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AERODROME DESIGN MANUAL

PART 2. TAXIWAYS, APRONS AND HOLDING BAYS

FOURTH EDITION

AMENDMENT NO. 1

1. To incorporate this amendment, insert the following new and replacement pages in Doc 9157, Part 1, (Fourth Edition):

- | | |
|-----------------------|---------------------|
| a) Pages (v) to (vii) | — Table of Contents |
| b) Pages 1-1 to 1-58 | — Chapter 1 |
| c) Pages 2-1 to 2-8 | — Chapter 2 |
| d) Pages 3-1 to 3-18 | — Chapter 3 |

2. Record the entry of this amendment on page (ii).

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Chapter 1

TAXIWAYS

1.1 TAXIWAY SYSTEMS

Functional requirements

1.1.1 Maximum capacity and efficiency of an aerodrome are realized only by obtaining the proper balance between the need for runways, passenger and cargo terminals, and aircraft storage and servicing areas. These separate and distinct aerodrome functional elements are linked by the taxiway system. The components of the taxiway system therefore serve to link the aerodrome functions and are necessary to develop optimum aerodrome utilization.

1.1.2 The taxiway system should be designed to minimize the restriction of aircraft movement to and from the runways and apron areas. A properly designed system should be capable of maintaining a smooth, continuous flow of aircraft ground traffic at the maximum practical speed with a minimum of acceleration or deceleration. This requirement ensures that the taxiway system will operate at the highest levels of both safety and efficiency.

1.1.3 For any given aerodrome, the taxiway system should be able to accommodate (without significant delay) the demands of aircraft arrivals and departures on the runway system. At low levels of runway utilization the taxiway system can accomplish this with a minimum number of components. However, as the runway acceptance rate increases, the taxiway system capacity must be sufficiently expanded to avoid becoming a factor which limits aerodrome capacity. In the extreme case of runway capacity saturation, when aircraft are arriving and departing at the minimum separation distances, the taxiway system should allow aircraft to exit the runway as soon as practical after landing and to enter the runway just before take-off. This enables aircraft movements on the runway to be maintained at the minimum separation distance.

Planning principles

1.1.4 Runways and taxiways are the least flexible of the aerodrome elements and must therefore be considered first when planning aerodrome development. Forecasts of future activity should identify changes in the rate of aircraft movements, the nature of the traffic, type of aircraft and any other factors affecting the layout and dimensioning of the runway and taxiway systems. Care should be taken not to place so much attention on the present needs of the system that later phases of development that have equal or greater importance are neglected. For example, if an aerodrome is forecast to serve a higher category of aircraft type in the future, the current taxiway system should be designed to accommodate the greatest separation distances that ultimately will be required (see Table 1-1).

1.1.5 In planning the general layout of the taxiway system, the following principles should be considered:

- a) taxiway routes should connect the various aerodrome elements by the shortest distances, thus minimizing both taxiing time and cost;
- b) taxiway routes should be as simple as possible in order to avoid pilot confusion and the need for complicated instructions;

- c) straight runs of pavement should be used wherever possible. Where changes in direction are necessary, curves of adequate radii, as well as fillets or extra taxiway width, should be provided to permit taxiing at the maximum practical speed (see Section 1.4 and Appendix 1);
- d) taxiway crossings of runways and other taxiways should be avoided whenever possible in the interests of safety and to reduce the potential for significant taxiing delays;
- e) taxiway routings should have as many one-way segments as possible to minimize aircraft conflicts and delay. Taxiway segment flows should be analysed for each configuration under which runway(s) will be used;
- f) the taxiway system should be planned to maximize the useful life of each component so that future phases of development incorporate sections from the current system; and
- g) ultimately, a taxiway system will perform only as well as its least adequate component. Therefore, potential bottlenecks should be identified and eliminated in the planning phase.

1.1.6 Other important considerations when planning a taxiway system include the following:

- a) taxiway routes should avoid areas where the public could have easy access to the aircraft. Security of taxiing aircraft from sabotage or armed aggression should be of primary importance in areas where this is of particular concern;
- b) taxiway layouts should be planned to avoid interference with navigation aids by taxiing aircraft or ground vehicles using the taxiway;
- c) all sections of the taxiway system should be visible from the aerodrome control tower. Remote cameras can be used to monitor sections of taxiways shadowed by terminal buildings or other aerodrome structures if such obstructions cannot be practically avoided;
- d) the effects of jet blast on areas adjacent to the taxiways should be mitigated by stabilizing loose soils and erecting blast fences where necessary to protect people or structures (see Appendix 2); and
- e) the location of taxiways may also be influenced by ILS installations due to interferences to ILS signals by a taxiing or stopped aircraft. Information on critical and sensitive areas surrounding ILS installations is contained in Annex 10, Volume I, Attachment C.

1.1.7 There should be a sufficient number of entrance and exit taxiways serving a specific runway to accommodate the current demand peaks for take-offs and landings. Additional entrances and exits should be designed and developed ahead of expected growth in runway utilization. The following principles apply to the planning of these taxiway system components:

- a) the function of exit taxiways is to minimize the runway occupancy time of landing aircraft. In theory, exit taxiways can be located to best serve each type of aircraft expected to use the runway. In practice, the optimum number and spacing are determined by grouping the aircraft into a limited number of classes based upon landing speed and deceleration after touchdown;
- b) the exit taxiway should allow an aircraft to move off the runway without restriction to a point clear of the runway, thus allowing another operation to take place on the runway as soon as possible;

Table 1-1. Design criteria for a taxiway

Physical characteristics	Code letter					
	A	B	C	D	E	F
Minimum width of:						
taxiway pavement	7.5 m	10.5 m	18 m ^a 15 m ^b	23 m ^c 18 m ^d	23 m	25 m
taxiway pavement and shoulder	—	—	25 m	38 m	44 m	60 m
taxiway strip	31 m	40 m	52 m	74 m	87 m	102 m
graded portion of taxiway strip	22 m	25 m	25 m	38 m	44 m	60 m
Minimum clearance distance of outer main wheel to taxiway edge	1.5 m	2.25 m	4.5 m ^a 3 m ^b	4.5 m	4.5 m	4.5 m
Minimum separation distance between taxiway centre line and: centre line of instrument runway code						
number 1	82.5 m	87 m	—	—	—	—
number 2	82.5 m	87 m	—	—	—	—
number 3	—	—	168 m	176 m	—	—
number 4	—	—	—	176 m	182.5 m	190 m
centre line of non-instrument runway code						
number 1	37.5 m	42 m	—	—	—	—
number 2	47.5 m	52 m	—	—	—	—
number 3	—	—	93 m	101 m	—	—
number 4	—	—	—	101 m	107.5 m	115 m
taxiway centre line object	23 m	32 m	44 m	63 m	76 m	91 m
taxiway ^e	15.5 m	20 m	26 m	37 m	43.5 m	51 m
aircraft stand taxilane	12 m	16.5 m	22.5 m	33.5 m	40 m	47.5 m
Maximum longitudinal slope of taxiway:						
pavement	3%	3%	1.5%	1.5%	1.5%	1.5%
change in slope	1% per 25 m	1% per 25 m	1% per 30 m	1% per 30 m	1% per 30 m	1% per 30 m
Maximum transverse slope of:						
taxiway pavement	2%	2%	1.5%	1.5%	1.5%	1.5%
graded portion of taxiway strip upwards	3%	3%	2.5%	2.5%	2.5%	2.5%
graded portion of taxiway strip downwards	5%	5%	5%	5%	5%	5%
ungraded portion of strip upwards or downwards	5%	5%	5%	5%	5%	5%
Minimum radius of longitudinal vertical curve	2 500 m	2 500 m	3 000 m	3 000 m	3 000 m	3 000 m
Minimum taxiway sight distance	150 m from 1.5 m above	200 m from 2 m above	300 m from 3 m above	300 m from 3 m above	300 m from 3 m above	300 m from 3 m above

- Taxiway intended to be used by aeroplanes with a wheel base equal to or greater than 18 m.
- Taxiway intended to be used by aeroplanes with a wheel base less than 18 m.
- Taxiway intended to be used by aeroplanes with an outer main gear wheel span equal to or greater than 9 m.
- Taxiway intended to be used by aeroplanes with an outer main gear wheel span less than 9 m.
- Taxiway other than an aircraft stand taxilane.

