Smart Structures
Professor Mohammed Rabius Sunny
Department of Aerospace Engineering
Indian Institute of Technology, Kharagpur
Week - 01
Lecture No - 02
Introduction to Smart Structures (continued)

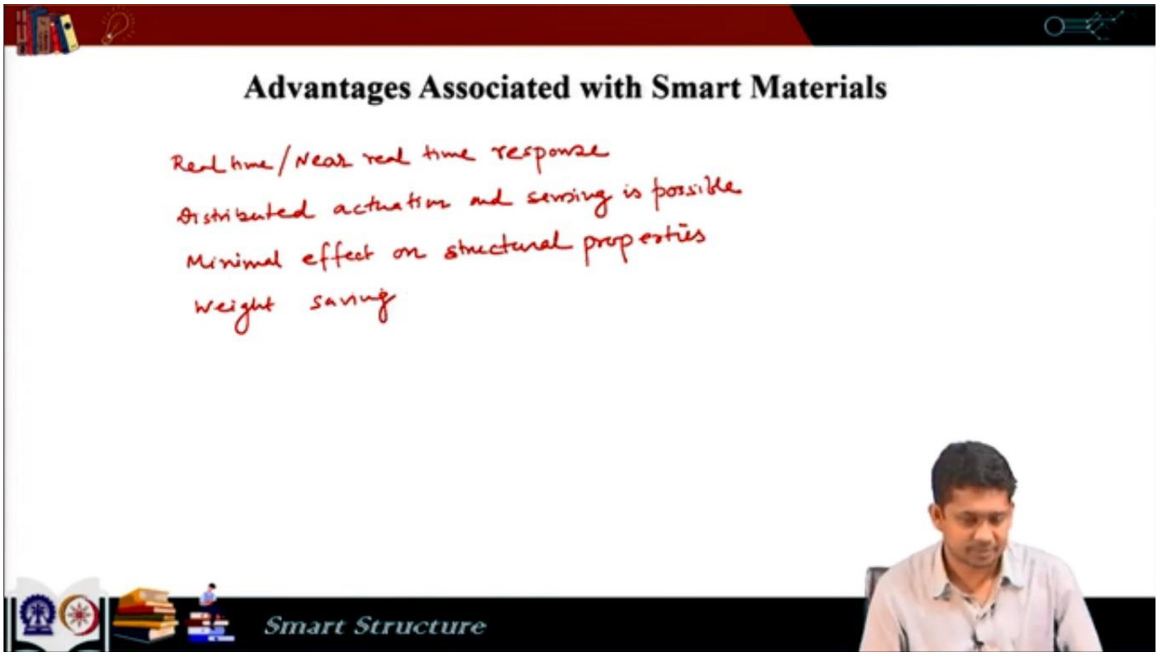
Welcome to the second lecture.

We will start with the advantages associated with the smart materials. So, when we use the smart material sensors and actuators in a structure, we get quite a few benefits. One is we get real time or near real time response. We saw in the last lecture that most of the smart materials as a response time in the order of microseconds. And distributed actuation and sensing is possible.

So, we can have these small smart material actuators distributed throughout the surface. So, where this distributed actuation is quite helpful, where it comes to shape control. Similarly, with distributions distributed sensing, a monitoring job is also more accurate. And then we can have minimal effect on structural properties.

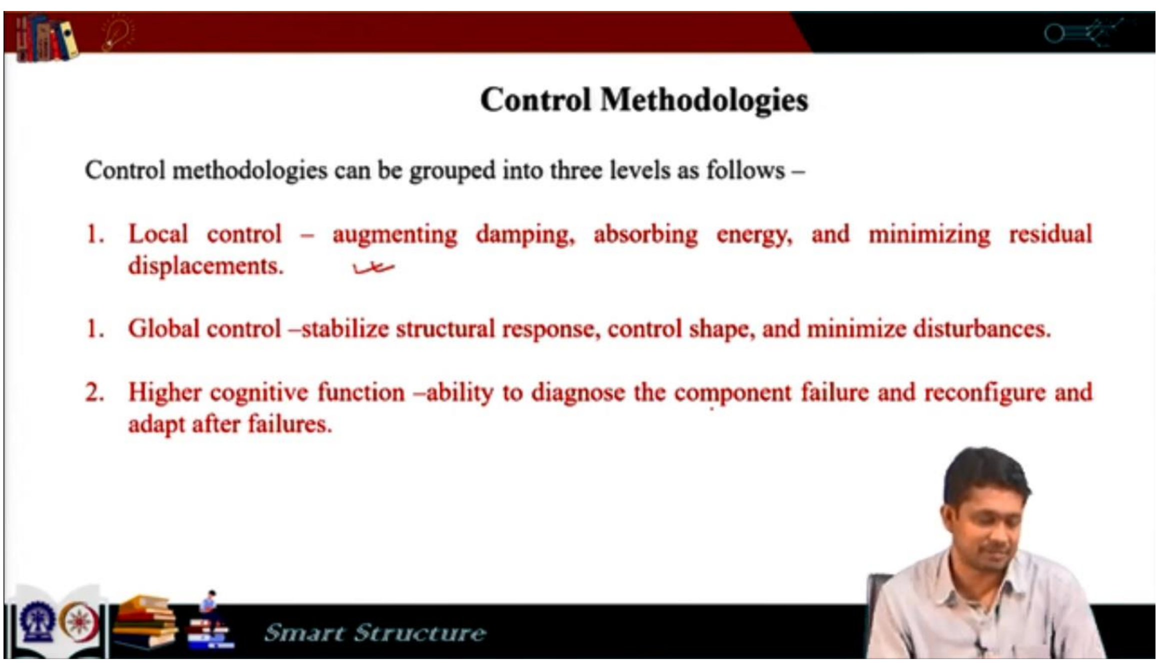
We have seen that these smart materials come with different mechanical properties. For example, if we talk about piezoelectrics, even we have seen that the elastic modulus of the piezo ceramics and the piezo films are quite different. So, depending on the property of the structure, we can choose a piezoelectric material which goes well with the host structure. So, for example, in case of flexible structures, generally PVDF is used because of its low elastic modulus and so on. And also we can get weight saving because they are kind of light weight.

(Refer Slide Time: 02:52)



Now, we have talked about the control of structures using piezoelectrics. So, we do some sensing and based on what we sense, we fire the actuators and do the structural control. When it comes to control, there are generally three types of controls. Local control, local control is helpful in augmenting damping, absorbing energy and minimize residual displacements. So, these are the main applications of local controls.

(Refer Slide Time: 03:49)

