Aircraft Structures - 1
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Module No - 02
Lecture No - 06
Airworthiness of an Aircraft

Welcome back to aircraft structures one course this is Anup Ghosh from aerospace engineering department IIT Kharagpur. This is the first lecture of the second week we will learn about airworthiness of an aircraft. So before we go into the topic in detail today we will let us see what we have covered.

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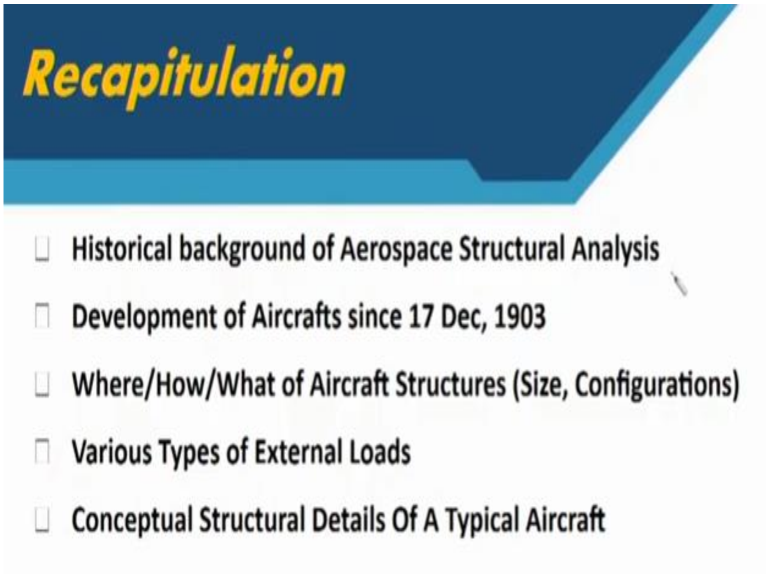

So far we have covered so far historical background of aerospace structural analysis development of aircraft. The first point if we look at first point is basically the history of solid mechanics we have seen and that is what leads the path for analysis of structures. And then in the next lecture, we have covered development of aircraft since 17 December 1903 from the Kitty Hawk flight till date whatever we have seen and then where how what of aircraft with respect to size and configuration.

We have seen various sizes from small to big and but we have also observed that from structures point of view there is not much change but according to configuration we need to have some change in the structural design. Various types of external loads you have seen where from the external loads come how does it come? The loads are the basic thing which we need to withstand so loads will come in our discussion again and again today also we will discuss about loads.

So that was an introduction to the external loads and we will do more detail about loads conceptual structural detail of a typical aircraft in this we have a seen in articulated fashion what is there inside a wing what is there fuselage how does it look like what are the structural components called and all those things nomenclatures all those things we have already covered.

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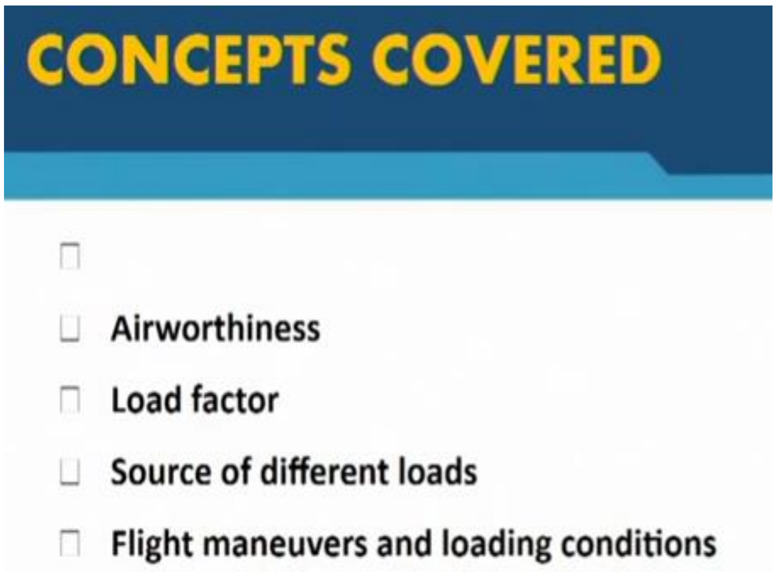

And in today's lecture what we will do we will cover the airworthiness will cover load factor source of different loads flight maneuvers and loading conditions. So flight according to flight maneuvers how the loading condition changes that we will see. So let us have some before we go to the airworthiness.