- c) an exit taxiway can be either at a right angle to the runway or at an acute angle. The former type requires an aircraft to decelerate to a very low speed before turning off the runway, whereas the latter type allows aircraft to exit the runway at higher speeds, thus reducing the time required on the runway and increasing the runway capacity (details about the location and geometry of the acute angle type [called rapid exit taxiway] are presented in Section 1.3 and Appendix 5); and
- d) a single runway entrance at each end of the runway is generally sufficient to accommodate the demand for take-offs. However if the traffic volume warrants, the use of bypasses, holding bays or multiple runway entrances can be considered (see Chapter 2).

1.1.8 Taxiways located on aprons are divided into two types as follows (see Figure 1-1):

- a) apron taxiway is a taxiway located on an apron and intended either to provide a through taxi route across the apron or to gain access to an aircraft stand taxilane; and
- b) aircraft stand taxilane is a portion of an apron designated as a taxiway and intended to provide access to aircraft stands only.

1.1.9 The requirements for apron taxiways regarding strip width, separation distances, etc., are the same as for any other type of taxiway. The requirements for aircraft stand taxilanes are also the same except for the following modifications:

- a) the transverse slope of the taxilane is governed by the apron slope requirement;
- b) the aircraft stand taxilane does not need to be included in a taxiway strip; and
- c) the requirements for the separation distances from the centre line of the taxilane to an object are less stringent than those for other types of taxiways.

1.1.10 Aircraft stand lead-in lines, which branch off to the parking positions, are not considered to be a part of the aircraft stand taxilane and, therefore, are not subject to the requirements for taxiways.

1.1.11 Figure 1-2 provides a reference to the minimum separate distances as provided in Table 3-1 of Annex 14, Volume I, for each of the taxiways and taxilanes mentioned in Figure 1-1.

Stages in taxiway system development

1.1.12 To minimize current construction costs, an aerodrome's taxiway system should be only as complex as needed to support the near-term capacity needs of the runway. With careful planning, additional taxiway components can be added to the system in stages to keep pace with the growth in aerodrome demand. Different stages in taxiway system development are described in the following paragraphs (see Figure 1-3):

- a) a minimum aerodrome taxiway system, supporting a low level of runway utilization, can consist of only turnaround pads or taxiway turnarounds at both ends of the runway and a stub taxiway from the runway to the apron;
- b) traffic growth which results in a low to moderate level of runway utilization may be accommodated by building a partial parallel taxiway to connect one or both turnarounds (parallel taxiways provide safety benefits as well as greater efficiency);
- c) as runway utilization increases, a full parallel taxiway can be provided by completing the missing sections of the partial parallel taxiway;