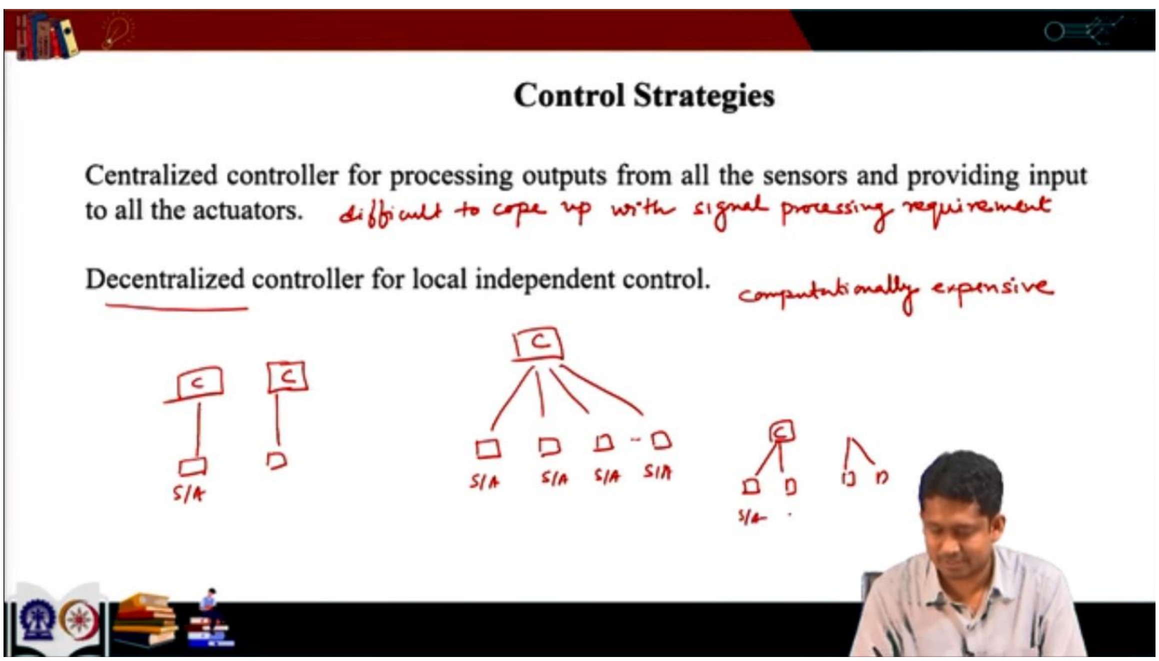


So, it means control in a local zone. In a global control, the most benefit is achieved when we try to do the stabilize, when we try to stabilize structural response, control shape and minimize disturbances. And then there is something called higher cognitive function where which has ability to diagnose the component failure and reconfigure and adapt itself after the failure. Now, control strategies also can be various. So, we have something called decentralized controller.

So, in a decentralized controller, may be one or a collection of small sensors and actuators is controlled by an individual controller. So, there are separate controllers for a separate sensor actuator or a small collection of sensors and actuators. Then there is something called centralized controller. In a centralized controller, a collection of sensors and actuators or a large collection of sensors and actuators so to say, can be controlled by one centralized controller. Now, there are some advantages and disadvantages of these two these two strategies.

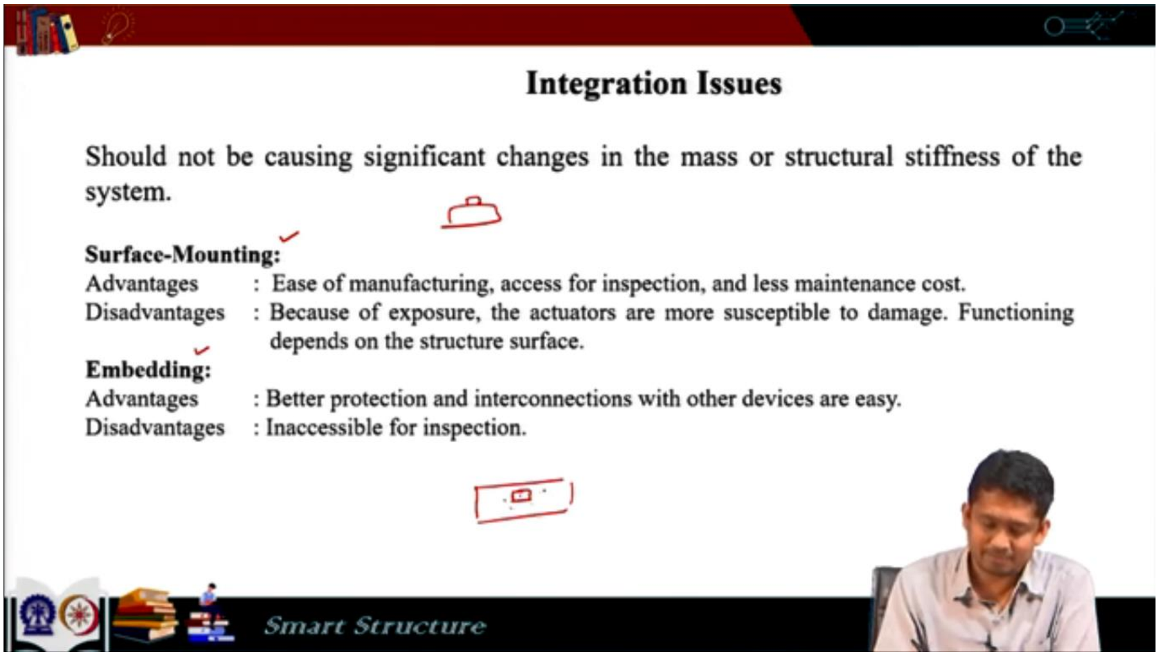
Decentralized controller is generally computationally expensive and centralized controller, here it is difficult to cope up with high signal processing requirement. And then there is something called hierarchical control. So, here there are different levels. So, may be we have a set of sensors and actuators for which there is a controller and then again that is controlled by another controller. So, you can define a hierarchy like that.

(Refer Slide Time: 05:40)

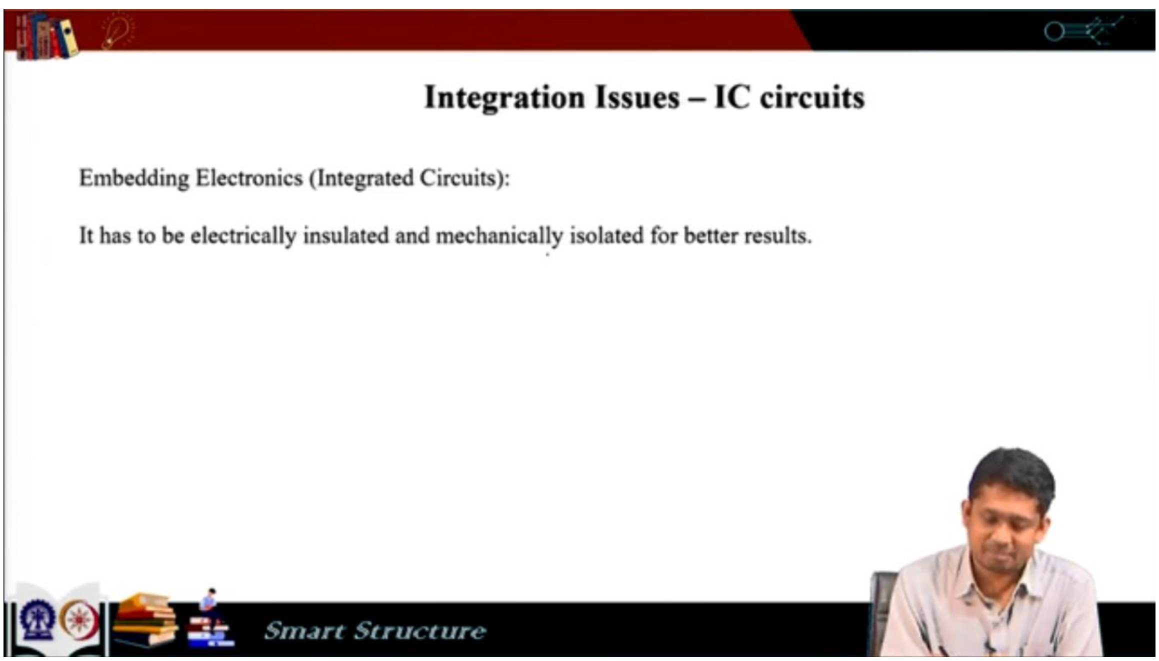


Now, we will talk about the integration issues. So, when we try to integrate a smart material in a structure, our goal should be that first of all we should we should be able to do the sensing properly or the actuation properly and also it should not cause significant change in the mass or stiffness of the structure. Now, there are generally two type of integration, one is surface mounting, one is embedding. Surface mounting at the name says we just put it at the surface. Here the advantages are ease of manufacturing, access for inspection because it is a surface we can do inspection properly and maintenance is easier.

