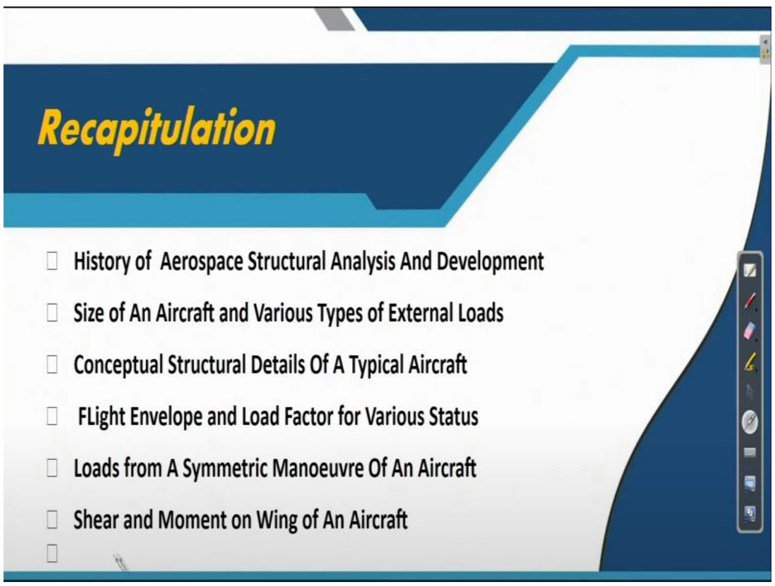
Aircraft Structures - 1

Prof. Anup Ghosh
Department of Aerospace Engineering
Indian Institute of Technology - Kharagpur

Module No - 02
Lecture No - 10
Distribution of Load on the Fuselage

Welcome back to aircraft structures one course. This is Professor Anup Ghosh from aerospace engineering department IIT Kharagpur we are at the tenth lecture today. We have already learned the wing moment and shear calculation due to external loads. Today we will be covering distribution of loads on fuselage. Present lecture will cover only how do we need to preprocess we need to prepare the loads properly to find out shear our bending moment in fuselage that we will do.

(Refer Slide Time 01:14)

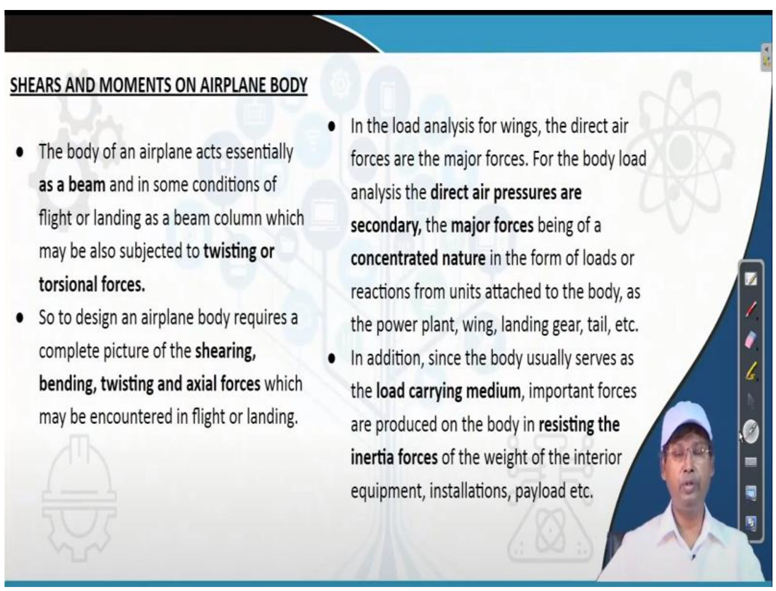


To do that let us proceed before we proceed as I have mentioned in brief that in past class we have done shear and moment and wing of an aircraft. And before that loads and other things we have done. So with that consideration let us move forward for the fuselage load.

(Refer Slide Time 01:40)

So distribution of distribution of loads and moments along the fuselage is our aim. How the loads come where from what are the components, we need to take care and from there how do we distribute it. Not only distribution it also needs to be rearranged rearrangement of load for analysis.

(Refer Slide Time 02:02)



So before we go for the arrangement earlier (()) (02:07) or the fuselage we need to definitely learn a little bit about what exactly we are going to do shear and moment on airplane body that is our aim. The body of an airplane acts essentially as a beam. So complete aircraft we are considering as a beam and is in some condition of flight or landing as a beam column which maybe also subjected to twisting or torsional forces.

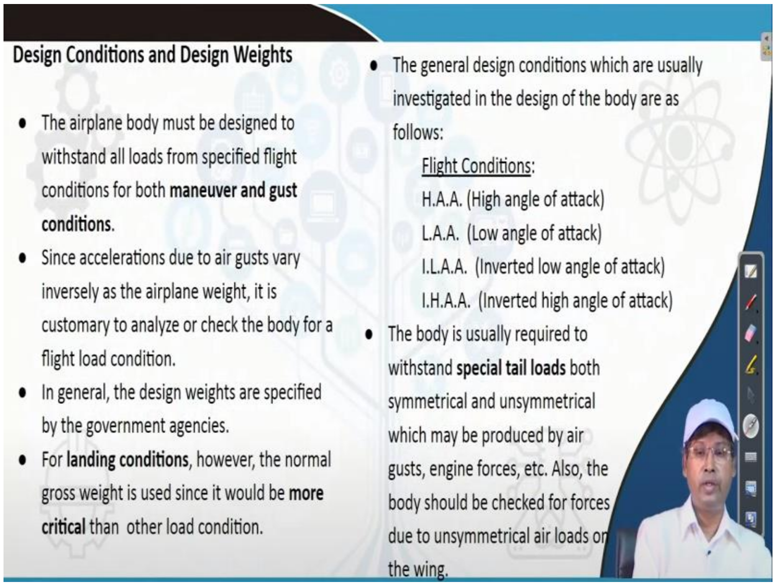
So it may have some axial force that is why beam column because of acceleration in the forward direction or retardation. It may have twist say for a case while 2 engine craft not the type of aircraft we have considered in our last example or the example what we will solving. If it is a 2 engine aircraft amounted on wing and because of some reason there is a failure on the failure of 1 engine that will create huge bending as well as torsional moment not only that because of rolling there could be a torsional moment.

