United Kingdom Overseas Territories Aviation Circular

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190-16
191-1

Design of Aerodromes

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GENERAL

Overseas Territories Aviation Circulars are issued to provide advice, guidance and information on standards, practices and procedures necessary to support Overseas Territory Aviation Requirements. They are not in themselves law but may amplify a provision of the Air Navigation (Overseas Territories) Order or provide practical guidance on meeting a requirement contained in the Overseas Territories Aviation Requirements.

PURPOSE

This Overseas Territory Aviation Circular provides guidance to certificate holders and applicants planning to apply for an aerodrome certificate on the design of aerodromes.

RELATED REQUIREMENTS

This Circular relates to OTAR Part 139, 190 and 191.

CHANGE INFORMATION

Issue 2.00 adds references to OTACs 139 and 190.

ENQUIRIES

Enquiries regarding the content of this Circular should be addressed to Air Safety Support International at the address on the ASSI website www.airsafety.aero or to the appropriate Overseas Territory Aviation Authority.

CONTENTS

1. Introduction

1.1 OTAR Part 191 defines the requirements for the design of aerodromes in line with the Standards and Recommended Practices in ICAO Annex 14. OTAR Part 139 defines the requirements for the certification of aerodromes and OTAR Part 190 defines the requirements for aerodrome operations.

1.2 ICAO Doc 9157 contains additional information related to the design of aerodromes.

1.3 This OTAC draws attention to information and details behind the design of aerodromes that must be considered when constructing or making changes to a certificated aerodrome or related facility.

2. General Aerodrome Design

2.1 Potential aerodrome certificate holders should consider the architectural and infrastructure-related requirements for the optimum implementation of international civil aviation security measures defined in OTAR Part 178. The same philosophy should be considered when designing and constructing new facilities and alterations to existing facilities at an aerodrome.

2.2 Environmental assessment processes have proven to be an important part of any airport development project. Potential environmental impacts can be identified before they occur and before irrevocable decisions on the design of a project are made. Mitigation of environmental impacts can and should be made an integral part of the planning process.

3. Runways

3.1 Aerodrome Reference Code

3.1.1 The aerodrome reference code aims to establish a straightforward approach for linking the various specifications related to aerodrome characteristics. This will ensure that the resulting aerodrome facilities are compatible with the aircraft intended to operate there.

3.1.2 The code consists of two components that are related to the aircraft's performance specifications and dimensions. Element 1 is a numerical value determined by the aeroplane's reference field length, while element 2 is a letter assigned based on the aeroplane's wingspan.

3.1.3 To determine the applicable specifications, the more relevant code element or a combination of the two elements is considered. The code letter or number chosen for design purposes corresponds to the critical aircraft characteristics for which the facility is being constructed. When implementing the pertinent specifications from OTAR 191, the first step is to identify the aircraft type which the aerodrome intends to accommodate, followed by selecting the two code elements.

3.1.4 To determine the code number for element 1, consult Table 1 and select the code number corresponding to the highest aeroplane reference field length among the aircraft intended to use the runway. The aeroplane reference field length is defined as: *the minimum runway length required for take-off at maximum certificated take-off mass, sea level, standard atmospheric conditions, still air, and a zero runway slope, as specified in the aircraft flight manual or equivalent documentation provided by the aircraft manufacturer.*

3.1.5 To determine the code letter for element 2, refer to Table 1 and identify the code letter that corresponds to the largest wingspan of those aircraft types which intend using the facility. This table provides a comprehensive reference for matching aircraft wingspans to corresponding code letters.

3.1.6 For aircraft equipped with foldable wingtips, the reference code letter may vary depending on the position of the wings. During operations at an aerodrome, the wingspan configuration and subsequent manoeuvres of the aircraft should be considered.

Table 1: Aerodrome reference code

Code element 1	
Code number	**Aeroplane reference field length**
1	Less than 800 m
2	800 m up to but not including 1 200 m
3	1 200 m up to but not including 1 800 m
4	1 800 m and over
Code element 2	
Code letter	**Wingspan**
A	Up to but not including 15 m
B	15 m up to but not including 24 m
C	24 m up to but not including 36 m
D	36 m up to but not including 52 m
E	52 m up to but not including 65 m
F	65 m up to but not including 80 m

3.2 Siting and Orientation of Runways

3.2.1 Numerous factors influence the selection of runway location, orientation, and number. The most significant elements include:

1) Meteorological conditions, particularly the impact of wind patterns on runway, aerodrome functionality and the presence of localised fogs, significantly influence the decision regarding runway positioning and orientation;

2) topography of the aerodrome site and its surroundings;

3) type and amount of air traffic to be served, including air traffic control aspects;

4) aeroplane performance;

5) environmental considerations, including noise

3.2.2 The primary runway, considering all feasible factors, should be positioned along the prevailing wind direction. All runways should be aligned to ensure that approach and departure paths are clear of obstacles and, ideally, avoid routing aircraft over densely populated or noise-sensitive areas.

3.2.3 The number of runways must be adequate to accommodate the anticipated air traffic volume, which encompasses the frequency of aircraft arrivals and departures and the variety of aircraft types during peak traffic periods. The decision regarding the total number of runways required should also consider the aerodrome usability factor and economic aspects.

3.2.4 Specific consideration should be given to whether the aerodrome will be operated in all weather conditions or solely within Visual Meteorological Conditions (VMC), and whether it is intended for both daytime and nighttime operations or solely during daylight hours.

3.2.5 The number and alignment of runways at an airport should ensure that the airfield is usable for at least 95 percent of the time by the aircraft it is intended to serve.

3.2.6 To maintain a 95% usable airfield for all aircraft types, the following maximum crosswind components are considered safe for landing and take-offs:

1) For aircraft with a reference field length of 1500 metres or more, a maximum crosswind of 37 km/h (20 knots) is typically assumed. However, if poor runway braking conditions are prevalent, a maximum crosswind of 24 km/h (13 knots) may be more appropriate.

2) For aircraft with a reference field length of 1200 metres or greater but less than 1500 metres, a maximum crosswind of 24 km/h (13 knots) is considered acceptable.

3) For aircraft with a reference field length of less than 1200 metres, a maximum crosswind of 19 km/h (10 knots) is deemed safe for landing and take-offs.

3.2.7 To accurately estimate the usability factor, reliable wind distribution data spanning at least five years should be used. Wind observations should be taken at least eight times daily, evenly spaced throughout the day. These observations should account for the following:

1) Wind statistics are often presented in speed and direction ranges, and the accuracy of the usability factor calculation depends on the assumed distribution of observations within these ranges, in the absence of conclusive concrete information about the actual distribution, a uniform distribution is generally assumed, which tends to yield a slightly conservative estimate of the usability factor.

2) The maximum mean crosswind components provided are for normal circumstances. At specific aerodromes, these values may need to be adjusted based on several factors, including:

   a) Variations in handling characteristics and maximum permissible crosswind components among different aircraft types, including future aircraft, within the three groups specified in the document.

b) Frequency and intensity of wind gusts.

c) Presence and type of turbulence.

d) Availability of a backup runway.

e) Runway width.

f) Runway surface conditions. Water, snow, slush, and ice significantly reduce the allowable crosswind component.

g) Wind strength associated with the limiting crosswind component.

3.2.8 The 95% usability factor required by OTAR Part 191 applies to all weather conditions. However, it's helpful to analyse wind speed and direction for different visibility levels. Wind speed and direction data can usually be obtained from government weather bureaus. Wind velocities are usually grouped into 22.5-degree increments (16 points of the compass). Weather records provide information on the percentage of time certain combinations of ceiling and visibility occur (for example, ceiling 500 to 274 metres; visibility 4.8 to 9.7 kilometres) and the percentage of time winds of a specific velocity occur from different directions (for example, north-northeast, 2.6 to 4.6 knots). Directions are specified relative to true north.

3.2.9 In some cases, wind data may not be available for a new location. If so, records from nearby measuring stations can be consulted. If the surrounding area is fairly flat, data from these stations should provide an indication of the winds at the proposed aerodrome site. However, if the terrain is hilly, the topography may influence the wind pattern, and it is inadvisable to rely on data from stations located far from the site. In such cases, a study of the region's topography and consultation with local residents may provide some guidance. Whenever possible, a wind study of the site should be conducted. This could involve installing wind gauges and recording wind data. Guidance on preparing and analysing wind data for aerodrome planning purposes is provided in the Airport Planning Manual (Doc 9184) Part 1 Master Planning.

3.2.10 Due to their small size, it can be difficult for the Overseas Territories to obtain the required space to construct or expand aerodrome infrastructure. Therefore, best efforts to comply with the usability factor should be demonstrated when presenting plans to the Governor.

3.2.11 Wind patterns and intensities can significantly differ when visibility is reduced compared to when visibility is good. Analysing wind conditions under poor visibility and/or low cloud base at the aerodrome, including the frequency of these conditions and the accompanying wind direction and speed, is essential to ensure safe and efficient aircraft operations.

3.2.12 The topographical characteristics of the airfield and its vicinity should be carefully evaluated, focusing on the following aspects:

1) Conformity with obstacle limitation surfaces (OLSs) to ensure safe aircraft operations.

2) Current and anticipated land utilisation. Runway orientation and layout should prioritise shielding particularly sensitive areas, such as residential neighbourhoods, schools, and hospitals, from the detrimental effects of aircraft noise.

3) Determination of the required runway lengths for present and future needs.

4) Assessment of construction expenses.

5) Evaluation of the feasibility of installing suitable visual and non-visual approach aids to enhance landing safety.

3.2.13 When determining the placement of runways, several key ATS factors should be considered:

1) Proximity to other airfields or air traffic control (ATC) routes, as this can influence traffic patterns and potential conflicts.

2) Traffic density impacts the number of runways needed to efficiently accommodate expected air traffic volumes.

3) Air traffic control (ATC) capabilities and missed approach procedures, ensuring the runways are aligned to facilitate effective air traffic management and contingency plans for aborted landings.

3.2.14 When determining the alignment of a runway, the impact on wildlife, the local ecosystem, and noise-sensitive communities should be carefully evaluated. The runway orientation should be chosen to minimise disruption to wildlife habitats and preserve the natural environment. Additionally, the runway alignment should be carefully considered to minimise noise pollution in residential areas and sensitive ecosystems.

3.2.15 The noise generated by aircraft operations at and around airports is often regarded as the primary environmental concern associated with these facilities. The majority of noise exposure is concentrated in the areas directly beneath and adjacent to the flight paths of departing and arriving aircraft. Careful selection of the aerodrome's location and thoughtful planning of surrounding land use can significantly mitigate and potentially eliminate the noise pollution associated with aerodrome flight operations.

3.3 Runway Threshold

3.3.1 The threshold, the designated starting point for landings, is typically positioned at the end of a runway, provided there are no obstacles protruding above the designated approach surface. However, due to specific site conditions, it may be necessary to relocate the threshold permanently. While considering the threshold's location, factors such as the height of the Instrument Landing System (ILS) reference datum and the determination of obstacle clearance limits should also be taken into account.

3.3.2 When assessing whether any obstacles extend above the approach surface, consideration should be given to mobile objects such as vehicles on roadways, trains, and other movable structures.

3.3.3 To satisfy the intention of the inner horizontal surface described above, it is desirable that authorities select a datum elevation from which the top elevation of the surface is determined. Selection of the datum should take amount of:

1) the elevations of the most frequently used altimeter setting datum points;

2) minimum circling altitudes in use or required; and

3) the nature of operations at the airport.

3.3.4 For relatively level runways, the choice of datum is not critical, but when the thresholds differ by more than 6 metres, the datum selected should have particular regard to the factors above. For complex inner horizontal surfaces (Figure 1-2), a common elevation is not essential, but where surfaces overlap the lower surface should be regarded as dominant.

3.3.5 If an obstacle exists above the approach surface and cannot be removed, it may be necessary to permanently relocate the runway threshold to ensure safe landing operations.

3.3.6 To fulfil the obstacle limitation guidelines set forth in OTAR Part 191, the runway threshold should be relocated farther down the runway to ensure that no obstacles encroach upon the approach surface.

3.3.7 The relocation of the threshold from the end of the runway will inevitably reduce the available landing distance. This reduction in landing distance may be more significant than the presence of marked and lighted obstacles protruding above the approach surface. Therefore, the decision to relocate the threshold should be based on the optimum balance between having a clear approach surface and having an adequate landing distance. Factors that should be considered include the types of aircraft that will use the runway, the visibility and cloud base conditions, the position of the obstacles relative to the threshold and extended centre line, and the significance of the obstacles for the precision approach runway.

3.3.8 Regardless of the landing distance considerations, the selected threshold position should not result in an approach surface slope that exceeds 3.3% for code number 4 runways or 5% for code number 3 runways.

3.4 General Factors Affecting Runway Length

3.4.1 Several factors influence the determination of the appropriate runway length:

1) Performance Characteristics and Operating Masses of Aircraft: The runway length should accommodate the aircraft's performance capabilities and operating weights that are expected to utilise the airfield. Larger, heavier aircraft require longer runways to achieve safe take-off and landing distances.

2) Weather Conditions: The runway length should consider prevailing weather conditions, particularly surface wind speed and temperature. Strong winds and high temperatures can affect aircraft performance and require longer runways for safe operations.

3) Runway Characteristics: The runway's slope and surface condition also influence the required length. Runways with steeper slopes or uneven surfaces may necessitate longer lengths to ensure safe and efficient operations for various aircraft types.

4) Aerodrome Location Factors: The airfield's location and elevation can impact runway length considerations. Aerodromes at higher elevations experience lower barometric pressure, influencing aircraft performance and requiring slightly longer runways. Additionally, topographic constraints, such as surrounding hills or mountains, may affect the usable runway length and require adjustments based on the specific site conditions.

3.4.2 The relationship between runway length and aeroplane performance characteristics is discussed in section 3.

3.4.3 The greater the headwind down a runway, the shorter the runway length required by an aeroplane taking off or landing. Conversely, a tailwind increases the length of runway required. The higher the temperature, the longer the runway required because higher temperatures create lower air densities, resulting in lower output of thrust and reduced lift.

3.4.4 The effect of runway slopes on runway length requirements is discussed in detail in Appendix 2. However, it is evident that an aeroplane taking off on an uphill gradient requires more runway length than it would on a level or downhill gradient; the specific amount depends on the elevation of the aerodrome and the temperature.

3.4.5 All other factors being equal, the higher the elevation of the aerodrome with correspondingly lower barometric pressure, the longer the runway required. The runway length which can be provided at an aerodrome may be constrained by property boundaries or topographical features such as mountains, the sea or steep valleys.

3.4.6 Unless a runway is accompanied by a stopway and/or clearway, the actual length of a primary runway should be sufficient to accommodate the operational needs of the aircraft it is designed to serve. The runway length should be at least as long as the greatest length determined by applying adjustments for local conditions to the operating and performance characteristics of the relevant aircraft.

3.4.7 Both take-off and landing distances should be factored in when determining the required runway length and the feasibility of conducting operations from both ends of the runway. Local conditions such as elevation, temperature, runway slope, humidity, and surface characteristics may need to be considered when assessing the runway's suitability for operations under various conditions.

3.4.8 In the absence of aircraft performance data, a primary runway's length can be estimated using general correction factors. However, for the most accurate information, refer to the aircraft manufacturer's Aeroplane Characteristics for Airport Planning document.

3.4.9 The decision to incorporate a stopway and/or clearway in place of extending the runway length depends on the physical conditions beyond the runway's end and the operational performance requirements of the intended aircraft. The lengths of the runway, stopway, and clearway are determined by the aircraft's take-off performance, but a verification should also be conducted to ensure that the landing distance required by the runway's users is adequately accommodated. However, the length of a clearway cannot exceed half the available take-off run length.

3.5 Aircraft Performance Factors Affecting Runway Length

3.5.1 Before delving into the connection between aircraft performance parameters and runway length requirements, it's crucial to clarify certain operational terms:

1) Decision speed (V1) is the speed chosen by the operator at which the pilot, having recognised a failure of the critical engine, decides whether to continue the flight or initiate the application of the first retarding device. If the engine failure occurs before the decision speed is reached, the pilot should stop; if failure occurs later, the pilot should not stop but should continue the take-off. As a general rule, a decision speed is selected which is lower, or at most, equal, to the take-off safety speed (V2). It should however exceed the lowest speed at which the aeroplane can still be controlled on or near the ground in the case of failure of the most critical engine; this speed may be given in the aeroplane flight manual.

2) Take-off safety speed (V2) is the minimum speed at which the pilot is allowed to climb after attaining a height of 10.7 m (35 ft) to maintain at least the minimum required climb gradient above the take-off surface during a take-off with one engine inoperative.

3) Rotation speed (VR) is the speed at which the pilot initiates rotation of the aeroplane to cause the raising of the landing gear.

4) Lift-off speed (VLOF) in terms of calibrated airspeed, is the speed at which the aeroplane first becomes airborne.

3.5.2 Engine failure following V1 allows sufficient speed and runway remaining for a safe take-off. However, the resulting high speed poses a challenge for stopping within the available distance.

3.5.3 The decision speed, V1, isn't a fixed value but a pilot-selectable parameter determined by factors like runway length, aircraft weight, environmental conditions, and available stopping distance. Typically, higher V1 values are chosen when longer runways are available.

3.5.4 The ideal decision speed ("V1") can be chosen so that the required take-off distance and the required stopping distance are both equal to the available runway length, creating a "balanced field length." This length can also be achieved using a shorter runway combined with equal-length "clearway" and "stopway" areas on both ends. While this saves runway length, it increases the total required space.

3.5.5 In case economic considerations preclude the provision of stopway and, as a result only runway and clearway are to be provided, the runway length (neglecting landing requirements) should be equal to the accelerate-stop distance required or the take-off run required whichever is the greater. The take-off distance available will be the length of the runway plus the length of clearway.

3.5.6 The minimum runway length and the maximum stopway or clearway length to be provided may be determined as follows, from the data in the Aeroplane Flight Manual for the aeroplane considered to be critical from the viewpoint of runway length requirements:

1) When economically feasible, the runway and adjacent areas should be designed for a "balanced field length," ensuring safe take-off and stopping. The runway itself can be shorter if additional stopway (both ends) and clearway are provided. The runway length is determined by the longer of take-off or landing distance, while stopway and clearway lengths are equal to each other.

2) In the absence of a stopway, the minimum runway length is determined by the longer of two factors: the landing distance and the stopping distance associated with the slowest practical take-off speed. Any additional take-off distance needed beyond the runway can be provided as a clearway at both ends.

3.5.7 In addition to the above consideration, the concept of clearways in certain circumstances can be applied to a situation where the take-off distance required for all engines operating exceeds that required for the engine failure case.

3.5.8 To avoid wasting resources on repeated repairs, a stopway must be robust enough to withstand numerous landings by the intended aircraft without causing structural damage.

3.5.9 Taking as a schematic illustration Figure 191-1 (a) the case of an aeroplane standing at the entrance end A of a runway, the pilot starts the take-off, the aeroplane accelerates and approaches the decision speed (V1) point B. A sudden and complete failure of an engine is assumed to occur and is recognised by the pilot as the decision speed (V1) is attained. The pilot can either:

1) Brake until the aeroplane comes to a standstill at point Y (the accelerate-stop distance); or

2) Continue accelerating until reaching the rotation speed (VR), point C, at which time the aeroplane rotates and becomes airborne at the lift-off speed (VLOF), point D, after which it reaches the end of the take-off run, point X, and continues to the 10.7 m (35 ft) height at the end of the take-off distance, point Z.

3.5.10 Figure 191-1 b) illustrates a normal, all-engines operating, case where d’1 and d’3 are similar to d1 and d3, respectively, in Figure 191-1 a).

3.5.11 The engine-inoperative take-off and accelerate-stop distances will vary according to the selection of the decision speed (V1). If the decision speed is reduced, the distance to point B (Figure 191-1 a) is reduced, as is the accelerate-stop distance; but the take-off run and take-off distances are increased as a larger part of the take-off manoeuvre is carried out with an engine inoperative. Figure 191-2 illustrates the probable relationship which may exist between the accelerate-stop distances, the take-off distances, and the take-off runs with respect to variations in the decision speed, (V1), within the limits stated in 3.5.1.

3.5.12 The take-off performance characteristics of a given aeroplane will not necessarily encompass the range of decision speeds shown in Figure 191-2. Rather, under specified conditions, an individual aeroplane may be found to be restricted to within one of the areas indicated by the horizontal brackets a, b or c. In the case illustrated by bracket a, the take-off distance with an engine inoperative is critical. The logical selection of V1, point (1), would be to have it equal V2 or VR depending on the aeroplane's take-off characteristics. In the case illustrated by bracket b, the accelerate-stop distance is critical from the V2 speed down to a point where ground controllability may become critical. The logical selection of V1 would be to keep it as low as is practical, point (2). In the case illustrated by bracket c, which is the more general case, the accelerate-stop distance is critical at V1 speeds near the V2 speed and the take-off distance is critical at speeds near the minimum speed for controllability, in this case the V1 speed selected is usually the optimum, i.e. the V1 at which the two distances are equal, point (3). If the all-engines operating take-off distance is critical in one or more of the cases cited, the range of possible V1 speeds is somewhat enlarged because that distance is independent of the V1 speed.

3.5.13 It will be seen that the total length required is the least in the case of the optimum decision speed (V1), and this is always true. Normally, therefore, the runway should be constructed to this length. However, the part of the accelerate-stop distance not required for the take-off run (the length B in Figure 191-3) will be used very rarely and may therefore be constructed more economically than the part A required for take-off run, i.e. the runway itself. Further, during take-off, the length B + C will only be flown over during the initial climb to the height specified in ICAO Annex 6 and is not expected to bear the mass of the aircraft; it requires only to be clear of obstacles.

3.5.14 In certain circumstances, the construction of runways with surfaces such as stopways and clearways may prove to be more advantageous than the construction of conventional runways. The choice between a solution involving a conventional runway and one in which a combination of these surfaces is used, will depend on the local physical and economic conditions, size and clearances of the site, soil characteristics, possibility of acquiring land, plans for future development, nature and cost of available materials, time interval required for carrying out the work, acceptable level of maintenance charges, etc. In particular, the construction of stopways at each end of the runway (since there are normally two directions for take-off) may frequently be an economical first stage in the extension of an existing runway. The stopways, which are not used for landings and are used by the aeroplane only in exceptional cases during take-off, can frequently be provided without considerable expenditure, and their establishment is operationally equivalent for the aeroplane to a lengthening of the runway.

3.5.15 In order to choose between the non-conventional runway and the preferred conventional runway, it is necessary to determine the proportions of clearway or clearway/stopway which may be provided. Figure 191-3 illustrates how this can be done for a particular aeroplane under one set of conditions of altitude, temperature, take-off mass, etc. As shown above, the distance for the take-off run, the take-off distance and the accelerate-stop distance for a particular aeroplane during take-off depend on the choice of the decision speed V1. Within a certain range (as noted in 3.5.1) any value of V1 can be chosen and consequently many combinations of runway, stopway and clearway would appear to be possible. The minimum requirements for the design of a non-conventional runway will normally include a runway and a clearway, or a runway and a combination clearway/stopway, depending on the V1 speeds used. This is illustrated in Figure 191-3.

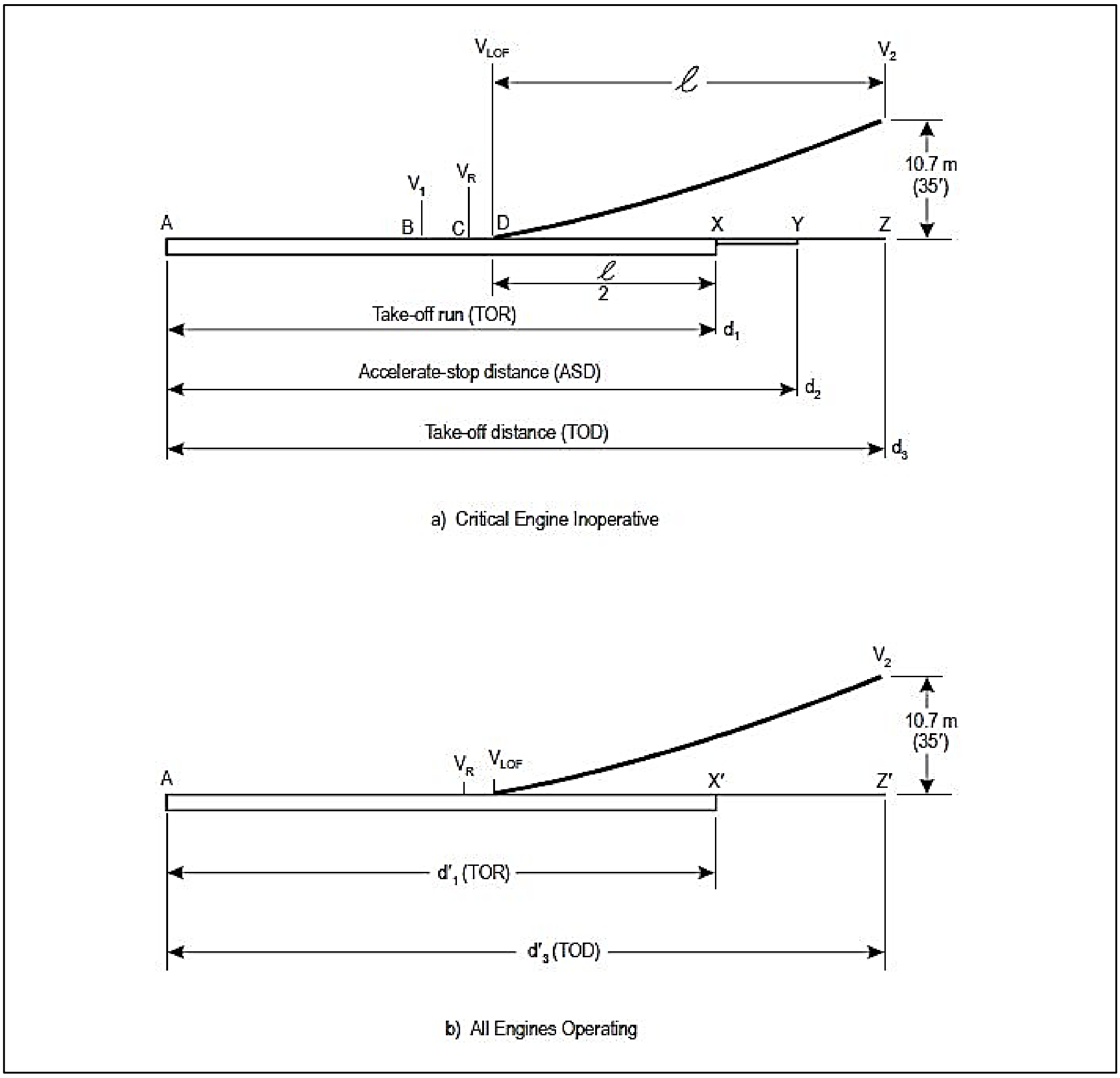
3.5.16 Expansion of a conventional runway to a non-conventional runway to accommodate an increase in mass of the critical aeroplane is illustrated in Figure 191-4. In Figure 191-4 a), the critical aeroplane uses the optimum V1 speed, point 3, at mass W0 on the existing runway. With the mass increased to W1, the optimum V1 speed is somewhat increased, point 3'. The mass increase is limited to that which results in take-off run (d1) equal to the length of runway. The additional take-off distance and accelerate-stop distance can be accommodated by a combination clearway/stopway. In Figure 191-4 b), two cases are cited. In the first case, the aeroplane's V1 speed is at point 1. The new V1 speed, point 1', would increase if the initial climb out speed (V2) increased due to the mass change. The mass increase is limited to that which would result in a take-off run (d1) at mass W1 equal to the take-off distance (d3) at mass W0. The increase in take-off distance can be accommodated by a clearway. In the second case, the aeroplane's V1 speed is at point 2. The V1 speed, point 2', would probably be held constant. The mass increase would be limited by the increased take-off distance d3 at mass W1 if a clearway was not to be provided. The increase in accelerate-stop distance can be accommodated by a stopway. Note that any further increase in mass will require the use of a combined clearway/stopway. The effect caused by the all-engines-operating case can readily be seen by a comparison of Figure 191-3, (a) and (b). Lower values of V1 are of no interest since they result in both greater take- off run and take-off distance.

