Introduction to Aircraft Design
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Lecture - 81
Aircraft Loads

Hello, let us have a look at how the loads acting on the aircraft are estimated or specified for various conditions.

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There are essentially four type of loads. One is the air loads, which basically come because of the relative motion between the aircraft and the ambient air. There are inertia loads, which come due to changes in the acceleration to which the aircraft is imposed. There are power plant loads which come due to the operation of the power plant and there are miscellaneous loads which are categorized under others.

Under the air loads, we have maneuver loads, gusts loads, buffet loads and the control deflection or the loads due to control deflection. Under the powerplant load, we have the thrust, the torque, the gyroscopic moment, vibration because of the oscillations, the pressure on the ducts, hammershock, seizure and propeller blade loss. Under inertial loads, we have loads because of acceleration, because of rotation, because of the dynamic motion, vibrations and flutter.

Under others we have the loads acting due to towing, due to jacking of the aircraft because of the cabin pressurization, because of the bird strike, because of the control system actuation, loads acting during crashes, and loads because of the fuel pressure. So the various components of the aircraft and the various systems of the aircraft they have to be designed to keep in mind that all these kinds of loads they are able to carry within the specified limits.

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Let us take for example the loads acting during landing and takeoff. During takeoff there could be three kinds of load. One is the load acting when you have a catapult take off. In a catapult takeoff you provide energy to the aircraft. You literally throw it with some force and this force is provided by the catapult. Most of these cases are applicable for aircraft which are launched on the air carriers, on the naval air carriers.

Catapults are generally steam powered or they could also be powered by other means. During aborted takeoff when you have to you know stop the takeoff and abort it for a safety issue there will be huge loads acting on the landing gear because of the braking. And then there are loads acting during taxiing when you have a takeoff. Now the taxi loads have to take care of loads acting when there are bumps as well as load acting when there are turnings.

When you come into land, various types of loads have to be incorporated in the testing. The first is the vertical load factor which acts when you come into land because you are transforming the aircraft from a flying vehicle in the air to one that moves on the ground. So during the transition from air to ground, there will be impact and that impact will lead to a vertical load factor.

The normal value of this vertical load factor could be around 1.5 to 2, even higher. Then you have spin-up and spring-back loads. When suddenly the aircraft during landing the aircraft the landing gear is normally stored inside. And when you bring it down, at that time you can have spin-up and spring-back loads. The landing could happen with crabbed conditions.

So that leads to the loads, side loads. You may have landing on one wheel instead of multiple wheels. You may have an arrested landing in which the aircraft engages with a cable on the ship after coming into land and that cable actually absorbs all the energy and brings the aircraft to stop in a small distance. And then there are loads acting because of the braking.

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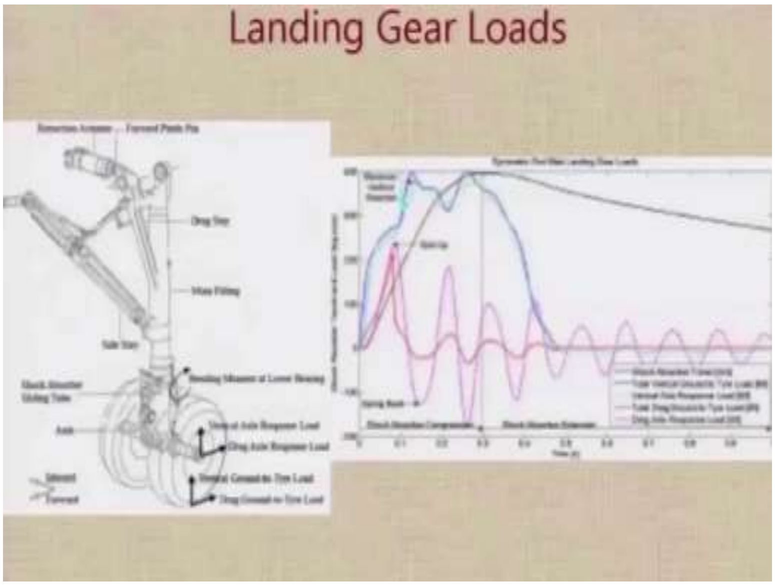

So you can see here the landing loads can be very high and they can also vary as a function of time.

