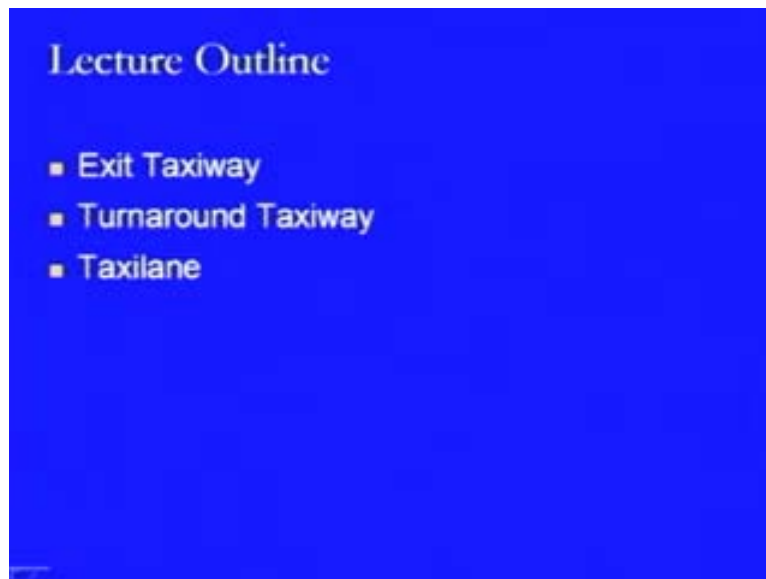


**Transportation Engineering - II**  
**Dr. Rajat Rastogi**  
**Department of Civil Engineering**  
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**Lecture - 35**  
**Exit Taxiway**

Dear students, we are back with the lecture series of course material on Transportation Engineering - II. From the previous lecture, we have started with the taxiways, once we have completed about the runways. A taxiway, as we have discussed, is another important aspect or a component of any airport, which provides the connectivity and access between the runway strip and the terminal building or the apron related to the terminal building. So, in that sense it is one of the component which creates its effect on the airport capacity, because the way by which the aircrafts can be turned around and it can be taken away from the runway strip as fast as possible will create its effect on the total capacity which can be handled by any of the airport.

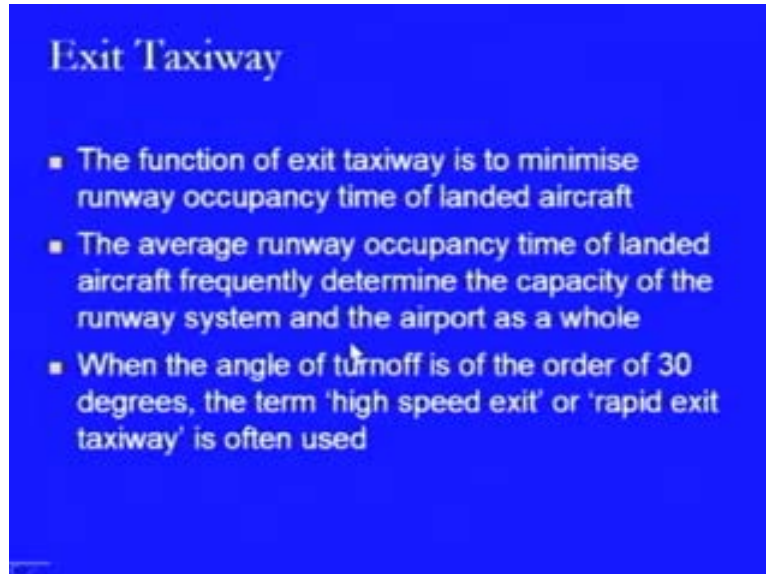
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In continuation of the same, so in today's lecture we will be discussing about exit taxiway, a specific type of a taxiway which is used for providing that type of movement from a runway strip to the terminal apron. So, in that case, in this particular lecture we will be taking up exit taxiway, the turnaround taxiway and taxilane. These

are the three major components or the three specific types of components of the taxiway which we can discuss.

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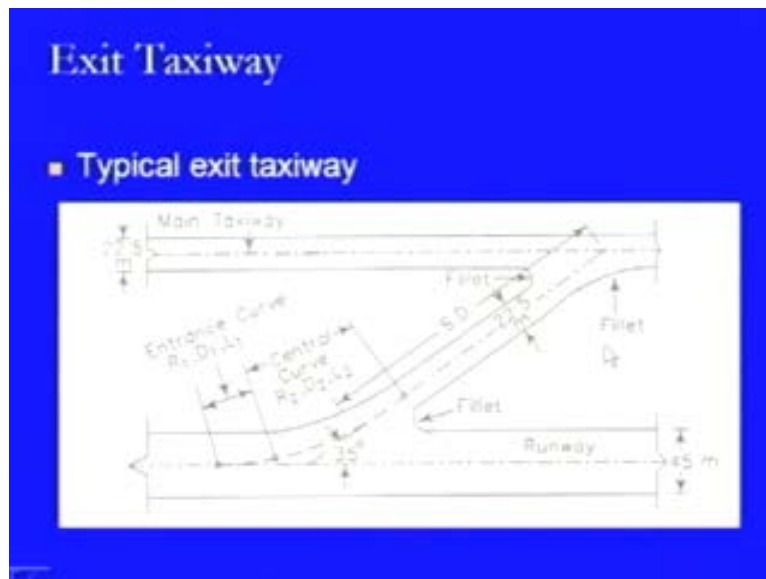
We will be starting with exit taxiway. Exit taxiway, the function of this exit taxiway is basically to minimize the runway occupancy time of landed aircrafts. As we have discussed previously that the taxiway, the main function of a taxiway is to provide an access between runway strip and the terminal building. So, in that sense, it provides the pathway for those aircrafts which have landed on the runway strip and now proceeding towards the terminal building or those aircrafts which are being there on the terminal building apron and now they are proceeding towards the runway strip for take-off.

In both the conditions, as we have seen and we have discussed previously is that, if there are more than one taxiway, then we try to provide the unidirectional movement and in that sense only, here we discussing the exit taxiway, where at number of locations we provide ..... from where any landing aircraft can come out of the runway strip, so that the runway does not remain occupied by that aircraft and it can be utilized for another operation, maybe landing or take-off. So, that is why the main function here is or the objective here is to minimize the runway occupancy time.

The average runway occupancy time of any landed aircraft frequently determines the capacity of the runway system and not only the runway system, but it also determines the overall capacity of any airport. So, that is obvious, because if any air aircraft is taking more time at the time of landing before coming towards the terminal building apron, then no other operation can take place on that runway strip. So, it means we are reducing the overall capacity of not only the traffic handling capacity of the runway strip, but also of the airport. So, that is why this average number of occupancy time in an important factor and it is to be measured and optimized in the sense that it is minimum as far as possible.

Now, when the angle of turnoff is of the order of 30 degrees, then the term high speed exit or rapid exit taxiway is used. That depends on at what particular angle the exit taxiway is being provided. If this is being provided at an angle of around 30 degrees, then we say that this turn will be taken up at a higher speed and that is why this is high speed exit or rapid exit taxiway.

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Now, there are certain typical exit taxiways. Now, this is one of the diagrams which try to define that how the taxiway is being, exit taxiway is being provided. Now, here this is the runway strip and on this runway strip an aircraft will be landing from this direction that is from left hand side and will be moving towards the right hand side and there is a taxiway which is parallel lane or parallel pathway or paved area being

provided with respect to this runway strip. So, the aircraft has to be taken from this runway strip to this main taxiway, so that this particular runway can be utilized for some other purpose. So, in that sense, a connectivity is being provided between this taxiway and this runway strip and this is what is this type of a connectivity and this connectivity is known as exit taxiway.

That is it is trying to provide an exit from the runway strip and then, it comes towards the taxiway. So, in that sense, the number of design features has been shown here. This is the runway strip which is in natural condition whatever is the width being defined, like here the width being defined here is 45 metres which is for the higher category of an airport and at this level, the angle of turning from this side this is 35 degrees, whereas accordingly from this side it is 180 minus 35 degrees and here, the two curves are being provided. There is one curve which is known as the entrance curve. The length of this entrance is  $L_1$  with the radius  $R_1$  and the degree with which this turn is taking place is defined by  $D_1$ , whereas there is a circular central curve which is provided in this location and this is having a length  $L_2$  with the radius  $R_2$  and the deflection angle as  $D_2$ .

So, there is a relationship between this deflection angle  $D_2$  and another deflection angle  $D_1$  and that is how we can calculate them as we will be seeing when we will be computing the values for all these different design parameters. Now, in this particular location where there is a turn at this point as we have seen previously or we will be looking in today's lecture too that if there is any plane which is taking a turn, then there are different ways by which it can be done. Either the nose maybe moving along the centreline of the pathway or there is another method in which the pilot uses the judgemental approach and tries to negotiate the curve, wherein the nose gear will be going away from the centreline. But, at the same time, the inner gear of the main gear on the wing will remain within the area, which is away from the inner side of the pavement.