3.5.17 The runway length determined from the take-off performance charts is the greater of either:

1) The balanced field length, that is, the runway length required when the take-off distance with one engine inoperative and accelerate-stop distance are equal or

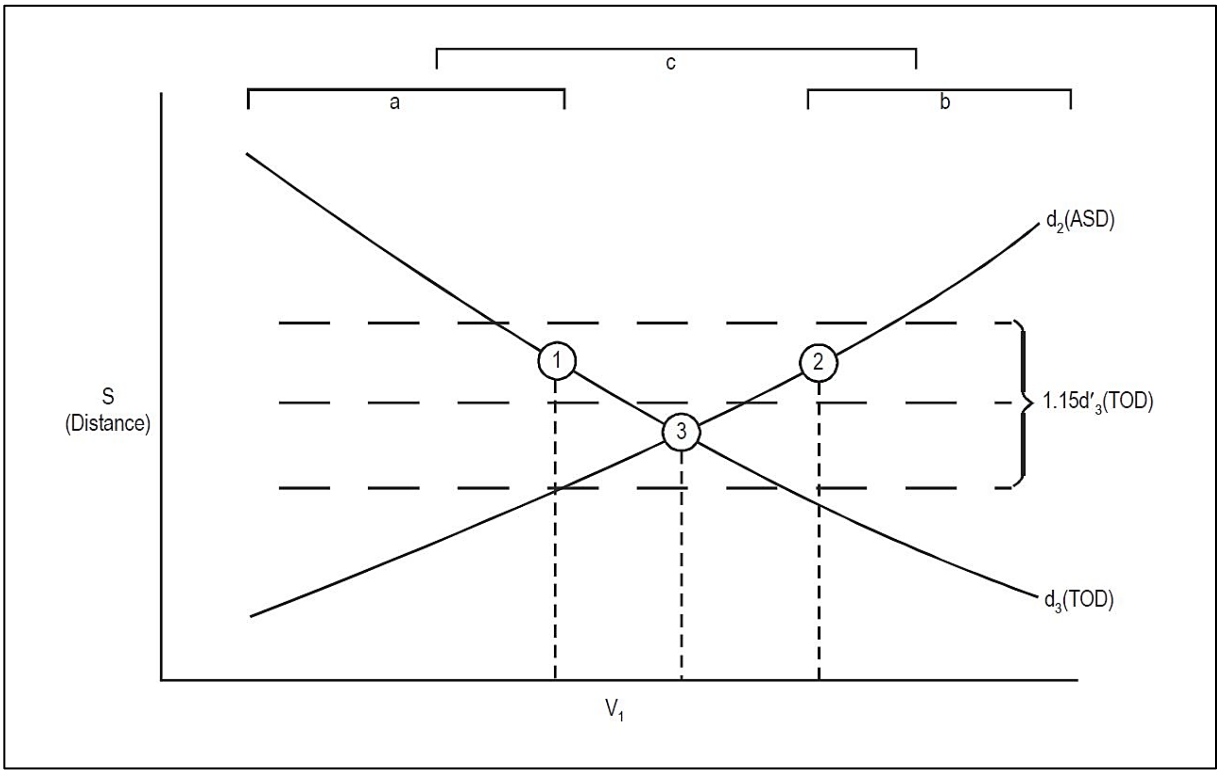
2) 115 % of the take-off distance with all engines operative.

Figure 191-1 Take-off Performance



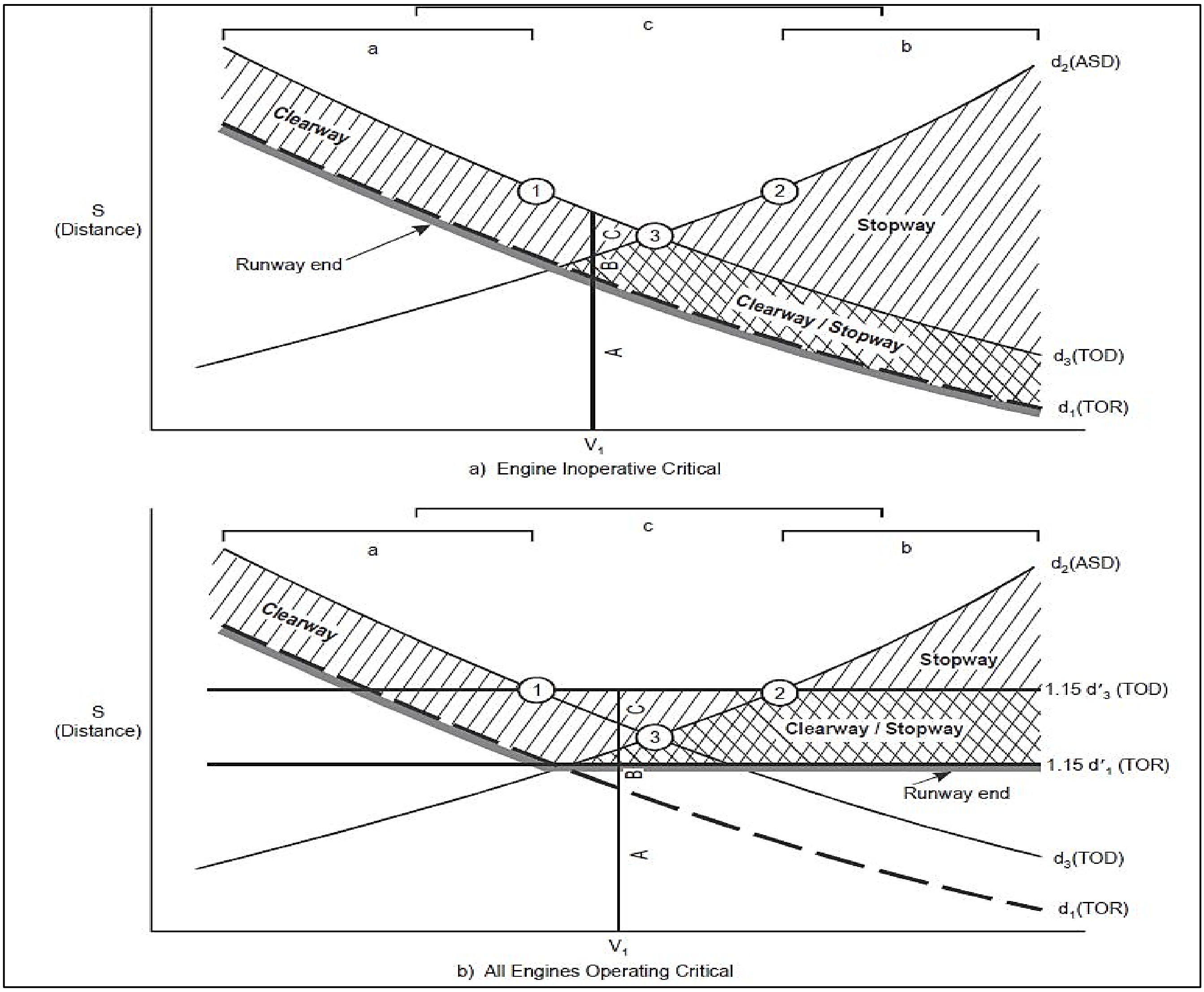
Source: ICAO Doc 9157 Part 4

Figure 191-2 Accelerate-Stop Distance vs. Take-off Distance: Mapping the Impact of Decision Speed



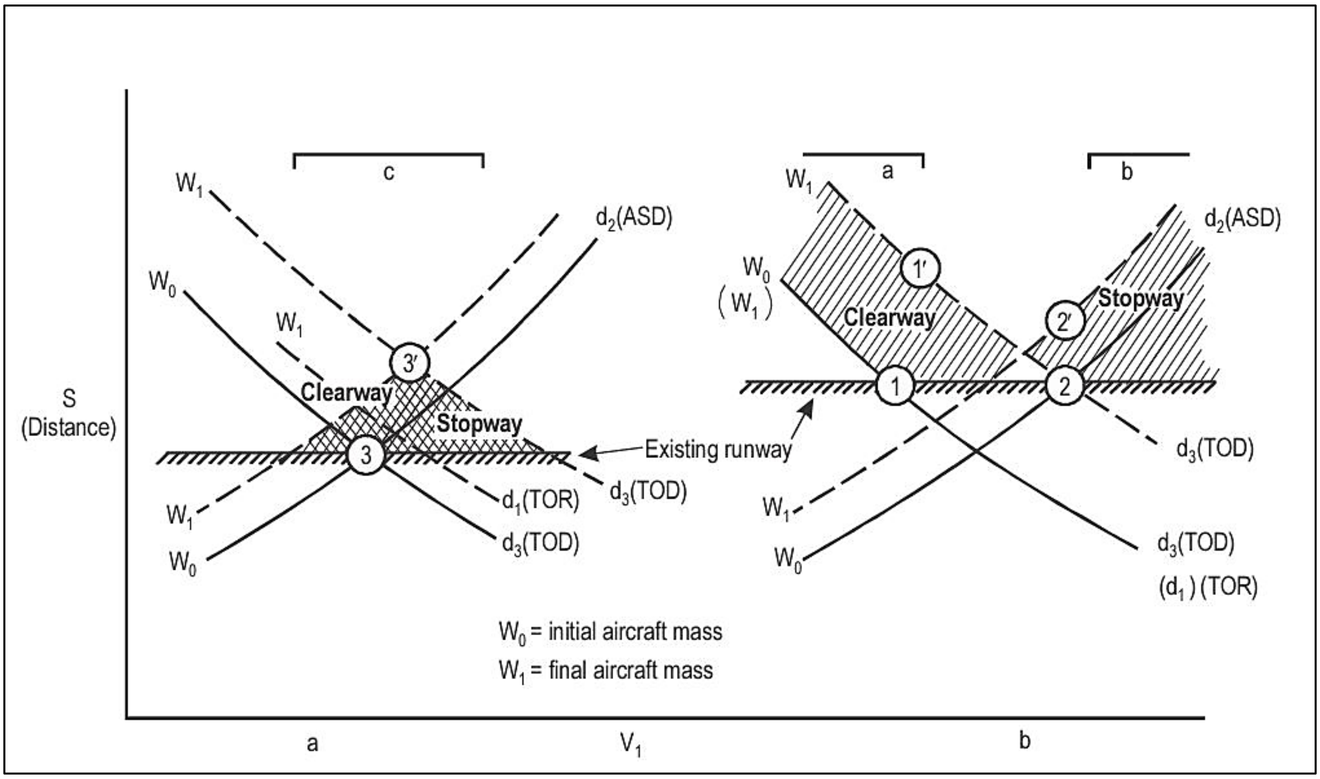
Source: ICAO Doc 9157 Part 1

Figure 191-3 Conventional Runway Design with Clearway/Stopway



Source: ICAO Doc 9157 Part 1

Figure 191-4 Runway Expansion vs Increase in Aeroplane Mass



Source: ICAO Doc 9157 Part 4

3.6 Calculation of Declared Distances

3.6.1 The introduction of stopways and clearways and the use of displaced thresholds on runways has created a need for accurate information regarding the various physical distances available and suitable for the landing and take-off of aeroplanes. For these purposes, the term "declared distances" is used with the following four distances associated with a particular runway:

1) Take-off run available (TORA), i.e. the length of runway declared available and suitable for the ground run of an aeroplane taking off.

2) Take-off distance available (TODA), i.e. the length of the take-off run available plus the length of the clearway, if provided

3) Accelerate-stop distance available (ASDA), i.e. the length of the take-off run available plus the length of the stopway, if provided.

4) Landing distance available (LDA), i.e. the length of the runway which is declared available and suitable for the ground run of an aeroplane landing.

3.6.2 OTAR 191 stipulates the calculation of declared distances for a runway intended for use by international commercial air transport, and OTAR 175 stipulates the reporting of declared distances for each direction of the runway in the State Aeronautical Information Publication (AIP). Figure 191-5 illustrates typical cases, and Figure 191-6 shows a tabulation of declared distances.

3.6.3 Where a runway is not provided with a stopway or clearway and the threshold is located at the extremity of the runway, the four declared distances should normally be equal to the length of the runway as shown in Figure 191-5(A).

3.6.4 Where a runway is provided with a clearway (CWY), then the TODA will include the length of clearway as shown in Figure 191-5 B).

3.6.5 Where a runway is provided with a stopway (SWY), then the ASDA will include the length of stopway as shown in Figure 191-5 C).

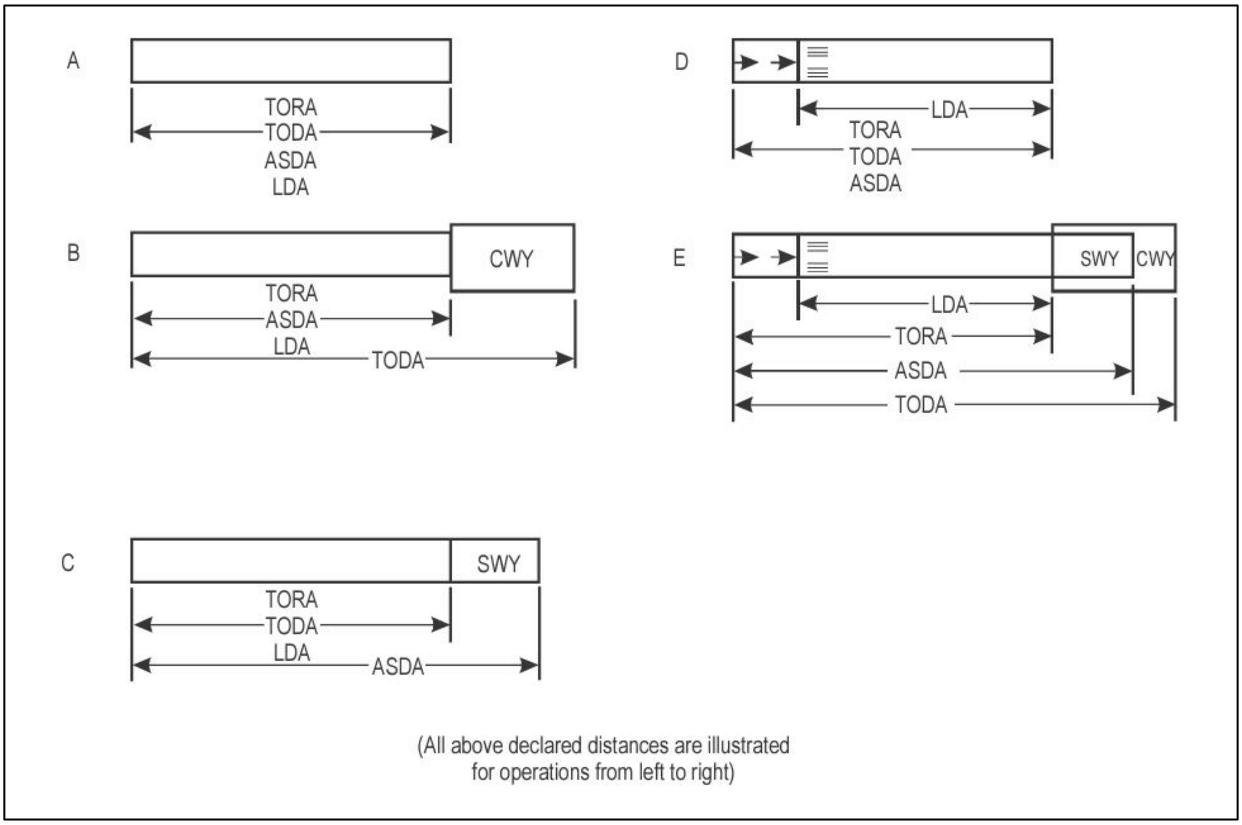
3.6.6 Where a runway has a displaced threshold, then the LDA will be reduced by the distance the threshold is displaced as shown in Figure 191-5 D). A displaced threshold affects only the LDA for approaches made to that threshold; all declared distances for operations in the reciprocal direction are unaffected.

3.6.7 Figures 3-1B through Figure 191-5 D) illustrates a runway provided with a clearway, a stopway or having a displaced threshold. Where more than one of these features exist then more than one of the declared distances will be modified - but the modification will follow the same principle illustrated. Figure 191-5 E) illustrates the situation where all these features exist.

3.6.8 A suggested format for providing information on declared distances is given in Figure 191-6. If a runway direction cannot be used for take-off or landing, or both, because it is operationally forbidden, then this should be declared and the words "not usable" or the abbreviation "NU" entered.

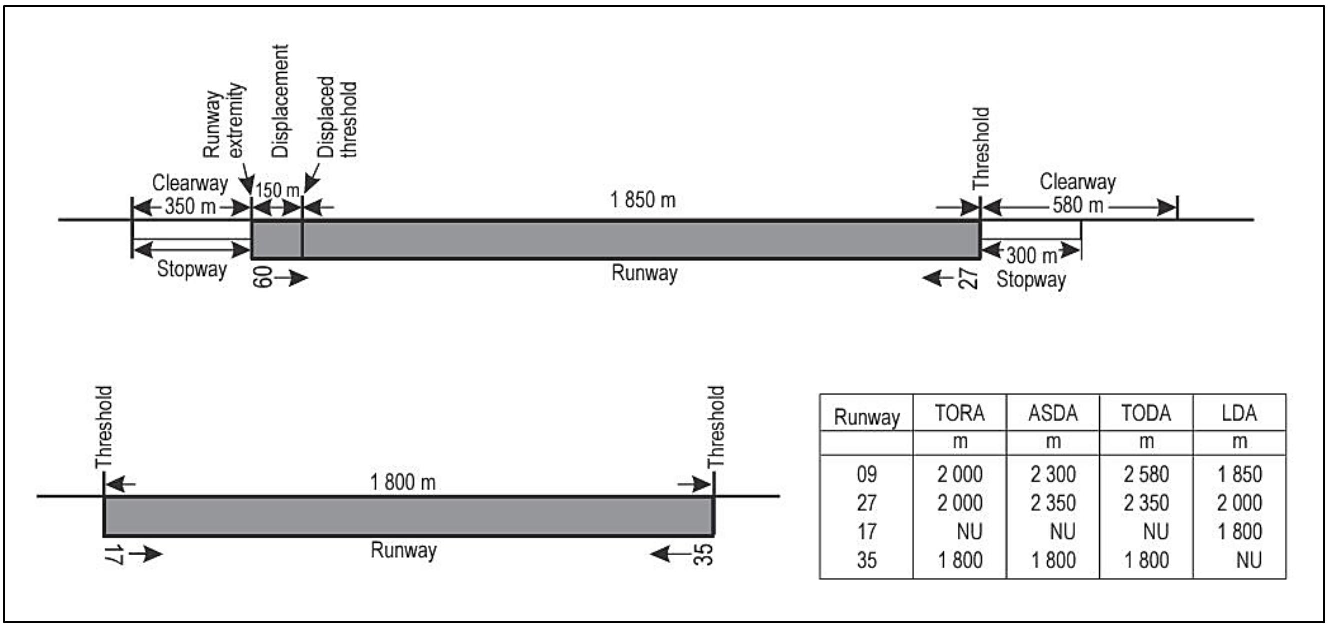
3.6.9 Where provision of a runway end safety area may involve encroachment in areas where it would be particularly prohibitive to implement, and the appropriate authority considers a runway end safety area essential, consideration may have to be given to reducing some of the declared distances.

Figure 191-5 Declared Distances



Source: ICAO Doc 9157 Part 1

Figure 191-6 Format Depicting Declared Distances



Runway	TORA	ASDA	TODA	LDA
	m	m	m	m
09	2 000	2 300	2 580	1 850
27	2 000	2 350	2 350	2 000
17	NU	NU	NU	1 800
35	1 800	1 800	1 800	NU

Source: ICAO Doc 9157 Part 1

3.7 Runway Length Corrections for Elevation, Temperature and Slope

3.7.1 In the absence of the appropriate flight manual, estimating the necessary runway length necessitates the application of generic correction factors. As a foundational step, a baseline length is established for the runway, capable of fulfilling the operational needs of the anticipated aircraft. This baseline length, selected for planning purposes within the airfield, reflects the required distance for take-off or landing under standardised atmospheric conditions (with zero elevation, wind, and runway slope).

3.7.2 The basic length selected for the runway should be increased at the rate of 7% per 300 m elevation.

3.7.3 The runway length established in section 3.7.2 shall be further augmented by a factor of 1% for each 1°C by which the aerodrome reference temperature surpasses the standard temperature for its elevation (see Table 191-1). Nevertheless, if the aggregate correction for both elevation and temperature exceeds 35%, a dedicated investigation is mandated to determine the necessary adjustments. Furthermore, the operational characteristics of certain aircraft may necessitate modifications to these standard correction factors based on the results of aeronautical studies conducted with respect to the specific site conditions and the operational requirements of such aircraft.

3.7.4 To calculate the aerodrome reference temperature, find the month with the highest average daily temperature. Take that average and add one-third of the difference between it and the average of the highest daily temperatures in that same month.

Aerodrome reference temperature = $T1 + \frac{T2 - T1}{3}$

T1 = the monthly mean of the average daily temperature for the hottest month of the year.

T2 = the monthly mean of the maximum daily temperature for the same month. The values of T1 and T2 are determined over a period of years. On any day, it is easy to observe the maximum and minimum temperature, t2 and t1, respectively.

Average daily temperature = $\overline{t1 + t2}$

Maximum daily temperature = t2

For a thirty-day month, therefore, the monthly mean of the average daily temperature, T1 = $\frac{1}{30}$ of the thirty values of $\frac{t1 + t2}{2}$ obtained once every day in the hottest month, all added together. Similarly, the monthly mean of the maximum daily temperature T2 = $\frac{1}{30}$ of the thirty values of t2 obtained once every day in the hottest month, all added together.

Table 191-1 Standard Atmosphere Values

Altitude (m)	Temperature (Centigrade)	Pressure (kg/m^3)
0	15.00	1.23
500	11.75	1.17
1 000	8.50	1.11
1 500	5.25	1.06
2 000	2.00	1.01
2 500	- 1.25	0.96
3 000	- 4.50	0.91
3 500	- 7.75	0.86
4 000	- 10.98	0.82
4 500	- 14.23	0.78
5 000	- 17.47	0.74
5 500	- 20.72	0.70
6 000	- 23.96	0.66

Source: ICAO Doc 9157 Part 1

3.7.5 Where the basic length determined by take-off requirements is 900 m or over, that length should be further increased at the rate of 10% for each 1% of the runway slope as defined by OTAR Part 191.

3.7.6 At aerodromes where temperature and humidity are both high, some addition to the runway length determined under 3.7.5 may be necessary, even though it is not possible to give exact figures for the increased length required.

3.8 Examples of the Application of Runway Length Corrections

3.8.1 The following examples illustrate the application of the runway length corrections.

Example 1

Data	
runway length required for landing at sea level in standard atmospheric conditions	2 100m
runway length required for take-off at a level site at sea level in standard atmospheric conditions	1 700m
aerodrome elevation	150m
aerodrome reference temperature	24°C
temperature in the standard atmosphere for 150 m	14.025°C
runway slope	0.5%

Corrections to runway take-off length	
runway take-off length corrected for elevation = $\left[1700 \times 0.07 \times \frac{150}{300}\right] + 1700 =$	1 760m
runway take-off length corrected for elevation and temperature = $\left[1760 \times (24 - 14.025) \times 0.01\right] + 1760 =$	1 936m
runway take-off length corrected for elevation, temperature and slope = $\left[1936 \times 0.5 \times 0.10\right] + 1936 =$	2 033m
Correction to runway landing length: runway landing length corrected for elevation = $\left[2100 \times 0.07 \times \frac{150}{300}\right] + 2100 =$	2 174m
Actual runway length =	2 175m

Example 2

Data	
runway length required for landing at sea level in standard atmospheric conditions	2 100m
runway length required for take-off at a level site at sea level in standard atmospheric conditions	2 500m
aerodrome elevation	150m
aerodrome reference temperature	24°C
temperature in the standard atmosphere for 150 m	14.025°C
runway slope	0.5%

Corrections to runway take-off length	
runway take-off length corrected for elevation = $\left[2500 \times 0.07 \times \frac{150}{300}\right] + 2500 =$	2 588m
runway take-off length corrected for elevation and temperature = $[2588 \times (24 - 14.025) \times 0.01] + 2588 =$	2 846m
runway take-off length corrected for elevation, temperature and slope = $[2846 \times 0.5 \times 0.10] + 2546 =$	2 033m
Correction to runway landing length: runway landing length corrected for elevation = $\left[2100 \times 0.07 \times \frac{150}{300}\right] + 2100 =$	2 174m
Actual runway length =	2 988m

3.9 Runway Physical Characteristics – Width

3.9.1 The primary parameter for determining the width of a runway is the Outer Main Gear Wheel Span (OMGWS) of the aeroplane the runway is intended to serve. The width of a runway should be not less than the appropriate dimension specified in Table 191-2.