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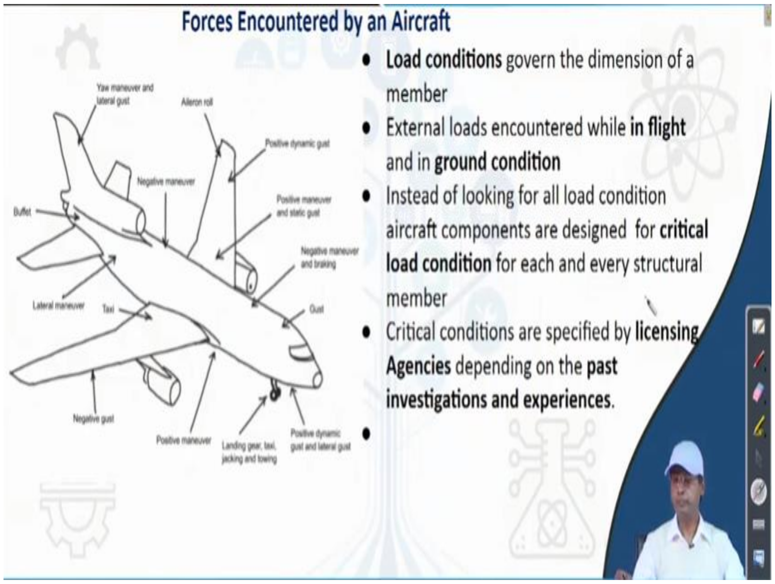

Let us see some basic considerations on loads again if we look at this slide the load conditions govern the dimensions of a member that is always true under load we generally change the dimension, we need to change the material we need to because we need to withstand the load it has to support the load to serve its purpose. External loads encountered while in flight and in the ground in general in aircraft in 2 tier in these are the 2 conditions in flight and in the ground with different types of loads come in ground towing, wasting, pulling all those loads come even taxing or those load in during flight different maneuver loads will generally come.

So all those things we need to encounter instead of looking for all load condition aircraft components are designed for critical load conditions. For each and every structural member so this is important critical load conditions see previously also we have discussed different loading conditions and the picture if we look at this picture we see that there are different loads indicated and those loads are on which it is designed the aircraft and which for those loads which section is more vulnerable that is indicated there.

But here the critical load condition that we need to find out and those critical load conditions are specified by licensing agencies. Licensing agencies mean there are agencies; who certifies the design who certifies the fabrication who certifies the flight testing. So these licensing agencies; certifies everything then only it is allowed to fly that is the reason flight is so safe than any other journey.

So depending on the past investigation and experience so the licensing agencies improve their experience they are critical conditions load conditions and accordingly we continue for design.

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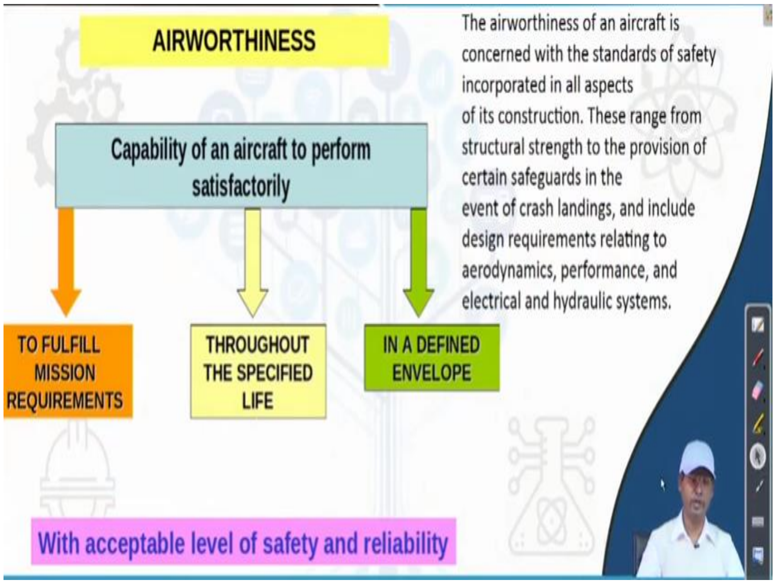

So let us come back to the topic of airworthiness where from it comes if you look a discussion here a kind of definition the airworthiness of an aircraft is concerned with the standards of safety incorporated in all aspects of its construction it is concerned about the safety incorporation while it is being constructed while it is being designed in all cases. This range from structural strength to the provision of certain safeguards in the event of a crash landing and include design requirement relating the aerodynamics performance and electrical and hydraulic systems.

So it looks into everything it looks into the overall design of aircraft in with respect to aerodynamics with respect to electrical and hydraulic design every aspect. But from our point of view we will be considering we will be looking into the airworthiness requirements in our structural point of view a brief is all given here in a diagram form. We define that capability of an aircraft to perform such satisfactorily.

The airworthiness actually looks into the safety capability of an aircraft to perform satisfactorily with safety how does it perform satisfactorily that is the aim of airworthiness criteria. To fulfill mission requirements every flight has a mission requirement in civil aviation as a mission requirement to carry passengers from one airport to the other. Like that mission requirements varies recent days we see lot of jungle fires or forest fires are coming up for that there are specific aircrafts to fight those.

So that remains requirement of that particular mission is to fight against the fire like that there are agricultural aircrafts the agricultural aircrafts mission is in general is to spray required amount of maybe pesticide may be nutrients to the field like that depending on the mission it as different type of requirements or say a fighter aircraft has a different type of requirement. So all those requirements depending on the requirements generally airworthiness criteria come and accordingly it has to be satisfied.

Throughout the specified life this is another important thing this is not only to satisfy the requirement whether it is able to satisfy it throughout the life that is also important. So it tries to ensure that it needs to be tested after certain flight hour all those requirements are specified in these safety guideline. In a defined envelope so that is what we were discussing this defined envelope some of you probably have some idea what is envelope flight envelope but if you do not have any idea of flight envelope means how much force how long it can fly all those things are defined in a flight envelope.