(Refer Slide Time: 07:05)



(Refer Slide Time: 07:18)

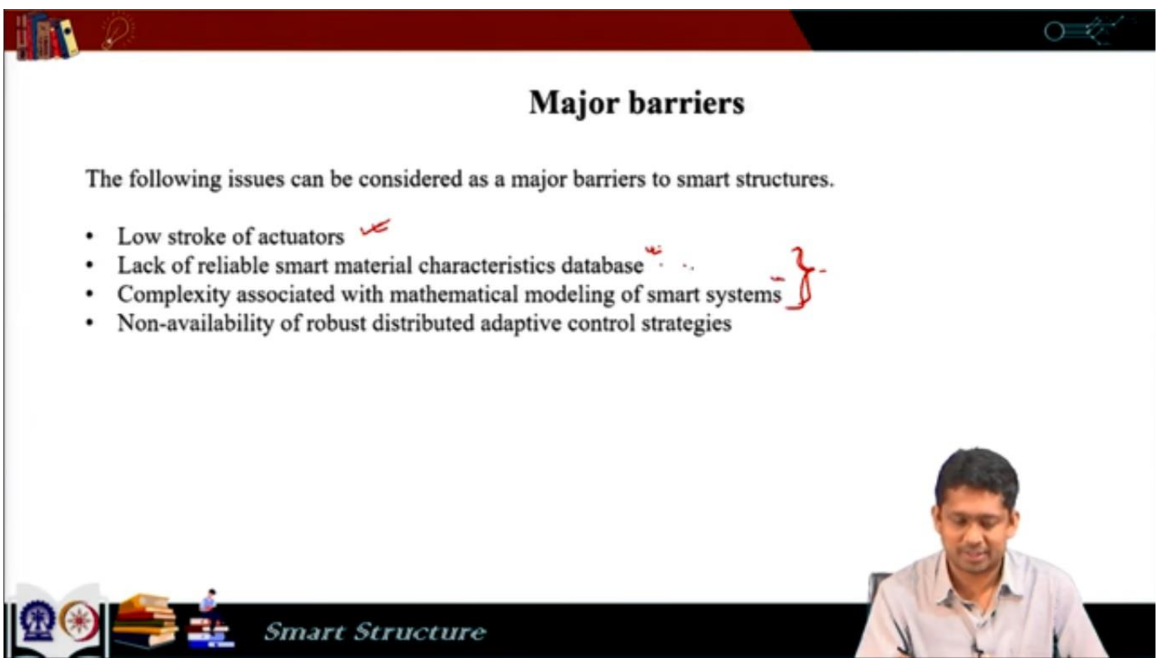


However, they are exposed and that is why they are susceptible to damage and that is why there is another kind of mounting that is called embedding. So, where the actuator or sensor is embedded in the structure because it is embedded it gets better protection for the external factors and it is its interconnection with other device is easy, but it is not accessible for inspection. When it comes to integration of IC circuits, it has to be electrically insulated and mechanically isolated for better results. Now, there are some disadvantages also. First of all, the actuators have low stroke, we have seen that the traditional actuators have higher stroke than the smart materials and there is lack of reliable smart material characteristic database and there is complexity associated with mathematical modeling of smart systems.

So, if you want to design a smart structure with proper sensing and actuation capabilities, we need to see how the structure behaves when the material is integrated in it and that needs a rigorous mathematical modeling. And so, this course is about these two aspects. So, here we want to do the proper material modeling itself. So, that we can have a good material database and we want to do a proper mathematical modeling of the structure where the smart structure is fitted to a host structure. So, this is the goal of this course to address these two challenges.

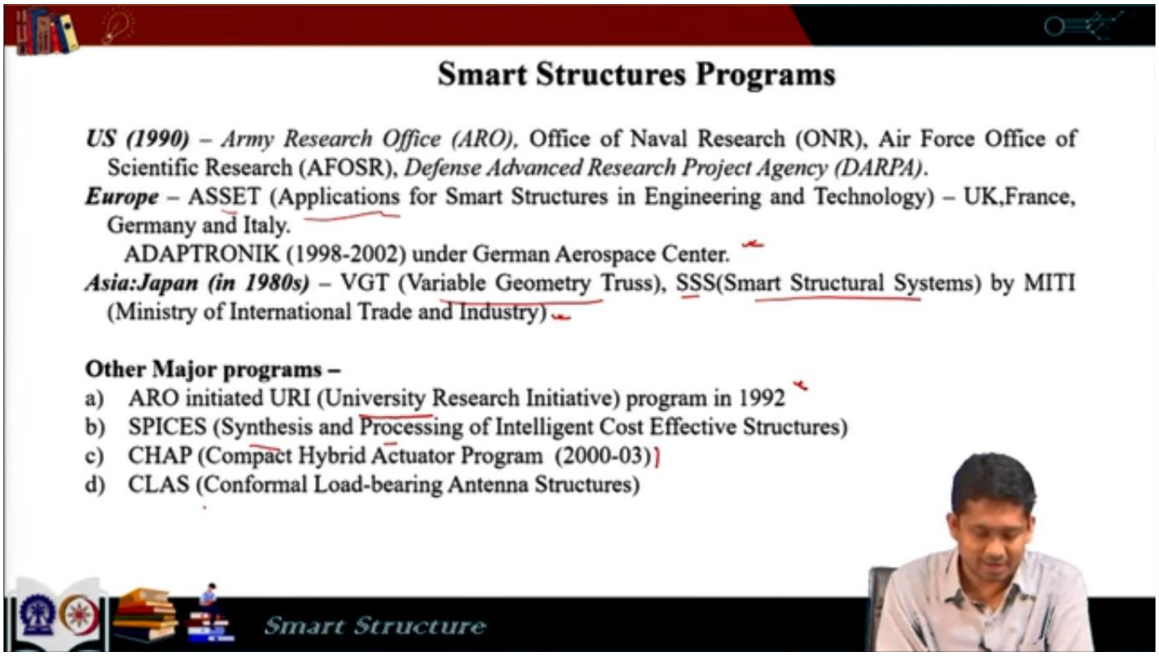
And another barrier is non availability of robust distributed adaptive control strategies. So, as I said that these smart structures or designing a smart structure is a interdisciplinary job. So, it needs various domains of expertise. Now, we will talk about some of the prominent or major smart structure programs. In US army research office of office of naval research board, air force office of scientific research and defense advanced research project agency, they came up with several smart structure programs.

(Refer Slide Time: 08:48)



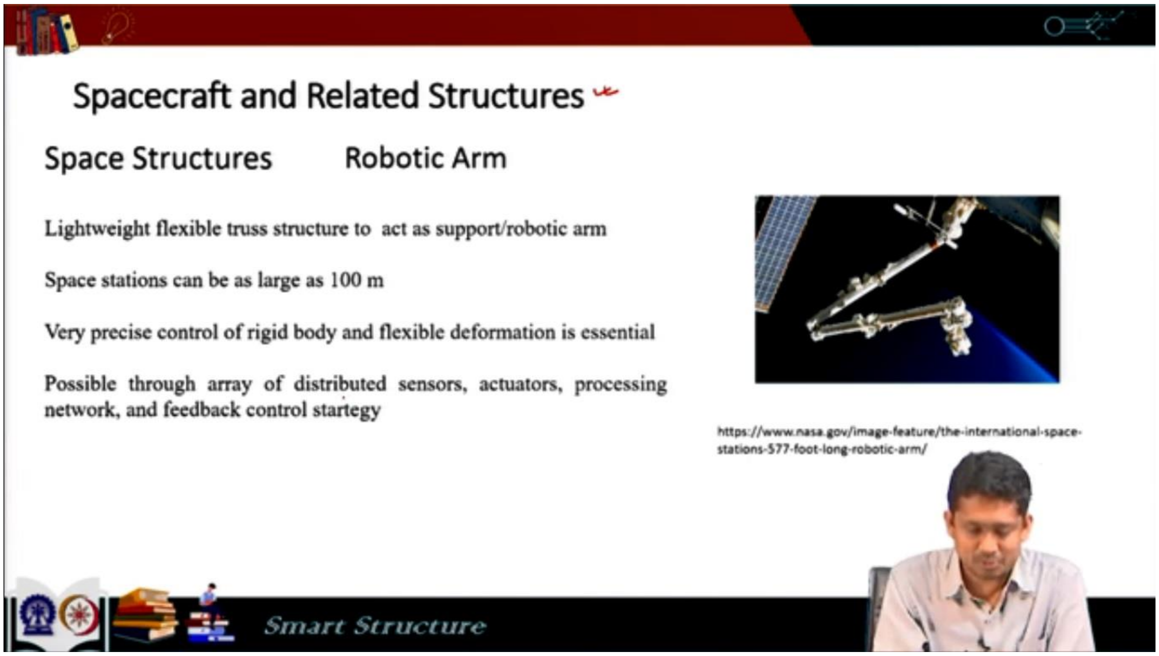
In Europe there is application for smart structures in engineering and technology asset program. So, UK, France, Germany or Italy were the participants. Adoptronic under German aerospace center that was also another program. In the Asian countries Japan in 1980s they had VGT, Varial Geometry Trust, SSS smart structural systems. It was by MITI, Ministry of International Trade and Industry.