3.9.2 The runway widths shown in Table 191-2 are the minimum widths considered necessary to ensure the safety of operations. The factors affecting the width of runways are:

1) deviation of an aeroplane from the centre line at touchdown;
2) cross-wind condition;
3) runway surface contamination (e.g. rain, snow, slush or ice);
4) rubber deposits;
5) approach speeds used;
6) visibility;
7) human factors

Table 191-2 Runway Widths

	Outer Main Gear Wheel Span (OMGWS)			
Code Number	Up to but not including 4.5m	4.5m up to but not including 6m	6m up to but not including 9m	9m up to but not including 15m
1a	18m	18m	23m	-
2a	23m	23m	30m	-
3	30m	30m	30m	45m
4	-		45m	45m

3.9.3 Studies using simulators to recreate take-offs with engine failure and crosswinds on contaminated runways, along with observations at numerous airports, demonstrate the operational necessity of the current runway width specifications for different aircraft categories. Any planning to use narrower runways than recommended should involve careful analysis of the potential consequences for safety, efficiency, on-time performance, and overall airport capacity.

3.10 Runway Physical Characteristics – Sight Distance

3.10.1 Where slope changes cannot be avoided, they should be such that there will be an unobstructed line of sight from:

1) any point 3 m above a runway to all other points 3 m above the runway within a distance of at least half the length of the runway where the code letter is C, D or E;

2) any point 2 m above a runway to all other points 2 m above the runway within a distance of at least half the length of the runway where the code letter is B; and

3) any point 1.5 m above a runway to all other points 1.5 m above the runway within a distance of at least half the length of the runway where the code letter is A.

3.10.2 Ensuring unobstructed sight along the entire single runway is essential where there's no full-length parallel taxiway.

3.11 Distance Between Slope Changes

3.11.1 Undulations or appreciable changes in slopes located close together along a runway should be avoided. The distance between the points of intersection of two successive curves should not be less than:

1) 30 000 m where the code number is 4;

2) 15 000 m where the code number is 3; and

3) 5 000 m where the code number is 1 or 2; or

4) 45m

whichever is greater.

3.11.2 The following example illustrates how the distance between slope changes is to be determined (see Figure 191-7):

D for a runway where the code number is 3 should be at least

15 000 [|x-y| + |y-z|] m

|x-y| being the absolute numerical value of x-y

Assuming x = +0.01

y = -0.005

z = +0.005

then |x-y| = 0.015

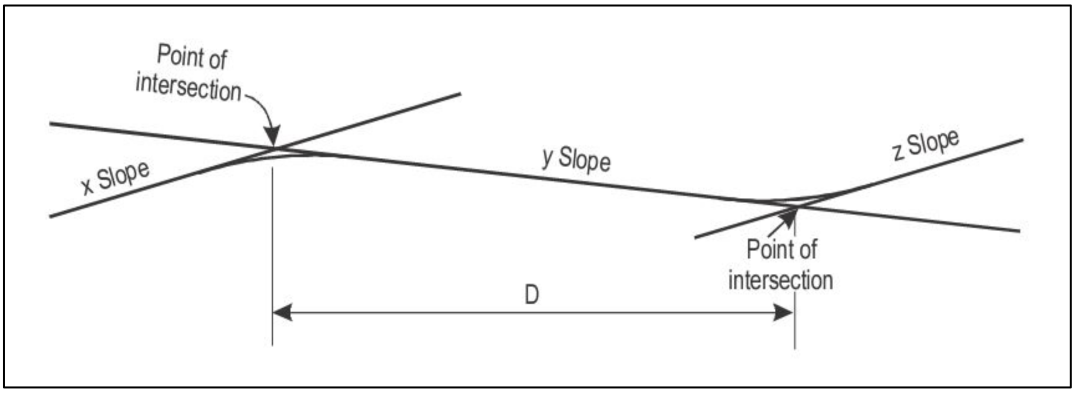
|y-z| = 0.01

To comply with the specifications, D should be not less than:

15 000 (0.015 + 0.01) m,

that is, 15 000 × 0.025 = 375 m

Figure 191-7 Profile on centre line of runway



Source: ICAO Doc 9157 Part 1

3.12 Runway Surface and Texture

3.12.1 Runway surfaces must be constructed to maintain optimal friction for braking and prevent irregularities that could disrupt aircraft control during take-off and landing. Unevenness can cause excessive vertical movement, pitch instability, and vibrations, hindering pilot ability to safely operate the aircraft.

3.12.2 To establish acceptable tolerances for runway unevenness, good engineering practices recommend a specific construction standard for short distances (3 metres). This involves ensuring, by using a 3-metre straight-edge placed anywhere on the runway surface in any direction, that the maximum deviation between the straight-edge bottom and the pavement surface does not exceed 3 millimetres, excluding areas like camber crowns and drainage channels.

3.12.3 Caution should also be exercised when inserting runway lights or drainage grilles in runway surfaces to ensure that adequate smoothness of the surface is maintained.

3.12.4 Aircraft operations and foundation movement gradually introduce surface irregularities. Minor deviations from the specified tolerances are generally acceptable. However, isolated bumps exceeding 2.5 cm to 3 cm over 45 m can pose challenges. Precise guidelines for maximum allowable irregularities are challenging to establish due to variations in aircraft characteristics, including mass, distribution, undercarriage design, and landing speed. Additionally, a sequence of seemingly acceptable individual irregularities can collectively induce significant dynamic loads on the aircraft or severe vibrations, potentially hindering instrument readability in the cockpit.

3.12.5 Measuring the actual response of an aircraft traversing a specific runway surface provides valuable data on the dynamic loads experienced during take-off and landing. Ground-run simulation models, utilising real or planned surface profiles, offer a powerful tool for objectively evaluating runway and taxiway quality. This approach enables pre-emptive analysis of the impact of surface modifications on aircraft response, minimising uncertainties and facilitating cost-benefit assessments. The simulation focuses on critical undercarriage loads as a key indicator of acceptable surface unevenness.

3.12.6 Runway deformations over time can exacerbate water pooling. Shallow pools, as little as 3 mm deep, particularly when encountered by landing aircraft at high speeds, can induce aquaplaning, a phenomenon sustained on wet runways by even shallower water depths. Therefore, proactive measures to prevent pooling are essential, especially in freezing conditions, where potential ice formation poses additional risks.

3.12.7 Wet weather runway friction is crucial for aircraft safety. Years of research and operational experience have established properly engineered and maintained asphaltic and Portland cement concrete surfaces as reliable solutions. Nevertheless, the door remains open for innovative materials that meet these critical friction requirements.

3.12.8 To verify the achieved friction characteristics of a newly constructed or resurfaced runway against its design objectives, continuous friction measurements employing self-wetting functionality are essential. This method provides comprehensive data under simulated wet conditions, thereby guaranteeing adequate and consistent grip for safe aircraft operations. Guidance on friction characteristics of new runway surfaces is given in the Airport Services Manual (Doc 9137), Part 2.

3.12.9 When the surface is grooved or scored, the grooves or scorings should be either perpendicular to the runway centre line or parallel to non-perpendicular transverse joints, where applicable. Guidance on methods for improving the runway surface texture is given in the Aerodrome Design Manual, Part 3 — Pavements.

3.13 Runway Strip

3.13.1 A runway strip extends laterally to a specified distance from the runway centre line, longitudinally before the threshold, and beyond the runway end. It provides an area clear of objects which may endanger aeroplanes. The strip includes a graded portion which should be so prepared as to not cause the collapse of the nose gear if an aircraft should leave the runway. There are certain limitations on the slopes permissible on the graded portion of the strip. The runway strip is also required to protect ILS/MLS sensitive/critical areas. Within the strip, there is an object-free area. Any equipment or installation, required for air navigation or for aircraft safety purposes, located in this object-free area, should be frangible and mounted as low as possible. A runway and any associated stopways are included in a strip.

3.13.2 Runway strips must be free of unauthorised obstacles for safe aircraft operations. Essential equipment, if unavoidable, should be minimised in size and mass, designed to break apart upon impact, and strategically positioned to minimise potential risk.

3.13.3 No fixed object, other than visual aids required for air navigation or those required for aircraft safety purposes and which must be sited on the runway strip, and satisfy the relevant frangibility requirement in OTAR Part 191 shall be permitted on any part of a runway strip of a precision approach runway delineated by the lower edges of the inner transitional surfaces.

3.13.4 Essential navigation or safety equipment, unavoidable in the runway strip, must be minimised in size and height. They must be frangible and strategically positioned to minimise risk to aircraft. During runway use for landing or take-off, no mobile objects are permitted in this critical area.

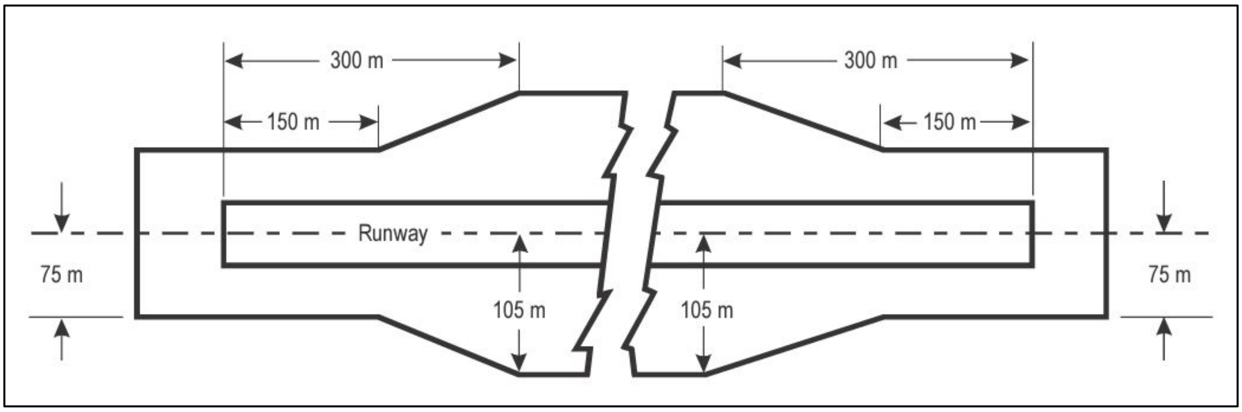
3.13.5 Measures should be implemented within the runway strip vicinity to prevent aircraft wheels sinking into the ground from encountering abrupt vertical obstacles, such as the drainage elements mentioned in 3.12.6. Significant damage to landing gear can occur in such scenarios. Particular attention should be paid to runway lighting installations and other objects within the strip or at intersections with taxiways or other runways. In cases where flush surfaces are unavoidable (e.g., taxiway intersections), a gradual transition can be achieved by chamfering the vertical face downward from the construction to a minimum depth of 30 cm below the strip surface. Other objects not requiring surface level positioning should be buried to a minimum depth of 30 cm.

3.13.6 The positioning and configuration of drainage systems within runway strips require careful consideration to mitigate potential damage to aircraft that inadvertently exit the runway surface. Open-air or covered stormwater conveyance structures must be installed at or below the level of the surrounding ground to ensure they do not protrude and constitute an obstacle to safe aircraft operation.

3.13.7 Particular attention must be given to the design and maintenance of an open-air storm water conveyance in order to prevent bird attraction: if needed, it can be covered by a net. Guidance on wildlife control and reduction can be found in the Airport Services Manual (Doc 9137) Part 3 — Wildlife Hazard Management.

3.13.8 Consideration may be given to adopting a wider runway strip for precision approach runways designated as code number 3 or 4. Figure 191-8 displays the dimensions and configuration of a potential wider strip for such runways, informed by research on aircraft runway excursions. This proposed strip design features a graded portion extending to a distance of 105 meters from the runway centre line, with a gradual reduction to 75 meters at both ends for a length of 150 meters from the runway extremity.

Figure 191-8 Graded portion of a strip including a precision approach runway, where the code number is 3 or 4, denoting Longitudinal Slope changes



Source: ICAO Doc 9157 Part 1

3.13.9 In instances where adequate drainage necessitates the implementation of an open-air storm water conveyance system within the non-graded segment of a runway strip, its installation should prioritise maximal separation from the paved runway surface. Moreover, the aerodrome rescue and firefighting protocols must explicitly acknowledge the location and potential implications of such open-air water conveyances in emergency response scenarios.

3.13.10 In consideration of the graded strip's function as a critical safety element for aircraft running off the runway, its design must effectively minimise the risk of nose landing gear collapse while also providing controlled deceleration. To achieve this dual objective, a tiered approach is recommended:

1) Underlying Prepared Surface: The soil layer approximately 15 cm below the finished surface is prepared to a specified California Bearing Ratio (CBR) value of 15-20, ensuring adequate load-bearing capacity and limiting nose gear penetration beyond the intended depth.

2) Deceleration Layer: The top 15 cm layer, composed of less compacted soil, is optimised for frictional characteristics to promote controlled deceleration of the aircraft while mitigating potential damage.

3.13.11 For a precision approach runway it may be desirable to adopt a greater width where the code number is 3 or 4. Figure 191-8 shows the shape and dimensions of a wider strip that may be considered for such a runway. This strip has been designed using information on aircraft running off runways. The portion to be graded extends to a distance of 105 metres from the centre line, except that the distance is gradually reduced to 75 metres from the centre line at both ends of the strip, for a length of 150 metres from the runway end.

3.14 Runway End Safety Area (RESA)

3.14.1 Analysis of ICAO Aircraft Accident/Incident Data Reports (ADREP) reveals a significant prevalence of aircraft sustaining substantial damage due to undershooting or overrunning runways during landing and take-off operations. To mitigate the severity of such occurrences, the implementation of dedicated Runway End Safety Areas (RESA) extending beyond the conventional runway strip is deemed essential. These RESAs must possess adequate load-bearing capacity to accommodate an aircraft excursion and remain devoid of any non-frangible equipment or installations to minimise potential for further damage.

3.14.2 The dimensioning of a RESA necessitates a comprehensive assessment of reasonably probable adverse operational factors that could contribute to runway overruns and undershoots. On precision approach runways, the ILS localiser typically represents the first significant obstacle in the RESA's path, serving as the minimum terminal point for its extension. Under other circumstances, the presence of roads, railways, or other constructed or natural features may necessitate extending the RESA beyond the conventional minimum to encompass potential impact points and mitigate associated risks.

3.14.3 A comprehensive study of the ICAO ADREP data pertaining to runway overruns reveals that a conventional 90-metre RESA would effectively contain approximately 61% of such occurrences, with the recommended 240-meter distance encompassing 83%. Nevertheless, the potential for overruns exceeding even the extended 240-meter RESA is recognised. Consequently, regardless of the chosen RESA length beyond the standard, prioritising the minimisation of both the probability and potential repercussions of runway overruns to the absolute maximum extent feasible remains paramount.

3.14.4 Objects on the runway end safety area, beyond designated navigation or safety equipment, shall be considered obstacles and removed whenever possible due to potential aircraft hazard. Any essential equipment or installations unavoidable in this critical area must adhere to frangibility requirements, minimising their physical impact upon aircraft in the event of accidental contact. Furthermore, their optimal siting within the safety area is crucial for reducing potential risk to a minimum.

3.14.5 In conjunction with the designated runway strip, a RESA should be established to offer a cleared and levelled expanse for accommodating aircraft which unintentionally under- or overshoot the intended landing or take-off area. While the RESA's surface characteristics need not match the stringent quality standards of the runway itself, it must be adequately cleared and graded to ensure safe deceleration and limit potential aircraft damage in such eventualities.

3.14.6 The slopes of a runway end safety area should be such that no part of the runway end safety area penetrates the approach or take-off climb surface.

3.14.7 To accommodate aeroplanes making auto-coupled approaches and automatic landings (irrespective of weather conditions) it is desirable that slope changes be avoided or kept to a minimum on an area symmetrical about the extended runway centre line approximately 60 metres wide, and 300 metres long before the threshold of a precision approach runway. This is desirable because these aeroplanes are equipped with a radio altimeter for final height and flare guidance, and when the aeroplane is above the terrain immediately prior to the threshold, the radio altimeter will begin to provide information to the automatic pilot for auto-flare. Where slope changes cannot be avoided, the rate of change between two consecutive slopes should not exceed 2% per 30 metres.

3.15 Arresting Systems

3.15.1 Properly designed arresting systems play a crucial role in mitigating the consequences of runway overruns. Engineered Materials Arresting Systems (EMAS), utilising beds of energy-absorbing materials that crumble under aircraft weight, have become a popular choice at many airports due to their predictable and effective performance. Alternatively, military airfields commonly employ cable/hook-wire arresting systems, designed to capture and securely anchor aircraft overruns through a mechanical engagement process.

3.15.2 The implementation of standard or recommended RESA on existing runways poses significant challenges, particularly for those constructed prior to the stricter requirements adopted in 1999. Natural obstacles, local development, and environmental constraints are frequent impediments, rendering the costs of extended RESA potentially disproportionate to the anticipated safety benefits. In recognition of this, Amendment 11-A to Annex 14, Volume I introduces a provision whereby, upon installation of an approved arresting system and subject to State acceptance, the standard or recommended RESA length may be reduced based on the specific system design.

3.15.3 For certain runways, particularly those with limited space or environmental constraints, achieving the standard Runway End Safety Area (RESA) length might be impractical. In such situations, a potential solution involves shortening the runway itself and installing an arresting system in the remaining space. This system offers independent deceleration capabilities, unaffected by factors like aircraft braking performance, contamination, or weather conditions, ultimately enhancing overall safety.

3.15.4 Installing aircraft arresting systems requires government authorisation, necessitating the development of specific acceptance procedures. These procedures typically involve two key steps: evaluating the technical design of the system (type evaluation) and ensuring its proper implementation and maintenance within the specific airport environment (in-situ project acceptance). However, depending on the circumstances, alternative evaluation methods may be considered.

3.15.5 Appendix A provides guidance on the performance and compatibility requirements for arresting systems. These requirements may be considered as an initial draft for national rules, or to be used directly as applicable provisions. A list of the national provisions of four States containing materials relevant to arresting systems is also included.

3.15.6 The presence of an arresting system shall be published in the aerodrome AIP entry and information/instructions promulgated to local runway safety teams and others to promote awareness in the pilot community. The serviceability of aircraft arresting systems is to be announced in a NOTAM. It is also good practice to represent the availability of arresting systems in aeronautical charts in an easily perceivable manner.

3.16 Clearways and Stopways

3.16.1 Objects within the clearway, the designated airspace extending beyond the runway, pose a potential hazard to aircraft and should be removed wherever feasible. Essential navigation equipment unavoidable in this area must be minimised in size and height, constructed with frangible design principles for impact mitigation, and strategically positioned to minimise risk to approaching or departing aircraft.

3.16.2 The surface of a paved stopway should be so constructed as to provide a good coefficient of friction, compatible with that of the associated runway, when the stopway is wet.

3.16.3 The friction characteristics of an unpaved stopway should not be substantially less than that of the runway with which the stopway is associated.

3.16.4 A stopway should be prepared or constructed so as to be capable, in the event of an abandoned take-off, of supporting the aeroplane which the stopway is intended to serve without inducing structural damage to the aeroplane.

4. Taxiways

4.1 Taxiway Systems

4.1.1 Achieving maximum capacity and efficiency at an airport requires a delicate balance between runway capacity, terminal throughput for passengers and cargo, and dedicated space for aircraft storage and servicing. These distinct elements are intertwined by the network of taxiways, which act as arteries for optimal movement and utilisation of the entire airport.

4.1.2 The capacity of an airport's taxiway system should be directly proportional to the runway acceptance rate. This means that at low traffic levels, a basic layout with minimal taxiways can handle the flow. However, as the rate of accepted take-offs and landings increases, the taxiway system must expand to prevent it from becoming the limiting factor for the overall airport capacity. In the ultimate scenario where runways are operating at full capacity and aircraft are spaced at minimum separation distances, the taxiway system needs to efficiently expedite departures after landing and minimise waiting times for entries before take-off. This ensures that runway operations can maintain the minimum separation standards even under peak pressure.

4.1.3 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, suppose an aerodrome is forecasted to serve a higher category of aircraft type in the future. In that case, the current taxiway system should be designed to accommodate the greatest separation distances that will ultimately be required (Table 191-3).

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

1) taxiway routes should connect the various aerodrome elements by the shortest distances, thus minimising both taxiing time and cost.

2) taxiway routes should be as simple as possible in order to avoid pilot confusion and the need for complicated instructions.

3) 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.

4) 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.

5) taxiway routings should have as many one-way segments as possible to minimise aircraft conflicts and delays. Taxiway segment flows should be analysed for each configuration under which runway(s) will be used.

6) the taxiway system should be planned to maximise each component's useful life so that future development phases incorporate sections from the current system.

7) 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.

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

1) 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.

2) taxiway layouts should be planned to avoid interference with navigation aids by taxiing aircraft or ground vehicles using the taxiway.

3) 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.

4) the effects of jet blast on areas adjacent to the taxiways should be mitigated by stabilising loose soils and erecting blast fences where necessary to protect people or structures.

5) 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.

Table 191-3 Design Criteria for Taxiways

	Outer Main Gear Wing-span (OMGWS)					
Physical Characteristics	Up to but not including 4.5 m	4.5 m up to but not including 6 m	6 m up to but not including 9 m	9 m up to but not including 15 m	9 m up to but not including 15 m	9 m up to but not including 15 m
Minimum width of taxiway pavement	7.5m	10.5m	15m[1 2] 17m[3]	23m[2]	23m	23m
Graded portion of taxiway strip	20.5m	22m	25m	37m	38m	44m
Minimum clearance distance of outer main wheel to taxiway edge	1.5m	2.25m	3m[1] 4m[3]	4m	4m	4m
	Code Letter					
Physical Characteristics	A	B	C	D	E	F
Minimum width of: taxiway pavement	-	-	25m	34m	38m	44m
Minimum width of: shoulder taxiway strip	31m	40m	52m	74m	87m	102m
Minimum separation distance between taxiway centre line and centre line of instrument runway code						
Code 1	77.5m	82m	88m	-	-	-
Code 2	77.5m	82m	88m	-	-	-
Code 3	-	152m	158m	166m	172.5m	180m
Code 4	-	-	158m	166m	172.5m	180m
Minimum separation distance between taxiway centre line and centre line of non-instrument runway code						
Code 1	37.5m	42m	48m	-	-	-
Code 2	47.5m	52m	58m	-	-	-
Code 3	-	87m	93m	101m	107.5m	115m
Code 4	-	-	93m	101m	107.5m	115m
Minimum separation distance between taxiway centre line and taxiway centreline object	23m	32m	44m	63m	76m	91m

Minimum separation distance between taxiway centre line and taxiway [4]	15.5m	20m	26m	37m	43.5m	51m
	Code Letter					
Physical Characteristics	A	B	C	D	E	F
Minimum separation distance between taxiway centre line and aircraft stand taxi lane	12m	16.5m	22.5m	33.5m	40m	47.5m
Maximum longitudinal slope of taxiway pavement	3%	3%	1.5%	1.5%	1.5%	1.5%
Maximum longitudinal slope of taxiway change in slope	1% per 25m	1% per 25m	1% per 30m	1% per 30m	1% per 30m	1% per 30m
Maximum transverse slope of taxiway pavement	2%	2%	1.5%	1.5%	1.5%	1.5%
Maximum transverse slope of graded portion of taxiway strip upwards	3%	3%	2.5%	2.5%	2.5%	2.5%
Maximum transverse slope of graded portion of taxiway strip downwards	5%	5%	5%	5%	5%	5%
Maximum transverse slope of ungraded portion of strip upwards or downwards	5%	5%	5%	5%	5%	5%
Minimum radius of longitudinal vertical curve	2 500m	2 500m	3 000m	3 000m	3 000m	3 000m
Minimum taxiway sight distance	150m from 1.5m above	200m from 2m above	300m from 3m above	300m from 3m above	300m from 3m above	300m from 3m above

[1] Taxiway intended to be used by aeroplanes with a wheelbase less than 18 m
[2] On straight portions·
[3]Taxiway intended to be used by aeroplanes with a wheelbase equal to or greater than 18 m.
4 Taxiway other than an aircraft stand taxi lane.

4.1.6 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 utilisation. The following principles apply to the planning of these taxiway system components:

1) the function of exit taxiways is to minimise 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;

2) 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;

3) 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 are presented in Section 4 and Appendix B);

4) 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 it, the use of bypasses, holding bays, or multiple runway entrances can be considered.

4.1.7 Taxiways located on aprons are divided into two types as follows (see Figure 191-9):

1) 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.

2) aircraft stand taxilane is a portion of an apron designated as a taxiway and intended to provide access to aircraft stands only.

4.1.8 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:

1) the transverse slope of the taxilane is governed by the apron slope requirement;

2) the aircraft stand taxilane does not need to be included in a taxiway strip;

3) 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.

4.1.9 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.

4.1.10 Figure 191-10 provides a reference to the minimum separate distances as provided in Table 6 of OTAR 191, for each of the taxiways and taxilanes mentioned in Figure 191-8.

