Introduction to Aircraft Design
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Lecture - 84
Morphing of Aircraft Configurations

Hello, today we will look at morphing of aircraft configurations.

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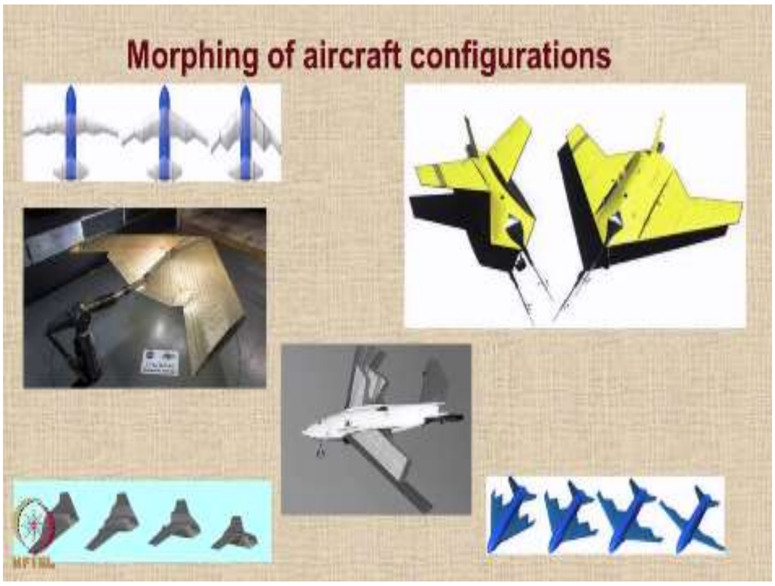

In this image, you can see a lot of examples of how morphing has been proposed for various types of aircraft.

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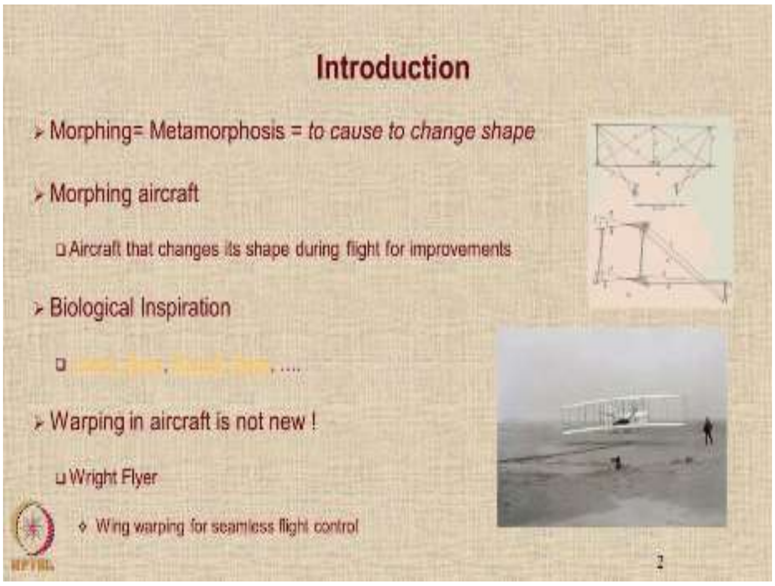

Let us first have a basic understanding of what exactly is morphing. Morphing basically is metamorphosis that is the genesis of this word morphing. And the dictionary meaning of metamorphosis is to cause to change shape. Now as school students we have heard about the metamorphosis of large way into butterfly etc. Morphing aircraft is an aircraft that changes its shape during flight for some improvements.

Now these improvements can be of various types. We will look at some of them in a few slides ahead. The inspiration for morphing has come from our observation of the nature around us. Two examples are the honeybees and the bumble bees. Let us have a look at how honeybees morph themselves. **(Video Starts: 01:33) (Video Ends: 02:25)**. Here is one more example from nature that of the bumble bees.

(Video Starts: 02:30) (Video Ends: 03:00). So there is a joke which says which goes that the bumble bee has not done any course in aerodynamics or flight dynamics. And as per the theory, the bumblebee is not supposed to be able to fly. But the bumblebee have not done any course and therefore it can fly. Warping is not new.

In fact, the first aircraft to successfully manage heavier than air sustained flight on a power demand system, the Wright Flyer one that also had warping. Let us see a small video clip about Wright brothers. **(Video Starts: 03:43) (Video Ends: 04:17)**. The Wright Flyer employed warping for seamless flight control as you must have seen in the video clip also.

And you can also see in this image which shows that the controls were such that the tips of the wing were warped to give the action that we get from the ailerons. That is the role control.

