

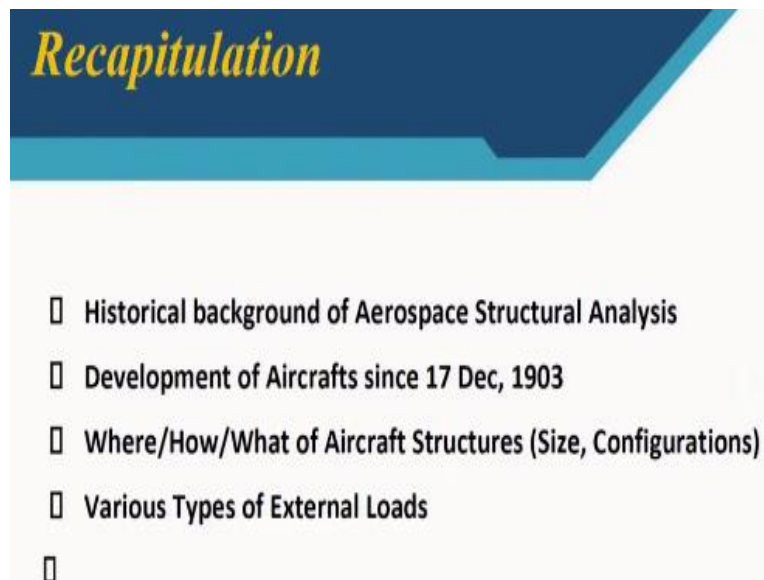
Aircraft Structures - I
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Module – 1
Lecture – 5
Conceptual Structural Details of a Typical Aircraft

Welcome back to aircraft structures 1 course. Myself Anup Ghosh from Aerospace Engineering Department, IIT Kharagpur. We are in the last lecture of week 1. This is the fifth lecture. In this lecture, we will cover the conceptual structural detail of a typical aircraft and we will continue further for more analysis in the forthcoming week.

So with this week's lecture, we will complete the introduction of aircraft structures, .how does it look like, how the loads come to the aircraft and how does it internally look like, what is the principle of fabrication and construction of aircraft structures and with those things we will conclude, but before we conclude or go forward for today's lecture what we have done this week in our last 4 lectures are as follows.

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We have covered the historical background of aerospace structural analysis that is basically the history of solid mechanics starting from the experiment of Leonardo da Vinci to maybe Koiter, Donnell shell theories, in between various others like Bernoulli, Timoshenko, Hooke, many others are there to contribute. We have learned the first flight and a brief history of aviation.

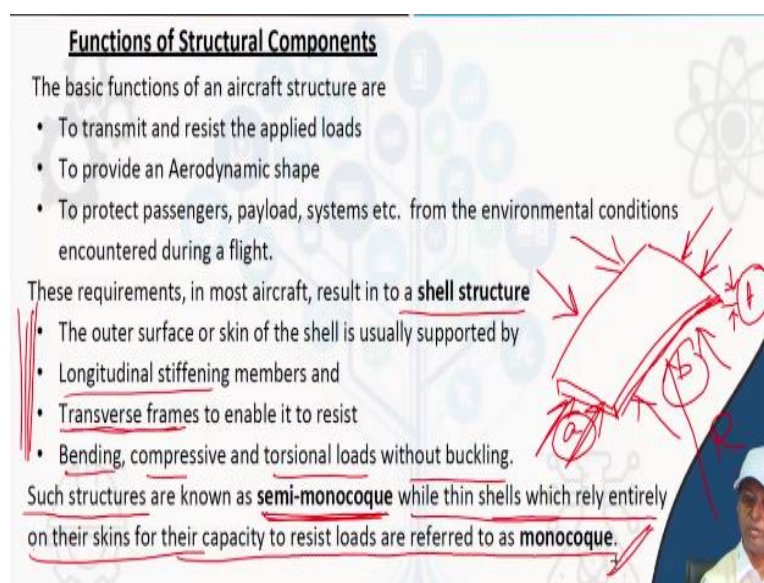
We have come across how big the structures are, what difference, do we have any difference between the construction of a huge aircraft and a small aircraft. We have seen there is no such difference in construction, only size changes according to the requirement, definitely structural details and design changes depending on the configuration.