Whether how much G load it can sustain how much angle of attack it can sustain all those things are defined by this flight envelope. Whether how much roll or pitching rate it can achieve all those things are defined here with acceptable level of safety and reliability. So this governing with respect to these points the airworthiness defines the criteria and we need to follow it so for structural point of view let us see how these things come into our consideration.

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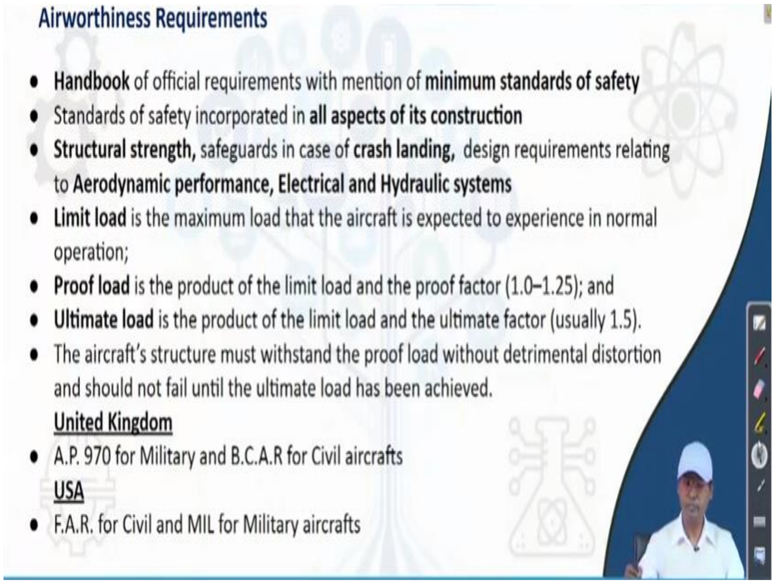

Airworthiness requirement in case of structures handbook of official requirements with mention of minimum standards of safety, incorporated in all aspects of its constructions structural strength safeguards in case of crash landing design requirement relating to the aerodynamic performance electrical and hydraulic systems. Limit load so this is something new we have not discussed a limit load is the maximum load that the aircraft is expected to experience in normal operation proof load is the product of the limit load and the proof factor which generally ranges in between 1 to 1.25.

And ultimate load is the product of the limit load and the ultimate factor that is usually 1.5 so generally we find out depending on the flight envelope depending on the performance we find out the limit load and then with respect to whatever we need to find out proof load or the limit load we generally find it out and accordingly we do. These the aircraft structure must withstand the proof load without detrimental distortion and should not fail until the ultimate load has been achieved.

And this is where the proof load comes in United Kingdom has a different guideline for airworthiness that is AP 970 for military and DCAR for civil aircrafts USA has its own guideline that is FAR for civil and MIL for military aircraft. Like that almost all countries have their own guidelines these 2 countries come first because they initiated it first.

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Airworthiness Agencies / Regulation

COUNTRY	CIVIL AIRCRAFT	MILITARY AIRCRAFT
USA	Federal Aviation Requirements (FAR) of Federal Aviation Agency (FAA) – Washington	Dept. of Defence Military Specification
UK	Civil Aviation Authority (CAA) in 1972 became Air Registration Board – uses British Civil Aviation Regulation (BCAR)	MOD, Procurement Executive , Def-Stan-00 970
France	Director General De Le Aviation Civil (DGCA) – Regale Air (Air Norms)	Air Standards by Director Technique Construction, Aeronautics (DGTC)
Germany	Luftfahrt Bundesamt	Ministry of Defence
Russia CIS	Chairman, Interstate Aviation Committee	Ministry of Defence
India	Aircraft Act, 1934 Director General of Civil Aviation (DGCA)	Design Approval, CEMILAC, Quality Assurance, DGAQA

So if we so airworthiness agencies are there in all countries here is the small list of airworthiness agencies in USA, in UK already we have said and which organization acts to implement those regulations are listed on the right hand side table right hand side column. So in case of USA Federal Aviation requirements or Federal Aviation agency Washington is the responsible agency for the civil aircraft and department of defense and military specifications sorry.

For in UK civil Aviation authority CAA in 1972 became air registration board uses British Civil Aviation regulation. MOD procurement executive Def-Stan-00 970 is the military aircraft organization like that similarly we have different organization. For France we have different organization for Germany we have different organizations for Russia like that we have different organization in India also.

Aircraft act 1934 director general of civil aviation more popularly known as DGCA is the agency which governs everything. If he were aware of the recent development DGCA has come out with some regulation with respect to the small UAV's. Like that they time to time improve their guidelines they revise their guidelines and design requirements implement those regulations like that for military aircraft design approvals CEMILAC is the organization quality and assurance DGAQA is the organization.

For design approval the CEMILAC is the organization who approves the design like the LCA aircraft light combat aircraft or the ALH advanced light helicopter what we have already developed our country have already developed. So in that case the CEMILAC is the organization who approves the design and for quality and other DGAQA is the organization who takes care of this.