(Refer Slide Time: 02:52)



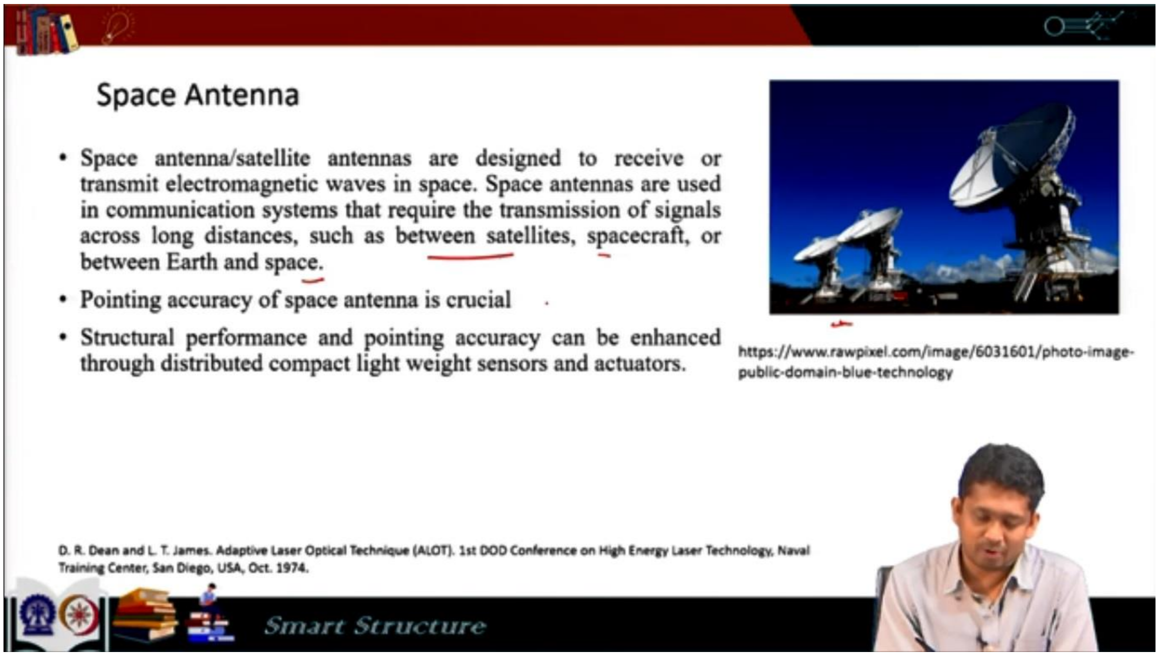
And other major programs ARO initiated URI, University Research Initiative that was in 1992, SPICES, Synthesis and Processing of Intelligent Cost Effective Structures, CHAP Compact Hybrid Actuator Program that was in 2002 to 2003, CLAS Conformal Node Bearing Antenna Structure. Now, let us look into some specific applications in various domains. So, we will start with the domains of spacecraft and related structures. So, this is a space spacecraft structure and we can see that it has a robotic arm like that this is the actual view of it. Now, this structures can be as large as 100 meter and this robotic arms are used to proper positioning of the equipment.

(Refer Slide Time: 11:10)



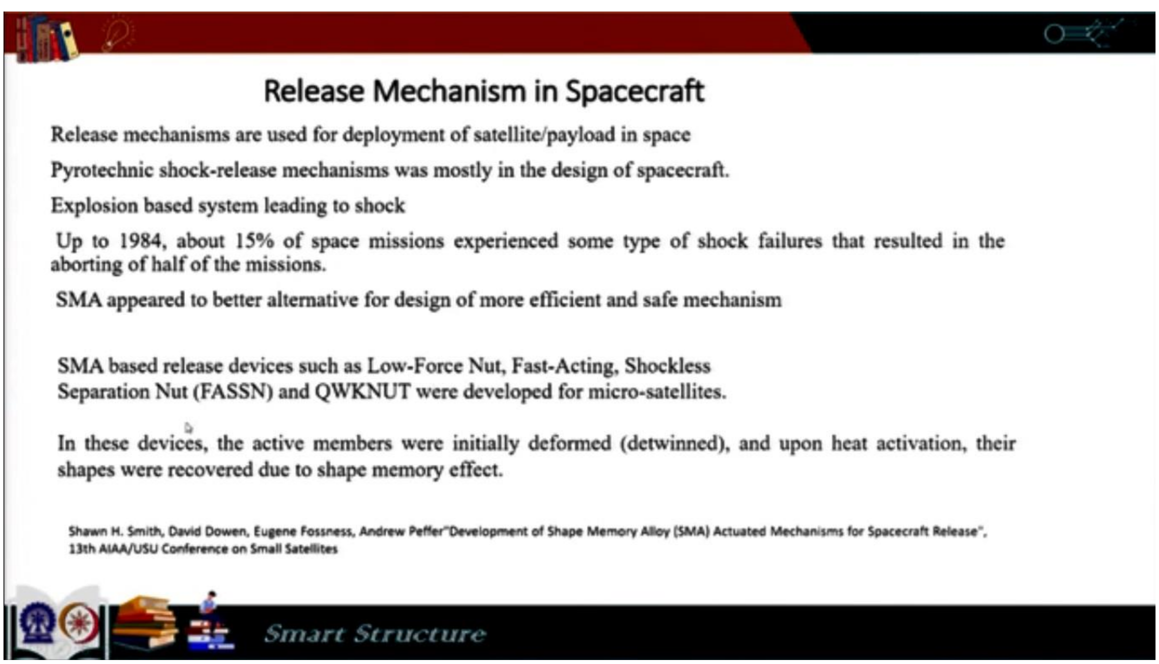
Now, needless to say for a precise control of this arm is needed for proper positioning. Now, this structures inside have truss structure and this structure has complex rigid and flexible modes. So, a proper control of this different modes is essential and that is possible through distributed sensors actuators, processing network and feedback control strategy. Space antennas or satellite antennas are designed to receive and transmit electromagnetic waves, here we can see some images. These antennas are used in communication systems and this communication can be these are long distance communications it can be between two satellites between satellites spacecraft and between earth and space also.

(Refer Slide Time: 11:47)