So to design an airplane body it requires a complete picture of the shearing, bending, twisting and axial forces which may be encountered in flight or landing. So during flight or landing all these shearing bending twisting or axial forces may occur. Keeping in mind that for 1g consideration or unit load consideration we will try to solve the problem. In the load analysis for wings, the direct air forces are the major forces.

For the body load analysis the direct air pressures are secondary. So this is a major differences difference between the being load analysis and the body loaded fuselage load analysis direct air pressures are secondary. The major forces being of a concentrated nature in the form of loads or reactions from the units attached to the body as the power plant as I just now mentioned the engines wing, landing gear, tail etc.,

So all these wings will produce some or the other shear or bending moment on the fuselage. In addition since the body usually serves as the load carrying medium important forces are produced on the body in resisting the inertial forces of the weight of the interior equipment, installation, payloads etc., So it also whatever internal things are there like the equipment and other installations or payloads that also it needs to carry. So that has also to be considered.

(Refer Slide Time 05:30)



Design condition and design weight the airplane body must be designed to withstand all loads for specified flight conditions for both maneuver and gust conditions. Since acceleration due to air gusts vary inversely as the airplane weight it is customary to analyze or check the body for a flight load condition. This why it is inversely unless how the gusts acts we want to spend time on that but let us consider that happens in general the design weights are specified by the govern sorry government agencies.

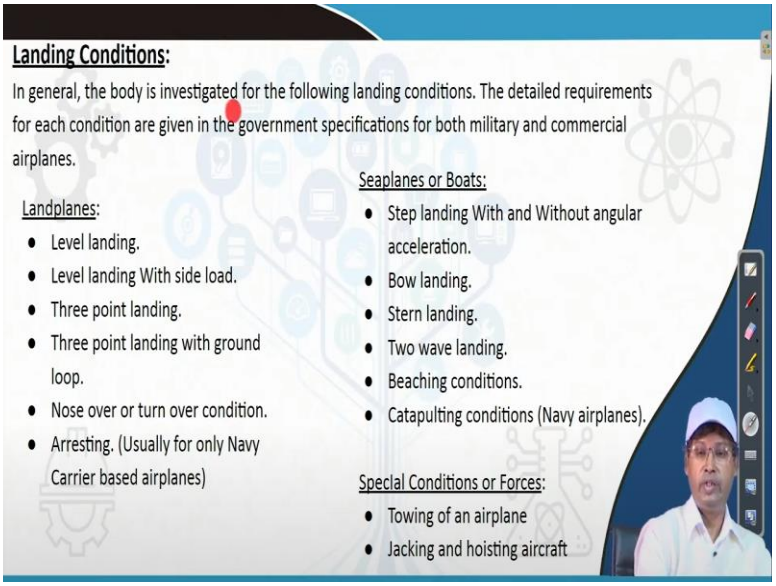
So this design weights are specified by government agencies as we have discussed the air ordinance agencies are certification agencies they provide the critical conditions and from there we try to put. For landing conditions however the normal gross weight is used since it would be more critical than other load conditions and landing condition is a very critical condition of fuselage load analysis.

For this reason we will see how many landing conditions may exist and we may need to take care. The general design conditions which are usually investigated in the design of the body are as follows. The general design condition except landing what is generally followed already we have discussed how a wing which section of wing gets most stressed because of high angle of attack.

Positive high angle of attack or negative high angle of attack, low angle of attack positive or negative inverted low angle that is the negative one that is why I is there and the inverted high angle of attack. So all the 4 conditions as we have already considered in case of wing structures that we need also to be considered here. But in real design we need to consider but here in the example we probably you would not do.

The body is usually equipped sorry body is usually required to withstand special tail loads both symmetrical and asymmetrical which may be produced by air gusts, engine forces, etc., Also the body should be checked for forces due to unsymmetrical air loads on the wing. So what are the gust engine loads, unsymmetrical air loads? All these things already we have discussed but to remember to study these are all noted down as a specific case.

(Refer Slide Time 08:29)