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Airloads	**Landing**	**Other**
Maneuver	Vertical load factor	Twoing
Gust	Spin-up	Jacking
Control deflection	Spring-back	Pressurization
Component interaction	Crabbed	Bird strike
Buffet	One wheel	Actuation
	Arrested	Crash
	Braking	
Inertia Loads	**Takeoff**	**Power plant**
Acceleration	Catapult	Thrust
Rotation	Aborted	Torque
Dynamic	**Taxi**	Gyroscopic
Vibration	Bumps	Vibration
Flutter	Turning	Duct Pressure

So okay we are more to the requirement with respect to the structures so with respect to the structures has we have seen where from the load comes, how those load come to the aircraft those are some of the important points why we think of designing of aircraft we need to think where from it may come. So that is the reason this table groups different sources of aircraft load so if we look at the sources first is the air load then during landing then other loads are definitely we will come other loads include other loads category inertia land category, takeoff, taxing, power plant.

So let us start with the air load maneuver is the certain type of movement of aircraft due to which what are the types of load comes it may come to mind if to move what are the load structure may experience. Actually for different change of acceleration different type of loads inertia loads comes to aircraft and that becomes a predominant criteria for design. During gust or the sudden change of wind velocity and direction that creates a sudden again finally it gives the change of acceleration and that gets creates inertia load.

Not only that sometimes it leads to the sudden loss of lift and if it losses the lift suddenly it acts like and impact to the total aircraft. Control deflection for maneuvering for certain direction change we always need to have a control deflection and that control deflection induces load and that load we need to take care component interaction. Different components interact this is very interesting criteria we say different components interact means it is difficult with the understanding you have to describe now.

Component interaction may be the highest example we may say the fluttering or maybe interaction between a controls 2 different controls surfaces. Now we go to the buffeting is a certain type of aerodynamics phenomena due to which a periodic oscillation comes and that is experienced generally by the tail plane and that has to be taken care. During landing vertical load factor we will work out this thing in our in some example later on.

Spin up if it spins up that means after touching down if it spins up sorry it is not that it is the spin up of the wheel springing back it is also related to the spinning back of the wheel that it produces inertia. Crabbed landing this is very important things there are in many videos available in internet you may look at it crabbed landing is very interesting and really a beautiful example of how the control system has developed in case of aircraft control.

So while in aircraft lands with angular fashion in an airport so that is what the crabbed landing is and then one wheel sometimes during crabbed landing or some other condition also one wheel touches down and that creates huge impact that that has to be taken care. Arrested landing and breaking these are 2 special cases arrested landing is that in case of aircraft carrier landing they are arresting hooks are there and that arrest the landing will solve example with respect to this.

Other landing loads coming from the towing we need tow an aircraft we need to jack an aircraft pressurization the fuselage is pressurized bird strike this is very bad unwanted incidents but we need to take care of it. Unfortunately bird strike and we need to have a safe design for that actuation of different control surfaces and crash which is not at all a desired condition but we need to have some kind of safety for crash.

So inertia loads due to acceleration as I told you all this maneuvers also finally goes to the acceleration change of acceleration. But this is a inertia load talks about a regulation acceleration of the aircraft rotation regular, rotation dynamics load because of the various other dynamics criteria involved in during flight. Vibration and flatter all these things in introduces the inertia loads and that those loads we need to talk about.

During takeoff catapult take off like the arrested landing in carriers aircraft carriers we need to have catapult takeoff system and that catapult is generally attacked to some fuselage junction. So those has to be designed properly aborted takeoff if it is for some reason aborted what are the forces come and when it is getting aborted all those things we need to take care bumps and turning these are as I told you during taxing the aircraft is full of fuel even a small bump creates a huge load on the wing fuselage junction.

Power plant from their only the total thrust comes and that gets transferred to the wing and to the total air craft. For partial failure it creates a huge torque to the total system it also creates gyroscopic effect because of it is rotation. Vibration due to its own source of vibration duct pressure is another source of loads we from the power plant we need to take care.

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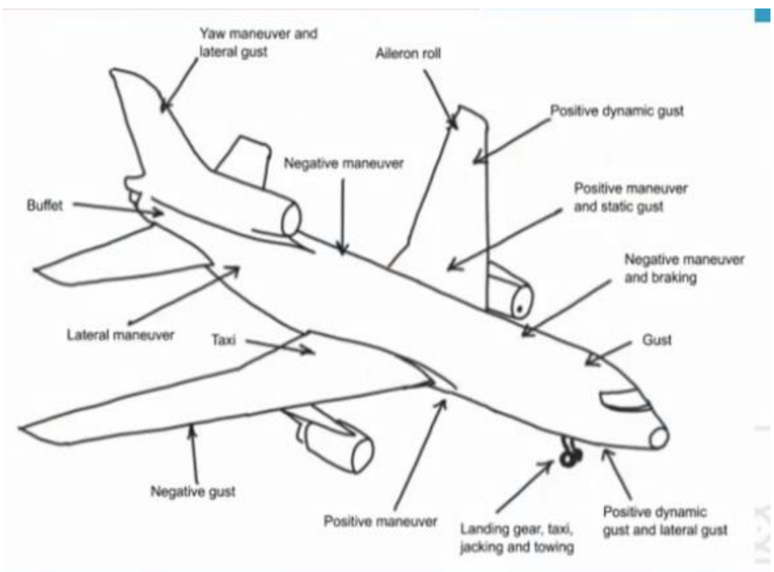