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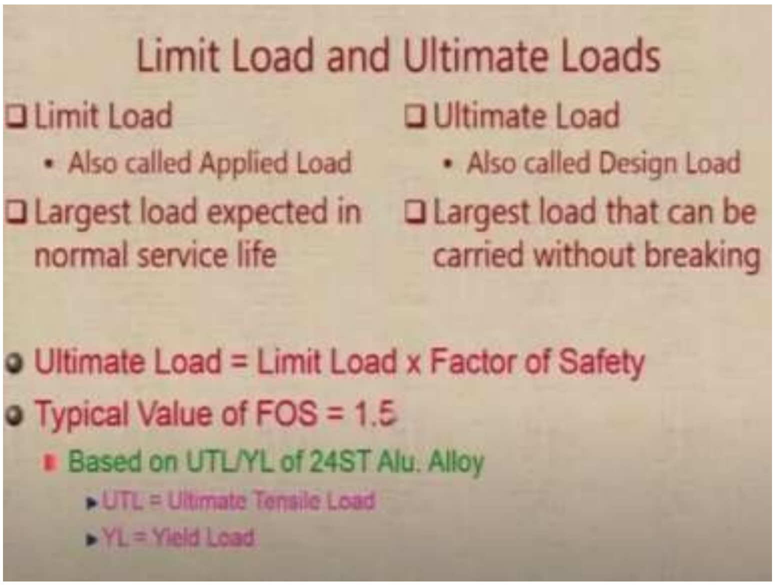

At this point, we need to understand the difference between two important terms. The limit load and the ultimate load. The limit load also called as the applied load is essentially the largest load that you expect the aircraft's component to sustain during its normal service life. The ultimate load or the design load basically is the largest load that it can take without breaking.

So in between the two of them, we have the factor of safety. So the ultimate load will be factor of safety times higher than the limit load. The typical value of factor of safety for aircraft is 1.5 but there are cases when you use load factors of as low as 1.1. And in some cases we also use slightly higher load factors.

This value has come from the ratio of the ultimate tensile load and the yield load of standard aluminum alloy which was used in the aircraft. So from there we flow we have this value of 1.5.

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Let us look at the limit loads which typical limit load that act on a fighter aircraft, okay. So starting from the yaw. So when the aircraft is in a vertical condition in a level flight and you have a very high speed flight, let us say Mach number is 0.9 and at that condition you are now exposing the aircraft to yawing, at that time there will be heavy load active on the vertical tail.

Inside the fuselage you are going to have fuel pressure. So that fuel pressure is going to give a load onto the system and to the structure, okay. Now the inboard wing is going to be exposed to a lot of compressive load during flight and that can cause buckling. Similarly, there can be a spring back because of landing. There could be loads on the inlet, because of the sudden motion of air.

The nose boom is going to get some load and that load you can notice there are different values specified for various conditions.

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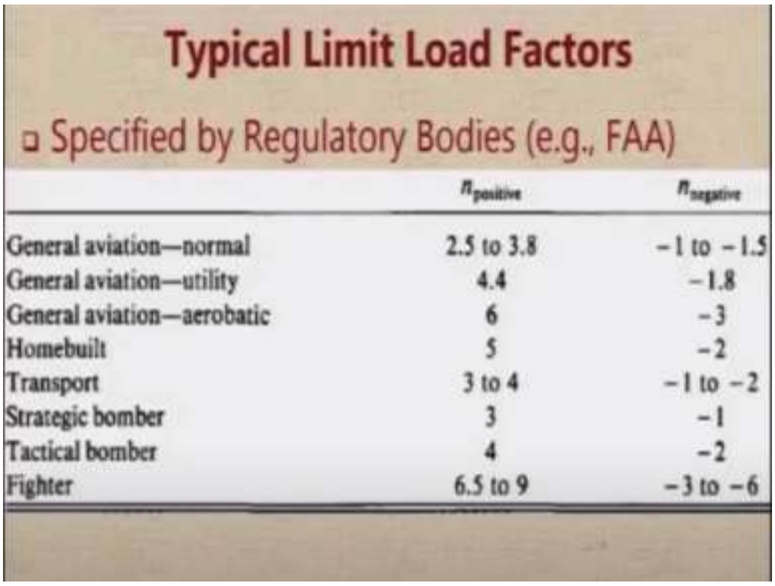

Typical Limit Load Factors

- Specified by Regulatory Bodies (e.g., FAA)

	$n_{positive}$	$n_{negative}$
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
Strategic bomber	3	−1
Tactical bomber	4	−2
Fighter	6.5 to 9	−3 to −6

So if you look at the regulatory bodies, they specify the typical limit load factors. Now here we are talking about the vertical load factor. Depending on the category of the aircraft, the different vertical load factors are specified. And notice that the load factors are specified for positive as well as negative conditions. And generally the load factors on the negative side are typically half the value of the values of the maximum positive load factor.