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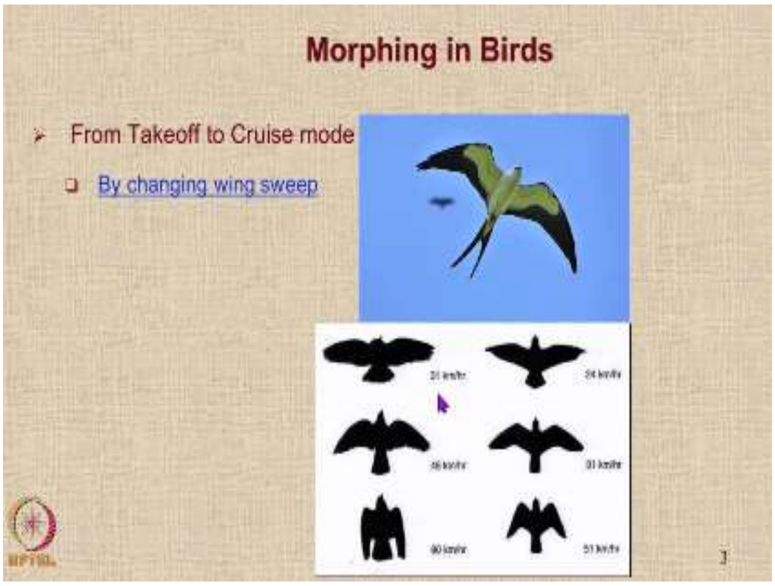

The biggest inspiration for morphing comes from birds. Birds demonstrate a fantastic variety and levels of morphing. For example, birds change their shape from takeoff to cruise mode by changing their sweep. As you can see here, at different speeds, the same bird puts its wings in different configurations, okay.

So as we know from basic aerodynamics, the higher speed is suitable for, higher sweep is suitable for flight at higher speeds, so by changing the wing sweep. Let us have a look at a very interesting video in which there are five birds, which we will launch from a particular location in different configurations. And the best one is the last one. **(Video Starts: 05:40) (Video Ends: 06:50).**

So as you must have seen, the last bird was able to launch and then turn its orientation midway during the flight.

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Birds also go from cruise to dive mode by changing their wing profile. So the picture on the right shows a sequence of images shot of a gannet when it goes into a dive to fish. And this is a close up of the same picture. But the beauty is appreciated only when you see this happening in slow motion.

So I am going to show you a small video clip which will capture the motion of the gannet as it converts its wings from low sweep to very high sweep when it goes into a dive. Watch this. **(Video Starts: 07:42) (Video Ends: 08:10)**.

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So let us look at morphing of wings in eagles, okay. Eagles are also very well known. Now look at this particular picture in which you see that the wingtips have these three you know, deflected feathers. They are acting like the winglets. Look at the landing here, how beautifully it is oriented, okay. Here you see an eagle changing its configuration midway to turn. This is an eagle which is on an approach to land.

So this is how it comes in at very high angle of attack to land. It takes its wings very much behind and then finally it can perch on a small stone. So the eagle demonstrates morphing of a very high order. No human created device can demonstrate such a beautiful amount of morphing.

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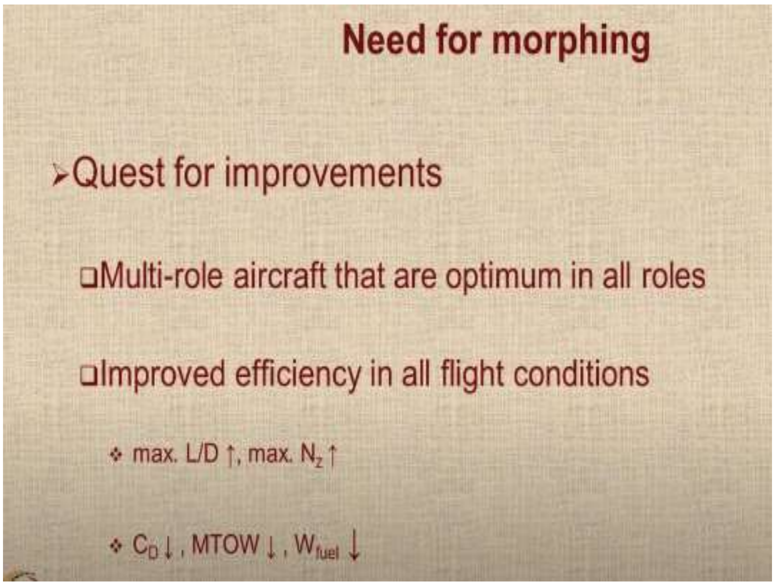

What is the need for morphing? As I said morphing is shape change for improvement. There is a constant quest for improvement in aerospace engineering. We are looking for multi-role aircraft which are optimum in all the roles not that you use it for one particular role optimally and in the other roles it is suboptimal. No, we want it to be optimal in all the roles. We would like to have improved efficiency in all flight conditions, not just one.