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In the last lecture, we have seen various types of external loads encountered by an aircraft and today we will cover other concepts covering the principles of stressed skin structure, external loads again will come, basic structural components of an aircraft. Basically, we will be giving stress today on this.

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So functions of structural components if we look at those are basic aircraft structures. The

basic functions of an aircraft structures are to transmit and resist the applied load. This is true as well for any structure, so it is covered that way. To provide an aerodynamic shape, this is something important, some nowadays in buildings also it is followed to reduce drag, but here it is having a different purpose that is the aerodynamic shape that is the important shape which provides the lift and an aircraft fly.

To protect passengers, payload, systems, etc from environmental conditions encountered during a flight. This is another very important thing. Anything we put inside an aircraft that generally comes unless we create some artificial pressurized cabin and air-conditioned cabin, it is supposed to experience probably minus 55 degree centigrade of temperature, minus 55 degree centigrade of temperature is really a very cool environment.

So we need to think about those while we design structure, we need to think about all other avionics and other components while we design those things. Not only that pressure also reduces, so depending on those environmental conditions, we need to design the components or the structural components has to withstand those types of environmental loads and it also needs to protect the payloads, say it is carrying passenger it needs to protect the passengers.

Passengers cannot fly at minus 55 degree centigrade or minus 60 degree centigrade temperature, so it has to be protected from that environment. The requirements in most of the aircraft resulting in a shell structure. The shell cell structure is as I have said in our first lecture, shell structure is something which is curved structure and say if I have a panel which is having some curvature and this thickness is small with respect to other two dimensions.

Say this is a this is b and say if this is t , so if t is very very small with respect to a and b , we call that plate, but while it has a curvature, while it has a radius of curvature, it is curved in nature we generally call that as a shell structure. So if we look at the aircraft structures, most of the structures are shell structures. So we need to design those shell structures. So the outer surface of the skin of a shell is usually supported by longitudinal stiffening members and transverse frames to enable it to resist.

So what is there inside? We have seen the photographs many times, but we also need to see in more detail what is there inside. There are longitudinal stiffening members, and there are transverse frames. So this is some bulkhead in case of the fuselage, this is ribs in case of the

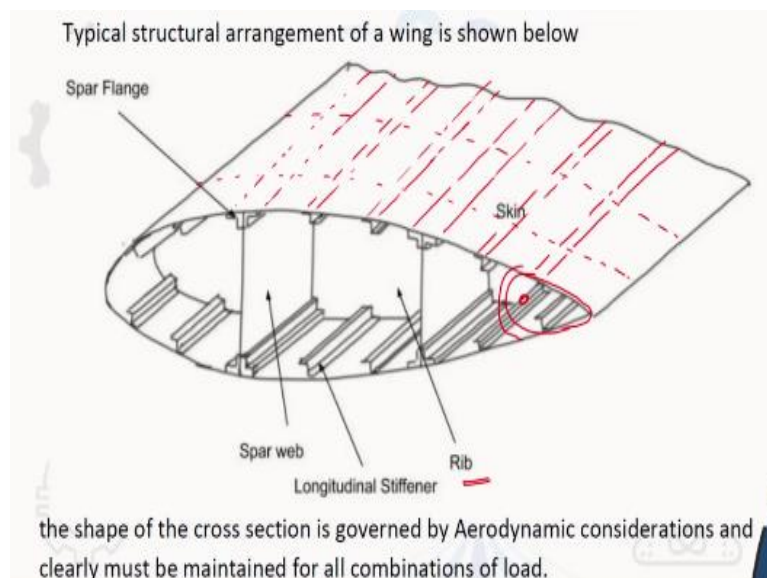
wing, but all these structures as I said, this transverse frame or the longitudinal stiffening members are supposed to encounter bending, compression and torsional loads.

Bending, compression and torsional loads you are already introduced in your first year courses in your mechanics courses, so I do not need to talk about much. You are already also introduced with the buckling, and we have introduced with the column buckling. Euler column formula already you have studied, but here we need to consider buckling of the plate as well as shells. So if this is the plate and there are forces like this, this plate may buckle.