4.1.11 To minimise 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 191-11):

1) a minimum aerodrome taxiway system, supporting a low level of runway utilisation, 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;

2) traffic growth which results in a low to moderate level of runway utilisation, 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);

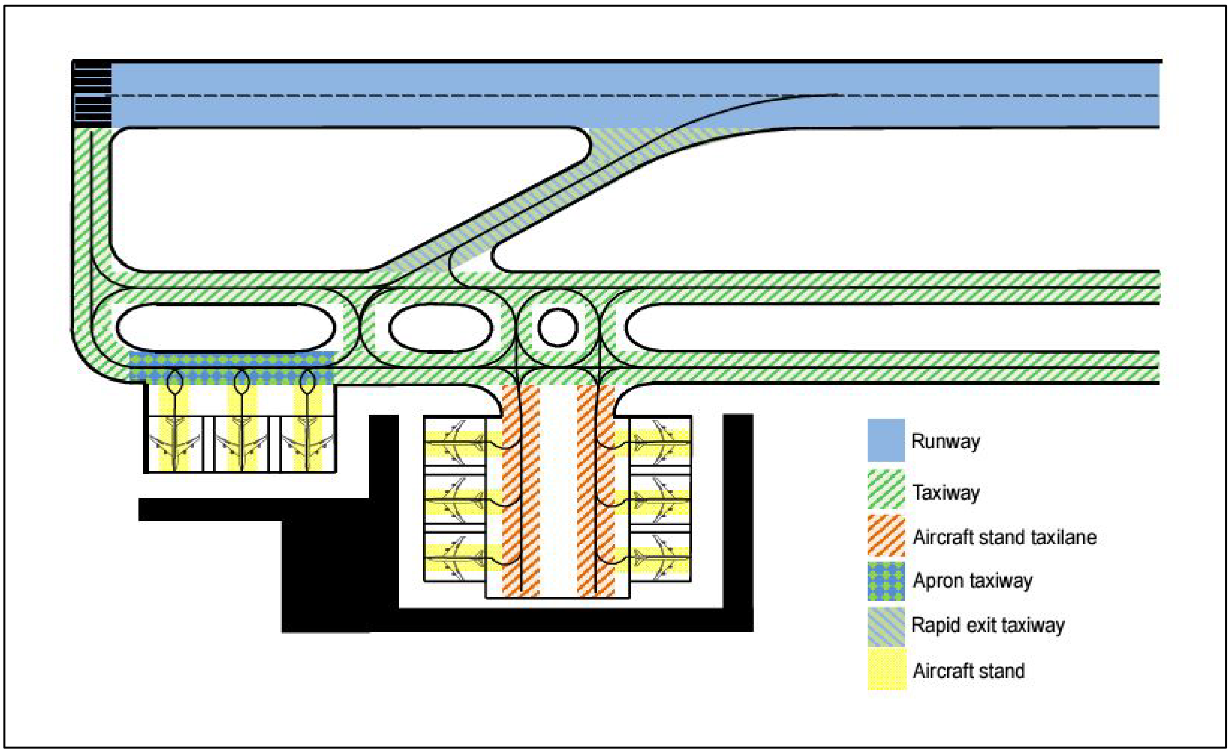
3) as runway utilisation increases, a full parallel taxiway can be provided by completing the missing sections of the partial parallel taxiway;

4) exit taxiways, in addition to the ones at each runway end, can be constructed as runway utilisation increases toward saturation;

5) 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;

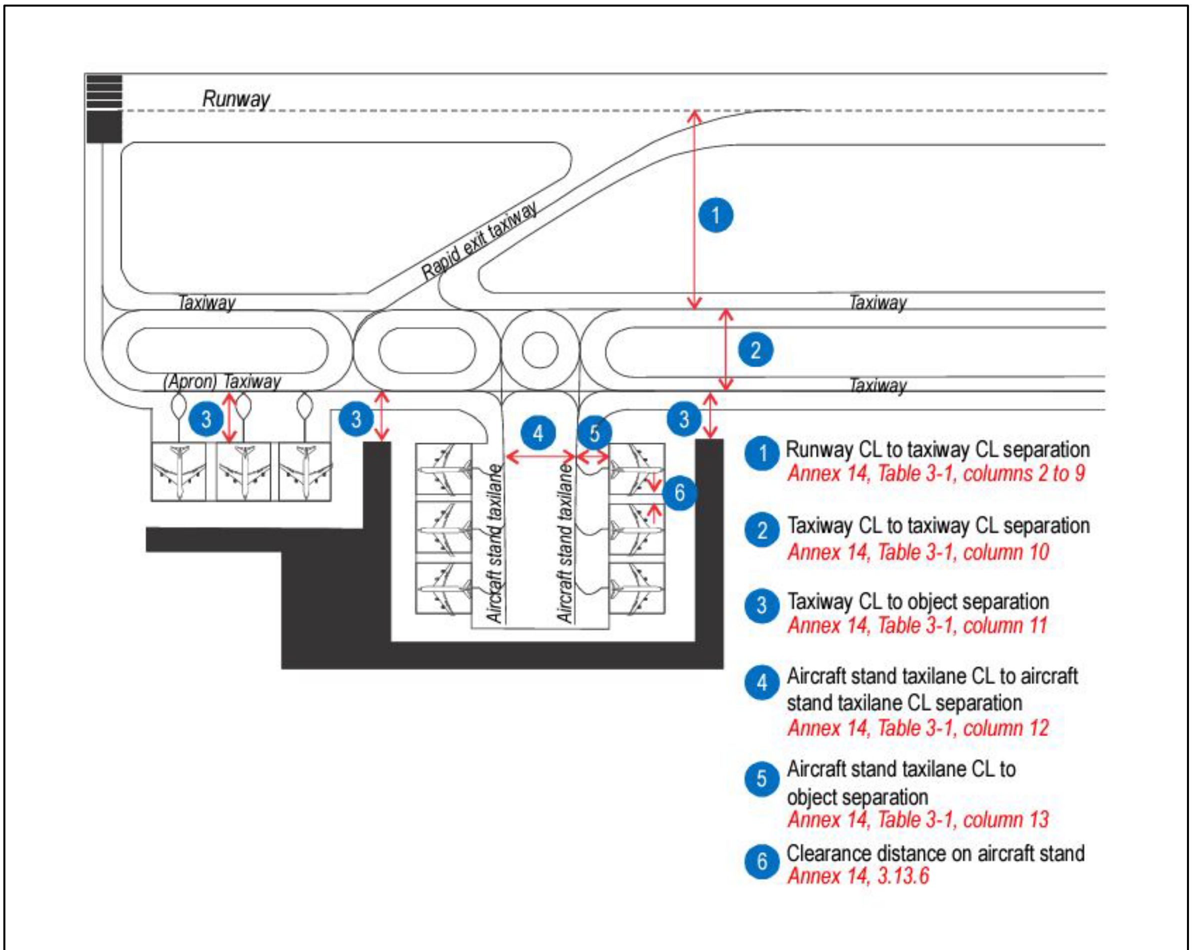
6) a dual-parallel taxiway, located outboard of the first parallel taxiway, should be considered when movement in both directions along the taxiway is desirable. With this second taxiway, a one-way flow network can be established for each direction of runway use. The need for the dual-parallel system increases proportionately to the development alongside the taxiway.

Figure 191-9 Taxiways on Aprons



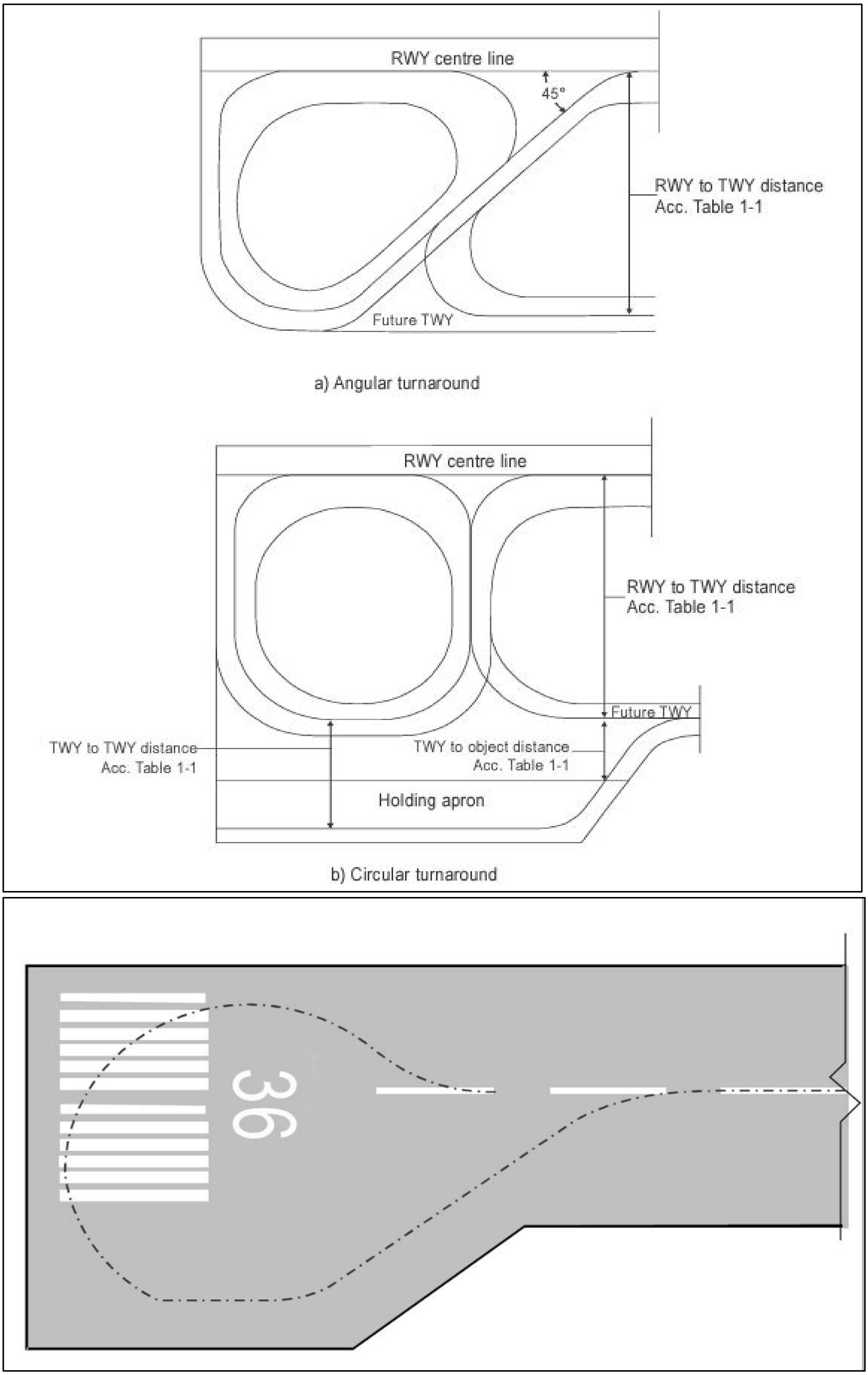
Source: ICAO Doc 9157 Part 2

Figure 191-10 Taxiway Minimum Separation Distances



Source: ICAO Doc 9157 Part 2

Figure 191-11 Turnarounds



Source: ICAO Doc 9157 Part 2

4.1.12 Standardised taxiway names enhance airport safety by improving pilot awareness and minimising the risk of navigational errors that could lead to runway crossings.

4.1.13 These guidelines are primarily for designing new airports. For existing airports, they're useful during master plan updates or major taxiway network changes. However, retrofitting existing airports with these guidelines could be expensive, especially for medium-sized and large ones. The cost-benefit trade-off should be carefully analysed before implementation. Smaller airports with fewer designators might not need these changes at all.

4.1.14 Changing taxiway names requires thorough safety assessments, but implementation comes with challenges like operational disruptions, retraining, and document updates. Careful transition planning and flexibility for future adjustments are crucial for success.

4.1.15 Before applying these guidelines to a large chunk of existing facilities, a thorough risk assessment, impact study, and cost-benefit analysis are mandatory. Expect limitations and challenges, especially at major airports where frequently used taxiway names might be limited by the alphabet. Open communication with all stakeholders, including airlines, pilots, air traffic controllers, and ground handlers, is crucial for a smooth transition.

4.1.16 The general principles are:

1) the taxiway nomenclature system has, as a primary purpose, to provide a clear, logical and convenient system to pilots and air traffic controllers.

2) in accordance with Annex 14, Volume. I, Chapter 5, a taxiway shall be identified by a designator that is used only once on an aerodrome comprising a single letter, two letters or a combination of a letter or letters followed by a number.

3) the assignment of letters for the designation of taxiways starts at one end of the aerodrome and follows a consistent sequence to the opposite end (e.g. east to west, north to south, clockwise, counter-clockwise).

4) in accordance with Annex 14, Volume. I, Chapter 5, the use of the letters I, O or X shall not be used to avoid confusion with the numerals 1, 0 and closed marking.

5) in accordance with Annex 14, Volume. I, Chapter 5, when designating taxiways the use of words such as ‘INNER’ and ‘OUTER’ should be avoided wherever possible. Apron stand designators should not be the same as taxiway designators.

6) taxi routes are used by the appropriate air traffic service (ATS) authority as a means to reduce congestion on ground frequencies and increase the predictability of taxi clearances. Care should be taken while coding or naming these standard taxi routes so that they do not create confusion with the taxiway nomenclature.

4.1.17 Primary taxiways (i.e. one that serves a frequently used traffic route):

1) frequently used taxiways have to be restricted to one letter only, e.g. A (Alpha).

2) a taxiway parallel to a runway is automatically considered as a primary taxi route and has to be designated by a single letter.

3) a primary taxiway may include a curved section. Where another taxiway joins the primary taxiway, that taxiway has to be assigned a separate designator.

4.1.18 Taxiways connecting to runways:

1) taxiways that connect to a runway have an alpha-numeric designation (e.g. C1, C2, C3...C12). The numbering starts from the number one (1) at one end of the runway and follows a consistent sequence to the other end of the runway. This sequence has to be initiated in the direction of the most common use of the runway.

2) where additional taxiways are expected to be constructed as per the airport master plan, the sequence mentioned in para 4.1.18 (1) for numbering the taxiways may be reserved for future taxiway(s). This prevents renumbering of the entire taxiway system at a later date. A safety assessment has to be conducted before deciding to omit certain taxiway nomenclature in the sequence for future requirements (see Figure 191-12).

3) where one parallel taxiway serves two runways, the numbers for the connecting taxiways has to increment sequentially for the first runway and has not to be continued on the second runway (see diagram below). The numbering for the connecting taxiways for the second runway starts again from the number one (1) using a new single letter.

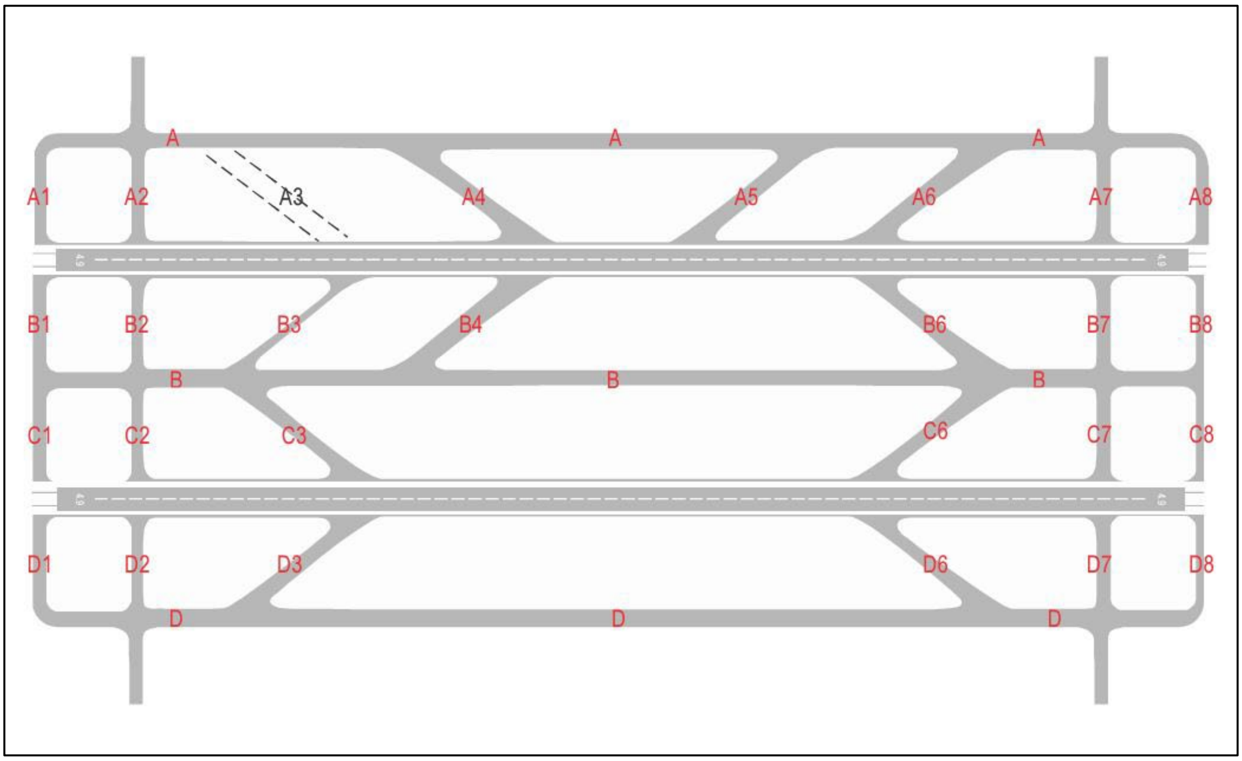
4) when a taxiway crosses a runway, a different designator has to be used on either side of the runway.

4.1.19 Other taxiways:

1) when a taxiway crosses a primary taxiway, different designators have to be used on either side of the primary taxiway based on local conditions and safety assessments.

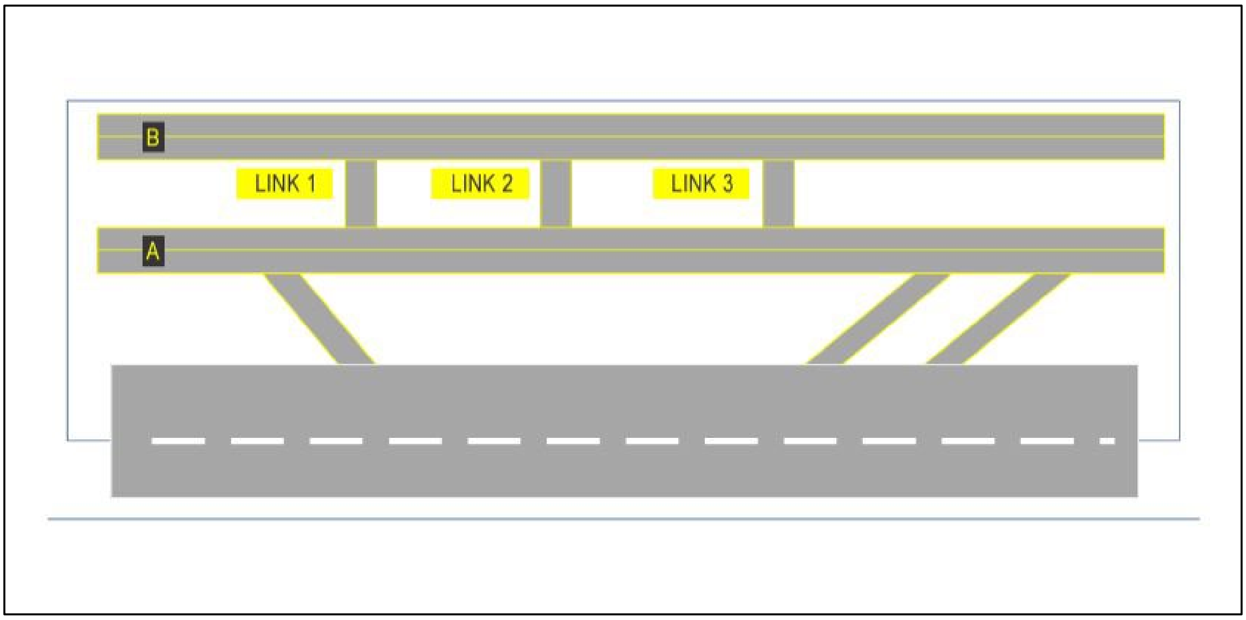
2) may have short taxiways that connect two taxiways. In some instances, they are named as "LINK 1, LINK 2, etc." and the naming of these taxiways follows a logical sequence according to the airside layout and network of taxiways. If appropriate, mainly depending of the length of these taxiways and if the place is available, this practice may be considered. These taxiways do not cross any other taxiway. The sequence has to be similar to that used for the designation of taxiways.

Figure 191-12 Suggested Nomenclature for Complex Taxiway System



Source: ICAO Doc 9157 Part 2

Figure 191-13 Nomenclature for Connecting Taxiways



Source: ICAO Doc 9157 Part 2

4.2 Taxiway Layout Alternatives

4.2.1 When assessing alternative taxiway configurations, a critical aspect is analysing their operational efficiency within the context of the existing runway and apron layouts. More intricate infrastructure arrangements present increased potential for cost reductions through comparative evaluation of diverse taxiway systems. To facilitate this analysis, numerous computerised aircraft traffic flow simulation models have been developed by various stakeholders, including consultants, airlines, and airport authorities.

4.2.2 For example, the United States Federal Aviation Administration (FAA) 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:

1) aircraft mix
2) traffic volume
3) peak traffic volume
4) aerodrome layout
5) terminal destinations of aircraft
6) runway configurations
7) taxiway configurations
8) rapid exit taxiways
9) use of particular runways by categories of aircraft

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

1) taxiing fuel costs
2) taxiing distances
3) taxiing travel times
4) taxiing delays
5) runway arrival and departure delays

4.3 Aircraft Taxi Distances

4.3.1 Minimising aircraft taxi distances prioritises optimising ground movement efficiency. This translates to reduced taxi times, thereby conserving fuel and enhancing aircraft utilisation while ultimately bolstering operational safety. Heavily loaded aircraft, particularly during take-off preparation, stand to benefit the most from streamlined taxiway routing. Even smaller airports should incorporate this design philosophy to maximise operational performance and efficiency.

4.3.2 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.

4.3.3 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 the acceptable upper limit, and where unfavourable factors exist, such as those requiring frequent brakes, this limit may have to be reduced.

4.3.4 Airport master plans, regardless of size, must prioritise minimising taxi distances, particularly for departing aircraft, to achieve both economic and safety benefits. Strategically placed rapid exit taxiways can shorten routes for both landing and departing planes, while take-offs from taxiway intersections and further rapid exits reduce distances and runway occupancy time and boost overall runway capacity. This holistic approach ensures efficient and safe ground operations, maximising airport efficiency for all sizes and types of traffic.

4.4 Physical Characteristics Design Criteria

4.4.1 Design criteria for taxiways are less stringent than those for runways since aircraft speeds on taxiways are much slower than those on runways. Table 191-3 shows the main physical characteristics and design criteria recommended for a taxiway in accordance with the specifications in OTAR Part 191. It should be emphasised that with respect to the clearance distance between the aircraft's outer main wheel and the taxiway's edge, it is assumed that the aircraft's cockpit remains over the taxiway centre line markings.

4.5 Aerodrome Reference Code

4.5.1 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's 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 wingspan.

4.5.2 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 OTAR Part 191, the aeroplanes which the aerodrome is intended to serve are identified first, followed by the two elements of the code.

4.5.3 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 191-4.

4.5.4 The code number for Element 1 shall be determined from Table 191-4, 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 certificating 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”.

4.5.5 The code letter for Element 2 shall be determined from Table 191-4, selecting the code letter which corresponds to the greatest wing-span of the aeroplanes for which the facility is intended.

4.5.6 The wingspan component is relevant for aerodrome characteristics related to separation distances (e.g. obstacles, strips), while OMGWS components impact ground-based manoeuvring characteristics (e.g. runway and taxiway widths). The two determining components should be used separately since using the most demanding component may cause overdesign, either for separations or runway/taxiway width for some aeroplane types. As the OMGWS is the relevant parameter for determining runway width, taxiway width and graded portion of taxiway strips, it is referenced directly in the relevant provisions to avoid the complexity of a third code element.

Table 191-4 Aerodrome Reference Code

Code Element 1	
Code Number	Aeroplane reference field length
1	Less than 800 m
2	800 m up to but not including 1 200 m
3	1 200 m up to but not including 1 800 m
4	1 800 m and over
Code Element 2	
Code Letter	Wingspan
A	Up to but not including 15 m
B	15 m up to but not including 24 m
C	24 m up to but not including 36 m
D	36 m up to but not including 52 m
E	52 m up to but not including 65 m
F	65 m up to but not including 80 m

Source: ICAO Doc 9157 Part 2

Table 191-5 Aircraft Speeds Versus Radius of Curve

Speed (km/h)	**Radius of Curve (m)**
16	15
32	60
48	135
64	240
80	375
96	340

Source: ICAO Doc 9157 Part 2

4.5.7 Minimum taxiway widths are shown in Table 191-3. 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.

4.5.8 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 191-3.

4.5.9 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 191-5 shows values of allowable aircraft speeds for given radii of curvature based on a lateral load factor of 0.133 g. 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 191-3. It is to be noted that compound curves may reduce or eliminate the need for extra taxiway width.

4.5.10 To ensure that the minimum wheel clearance distances specified in Table 191-3 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 ICAO Doc 9157.

4.5.11 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 191-3. 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 ICAO Doc 9157 and OTAC 139-24.

4.5.12 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.

4.5.13 Formulas and separation distances are shown in Table 191-6 and illustrated in Figure 191-14. 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 191-3).

4.5.14 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”.

4.5.15 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 191-14) 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.