So for example, we would like to maximize the lift over drag coefficient. We would like to maximize the N_z so that we have much better turning performance. At the same time we would like to reduce the drag coefficient. We would make it lighter by reducing the max takeoff weight. And also we want to reduce the fuel consumed in the mission.

So many of these requirements can be conflicting, but we want to meet them simultaneously. And one way of doing this is to morph the configuration.

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There are some benefits of morphing. One is there can be improved aircraft performance. So there are two distinct ways or two distinct approaches to morphing. One of the aim is to improve the aircraft performance by expanding its flight envelope. For this we carry out morphing at high amplitude but low frequency. But by this I mean that you do it once in a while.

That means, low frequency. You do not do it regularly. You do it a few times in the mission. But when you do it, you have high amplitude which means the amount by which the aircraft morphs is quite large. Another application of morphing would be to replace the conventional control surfaces so that we have improved performance and stealth. Or we could reduce the drag which leads to an improvement in the range.

The other application of morphing could be to reduce vibration or flutter or to control the flutter. Now here we have high frequency but low amplitude. That means we morph almost all the time, but the amount of morphing is very small. The problem is that these benefits of morphing do not come free of cost. There is no free lunch, okay. Whenever you go for morphing, there is an increase in the cost complexity and weight.

And therefore, you have to decide whether to morph or not keeping in mind that the benefits because of morphing should be more than the problems because of the increased cost complexity and weight that are created because of morphing.

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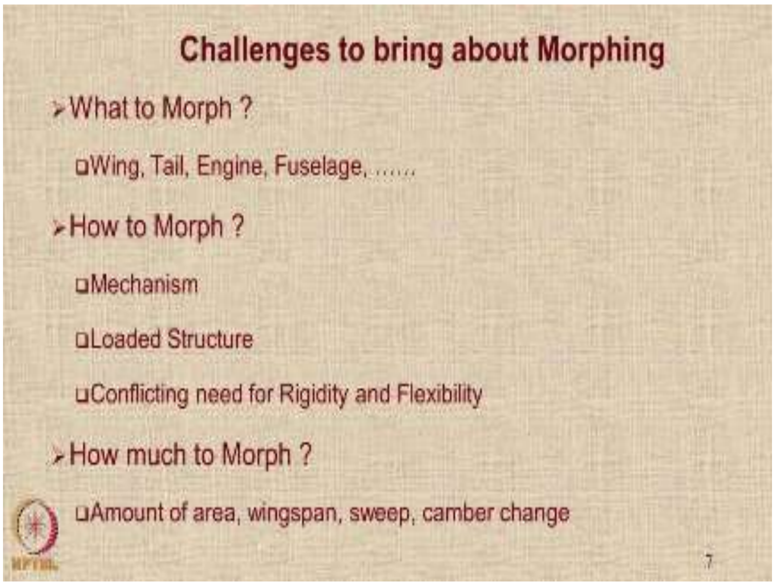

It is not easy to morph. There are several challenges. First question is what do you morph? Do we morph the wing or the tail or the engine or the fuselage? Please note even engines are routinely morphed because the nozzle for example, you know of the jet engine aircraft is of a variable diameter. So the diameter is reduced when the jet exhaust velocity is increased.

Similarly, there are inlet guide vanes which also are going to change at some angle right. Sometimes they are fixed but they can also be actively moved. Wing, tail, engine, there are many choices. Okay, let us say we decided that we have to morph the tail. Then the next question is how do you morph? Do you morph using a mechanism? Do you morph by having a loaded structure in which the loads themself cause the deflection?

And when we do this there are conflicting need for rigidity and flexibility. From the point of view of rigidity we want the aircraft to not have any flexible parts or parts which can be easily deformed. But from the point of flexibility, we need to have parts which can be easily deformed. So there is a conflicting requirement for rigidity from the structural point of view and flexibility from the morphing point of view.

The next question is how much to morph? How much area? What wingspan or how much sweep or how much camber should be changed? Because as I mentioned, the benefits have to outweigh the costs complexity weight and the negatives.