So we need to consider the buckling load of the skin and local buckling really creates a problem that is a very governing criteria to design skin. Such structures are known as semi-monocoque. So by such structures, what do you want to mean? Thus by such structures which you want to mean the structures which consist of these longitudinal stiffening members, which consists of transverse frames are the structures known as semi-monocoque structures.

So as if we look at all aircraft structures nowadays are semi-monocoque structures, while thin shells which rely entirely on their skin for their capacity to resist load are referred to as monocoque structures. So these structures whatever we have seen those are same monocoque structures and shell which rely entirely on skins for their capacity to resist loads are referred to as monocoque structures. Monocoque structures are nowadays not used okay. So let us move to the next slide.

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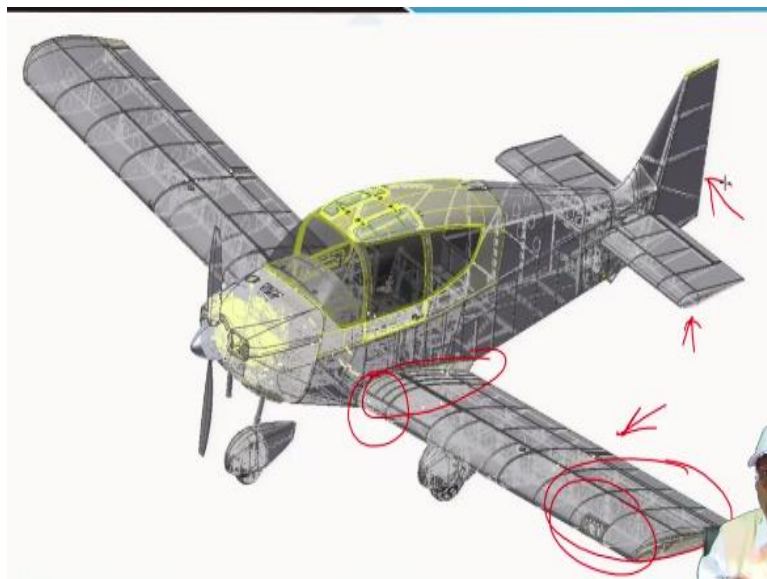


Okay in this slide, we will see the typical structural arrangement of a wing and that structural arrangement is drawn here. In this structural arrangement, whatever we see is this is the rib portion. This is already okay pointed out. This is the rib, rib if we look at okay, one portion is missing, not missing, it would not be visible, but say rib is from here it is inside, like that there are ribs also inside and if we look at this spar, this spar continues this way with the spar flanges and this is the longitudinal stiffeners.

These are the stiffeners, this also continues, this is inside. So if we look at the wing structure, there are many such stiffeners and to mention that this is not that easy structure as we see here because sometimes there are aileron here, aileron comes this way, this is the portion of the aileron. We need to separate it out from here. There are hinges which attach to it. The shape of the cross-section is governed by the aerodynamic considerations and clearly must be maintained for all combination of loads.

So this shape, the rib shape governs the shape of the rib if we look at, this is the rib shape, that is the airfoil section shape and that produces the lift, we need to maintain that for every situation.

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So again if we look at the wing rib construction that is to some extent more prominent here how all those ribs come. If you notice a number of ribs increases here in the root section and it reduces at the tip sections. The interval between the consecutive rib is less on the tip section whereas in the root section it is more and you can also notice that the basic construction detail of wing, horizontal tailplane and vertical tailplane are similar.

So construction detail of this, this and this is similar, only size and other loads govern the design okay.

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Transverse Frames or Ribs:

- These follow and maintain the Aerodynamic shape.
- They also act with the skin in resisting the distributed Aerodynamic pressure loads.
- They distribute any concentrated loads for example
 - undercarriage and
 - additional wing store loads,

to the structure and redistribute stresses around discontinuities (doors).

- Ribs increase the column buckling stress of the longitudinal stiffeners by providing
 - end restraint and
 - establishing/reducing their column length. [Previous Slide](#)

(in a similar manner they increase the plate buckling stress of the skin panels).