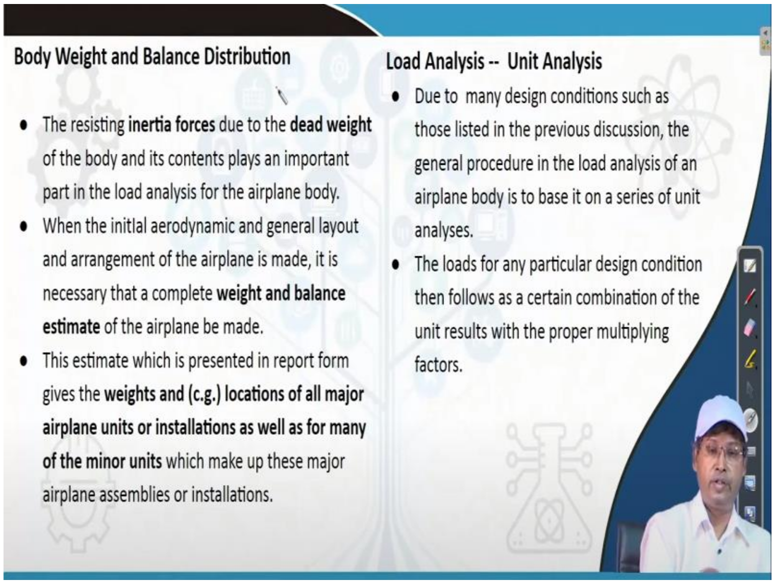


Landing condition as I told you landing condition is very critical condition. In landing condition in general the body is investigated airplane body is investigated for the following landing conditions. The detailed requirements for each condition are given in the government specification for both military and commercial airplanes. So certifying agencies generally give this different; certifying agencies for different condition for land planes.

Level landing with side load, 3 point landing with ground loop, Nose over or turn over condition, arresting usually this is not a normal condition as it is mentioned it is usually for navy or carrier based airplanes. So all these critical cases we are supposed to consider for during landing and for land planes for seaplanes or boats. Step landing with and without angular acceleration, bow landing, stern landing, 2 wave landing, beaching conditions, catapulting conditions again this is not usual case.

For special conditions these are landing conditions for special conditions you also need to consider the fuselage or body shear force and moment and 2 of the more most important things are in listed here that is towing of an airplane or jacking and hoisting of aircraft. These are required towing is required almost every day for every flight but jacking and hoisting are required for maintenance.

(Refer Slide Time 10:24)



Body weight and balance distribution so this is where a special group of engineers come in they prepare the body weight and balance distribution. Let us see how it is prepared and how that uses that is used for the analysis. The resting sorry the resisting inertia force due to the dead weight of the body and it is content plays an important part in the load analysis of the airplane body. So inertia forces and dead weight we need to consider.

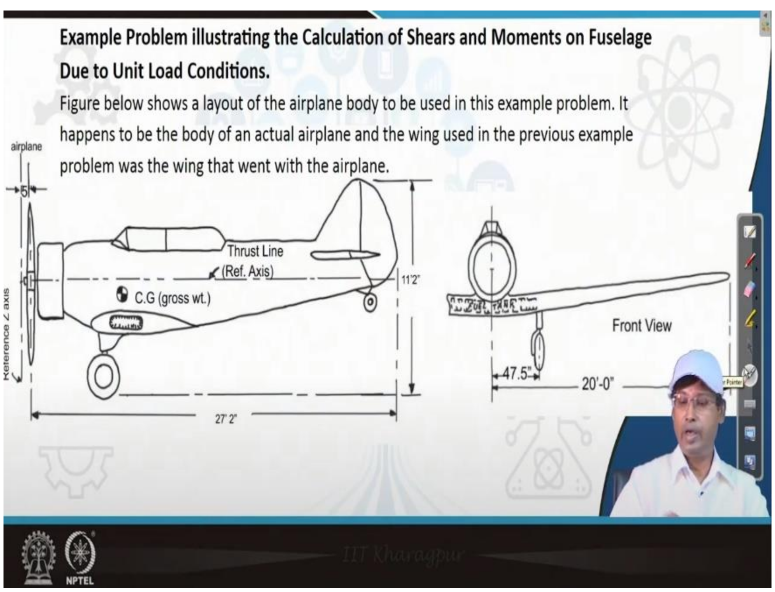
When the initial aerodynamic and the general layout and arrangement of the airplane is made it is necessary that a complete weight balance estimate. I repeat weight and balance estimate of the airplane is made. This estimate which is presented in report form gives the weights and c.g. locations of all major airplane units or installations as well as for many of the minor units. So whatever they are inside all components weight and their cg locations are put in weight and balance estimation sheet.

Which makes up this major airplane assemblies or installations load analysis or unit analysis. So unless we have the weight balance estimation sheet for a certain aircraft we cannot do that those light weight analysis here and want the moment distribution. Load analysis unit analysis this already are to some extent have got the idea what is unit analysis is due to many design condition such as those listed in the previous discussion the general procedure in the load analysis of an airplane body is to base it on a series of unit analysis.

So we will see in future classes that we will consider unit analysis in the transverse direction in Z direction we will consider unit analysis in the forward direction will also consider unit analysis because of the tail load. That is what is mentioned here for different design conditions we need to carry out the unit analysis. The loads for any particular design condition then; follows as a certain combination of the unit results with the proper multiplying factors.

So once we have these different load conditions as unit analysis depending upon the particular design criteria we need have a combination of those in unit analysis and we need to find out the final load coming shear force bending moment coming on the fuselage.

(Refer Slide Time 13:43)