Table 191-6 Minimum Separation Distances Between Taxiways and Between Taxiways and Objects (dimensions in metres)

Separation Distances	Code Letter					
Between apron taxiway/taxiway centre line and apron taxiway/taxiway centre line:	**A**	**B**	**C**	**D**	**E**	**F**
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	4.0	4.0	4.0
+ Increment (Z)	6.5	5.75	5.0	7.0	7.0	7.0
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	4.0	4.0	4.0
+ Increment (Z)	6.5	5.75	5.0	7.0	7.0	7.0
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

Source: ICAO Doc 9157 Part 2

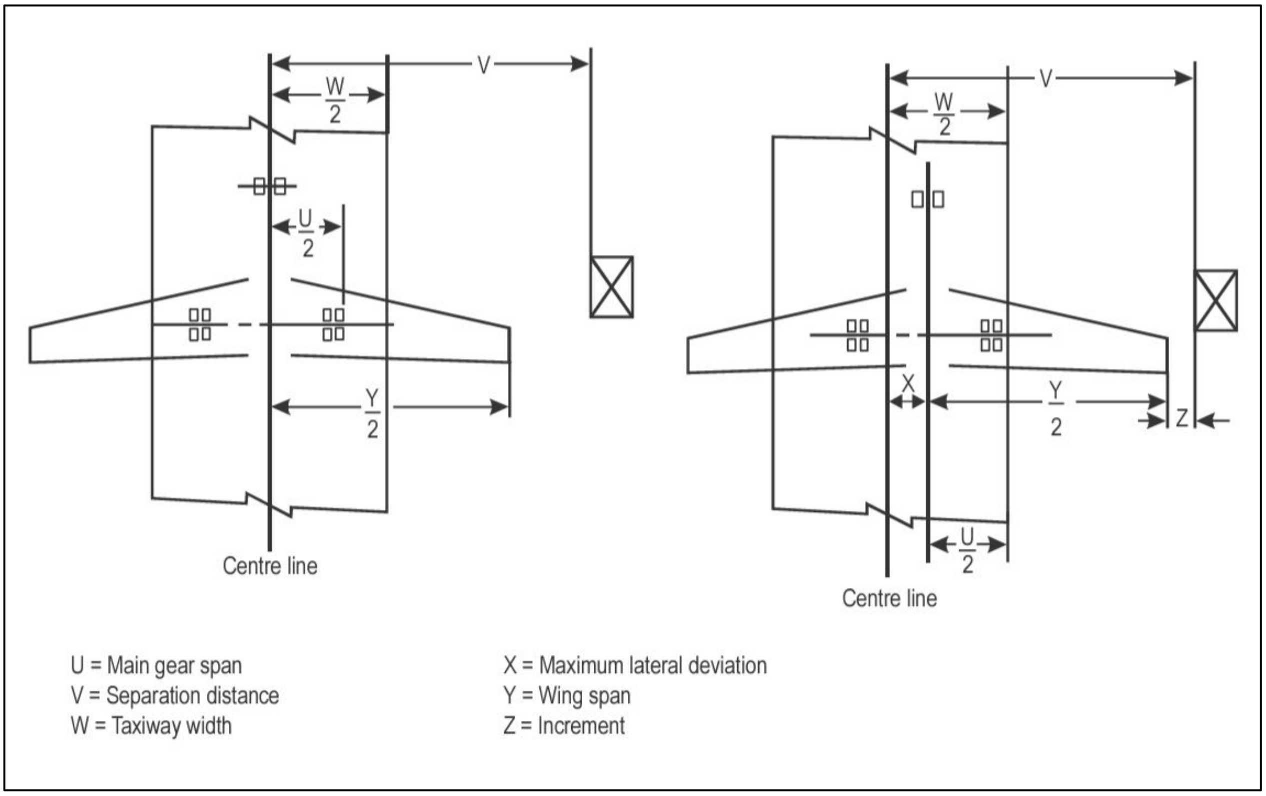
4.5.16 A graduated increment scale rather than a constant increment for all code letters has been selected because:

1) pilot judgement of clearance distance is more difficult in aircraft with larger wing-spans, particularly when the aircraft has swept wings;

2) the momentum of larger aircraft may be higher and could result in such aircraft running farther off the edge of a taxiway.

4.5.17 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.

Figure 191-14 Separation Distance to an Object



Source: ICAO Doc 9157 Part 2

4.5.18 Taxiway and apron taxiway clearances are spaced further apart from objects compared to other areas. This is because objects near these taxiways are usually permanent, increasing the chance of a collision compared to two moving aircraft briefly crossing paths. Additionally, fixed objects like fences or walls can run alongside taxiways for long stretches, creating a continuous risk. Even parked vehicles near roads bordering taxiways can unintentionally reduce safety margins.

4.5.19 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 191-7. 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 OTAR 191, Table 6 and Table 7, 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 191-3.

Table 191-7 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**
½ Wing-span (Y)	7.5	12	7.5	12	7.5	12	18	26	18	26	32.5	40
+ ½ Strip width												
non-instrument runway	30	30	40	40	75	75	75	75	75	75	75	75
Total OR (see below)	37.5	42	47.5	52	82.5	87	93	101	93	101	107.5	115
½ Wing-span (Y)	7.5	12	7.5	12	7.5	12	18	26	18	26	32.5	40
+ ½ Strip width												
instrument runway	70	70	70	70	140	140	140	140	140	140	140	140
Total	77.5	82	77.5	82	147.5	152	158	166	158	166	172.5	180

Source: ICAO Doc 9157 Part 2

4.6 Rapid Exit Taxiways (RETS)

4.6.1 A rapid exit taxiway is a taxiway connected to a runway at an acute angle and designed to allow landing aeroplanes to turn off at higher speeds than those achieved on other exit taxiways, thereby minimizing runway occupancy time.

4.6.2 A decision to design and construct a rapid exit taxiway is based upon analyses of existing and contemplated traffic. The main purpose of these taxiways is to minimize aircraft runway occupancy and thus increase aerodrome capacity. When the design peak-hour traffic density is approximately less than 25 operations (landings and take-offs), the right-angle exit taxiway may suffice. The construction of this right-angle exit taxiway is less expensive, and when properly located along the runway, achieves an efficient flow of traffic.

4.6.3 Pilot speeds on rapid exit taxiways vary widely. Studies suggest speeds around 46 km/h (25 kt) are common, but some airports see speeds exceeding 92 km/h (49 kt) in good conditions. For safety, a speed of 93 km/h (50 kt) is used to design these taxiways, but planners may choose a lower speed for optimal runway exit placement. Pilot cooperation is key to maximizing their benefit. Training on rapid exit taxiways could encourage wider use.

4.6.4 The following basic planning criteria should be considered when planning rapid exit taxiways to ensure that, wherever possible, standard design methods and configurations are used:

1) for runways exclusively intended for landings, a rapid exit taxiway should be provided only if dictated by the need for reduced runway occupancy times consistent with minimum inter-arrival spacings.

2) for runways where alternating landings and departures are conducted, time separation between the landing aircraft and the following departing aircraft is the main factor limiting runway capacity;

3) as different types of aircraft require different locations for rapid exit taxiways, the expected aircraft fleet mix will be an essential criterion;

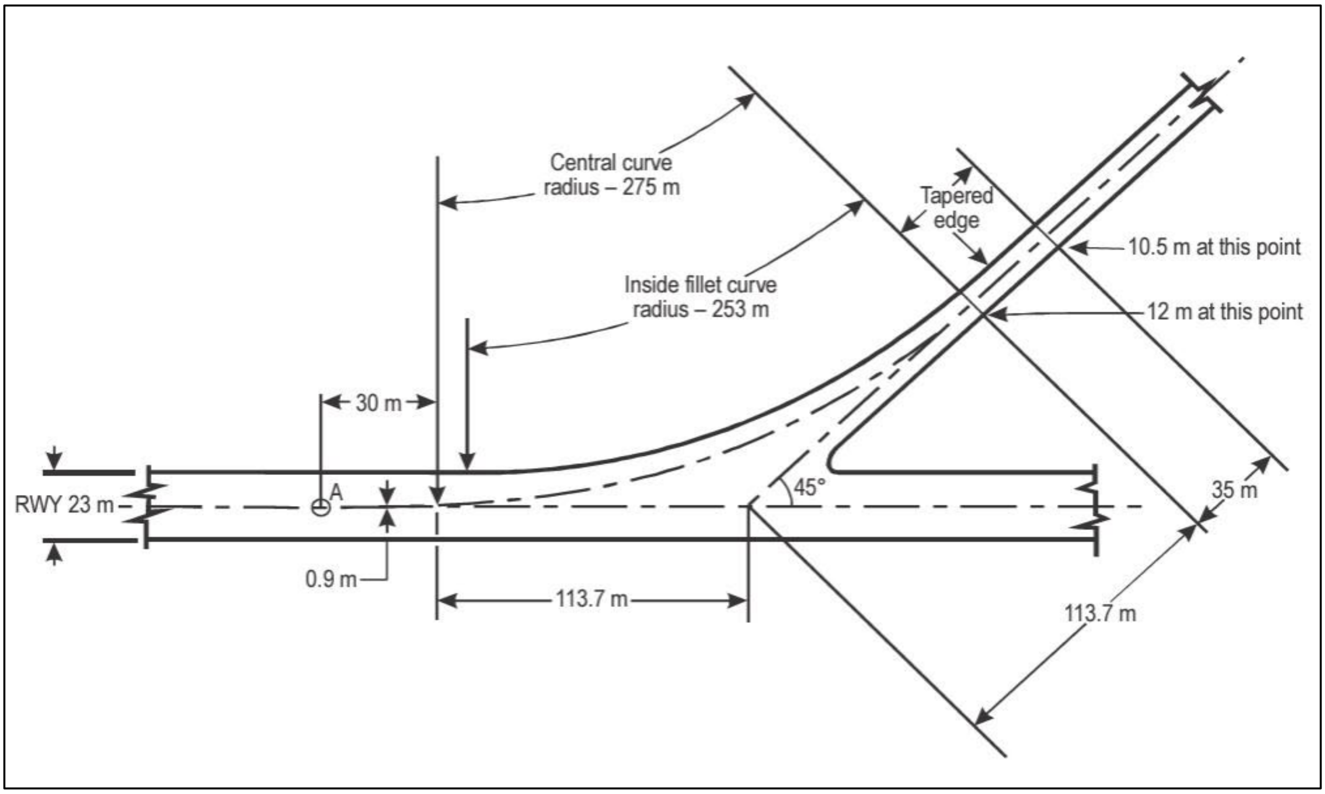
4) the threshold speed, braking ability and operational turn-off speed (Vex) of the aircraft will determine the location of the exits.

4.6.5 The location of exit taxiways in relation to aircraft operational characteristics is determined by the deceleration rate of the aircraft after crossing the threshold. To determine the distance from the threshold, the following basic conditions should be considered:

1) threshold speed;

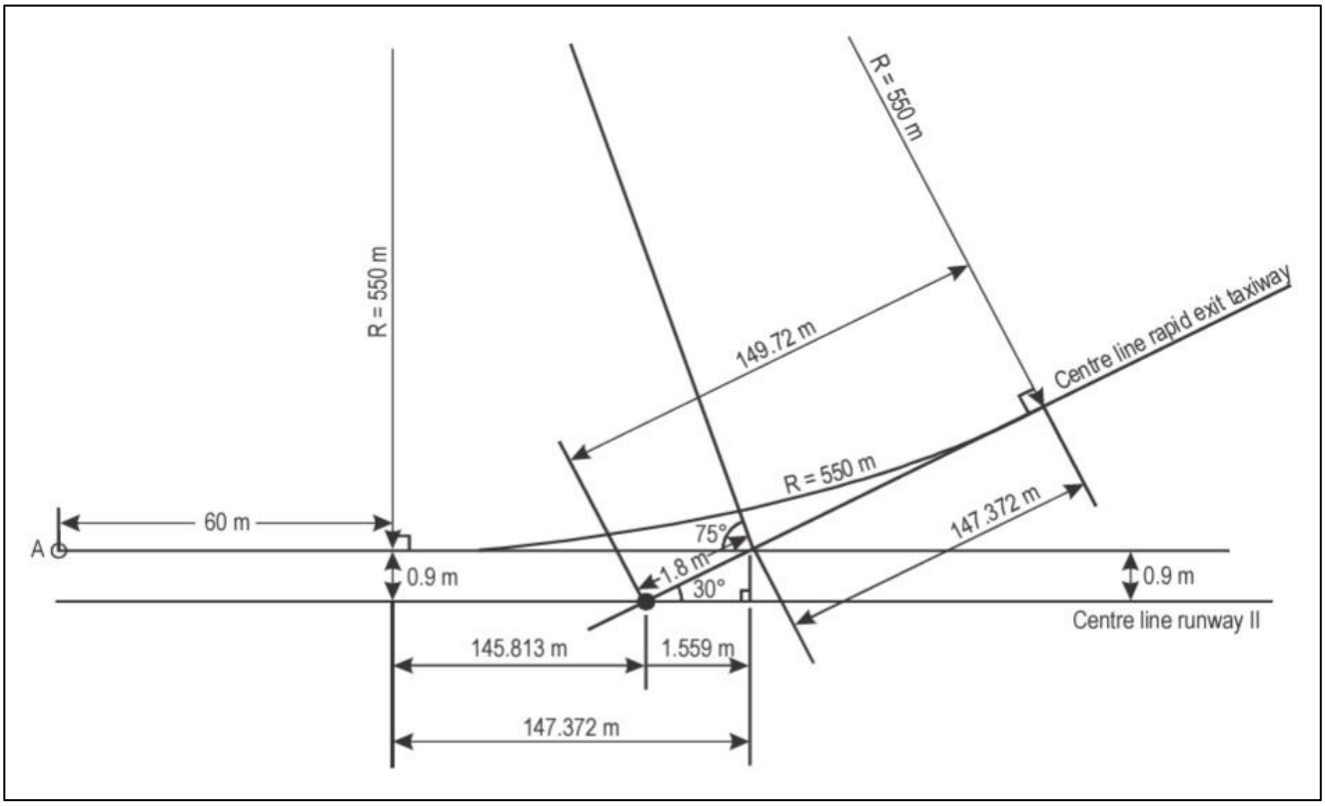
2) initial exit speed or turn-off speed at the point of tangency of the central (exit) curve (point A, Figures 191-15 and 191-16).

Figure 191-15 Design for rapid exit taxiways. Code 1 or 2



Source: ICAO Doc 9157 Part 2

Figure 191-16 Design for rapid exit taxiways. Code 3 or 4



Source: ICAO Doc 9157 Part 2

4.6.6 The optimal placement and number of rapid exit taxiways for a specific aircraft group is a recognised challenge due to the multitude of relevant criteria. While many operational parameters are inherently tied to the type of aircraft and its landing and braking behaviour, certain criteria remain relatively independent of the specific aeroplane model.

4.6.7 Accordingly, a methodology, known as the Three Segment Method, was developed which permits the determination of the typical segmental distance requirements from the landing threshold to the turn-off point based on the operating practices of individual aircraft and the effect of the specific parameters involved. The methodology is based on analytical considerations supplemented by empirical assumptions, as described below.

4.6.8 For the purposes of exit taxiway design, the aircraft are assumed to cross the threshold at an average of 1.3 times the stall speed in the landing configuration at maximum certificated landing mass with an average gross landing mass of about 85 per cent of the maximum. Further, aircraft can be grouped on the basis of their threshold speed at sea level as follows:

1) Group A – less than 169 km/h (91 kt)

2) Group B – between 169 km/h (91 kt) and 222 km/h (120 kt)

3) Group C – between 224 km/h (121 kt) and 259 km/h (140 kt)

4) Group D – between 261 km/h (141 kt) and 306 km/h (165 kt), although the maximum threshold crossing speed of aircraft currently in production is 282 km/h (152 kt)

Note: The FAA provide a useful tool for reviewing aircraft approach speeds which can be found by visiting this link: https://www.faa.gov/airports/engineering/aircraft_char_database/data

4.6.9 Using the Three Segment Method, the total distance required from the landing threshold to the point of turn-off from the runway centre line can be determined according to the method illustrated in Figure 191-17. The total distance S is the sum of three distinct segments which are computed separately.

Segment 1: Distance required from landing threshold to main gear touchdown (S_1).

Segment 2: Distance required for transition from main gear touchdown to establish stabilized braking configuration (S_2).

Segment 3: Distance required for deceleration in a normal braking mode to a normal turn-off speed (S_3).

V_{th} Threshold speed based on 1.3 times the stall speed of assumed landing mass equal to 85 per cent of maximum landing mass. Speed is corrected for elevation and airport reference temperature.

V_{td} Assumed as Vth minus 5 kt (conservative). Speed decay considered representative for most types of aircraft.

V_{ba} Assumed brake application speed.

V_{th} minus 15 kt (wheel brakes and/or reverse thrust application)

V_{ex} Nominal turn-off speed:
Code number 3 or 4: 30 kt
Code number 1 or 2: 15 kt

Note: The above is for standard rapid exit taxiways according to Figure 191-15 and 191-16.

Note: For other types of exit taxiways see Table 191-8 and Figure 191-18 for turn-off speed.

S_1 Empirically derived firm distance to mean touchdown point, corrected for downhill slope and tailwind component where applicable.

Aircraft category C and D: S_1 = 450m
Correction for slope: + 50m / - 0.25%
Correction for tailwind: +50m /+ kt

Aircraft category A and B: S_1 = 250m
Correction for slope: + 30m / - 0.25%
Correction for tailwind: + 30m / + 5 kt

S_2 The transition distance is calculated for an assumed transition time (empirical) Dt = 10 seconds at an average ground speed of:

$S_2 = 10 \times V_{av}$ [V_{av} in m/s], or

$S_2 = 5 \times (V_{th} - 10)$ [V_{th} in kt]

S_3 The braking distance is determined based on an assumed deceleration rate 'a' according to the following equation:

$$S_3 = \frac{V_{ba}^2 - V_{ex}^2}{2a} \text{ [V in m/s, a in m/s}^2\text{], or}$$

$$S_3 = \frac{(V_{th} - 15)^2 - V_{ex}^2}{8a} \text{ [V in kt, a in m/s}^2\text{]}$$

Note: A deceleration rate of a = 1.5 m/s^2 is considered a realistic operational value for braking on wet runway surfaces.

4.6.10 The final selection of the most practical rapid exit taxiway location(s) must be considered in the overall planning requirements, considering other factors such as:

1) location of the terminal or apron area;

2) location of other runways and their exits;

3) optimisation of traffic flow within the taxiway system with respect to air traffic control procedures;

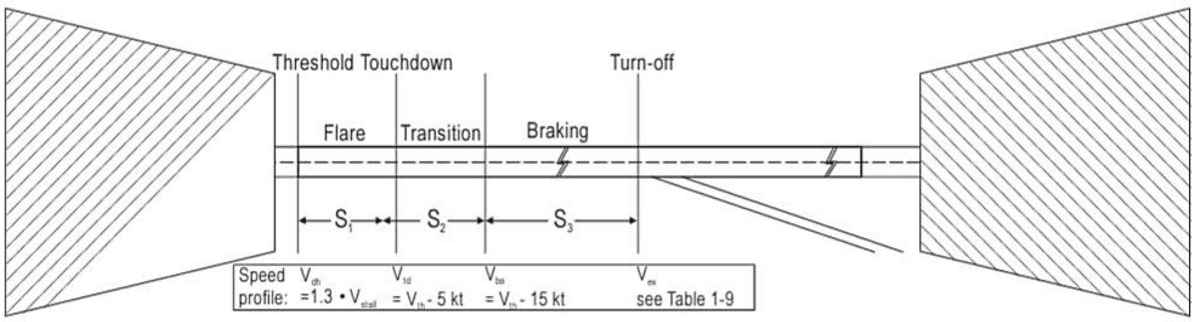
4) avoidance of unnecessary taxi rerouting.

4.6.11 Furthermore, there may be a need to provide additional exit taxiways; especially at long runways; after the main rapid exit(s) depending upon local conditions and requirements. These additional taxiways may or may not be rapid exit taxiways. Intervals of approximately 450 m are recommended up to within 600 m of the end of the runway.

4.6.12 Some aerodromes have heavy activity of aircraft in code number 1 or 2. When possible, it may be desirable to accommodate these aircraft on an exclusive runway with a rapid exit taxiway. At those aerodromes where these aircraft use the same runway as commercial air transport operations, it may be advisable to include a rapid exit taxiway to expedite ground movement of the small aircraft. In either case, it is recommended that this exit taxiway be located at 450 m to 600 m from the threshold.

4.6.13 As a result of Recommendation 3/5 framed by the Aerodromes, Air Routes and Ground Aids Divisional Meeting (1981), ICAO in 1982 compiled data on actual rapid exit taxiway usage. The data, which were collected from 72 airports and represented operations on 229 runway headings, provided information on the type of exit taxiway, distances from threshold to exits, exit angle and taxiway usage for each runway heading. During the analysis it was assumed that the sample size of the surveyed data was equal for each runway heading. Another assumption was that whenever an aircraft exited through an exit taxiway located at an angle larger than 45°, the aircraft could have exited through a rapid exit taxiway, had there been a rapid exit taxiway on that location (except the runway end). The accumulated rapid exit usage versus distance from thresholds is tabulated in Table 191-9. This means that had there been a rapid exit taxiway located at a distance of 2200 metres from thresholds, 95 per cent of aircraft in group A could have exited through that exit taxiway. Similarly, rapid exit taxiways located at 2300 metres, 2670 metres and 2950 metres from thresholds could have been utilized by 95 per cent of aircraft in groups B, C and D, respectively. The table shows the distances as corrected by using the correction factors suggested in the study carried out by the Secretariat and presented to the AGA/81 Meeting, namely, 3 per cent were 300 m of altitude and 1 per cent per 5.6°C above 15°C.

Figure 191-17 Three Segment Method



Source: ICAO Doc 9157 Part 2

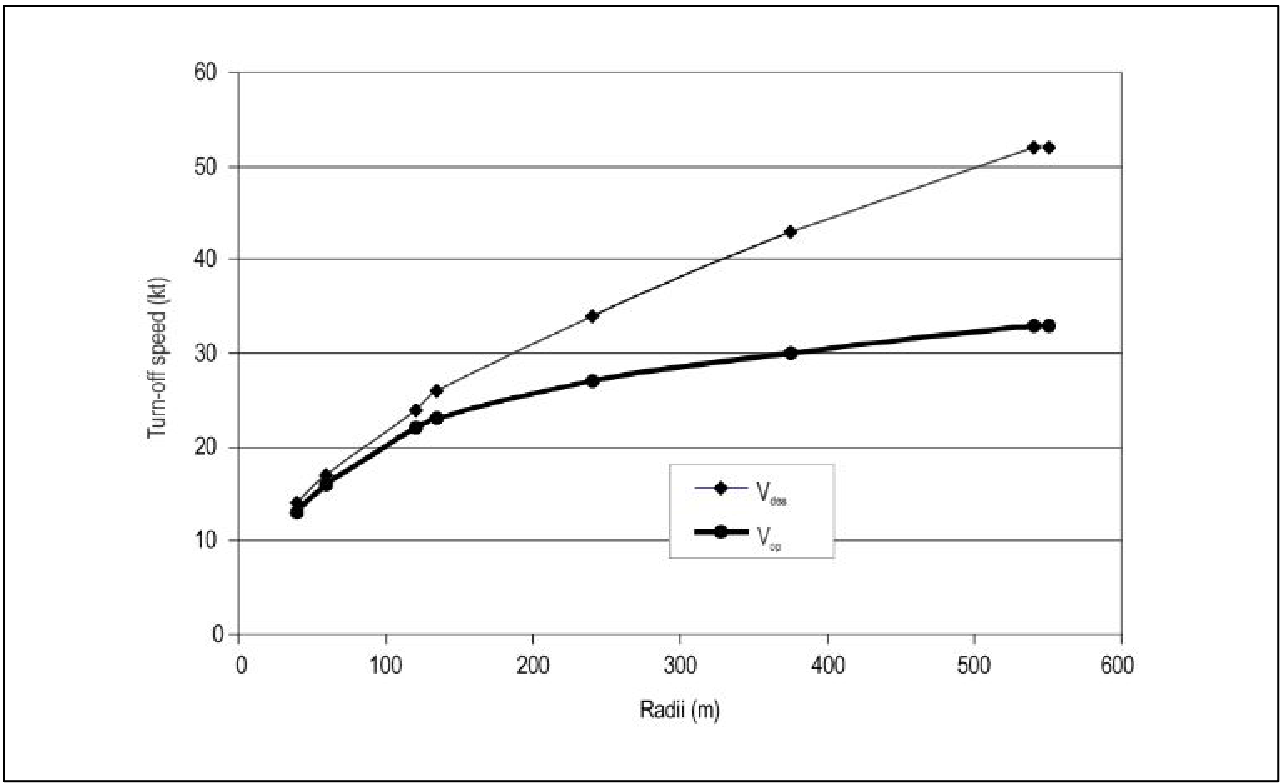
Table 191-8 Aircraft speed versus the radius of a rapid exit taxiway

Radii R (m)	V_{des} (kt)	V_{op} (kt)
40	14	13
60	17	16
120	24	22
160	28	24
240	34	27
375	43	30
550	52	33

Source: ICAO Doc 9157 Part 2

Note: Based on the design exit speed Vdes complying with a lateral acceleration of 0.133 g, the operational turn-off speed Vop is determined empirically to serve as the criterion for the optimal location of the exit.

Figure 191-18 Aircraft speed versus the radius of a rapid exit taxiway



Source: ICAO Doc 9157 Part 2

Table 191-9 Accumulated rapid exit usage by distance from threshold (m)

Aircraft Category	50%	60%	70%	80%	90%	95%	100%
A	1170	1320	1440	1600	1950	2200	2900
B	1370	1480	1590	1770	2070	2300	3000
C	1740	1850	1970	2150	2340	2670	3100
D	2040	2190	2290	2480	2750	2950	4000

Source: ICAO Doc 9157 Part 2

4.6.14 Figures 191-15 and 191-16 present some typical designs for rapid exit taxiways in accordance with the specifications given in Annex 14, Volume I. For runways of code number 3 or 4, the taxiway centre line marking begins at least 60 m from the point of tangency of the central (exit) curve and is offset 0.9 m to facilitate pilot recognition of the beginning of the curve. For runways of code number 1 or 2, the taxiway centre line marking begins at least 30 metres from the point of tangency of the central (exit) curve.

4.6.15 A rapid exit taxiway should be designed with a radius of turn-off curve of at least:

275 metres where the code number is 1 or 2; and

550 metres where the code number is 3 or 4

to enable exit speeds under wet conditions:

93 km/h (50kt) where the code number is 3 or 4, and

65 km/h (35kt) where the code number is 1 or 2

4.6.16 The radius of the fillet on the inside of the curve at a rapid exit taxiway should be sufficient to provide a widened taxiway throat in order to facilitate recognition of the entrance and turn-off onto the taxiway.

4.6.17 A rapid exit taxiway should include a straight distance after the turn-off curve sufficient for an exiting aircraft to come to a full stop clear of any intersecting taxiway and should not be less than the following when the intersection angle is 30°:

1) Code 1 or 2: 35 metres
2) Code 3 or 4: 75 metres

Note: The above distances are based on deceleration rates of 0.76 m/s2 along the turn-off curve and 1.52 m/s2 along the straight section.

4.6.18 The intersection angle of a rapid exit taxiway with the runway should not be greater than 45° nor less than 25° and preferably should be 30°.

4.7 Taxiway Shoulders and Strips

4.7.1 A shoulder is an area adjacent to the edge of a full-strength paved surface so prepared as to provide a transition between the full-strength pavement and the adjacent surface. The main purpose of the provision of a taxiway shoulder is to prevent jet engines that overhang the edge of a taxiway from ingesting stones or other objects that might damage the engine, to prevent erosion of the area adjacent to the taxiway, and to provide a surface for the occasional passage of aircraft wheels. A shoulder should be capable of withstanding the wheel loading of the heaviest airport emergency vehicle. A taxiway strip is an area, including a taxiway, intended to protect an aircraft operating on the taxiway and to reduce the risk of damage to an aircraft accidentally running off the taxiway.