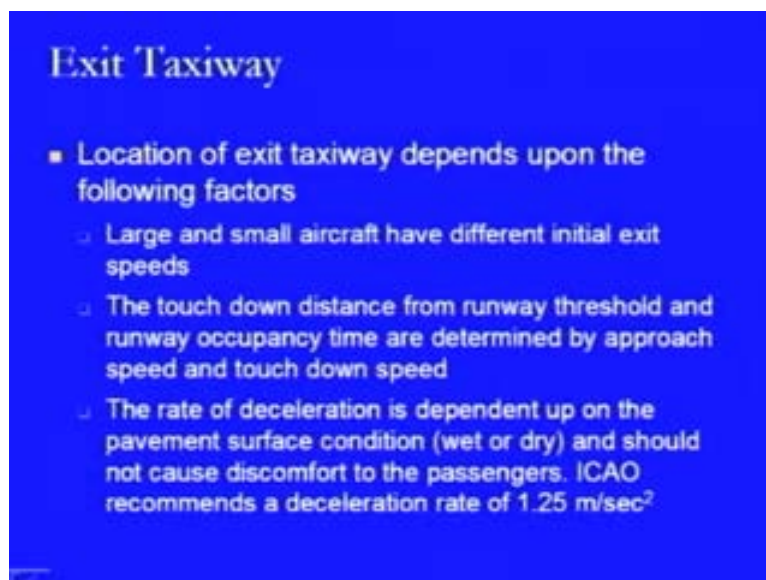
So, in that sense there is always a possibility depending on the type of the method that we are moving away from the edge of the pavement and therefore, this paved area is to be provided which is known as fillet. So, there will be extension of this paved area towards the inner side and that particular area will become the fillet area. Now, here

the width of the exit taxiway and the width of the main taxiway is also being shown, which is 22.5 metres, again being provided for a higher category of airports and a fillet is to be provided on this side as well as on this side. So, these two areas are also for fillets and then, there is a side distance which is being provided. This is the side distance being provided from the centre of this curve, central curve towards the point of intersection of this centreline of the exit taxiway with the main taxiway.

At the same time, there is another design parameter which is the distance between the centreline of this main taxiway and the centreline of the runway strip which is termed as the separation distance between the runway and the taxiway. So, that separation distance needs to be calculated. So, these are some design features which have their significance in the design of any exit taxiway and we will be looking at all these design features and the computation of the design parameters.

Now, we first of all look at the conditions, which define the location of any exit taxiway.

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### Exit Taxiway

- Location of exit taxiway depends upon the following factors
  - Large and small aircraft have different initial exit speeds
  - The touch down distance from runway threshold and runway occupancy time are determined by approach speed and touch down speed
  - The rate of deceleration is dependent up on the pavement surface condition (wet or dry) and should not cause discomfort to the passengers. ICAO recommends a deceleration rate of  $1.25 \text{ m/sec}^2$

There are certain factors on which this may be depending and the factors are like for large and small aircraft, we may require any different initial exit speeds. That is one particular condition that is also known to us, because it all depends upon the type of the propulsion power which is being provided on any of the aircraft and if the aircraft

is big enough, then the power will also be more and therefore, the speed with which it will be landing will be more as compared to the smaller aircrafts. Therefore, we have to look at what is the exit speed of different type of aircrafts which will be using that airport and the exit taxiway.

Then, there is a touch down distance at which the aircraft will be touching the pavement surface, when it is coming along the flight path and descending on the runway strip. So, this touchdown distance from the runway threshold and the runway occupancy time, these both are needed to be determined and they will be dependent on the approach speed with which it is crossing the threshold and the touchdown speed. So, these are the two values which are another important factor or parameter, which will be defining that for how much time period an aircraft is going to remain on the runway strip.

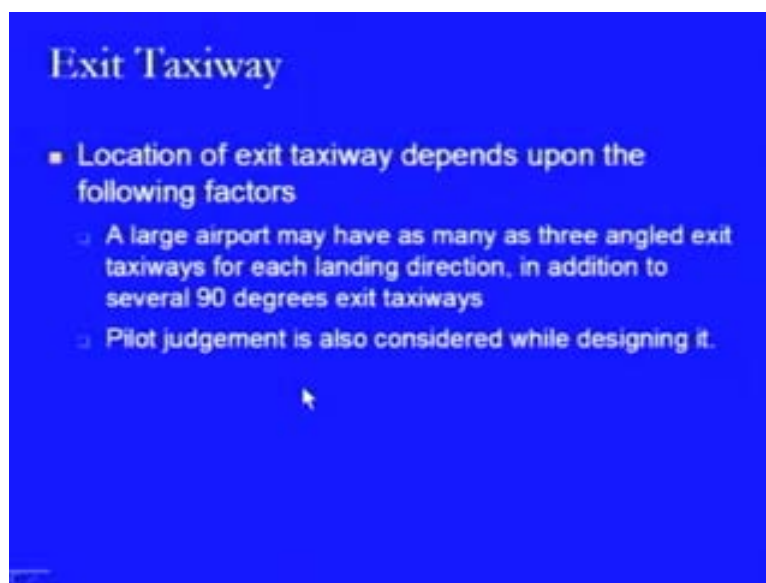
If the aircraft is crossing the runway threshold with the smaller speed, lesser speed, then it will be touching down a little earlier or may touchdown at a pre-specified point, but then it will be coming towards the exit taxiway location with smaller speed and therefore, there is more of occupancy time in this case. Whereas, an aircraft coming with the higher speed, at touchdown location also it is having a higher speed, then it will be moving with the same that big higher speed and therefore, the chances of occupancy time will remain lesser. So, that is another design parameter or factor which will create its effect on occupancy time.

Then, another factor is the rate of de-acceleration here and this rate of this de-acceleration is also dependent on certain parameters like the pavement surface condition. Within this pavement surface condition, it may be a possibility that this is in the wet condition or it is in the dry condition. So, on both these conditions, then it is having a different coefficient of friction which creates its effect. At a time the aircraft is trying to de-accelerate or the pavement surface will be providing some resistance in the opposite direction. Obviously, in the dry condition, the coefficient of friction will be more as compared to wet condition.

So, in that case, in the case of a dry condition, the rate of de-acceleration will be more and therefore, the aircraft can be brought to a desired smaller speed earlier as

compared to wet condition and another factor is that this rate of de-acceleration should be such that the passengers should not feel jerks or there should not be any discomfort to them at the time when the aircraft is trying to reduce its speed. So, these are the two factors which creates its effect or which governs the value of rate of de-acceleration. As far as ICAO is concerned, then ICAO has recommended de-acceleration rate of 1.25 metre per square second. So, that is the rate which can be used if it is not being specified, otherwise by any of the other airport authority governing the air navigation in any of the country.

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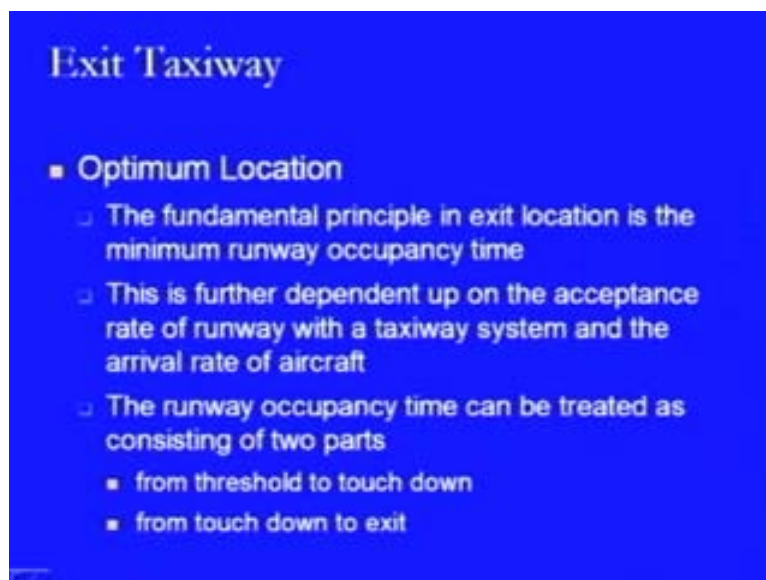


Now, further there is another factor like we have to look at the size of the airport and if there is a large airport, then there may be as many as three angled exit taxiways for each landing direction. In addition this will be there with respect to the several 90 degrees exit taxiways. So, it depends, means if it is going to be used by a large number of aircrafts and the frequency of their landing is much more, then in that case we require a number of taxiways and these taxiways, the exit taxiways we will provide it. There may be the angled taxiways provided and the 90 degree taxiways being provided. So, it is a combination of these which needs to be provided. What it says is that other than the 90 degrees exit taxiways which have been provided, there should be three angled taxiways for each landing direction.

Now the three angled taxiways will be spaced at different distances along the runway strip, so that they can take care of different types of aircrafts which will be landing with respect to the propulsive power with them and the efficiency or the fastness or rapidity with which those aircrafts can be taken away from the runway strip towards the main taxiways. While designing these exit taxiways or locating these exit taxiways, another factor which is also taken into consideration is pilot judgement

At times, the pilot judges for themselves that they have raised the speed by which they can now take a turn and can move towards the taxiway and so, after what particular time interval that is being **felt** on the basis of that way also the exit taxiway can be located along the runway strip.

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**Exit Taxiway**

- **Optimum Location**
  - The fundamental principle in exit location is the minimum runway occupancy time
  - This is further dependent up on the acceptance rate of runway with a taxiway system and the arrival rate of aircraft
  - The runway occupancy time can be treated as consisting of two parts
    - from threshold to touch down
    - from touch down to exit

Now, once we are looking and once we are talking about the location of any exit taxiway along the runway strip, then the one thing which can be looked upon is the optimum location of that exit taxiway and in this case, the fundamental principle remains is that it should be having the minimum runway occupancy time and this is what we have just discussed before also when we started our this lecture. What it wants to say is that, as we have discussed before that the runway should be occupied for as lesser time as possible for landing. So, that remains the fundamental principle. So, we have to locate it such way that the delays are not there.



Further, it is dependent upon the acceptance rate of the runway with a taxiway system and the arrival rate of the aircraft. These are some other factors which govern whether we are having the optimum location or not. What it tries to say is that there are two things which are happening. One is that the runway system is having the arrival rate of the aircrafts. On the basis of the number of aircrafts which are going to land on that airport, there will be a specified arrival rate at which these aircrafts will be coming and then, there is another rate which is known as the acceptance rate of that runway.