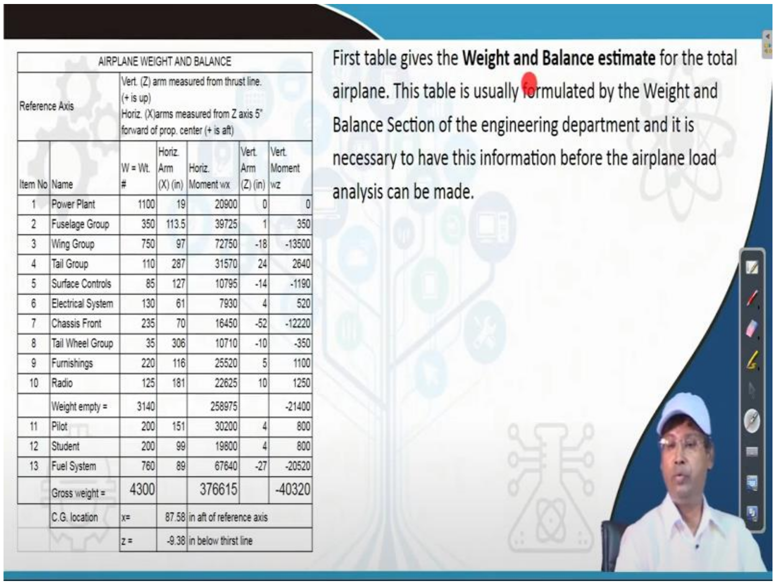


So our example is this aircraft this is a text book problem we have already solved the wing for bending moment and shear force. Example problem illustrates the calculation of shear and moments on fuselage due to unit load condition. Will cover the shear and moment in future class but that starts here that is why it is stated here. We will only do in this lecture that distribution and re distribution of the loads coming on the fuselage and how do we need to carry out that for unit load analysis.

Figure below shows a layout of the airplane body to be used in this example problem. It happens to be the body of an actual airplane and the wing used in the previous example problem was the wing that went with the airplane. So important things we should notice here that we are considering the reference axis we are considering the reference axis 5 inch forward the tip of the propeller this one.

We are considering the X axis this is the Z axis we are considering we are considering the X axis here going passing through the center of the propeller the tail height is the tail plane height tip height is about 11 feet 2 inch and the total length is about 27 width 2 inch. This is the thrust line we are considering cg is little bit below the first line and the wing though we would not be using for this analysis the dimension is given here it is 20 feet and the distance to the landing gear is 47.5 inch.

(Refer Slide Time 15:54)



AIRPLANE WEIGHT AND BALANCE						
Reference Axis		Vert. (Z) arm measured from thrust line. (+ is up) Horiz. (X)arms measured from Z axis 5" forward of prop. center (+ is aft)				
Item No	Name	W = Wt. #	Horiz. Arm (X) (in)	Horiz. Moment wx	Vert. Arm (Z) (in)	Vert. Moment wz
1	Power Plant	1100	19	20900	0	0
2	Fuselage Group	350	113.5	39725	1	350
3	Wing Group	750	97	72750	-18	-13500
4	Tail Group	110	287	31570	24	2640
5	Surface Controls	85	127	10795	-14	-1190
6	Electrical System	130	61	7930	4	520
7	Chassis Front	235	70	16450	-52	-12220
8	Tail Wheel Group	35	306	10710	-10	-350
9	Furnishings	220	116	25520	5	1100
10	Radio	125	181	22625	10	1250
	Weight empty =	3140		258975		-21400
11	Pilot	200	151	30200	4	800
12	Student	200	99	19800	4	800
13	Fuel System	760	89	67640	-27	-20520
	Gross weight =	4300		376615		-40320
	C.G. location	x=	87.58	in aft of reference axis		
		z =	-9.38	in below thirst line		

This is what the airplane weight and balance sheet is unless we have the airplane weight balance sheet it is difficult to go forward for the shear and bending moment calculation of fuselage or the airplane body. First table gives the weight and balance estimation estimate for the total airplane. This table is usually formulated by the weight and balance section. As I told you a group of engineering; are dedicated for this of the engineering department and it is necessary to have this information before the airplane load analysis can be made.

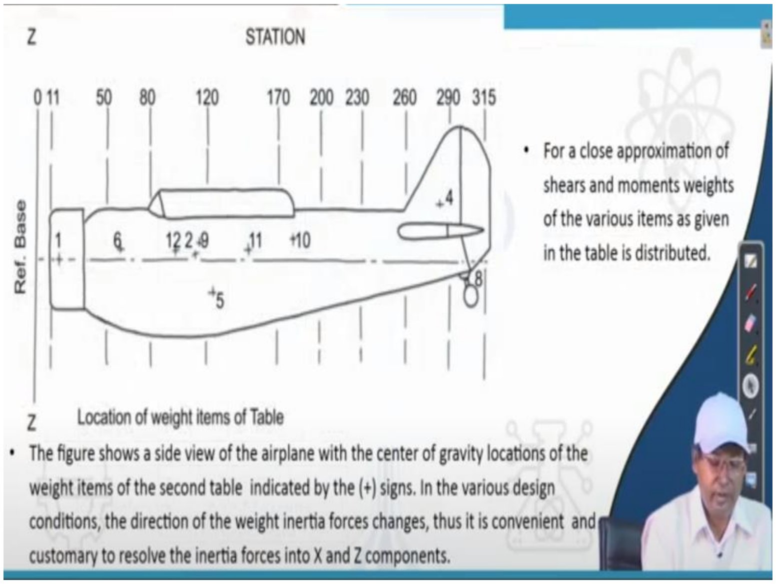
So let us try to look at the points what is there in this power plant weight is 1100 pound. Before that the vertical Z arm measures from the thrust line positive is upward. Horizontal X arms measures from Z axis 5 inch forward of prop Z axis situated 5 inch forward of prop center positive is aft that means towards the tail plane. So power plant location is 9 inch on X at the thrust line that is why it is 0 vertical moment is 0.

Whereas because of it is 19 inch away the moment about the Z axis is simple multiplication of these 2 quantity we are getting this. So this column is nothing but multiplication of these 2. This column is nothing but multiplication of these 2 instead of that like considering it that way we may consider it something like that what is the moment produced about the axis we have considered. These are the moment this is about Z axis this is about X axis.