4.7.2 The widths to be provided for taxiway shoulders and strips are given in Table 191-3. It may be noted that shoulders 5.5 metres wide for code letter D,7.5 metres wide for code letter E and 10.5 metres wide for code letter F on both sides of the taxiway are considered to be suitable. These taxiway shoulder width requirements are based on the most critical aircraft operating in these categories, at this time. On existing airports, it is desirable to protect a wider area should operations by new larger aircraft be intended, as the possibility of potential foreign object damage and the effect of exhaust blast on the taxiway shoulder during break away will be higher. The taxiway shoulder width is considered suitable when it protects the inboard engines of the critical aircraft which are much closer to the ground than the outboard engines.

4.7.3 The graded portions to be provided for taxiways are based on the maximum OMGWS of a group and on the deviation of one aircraft from the taxiway centre line and the increment (Z), but in any case, not lower than the required shoulder width as shown in Table 191-3.

4.7.4 Taxiway shoulders shall be flush with the adjacent taxiway surface for a smooth transition. The taxiway strip, including any shoulder, must also have a level surface. The graded portion of the strip needs to maintain specific slopes: a maximum upward slope of 2.5% relative to the taxiway's transverse slope and a maximum downward slope of 5% for code letters C, D, E, or F. Code letters A or B allow for a slightly steeper upward slope of 3% while maintaining the 5% downward limit. These slopes are measured relative to the taxiway's transverse slope (upward) and the horizontal plane (downward). Furthermore, the graded area within the strip must be free of holes or ditches. The taxiway strip itself serves as a designated safety area and needs to be clear of objects that could endanger taxiing aircraft. Drainage within the strip requires careful consideration to prevent damage to aircraft that may veer off the taxiway. Suitably designed drain covers may be necessary to achieve this.

4.7.5 All obstacles within the designated taxiway strip distance (see Table 191-3) are prohibited with the exception of signs and other essential objects required for air navigation. These exceptional objects must be frangible, designed to shatter upon impact with minimal aircraft damage. Additionally, their placement within the strip needs careful consideration to minimize the risk of being struck by any part of a taxiing aircraft, including propellers, engine pods, and wings. As a general guideline, the maximum height of any object within the strip should not exceed 30 cm above the taxiway edge level.

4.7.6 Taxiway shoulders and the graded portions of strips should be obstacle-free to minimize aircraft damage during accidental or emergency use. These areas must be constructed to withstand the weight of rescue and firefighting vehicles, as well as allow for safe access across their entire width. For taxiways accommodating turbine-engined aircraft, special considerations are necessary. Jet engines overhanging the taxiway edge can ingest debris from the shoulders, and engine blast can dislodge material from adjacent surfaces, posing a hazard to personnel, aircraft, and facilities. Therefore, specific precautions must be taken to mitigate these risks. The selection of a suitable shoulder surface depends on local conditions, planned maintenance methods, and cost. While natural surfaces like turf may be adequate in some cases, others may require artificial surfaces. Regardless of the chosen material, it should minimize dust and debris generation while meeting the minimum load-bearing capacity for emergency vehicles.

4.7.7 Under most taxiing conditions, blast velocities are not critical except at intersections where thrusts approach those on breakaway. With the present criteria of up to 23 metre wide taxiways, the outboard engines of the larger jets extend beyond the edge of the pavement. For this reason, treatment of taxiway shoulders is recommended to prevent their erosion and to prevent the ingestion of foreign material into jet engines or the blowing of such material into the engines of following aircraft. The material below presents concise information on methods of protection of marginal areas subject to blast erosion and of those areas which must be kept free from debris to prevent ingestion by overhanging turbine engines. Additional information can be found in Appendix C.

4.7.8 Studies on jet blast and its effects have explored the development of the blast profile and velocity contours. These factors are considered in relation to engine type, aircraft mass and configuration, variations in thrust settings, and the influence of crosswinds. The research has shown that heat associated with the jet wake is negligible compared to the force of the blast. Heat dissipates more rapidly with distance than blast force, and personnel, equipment, and structures are not normally positioned in the upper areas where jet heat is strongest during operations. The studies indicate that objects in the path of a jet blast experience several forces including the dynamic pressure exerted by the high-speed gases impacting the surface, drag forces generated as the gases move past an object, and uplift forces caused by either pressure differentials or turbulence within the jet blast.

4.7.9 Cohesive soils, when loosened, are susceptible to erosion by jet blast. For these soils, protection that is adequate against the natural erosive forces of wind and rain will normally be satisfactory. The protection must be a kind that adheres to the clay surfacing so that the jet blast does not strip it off. Oiling or chemical treatment of a cohesive soil surface are possible solutions. The cohesion required to protect a surface from blast erosion is small; normally, a plasticity index (PI) of two or greater will suffice. However, if the area is periodically used by ground vehicles with their equipment, a PI of six or more will be necessary. There should be good surface drainage for these areas if equipment moves over them since this type of surface will be softened by ponding. Special consideration must be given to highly plastic cohesive soils subject to more than about a 5 per cent shrinkage. For these soils, good drainage is very important since they become extremely soft when wet. When dry, these soils crack and become subject to greater lift forces. Fine, cohesionless soils, which are the most susceptible to erosion by blast, are considered to be those which do not have the cohesive properties defined above.

4.7.10 The design of taxiway shoulder and blast pad thickness must consider both the weight of the heaviest aircraft the runway is designed for (critical aircraft) and the critical axle load of emergency or maintenance vehicles that may need to access the area. Additionally, several other factors influence the optimal thickness, such as:

1) the minimum design thickness required for shoulder and blast pads to accommodate the critical aircraft can be taken as one half of the total thickness required for the adjacent paved area;

2) the critical axle load of the heaviest emergency or maintenance vehicle likely to traverse the area should be considered in the determination of the pavement thickness. If this thickness is greater than that based on a) above, then this design thickness should be used for shoulder and blast pads;

3) for wide-body aircraft such as the A330, A340, A350, B767, B777, B787, MD11, L1011 or smaller, the recommended minimum surface thickness, if bituminous concrete on an aggregate base is used, is 5 cm on shoulders and 7.5 cm on blast pads. For aircraft such as the B747 or larger, an increase of 2.5 cm in this thickness is recommended;

4) the use of a stabilized base for shoulders and blast pads is also recommended. A 5 cm bituminous concrete surface is the recommended minimum on a stabilized base;

5) the same compaction and construction criteria for sub-grade and pavement courses in shoulder and blast areas should be used for full-strength pavement areas. It is recommended that a drop-off of approximately 2.5 cm be used at the edge of the full-strength pavement, shoulders and blast pads to provide a definite line of demarcation.

5. De-icing/Anti-Icing Facilities

5.1 Location and factors affecting de-icing/anti-icing facilities

5.1.1 Centralized de-icing/anti-icing facilities near terminals offer a potential solution, but their effectiveness hinges on two factors. First, high demand for gate positions shouldn't lead to excessive delays and congestion for aircraft waiting for de-icing. Second, the taxi time from the terminal to the runway must be shorter than the holdover time of the de-icing fluid to ensure its effectiveness during taxi and take-off. Off-gate or remote de-icing facilities can address these limitations. They can improve aircraft utilisation by keeping de-icing separate from gate operations, minimise holdover time concerns with shorter taxi distances, and potentially offer greater flexibility to adapt to changing weather conditions due to their remote locations.

5.1.2 An off-gate facility along a taxiway may lead to queuing of aeroplanes and thus should have bypass taxiing capability as shown in Figure 191-20. An off-gate facility better permits collection of de-icing/anti-icing fluid run-off for its safe disposal than do aircraft stands. Where holding bays of adequate size and capacity are provided, these could be used for de-icing/anti-icing of aeroplanes, provided all the above requirements are fulfilled. The taxiing routes for access to the de-icing/anti-icing pads should have minimum turns and intersections for expediting the movement of aeroplanes, while not affecting operational safety.

5.1.3 To ensure efficient de-icing/anti-icing operations and minimise the risk of runway incursions by service vehicles, vehicle service roads or staging areas may be necessary. These roads should be designed with both operational and safety considerations in mind. This includes preventing runway/taxiway incursions while also minimising negative environmental impacts like de-icing fluid runoff. Additionally, the placement of these roads should not compromise the emergency response times of airport rescue and firefighting vehicles. Appropriate signage for surface movement guidance and control (SMGC) may also be required, such as vehicle stop signs or road-holding position signs.

5.1.4 The size of a de-icing/anti-icing facility is dependent on the size of the aircraft, the number of aircraft requiring the treatment, the meteorological conditions, the type and capacity of the dispensing equipment used and the method of treatment. An indication of the total size of the facility could be estimated from the number of aircraft requiring treatment at a given time. The transit time of de-icing/anti-icing vehicles between the refilling/storage area and the de-icing/anti-icing facilities should also be considered.

5.2 Factors affecting the number of de-icing/anti-icing pads

5.2.1 Several factors determine the number of pads required, including:

1) the meteorological conditions at airports where wet snow or freezing rain conditions are more prevalent, a greater number of de-icing/anti-icing pads are recommended to be provided to prevent unacceptable delays;

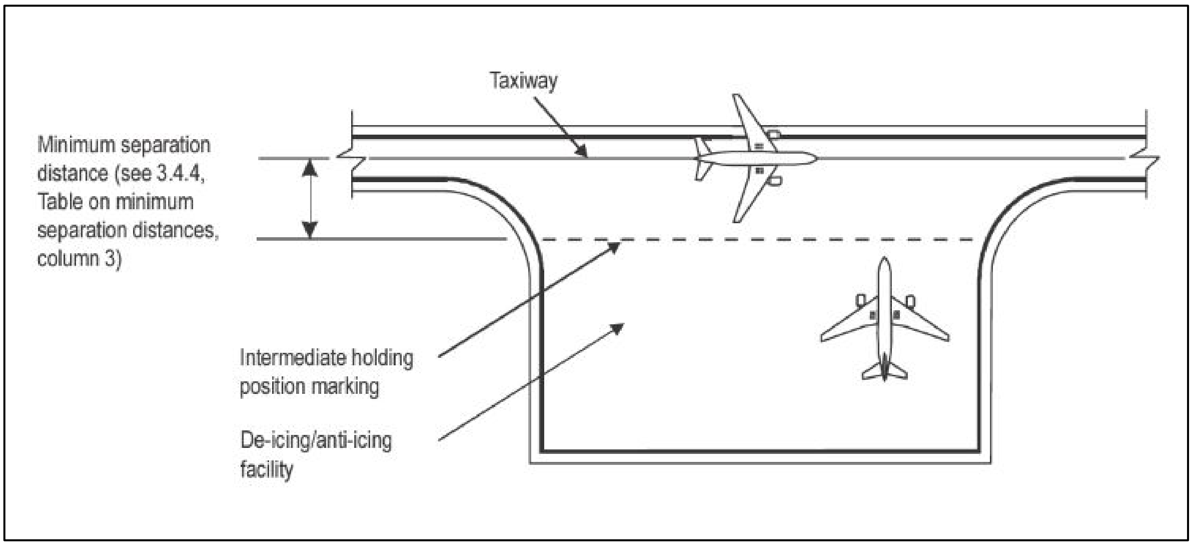
2) the type of aeroplanes to be treated — narrow-body aeroplanes require less processing time than do wide-body aeroplanes. Aeroplanes with fuselage-mounted engines require more processing time than those with wing-mounted engines;

3) the method of application of de-icing/anti-icing fluid — the method may be either the one-step or twostep de-icing/anti-icing procedure. As the latter procedure results in longer occupancy times, the number of de-icing/anti-icing pads required should be based on the two-step procedure for flexibility and also to ensure that the maximum aeroplane departure flow rates are not adversely affected;

4) the type and capacity of the dispensing equipment used — mobile de-icing/anti-icing equipment with small tank capacities and requiring extended fluid heating times can increase application times and adversely affect the aeroplane departure flow rates;

5) the departure flow rates — the number of aeroplanes to be treated should match the number of take-off operations that can be cleared to minimize possible delays and airport congestion.

Figure 191-20 Minimum separation distance on a de-icing/anti-icing facility



Source: ICAO Doc 9157 Part 2

5.3 Environmental considerations affecting de-icing/anti-icing pads

5.3.1 The size of a de-icing/anti-icing pad should be sufficient to accommodate the parking area required for the most demanding aeroplane. Additionally, a 3.8 metre vehicle movement area needs to be provided entirely around the perimeter of each pad to ensure efficient equipment operation without overlap between adjacent pads. Furthermore, the total size of the de-icing/anti-icing facility must be planned while considering the minimum clearances specified in OTAR 191.

5.3.2 Excess de-icing/anti-icing fluid running off an aeroplane poses the risk of contamination of ground water if allowed to mix with other surface run-off. Furthermore, the fluids also have an adverse effect on the pavement surface friction characteristics. Therefore, it is imperative that an optimum quantity be used. Nevertheless, all excess fluids must be properly collected to prevent ground water contamination. All surface run-off from such areas must be adequately treated before discharging into storm water drains.

5.3.3 One option for managing de-icing/anti-icing fluid runoff involves collecting it all at a designated point for proper treatment before releasing it into storm water drains. Grooved pavements can aid in efficiently capturing any excess fluids. This approach proves to be particularly advantageous for remote de-icing/anti-icing pads where collection and handling are generally simpler compared to aircraft stands.

6. Visual Aids

6.1 Signal panels and signal areas

6.1.1 The designation of a signal area is only necessary when visual ground signals are the intended method for communicating with airborne aircraft. This may be the case for airports lacking an aerodrome control tower, flight information service unit, or for aircraft not equipped with radios. Visual signals can also be a backup in case of two-way radio communication failure. However, it's important to acknowledge that most information conveyed through visual ground signals is typically already available in Aeronautical Information Publications (AIPs) or Notices to Airmen (NOTAM). Therefore, a thorough evaluation of the need for visual ground signals should be conducted before establishing a dedicated signal area.

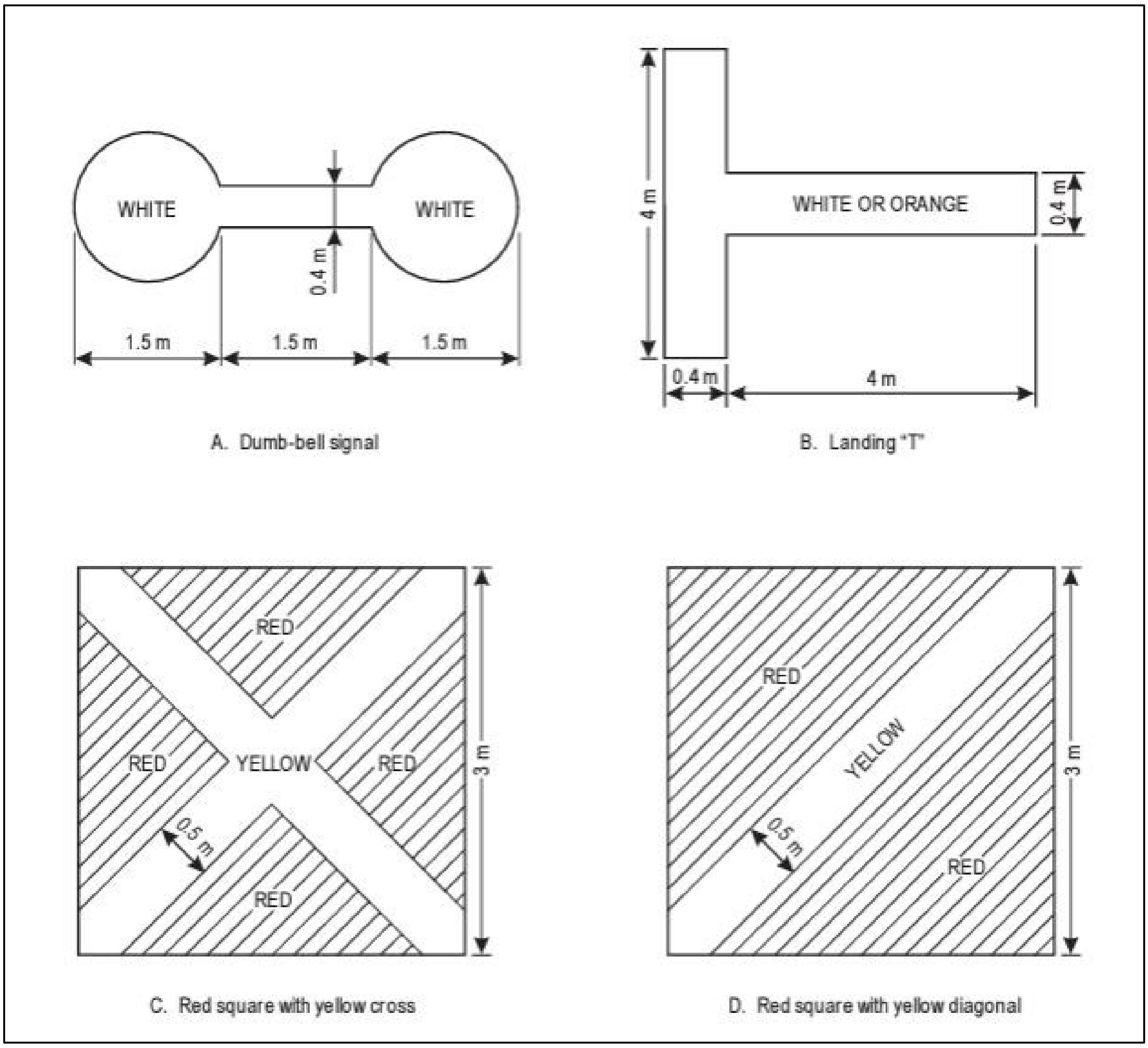
6.1.2 ICAO Annex 2, Chapter 4 includes specifications on ten different types of visual ground signals which cover such aspects as the shape, colour(s), location and purpose of each signal. Additionally, OTAR 191 includes detailed specifications on the landing direction indicator and the signal area. The following paragraphs explain briefly how the signal area, the signal panels and the landing “T” should be constructed.

6.1.3 The signal area, when designated, must be a level, even horizontal surface measuring at least 9 metres square. To prevent cracking caused by uneven settling, it should be constructed from cement concrete reinforced with an adequate amount of steel. The top surface needs a smooth finish achieved with a steel trowel and painted with a suitable contrasting colour. This contrasting colour choice should ensure clear visibility of the signal panels displayed on the area. Finally, a white border with a minimum width of 0.3 meters should encircle the entire signal area.

6.1.4 Dumb-bell signal should be constructed of wood or other light material. The dumb-bell should consist of two circles 1.5 metres in diameter connected by a crossbar 1.5 metres long by 0.4 metres wide, as shown in Figure 191-21. It should be painted white.

6.1.5 Landing “T” should be constructed of wood or other light material and its dimensions should correspond to those shown in Figure 3-1B. It should be painted white or orange. The landing “T” should be mounted on a cement concrete pedestal adequately reinforced with steel bars to avoid cracks resulting from unequal settlement. The surface of the pedestal should be finished smooth with a steel trowel and coated with paint of the appropriate colour. The colour of the pedestal should be chosen to contrast with the colour of the landing “T”. Before fastening the landing “T” base to the concrete pedestal, the mounting bolts should be checked for correct spacing. The landing “T” should be assembled and mounted in accordance with the manufacturer’s installation instructions. It should be free to move about a vertical axis so that it can be set in any direction. The undersurface of the landing “T”, when mounted on its pedestal, should be not less than 1.25 m above ground level. Where required for use at night, the landing “T” should either be illuminated or outlined by white lights.

Figure 191-21 Signal panels and landing ‘T’



Source: ICAO Doc 9157 Part 4

6.1.6 Red square with yellow cross - The dimensions of this signal panel, which relates to prohibition of landing, should correspond to those shown in Figure 191-21. The signal panel can be constructed using a 3 m × 3 m galvanized iron sheet. The yellow cross should first be painted and then the remaining area should be painted red. The signal panel should be provided with at least two handles to facilitate handling.

6.1.7 Red square with yellow diagonal - This signal panel, which is shown in Figure 191-21, should be constructed generally following the principles explained in the preceding paragraph. The only difference is that the signal panel will show a yellow diagonal in lieu of the yellow cross.

6.2 Apron and stand markings

6.2.1 Aircraft stands are typically positioned close together to minimize paved areas and passenger walking distances. However, this close proximity necessitates precise control over aircraft manoeuvring to ensure safe separation from adjacent aircraft, buildings, and service vehicles on the apron. Two other considerations are crucial: minimizing the blast impact on neighbouring stands and ensuring the designated manoeuvring area can accommodate the turning capabilities (castoring limitations) of all aircraft using the stand. Specific clearances between manoeuvring aircraft and other objects are provided in Annex 14, Volume I, Chapter 3. To further enhance safety during manoeuvring, control of ground equipment and vehicles is essential. This means keeping such equipment and vehicles outside of predetermined safety lines whenever aircraft are manoeuvring or left unattended.

6.2.2 There are two recognized ways for aircraft to follow guide-lines. In one, the nose of the aircraft (or pilot's seat) is kept over the line; in the other, the nose wheel traces the line. Annex 14, Volume I, Chapter 3 specifies that the taxiway curves should be designed so as to provide the required clearances when the cockpit of the aeroplane remains over the taxiway centre line markings. This is primarily because of the difficulty the pilot would have in ensuring that the nose wheel follows the guide-lines. In some aircraft, the nose wheel is displaced as much as 5 m behind the cockpit. The requirements for aircraft stand markings, however, are not comparable to those for taxiway centre line markings. There are two differences in the manoeuvring of aircraft on aircraft stands:

1) because of reduced area for manoeuvring, much smaller radii of turn are needed; and

2) trained marshallers are often used to assist in the manoeuvring of the aircraft.

6.2.3 Aircraft stand markings consist of guide-lines to denote the path to be followed by aircraft and reference bars to provide supplementary information. Guide-lines may be separated into:

1) lead-in lines;

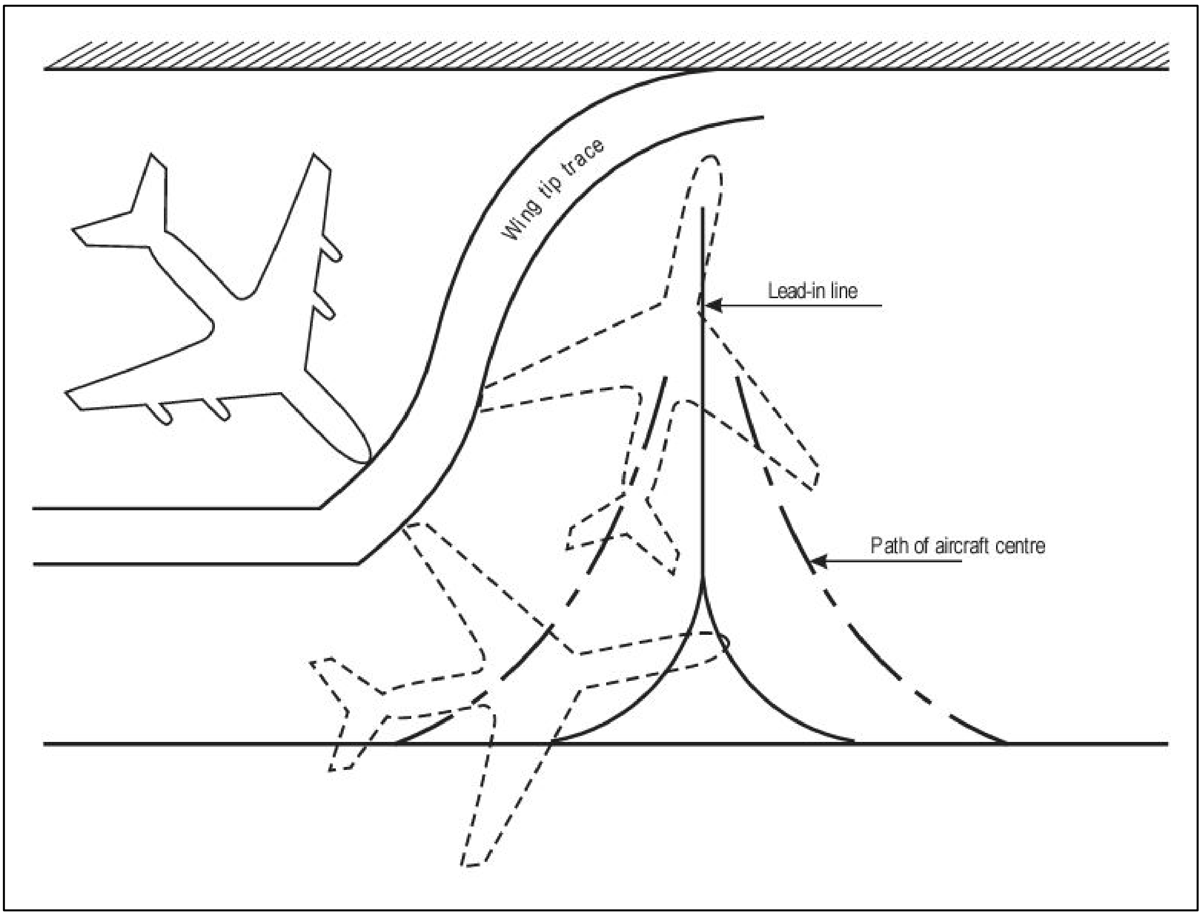
2) turning lines;

3) lead-out lines

6.2.4 These lines provide guidance from apron taxiways into specific aircraft stands. They may be required to enable taxiing aircraft to maintain a prescribed clearance from other aircraft on the apron. They may be considered as important as the turning line to align the aircraft axis with the predetermined final position. For nose-in stands, the lead-in lines will mark the stand centre line to the aircraft stopping position. There will be no lead-out lines and the tractor drivers will use the lead-in lines for guidance during the push-back manoeuvre.