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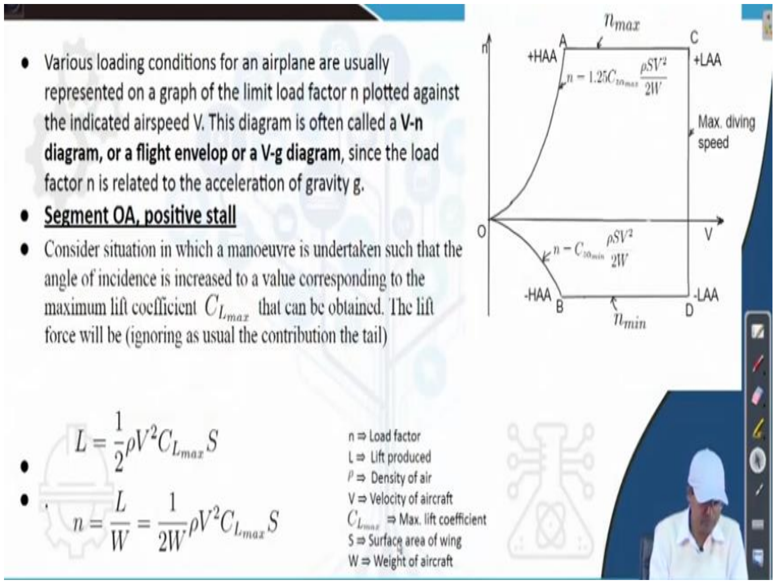

So this is very important slide this is phenomena is very important as I was discussing that the flight envelope is the important thing. So what is flight envelop in one sense this is flight angle of what is this is let us try to learn. This is a plot of n the load factor with respect to the V. Various loading conditions for an airplane are usually represented on a graph of a limit load factor n plotted against the indicated airspeed V.

This diagram is often called V-n diagram or a flight envelope or a V-n diagram V-g diagram sorry. Since the load factor n is related to that acceleration of the gravity g it justifies this now let us see how this diagram is developed and why do we need to have this diagram for different type of aircraft this flight and envelope is fixed. Say for a civil aviation generally this n values maximum values are fixed in minimum values are fixed and V max is also fixed so all this things are fixed.

So these things are generally this part of the plot is generally found out from the high positive high angle of attack and these portion low positive low angle of attack from here to here and whenever there the limit of speed air speed comes their it comes suddenly down we should not cross that and that crossing may lead to some other failure other problems different values of n and this portion is generally governed by the negative low angle of attack and this is again this actually this total portion is not very intentional portion.

For a certain desired manoeuver but this portion is generally encountered negative lower angle of attack negative high angle of attack. So these 2 portions are generally during the stall it happens and it is generally kept as the value 1.25 times the general value obtain for n. And in case of negative we generally do not compromise we do not keep margin that of 0.25. So let us see how do we do considering situation in which a manoeuver is undertaken such that the angle of incident is increased to a value corresponding to the maximum lift coefficient that is CL max that can be obtained.

Lift force will be so this is a formula we need to memorize now lift force is half rho V square CL max and S. What is rho? Rho is the density of air V is the velocity of the aircraft here it is mixed actually this is airspeed so this is the air speed and then CL max is the maximum lift coefficient and S is the surface area of V. So n this is the definition of n if we say n = lift / W so if lift is this, whatever we have said this becomes something W comes in the denominator.

So that is what is given here you see only instead of CL max here it has been said as CZ max that actually is the component, which is considered for indetermination not the lift in the direction of Z what is the coefficient lift in the direction upward what is the coefficient that and 1.25 that. So this is the highest point curve it should be maintained that means it is having a high angle of attack slowly while it is increasing the velocity the n value increases, and there is a limit up to which it can increase this portion is called the stall portion and this is positive stall and this is the negative stall portion.

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Typical Limit Load Factors		
	n (Positive)	n (Negative)
General Aviation -- normal	2.5 to 3.8	-1 to -1.5
General Aviation -- utility	4.4	-1.8
General Aviation -- aerobatic	6	-3
Homebuilt	5	-2
Transport	3 to 4	-1 to -2
Stratagic bomber	3	-1
Tactical bomber	4	-2
Fighter	6.5 to 9	-3 to -6

Typical values of limit load factors these are some from the guidelines available so for general aviation normally it is 2.5 to 3.8 for n negative is -1 to -1.5. For general aviation utility aircraft it is little bit more in positive that is 4.4 general aviation aerobatic it is 6 it needs to go for a different type of maneuver and that maneuver needs a high G requirement and we need to follow that and negative also it does because some times for aerobatic reasons its flies even inverted.