Acceptance rate of that runway means that whether the runway is in position to take any aircraft which is approaching this airport and this is obviously going to be dependent on the overall capacity of the airport and the provision of the taxiways by which the runway becomes empty and when there is no other aircraft from the runway strip, then the next aircraft can utilize that for landing. So, therefore the acceptance rate of the runway strip and the arrival rate of the aircraft on the airport, these are the two things which will be governing the occupancy time and the optimum location. The runway occupancy time, then in that case can be treated as consisting of two parts. One is that from the threshold to the touchdown and another is from the touchdown to exit. That is the two main constituents of computing the runway occupancy time.

As we have discussed that an aircraft, if this is the runway strip and then, the aircraft is landing from this side, so this is the end of the runway strip. So, that is the threshold and if the aircraft is crossing this threshold and is touching the runway strip somewhere, so how much it has taken, so as to touch this runway, this particular touchdown point, so that is one of the time periods and then, once it has touched here and there is an exit taxiway being provided here, so how much time it takes to reach from this touchdown point to the exit taxiway, so that it can take a turn around and come out of the runway strip. So, in that sense the total occupancy of this runway strip will be constituting of two components.

One is the time being taken between threshold and touchdown point and the other is the time being taken from the touchdown point to the **exit taxi** exit condition. So, here it is going to be controlled by the speed with which the aircraft is crossing the threshold and here it is going to be controlled by the touchdown speed and the speed

of the exit. So, these are the two speeds which will be there. Here, it is speed from threshold to touchdown, so they will be taking three speeds into consideration in that sense.

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**Exit Taxiway**

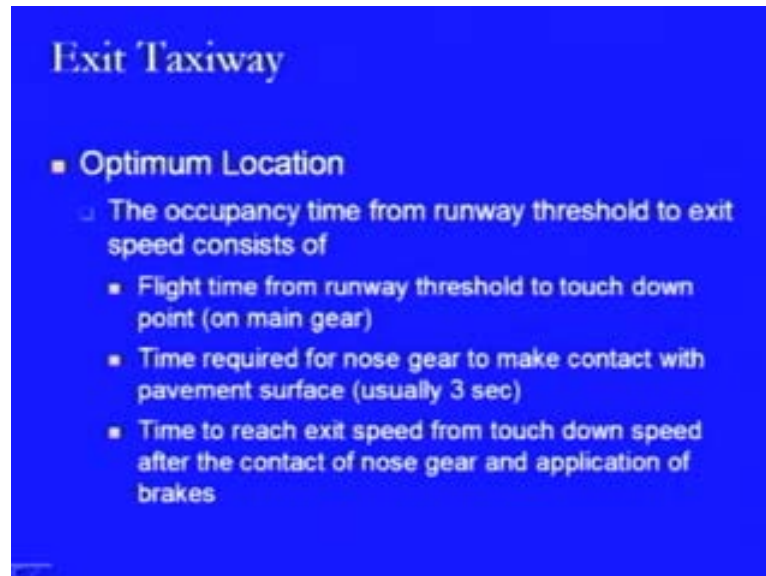
- **Optimum Location**
  - The distance from runway threshold to exit speed
$$S_E = S_{TD} + (V_{TD}^2 - V_E^2) / 2a$$
where,  $S_{TD}$  = aircraft touch down distance  
 $V_{TD}$  = aircraft touch down speed  
 $V_E$  = aircraft exit speed  
 $a$  = average runway deceleration rate from touch down to exit speed

So, if we want to compute the distance from the runway threshold to the exit speed condition, then it will be given by the value  $S_E$  equals to that is the distance for the exit condition or the distance for the exit taxiway will be equals to  $S_{TD}$ , where  $S_{TD}$  is the aircraft touchdown distance. That is once it has crossed the threshold and touches the pavement at some point and within that particular, those two points whatever is the distance being covered that is  $S_{TD}$  plus it is  $V_{TD}$  square minus  $V_E$  square divided by  $2a$ . So, here this  $V_{TD}$ ,  $V_{TD}$  is the aircraft touchdown speed, the speed at which it is touching down the pavement surface and  $V_E$  is the aircraft exit speed at which it is coming out of the runway strip and this  $a$ , this is the average runway deacceleration rate from touchdown to the exit speed.

So, on the basis of this value, so if this is known to us depending on the speed between this is the aircraft touchdown distance that is the distance being known most of the time, because this is defined that for this type of an aircraft, it is going to touch at this position based on its flight path and based on its speed at which it is crossing the threshold. So, that is ..... known generally and therefore, this value can be taken directly. Otherwise, this can also be computed on the basis of the speed of an aircraft

at the threshold point and the speed of the aircraft at the touchdown point. So, with respect to those two speeds, we can compute the value.

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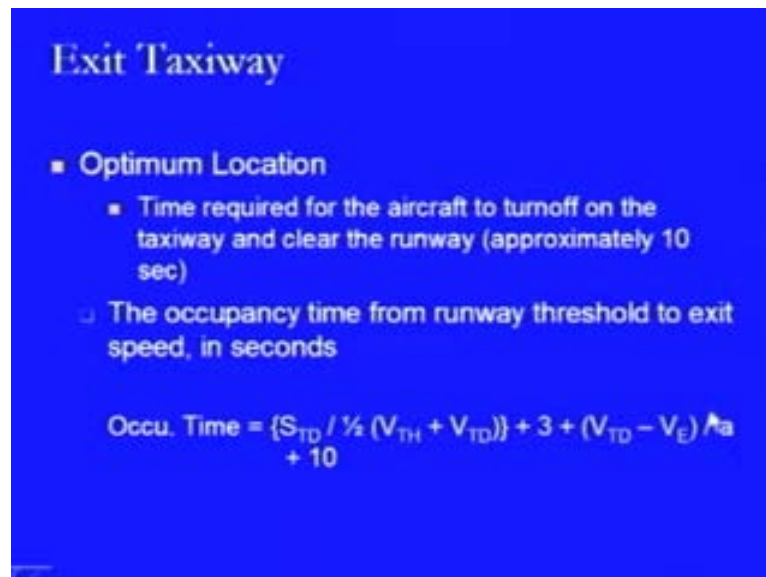


Now, this occupancy time, which we have been discussing, from the runway threshold to exit speed consists of the flight time from the runway threshold to touchdown point. Because, here now if we are interested to find out the time in the, just previously what we have seen is the distance which is being moved and that distance probably is the overall distance which is required for locating the exit taxiway. So, after reaching that particular distance, then exit taxiway can be provided at that location and which will be probably the optimum location for that aircraft.

Now, another thing which we are interested in is to minimize the occupancy time and in that sense it is going to be consisting of like the flight time from the runway threshold to the touchdown point. That is one aspect as we have discussed. Another thing is the time required for the nose gear to make contact with the pavement surface, because when it touches down the pavement, the aircraft then at that point it is the main gears which are provided below the wings. So, first of all those main gears touch the ground and once they have touched the ground, then after that slowly the nose gear touches the ground. So, there is some gap between this whole movement and this is usually 3 seconds. So, it means we have to take this 3 seconds into consideration and then, there is a time to reach the exit speed from the touchdown speed. So, there is

a change from touchdown speed to the exit speed, where the exit speed is lower than the touchdown speed and that is happening after the nose gear has contacted the pavement surface and the brakes have started being applied. So, in that particular condition then we are looking at this change over.

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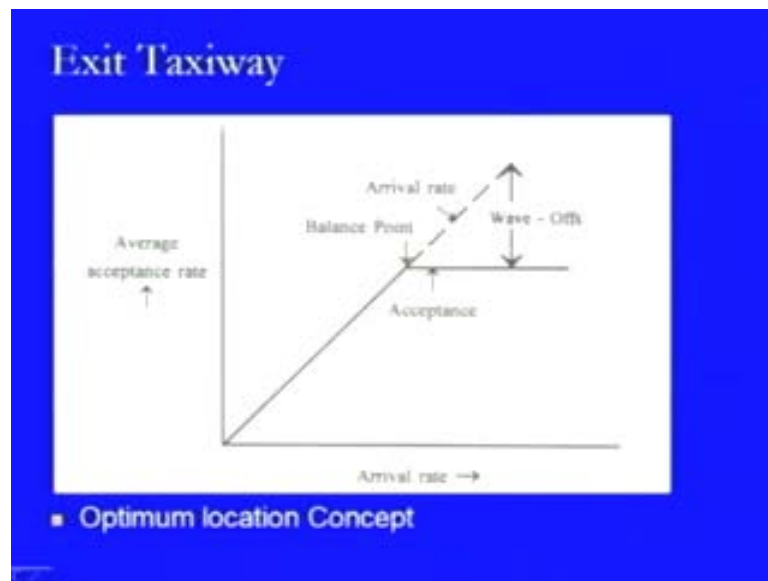
**Exit Taxiway**

- Optimum Location
  - Time required for the aircraft to turnoff on the taxiway and clear the runway (approximately 10 sec)
  - The occupancy time from runway threshold to exit speed, in seconds

$$\text{Occu. Time} = \left\{ S_{TD} / \frac{1}{2} (V_{TH} + V_{TD}) \right\} + 3 + (V_{TD} - V_E) / a + 10$$

Another is the time required for the aircraft to turnoff on the exit taxiway and clear the runway. Approximately this is taken as 10 seconds. So, we have two constant values - 3 seconds and 10 seconds and then, in between those we have a certain time period, which needs to be computed on the basis of speeds. Therefore, this runway time from runway threshold to exit speed in seconds can be given by this occupancy time equals to  $S_{TD}$  divided by half of  $V_{TH}$  plus  $V_{TD}$  and this whole has been added to 3 seconds that is the time which has been taken by the nose gear to touch the pavement surface plus the change in the speed from touchdown to the exit that is  $V_{TD}$  minus  $V_E$  divided by  $a$ . That is the de-acceleration speed, because the brakes are being applied, so as to reach this value of  $V_E$  plus 10 seconds being given, so that the aircraft can take a turn around or turnoff and can come towards the taxiway. So, that is the overall time period which is to be considered and this time is the occupancy time of any runway strip and this needs to be minimized.