So the transverse frame or ribs more details on that. So these follow and maintain the aerodynamic shape. They also act with the skin in resisting the distributed aerodynamic pressure loads, whatever pressure loads come on the skin that gets transferred through the rib. They distribute any concentrated load, for example, undercarriage load, additional wing store loads. So if we go back to the previous slide, we will see that in this particular case, there is no undercarriage load.

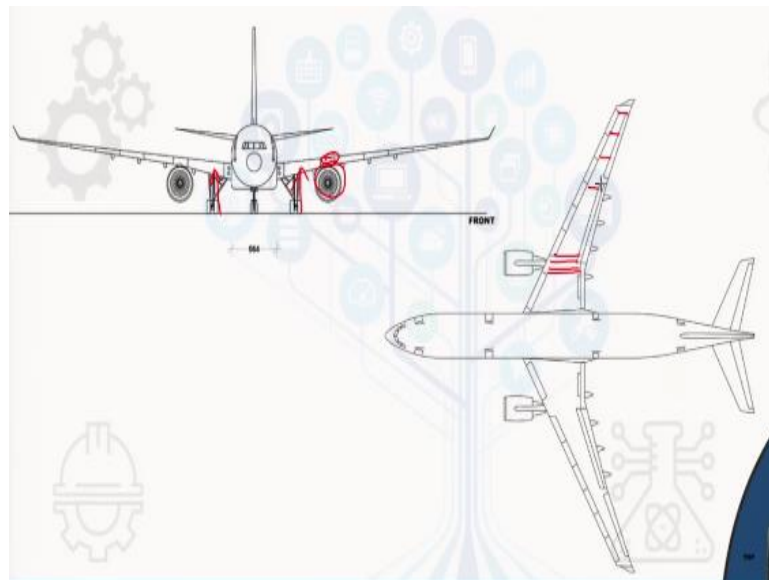
Additional wing store loads are also not there, but in case of military aircraft or say an agricultural aircraft needs to carry additional store load about the undercarriage load while the landing gear is attached to the wing that time it requires to carry those to the structure and distribute this. All these loads are carried to the structure and redistribute stresses around discontinuities. So redistribution of stresses around discontinuities is another important part.

Ribs increase the column buckling stress of longitudinal stiffeners by providing end restraint, establishing or reducing the column length. So if we look at this if we increase the number of ribs, the panel size here is this much, whereas panel size in the root section is this, here also it is big, the skin panel it is big. So this reduces or increases the size of the panel thereby it enhances the buckling property of the skin.

So buckling stresses of the longitudinal stiffeners by end restraint, so it provides end restraints, establishing or reducing their column length. So this is not only for skin, as I told you if we look at the stiffeners, these stiffeners also are attached to the skin, so that length here column is some member which carries the axial load, this length is reduced with a number of ribs. In a similar manner, they increase the plate buckling stress of the skin panels, plate or shell buckling stress of the skin panels.

So the ribs not only distribute loads coming from the undercarriage, from wing store, not only provides the aerodynamic shape. It also enhances the capability of the other members like as it is said the plate and shell buckling parameter it enhances. It also enhances the column length of the stiffeners. So ribs have various properties and it serves that way.

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So this is one-two views of an aircraft to have a better understanding. As I told you this undercarriage load is coming directly to the wing and number of ribs required here are more. Wherever the engine is attached that portion also has to be designed those ribs, a number of ribs here are more whereas the number of ribs probably are less on the wing tip side. So depending on those things, this view assists us to know where and how the ribs are used.

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Ribs

In the **outer portion of the wing**,

- Ribs act primarily as formers for the airfoil shape since it is a low load carrying section.
- An extremely light weight structure is sufficient for the purpose.

Nearer the root section,

- Ribs are required to absorb and transmit large concentrated applied loads, such as
 - from the undercarriage,
 - engine thrust and
 - fuselage attachment point reactions etc.

In the **middle of the wing**, ribs support

- hinge reactions from aileron,
- flaps and other control surfaces.