So home build aircrafts are generally allowed up to 5g and in negative -2g for transport aircraft it is 3 to 4g. And -1 to -2g strategic bombers that is 3 is the general limit -1 like that for tactical bomber we have some limits for fighter aircrafts this is also very high like the aerobatic aircraft because it needs to go through different type of maneuvers critical maneuvers to fight.

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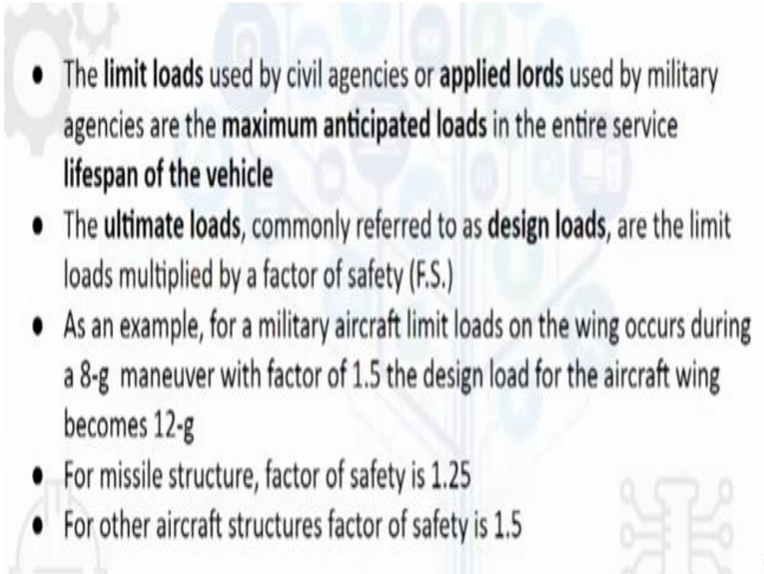

The limit loads used by civil agencies are applied loads used by military agencies are the maximum anticipated loads in the inter service life span of the vehicle the ultimate loads commonly referred to the design loads refer to as the design loads are the limit load multiplied by a factor of safety. As an example for a military aircraft the limit loads on the wing occurs during a 8-g maneuver we with factor of 1.5 of the design load for aircraft wing becomes 12-g.

So for an military aircraft 8-g becomes 12-g with a factor of safety 1.5 for missile structure the factor of safety is 1.25 for other aircraft structure the factor of safety is 1.5. So limit load and ultimate loads are 2 loads which we need to find out limit load is the load experienced and ultimate load is with factor of safety what we used for design.

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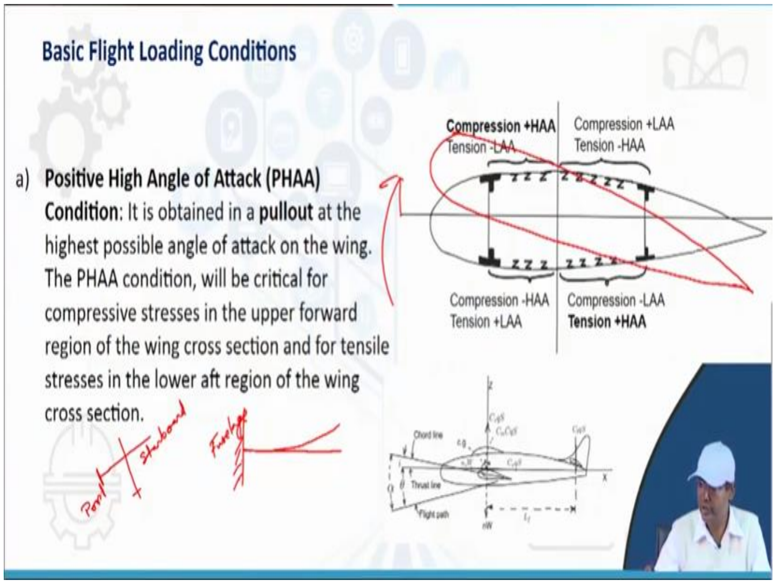

Okay so this is some typical conditions at different angle of attack for design purpose what we have seen in the flight envelope. So if you look at the positive high angle of attack condition it is obtained in a pull out at the highest possible angle of attack on the wing. The positive high angle of attack condition will be critical for compressive stresses in the upper forward region of the wing upper forward region of the wing across section and for tensile stresses in the lower aft region of the wing that is this portion.

Now if we understand try to understand one, others also will be much easier if we try to high angle of attack as I told you it happens in general during positive stall. So if we look at an to an aircraft with a line diagram if we say this is starboard and this is port side and if we look at this section as this section at the tip what is happening for positive high angle of attack actually the air fall is something like this.

Not only this because of positive high angle of attack if we look at this if this is the fuselage and if this is the wing it deflects like this. So what is happen at route this portion definitely the top portion is definitely under compression and the bottom portion is definitely under tension because it is deflecting this way. Now it says that highest possible angle of attack on the positive high angle of attack condition will be critical for compressive stresses in the upper forward region why it is saying the upper forward region will be more critical?

Because with respect to the fuselage this angle is not same throughout the along the wing, so because of that they are always will be some moment acting this way and that will increase the compression on this region more in comparison to this region. And similarly since it is deflecting in this manner that will equally increase tension in this region that is the region it says for positive high angle of attack condition it is obtained this is why when do we get in case of pullout maneuver we get it.