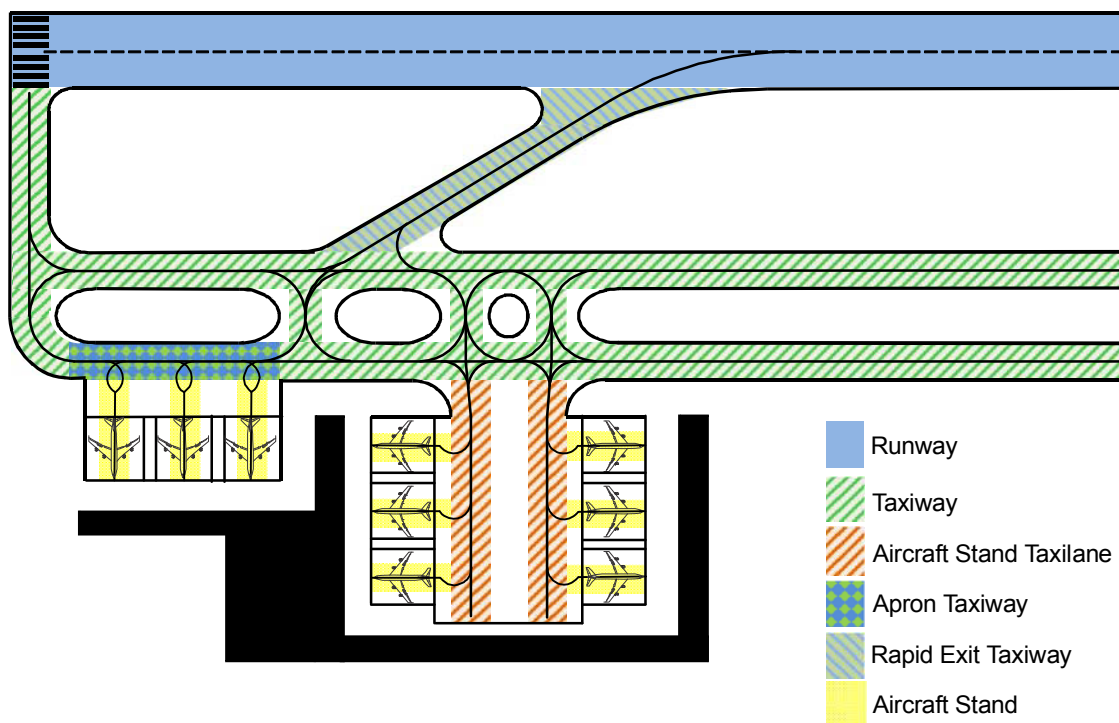


Figure 1-1. Taxiways on aprons

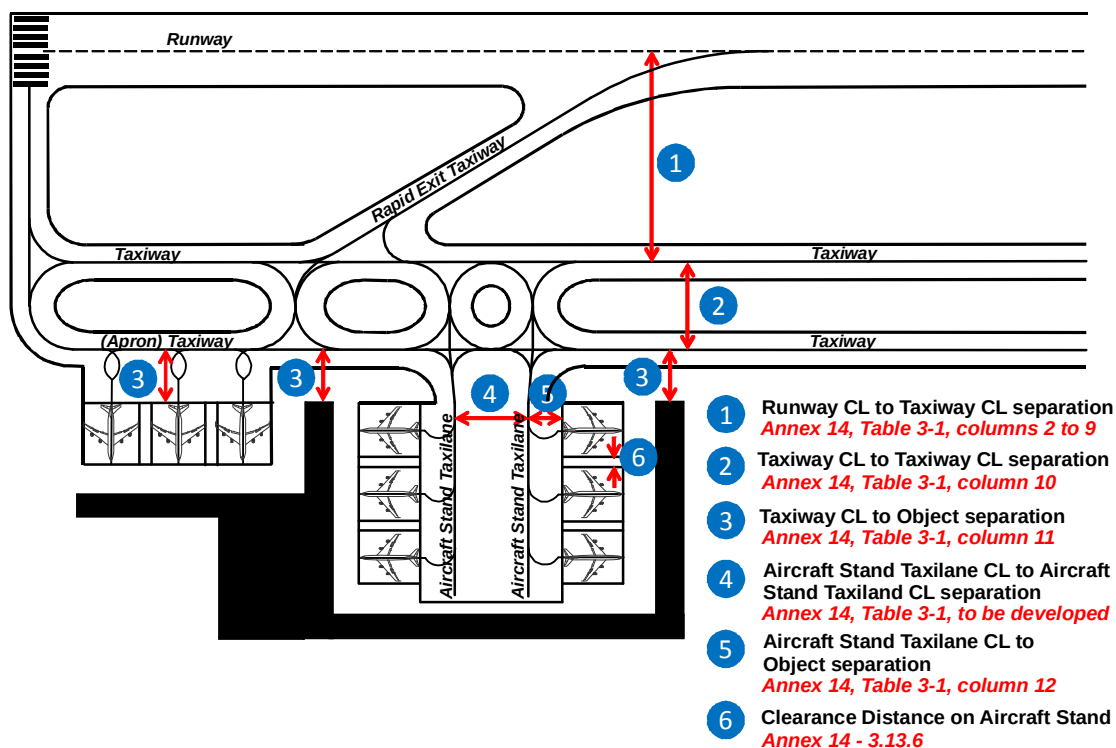


Figure 1-2. Taxiway minimum separation distances

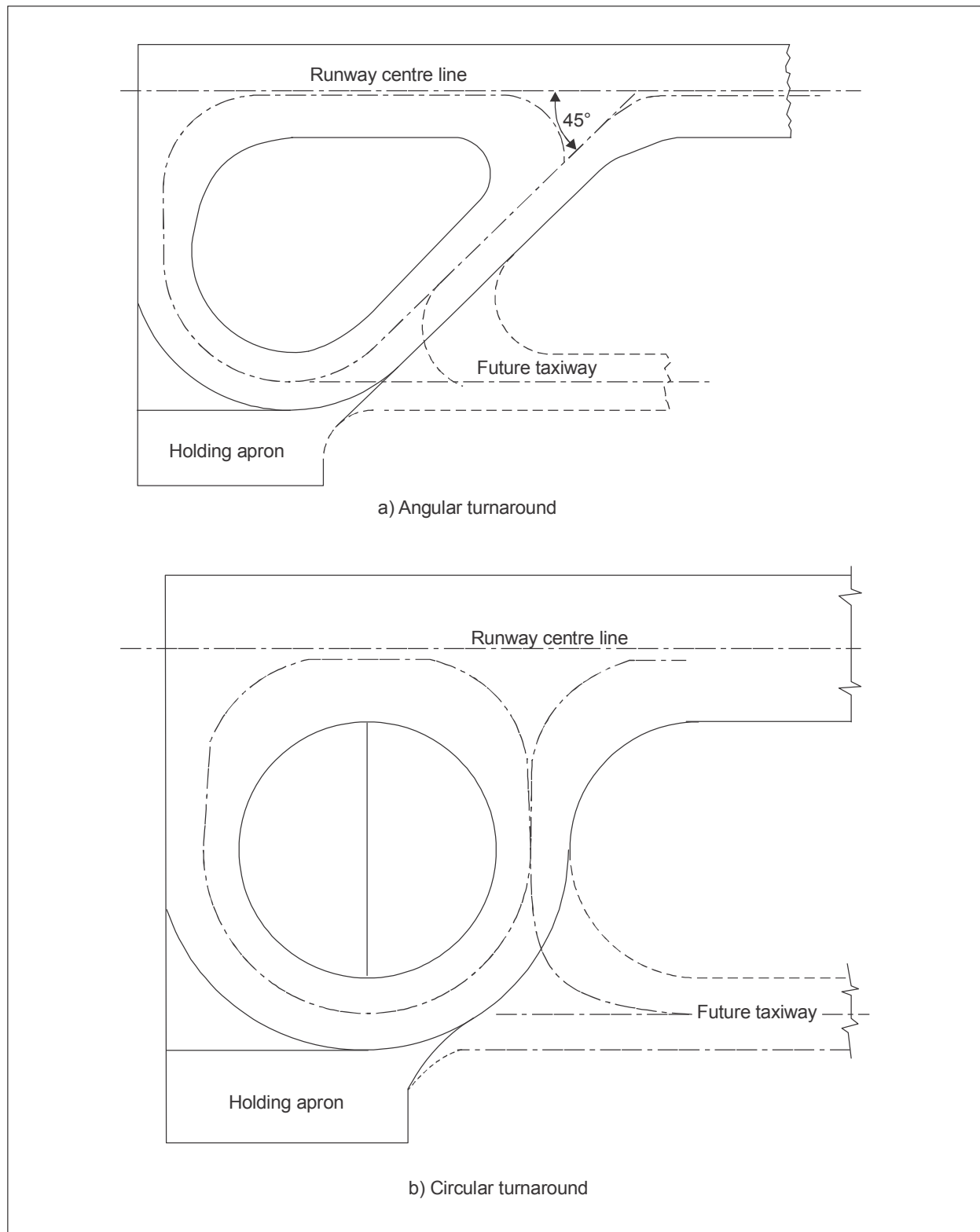


Figure 1-3. Turnarounds

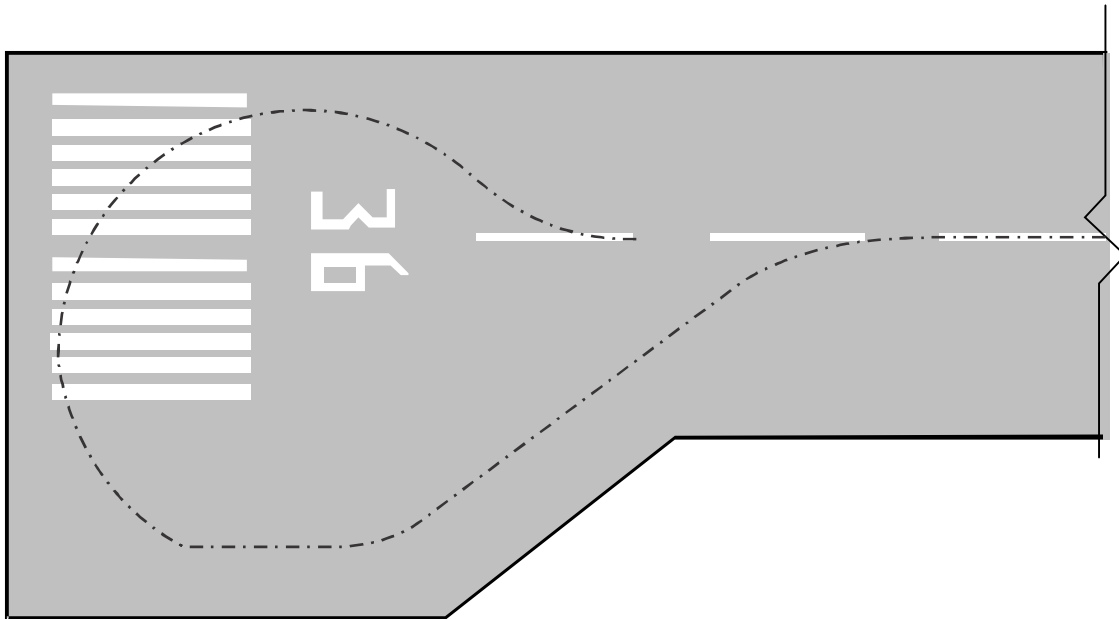


Figure 1-3. (cont)

- d) exit taxiways, in addition to the ones at each runway end, can be constructed as runway utilization increases toward saturation;
- e) holding bays and bypass taxiways can be added to further enhance runway capacity. These facilities seldom restrict the attainment of full aerodrome capacity within the existing aerodrome property because land is usually available to permit their construction; and
- f) a dual-parallel taxiway, located outboard of the first parallel taxiway, should be considered when movement in both directions along the taxiway is desirable. With this second taxiway, a one-way flow network can be established for each direction of runway use. The need for the dual-parallel system increases in proportion to the amount of development alongside the taxiway.