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Now, here we are looking at the concept of this optimum location concept which, in the starting when we were discussing about the various factors, we have come across that they are two different types of rates which govern that how we can find out the optimum location. Here those rates are like the average occupancy rates, acceptance rate and the arrival rate. So, this arrival rate is the rate at which the aircrafts are reaching any airport and this acceptance rate is related to the runway strip with which it is being able to accept the aircraft for landing.

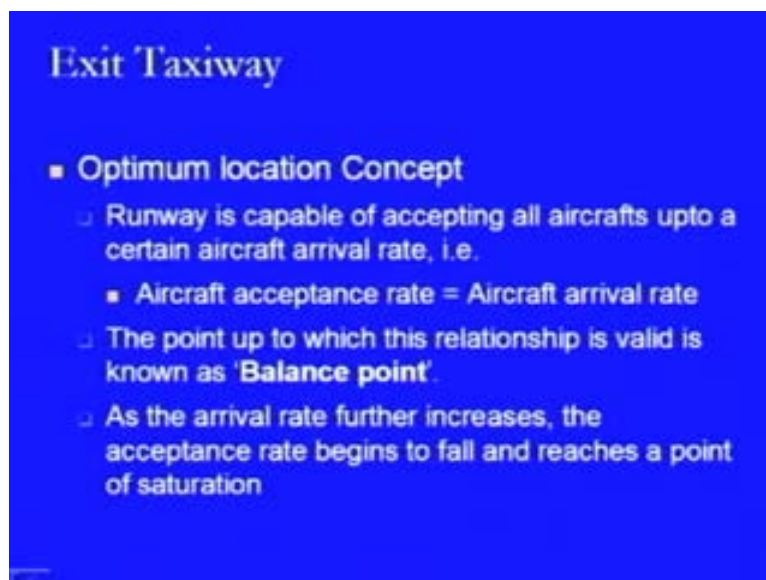
Now, so far the arrival rate and the acceptance rate, both are same. We will get a curve something like this. So, this is the curve, this is a straight line profile, which shows and which is moving at 45 degrees. So, this shows that whatever is the rate, the aircraft is being accepted in this system. But then after sometime, after some particular rate the condition will come, where in the arrival rate will remain, but the runway strip is not in a position or the overall airport is not in a position to accept further aircrafts.

It means, now at this particular position, though if both the things would have remained same, then this should have been the curve. But here, now because that is not the condition, so the arrival rate remains the same. That is it is coming with the same rate still as like this, but the acceptance has reached the saturation point and therefore, there is no further possibility of accepting any other aircraft on this airport

and therefore, it becomes constant like this. So, at this point where it becomes constant, where still the arrival rate is increasing, then this point is known as the balancing point. That is the aircraft, this airport is in a position to accept the number of aircrafts which are going to be defined by this point of intersection or this point of change over in the value of acceptance rate, where the acceptance rate becomes constant. So, this is the, this is going to define the overall capacity of any airport in this particular way.

Now, here when the arrival rate is still there, that means there are still the aircrafts which are coming on, but they cannot be accepted, so therefore there is going to be a difference between the two values. That is the acceptance rate and the arrival rate and this value is known as wave-off, means these are the number of aircrafts which needs to be turned away from the airport or probably they have to be told to keep circling at the top of the airport, so that as soon as they have, airport has the space, can accommodate any more aircraft, then they will allow one of them to land and that is how it will go on.

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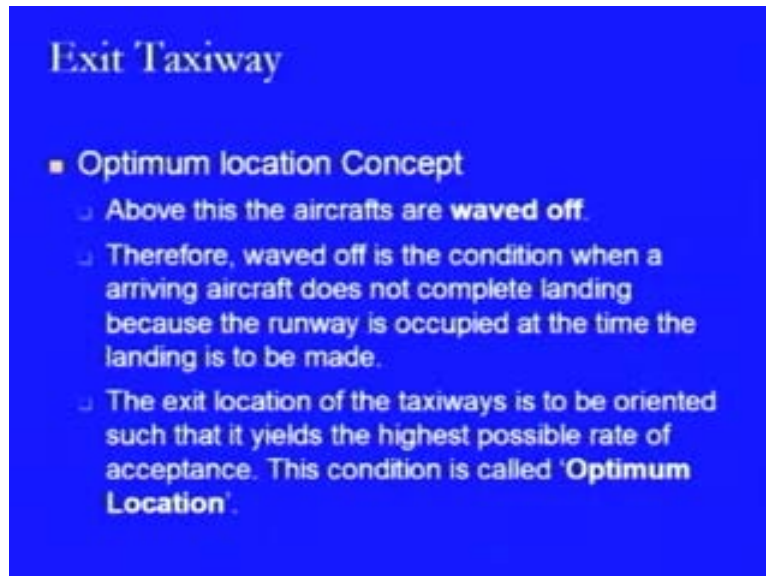
**Exit Taxiway**

- **Optimum location Concept**
  - Runway is capable of accepting all aircrafts upto a certain aircraft arrival rate, i.e.
    - Aircraft acceptance rate = Aircraft arrival rate
  - The point up to which this relationship is valid is known as '**Balance point**'.
  - As the arrival rate further increases, the acceptance rate begins to fall and reaches a point of saturation

So, in this case the runway is capable of accepting all the aircrafts up to a certain arrival rate. That is if these two rates are same, then this particular point at which this relationship becomes valid or up to which this relationship becomes valid, is known

as the balancing point, that already we have seen in the figure. Now, as the arrival rate further increases, the acceptance rate begins to fall and it reaches a point of saturation.

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### Exit Taxiway

- Optimum location Concept
  - Above this the aircrafts are **waved off**.
  - Therefore, waved off is the condition when a arriving aircraft does not complete landing because the runway is occupied at the time the landing is to be made.
  - The exit location of the taxiways is to be oriented such that it yields the highest possible rate of acceptance. This condition is called '**Optimum Location**'.

So, after this point of saturation, then whatever aircrafts are coming after that, as I have told you, they need to be waved off and therefore, the waved off is the condition when the aircraft arriving at an airport does not complete landing, because the runway is occupied at the time the landing is to be made. So, that is the situation on any of the airport and this happens at number of times, if there are metrological problems **associated** at that airport. Now, this exit location of the taxiway is to be oriented such that, it yields the highest possible rate of acceptance and if we can orient in this form, then this condition is known as optimum location. So, that is how we can locate the optimum location of any exit taxiway.



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Exit Taxiway	
■ Optimum location distance	
□ FAA recommends the following optimum distances of the exitway from runway threshold for different types of aircrafts,	
Twin engine propeller driven transport And large twin-engine general aviation Aircraft	750 m
Four-engine propeller driven transport, turbo prop and twin-engine turbo jet	1200 m
Large turbo jet transport	1800 m

Now, within this exit taxiway, FAA recommends that the following optimum distance of the taxiway from runway threshold can be taken up depending on what type of aircraft is going to use any airport. Like in this case if there is twin engine propeller driven transport aircraft with the large twin engine general aviation or aircraft and these are the two types of the aircrafts if they are there, then as per FAA the optimum distance of the exit taxiway from runway threshold is 750 metres. Whereas, if there is four-engine propeller driven transport aircraft or Turbo prop or twin-engine turbo jet, then in that case it requires 1200 metres as distance, whereas if it is a large turbo jet transport aircraft, then it requires 1800 metres. So, as the size of the aircraft, as the propulsive power of the aircraft is increasing, keep on increasing, then this distance also keep on increasing.



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## Exit Taxiway

- Optimum location distance
  - Corrections to the optimum distances of the exitway from runway threshold,
    - Altitude and Temperature correction for distance
$$S_c = [(S + M) (76/P) (4.92 + 1.8T) / 5.19] - M$$

So, in this case, we look at, there are certain corrections which needs to be provided for the optimum distance of any exit taxiway and one such correction is for the altitude and temperature and this is given by this equation as  $S_c$ . That is the correction for the distance  $S$  equals to  $S$  plus  $M$  multiplied with the 76 divided by  $P$  and it is further multiplied with 4.92 plus 1.8 times of  $T$  and it is here divided by 5.19 and then the whole value, from whole of the value  $M$  is subtracted that is minus  $M$ .