The highest possible angle of attack on the wing in the upper forward section the positive high angle of attack condition will be critical for compressive stresses in upper forward region of the wing across section. And for tensile stresses in the lower act region of the wing across section so accordingly as we have just now discussed because of this 2, 3 dimensional phenomena the port side trailing tip if we look at it will reflect something like this way, and we will have to will we can easily understand why compression is more important in this region why the maximum tension is more important in this region. So let us go further for other condition and cases.

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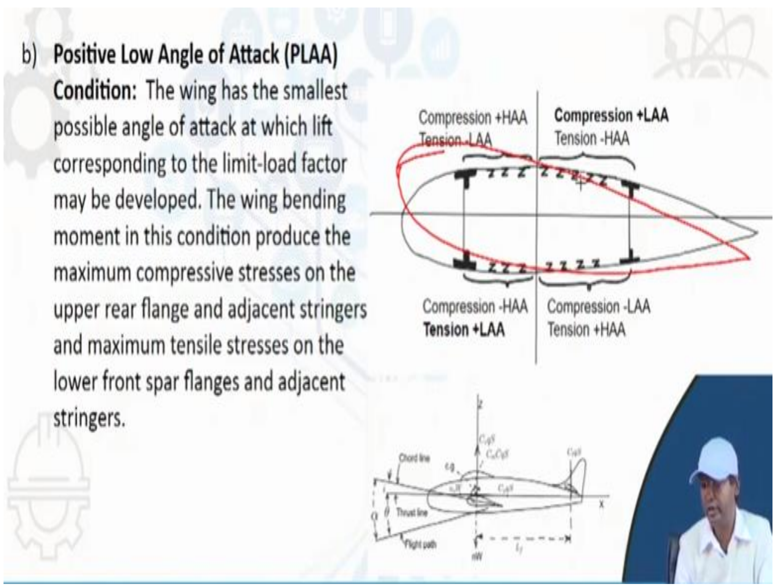

So this is another positive low angle of attack during generally cruise condition it happens the wing has the smallest possible angle of attack at which lift corresponding to the limit load factor may be developed. The wing bending moment in this condition produces the maximum compressive stress on the upper rear flange and adjacent stringer and maximum tensile stresses on the lower front spar flanges and adjacent stringers.

So this time the most important portions sections are those for compression and this for tensile see it is similar but since the it is not high angle of attack, that is the reason the this section does not remain so important whereas this section becomes more important for design. So similarly but the phenomena remains almost same only thing it may happen that what we have seen since it is low angle of attack probably the angle of attack we absorbed may be something like this.

And this will definitely not produce much load on this region whereas it will produce much load compressive load in this region.

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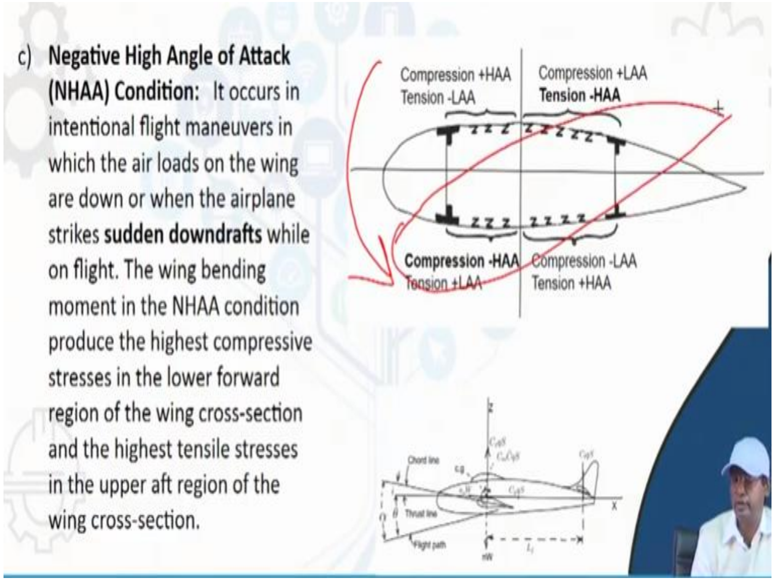

Similar manner we may see other 2 important conditions that is negative high angle of attack condition it occurs in intentional flight maneuvers as I were discussing in which the air loads on the wing are down or when the airplane strikes sudden downdrafts while on flight. The wing bending moment in the negative high angle of attack condition produce the highest compressive stresses in the lower forward region of the wing cross section, and the highest tensile stresses in the upper aft region of the wing cross section.

So similar way if we consider this as the poor side tip of the wing what will happen? It will happen that there will be a huge moment like this and it will be something like this.