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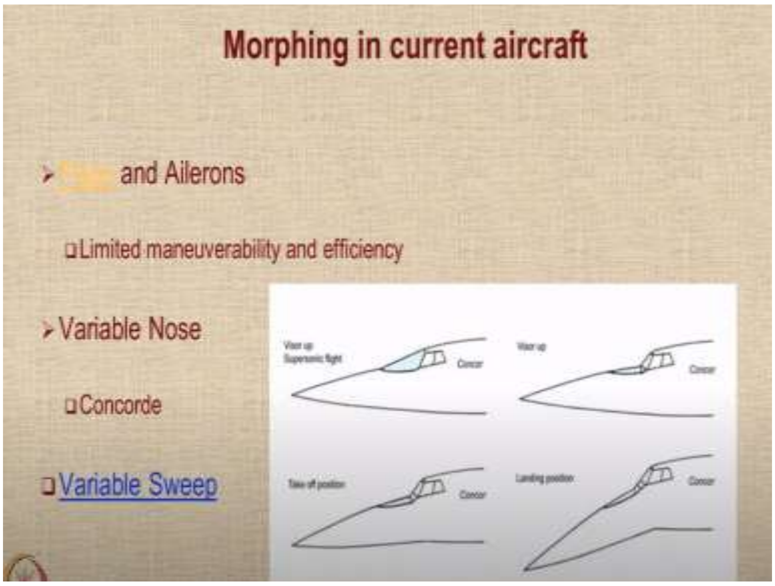

Morphing happens also in current aircraft. Flaps are all, everybody knows about flaps, okay.

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You can see these are the flaps which are the surfaces mounted on the trailing edge of the aircraft. This is another view of the flaps. You can see that not only do they deflect downwards they also create gaps between them. These are called as slotted flaps okay. And there are also flaps in the leading edge, the leading edge flaps as you can see this aircraft the leading edge flaps are deflected downwards.

So you have trailing edge flaps, leading edge flaps and you have flaps with slots between them. So therefore, this is not something new, okay. Similarly, there is an example of morphing of the nose shape in Concorde, where there are four specific positions at which the nose of the aircraft can be deflected to. So let us watch a small video clips which explains these four positions and what the purposes, okay.

(Video Starts: 14:54) (Video Ends: 16:16). So we saw that there is something called as a visor, which also can be retracted and extended. It covers the windshield. And there are some situations in which the visor is retracted, in some it is extended. We all know also about variable sweep wings. This is not something new.

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So variable sweep, here is an example of variable sweep in which the wing can have various positions. And in our own country, we have had experience of operating this aircraft MiG-23 and 27M. It also has got three specific positions at which the wing sweep can be created. There is a 16 degree 45 minutes position for the low speed flight takeoff and landing.

There is an approximately 45 degree sweep for transonic maneuvering flights and during maneuvering flight and transonic flight and there is a 72 degrees sweep for the high speed dash. Let us see a small video on how this is achieved in F-111 using a lever that the pilot deflects. **(Video Starts: 17:27) (Video Ends: 20:02)**. So this technology is not new, it is there for a long time.

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We also have variable camber, okay. In variable camber such as this aircraft, the F-18 Super Hornet, you can actually change the camber of the wing to desired value at various mission segments. But this experiment was ultimately not very successful and it was concluded that the cost and complexity and the weight because of the morphing on a big aircraft like this by variable camber is more than the benefits.

So it was an experimental aircraft, but it has not been implemented in any production aircraft. Morphing is possible using some structural technologies. One is you can change the planform using rigid mechanisms, okay. For this you can have extension of wing, you can fold the wing, or you can sweep the wing.

Or you may have compliant mechanisms, mechanisms which provide camber and twist, okay by having loads acting on them. You could also have vibration control systems, which are usually based on directly applying some force. And you can also have shaped control systems where there are actuators which affect the shape change. And there are some sensors onboard to measure the actual deflections.

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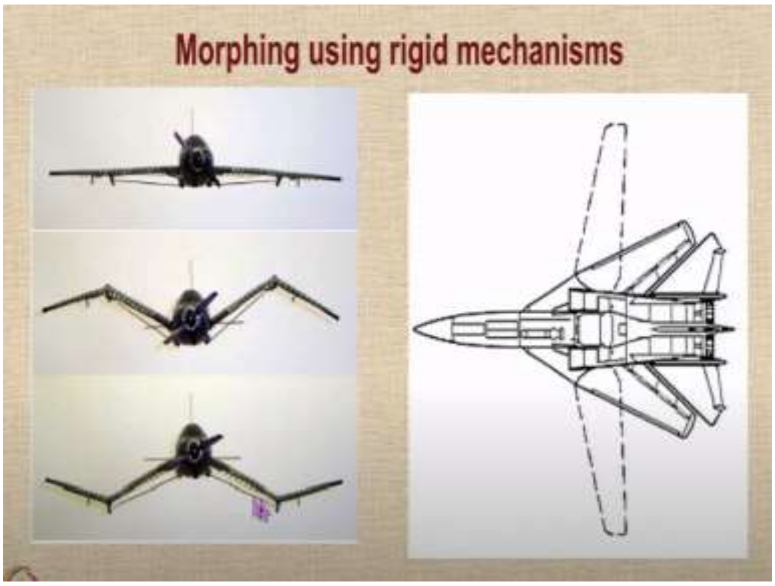

So here is an example of morphing using rigid mechanisms. You can see this is called as a Gullwing. So these levers which are projecting outside you can use them to deflect them to create these kind of morphings.