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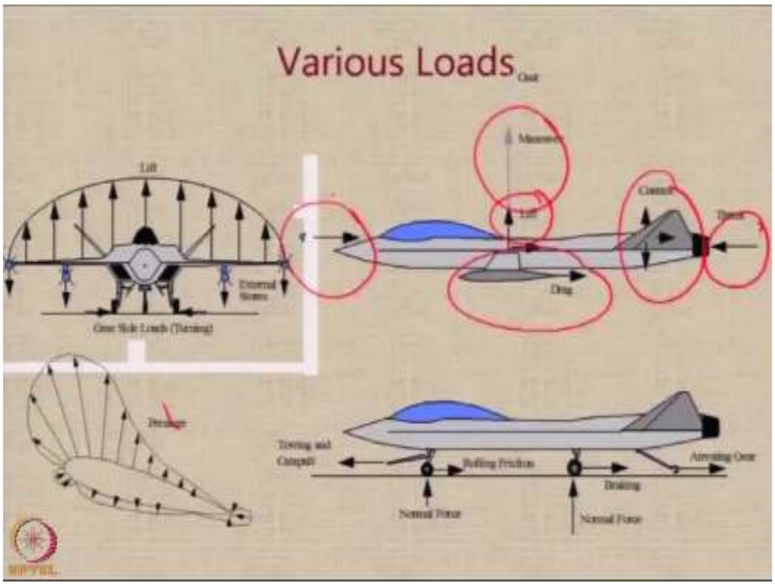

So you can see a typical aircraft is subjected to various kinds of loads. There will be a distributed loads because of the lift on the wing. There will be concentrated loads because of external stores mounted on the aircraft. There also will be loads on the wheel on the sides because of turning. The distributed load will have a distribution along the span and also along the chord as shown here.

When the aircraft is on the ground, you can have loads because of the towing and catapulting. You will have normal force acting on the landing gear when it comes in for at landing both main and the nose landing gear. There will be braking loads acting on the main landing gear when you are trying to reduce the landing distance. There will be rolling friction acting on the wheels when you are taking off.

There will be a load because of the arresting gear on the aircraft when you are using it on a naval air carrier. There will be loads because of the thrust that the engine produces. There will be loads because of the control forces that you create. There will be a load because of the lift to overcome the weight. There will be a load because of drag acting on the aircraft.

And there will be an increase in the load because of the maneuver. And there is always a dynamic pressure acting on the aircraft as it flies. So all these are going to be considered when we do the design of the aircraft.

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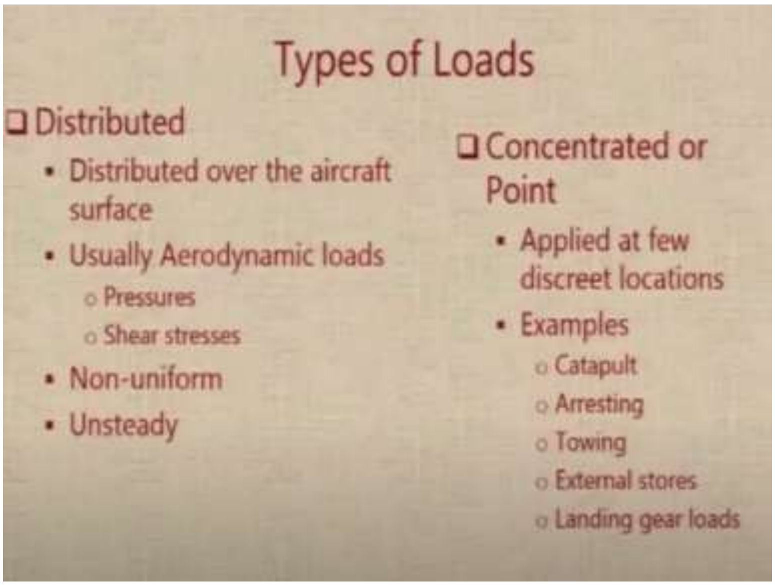

So the loads could be either distributed or concentrated. The distributed loads generally are the ones which are spread over the aircraft surface. Normally these are the aerodynamic loads, which come because of the pressures and the shear stresses. They are generally non-uniform and unsteady. You also have concentrated or point loads, which are applied at few discrete locations.