What are the other components there in the weight balance sheet fuselage group, wing group, tail group, surface control, electrical system, chassis front, tail wheel group, furnishing, radio. All these consist of the empty weight that is why these are summed up here pilot, student, fuel system here the student is written but it may be considered as passenger. Fuel system and the total gross weight considering the payload and pilot portion, payload portion as 4300 pound and the horizontal moment is coming at 376615 pound inch.

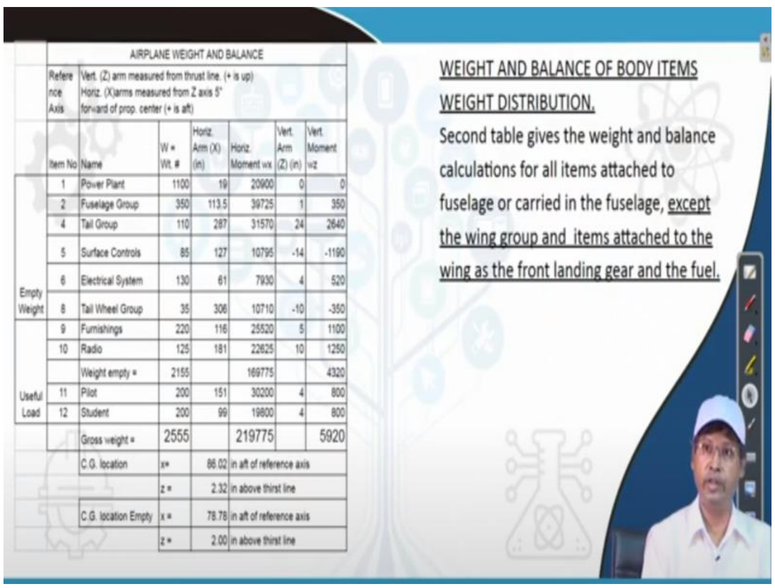
Whereas the vertical moment what we have that means, about the X axis is minus of 40320 pound inch. CG location from easy calculation you can find out the CG location that is 87.58 in aft of reference axis that means from the tip of the reference axis and in Z it is -9.38 that means below the thrust line that is the reason if we go to back or forward we will go because all these things are put on a nice drawing in the ok.

(Refer Slide Time 19:45)



This is the drawing of each and every part ok CG is not showed here is the CG. So CG is below the x line that is what it is we were discussing so it is there. So let us go to the next slide.

(Refer Slide Time 19:59)



AIRPLANE WEIGHT AND BALANCE

	Reference Axis	Vert. (Z) arm measured from thrust line. (+ is up) Horiz. (X)arms measured from Z axis 5" forward of prop. center (+ is aft)					
	Item No	Name	W = Wt. #	Horiz. Arm (X) (in)	Horiz. Moment wx	Vert. Arm (Z) (in)	Vert. Moment wz
Empty Weight	1	Power Plant	1100	19	20900	0	0
	2	Fuselage Group	350	113.5	39725	1	350
	4	Tail Group	110	287	31570	24	2640
	5	Surface Controls	85	127	10795	-14	-1190
	6	Electrical System	130	61	7930	4	520
	8	Tail Wheel Group	35	306	10710	-10	-350
Useful Load	9	Furnishings	220	116	25520	5	1100
	10	Radio	125	181	22625	10	1250
		Weight empty =	2155		169775		4320
	11	Pilot	200	151	30200	4	800
	12	Student	200	99	19800	4	800
		Gross weight =	2555		219775		5920
		C.G. location	x=	86.02	in aft of reference axis		
			z =	2.32	in above thirst line		
		C.G. location Empty	x =	78.78	in aft of reference axis		
			z =	2.00	in above thirst line		

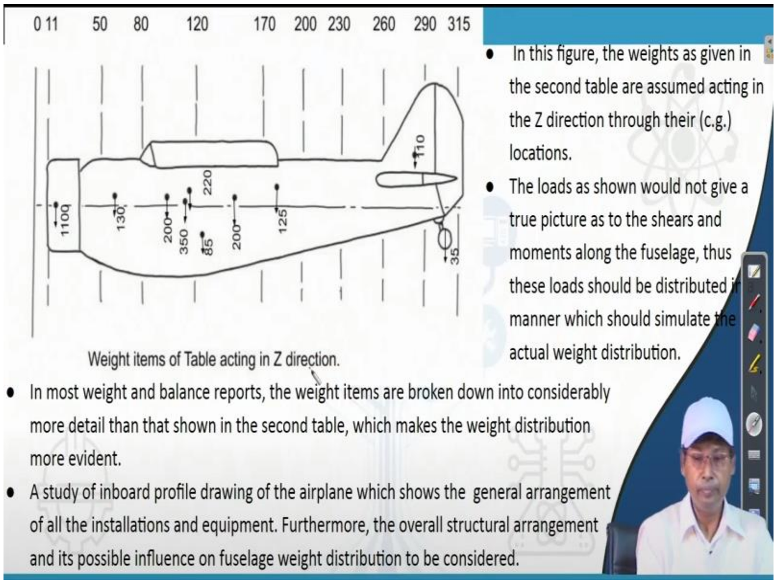
So in the next slide in the table we will see some components are not consider for the fuselage or your body shear and moment analysis. What are those conditions? If you look at it item 3 7 13 are not there. What are the items? Item 3 wing group is not considered. Item 7 chassis front is not considered. Item 13 fuel system is not considered. So wing group if we go further back wing group is actually this portion this is the fuel inside and what is the other one and the fuel?

Fuel inside, chassis front and wing group consisting of the portion as we have shown so these three items are not considered as the load carried by the fuselage why will because we assume that in practical consideration we see that load is directly carried by the landing gear not the fuselage. So that is the reason it would not come for the fuselage load analysis. So this table is further prepared for that and we have re return those parameters we have calculated the CG again considering gross weight as well as only empty weight.