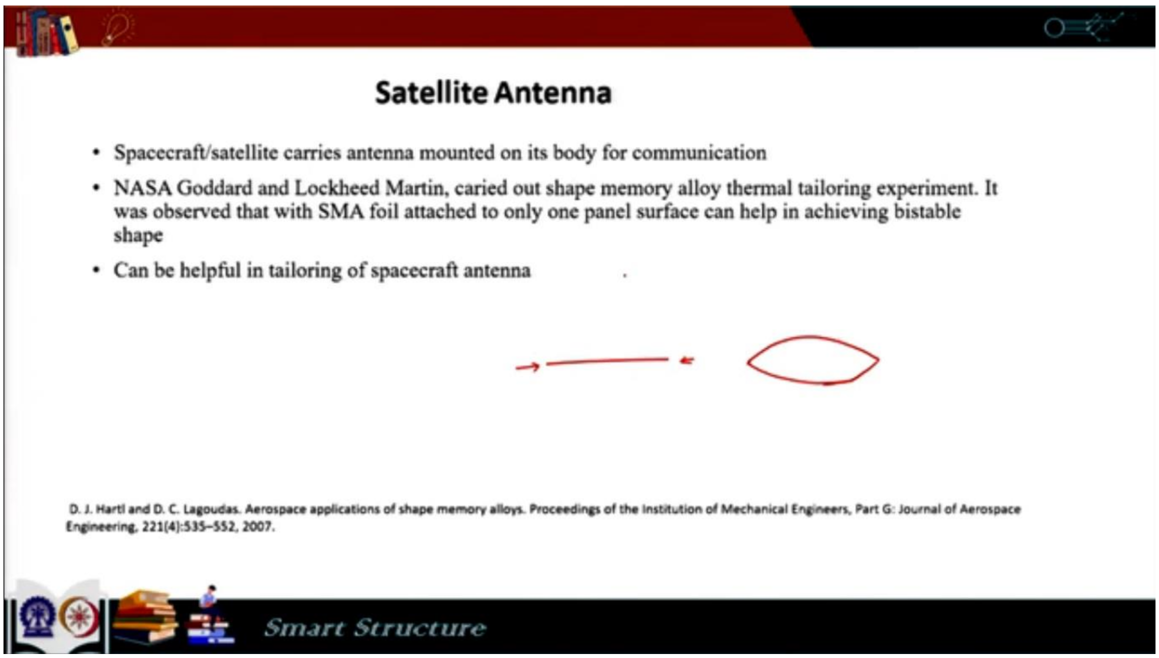
Now, for proper signaling the pointing accuracy of the antenna is important. Now, structural performance and pointing accuracy can be enhanced through distributed compact lightweight sensors and actuators. Now, we will talk about one special application of shape memory alloy actuators and that is for release mechanism in spacecrafts. Release mechanisms are used for deployment of satellites and payloads in space and for that most of the solutions were pyroelectric based. So, they used to have explosion and which lead to shock and because of the shock there were lot of failures.

(Refer Slide Time: 13:06)



In up till 1984 there were about 15 percent of the space missions that experience some kind of shock failures and which resulted in a version of half of the space missions. Now, various other solutions were tried, but the shock could not be avoided. So, finally, the solution came through shape memory alloys. As we know the shape memory alloy can be deformed and then when it is heated it generates the actuation force and that was used for release. So, various shape memory alloy solutions so, those devices are this like force nut, first acting, shockless, separation nut, QK nut they were developed for micro satellites.

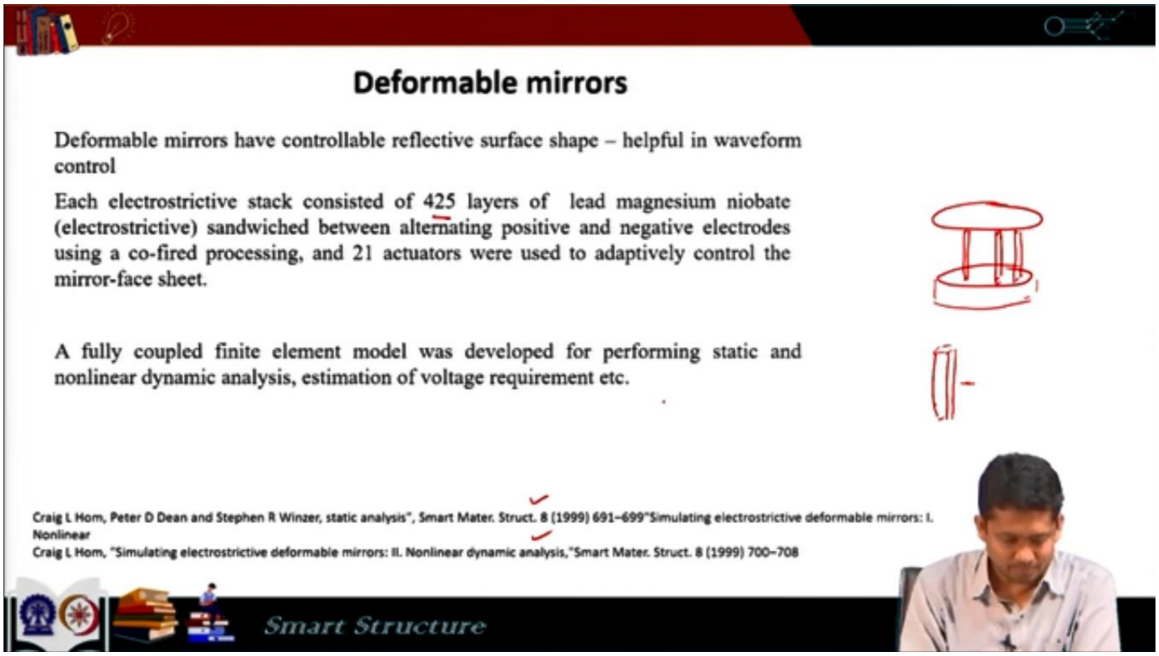
(Refer Slide Time: 14.12)



A good study of this can be found in this paper by Smith and others. Satellite antennas carries satellites carries antenna mounted on its body for communication and NASA Goddard and Lockheed Martin they carried out shape memory alloy thermal tenuring experiment and it was observed that shape memory alloy foil attached to only one parallel surface can help in achieving bi-stable shape. A bi-stable shape means a shape which is stable at two configurations. For example, a very simple example is a buckle beam. So, a buckle beam can be stable at these two shapes.

Now, there is a lot of research in the structural engineering community in finding out structures with bi-stability or even multi-stability also. And this kind of structures are quite helpful in tailoring as I can as we can see here. So, we can find some discussion on this in this paper. Here is one application of electro stick, electro stick actuators and that is for deformable mirrors. Deformable mirrors have controllable reflective surface and they are quite helpful in waveform control.

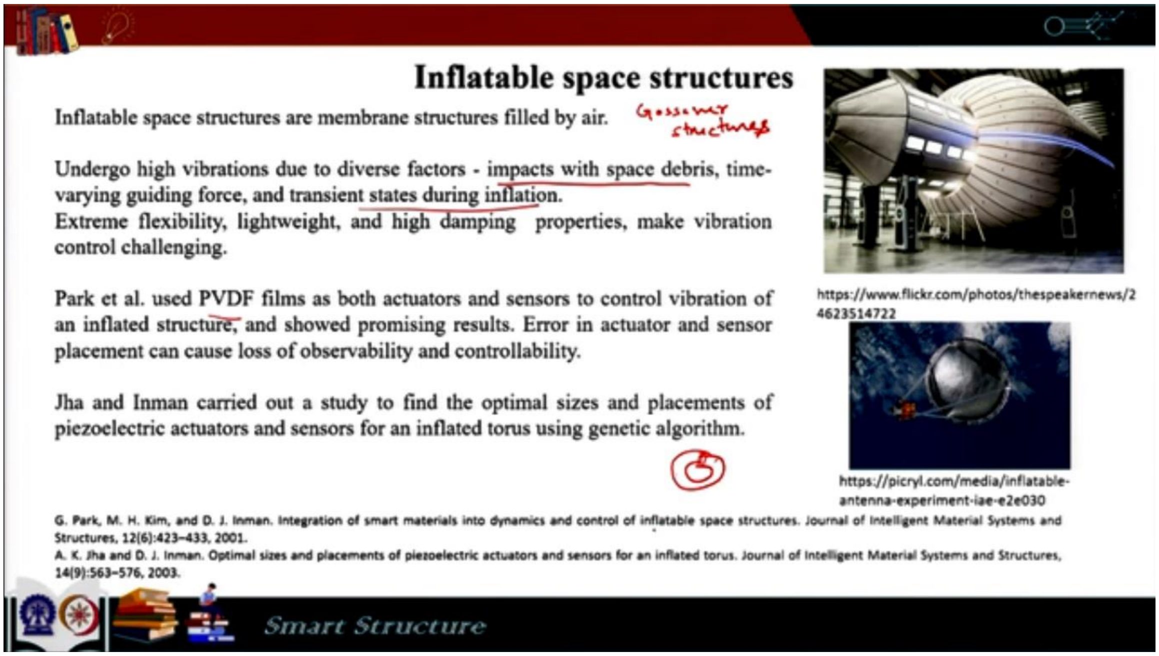
(Refer Slide Time: 15:39)



Now, here is a study which is described in this papers. So, here there is the configuration looks like this. So, you have plate which we call it a face sheet and then at the base there is a base plate. So, face sheet and base plate and they are connected by actuators. So, this is a very simplified schematic view of it and there are number of these actuators.