The examples are catapult loading, the arresting of the aircraft or towing of the aircraft on the ground, the load acting because of external stores, and the landing gear loads especially when you come in at land.

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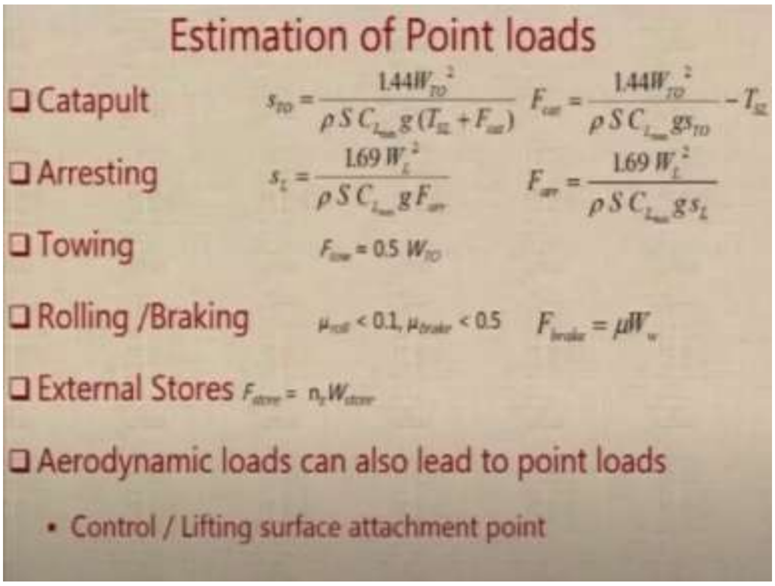

So for estimation of point loads, there are certain standard formula which are specified. For example, the load that is expected to be carried by a system where you have towing on the ground is half the aircraft weight. Similarly, there are certain suggestions available for how to estimate the value of the loads, okay. Now please note that the aerodynamic loading can also lead to point load sometimes.

For example, the control or lifting surface attachment point, because of the lift distribution, it will actually lead to a concentrated load.

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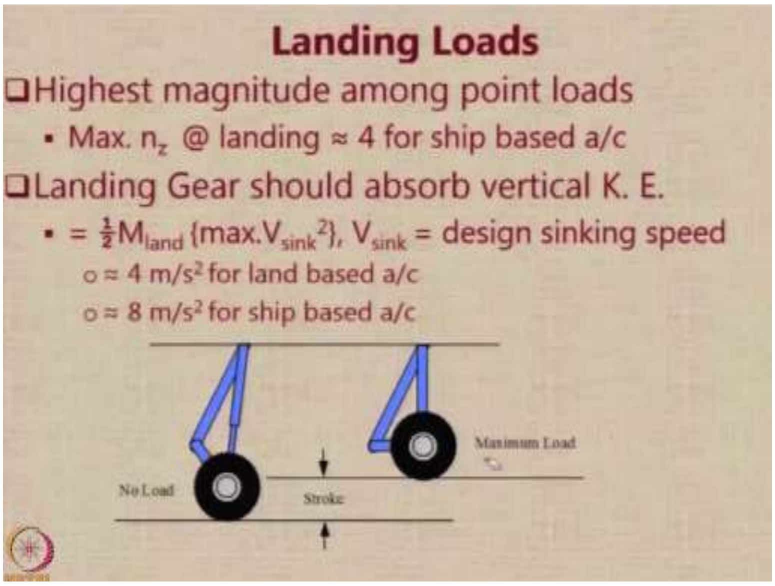

Let us look at the landing load because the landing loads generally have the highest magnitude among all the point loads. For a ship based aircraft, the vertical load factor at landing is assumed to be 4 because the landing gear is going to operate in a scenario when the aircraft is coming down and the ship is also moving up. The landing gear is supposed to absorb the vertical kinetic energy that is acting on the aircraft.