For additional information, see the *Airport Planning Manual* (Doc 9184), Part 1 — *Master Planning*.

Evaluating taxiway layout alternatives

1.1.13 An evaluation of alternative taxiway systems must take into account the operating efficiency of each system in combination with the runway and apron layouts it is designed to serve. The greater the complexity of the runway, taxiway and apron layouts, the greater the possibility for reducing operating costs through a comparison of alternative taxiway systems. Several computerized aircraft traffic flow simulation models have been developed for this purpose by consultants, aircraft operators and airport authorities.

1.1.14 For example, the United States Federal Aviation Administration has the Airfield Delay Model which simulates all significant aircraft movements performed on an aerodrome and its runway approach paths during an extended period of time. Such models are able to consider a variety of input variables such as:

- aircraft mix;
- traffic volume;
- traffic peaking;
- aerodrome layouts (taxiway and runway);
- terminal destinations of aircraft;
- runway configurations;
- taxiway configurations;
- rapid exit taxiways; and
- use of particular runways by categories of aircraft.

From these inputs, these models produce outputs for evaluation and comparison which include:

- taxiing fuel costs;
- taxiing distances;
- taxiing travel times;
- taxiing delays; and
- runway arrival and departure delays.

Aircraft taxi distances

1.1.15 The main reason to minimize aircraft taxi distances is to reduce taxi time and thus save fuel and enhance aircraft utilization and safety. Of particular importance are the taxi distances for the heavily loaded aircraft taxiing for take-off. Even small airports should have layouts which recognize this need.

1.1.16 At larger airports the issue of aircraft safety has greater significance. Detailed investigations have shown that when a fully laden aircraft is taxied over a distance varying from 3 to 7 km (depending upon the aircraft type, its tire size and type, and the ambient temperature), the tire carcass temperature during take-off can exceed a critical value of 120°C (250°F). Exceeding this critical temperature affects the nylon cord strength and rubber adhesion of the tire and significantly increases the risk of tire failure. The 120°C limit used in the industry applies to taxiing for take-off as well as the take-off run. At 120°C the nylon tensile strength is reduced by 30 per cent. Higher temperatures cause permanent deterioration of rubber adhesive properties. Tire failures during take-off are serious because they can result in an aborted take-off with braking being ineffective on those wheels having blown tires.

1.1.17 Taxi distances should therefore be kept to the minimum practicable. In the case of large wide-bodied aircraft, a distance of 5 km is considered to be the acceptable upper limit, and where unfavourable factors exist, such as those which require frequent use of brakes, this limit may have to be reduced.

1.1.18 Every airport master plan, irrespective of the size of the airport development, should recognize the need to minimize taxi distances, especially for departing aircraft, for both economy and safety. The suitable location of rapid exit taxiways can do much to reduce taxi distances for landing aircraft. Further, take-offs from taxiway intersections and the use of rapid exit taxiways not only reduce taxi distances and runway occupancy time but also increase runway capacity.

1.2 PHYSICAL CHARACTERISTICS DESIGN CRITERIA

General

1.2.1 Design criteria for taxiways are less stringent than those for runways since aircraft speeds on taxiways are much slower than those on runways. Table 1-1 shows the main physical characteristics design criteria recommended for a taxiway in accordance with the specifications in Annex 14, Volume I. It should be emphasized that with respect to the clearance distance between the outer main wheel of the aircraft and the edge of the taxiway, it is assumed that the cockpit of the aircraft remains over the taxiway centre line markings.

Aerodrome reference code

1.2.2 The reference code is intended to provide a simple method for interrelating the numerous specifications concerning the characteristics of aerodromes to ensure that the aerodrome facilities are suitable for the aeroplanes that are intended to operate at the aerodrome. The code is composed of two elements which are related to the aeroplane performance characteristics and dimensions. Element 1 is a number based on the aeroplane reference field length, and Element 2 is a letter based on the aeroplane wing span and outer main gear wheel span (OMGWS).

1.2.3 A particular specification is related to the more appropriate of the two elements of the code or to an appropriate combination of the two code elements. The code letter or number within an element selected for design purposes is related to the critical aeroplane characteristics for which the facility is provided. When applying the relevant specifications in Annex 14, Volume I, the aeroplanes which the aerodrome is intended to serve are identified first followed by the two elements of the code.

1.2.4 An aerodrome reference code — a code number and a letter — selected for aerodrome planning purposes shall be determined in accordance with the characteristics of the aeroplane for which an aerodrome facility is intended. Further, the aerodrome reference code numbers and letters shall have the meanings assigned to them in Table 1-2. A classification of representative aeroplanes by code number and code letter is included in Appendix 3.

1.2.5 The code number for Element 1 shall be determined from Table 1-2, selecting the code number corresponding to the highest value of the aeroplane reference field lengths of the aeroplanes for which the runway is intended. The aeroplane reference field length is defined as the minimum field length required for take-off at maximum certificated take-off mass, sea level, standard atmospheric conditions, still air and zero runway slope, as shown in the appropriate aeroplane flight manual prescribed by the certifying authority or equivalent data from the aeroplane manufacturer. Accordingly, if 1 650 m corresponds to the highest value of the aeroplane reference field lengths, the code number selected would be “3”.

1.2.6 The code letter for Element 2 shall be determined from Table 1-2, selecting the code letter which corresponds to the greatest wing span, or the greatest OMGWS, whichever gives the more demanding code letter, of the aeroplanes for which the facility is intended. For instance, if code letter C corresponds to the aeroplane with the greatest wing span and code letter D corresponds to the aeroplane with the greatest OMGWS, the code letter selected would be “D”.

Table 1-2. Aerodrome reference code

Code element 1		Code element 2		
Code number	Aeroplane reference field length	Code letter	Wing span	Outer main gear wheel span ^a
1	Less than 800 m	A	Up to but not including 15 m	Up to but not including 4.5 m
2	800 m up to but not including 1 200 m	B	15 m up to but not including 24 m	4.5 m up to but not including 6 m
3	1 200 m up to but not including 1 800 m	C	24 m up to but not including 36 m	6 m up to but not including 9 m
4	1 800 m and over	D	36 m up to but not including 52 m	9 m up to but not including 14 m
		E	52 m up to but not including 65 m	9 m up to but not including 14 m
		F	65 m up to but not including 80 m	14 m up to but not including 16 m

a. Distance between the outside edges of the main gear wheels.

Table 1-3. Aircraft speeds versus radius of curve

Speed (km/h)	Radius of curve (m)
16	15
32	60
48	135
64	240
80	375
96	540

Taxiway width

1.2.7 Minimum taxiway widths are shown in Table 1-1. The values selected for the minimum taxiway widths are based on adding clearance distance from wheel to pavement edge to the maximum OMGWS within its category.

Taxiway curves

1.2.8 Changes in direction of taxiways should be as few and small as possible. The design of the curve should be such that when the cockpit of the aeroplane remains over the taxiway centre line markings, the clearance distance between the outer main wheels of the aeroplane and the edge of the taxiway should not be less than those specified in Table 1-1.