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Similarly, when you go for compliant mechanisms, you usually go for these when there is a small amount of structural change, like when you want to have twist or camber change or an asymmetric wing change. So an example of this is F-111 mission adaptive wing which I already spoke about, that used compliant mechanism.

So those are basically systems mounted inside the structure which achieve twist camber and asymmetric wing changes.

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The current research and morphing is focused on smart materials, adaptive aeroacoustics, smart controls and also telescopic wing. So here is a short film by NASA which talks about what are the aims and ambitions of NASA in creating morphed aircraft. **(Video Starts: 22:40) (Video Ends: 24:02).**

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Shape memory alloys is one structural technology which is very useful in achieving morphing. Mostly it consists of piezoelectric devices and some kind of a, sometimes some kind of a truss structure. Here is an example of a shape memory alloy. So you can roll it and keep it in this condition for ease in transportation etc.

But when you apply either some electrical current or some temperature, it has a memory of a particular shape, in this case the aerofoil shape. So it will become an airfoil shape when you put it at particular temperature and it will come back to this or you can roll it back to this particular shape when you remove that particular input.

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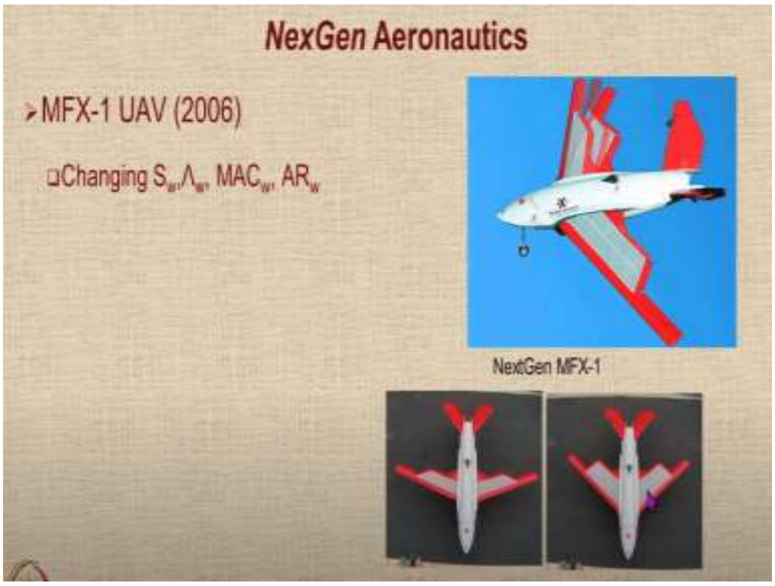

There is a company called NexGen Aeronautics which has experimented with morphing on small UAVs. The MFX-1 UAV as you can see on the screen was to change the wing area, to change the wing sweep, mean aerodynamic chord and the wing aspect ratio. And also it had asymmetric morphing as you can see only one wing is changing its sweep.

So this is an example of how the aircraft can have two different sweep positions and also slight increase in area.

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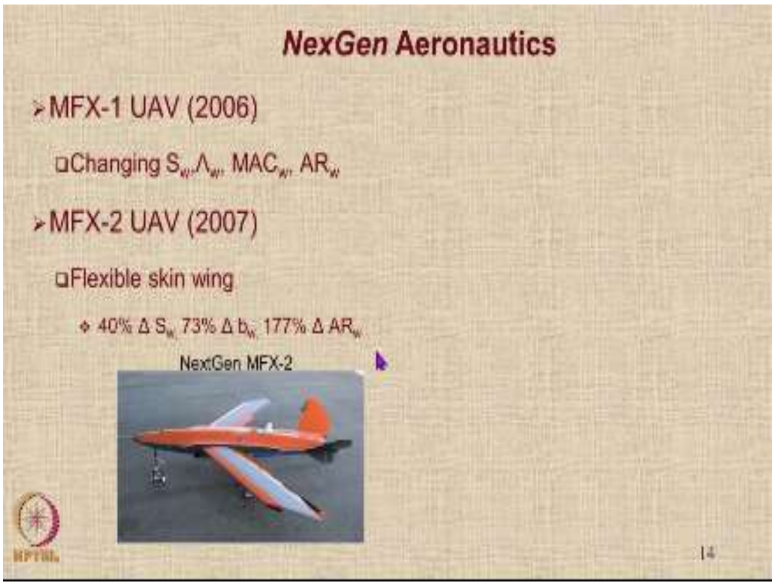

The MFX-2 UAV which came the next year, it had a flexible skin wing. It was seen that around 40% change in the wing area, 73% in wingspan and 177% in the aspect ratio was obtained in this particular aircraft.