More on ribs, let us see. The outer portion of the wing, ribs in the outer portion of the wing ribs act primarily as formers for the airfoil shape since it is a low load carrying section. As I told you in the previous slide, there the interval between the consecutive ribs it is much or density is low. It only maintains the shape and extremely lightweight structure is sufficient for the purpose. So that is the reason for the weight reduction number of ribs are reduced.

Near or the root section ribs are required to absorb and transmit large concentrated applied loads. Where from the large concentrated applied loads come, from the undercarriage as well as from engine as well as stores. So wing stores means if we look at if a military aircraft is carrying some warhead on the wing that is known as a store, deployable stores. So those while it is carrying it that there must be some provisions to carry the load.

That provision is taken care of by the ribs from the undercarriage, engine thrust, fuselage attachment points reactions, etc. In the middle of the wing, ribs support hinge reactions from aileron, flaps and other control surfaces. So mid-portion it is important for attaching the control surfaces. If we go back to the previous slide if we look at various control surfaces, these are all leading edge control surfaces, trailing edge control surfaces.

All these control surfaces have to be attached to the wing very efficient manner and that requires a lot of arrangement inside the wing and those are done.

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Wing Skins

It is an impermeable surface for

- Supporting the Aerodynamic pressure distribution
- From these the wing lift is generated.
- These Aerodynamic forces are transmitted
- To the ribs and stiffeners by the skin
 - through plate and membrane action.
- Shear and torsional loads are carried by the skin and spar webs,
- while axial and bending loads are reacted by the combined action of skin and longitudinal stiffeners.

Longitudinal stiffeners

These are attached to the skin and ribs thereby dividing the skin into small panels and increasing the buckling and failing stress of the skin.

Wing skins if we look at, it is an impermeable surface for supporting the aerodynamic pressure distribution. From there, the wing lift is generated. These aerodynamic forces are transmitted to the ribs and stiffeners by the skin. So it is to transfer the loads to the ribs as well as to the stiffeners through plate and membrane action. Shear and torsional loads are carried by the skin and spar webs.

While axial and bending loads are reacted by the combined action of the skin and longitudinal stiffeners. Longitudinal stiffeners if you talk about this is what the longitudinal stiffener is. These are attached to the skin and ribs thereby dividing the skin into small panels and increasing the buckling and failing stress of the skin. So these longitudinal stiffeners act to reduce the effective length of panels as well as columns.

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Spar Webs

These resist shear and torsional loads, they perform a secondary but significant function in stabilisation, with the skin.

Spar Flanges

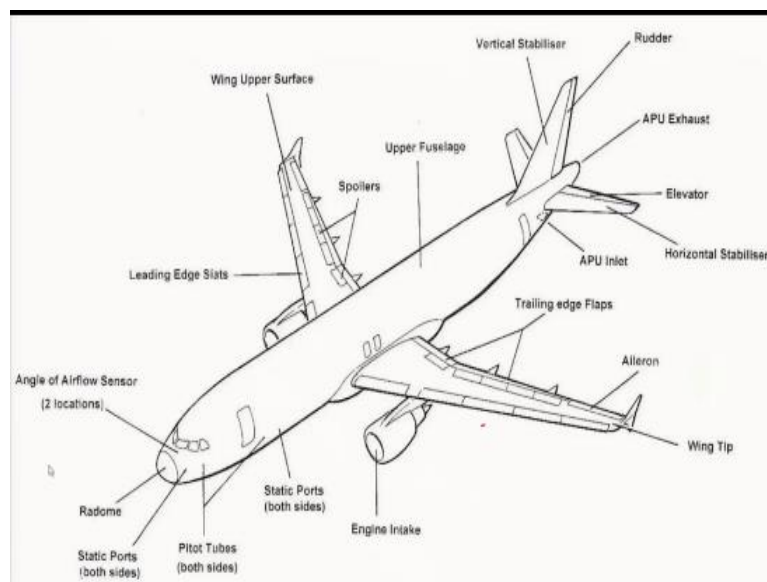
Spar flanges or caps are capable of supporting large compressive loads from axial and bending effects.

Above mentioned structural functions are applicable for wings, horizontal and vertical tail.