1.2.9 If curves are unavoidable, the radii should be compatible with the manoeuvring capability and normal taxiing speeds of the aircraft for which the taxiway is intended. Table 1-3 shows values of allowable aircraft speeds for given radii of curvature based on a lateral load factor of 0.133 g (see 1.2.22). Where sharp curves are planned and their radii will not suffice to prevent wheels of taxiing aircraft from leaving the pavement, it may be necessary to widen the taxiway so as to achieve the wheel clearance specified in Table 1-1. It is to be noted that compound curves may reduce or eliminate the need for extra taxiway width.

Junctions and intersections

1.2.10 To ensure that the minimum wheel clearance distances specified in Table 1-1 are maintained, fillets should be provided at junctions and intersections of taxiways with runways, aprons and other taxiways. Information on the design of fillets is given in 1.5.

Taxiway minimum separation distances

General

1.2.11 The separation distance between the centre line of a taxiway and the centre line of a runway, another taxiway or an object should not be less than the appropriate dimension specified in Table 1-1. It may, however, be permissible to operate with lower separation distances at an existing aerodrome if an aeronautical study indicates that such lower separation distances would not adversely affect the safety or significantly affect the regularity of operations of aeroplanes. Guidance on factors which may be considered in the aeronautical study is given in 1.2.28 through 1.2.66.

1.2.12 The distances are based on the maximum wing span of a group and on the deviation of one aircraft from the taxiway centre line a distance equal to the wheel-to-edge clearance and the increment (Z) for that group. It should be noted that, even in instances where a particular aircraft design (as a result of an unusual combination of large wing span and narrow gear span) might result in the wing tip extending farther from the centre line distance, the resulting clearance distance would still be considerably more than that required for aircraft to pass.

Separation distances between taxiways, and between taxiways and objects

1.2.13 Formulas and separation distances are shown in Table 1-4 and illustrated in Figure 1-4. The separation distances related to taxiways and apron taxiways are based on the aircraft wing span (Y) and the maximum lateral deviation (X) (the wheel-to-edge clearance specified in Table 1-1).

Table 1-4. Minimum separation distances between taxiways and between taxiways and objects (dimensions in metres)

Separation distances	Code letter					
	A	B	C	D	E	F
Between apron taxiway/taxiway centre line and apron taxiway/taxiway centre line:						
wing span (Y)	15.0	24.0	36.0	52.0	65.0	80.0
+ maximum lateral deviation (X)	1.5	2.25	3.0	4.5	4.5	4.5
+ increment (Z)	6.5	5.75	5.0	6.5	6.5	6.5
Total separation distance (V)	23.0	32.0	44.0	63.0	76.0	91.0
Between apron taxiway/taxiway centre line and object:						
½ wing span (Y)	7.5	12.0	18.0	26.0	32.5	40.0
+ maximum lateral deviation (X)	1.5	2.25	3.0	4.5	4.5	4.5
+ increment (Z)	6.5	5.75	5.0	6.5	6.5	6.5
Total separation distance (V)	15.5	20.0	26.0	37.0	43.5	51.0
Between aircraft stand taxilane centre line and aircraft stand taxilane centre line						
wing span (Y)	15.0	24.0	36.0	52.0	65.0	80.0
+ gear deviation	1.5	1.5	1.5	2.5	2.5	2.5
+ increment (Z)	3.0	3.0	3.0	5.0	5.0	5.0
Total separation distance (V)	19.5	28.5	40.5	59.5	72.5	87.5
Between aircraft stand taxilane centre line and object:						
½ wing span (Y)	7.5	12.0	18.0	26.0	32.5	40.0
+ gear deviation	1.5	1.5	1.5	2.5	2.5	2.5
+ increment (Z)	3.0	3.0	3.0	5.0	5.0	5.0
Total separation distance (V)	12.0	16.5	22.5	33.5	40.0	47.5

1.2.14 Lesser distances on aircraft stand taxilanes are considered appropriate because taxiing speeds are normally lower when taxiing on these taxiways, and the increased attention of pilots results in less deviation from the centre line. Accordingly, instead of assuming an aircraft is off the centre line as far as the maximum lateral deviation (X) would allow, a lesser distance is assumed which is referred to as “gear deviation”.

1.2.15 It may be noted that two factors have been used in the development of the formulas: the maximum lateral deviation/gear deviation and the wing tip clearance increment. These factors have different functions. The deviation factor represents a distance that aircraft might travel in normal operation. On the other hand, the increment (Z in Figure 1-4) is a safety buffer intended to avoid accidents when aircraft go beyond the taxiway, to facilitate taxiing by providing extra space, and to account for other factors influencing taxiing speeds.

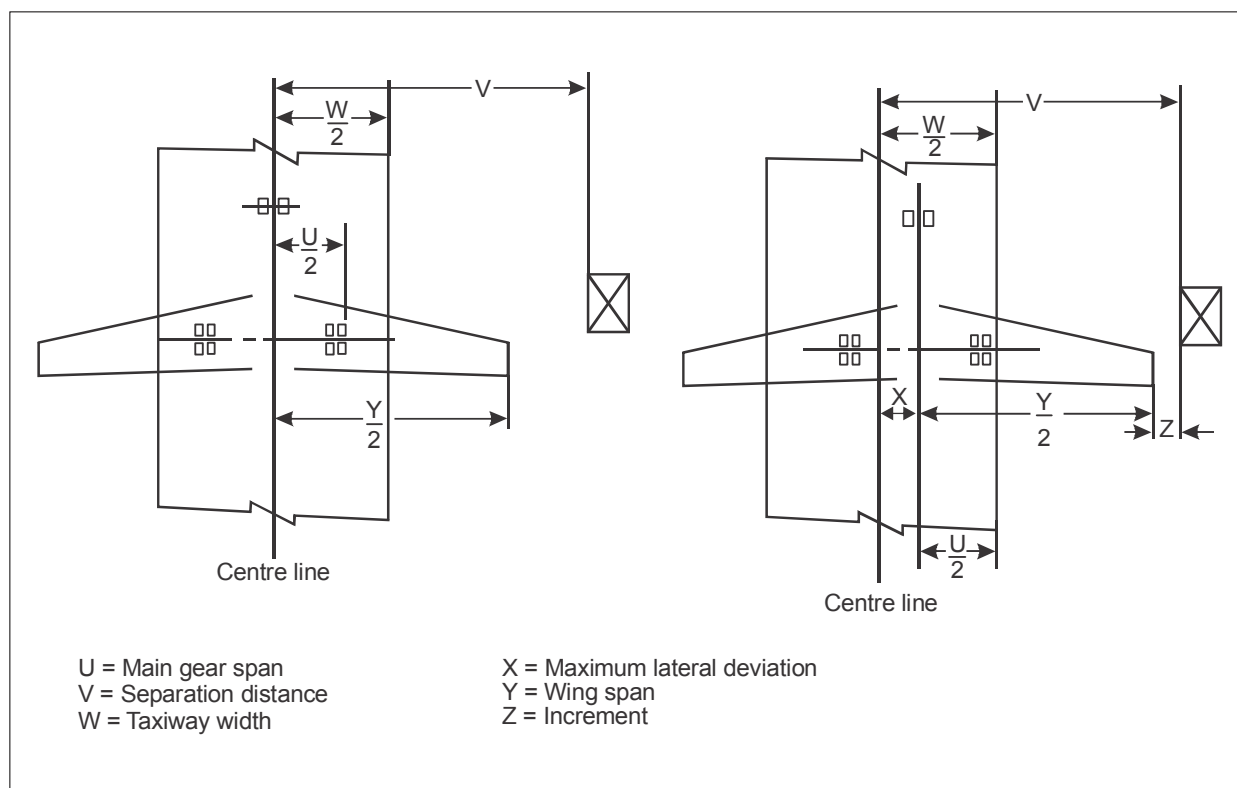


Figure 1-4. Separation distance to an object

1.2.16 A graduated increment scale rather than a constant increment for all code letters has been selected because:

- pilot judgement of clearance distance is more difficult in aircraft with larger wing spans, particularly when the aircraft has swept wings; and
- the momentum of larger aircraft may be higher and could result in such aircraft running farther off the edge of a taxiway.