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NASA is currently working on a project called as a MADCAT project which stands for mission adaptive digital composite aerostructure technologies. In this particular project, which is being done at MIT and California University. So you can see that the wing is consisting is created through an assembly of various small structures like this. And at the nodes, we have some sensors, okay.

So you can actually deflect and deform this particular basic element into any shape you want. And this is an example of a wing made up of many of these small structures. And here is a short film that describes the aim and the current status of this particular project. **(Video Starts: 26:40) (Video Ends: 28:39)**.

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Now this is an example of a project which has gone from conceptualization in 1998 to actual testing on an aircraft in around 2015, I think. So this is the FlexFoil active compliant trailing edge, which was invented by Prof. Sridhar Kota of mechanical engineering department of University of Michigan Ann Arbor. You can see here that the wing does not have any discontinued parts.

Normally when you deflect the flaps, they go down so they create a cavity. Here there is a flexible membrane attached to the root so they are not going down they are just deforming. So let us watch a short clip on this concept which explains how this concept went from the initial idea to the reality through various stages. **(Video Starts: 29:36) (Video Ends: 35:50).**

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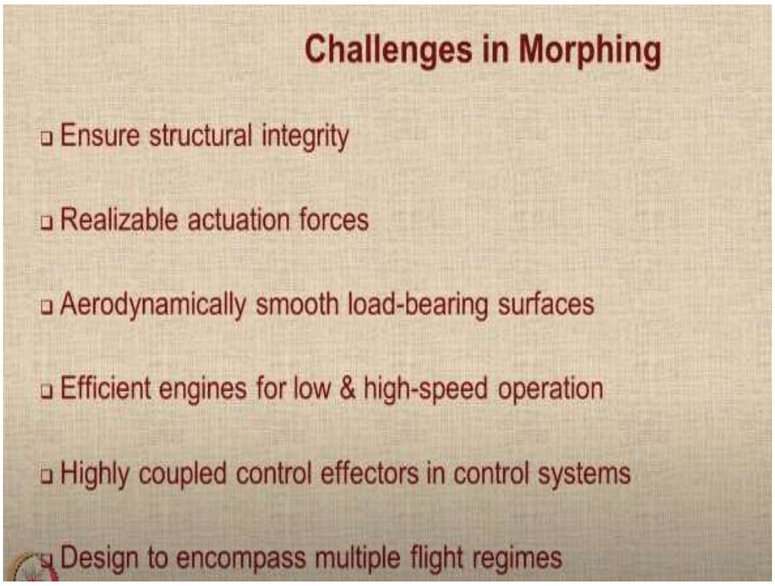

Let us look at the challenges in morphing. You have to ensure the structural integrity of the aircraft during morphing. The actuation forces that you require should be realizable. The load bearing surfaces have to be aerodynamically smooth. So you cannot have any projections etc. You also will need very efficient engines for low and high speed operation.

And the control surfaces will become coupled okay, because morphing will change the control surface configuration also. And as I mentioned in the beginning, morphing is carried out so that we can fly the aircraft optimally in multiple flight regimes.

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Let us move on to one special example of morphing which is inflatable wings for UAVs, okay. So here the wing is packed inside the fuselage like this so that you can launch this UAV like a barrel or like a small rocket kind of a thing. And then when needed, the wings will come out after they are inflated.

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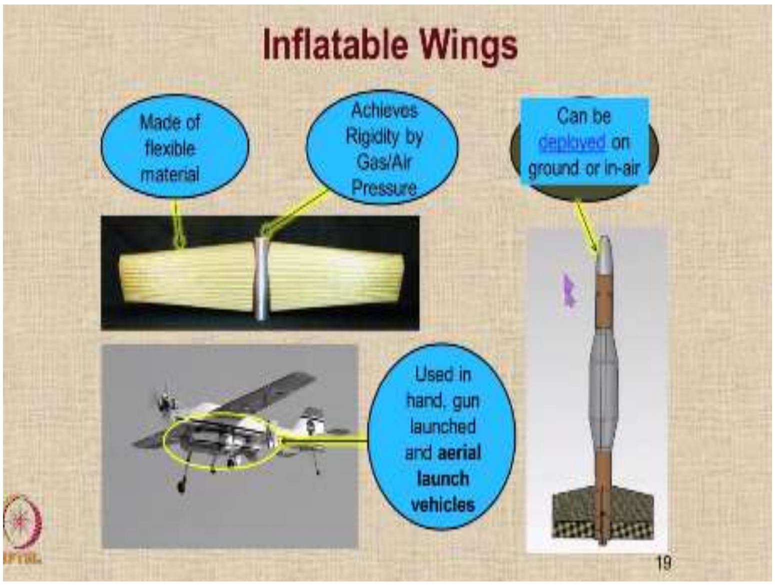

So as I mentioned, this is an example of inflatable wings. They are made up of flexible material and they achieve rigidity by gas, air, or air pressure, okay. You can use it in hand or gun launched and aerial launch vehicle such as this one which is mounted below this UAV. And they can be deployed on ground or air.