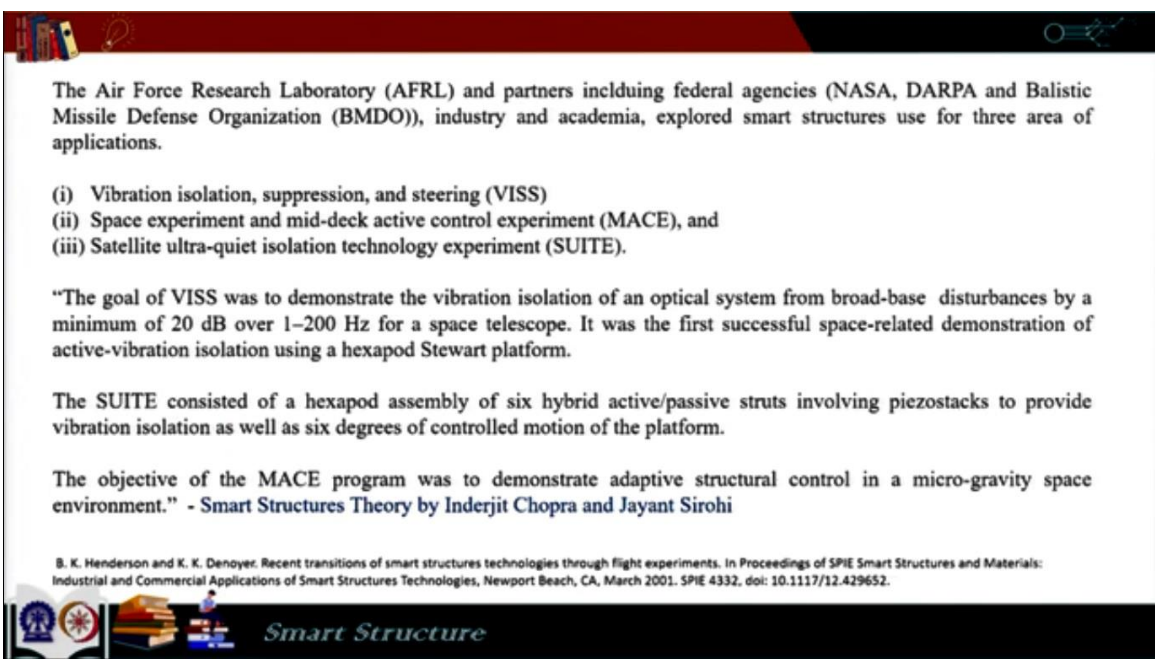
Now, each actuator actually it is composed of several stacks of the lead magnesium niobate electro stick tips. So, each act so, each of this stack had for 2 for 25 layers of lead magnesium niobate sandwiched between alternating positive and negative electrodes and there were 21 such actuators. Now, needless to say this is a quite complicated system. So, it is proper analysis is required. So, here a non-linear dynamic analysis and also static analysis was conducted by Hom and his co-authors.

(Refer Slide Time: 17:51)



Inflatable space structures they are also called Gosamore structures. So, these are ultra lightweight structures and there is tremendous amount of development in this kind of structures for space applications. So, they are main constituent is a membrane and this membranes are often under pre stress to keep the shape. Now, this is a quite flexible structures. So, it undergoes high non-linear vibration and there are several external factors for the vibrations.

(Refer Slide Time: 18:56)

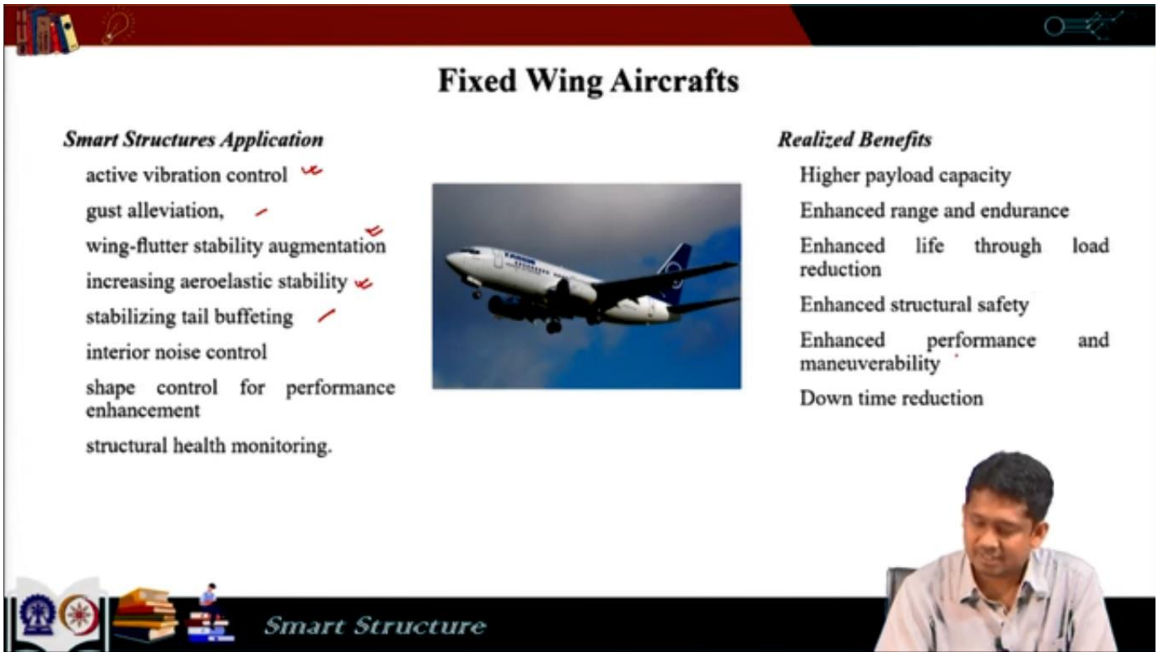


So, there can be impact with space debris time varying guiding force and transient state during inflation. So, there are extreme flexibility lightweight and high damping make the vibration control challenging. So, there was a study by Park and his co-authors they used PVDF films as actuators and sensors to control vibration of inflated structures and they showed some promising results. And they also demonstrated that error in actuator and sensor placement can cause loss of observability and controllability. Then in the same group Jha and Inman they carried out a study to find out optimal sizes and placements of piezoelectric actuators and sensors for inflatable torus using genetic algorithm.

Now, torus structures which looks like this which has a donor shape they also find lot of applications in this inflatable structures. So, it is inflated basically it is a inflated torus. So, here we can see one inflatable solar antenna that is a concept of NASA they also have this kind of torus structures. So, this torus structures were studied by Jha and Inman and they also found some they also showed some interesting conclusions. The Air Force Research Laboratory and partners including federal agencies and various industrial and academic bodies they explored smart structures used for three areas of applications.