So both CG we see that it is 86.02 while there is a change because of the payload that change and the fuel bond need to be adjusted during flight that is a different consideration of flight mechanics we would not discuss much about that. But in the Z direction there is not much change but we also need to consider that during flight. So weight and balance of body items weight distribution we are continuing.

Second table gives the weight and balance calculation for all items attached to the fuselage or carried in the fuselage except the wing group and items attached to the wing as the front landing gear and the fuel.

(Refer Slide Time 23:32)



So here all those items are shown with plus sign as item number 1, 2, 3 is missing 4 is here 5 is here, 6 is here like that all the items whatever listed I the word balance shape those things whatever required for fuselage load analysis that is even shown here for a close approximation of the shear and moments where moments weights of the various items as given in the table is distributed.

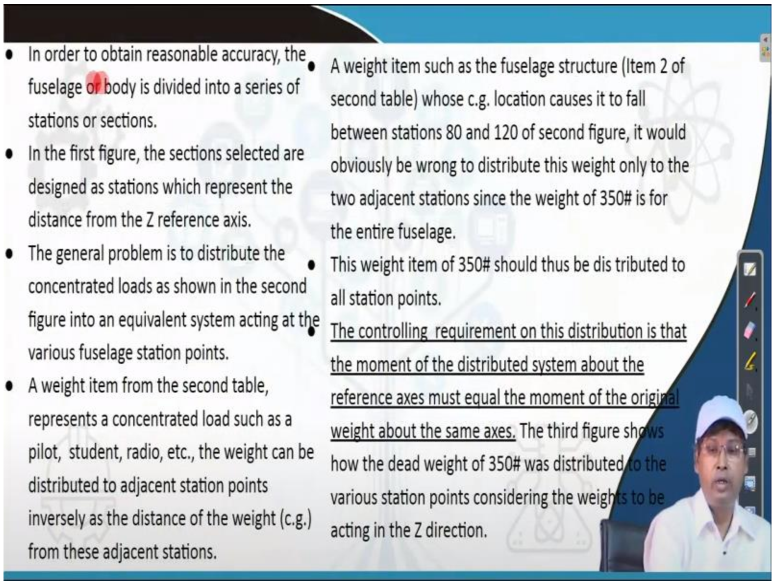
The figure shows a side view of the airplane with the center of gravity locations of the weights weight items of the second table indicated by plus signs. In the various design conditions, the directions of the weight inertia force changes thus it is convenient and customary to resolve the inertial forces into X and Z components. So from these point we will go for the resolving the forces in X and Z components.

So this is for vertical Z component weight items of table acting in Z direction in this figure the weights as given in the second table are assumed acting in the Z direction through their cg location. The loads as shown would not give a true picture as to the shears and moments along the fuselage, thus these leads loads sorry these loads should be distributed in a manner which should simulate the actual weight distribution.

So this is important which should simulate the actual weight distribution. Particularly these 350 load the fuselage load we will see we will come to that point in most weight and balance reports the weight items are broken down into considerable more detail than that shown in the second table which makes the weight distribution more evident. So if it is given in the weight balance table we need to use that otherwise the weight is given we will have to use it.

The study of inward profile drawing of the airplane which shows the general arrangement of all the installations and equipment is required. So that study we need to do unless we have the profile drawing it is difficult to distribute those loads furthermore the overall structural arrangement and its possible influence on fuselage weight distribution to be considered. So depending on the structural arrangement we need to distribute the fuselage weight that is most important and we need to carry that thing we need to do that thing.

(Refer Slide Time 25:56)



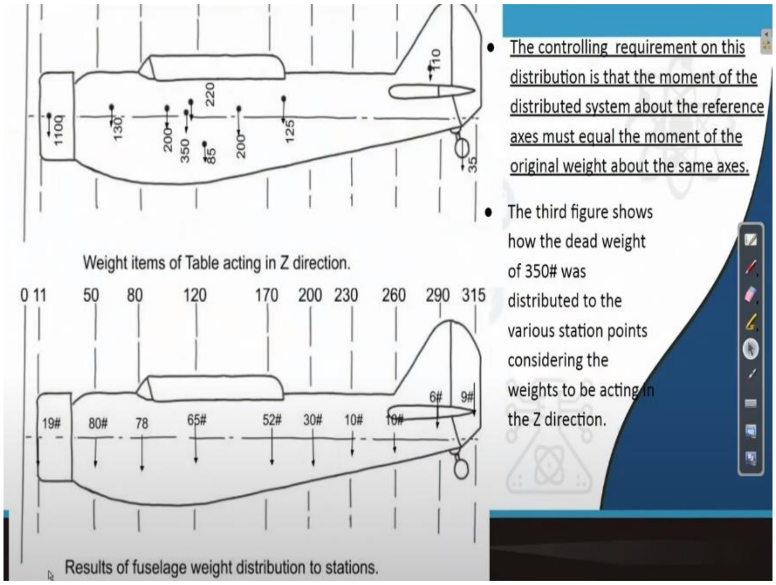
In order to obtain reasonable accuracy the fuselage or body is divided into a series of stations or sections. Better we go back these are the stations 0, 11, 55, 88, 120 like that these stations are generally divided and depending on the stations we need to carry out the load analysis. In this figure the sections selected are designed as station's which represents the distance from the Z reference axis. The general problem is to distribute the concentrated loads as shown in the second figure into an, equivalent system acting at the various fuselage station points.