1.2.17 The increments for the determination of the separation distances between an apron taxiway and an object are the same as those proposed between a taxiway and an object, the reason being that although apron taxiways are associated with aprons, it is thought that their location should not imply a reduction in taxiing speed. Aircraft will normally be moving at slow speeds on an aircraft stand taxilane and can therefore be expected to remain close to the centre line. A deviation of 1.5 m has been selected for code letters A to C. A deviation of 2.5 m has been adopted for code letters D to F. The use of a graduated scale for lateral deviation in a stand taxilane is considered appropriate since the ability of a pilot to follow the centre line is decreased in larger aircraft because of the cockpit height.

1.2.18 Larger increments have been selected for the separation distances between taxiway/object and apron taxiway/object than for other separation distances. These larger increments are considered necessary because normally objects along such taxiways are fixed objects, thus making the probability of a collision with one of them greater than that of one aircraft running off the taxiway just as another aircraft is passing that point on the parallel taxiway. Also, the fixed object may be a fence or wall which runs parallel to the taxiway for some distance. Even in the case of a road running parallel to a taxiway, vehicles may unknowingly reduce the clearance distance by parking off the road.

Separation distances between taxiways and runways

1.2.19 The separation distances are based on the concept of the wing of an aircraft centred on a parallel taxiway remaining clear of the associated runway strip. The formulas and separation distances are shown in Table 1-5. The separation distance between the centre lines of a runway and a parallel taxiway is based on the accepted principle that the wing tip of an aeroplane taxiing on the parallel taxiway should not penetrate the associated runway strip. However this minimum separation distance may not provide adequate length for the link taxiway connecting the parallel taxiway and the runway to permit safe taxiing of another aircraft behind an aircraft holding short of the runway at the holding position. To permit such operations, the parallel taxiway should be so located as to comply with the requirements of Annex 14, Volume I, Tables 3-1 and 3-2, considering the dimensions of the most demanding aeroplane in a given aerodrome code. For example, at a code E aerodrome, this separation would be equal to the sum of the distance of the runway holding position from the runway centre line, plus the overall length of the most demanding aeroplane, and the taxiway-to-object distance specified in column E of Table 1-1.

Table 1-5. Minimum separation distances between taxiway/apron taxiway centre line and runway centre line (dimensions in metres)

Code number	1		2		3				4			
Code letter	A	B	A	B	A	B	C	D	C	D	E	F
$\frac{1}{2}$ wing span (Y)	7.5	12	7.5	12	7.5	12	18	26	18	26	32.5	40
+ $\frac{1}{2}$ strip width												
(non-instrument approach runway)	30	30	40	40	75	75	75	75	75	75	75	75
Total	37.5	42	47.5	52	82.5	87	93	101	93	101	107.5	115
or												
$\frac{1}{2}$ wing span (Y)	7.5	12	7.5	12	7.5	12	18	26	18	26	32.5	40
+ $\frac{1}{2}$ strip width												
(instrument approach runway)	75	75	75	75	150	150	150	150	150	150	150	150
Total	82.5	87	82.5	87	157.5	162	168	176	168	176	182.5	190

Parallel taxiway geometry

1.2.20 The separation distances between parallel taxiways shown in Table 1-1 have been selected on the basis of desired wing tip clearances. There are other factors which should also be taken into account when evaluating the capability of making a normal 180-degree turn from one taxiway to another parallel taxiway. These include:

- maintaining a reasonable taxi speed to achieve high taxiway system utilization;
- maintaining specified clearance distances between the outer main wheel and the taxiway edge when the cockpit remains over the taxiway centre marking; and
- manoeuvring at a steering angle that is within the capability of the aircraft and which will not subject the tires to unacceptable wear.

1.2.21 To evaluate the taxi speed when making the 180-degree turn, it is assumed that the radii of curvature are equal to one-half of the separation distance indicated in Table 1-1, and as shown below:

Code letter	Radius (m)
A	11.5
B	16.0
C	22.0
D	31.5
E	38.0
F	45.5

1.2.22 The velocity in the turn is a function of the radius of the curve (R) and the lateral load factor (f). Thus, if it is assumed that the lateral load factor is limited to 0.133 g:

$$\begin{aligned} V &= (127.133 \times (f) \times R)^{1/2} \\ &= (127.133 \times 0.133 R)^{1/2} \\ &= 4.1120(R^{1/2}), \end{aligned}$$

where R is in metres.

The resulting allowable velocities are shown in Table 1-6.

1.2.23 Examination of Table 1-6 shows that a velocity of 25.35 km/h is achieved for code letter E. In the case of code letter F, the velocity would be 27.73 km/h. To achieve the same speed on taxiways associated with the other code letters, a separation distance of 80 m would be required. The separation distances for code letters A and B, however, may be unreasonably large when compared with those required by the desired wing tip clearance. In this connection, experience shows that small aircraft require a slower speed than larger aircraft because of their sensitivity to nose gear swivelling.

1.2.24 To evaluate the factors mentioned in 1.2.20 b) and c), a computer programme was developed by an aircraft manufacturer to show the motion of an aircraft during a 180-degree turn. A representative aircraft from each code letter was used (see Table 1-7). These aircraft were chosen for illustrative purposes because they have the greatest distance between the main gear and the cockpit of the aircraft within each code. The radius of the curve for each case is based on one-half of the minimum separation distance. The OMGWS is assumed to be the maximum allowed for the code letter, while the table shows the actual aircraft dimension for the distance between the main gear and the cockpit.

1.2.25 The ability to make a smooth turn depends, in part, on the allowable steering angle. Table 1-8 provides data for the representative aircraft. (The data shown in the last column are based on the data of Table 1-7 and assume 3-degree nose tire slip for Lear 55, F28 and MD80, and 5-degree nose tire slip for MD11 and B747.) The study revealed that the maximum angle required during the turn is within the limits given in Table 1-8 for all aircraft.

1.2.26 The solution for a 180-degree turn, which was arrived at by use of a computer programme, can also be determined by graphical means. The procedure requires a step-by-step movement of the cockpit along the centre line of the curve. The main gear is assumed to travel along a line that is formed by the original position of the mid-point between the main gear and the new position of the cockpit. This is illustrated in Figure 1-5.

1.2.27 It is significant to note that the computer programme results were based on increments of movement of 0.5 degrees. This is much too tedious for a graphical solution, and a comparison was made of the computer programme solution with a graphical solution in which the increments were 10 degrees. It was concluded that an error of approximately 2.4 m is introduced by the coarser increments of the graphical method. Increments of 5 degrees will reduce the error to approximately 1.5 m.

