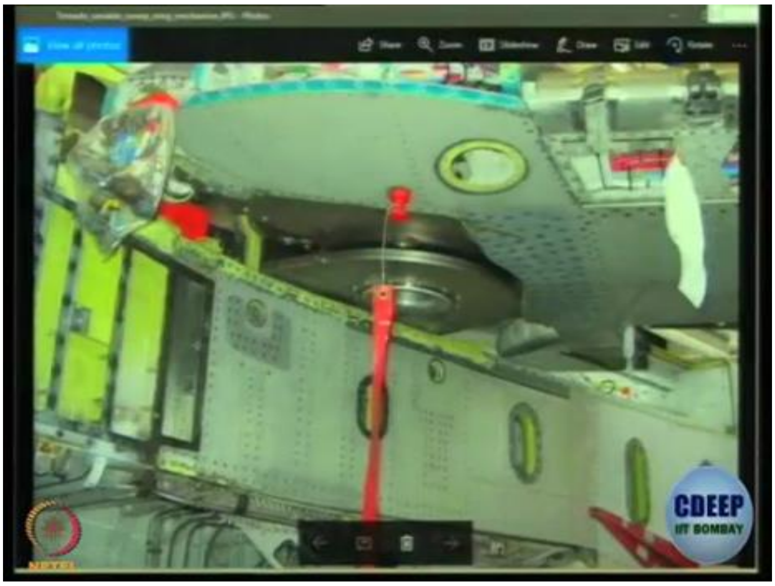
But there are severe limitations and problems because of this. Drag is lowered, Lateral stability is improved. Ok. Same thing like we have seen earlier.

(Refer Slide Time: 24:05)



But they are not popular today. You do not see many modern aircraft having very well sweep because they make the aircraft very heavy. And there is a rough approximation that an aircraft is 4 percent heavy if you make it swept back, variable sweep and it is huge penalty. Ok. So, MiG 27M weighs approximately 20 tons. 4 percent of 20 tons is a large amount of weight. I could carry fuel or I could carry armament instead of that. Then there are serious issues of maintenance and we were always having a problem in the maintenance.

(Refer Slide Time: 24:59)

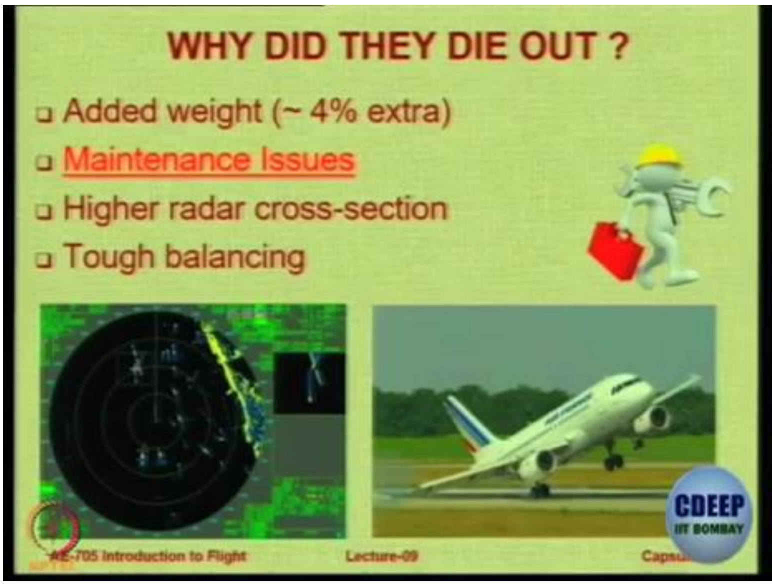


This is not MiG 27 sweeping mechanism, this is for I think F-111 or Tomcat I think it is a Tomcat. But just look at the size of the bearing, because the whole wing has to swing along one bearing, one on each side. Remember the bearing for MiG 27 was taller than me in height. I could actually go inside and stand with the raise on top and bottom. That is the size of the bearing and it was at least this much diameter.

So, such a thing has to now rotate and if there are two wings and if they do not rotate equally then you have disbalance. So, we always faced a problem in the maintenance of this particular component. And the largest number of problems which we encountered during maintenance of the aircraft was on the maintenance of the bearings. Remember the wing is not; it has got a slight anhedral.

So, you need to also balance, you have to be sure once it comes for maintenance, the wing is removed, you do many things, when you put it back then you find that the bearing is not moving smoothly or it is giving imbalance and this is was a night mare. So, all in all people say it is not worth it. Ok.

(Refer Slide Time: 26:19)



Then you have a higher radar cross section. Because you are providing variable sweep, so under some condition it is going to have low sweep and therefore it will have a much larger cross section. And in some condition it will have a lower one so the if you have a constant high sweep you have a lower cross section. Ok. So, in the next class we are going to look at 'Types of Drag' and what do we do to reduce them. Ok. Thank you.