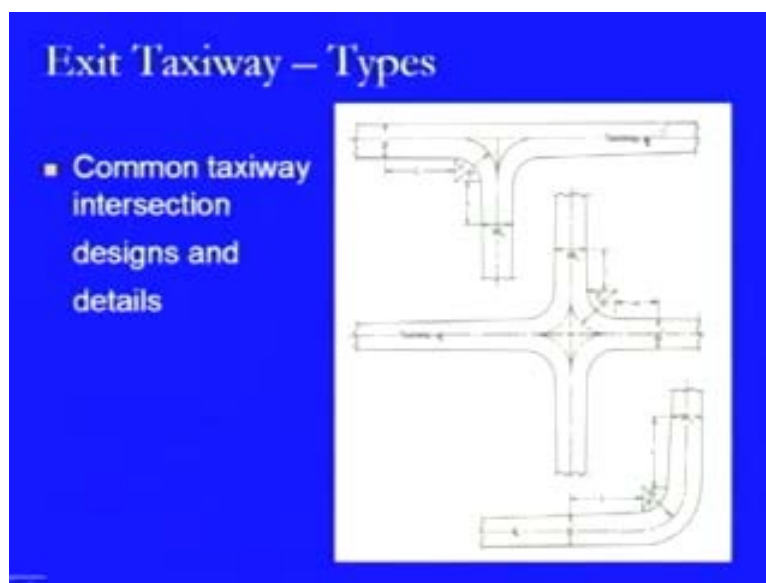
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## Exit Taxiway

- Optimum location distance
  - where
    - $S$  = distance from the runway end to the exit taxiway on a standard day (in meters)
    - $M$  = For turbo jet 150 and others 195
    - $P$  = Std. Air pressure in cm of mercury
    - $T$  = Average temperature of the hottest month
  - This assumes no wind condition. If there is a head wind of 16 km/hr then it may reduce the distance by 13.5%

Now, whatever these abbreviations which have been used here, we look at those abbreviations and they are S is the distance from the runway end to the exit taxiway on a standard day in metres, M is 150 for turbo jet and for others it is 195, P is the standard air pressure in centimetres of mercury, T is the average temperature of the hottest month. This assumes that there is no wind condition means there is no wind blowing. If there is a head wind of 16 kilometres per hour, then it is being observed experimentally that it may reduce the distance by 13.5%. So, the effect of wind if it is there, then it can be taken in this form.

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Now, some of the common taxiway intersection design and the details have been shown in this figure, where this is a T sort of a junction. We have the taxiway being provided here and this is the exit taxiway being provided. So, we have a curve from this side as well as from this side and this is the width of the taxiway, whereas this W T is the width of the exit taxiway and here, this is a straight portion and then, after that the ..... starts and goes up to a length L, whereas here also up to a length L, then we have a point of rotation and that is this defines the radius R.

So, similarly this a condition where there is a crossing being provided between a taxiway and an exit taxiway and it is taking the traffic further. So, these are the two or the two taxiways are crossing each other. So, similarly all the figures have been

shown here. Here it is in the form of a L taxiway that is it is sort of a turning the end of say, the runway strip and that is how we can see the two type difference.

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Exit Taxiway – Geometry						
■ Taxiway Exit Geometry						
Item	Airplane Design Group					
	I	II	III	IV	V	VI
Width (m)	7.5	10.5	15	22.5	22.5	30
Edge safety margin (m)	1.5	2.25	3	4.5	4.5	6
Centreline radius	22.5	22.5	30	45	45	51
Length of fillet lead-in	15	15	45	75	75	75

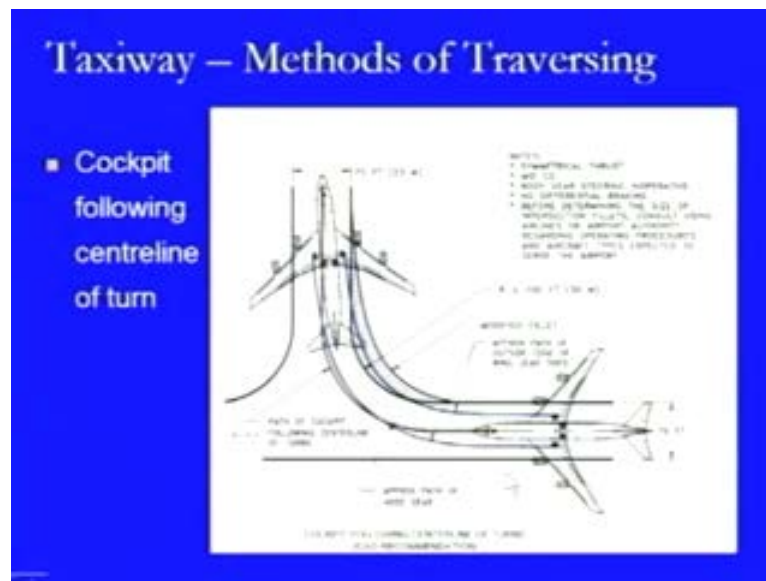
Now, another thing which is related to the exit taxiway is its geometric values and these geometric values are defined by the airplane design group and here, what we see is that the width ranges from 7.5 metres for a design group category I to 30 metres for a design group category of VI, whereas the edge safety margin again in metres varies from 1.5 metres at minimum to 6 metres at the maximum. Then, there is a centreline radius which varies from 22.5 metres for category I to 51 metres for the highest category that is VI. Length of the fillet also varies and initially it is 15 metres and then, for category III it is 45 metres and for the rest of the big categories it is 75 metres.

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Exit Taxiway – Geometry						
■ Taxiway Exit Geometry						
Item	Airplane Design Group					
	I	II	III	IV	V	VI
Fillet radius - Judgemental oversteering						
Symmetrical widening	18.75	17.25	20.5	31.5	31.5	33
One side widening	18.75	17.25	18	29	29	30
Fillet radius - Centreline tracking						
	18	16.5	16.5	25.5	25.5	25.5

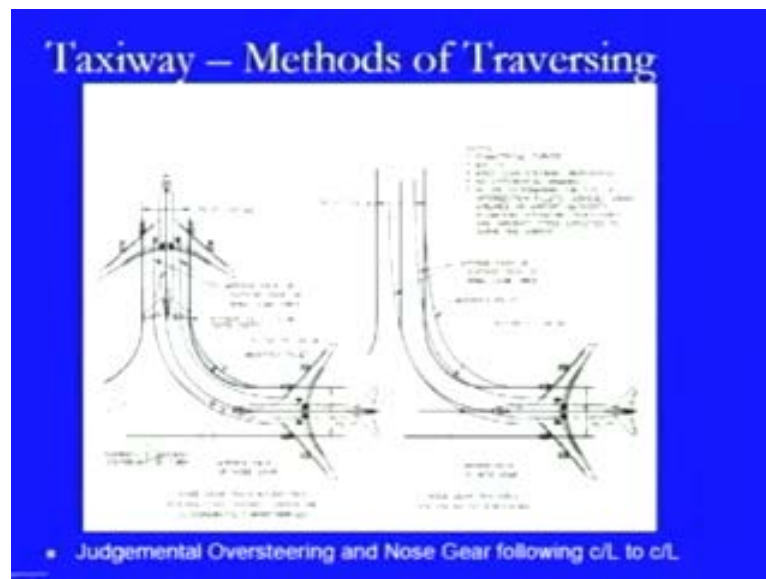
Then, further there are some more things like the fillet radius and this fillet radius can be computed on the basis of the type of the steering which is like judgemental oversteering and in this case, if it is symmetrical condition, it varies from 18.75 metres to 33 metres, again for the airplane design group ranging from category I to category VI. Then, if there is a widening and if there is one side widening, in this case it will be 18.75 metres to 30 metres. So, there is some variation in these values, a small difference and the fillet radius in the case of centreline tracking that is the nose of the aircraft is moving along the centreline, then in that case the value varies from 18 metres to 25.5 metres.

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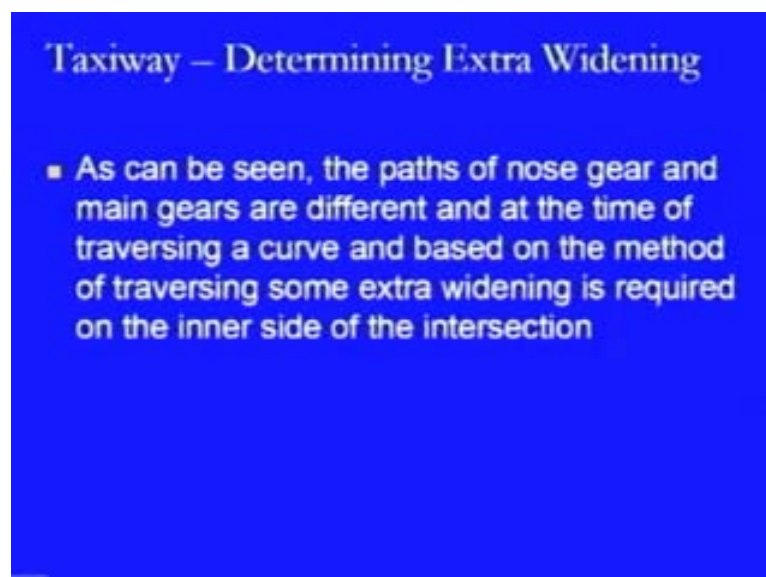
Now, we come to the methods of traversing. We have seen of course these methods of traversing before also, now we are looking at the same thing here that is the cockpit is following the centreline of the turn. That is this nose is moving along the centreline, so what we have seen is that it moves like this. But, while doing this way, there is a slight tilting of the aircraft towards the inner side and what is being observed that in this case, this wheel path will go away from the inner edge of the pavement surface. That is why the fillet needs to be provided with the full strength, so that it can take the load of the aircraft which is moving in this form. So, this is one method which is also recommended by ICAO.

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Whereas, there is another method like the judgemental oversteering method. In this judgemental oversteering method, this nose is not going along the centreline of the strip, whereas it goes a little away, so that this inner wing of the main gear it remains well within the edge of the pavement surface and therefore, we require a smaller size of the fillet in this case, if this type of method is being used. But, the nose is going a little away and it will come back to the position, after certain, once this curve is being negotiated. So, here there is no tilting of the aircraft and the aircraft remains within the same central position. So, that is another type of condition.

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So, in these cases we have to determine that by what particular value the extra widening needs to be provided or the fillet area needs to be provided. So, what we have seen is that the path of nose gear and main gears are different and then, at the time of traversing a curve and these are therefore, there is a method of traversing wherein some extra widening is required on the inner side of the intersection.