Table 1-6. Allowable velocities in a 180-degree turn

Code letter	Radius (m)	Velocity $V = 4.1120 (R^{1/2})$ (km/h)
A	11.5	13.94
B	16.0	16.45
C	22.0	19.29
D	31.5	23.08
E	38.0	25.35
F	45.5	27.73

Table 1-7. Assumed data for calculation of 180-degree turn

Code letter	Aircraft model	OMGWS (m)	Main gear to cockpit (m)	Radius of curvature (m)
A	Lear 55	4.5	5.7	11.5
B	F28	6.0	11.9	16.0
C	MD80	9.0	20.3	22.0
D	MD11	14.0	31.0	31.5
E	A340-600	14.0	37.4	38.0
E	B747	14.0	27.8	38.0
E	B777-300	14.0	34.2	38.0
F	A380	16.0	31.9	45.5

Table 1-8. Aircraft steering angles

Aircraft model	Maximum steering angle	Approx. maximum steering angle during 180-degree turn
Lear 55	55°	40°
F28	76°	45°
MD80	82°	65°
MD11	70°	70°
A340-600	75°	70°
B747	70°	50°
B777-300	70°	65°
A380	70°	45°

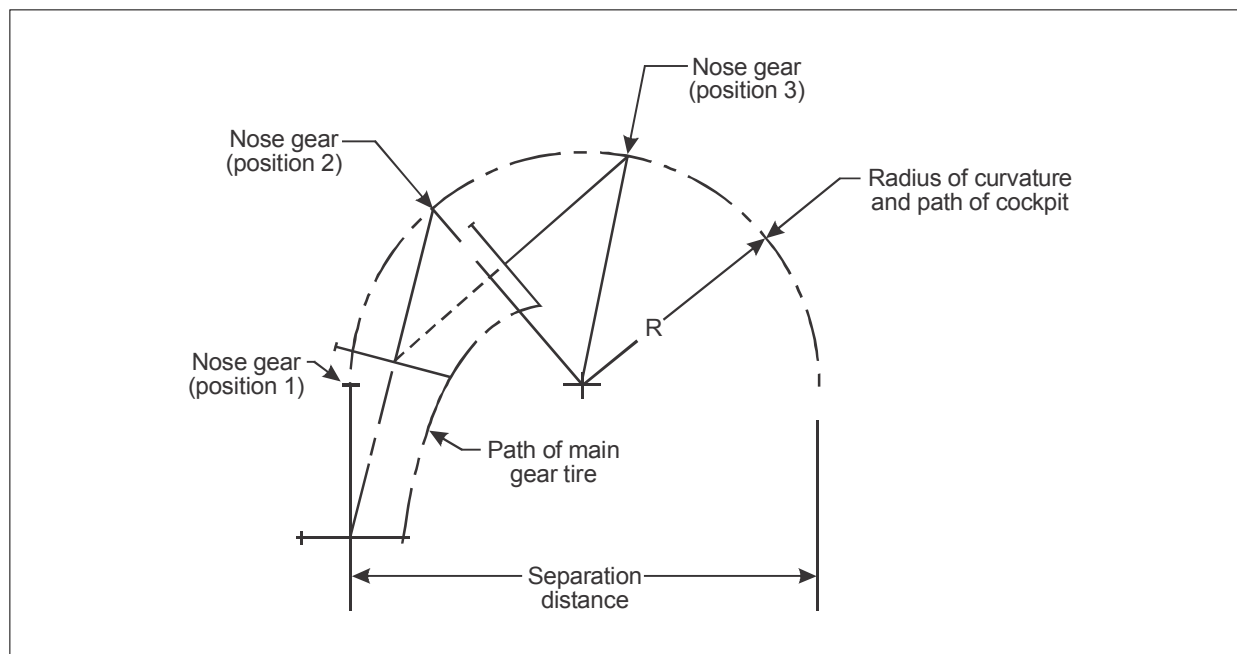


Figure 1-5. Graphical solution of a 180-degree turn

Aeronautical study relating to minimum separation distances

Introduction

1.2.28 The aim of the specifications in Annex 14, Volume I, is to give aerodrome planners a tool to design efficient aerodromes for safe aircraft operations. It is not intended, however, that the Annex be used to regulate aircraft operations. It may be permissible to operate at existing aerodromes with lower taxiway separation distances than those specified in the Annex if an aeronautical study indicates that such lower separation distances would not adversely affect the safety or significantly affect the regularity of operations of aircraft. The purpose of this material is to assist States in undertaking an aeronautical study by defining the criteria considered pertinent for the assessment of whether lesser dimensions than those specified in Annex 14, Volume I, Table 3-1 (reproduced in Table 1-1) are adequate for the operation of new larger aeroplanes in the specific operational environment at an existing aerodrome. This may also result in operational restrictions or limitations. Where alternative measures, operational procedures and operating restrictions have been developed, their details are reproduced in the aerodrome manual and reviewed periodically to assess their continued validity. It is expected that infrastructure on an existing aerodrome or a new aerodrome will fully comply with Annex 14, Volume I, specifications at the earliest opportunity. Further guidance to assess the compatibility of the operation of a new aeroplane with an existing aerodrome can be found in the *Procedures for Air Navigation Services (PANS) — Aerodromes* (Doc 9981).

Objectives and scope

1.2.29 The prime objective of an aeronautical study is to assess the adequacy of the protection provided by the existing layout for the operation of the critical aircraft with respect to:

- a) collision with another aircraft, vehicle or object;
- b) run-off from paved surfaces; and
- c) engine damage from ingestion.

1.2.30 The areas of concern which this assessment will address relate to specific functional requirements in terms of:

- a) distance between centre line of runway and centre line of taxiway;
- b) distance between centre line of taxiway and centre line of parallel taxiway;
- c) distance between centre line of taxiway and object;
- d) distance between centre line of aircraft stand taxilane and object;
- e) runway and taxiway dimensions, surface and shoulders; and
- f) protection of engines against damage from foreign objects.

It should be noted that every operational factor listed above need not be considered in all instances. Therefore, the appropriate authority should determine which factors are relevant to a risk analysis for a specific site. Additionally, the appropriate authority should define the parameters for each of the operational factors selected and assign a hierarchy of values to each of them, based upon subjective operational and engineering judgements.

Basic considerations

1.2.31 Operational experience with large aircraft at aerodromes not designed to the specifications dictated by that aircraft type has shown that a safe and regular operation is feasible, though subject to specific measures being implemented (the use of selected taxi routings, designated aircraft stand taxilanes, etc.). This may be due to the fact that a variety of adverse factors do not necessarily affect the operational environment at a certain aerodrome. Furthermore, analyses of accidents and incidents do not indicate that they are caused by inadequate margins that do not meet the specifications in Annex 14, Volume I. It may thus be assumed that the above considerations similarly apply to the operation of new larger aeroplanes, subject to the conditions resulting from the aeronautical study.

Assessment aspects

1.2.32 An aeronautical study will consist essentially of a risk analysis based on pertinent criteria to assess:

- a) probability of collision;
- b) probability of run-off; and
- c) risk of engine ingestion.

The majority of criteria being qualitative in nature, the assessment of risk levels cannot be expressed in absolute or quantitative terms. For the outcome of the study to be meaningful, it should be complemented by operational and engineering judgements. This suggests that the appropriate authority should consult with the aircraft operator when carrying out the assessment.

1.2.33 Referring to collision risk assessment, which addresses the separation/clearance distances provided, the relative risk level on the movement area (expressed in terms of probability of a collision to occur) is generally considered to increase in the following order of priority:

runway → taxiway → apron taxiway → aircraft stand taxilane

The increase in risk is attributed to:

- a) decreasing accounting for aircraft deviations from the centre line/guideline and associated incremental margins;
- b) increasing density of vehicles and objects; and
- c) increasing complexity of layouts giving rise to pilot distraction, confusion, misinterpretation, etc.