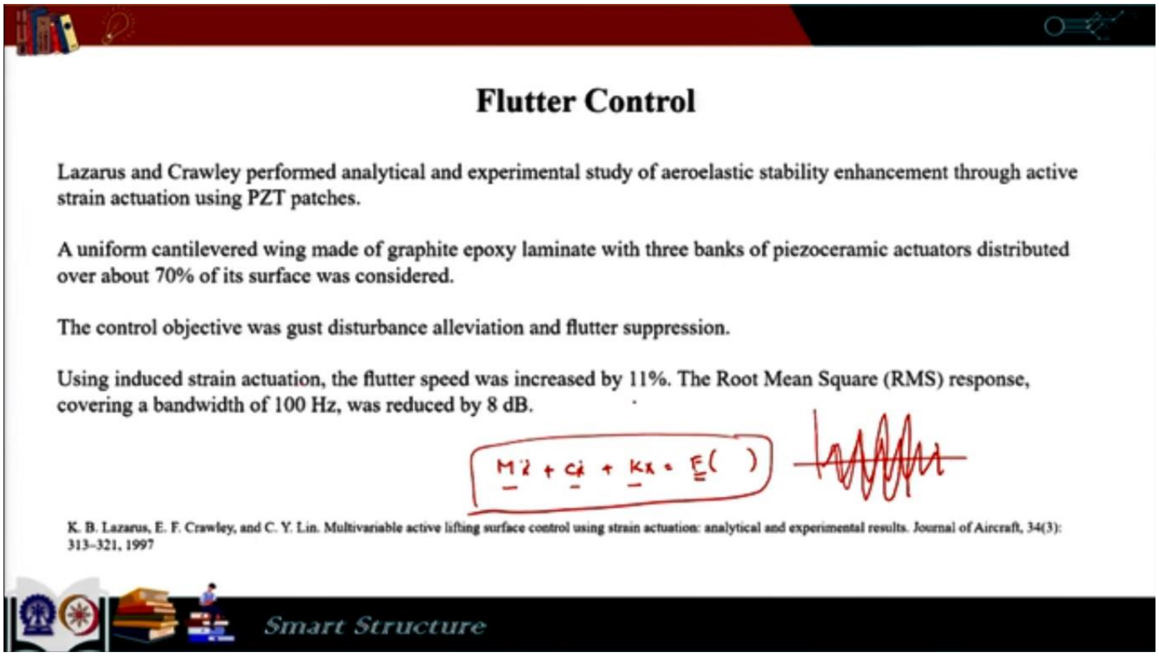
Vibration isolation, suppression and steering, space experiment and mid deck active control experiment and satellite ultra quiet isolation technology experiment. Now, the goal of the first one VISS was to demonstrate the vibration isolation of an optical system from broad base disturbances by a minimum of 20 decibel over 1 to 200 hertz for a space telescope. And it was the first successful space related demonstration of active vibration isolation using a hexapod stayward platform. The ACYTE it consisted of a hexapod assembly of 6 hybrid active passive struts involving involving piezo stacks to provide vibration isolation as well as 6 degrees of controlled motion of the platform. The objective was the MSE program was to demonstrate the demonstrate adaptive control in a micro gravity space environment.

(Refer Slide Time: 20:10)



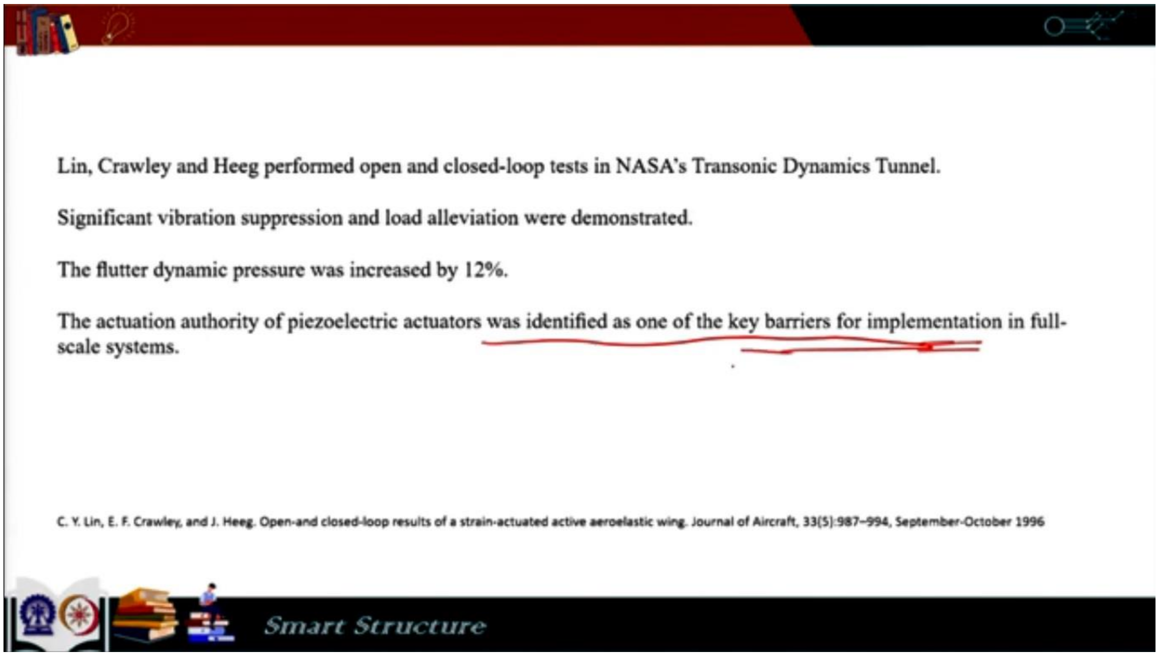
So, after this spacecraft related applications now we will go to fixed wing aircrafts. In fixed wing aircrafts the applications are there for active vibration control, gust alleviation, wing flutter stability augmentation, increasing aero elastic stability, stabilization of tail buffeting. So, we can see that there are lot of aero elastic applications. Then interior noise control, shape control for performance enhancement and structural health monitoring. The benefits that we get are enormous it increases in the payload capacity, enhanced range and endurance, enhanced life through load reduction, enhanced structural safety and enhanced performance and maneuverability and with structural health monitoring the down time of the vehicles can be reduced and which has lot of safety and economic implications.

(Refer Slide Time: 22:15)



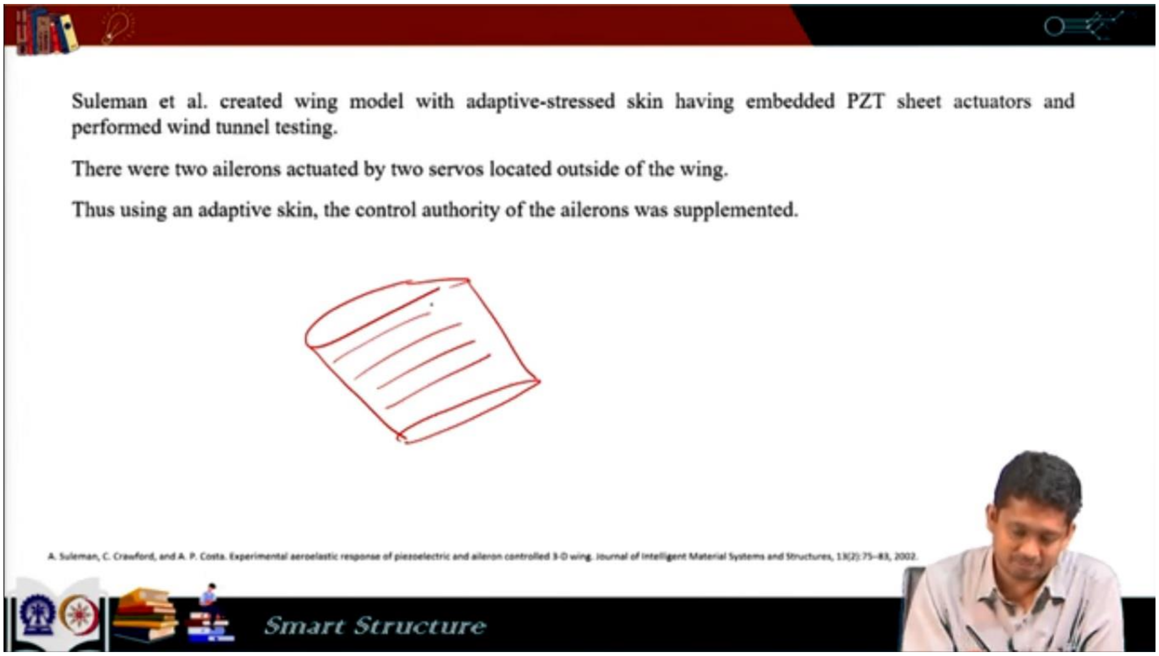
First we talk about some cases of flutter control. Now, flutter is a dynamic aero elastic instability. So, the dynamics of a aircraft wing in the aerodynamic environment can be written as this mx double dot plus cx dot plus kx standard form, where x is the displacements of the structure of various points in the structure and this aerodynamic force this also becomes a function of the structural states the displacement velocity. Now beyond a certain beyond a certain speed of the aircraft this system becomes such that the effective damping of the system becomes negative and then the structure shows some kind of unstable growing oscillation and that is called flutter.