This is the most important point in our discussion today. So we need to distribute the concentrated loads as shown in the second figure into an, equivalent system acting at the various fuselage station points. A weight item from the second table represents a concentrated load such as a pilot, student, radio, etc., The weight can be distributed to adjacent station points inversely as the distance of the weight from these adjacent stations.

A weight item such as the fuselage structure item 2 of the second table whose cg location causes it to fall between stations 80 and 120 of the second figure, it would obviously be wrong to distribute this weight only to the 2 adjacent stations since the weight 350 pound is for the entire fuselage. So we need to distribute this 350 pound along the length of the fuselage such that it represents for properly in those stations the fuselage weights.

These weight items of 350 pounds should thus be distributed to all station points. The controlling requirement on this distribution is that the moment of the distributed system about the reference access must be equal to the moment of the original weight about the same axis. The third figure shows how the dead weight of the 350 pound was distributed to the various station points considering the weights to be acting in the Z direction.

(Refer Slide Time 28:39)

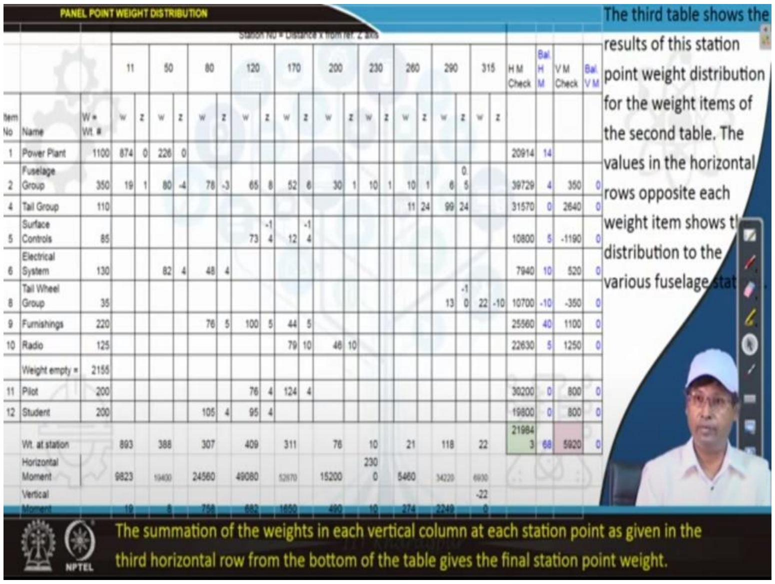


Let see the controlling requirement on this distribution is that the moment this already we have read so I am not going to read again thus for reference to this slide it is put down there. The third figure shows how the dead weight of this how the dead weight is distributed. All this mainly the 350 load this load is distributed at station 11 as 19 pound 80 pound 78, 65 all this way this has been done.

This is the iterative process not only iterative process this also requires a concept as well as drawing of similar aircraft for this distribution. Otherwise it will be very difficult to distribute the loads. Pleas look at the distribution this region is the highest load concentration. Because this region is the most load bearing section of the fuselage. And other section the load are not much those sections may carry a small amount of load and required loads whatever coming on the fuselage.

So depending on that concept it is not a easy task it cannot be distributed the way the this criteria match it is not only depending on this criteria it is also dependent on the practical consideration and experience of an engineer how to distribute the load.

(Refer Slide Time 30:13)



This is a table to carry out that distribution as I mention it is iterative process that iterative process is difficult to solve people used to do it with big charts and slide rules and calculator previously. But now it is people have the facility of the computer and it is generally tried using computer to distribute the load. This table is a very important table in our today's discussion. If you look at the previous 2, 3 slide discussion that 2, 3 slides discussion is completely given here in this row whatever is given.

So it is it look like a simple row but it is the result of the all calculations and experience. What is given? That 19 load if we take for example is at station 11 from the horizontal direction at X axis but it is also upward 1 inch from the thrust line, the other part 80 that is below 4 inch the thrust line. So it is not only that in only with respective to the Z axis the equilibrium is considered it is also that it is about the X axis also the equilibrium is considered.

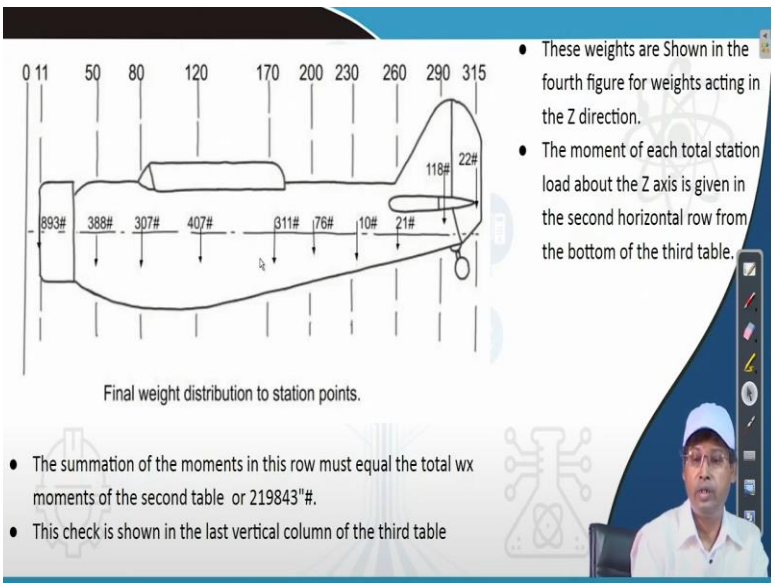
And if we look at the other all distributions this is 20914 is coming from the power plant the horizontal moment and we are summing up all this horizontal moment to this value and if we sum up these horizontal moment also this will give us this value. How do we get this horizontal moment weight at station is the addition of these 2 and that is multiplied by this 11 gives us the horizontal moment here?