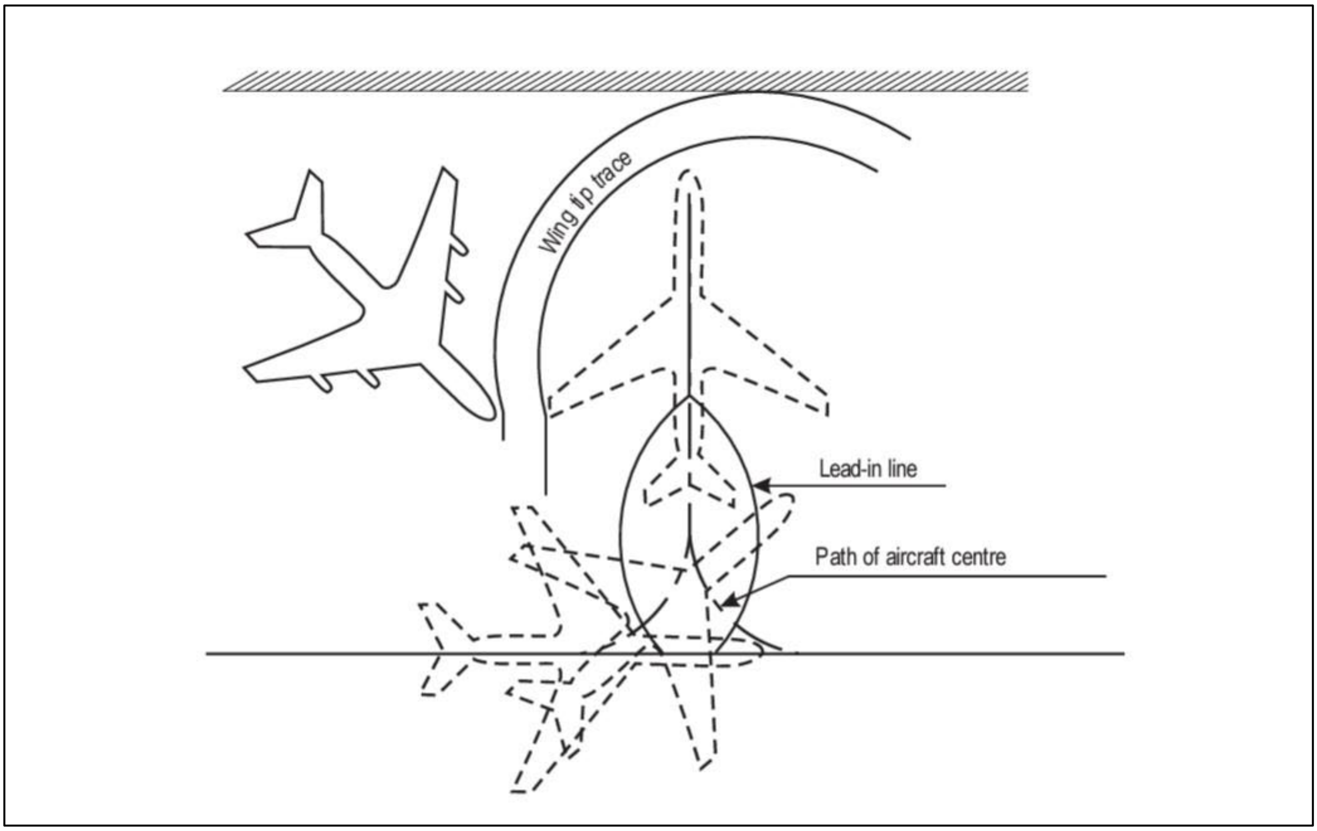
6.2.5 Figure 191-22 shows a simple lead-in line. The advantage of this line is that it presents the most natural method of turning and it is least likely to be mis-understood. Its disadvantages are that it is not suitable for marking a stand where the aircraft is to be located centrally over the lead-in line and that it requires more apron space than the type of marking that can achieve this. The lines are to be followed by the aircraft nose wheel. When these lines are used, it should be noted that the track of the aircraft centre is inside the curve of the guide-line. In some instances, the apron area available may require the use of a different type of marking. Figure 191-23 shows an offset lead-in line. When the aircraft nose wheel follows these lines, the centre of the aircraft does not cut as far inside the curve but makes a tighter turn. Consequently, the size of stand positions need not be as great. It should however be noted that while this type of marking positions the aircraft centrally over the lead-in line, a given line can only be fully suitable for one single aircraft type or where the aircraft geometry, in terms of the wheel- bases of all the different types using the stand, is virtually identical. Where it is necessary for a stand to be used by a variety of aircraft types and they do not have similar undercarriage geometry, yet the available space requires aircraft to be centrally positioned over the lead-in line, the aims are best achieved by using a short arrow at 90 degrees to the taxiway centre line, as in Figure 191-24. One drawback of this arrangement is that the entry point and degree of turn needed to align the aircraft centrally over the lead-in line are left to the pilot's judgement.

Figure 191-22 Nose-wheel lead-in line



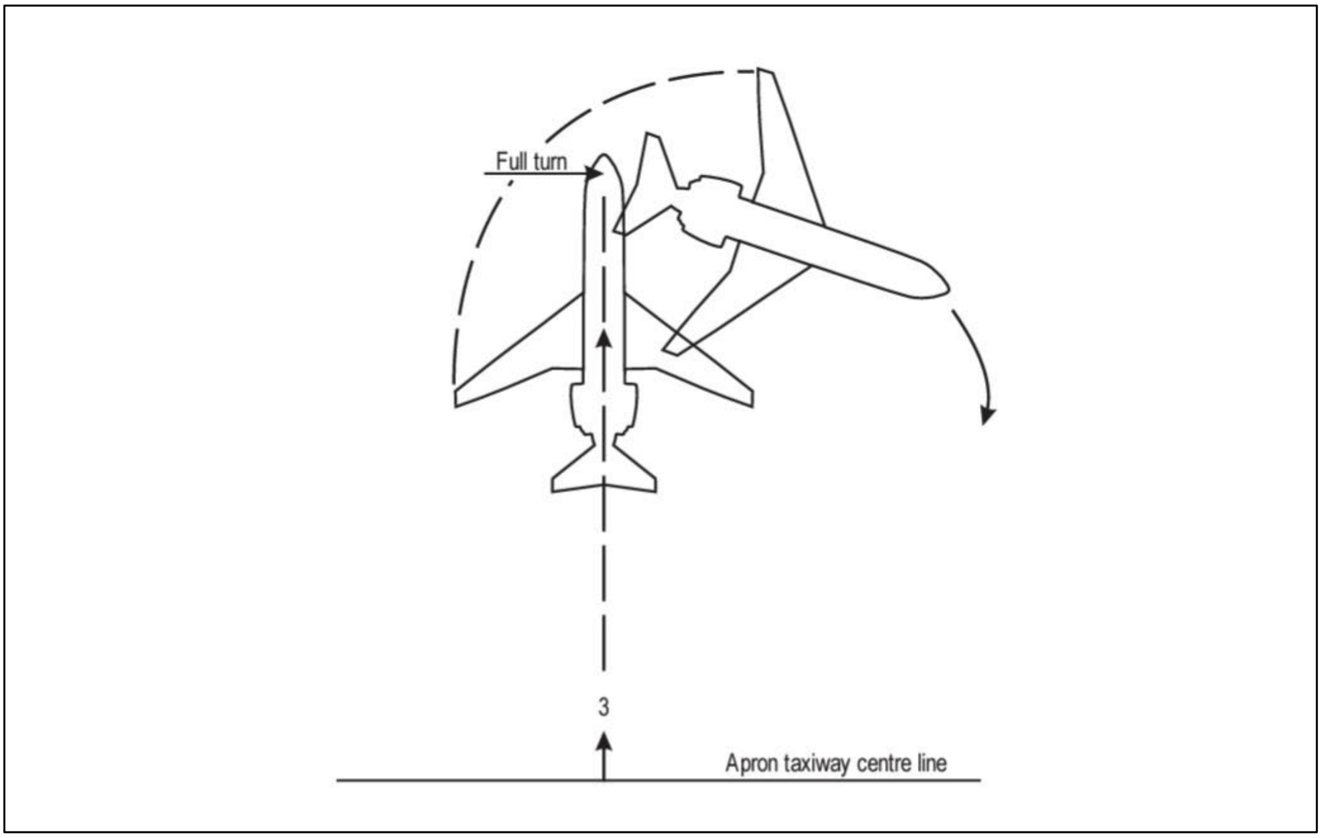
Source: ICAO Doc 9157 Part 4

Figure 191-23 Offset nose-wheel lead-in line



Source: ICAO Doc 9157 Part 4

Figure 191-24 Straight lead-in line



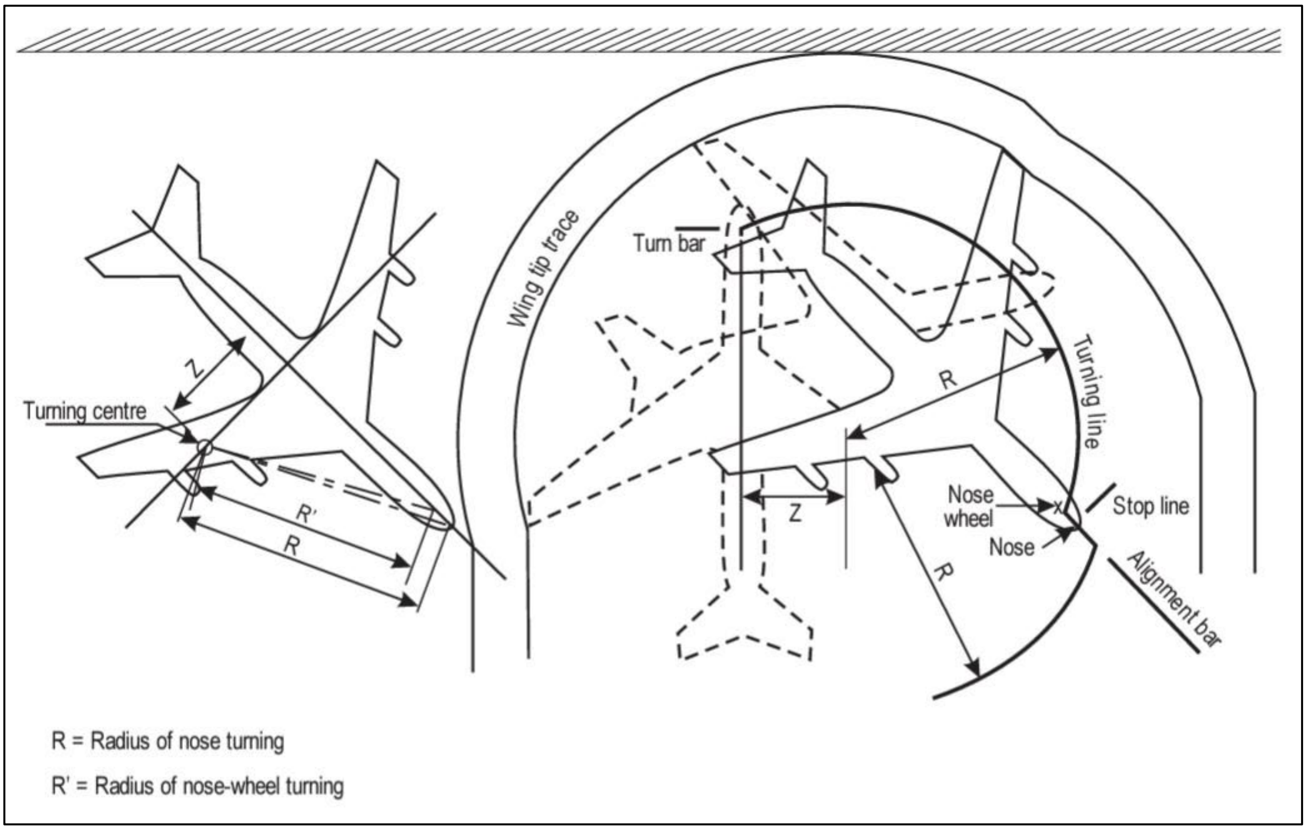
Source: ICAO Doc 9157 Part 4

6.2.6 Where the aircraft is required to make a turn on the stand prior to stopping or after “break away”, a turning line may be required for the aircraft to follow. The primary purpose of this line is to limit the turning of aircraft within the designated area in order to keep aircraft clear of obstacles and to aid in accurate positioning of the aircraft. The former is of special importance where clearances between the stand and near structures or other stands are marginal.

6.2.7 Figure 191-25 shows a typical example for a nose-wheel turning line. The line may be supplemented by reference bars (as shown) and as discussed later in 6.2.14.

6.2.8 For the straight portion the turning line should incorporate a straight portion at least 3 metres in length at the final aircraft position. This provides a 1.5 metre section prior to the final stopping position to relieve pressure on the landing gear and at the same time to correct the aircraft alignment, and a section 1.5 metres long after the stopping position to reduce the thrust required and, thereby, blast on “break away”. The length of the straight portion referred to above can be reduced to 1.5 metres in the case of stands meant for small aircraft.

Figure 191-25 Turn line and reference bars



Source: ICAO Doc 9157 Part 4

6.2.9 These lines, shown in Figure 191-26, provide guidance from stands to taxiways and ensure that the prescribed clearance from other aircraft and obstacles is maintained. Where aircraft must make a turn prior to leaving the stand to keep clear of the adjacent obstacles, the lead-out line may be as shown in Figure 191-26 a). Where the clearance from the adjacent stand is less marginal, the lead-out line of Figure 191-26 b) or c) might be practical. Offset nose-wheel lead-out lines, as shown in Figure 191-27, may be needed where clearances are marginal.

6.2.10 Method of computing the radii of curved portions of lead-in, turning and lead-out lines - Whether one uses a nose-wheel line or only a straight lead-in, as in Figure 191-24, the assumed or marked radius must be within the turning capability of the aircraft for which the stand is intended. In calculating the radius, one needs to assess the likely effect of blast which can result from using too tight a radius. It is also possible for the minimum acceptable radius of turn to vary with operators even though they are using the same aeroplane. Further, the smaller the turn radius and the larger the nose-wheel angle, the more likelihood there is of tire migration. In other words, while one may have, for example, 65 degrees of nose-wheel angle applied, the effective turn radius is equivalent only to some lesser angle, with possibly as much as a 5-degree loss. To determine the radii, therefore, one needs to consult the manuals issued by the aircraft manufacturers for airport planning purposes; the operators of the individual aeroplane types should also be consulted to find out to what extent they modify the manufacturer’s guidance for any reason. The individual apron situation would then need to be studied to see whether further modification would be necessary.

6.2.11 When a stand is used by different types of aircraft and alignment of aircraft is not of great importance, it may be possible to use one set of markings to serve all types. In such cases the largest turning radius is used. Any type of aircraft of the group can then manoeuvre with sufficient clearance if the nose wheel follows the guide lines. However, where the precise alignment of aircraft on the stand is essential, secondary guide lines may be necessary. Secondary guide lines are also necessary when a large aircraft stand must accommodate more than one small aircraft at the same time (see Figure 191-28). Such stands are commonly known as superimposed stands. In all these cases, the primary line should be for the most critical aircraft, i.e. the aircraft requiring the greatest manoeuvring area.

6.2.12 The guide lines should normally be continuous solid yellow lines at least 15 cm, but preferably 30 cm, in width. However, where a secondary guide line is provided, it should be a broken line to distinguish it from the primary line. Additionally, the type of aircraft that is to follow each line should be clearly indicated.

6.2.13 Where it is considered necessary to distinguish between lead-in lines and lead-out lines, arrow heads indicating the directions to be followed should be added to the lines. The designation number/letter of the stand should be incorporated in the lead-in line (see Figure 191-29). Additionally, a stand identification sign should be provided at the back of the stand, e.g. on the building or a pole, so as to be clearly visible from the cockpit of an aeroplane.

6.2.14 Reference bars – Examples of reference bars and their functions:

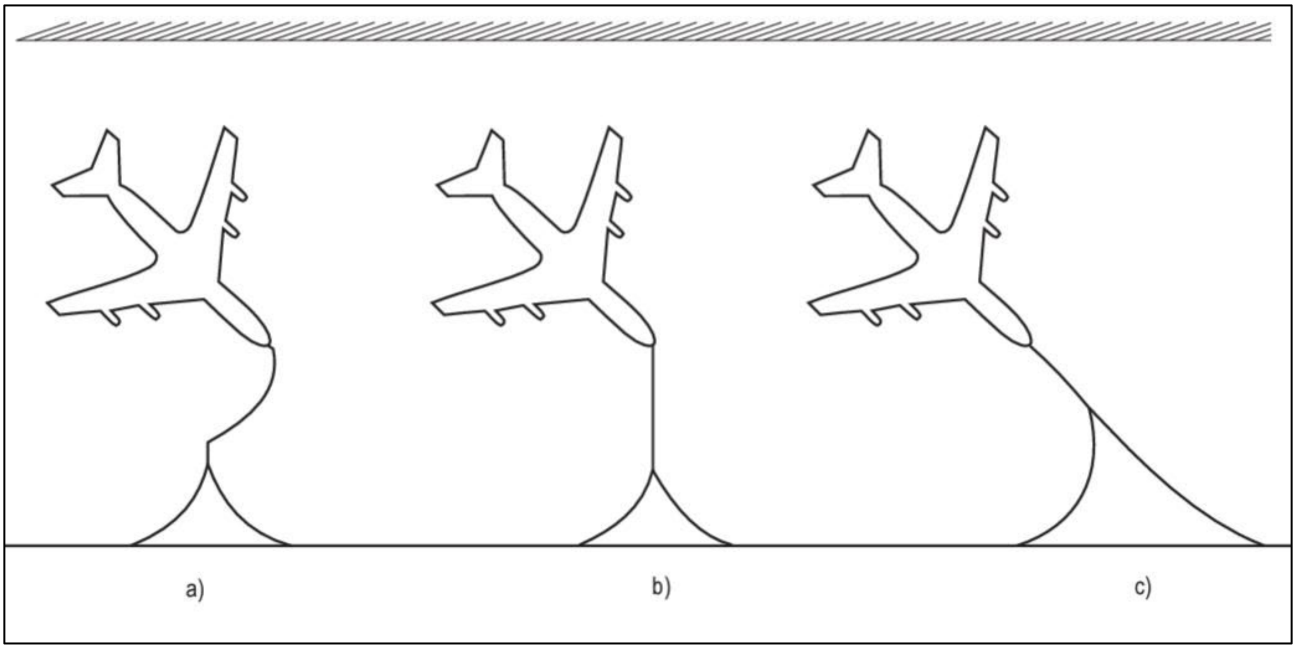
1) Turn bar - indicates the point at which to begin a turn

2) Stop line – indicates the point at which to stop

3) Alignment bar – assists in aligning the aircraft on the desired angle

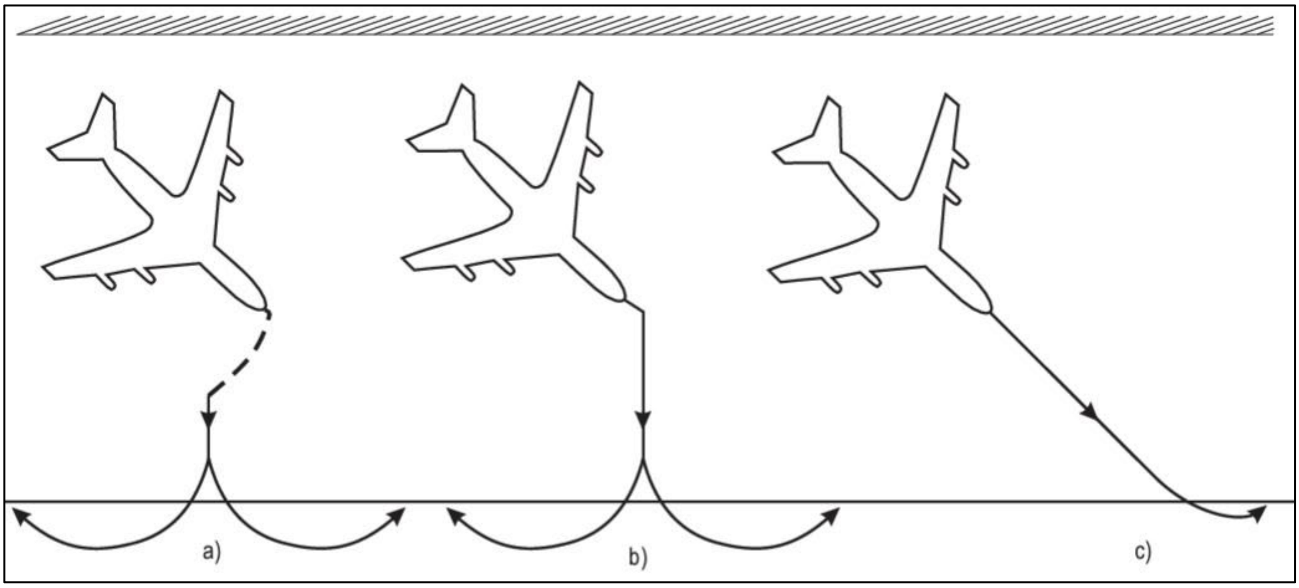
Note: Figure 191-29 shows examples of reference bars.

Figure 191-26 Simple nose-wheel lead-out lines



Source: ICAO Doc 9157 Part 4

Figure 191-27 Offset nose-wheel lead-out lines



Source: ICAO Doc 9157 Part 4

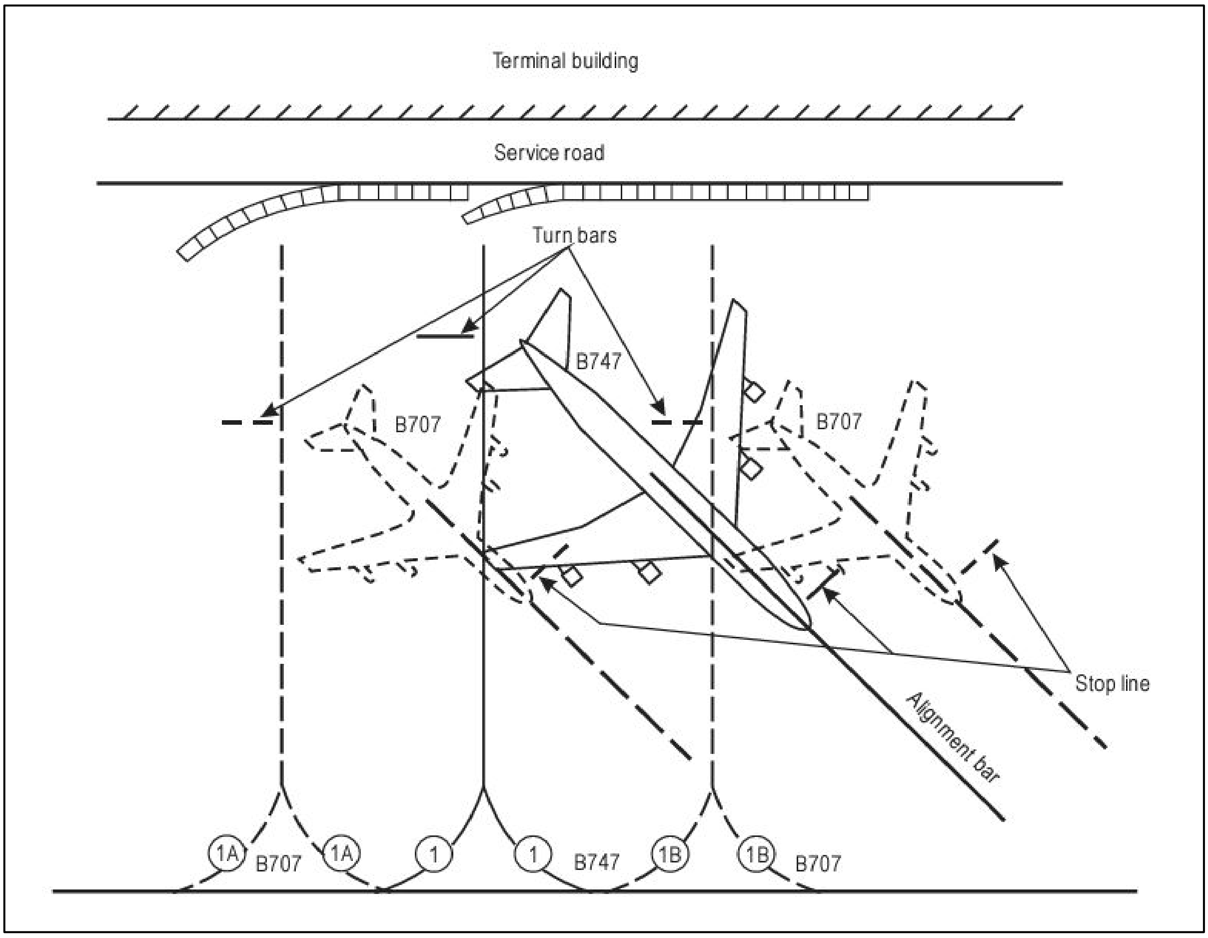
6.2.15 Characteristics of reference bars - Turn bars or stop lines should be in the order of 6 m in length and not less than 15 cm in width and of the same colour as the guide-line, i.e. yellow. They should be located to the left side of, and at right angles to, the guide-lines abeam the pilot seat at the point of turn and stop. The turn bars may include an arrow and the words “FULL TURN”, as in Figure 191-24. An alignment bar should be at least in the order of 15 m in length and 15 cm in width and be placed so as to be visible from the pilot seat.

6.2.16 Grouping of aircraft to reduce the number of turn bars and stop lines - Where an aircraft stand is meant to be used by several aeroplane types, it will be necessary to group them to reduce the number of turn bars and stop lines. There is, however, no agreed or widely used method for grouping aeroplanes. In the case of self-manoeuvring stands, one can group aeroplanes that have similar turning capabilities and geometry; it is even possible to include smaller aeroplanes that might have dissimilarities provided that, in following the guide lines, they do not transgress the outline of the area needed by other types which dictate the stand clearances. For nose-in stands, one is (perhaps) less concerned with size and turning capability than with such factors as exit locations and the type of passenger boarding bridge available. Where hydrant refuelling is installed, refuelling points must also be considered. One therefore needs to study the individual situation at each airport and tailor any grouping to facilities available, the mixture of aeroplane types and their numbers, apron layout, etc.

6.2.17 Coding system for turn bars and stop lines. Where an aircraft stand is used by two or three types of aircraft only, it is possible to indicate by a painted inscription the aircraft type for which each set of markings is intended. Where an aircraft stand is meant for several aircraft types, there may be a need to code the turn bars and stop lines to simplify the markings and to facilitate safe and expeditious manoeuvring of aircraft. There is, however, no agreed or widely used coding system. The coding system adopted should be such that pilots can understand and use it without difficulty.