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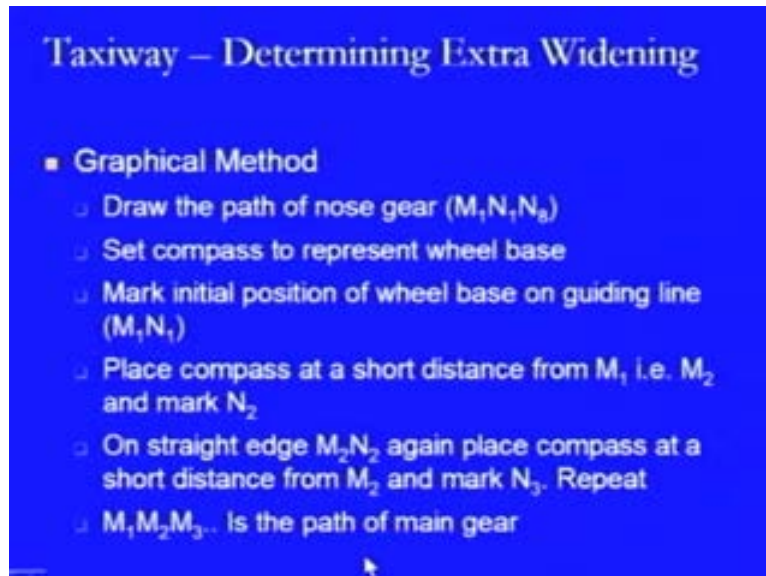
So, in that case, here we have this, another figure, where we are trying to show the same thing. This is the nose gear and this is the centreline. This is going along the centreline and these are the main gear threads and these are the body gear threads being provided behind those one. So, what we can say is that they are taking their own different turning conditions. So, this is the normal condition, they are going straight. This is the steering in this direction at an angle of some value that is known as castor angle and this castor angle can be at the maximum 70 degrees.

Now, the turning is going with respect to here. So, this is the point of turning. So, therefore this is the radius at which this turning is taking place and this is the pavement edge within which this remains and here, again in this particular side, the body gears that they are taking a turn in this direction and they will be coming towards this directions. Here, this angle can be at the maximum 13 degrees. So, the distance from this point to this axis on which these two wing gears are that is the wheel base which will be available at this condition. So, we will be using this wheel



base, so as to determine that in what particular position the curve will be negotiated by the nose gear and by the main gear.

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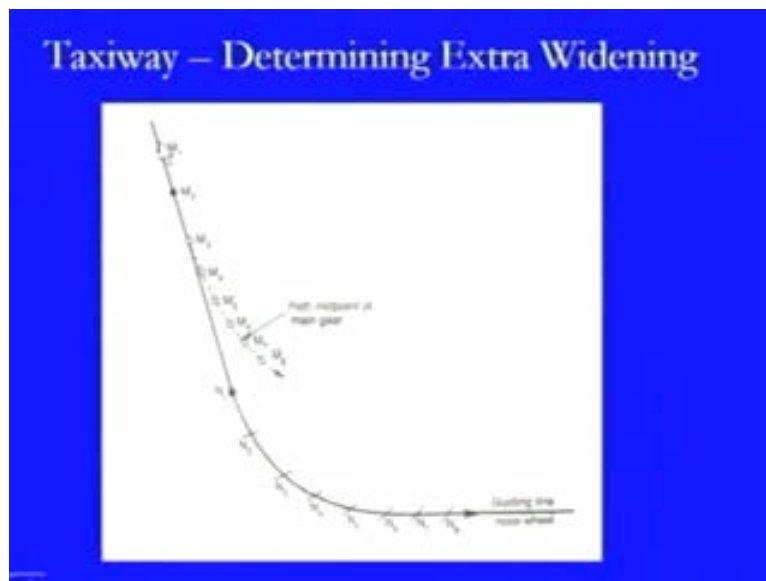


So, there is a graphical method of doing that and in that graphical method, first of all we draw the path of the nose gear, which say, being defined as  $M_1, N_1, N_8$ ; N for nose gear, M for main gear. Then, what we do is that we set our compass to represent the wheel base which we have seen in the previous figure and once we have got this distance, then we mark the initial position of the wheel base on any guiding line and say that is  $M_1N_1$ .

So, whatever is the path which we have, from this point  $M_1$  we take this much distance and just make a point on this curve. So, that will be  $M_1N_1$  position. Then, once we have done this, what we do is that we come a little lower than the value  $M_1$ , say to position  $M_2$ , which is lying on the same curve and then, we mark another location  $N_2$ . So, that is  $M_2N_2$  location. So, likewise we keep on going and again we place a compass at a short distance of  $M_2$  and mark  $N_3$  and we keep on repeating this and once we do this way, then we will be getting another locations of the points that is  $M_1, M_2, M_3$ , etc., and this particular line path will be known as the path of the main gear. So, that is how we can find out that how the paths will be differentiating.



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Here, we can see in this diagram that this is M 1, this is N 1 and then, this is N 8. So, this is the guiding line or this is the line along which the nose wheel will be moving. So, this is how it is going to happen. Now, the wheel base is equivalent to M 1 N 1. So, we have taken some point M 1 here and with the help of the compass, we have located the point N 1. Now, once we have done this, then we come short of this M 1 and we locate, take a point M 2 and cut it somewhere, so that we have another point N 2 at some distance here. So, that is lying on this **straight** and this is how we keep on going and we keep on marking the points on this side, so the distance from, like from M 8 to N 8 should remain equivalent to the distance as of the wheel base. So, whatever the path we are getting in this form, this path is the midpoint of the main gear path.

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## Taxiway – Design

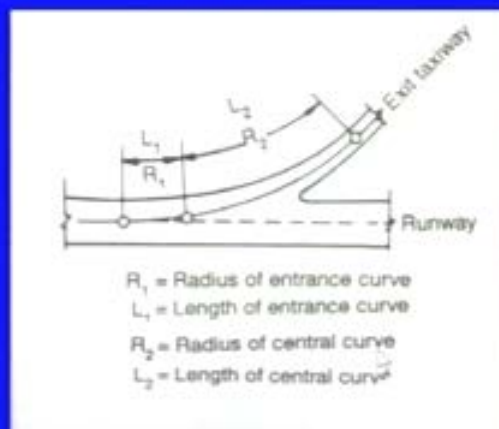
### ■ Following Principles govern the design

- For small aircraft the turn off exit speed is 65 km/hr at an exit taxiway angled 45° to the runway centreline
- Large aircraft can turn off at exit speed of 95 km/hr at 30° angle of intersection

Now, we come to the design of the taxiway and there are certain principles which govern the design. In the case of small aircraft, the turnoff exit speed is taken as 65 kilometres per hour at an exit taxiway angle of 45 degrees to the runway centreline, whereas in the case of large aircrafts this turnoff speed at the exit time is taken as 95 kilometres per hour, where the angle of intersection is taken as 30 degrees. So, that is the rapid condition of the exit taxiway.

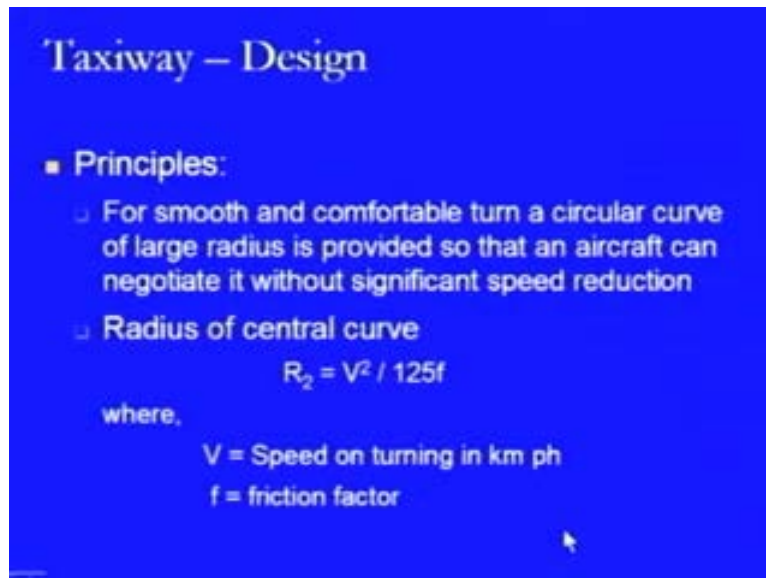
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## Taxiway – Design



This is a diagram which shows the components which we have to design that is this is the runway. From this point it starts moving away from the runway strip. So, this is initial curve that is L 1 with the radius R 1. Then, there is another central curve which is having length L 2 and radius R 2 and it moves in this form and then after this, again it will become a straight line.

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**Taxiway – Design**

- **Principles:**
  - For smooth and comfortable turn a circular curve of large radius is provided so that an aircraft can negotiate it without significant speed reduction
  - **Radius of central curve**
$$R_2 = V^2 / 125f$$
where,
$$V = \text{Speed on turning in km ph}$$
$$f = \text{friction factor}$$

Now, another thing is that for a smooth and comfortable turn, a circular curve of large radius is provided, so that an aircraft can negotiate it without significant speed reduction. That is the thing which we have seen as another curve that is central curve with the length L 2 and radius R 2 and the radius of this one can be found out by a formula V square divided by 125 f, where V is the speed on turning in kilometres per hour that is the speed with which it is taking a turn for exiting and f is the friction factor. Usually this friction factor is taken as 0.13.