So from the both sides we get the summation equal and we have the similarly the vertical moment, if we look at here this is multiply by 0 but 19 is multiplied by 1 that is the reason it is having the value of 19 and similarly the vertical moments sums up to this 5920. If you carry out this in a excel sheet you can easily select this row and check that this is summing to this 5920.

That could be a small error with respect to the previous table what we have seen but those errors are neglected to estimate the overall moment overall distribution of the weights along the Z and X axis. But this table shows the results of this station point where distribution for the weight items of the second table the values in the horizontal rows opposite each weight items show the distribution to the various fuselage station.

The summation of the weights in each vertical column at each station point as given in the third horizontal row from the bottom of the table gives the final station point weight final weight distribution to station.

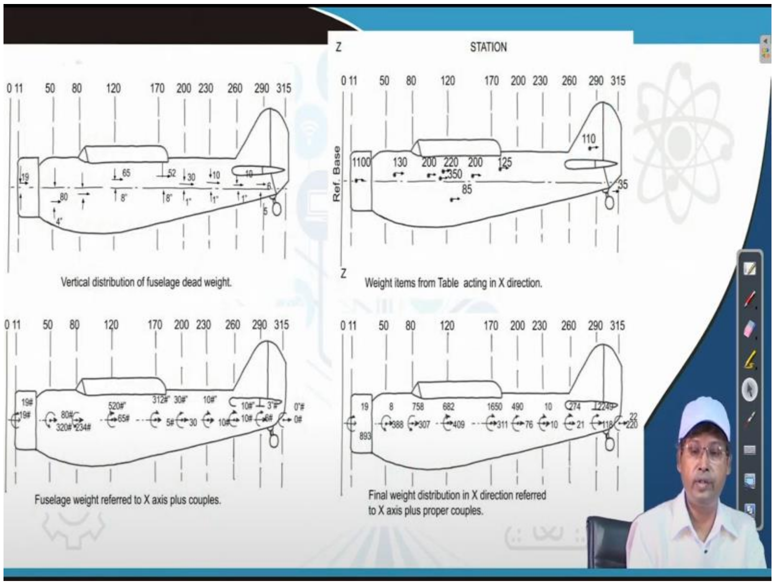
(Refer Slide Time 33:53)



So this is what were from do we get this let us go back. 893, 388, 307, 407, 893, 388, 307, 407 and 409 as I told you there could be a small mismatch between this figure and the calculation one. So please ignore that it is close 311, 76, 10, 21, 311, 76, 10, 21, 118 and 22. So all these are shown here the redistributed loads combine with all other internal as well as fuselage load and with this load distribution only we will carry out our shear force bending moment calculation.

These weights are shown in the fourth figure acting in the Z direction. The moment of each total station loads about Z axis is given in the second horizontal row from the bottom of the third table that means the previous table. The summation of the moments in this row must equal to the total wx moment of the second table or 219843 pounds inch or inch pound. This check is shown in the last vertical column of the third table.

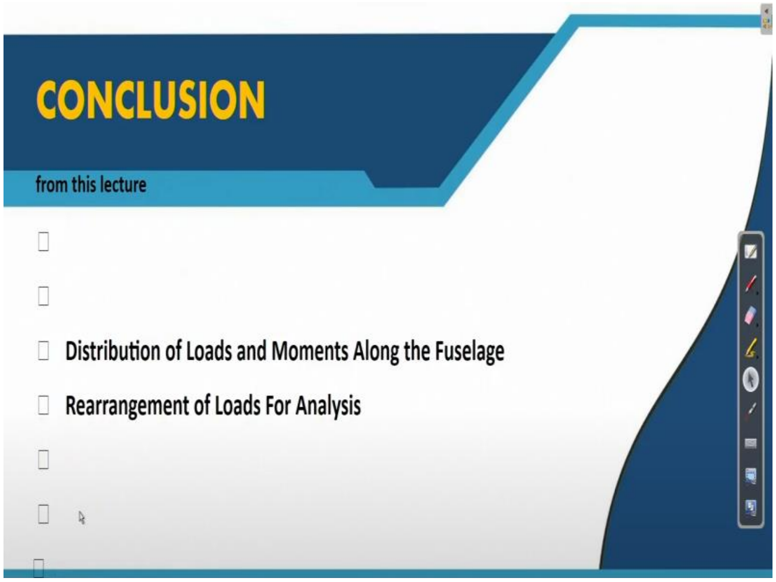
(Refer Slide Time 35:26)



Ok this is we have concepts in how it is distributed in in the vertical direction. This figure shows in the horizontal way how it is distributed 80 is acting here. This is the mistake the corresponding values is not put there you may please refer to the table. 65 is acting above the X line 52 is acting above the X line, and similar way on the X direction where the loads are acting all those things are shown here.

And the fuselage weight distribution to the X axis plus couple. So because of this distance a couple will be created that couple is shown here 80 and 320 is the couple 80 is the force 234 is the couple and I think this is 130 is the load here. Here the 65 is the load and 520 is the couple. And finally the final weight distribution, in X direction refer to X axis plus proper couples gives us this figure.

(Refer Slide Time 36:45)



And with this we will end today's this lecture and what we have learnt is that with respect to the vertical Z axis as well as X axis how the loads and moments are distributed to distribute the loads coming in the fuselage that has been discussed here. And along with that we will thank you for attending this lecture we will meet again with in the next lecture. Thank you.