Spar webs, this is what the spar web is. This portion is the spar web. These resist shear and torsional loads, and they perform a secondary but significant function in stabilization with the skin. Spar flanges, the spar flanges is this. This is generally consisting of 3 sections from this view if you look at and there are rivets. So this portion is known as the flange as you see here. Spar flanges or caps are capable of supporting large compressive loads.

So while the wing is deflecting, say this is the wing if it is deflecting this way while flying or while taxiing due to the other loads it is this way. So this portion will act to encounter compressive loads from axial and bending effects. So abovementioned structural functions are applicable for wings, horizontal and vertical tailplanes. So all these descriptions whatever we have done these are applicable equally for horizontal and vertical tails okay.

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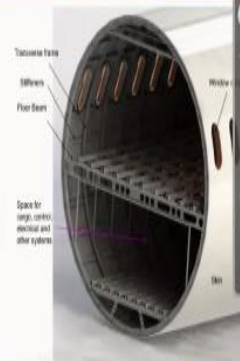



This slide gives us some introduction to the nomenclature or the portions, so quickly we will go through. This is radome, static port on both sides, pitot tubes on both sides, here also static ports are there. This is engine intake. This is wing tip portion, Aileron is this, trailing edge flaps, auxiliary power unit inlet, this is also an auxiliary power unit outlet. This is an elevator, horizontal stabilizer, rudder, vertical stabilizer, upper fuselage, spoilers, wing upper surface, leading edge slats, angle of airflow sensors.

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Fuselage

- Aerodynamic forces on the fuselage skin are relatively low;
- Fuselage supports large concentrated loads such as
 - wing reactions,
 - tailplane reactions,
 - undercarriage reactions and carries
 - payloads of different size and weight
- which may cause large inertia forces.
- An aircraft designed for high altitude flight must withstand internal pressure.
- The most efficient sectional shape for a pressurized fuselage is circular or a combination of circular elements.

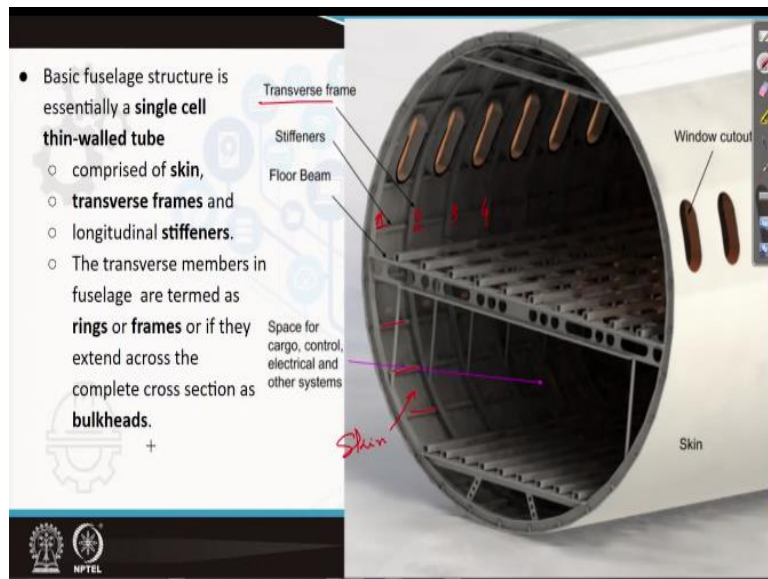
If we come to the fuselage, aerodynamic forces on this fuselage skin are relatively low. This generally protects the cargo as well as this is the cargo hold where this is the place where passengers seat. In case of cargo aircraft, all this portion is converted for carrying cargo. Fuselage supports large concentrated loads such as wing reactions. So total lift comes to the fuselage in a wing fuselage junctions, those wing reactions it has to carry.

Tailplane reactions for pitching moment, whatever pitching moment is coming from the horizontal tailplane that is carried by the fuselage. Undercarriage reactions and carries a payload of different size and weight, whatever undercarriage reaction comes whenever it is within the fuselage, it is for a cargo aircraft whatever we have seen AN-225, all those landing gears were attached to the fuselage.