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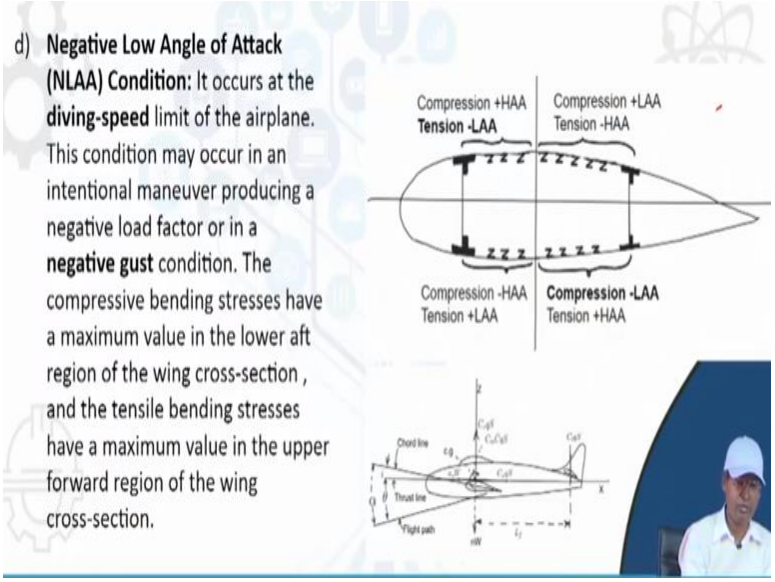

So similar way we can see that incase of the last possible case that is negative low angle of attack these are the 2 regions tension are important this region this and these are important it occurs at the diving speed limit of the airplane. This condition may occur in an international sorry intentional maneuver producing a negative load factor or in a negative gust condition. The compressive bending stresses have a maximum value in the lower act region of the wing cross section and the tensile bending stresses have a maximum value in the upper forward region of the wing cross sections.

So with respect to the flight maneuver and different condition with respect to the load factor flight envelope we now have a certain idea how which section the critical condition occurs and we need to continue our design procedure or fixing dimensions of different section to with stand the load we do.

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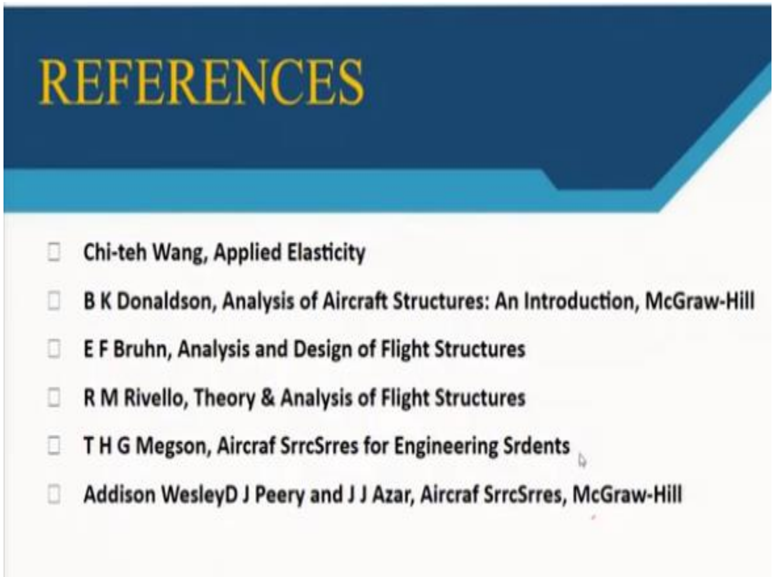

References are standard it is always a mixed not that always all the books are put into but many time more than 1 books are consulted and prepared the notice prepared.

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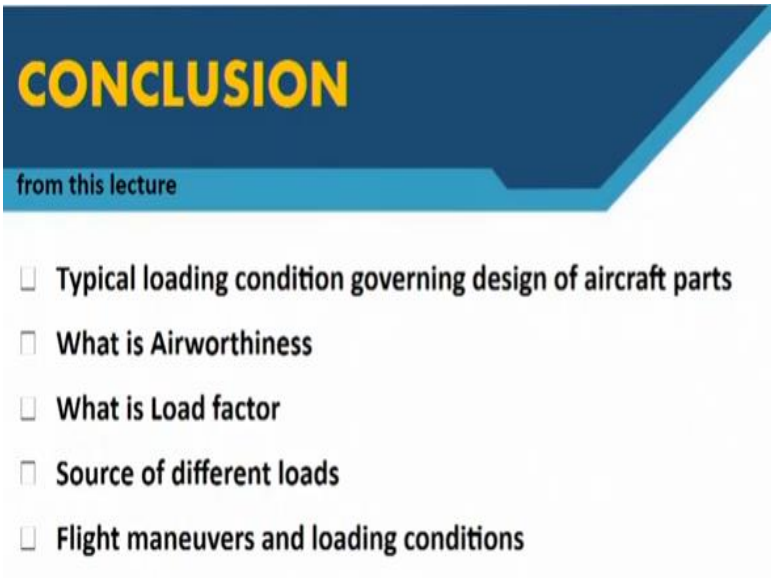

Following that if we go to the conclusions slide from this lecture today what we have done the typical loading condition governing design of aircraft parts. We have learned what is airworthiness we have got some fair idea about it what is load factor? So stress of different loads flight maneuvers and loading conditions how in case of different flight maneuvers different loading conditions appear and with that let me conclude today's lecture this lecture thank you will meet again with our next lecture.