And the sink speed of the aircraft, the effective sink speed is a very big factor that affects the landing gear load or the vertical load. The sink speed is assumed to be 4 meter per second square for land based aircraft and 8 meter per second for the ship based aircraft. Also notice that when there is no load the landing gear is extended and when there is a load acting on it, the landing gear actually deflects and under the maximum load condition, the landing gear should be able to withstand the loads.

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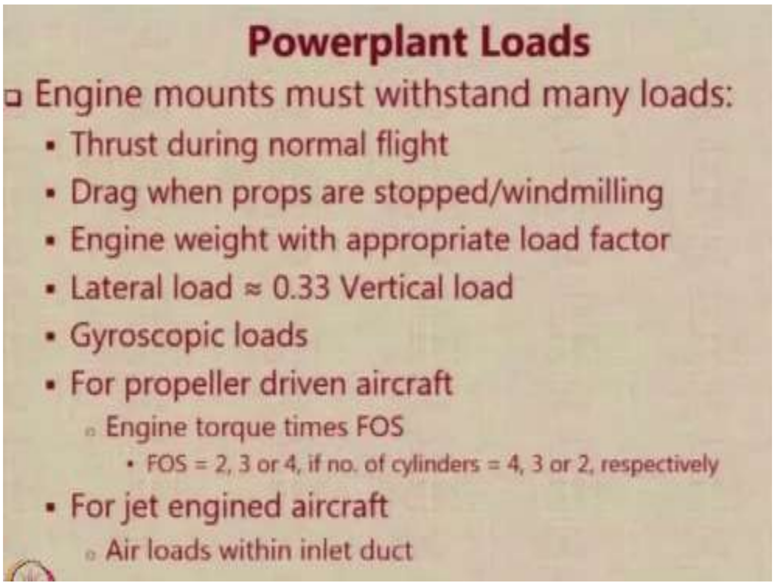

Powerplant also leads to a large amount of loading on the aircraft. The engine mounts must withstand many loads. They should withstand the loads because of thrust during normal flight. Then when the propeller stop or are windmilling there will be a drag. Then the engine also has a weight and when you go into maneuvers, there will be a maneuver load acting on this because of the load factor.

There are lateral loads also which are nearly one third of the vertical loads. There are gyroscopic loads because the engine consists of rotating parts. For a propeller driven aircraft, we have to assume some factor of safety which will be the engine torque times the factor of safety which could be 234 depending on the number of cylinders.

And for a jet engine aircraft, you will have loads acting on the intake because air will be literally brought to maybe brought to rest when it is coming inside the engine intake.

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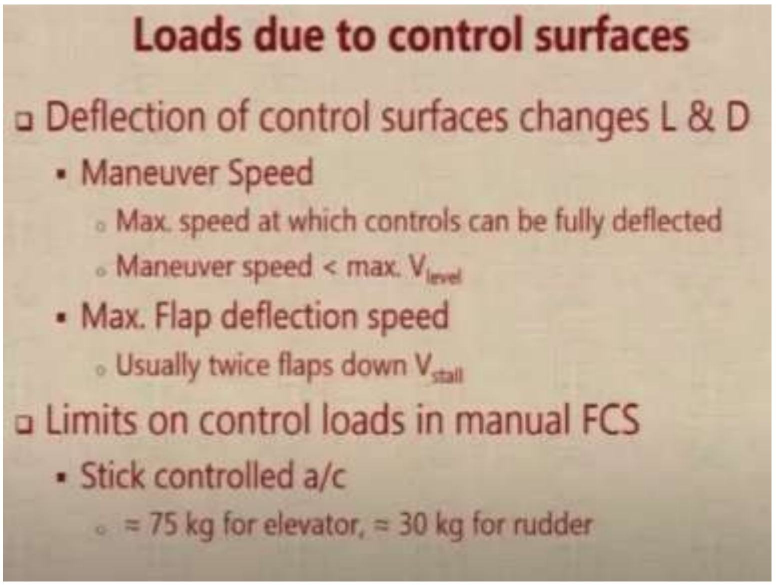

The deflection of the control surfaces also creates loads because it changes the lift and the drag distribution. So we have to be very careful that the control surfaces are deflected only below a speed at which it can take the load. There is a maximum speed at which the controls can be fully deflected. There is also a maximum speed for the flap deflection and these limit loads are mentioned in the control manual.