It was not on the wing like the previous schematic diagram we have seen in the last slide, which may cause large inertia forces because of the huge mass carried by the fuselage, it will definitely create inertia forces and the aircraft design for high altitude flight must withstand internal pressure. This is another important thing, internal pressure. Internal pressure is something which it has to be there to fly at that high altitude 11 kilometer from our surface at minus 55 degree or low pressure.

The most efficient sectional shape of the pressurized fuselage is circular, but it is not limited to circular, it sometimes comes as elliptical surface also or a combination of circular elements.

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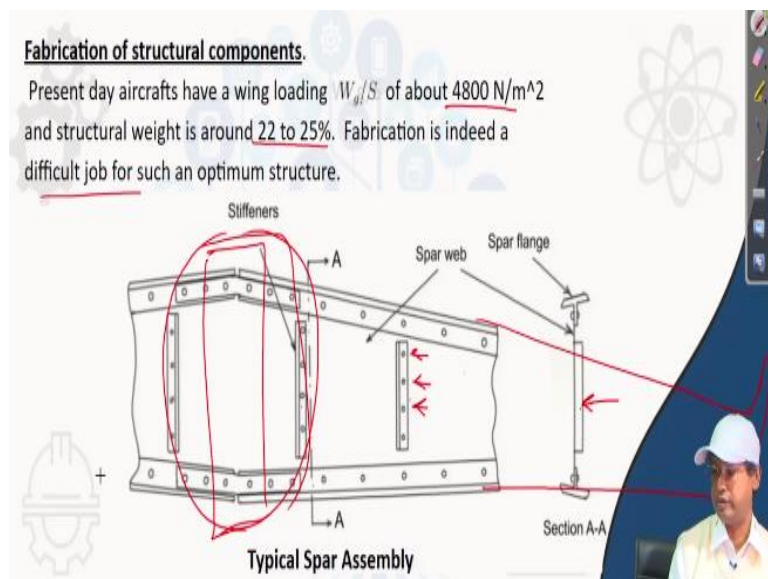


- Basic fuselage structure is essentially a **single cell thin-walled tube**
 - comprised of **skin**,
 - **transverse frames** and
 - longitudinal **stiffeners**.
 - The transverse members in fuselage are termed as **rings or frames** or if they extend across the complete cross section as **bulkheads**.

Some more details of the fuselage. The basic fuselage structure is essentially a single cell thin-walled tube. This is what the thin wall, outside wall is there that is the fuselage thin single cell comprises of skin, that outside skin. Transverse frame, these are the frames if I say this is the frame here, transverse frame 1, 2, 3, 4 like that there are many frames inside. Stiffeners, these are the stiffeners, there are many that reduce the effective length of the skin, this is the skin actually.

The buckling of the skin is prevented by reducing the effective length by stiffeners as well as bulkheads. Longitudinal stiffeners. The transverse members in the fuselage are termed as rings or frames or if they extend across the complete cross section as bulkheads. So depending on that type of things, it is either ring or frame or bulkhead.

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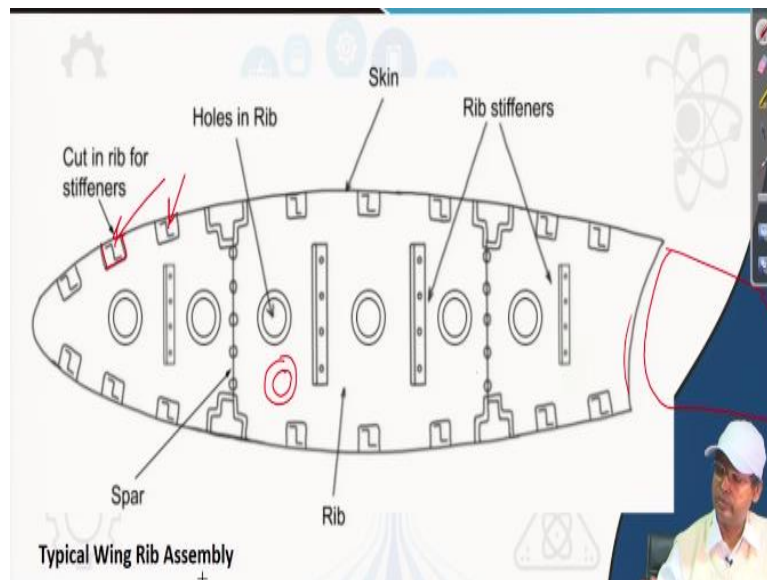
Fabrication of structural components.