(Refer Slide Time: 23:04)



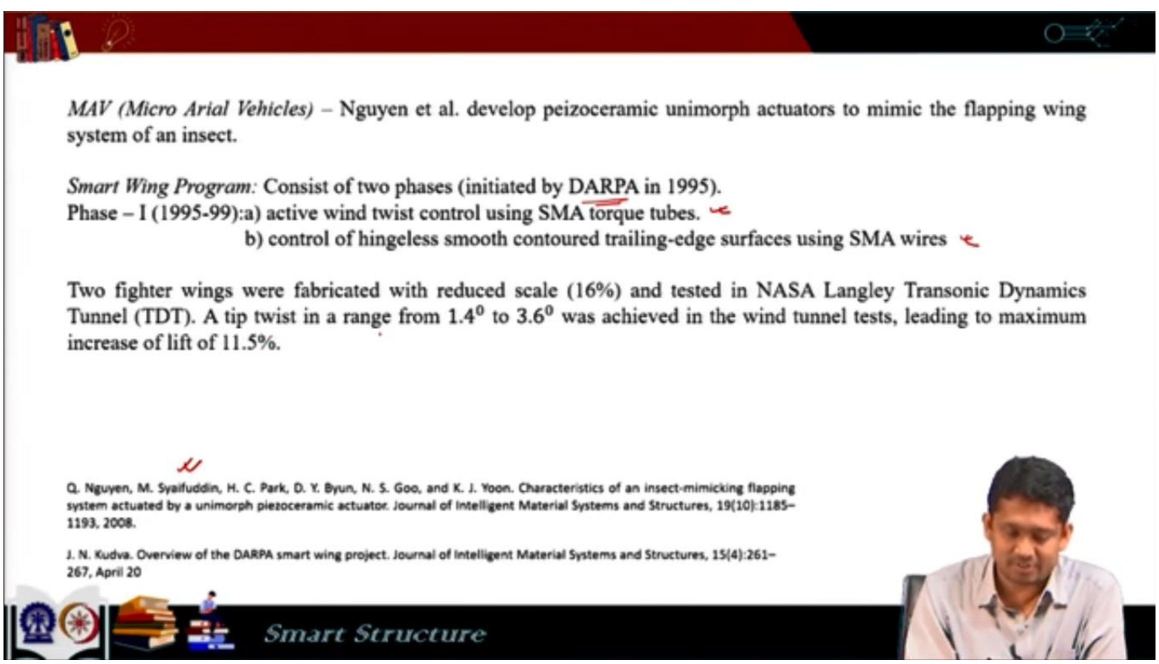
So, its control is necessary. So, with the help of proper control the vibration can be stabilized and it can be prevented from growing. Lozarez and Crowley they performed analytical and experimental study of aero elastic stability enhancement through active strain actuation using PZT patches. They used a uniform cantilever wing which was made of graphite epoxy laminate with three banks of piezoelectric actuators distributed over 70 percent of its surface. And here the control objective was gas disturbance alleviation and flutter suppression. And using induced strain actuation the flutter speed was increased by 11 percent.

(Refer Slide Time: 23:46)



The root mean square response covering a bandwidth of 100 hertz was reduced by 8 decibels. Lin, Crowley and Hig they performed open and closed loop tests in NASA's transonic dynamic tunnel. Significant vibration suppression and load alleviation was demonstrated. The flutter dynamic pressure was increased by 12 percent. The actuation authority of the piezoelectric actuators was identified as one of the key barriers in implementing in full scale system.

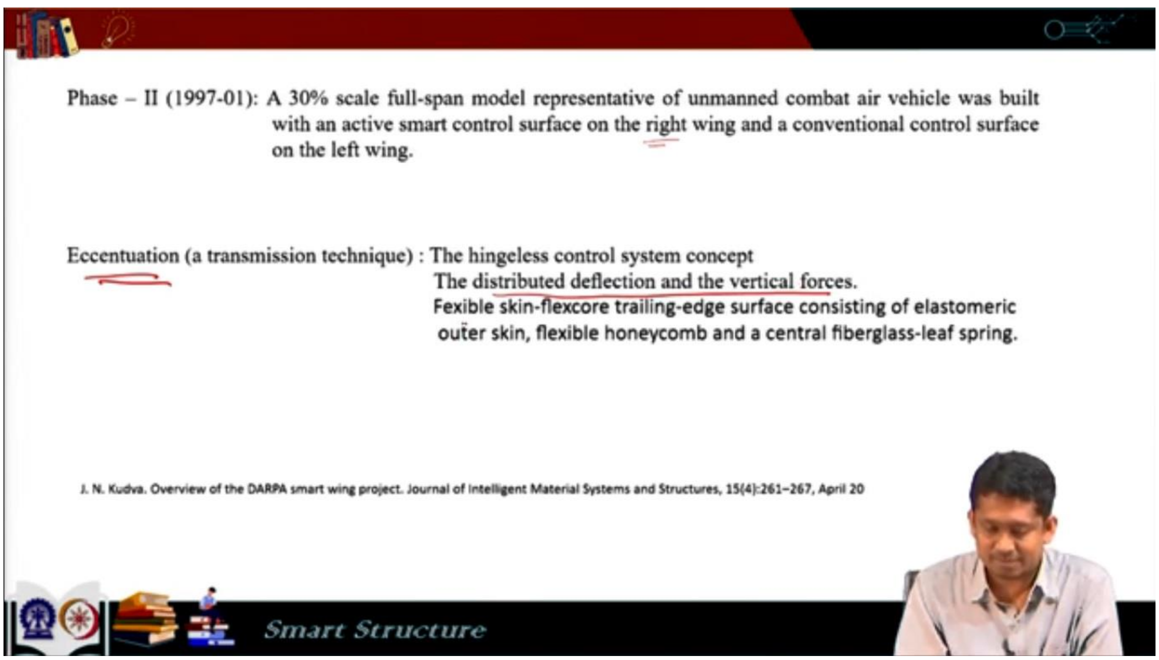
(Refer Slide Time: 24:46)



So, as we saw that the smart material actuators their actuation authority or the stroke is less than the traditional actuators. So, that is where they faced a barrier when it they try to implement it for full scale system. Now, Sullivan and others they created wing model with adaptive stress skin which had PZT sheet actuators and performed wind tunnel testing. So, there were two ailerons actuated by two servos located outside the wing and using the adaptive skin the control authority of the ailerons was supplemented. So, their adaptive skin concept was something like this.

So, if it is a wing the skin of the wing it in the under underneath of it there were distributed actuators. So, by having distributed actuation the skin could adapt to the external changes and that adaptive skin could supplement the control authority of the ailerons. Now, this piezoelectrics are quite useful in micro air vehicle also specially when there are flapping mechanism. So, here is one such example in this paper can be found. And then there was a smart wing program it was initiated by DARPA and that had two phases.

(Refer Slide Time: 25:45)



The first one was to active wind twist control using shape memory alloy torque tubes and the second one was control of hingeless smooth contour trailing edge surface using shape memory alloy wires. The two fighters were fighter wings were fabricated with reduced scale 16 percent and tested in NASA Langley transonic dynamic tunnel. A tip twist in a range from 1.4 degree to 3.6 degree was achieved with the wind tunnel tests which lead to maximum increase of lift by around 11.5 percent. In the phase 2 a 30 percent scale full scale full span model representative of unmanned combat air vehicle was built with an active smart control surface on the right wing and a conventional control surface on the left wing. So, their goal was to find out the effectiveness of the right wing over the left wing and for that they used a distributed actuation and they called it an eccentuation. So, that was a concept new concept that they used. So, this eccentuation is a hingeless control system the distributed deflection and the vertical forces is possible through it and it consisted of flexible skin flexible flex core trailing edge surface which had elastomeric outer skin flexible honeycomb and a central fiberglass lips more details can be found in this paper.

So, with this we will continue from it in the next lecture.

Thank you.