1.2.34 A crucial criterion for assessing the adequacy of existing separation/clearance distances for safe and regular operation of new larger aeroplanes is the accuracy with which aircraft taxi relative to the centre line/guideline on runways and taxiways:

- a) on straight portions; and
- b) on taxiway curves.

1.2.35 The following factors can impact on the accuracy or safety achieved in day-to-day operational environments and require, therefore, a detailed examination as applicable:

- a) quality of aircraft nose wheel guidelines (marking and lighting);
- b) quality of signs;
- c) visibility conditions;
- d) day or night;
- e) surface state (dry, wet, contaminated by snow/ice);
- f) taxi speed;
- g) pilots' attention;
- h) pilots' technique of negotiating turns;
- i) wind effects (cross-wind); and
- j) aircraft handling characteristics.

1.2.36 The provision of taxiing guidance, i.e. marking, lighting and signs which are adequately conspicuous in all operational conditions, together with good surface friction conditions, is considered paramount for achieving a high degree of taxiing accuracy. This is substantiated by the fact that the pilot of a large aeroplane, being unable to see the wing tips, will have to rely primarily on taxiing guidance, the accurate tracking of which will guarantee proper wing tip clearance.

1.2.37 Good surface friction characteristics are required because nose wheel steering effectiveness can become significantly degraded with large aeroplanes whenever the surface is other than dry, thereby challenging the execution of controlled turns. This is particularly true in the presence of a strong cross-wind.

1.2.38 The rationale used for determining separation distances for code letters E and F assumes a lateral deviation value of 4.5 m from the centre line for taxiways/apron taxiways on either straight or curved portions. For aircraft stand taxilanes the respective value is 2.5 m and is referred to as gear deviation.

1.2.39 Taxiway deviation studies, using a representative mix of aircraft types including large aeroplanes, were conducted at London/Heathrow and Amsterdam/Schipol airports. (See Appendix 4.) Results suggest that in favourable operating conditions (i.e. positive guidance provided by centre line lighting and marking and good surface friction characteristics), the mean deviation of main gears of aircraft from the centre line on straight taxiway portions is less than 4.5 m. It should be noted here, however, that the value of maximum deviation of main gears of most aircraft reached the 8 to 10 m range depending on aircraft type. With these provisions, a reduction of the deviation value accounted for in an aeronautical study may be acceptable relative to straight portions of taxiways, whereas the specified value should be retained if the above conditions are not met.

1.2.40 For taxiway curves, however, the situation is somewhat different. A fixed deviation of 4.5 m seen as adequate for defining separation/clearance distances does not account for the natural main gear track-in which results from the cockpit following the centre line. For new larger aeroplanes, the track-in allowance may be inadequate for the smaller turn radii of taxiways. Therefore, a detailed evaluation will be required to determine the path followed by the wing tip on the inside of the turn. The paths of the (inner) wing tips of B747-400 and MD11 aircraft are given in Tables 1-9 and 1-10, respectively, and illustrated in Figure 1-6. The maximum wing tip track-in for the newer aircraft, such as the B777-300, MD11, B747-400, B747-200 and A330-300/A340-300 are shown in Figures 1-7 through 1-11, respectively. For a study involving other new larger aeroplanes, it may be necessary to consult the aircraft manufacturers.

1.2.41 Design specifications are based on the assumption that, in taxiway curves, the cockpit is following the centre line of the taxiway. In day-to-day operations, however, pilots frequently use the straight-through or oversteering technique. This alternative practice may be taken into account when contemplating operations with reduced separation/clearance distances. This may apply, for example, in the case of curved parallel taxiways with the aircraft on the outer taxiway using the cockpit over the centre line technique while the aircraft on the inner taxiway applies the oversteering technique (e.g. main gear centre over centre line). Other measures of importance are taxiway turn fillet size and wing tip clearance in the terminal areas.

1.2.42 Apart from assessing the adequacy of separation/clearance distances given the relatively small deviations anticipated in normal operation, the aeronautical study may further require an assessment of the probability of collision due to large inadvertent excursions including run-offs from the paved surface.

1.2.43 Inadvertent excursions are guarded against by using an appropriate safety buffer (increment Z) which, however, does not make a differentiation with regard to the degree of risk involved. Accordingly, it may be assumed that the specified margins will provide adequate protection against a large variety of unfavourable operational factors.

Table 1-9. B747-400 inner wing tip plots (metres)

30 m radius				50 m radius				70 m radius			
Cockpit		Wing tip		Cockpit		Wing tip		Cockpit		Wing tip	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
-30.0	0.0	2.5	-45.2	-50.0	0.0	-17.5	-45.2	-70.0	0.0	-37.5	-45.2
-29.5	5.2	2.2	-40.5	-49.2	8.7	-17.9	-37.3	-68.9	12.2	-38.0	-34.1
-28.2	10.3	1.5	-36.8	-47.0	17.1	-18.8	-30.9	-65.8	23.9	-39.0	-24.8
-26.0	15.0	0.5	-34.0	-43.3	25.0	-19.9	-25.5	-60.6	35.0	-39.7	-16.6
-23.0	19.3	-0.7	-31.7	-38.3	32.1	-21.0	-20.8	-53.6	45.0	-40.1	-9.0
-19.3	23.0	-2.2	-30.0	-32.1	38.3	-22.0	-16.4	-45.0	53.6	-39.7	-1.8
-15.0	26.0	-3.9	-28.6	-25.0	43.3	-22.8	-12.3	-35.0	60.6	-38.6	5.1
-10.3	28.2	-5.8	-27.3	-17.1	47.0	-23.3	-8.3	-23.9	65.8	-36.6	11.6
-5.2	29.5	-7.8	-26.1	-8.7	49.2	-23.4	-4.4	-12.2	68.9	-33.7	17.6
0.0	30.0	-10.1	-24.8	0.0	50.0	-23.2	-0.6	0.0	70.0	-29.9	23.1
5.2	30.0	-11.7	-23.0	8.7	50.0	-21.4	3.2	6.1	70.0	-27.3	25.5
10.5	30.0	-12.1	-20.9	17.5	50.0	-17.4	6.6	12.2	70.0	-23.9	27.6
15.7	30.0	-11.5	-18.6	26.2	50.0	-11.8	9.3	18.3	70.0	-19.9	29.5
20.9	30.0	-9.9	-16.4	34.9	50.0	-5.3	11.5	24.4	70.0	-15.3	31.0
26.2	30.0	-7.5	-14.3	43.6	50.0	2.0	13.1	30.5	70.0	-10.4	32.3
31.4	30.0	-4.6	-12.5	54.2	50.0	9.7	14.3	36.7	70.0	-5.2	33.3
36.7	30.0	-1.2	-10.9	61.1	50.0	17.7	15.2	42.8	70.0	0.2	34.1
41.9	30.0	2.6	-9.5	69.8	50.0	25.9	15.8	48.9	70.0	5.7	34.8
47.1	30.0	6.7	-8.3	78.5	50.0	34.2	16.3	55.0	70.0	11.4	35.4
52.4	30.0	11.0	-7.3					61.1	70.0	17.2	35.8
57.6	30.0	15.5	-6.5					67.2	70.0	23.0	36.1
62.8	30.0	20.2	-5.8					73.3	70.0	28.9	36.4
68.1	30.0	24.9	-5.2					79.4	70.0	34.8	36.6
73.3	30.0	29.8	-4.7								
78.5	30.0	34.7	-4.3								

-90 degree turns

-Zero reference point (X = 0, Y = 0) is at turn centre