Present day aircrafts have a wing loading W_u/S of about 4800 N/m² and structural weight is around 22 to 25%. Fabrication is indeed a difficult job for such an optimum structure.

Some more detail about the spar. Present days the aircrafts have a wing loading of about 4800 Newton per meter square and the structural weight is around 22 to 25%. So construction is really very important and efficient. Fabrication is indeed a difficult job. So if we look at it the spar, this is the junction inside or in some cases inside the fuselage, in some cases this junction is not present, in small aircraft this type of junctions is present inside the aircraft.

If we look at a cross-section as I was drawing in the previous slide, this is the stiffener. This is the same stiffener we will see that is attached there with these rivets, these are the rivets and this is the spar flange portions. It changes from one section to the other and it continues to the tip. So this is the fuselage if we look at and this continues up to the tip if any winglet is there something, maybe something like this.

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This is further detail of the rib section. This is really consisting of many parts. This is the spar what we have seen the last slide and this is the portion created for passing the spar flange. This cutout in the rib, this is the cutout, this is actually a cutout in the rib through which the stiffener passes for the skin. All these z sections are stiffeners. We usually put more number of holes depending upon the requirement.

There are two rings because the holes are stiffened the edges that reduce the weight and not only that these holes are required for passing control wires, control rods as well as for fuel tanks, different other purposes the holes are used. These are the reef stiffener, since the section size is increasing to stiffen this portion these in-between stiffeners are used. This portion is curved because there are control surfaces will come here, so all these things a

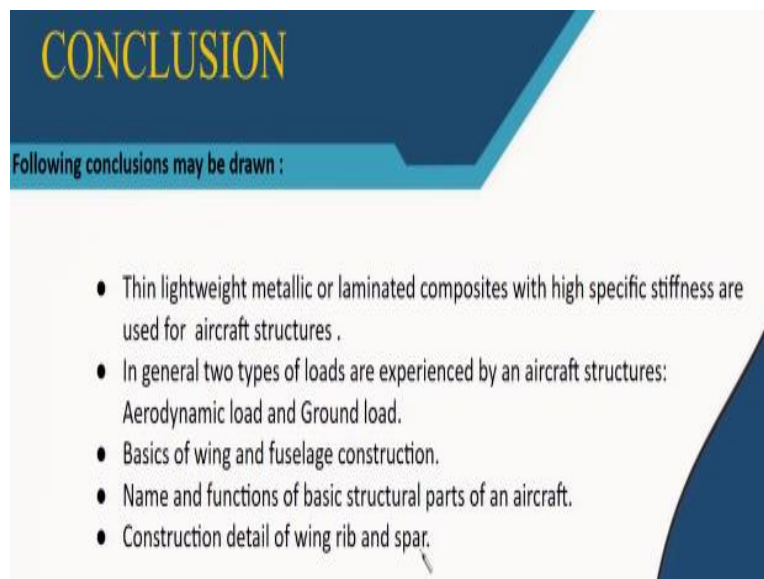
typical wing rim assembly.

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So with this, we come to the conclusion of today's lecture, maybe this week's lecture. All these are the standard references where from all these details are taken. Details are taken from Bruhn, details are taken from Megson and many other books.

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So at the end, we conclude that thin lightweight metallic or laminated composites with high specific stiffness are used for aircraft structures. In general, 2 types of loads are experienced by an aircraft structure, aerodynamic load and ground load. Basics of wing and fuselage constructions we have seen which is common for all types of aircrafts. Name and functions of basic structural parts of an aircraft we have seen.

Construction details of the wing, rib and spar we have seen. So with this, let us end today's lecture and we will go forward further for analysis in the coming week. Thank you for attending today's lecture. We will meet again in our next.