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## Taxiway – Design

- **Principles:**
  - It can be computed using Horonjeff formula as
$$R_2 = 0.388 W^2 / (\frac{1}{2}T - S)$$
where,
    - W = wheel base length of aircraft (m)
    - T = width of taxiway pavement (m)
    - S = distance between centre of main gear and edge of taxiway pavement (m)

Then, this is, this  $R_2$  value can also be computed by using the Horonjeff formula, which is  $0.388 W^2$  and this is divided by half of  $T$  minus  $S$ , where this  $W$  is the wheel base length of the aircraft in metres and  $T$  is the width of taxiway pavement in metres and  $S$  is the distance between the centre of main gear and edge of taxiway pavement, again in metres.

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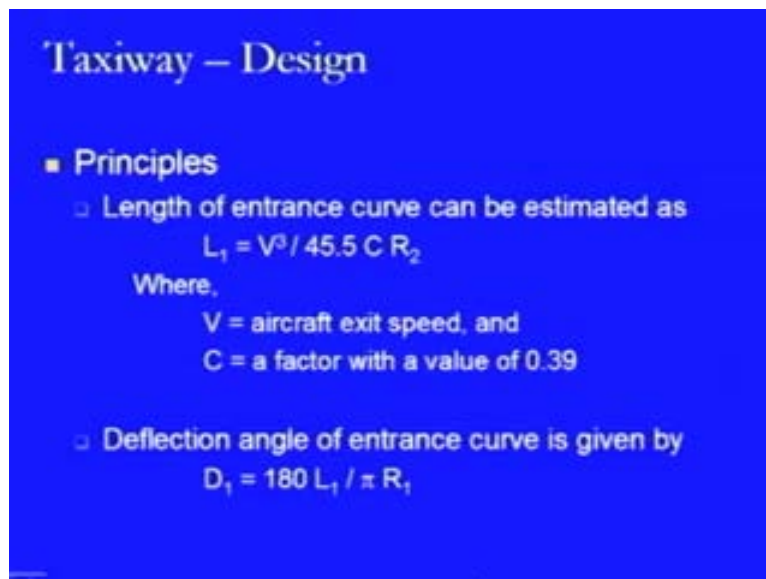
## Taxiway – Design

- **Principles:**
  - Slightly widened entrance gradually tapering to the normal width of taxiway is preferred. Fillets are used for widening.
  - A compound curve is provided with this reason. It reduces wear on nose gear and is relatively easier to lay in the field. Values of radius  $R_1$  are
    - 65km ph    517m
    - 80km ph    731m
    - 95km ph    941m

Now, there is a slightly widening entrance which is provided, which is gradually tapering to the normal width of the taxiway and this is preferred and the fillets are also

used for widening. In the case of this compound curve is provided, then it reduces the wear on the nose gear and it is relatively easier to lay in the field. In this case, the value of radius  $R_1$  that is being shown like in the previous diagram with the length  $L_1$ , here it is defined on the basis of the exit speed with which the aircraft is coming out of the runway and if it is 65 kilometres per hour, then this  $R_1$  is taken as 5.7 metres. If it is 80 kilometres per hour, then it is taken as 731 metres and if it is 95 kilometres per hour, then this value of  $R_1$  is taken as 941 metres.

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**Taxiway – Design**

- **Principles**
  - Length of entrance curve can be estimated as
$$L_1 = V^3 / 45.5 C R_2$$
Where,  
 $V$  = aircraft exit speed, and  
 $C$  = a factor with a value of 0.39
  - Deflection angle of entrance curve is given by
$$D_1 = 180 L_1 / \pi R_1$$

Now, the length of entrance curve is estimated as  $L_1$  and this is  $V$  cube divided by 45.5  $C$  multiplied with  $R_2$ . Now, here the  $V$  is the aircraft exit speed  $R_2$  is as computed previously that is the radius of the central curve and  $C$  is a factor which is normally taken as 0.39. Now, the deflection angle for the entrance curve that is for the initial curve of the compound curve is  $D_1$  and this can be computed as given by this formula like 180 into  $L_1$  divided by pi into  $R_1$  and we know the  $R_1$ , we know  $L_1$ , so we can compute the value of  $D_1$ .

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## Taxiway – Design

- Principles
  - Length of central curve is computed as
$$L_2 = \pi R_2 D_2 / 180$$
Where,
$$D_2 = \text{deflection angle of the central curve}$$
$$= \text{Turning angle (or coster angle)} - D_1$$
$$R_2 = \text{Radius of central curve}$$

Now, the length of the central curve is computed by the formula  $\pi$  into  $R_2$  into  $D_2$  divided by 180. So, these are all on the basis of the properties of the circular curve only. Now, here  $D_2$  is the deflection angle of the central curve and this can be computed by taking the coster angle or the turning angle and subtracting  $D_1$  from this value.  $R_2$  is the radius of the central curve.

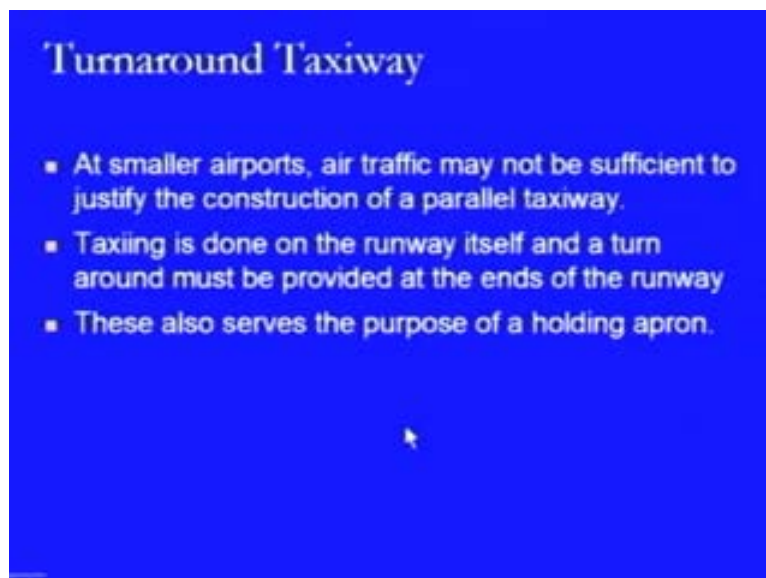
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## Taxiway – Design

- Principles
  - Sufficient distance must be provided to comfortably decelerate the aircraft after it leaves the runway. The stopping distance is computed as
$$SD = V^2 / 25.50 d$$
where,
$$d = \text{average rate of deceleration}$$
$$= 1 \text{ m/sq sec}$$

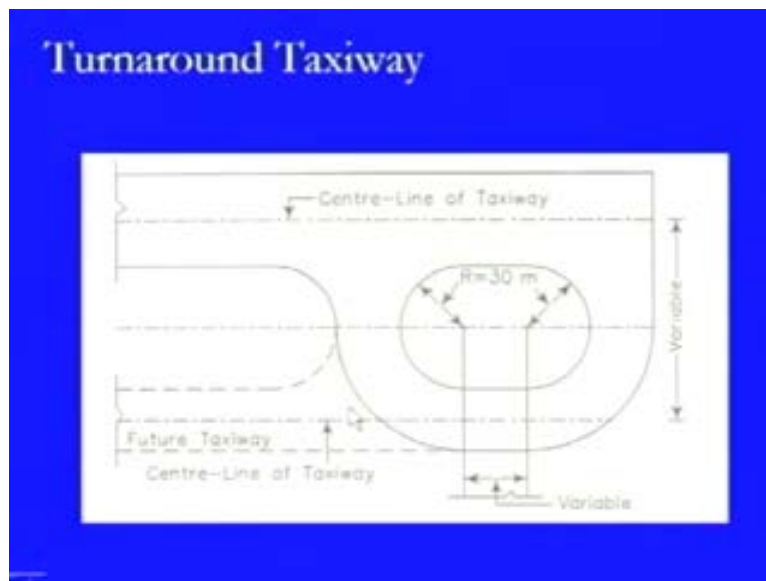
Then, there is a sight distance which needs to be provided and this sight distance defines the stopping distance, basically because this is the point up to which the aircraft can be stopped without any accident taking place. So, therefore this governs the comfortable deacceleration rate with which the aircraft is deaccelerating and leaving the runway strip and this can be computed by the equation as shown here that is  $SD = \frac{V^2}{25.50 \times d}$ , where this  $d$  is the average rate of deacceleration and if it is not known, then it is generally taken as 1 metre per square second. In the case of ICAO that is being defined as 1.25 metre per square second.

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Now, in the case of smaller airports, the air traffic may not be sufficient to justify the construction of parallel runways. So, in those cases, then what we provide is the turnaround taxiway, where the taxiing is done on the runway itself and a turnaround is provided at the end of the runway strip. So, that is the condition which is termed as the turnaround taxiway. These also serve the purpose of holding apron, means this is a type of the apron which is to be provided, which we will be discussing in the coming lectures. What we can understand is that it provides the condition where an aircraft can be stored for some time period, if there is an emergency. So, that is what a holding apron is. Therefore, it also helps in the way that it can be used as holding apron.

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Now, here in this figure, the same thing is being depicted, where this is the centreline of the taxiway or this may be the runway strip and then here, we are providing the turning of the aircraft and the aircraft comes up to this location, it takes a turn like this, comes back, this one and then goes in this direction and gets exited. So, that is the type of the turnaround condition being provided and this distance remains variable depending on the type of the aircraft, which are going to use this type of a facility. Most of the time, these aircrafts are of smaller size, because these facilities are provided generally on the smaller airports. In future, if this is to be extended and parallel taxiway needs to be provided, then this can be extended in this direction as been shown by dotted lines.



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Now, another type of feature is the taxilane. In the case of taxilane, this is portion of the aircraft parking area here being used for access between the taxiways and the aircraft parking position. So, that is how it is defined, so as we understand that in the case of the terminal buildings, the aircrafts will be standing just in front of the terminal buildings and if the similar sort of a condition is there or there is a parking of those aircrafts at the other side, then in between these two types of parking, there will be some pathway and that particular pathway is termed as taxilane, which provides the connectivity, which provides the area through which the aircrafts can move and can access either the parking area or can access the terminal building or ..... move towards the taxiways.