So for example, you can launch it like this and then when needed, the wings will come out let me show you a small video. **(Video Starts: 37:32) (Video Ends: 37:43).** So as you can see, the wings can come out when needed.

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The wing structure generally is of baffle type, where there are these partitions created. Or you can see this is an example of wing baffle structure. And this is a finger like bladder. Now there are many ways of doing it. One way could be that you make the baffle separately like this like a fingers like bladder system and then you insert it inside this particular structure and then inflate the wing.

Or you could also have only vertical members joined here, which are a part of the envelope itself.

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Now this goes into very deep levels in material science. Some of the candidates are PBO and zylon, because they are sensitive to compression failure, and they degrade when exposed to various wavelengths of light. So they are good, but they have these limitations. Kevlar is also very popular as an inflatable wing material because it has got high strength and it is much affordable.

And Vectran is another proprietary material which has excellent resistance to flex cracking and it has got negative environmental sensitivity. So if you are interested there is this paper which can be located and read for more detailed information about the materials used for the inflatable wings.

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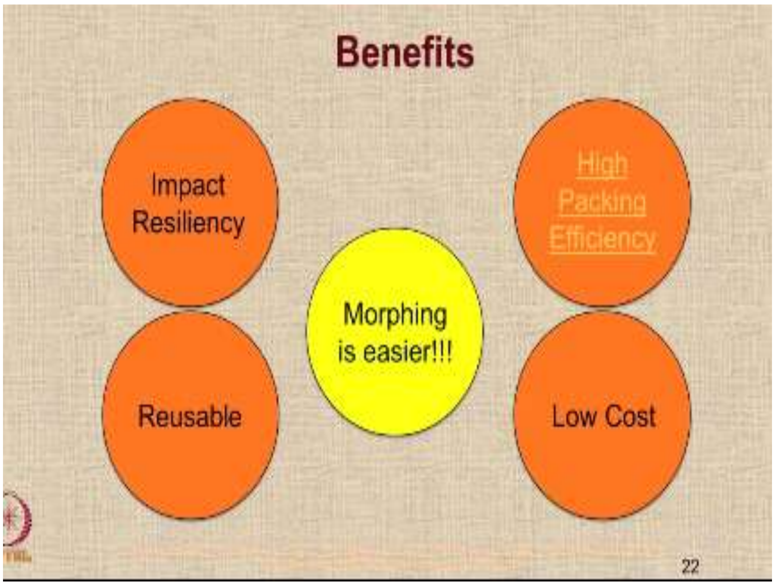

What are the benefits of inflatable wings? First of all, it gives impact resiliency to the aircraft. Many UAVs they break when they hit an obstacle during their flight. But in case of inflatable wings, probably you can make it very much resilient to impact. It gives you a high packing efficiency as an example.

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You can see that either the whole wing can be stored inside the fuselage like this or it can be rolled and packed in a very small volume. It has been seen that inflatable wings are a low cost solution of morphing and the wing is reusable. The best part of inflatable wing is that morphing is easy.

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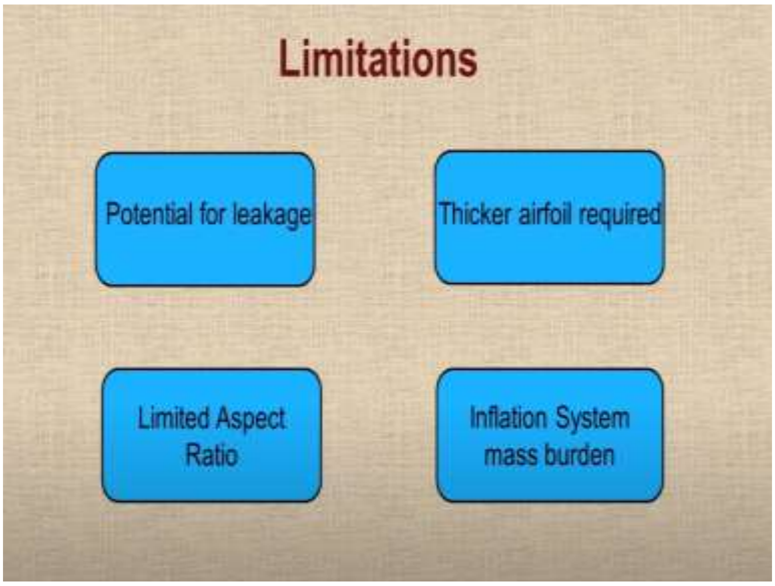

But there are also some limitations. One is there is a potential for leakage because it is inflatable structure. You require a thicker aerofoil because you cannot have very thin and sharp edged aerofoils with inflatable wings. The aspect ratio is limited because you cannot make it very slender because the air pressure will not then equally distribute towards the edges.