We have to also keep in mind how much load can be expected to be given by a typical pilot in a system where there is no assistance available from this flight control system, okay.

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Then inertial loads are because of the resistance of the mass and due to acceleration. Every component actually faces inertial load factor while flying and while maneuvering. The wing weight will produce torsional load on the wing and a special case of acceleration would be vibration and flutter. Also keep in mind that there will be huge inertial loads also because of the rotation of the aircraft during maneuvers.

For example, if you have tip tanks or missiles on an aircraft and this aircraft enters a large rolling rate, doors will lead to huge inertial loads, okay.

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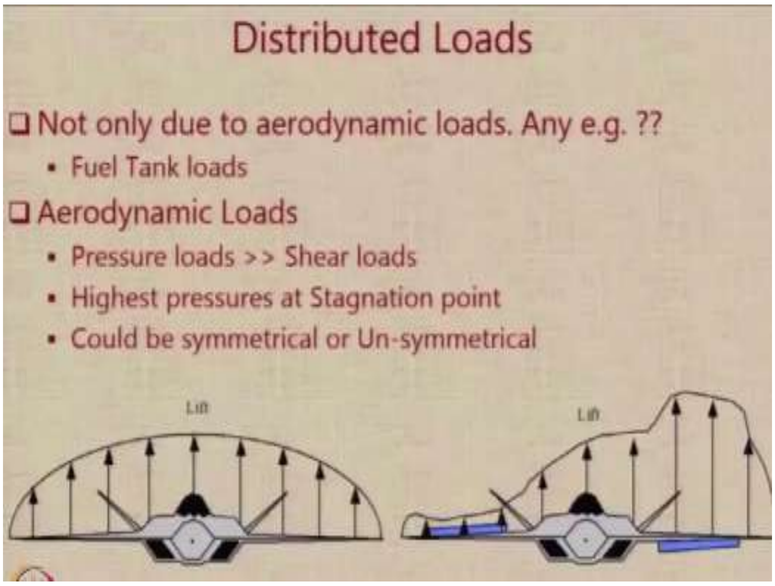

We have seen already that the aerodynamic loads could be symmetrical or unsymmetrical. Symmetrical when you have no deflection of control surfaces. But when we had deflection of ailerons for example, you can get an asymmetric load.

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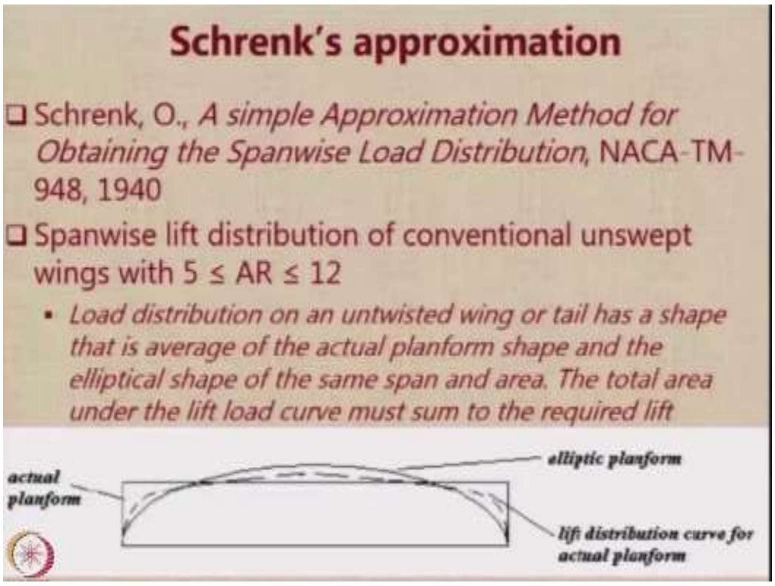

Now when you want to estimate the load distribution over the wing of a given planform, one easy approximation that we should use is called as a Schrenk's approximation. But this is applicable only for conventional unswept wings with aspect ratio between 5 and 12. What this approximation says is that the load distribution on an untwisted wing or a tail, it has a shape that is an average of 2.

One is the average of the actual planform shape and the elliptical shape of the same span and area. But the requirement is that the total area under the lift load curve must be must sum as the required lift. So in other words, you can use this method for estimating the load which is acting on a particular wing of a given geometry.