Now, as far as ICAO is concerned, it defines this taxilane as an aircraft stand taxilane as a portion of apron intended to provide access to only the aircraft stands. That is how it defines it. It simply speaks about the aircraft distance through which the aircraft will be moving and whatever portion of the taxilane is used for that purpose is taxilane.

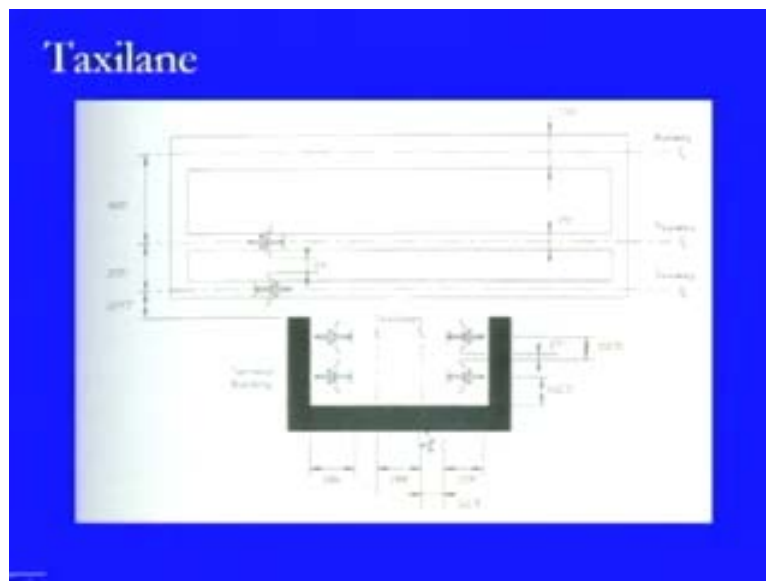
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So, in this photograph, a taxilane is being shown. Here, we can see that there is a terminal building on this side along with the terminal building on this side and these are the gate positions being provided, where the aircrafts can stand and the passengers can board the aircraft. Similarly is the condition on this side. We can see the aircrafts standing on this position and on this position and then, here we have the runway strip at the farthest condition, where we can see the take-off aircraft and the landing aircrafts simultaneously **doing** on two different runway strips and then, this is the taxiway being provided.

Here is another taxiway being provided. So, there are the parallel taxiways on which different aircrafts are moving. So, in this case, there is a connectivity being provided from these taxiways to this parking area that is this apron as well as this terminal apron. So, we have the terminal apron on these two sides and the aircraft is moving in between these two areas and this particular area is known as taxilane.

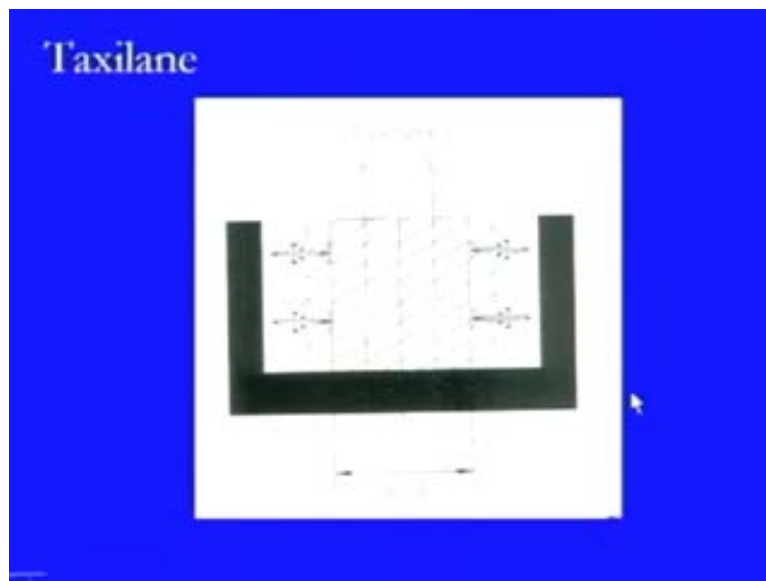
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Here is another figure, where the concepts have been shown that these are, this is the runway strip and these are the two parallel taxiways being provided and as we can see that there is a unidirectional movement on these taxiways, the aircraft moving towards left on this one and towards right on this one, so as to increase the safety as well as efficiency of the airport and then from this particular taxiway, then there is a connectivity being provided to this terminal building on which the aircrafts are being, there the aircraft stand is being provided on this side and this side for boarding of the passengers, similarly on this side.

So, whatever the space is being left in the centre, so that this aircraft can come to this direction and move towards the taxiway or from this side, it can come to this direction and can take a position on the stand. This area is taxilane. So, some of the details have also been shown that what is the distances which needs to be provided here.

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This is another close up of the same condition, where we have the taxilanes, two taxilanes being provided with their centrelines like this.

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### Taxilane - Design

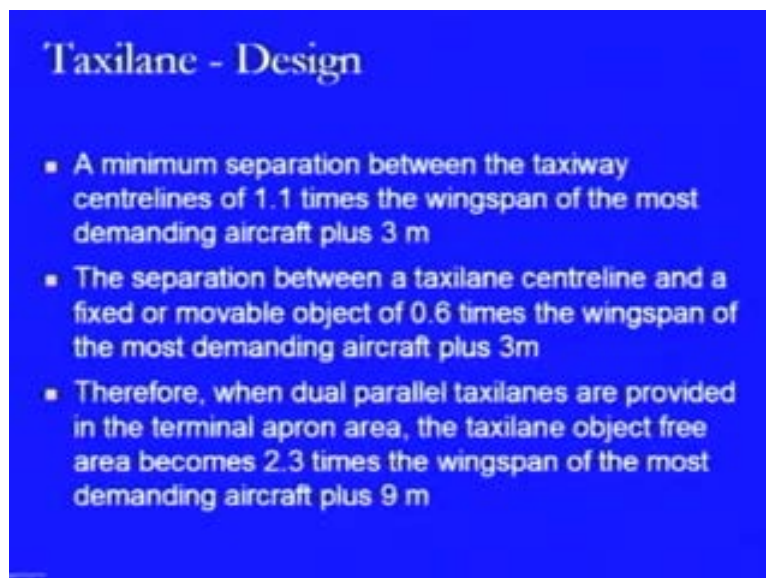
- Minimum taxiway centreline to taxilane centreline separation is provided as 1.2 times the wingspan of the most demanding aircraft plus 3 m
- The separation between a taxilane centreline and a parallel taxilane centreline or a fixed or movable object in the terminal area is predicted on a wing-tip clearance of approximately one-half that required for an apron taxiway. This is based on consideration
  - low taxiing speed in the area
  - taxiing is precise
  - special guidance techniques and devices are provided

So, in this case, we have to design this taxilane. So, what we need to consider is that the minimum taxiway centreline **to centreline** to taxilane centreline separation is provided as 1.2 times the wing span of the most demanding aircraft plus 3 metres. So, that is how we can compute the value between the two centrelines. Then, the separation between the taxilane centreline and the parallel taxilane centreline or a

fixed or movable object in the terminal area is predicted on a wing-tip clearance of approximately one half that required for an apron taxiway.

So, this is another thing which is to be considered and this is, here we have to look at the distance which is being provided in the case of apron taxiway and the clearance which is provided between the taxilane centreline and the fixed or movable object in the terminal area is half of that distance and this value is dependent on the low taxiing speed in the area, the taxiing is precise or not and special guidance techniques and devices which are provided for doing the taxiing.

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**Taxilane - Design**

- A minimum separation between the taxiway centrelines of 1.1 times the wingspan of the most demanding aircraft plus 3 m
- The separation between a taxilane centreline and a fixed or movable object of 0.6 times the wingspan of the most demanding aircraft plus 3m
- Therefore, when dual parallel taxilanes are provided in the terminal apron area, the taxilane object free area becomes 2.3 times the wingspan of the most demanding aircraft plus 9 m

Further, a minimum separation between the taxiway centrelines of 1.1 times the wingspan of the most demanding aircraft plus 3 metres can be provided, though the desirable, as we have seen previously, is 1.2 times the wingspan plus 3 meters. The separation between a taxilane centreline and the fixed or movable object is 0.6 times the wingspan of the most demanding aircraft plus 3 metres. So, everything is going to be governed by the wingspan of the most demanding aircraft or the biggest aircraft which is going to generally utilize that lane or that airport. Therefore, when dual parallel taxilanes are provided in any of the terminal apron area, then the taxilane object free area becomes 2.3 times the wingspan of most demanding aircraft plus 9 metres.

So, that is the overall size of any of the dual parallel taxilanes will become, as shown previously. So, 3 metres ..... 9 metres is taken on the, 3 metres on the two sides plus 3 metres in the centre of the two aircrafts. So, that is the clearance being provided as we have seen previously. So, this how we can design any of the taxilane.

So, in today's lecture what we have seen is that how we can design any of the exit taxilane, so that we can improve upon the airport capacity in terms of reducing the occupancy time of any aircraft on the runway strip and we have also seen the various design factors which creates its influence on finding the value of the occupancy time or as well as finding the distance at which optimally the exit taxiway needs to be located. Along with the taxiway, exit taxiway, we have also seen the design principles and the design parameters and their computation and then, we have also looked at two specific types of conditions which are termed as the taxi turnaround taxiway and taxilane. So, we will be stopping at this point and we will be continuing with our discussions on airport engineering in the coming lectures. Till then, goodbye and thank you to all of you.