And you have to always carry some inflation system which is either gas or air based and the mass burden of that adds to the mass of the whole aircraft.

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An important aspect in inflatable wings is rigidization. What is rigidization? Basically, we need to stiffen the wing fabric using an external agent after you deploy it. Why do we need it? There are several reasons. One reason is that this will help us to reduce the leakage. It will also make the wings stiffer so it can carry more loads.

It might be able to allow us to make thinner wings if we rigidize the surface. And the inflation and the system would be smaller and lighter if we have rigidization of the wing.

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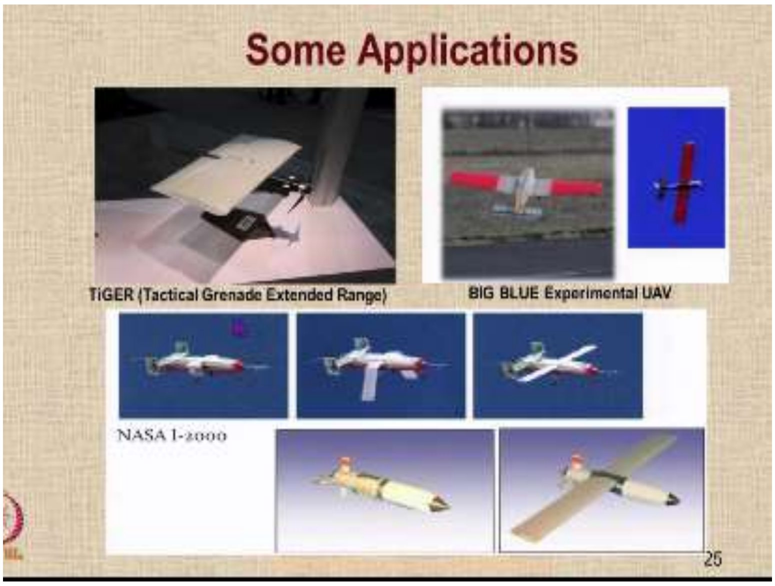

Let us look at some applications of inflatable wing UAVs. One good example is TIGER which is a Tactical Grenade Extended Range. In other words, it is a small you can say a small remotely controlled aerial vehicle, which is a carrier for a hand grenade so it increases the range of the grenade. There are other examples where you can see you launch it like a rocket or a missile and then you bring out the wings when needed to make it fly like an aircraft.

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So thank you for your attention. Here is a photograph of an aircraft which was mostly consisting of inflatable structure, except for the engines and the forward portion. This aircraft could be inflated on the spot by a pilot and then flown. The basic idea of this was to rescue people from the enemies during the Second World War. But when the proposal was given to the US Air Force, they said that we do not have any use. We do not have much use for an aircraft which can be brought down by a bow and arrow.

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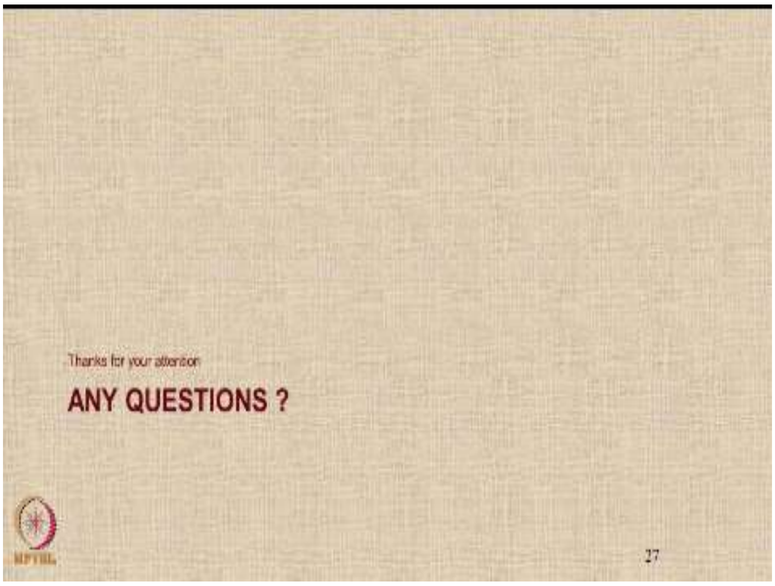

So I will be happy to answer any questions on the discussion board. Thank you.