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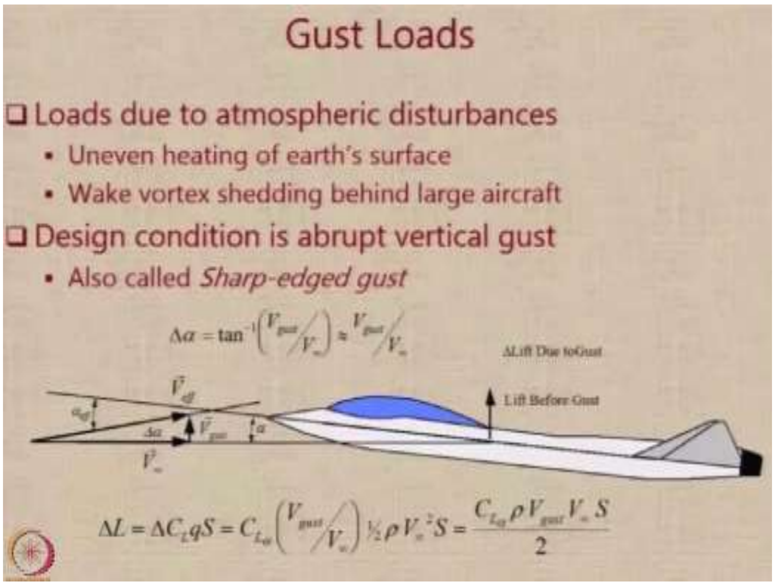

Gush loads are acting because of the atmospheric disturbances. The earth's surface is heated unevenly and behind a large aircraft there is always a wake vortex which can also create to disturb loads. The design condition for which we design the aircraft is a abrupt vertical gust also called as a sharp edged gust.

So essentially if the aircraft is flying level at a particular velocity V infinity and if there is a vertical gust V_G acting, that particular vertical gust it leads to an effective increase in the angle of attack by an amount delta alpha. And hence, it leads to additional lift. So the small angle delta alpha is actually almost equal to the ratio of the vertical gust velocity and the forward velocity. So the delta L created can be easily estimated.

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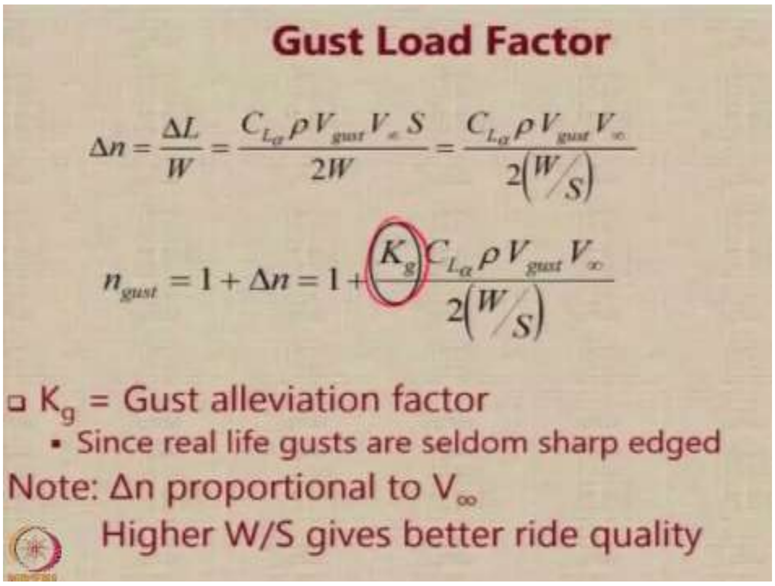

And with that you can get the value of delta n. So the delta n or the additional load factor because of the vertical gust we can notice it is a function of the lift curve slope, gust velocity, aircraft velocity, density and the wing loading of the aircraft. So aircraft which have got a very high wing loading for a given amount of vertical gust they will encounter lower delta N_z.

So aircraft with large wing loading are less prone to vertical loads because of the gusts. So the total load factor that is acting because of the gust will be the summation of the load factor in level flight which is 1 plus delta n. And there is a factor called K_g. This K_g factor is basically meant to take care of the fact that the real life gusts are seldom sharp edged.

They are normally not sharp edged, but they are having some kind of a variation. So as I mentioned higher W/S gives better ride quality. So if you have a low speed aircraft with a very high wing loading the delta n experienced by it for a given gust velocity is going to be lower. Thank you for your attention.