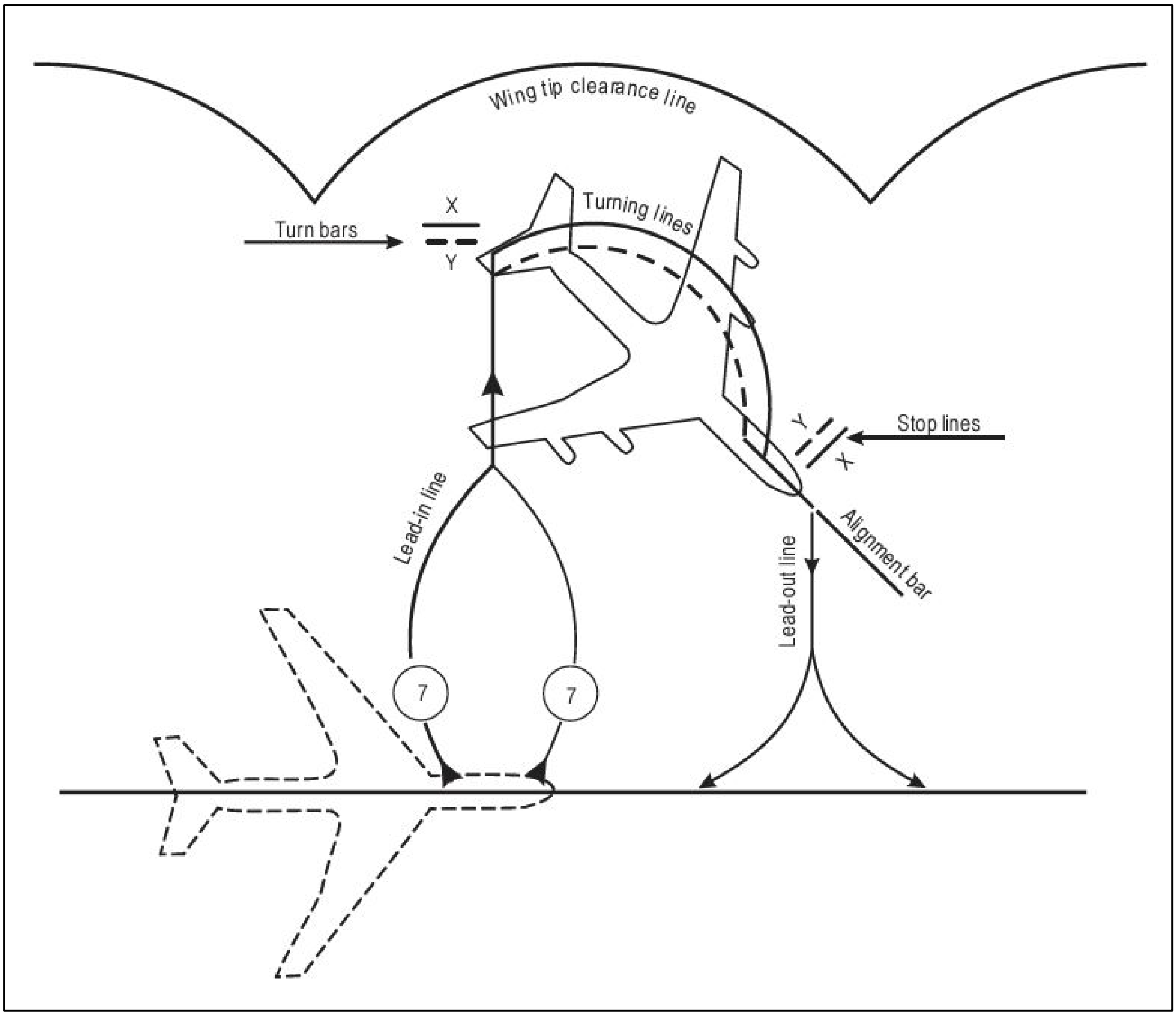
6.2.18 Towing lines - Where aircraft are to be towed, guide-lines may be needed for the operator of the tractor to follow.

Figure 191-28 Method of marking superimposed stands



Source: ICAO Doc 9157 Part 4

Figure 191-29 Example of reference bars



Source: ICAO Doc 9157 Part 4

6.2.19 Apron safety lines will be required on an apron to mark the limits of parking areas for ground equipment, service roads and passengers' paths, etc. These lines are narrower and of a different colour to differentiate them from the guide-lines used for aircraft.

6.2.20 Wing tip clearance lines should delineate the safety zone clear of the path of the critical aircraft wing tip. The line should be drawn at the appropriate distance mentioned in 6.2.1 outside the normal path of the wing tip of the critical aircraft. The width of the line should be at least 10 cm.

6.2.21 Equipment limit lines are used to indicate the limits of areas which are intended for parking vehicles and aircraft servicing equipment when they are not in use. Several methods are currently in use to identify which side of a safety line is safe for storage of such vehicles and equipment. At some airports, the words "Equipment Limit" are painted on the side used by ground equipment and readable from that side. The height of the letters is about 30 cm. At others, spurs or an additional line (a discontinuous line of the same colour or a continuous line of a different colour) is provided on one side of the safety line. The side on which such spurs or an additional line is located is considered safe for parking vehicles and equipment.

6.2.22 Passenger path lines are used to keep passengers, when walking on the apron, clear of hazards. A pair of lines with zebra hatching between them is commonly used.

6.3 Light intensity settings

6.3.1 The light intensity settings for taxiway lighting during daytime conditions are outlined in Table 191-10. These intensities are designed for the specific beam dimensions described in OTAR 191. They are applicable under background luminance conditions ranging from 1,000 to 40,000 candelas per square meter. However, for exceptionally bright days with a background luminance exceeding 40,000 cd/m² (e.g., sunlit fog), the maximum intensity setting should always be used. While the maximum setting is typically used during daytime, some regions may opt for lower intensities when conditions allow. This is because operating the lamps at a reduced intensity can significantly extend their lifespan.

6.3.2 Table 191-12 specifies light intensity settings for different visibility ranges (night conditions). The intensities specified apply, even though they differ from the main beam dimensions described in OTAR 191. According to ICAO Annex 3, Attachment D, the background luminances at standard night (to be used for RVR calculations from transmissometer readings) are defined as 4 cd to 50 cd per square metre. However, measurements at several airfields have shown that at the currently recommended intensity settings, back-ground luminances are lower than 15 cd per square metre. In good visibility and outside urban areas, background luminances may even be in the order of 0.1 cd per square metre or lower; under these conditions, the lowest intensity settings (Table 191-12, column 6) might be found useful.

6.3.3 Whereas Table 191-10 was developed on the basis of well-established practices, Table 191-12 is based on theoretical considerations combined with experience from flight trials. For each visibility condition, a range of intensity settings is presented. It is recommended that States adapt their intensity setting procedures such that the values, and especially the lighting intensity ratios given in Table 191-12, are followed as closely as possible to provide balanced lighting intensities.

Note: Table 191-11 specifies light intensity settings for dawn and dusk conditions (twilight). It is based on the assumption that the required settings are to be identified at values that lie between the values shown in Tables 191-10 and 191-12.

Note: Figures 191-30 to 191-32 present the data given in Tables 191-10 to 191-12 in graphical form. Each figure combines the appropriate data for each type of light. Information on the method used to develop this graphical presentation is given in this section.

Table 191-10 Light intensity adjustments for day conditions (1000 cd/m^2 to 40 000 cd/m^2)

Lighting System Element	RVR ≤ 800m (see Notes 2 and 3)	RVR 800m to 1500m (See Notes 2 and 4)	RVR 1500 m to AD Vis 5000m (see Note 5)	AD Vis ≥ 5000m (see Note 6)
Approach centre line and crossbars	20 000	20 000	10 00	-
Approach side row	5 000	5 000 (note 7)	2 500 (note 7)	-
Touchdown zone	5 000	5 000 (note 7 and 8)	2 500 (note 7)	-
Runway centre line	5 000 (note 8)	5 000 (note 7)	2 500 (note 7)	-
Threshold and wing bar	10 000	10 000	5 000	-
Runway end	2 500	2 500	2 500	-
Runway edge	10 000	10 000	5 000	-

Source: ICAO Doc 9157 Part 4

Note 1 For the purposes of developing this table, it is assumed that RVR values are based on an intensity of 10000cd and a background luminance of 10000 cd/m^2. Where RVR measurement is not available, meteorological visibility will apply.

Note 2 For RVR values less than 1500m, the intensity setting selected should provide the balanced lighting system required by OTAR Part 191.

Note 3 When the RVR is less than 400m or when the background luminance is greater than 10000 cd/m2, higher intensities would be beneficial operationally.

Note 4 When the background luminance is less than 10000 cd/m^2, an intensity half of those specified may be used.

Note 5 These intensities are to be used for approaches into low sun.

Note 6 At visibilities greater than 5 km, lighting may be provided at the pilot's request.

Note 7 Where these intensities cannot be achieved, the maximum intensity setting should be provided.

Note 8 The provision and operation of these lights are optional for these visibilities.

Table 191-11 Light intensity adjustments for twilight conditions (Note 1) (background luminance = 15 cd/m^2 to 1 000 cd/m^2)

Lighting System Element	RVR ≤ 800m	RVR 800m to 1500m	RVR 1500m to AD Vis 5000m	AD Vis 5000m to 8000m	AD Vis ≥ 8000m
Approach centre line and crossbars	5 000 – 10 000	3 000 – 6 000	1 500 – 3 000	500 – 1 000	150 - 300
Approach side row	1 000 – 2 000	500 – 1 000 (note 3)	250 – 500 (note 3)	100 – 200 (note 3)	-
Touchdown zone	1 000 – 2 000	500 – 1 000 (note 3)	250 – 500 (note 3)	100 – 200 (note 3)	-
Runway centre line	1 000 – 2 000	500 – 1 000 (note 3)	250 – 500 (note 3)	100 – 200 (note 3)	-
Threshold and wing bar	2 500 – 5 000	1 500 – 3 000	750 – 1 500	250 - 500	75 - 150
Runway end	2 500	1 500 – 2 500	750 – 1 500	250 - 500	75 - 150
Runway edge	2 500 – 5 000	1 500 – 3 000	750 – 1 500	250 - 500	75 - 150

Source: ICAO Doc 9157 Part 4

Note 1 To ensure that the values adopted for the different elements of the approach and runway lighting system are balanced, the intensity settings of the lighting systems should be uniformly in one part of the tolerance ranges shown, i.e. towards the top, the centre or the bottom.

Note 2 For the purposes of developing this table, it is assumed that RVR values are based on an intensity of 5000cd and a background luminance of 200 cd/m^2. Where RVR measurement is not available, meteorological visibility will apply.

Note 3 Where provided, these lights are to be operated at the intensities shown; however, their provision is optional for these visibilities.

Note 4 Where these intensity settings cannot be achieved, the maximum intensity setting should be provided.

Table 191-12 Light intensity adjustment for night conditions (note 1) (background luminance = 15 cd/m²)

Lighting System Element	RVR ≤ 800m	RVR 800m to 1500m	RVR 1500m to AD Vis 5000m	AD Vis 5000m to 8000m	AD Vis ≥ 8000m
Approach centre line and cross bars	1 000 – 2 000	600 – 1 200	300 - 600	100 - 200	50 - 100
Approach side row	250 - 500	150 – 300 (note 3)	100 – 150 (note 3)	25 – 40 (note 3)	-
Touchdown zone	200 - 500	150 – 300 (note 3)	100 – 150 (note 3)	25 – 40 (note 3)	10 – 20 (note 3)
Runway centre line (30m)	200 – 500 (note 4)	150 – 300 (note 3)	100 – 150 (note 3)	25 – 40 (note 3)	10 – 20 (note 3)
Threshold and wing bar	1 000 – 2 000	600 – 1 200	300 - 600	100 - 200	20 – 40 (note 3)
Runway end	1 000 – 2 000	600 – 1 200	300 - 600	100 - 200	20 - 40
Runway edge	1 000 – 2 000	600 – 1 200	300 - 600	100 - 200	20 - 40

Source: ICAO Doc 9157 Part 4

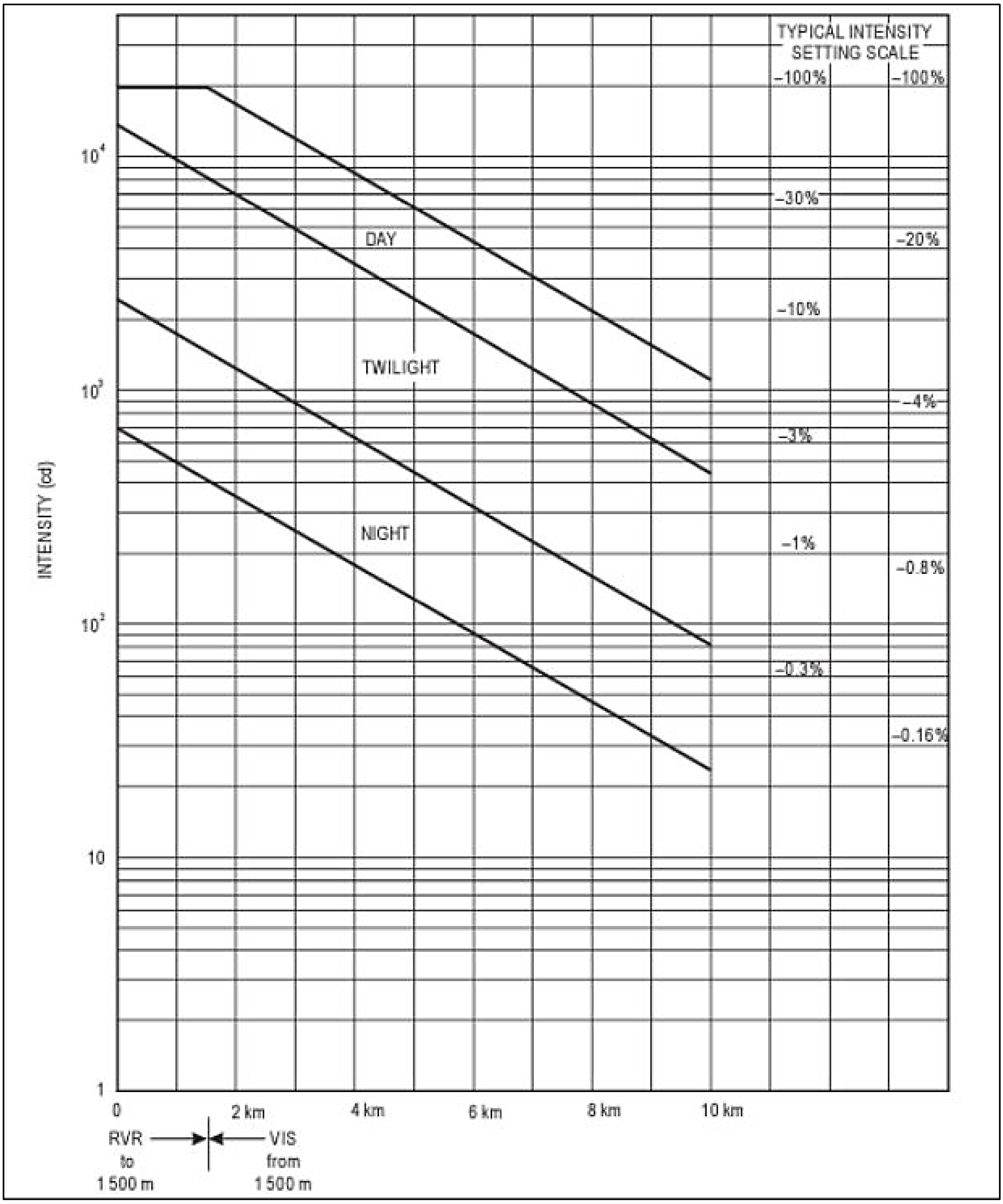
Note 1 To ensure that the values adopted for the different elements of the approach and runway lighting system are balanced, the intensity settings of the lighting systems should be uniformly in one part of the tolerance ranges shown, i.e. towards the top, the centre or the bottom.

Note 2 For the purposes of developing this table, it is assumed that RVR values are based on an intensity of 1000 cd and a background luminance of 15 cd/m². Where RVR measurement is not available, meteorological visibility will apply.

Note 3 Where provided, these lights are to be operated at the intensities shown; however, their provision is optional for these visibilities.

Note 4 These intensity settings may need to be increased for take-off in RVRs below 400m.

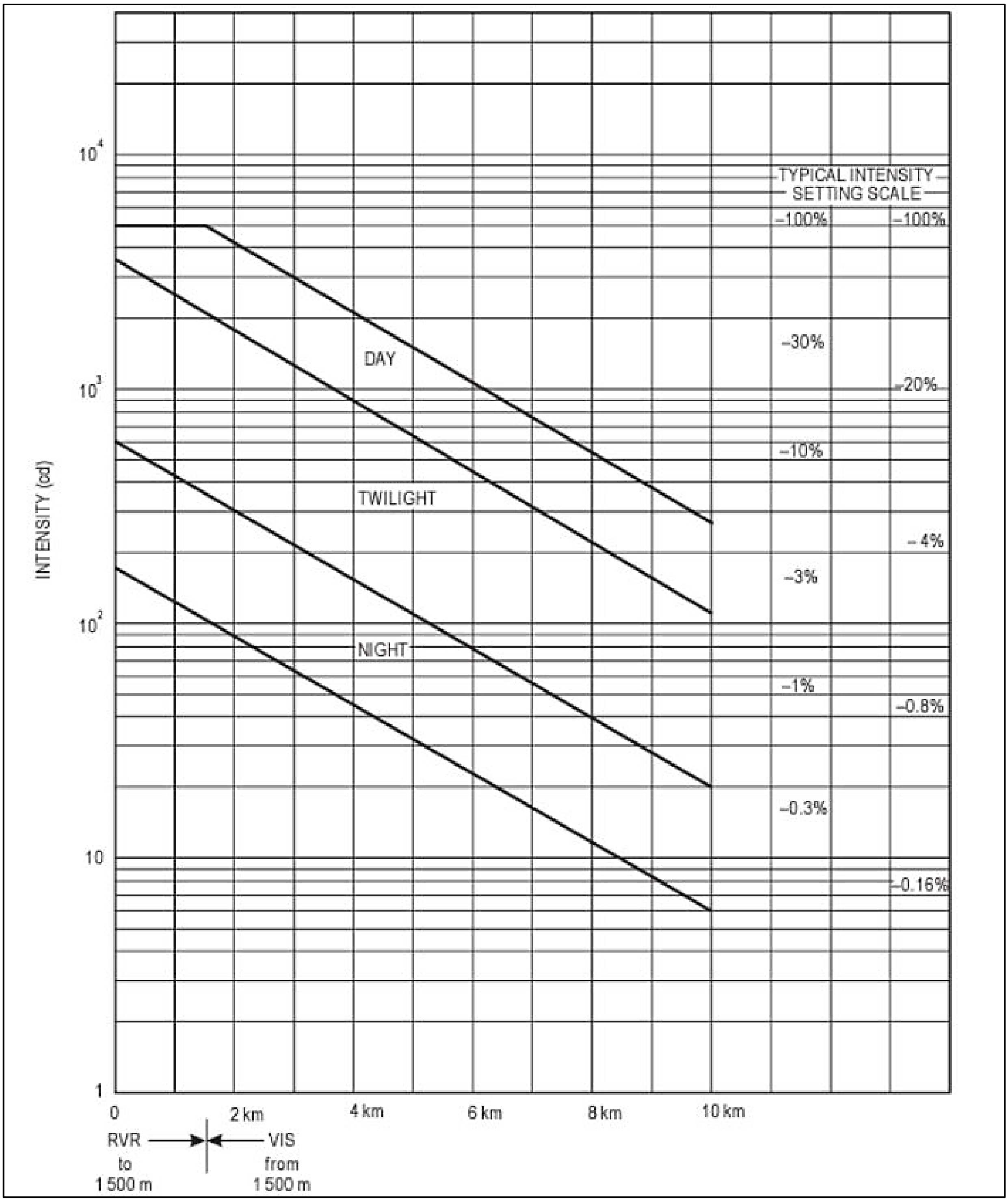
Figure 191-30 Approach centre line and crossbars



Source: ICAO Doc 9157 Part 5

Note: Day = background luminance 1000 to 40000 cd/m^2
Twilight = background luminance 15 to 1000 cd/m^2
Night = background luminance 15 cd/m^2

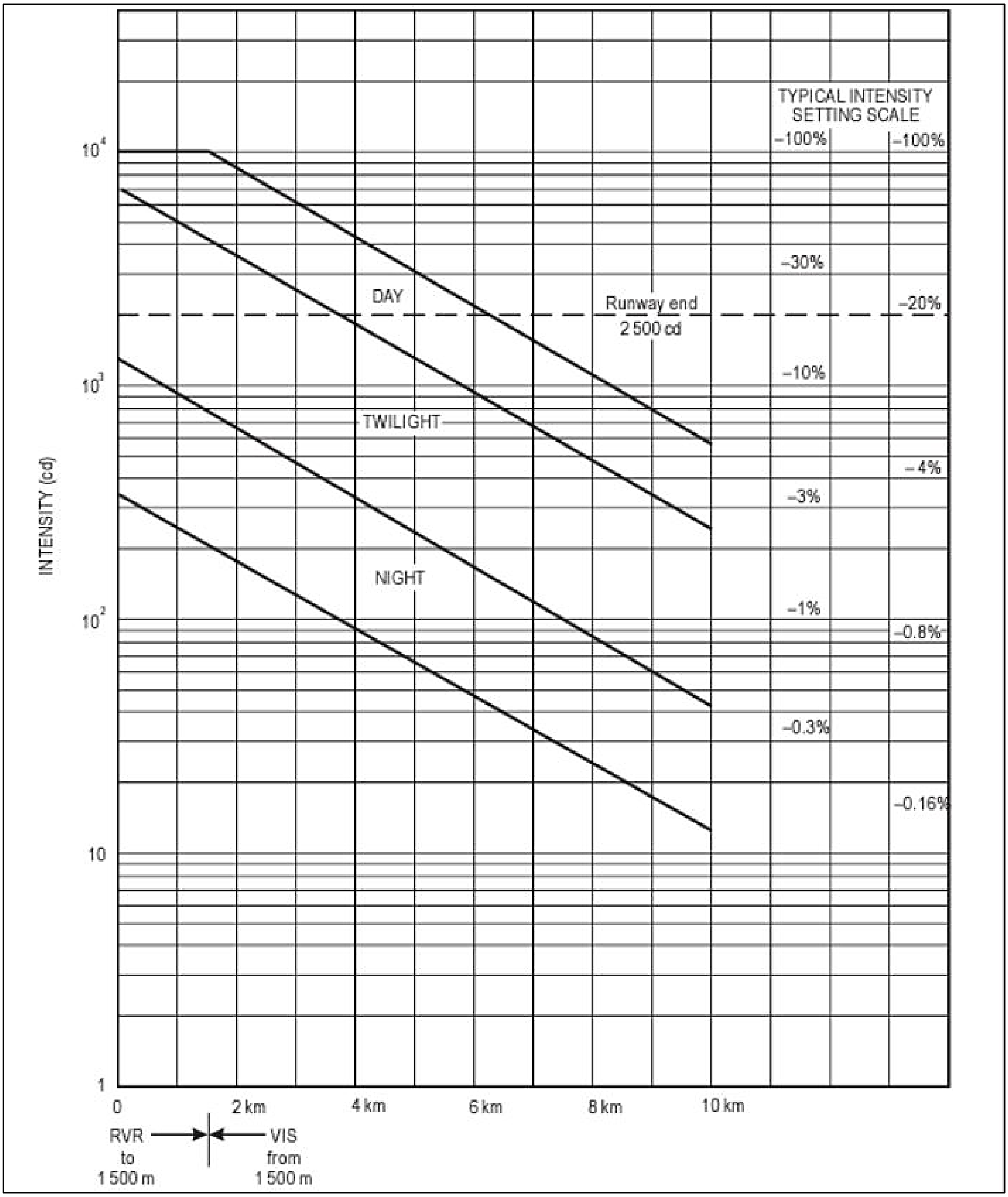
Figure 191-31 Approach side row, touchdown zone and runway centre line



Source: ICAO Doc 9157 Part 4

Note: Day = background luminance 1000 to 40000 cd/m^2
Twilight = background luminance 15 to 1000 cd/m^2
Night = background luminance 15 cd/m^2

Figure 191-32 Threshold and wing bar, runway end and runway edge



Source: ICAO Doc 9157 Part 4

Note: Day = background luminance 1000 to 40000 cd/m^2
Twilight = background luminance 15 to 1000 cd/m^2
Night = background luminance 15 cd/m^2

6.4 Lighting for non-instrument and non-precision approach runways

6.4.1 The specifications for this system are defined in OTAR Part 191. The pattern consists of a 420-m-long centre line located on the extended runway centre line and a crossbar to provide roll references at a distance of 300 metres from the threshold. The pattern is designed to support non-precision approaches, although it is advised that consideration should be given to the installation of precision approach Category I lighting systems for this type of operation if it is desired to enhance the guidance and make the task of the pilot easier.

6.4.2 It is recognized that it may be justified in some locations to reduce the length of the simple approach lighting system to a length that is practicable. For example, this action may be necessary where the terrain in the final approach area falls away steeply prior to the runway threshold.

6.4.3 While approach lighting is ideal, there are situations where installing it isn't feasible. In these cases, landings and take-offs (considered non-precision operations) will be restricted to good visibility during both day and night. Only when pilots can clearly see the runway edge, threshold, and end lights, or rely on other visual aids, will these operations be allowed.

6.4.4 It is recommended that a simple approach lighting system should also be installed where practicable to support non-instrument operations at night in good visibility conditions if the code number is 3 or 4.

6.4.5 Flashing runway threshold identification lights can be installed to improve visibility for pilots landing or taking off, especially if they need extra help finding and lining up with the runway. This is also an option when installing approach lighting isn't feasible.

6.5 Lighting for precision approach runways — category I

6.5.1 The specifications for this lighting are in OTAR Part 191. The appropriate paragraphs describe how the basic system is to be installed to support Category I precision approaches. The 900 m length of the system provides the necessary alignment and roll cues in the lowest Category I conditions of 200 ft decision height and an RVR of 550 m.

6.5.2 The alternative patterns shown in, Figure 191-33 both provide the cues required for Category I operations. System A specifically includes distance-from-threshold coding in the pattern and provides particularly strong roll cues that can be beneficial in the event of an aircraft being delivered by the non-visual approach system at or near the permitted deviation boundaries for this type of approach. System B may, in some cases, be more practicable to install due to the shorter length of the crossbar elements of the system. This pattern is recommended to be augmented by sequenced flashing lights to enhance the conspicuity of the centre line, as shown in Figure 191-33.

6.5.3 Sequenced flashing lights shine brightest when used in medium or good visibility. This is because the flashing pattern makes the approach lights stand out more. This is especially true during the day when there's low contrast between the ground and surrounding features, or at night in cluttered city environments with lots of non-aircraft lights that can be distracting for pilots.

6.5.4 The isocandela specification in OTAR Part 191 is used for all the steady burning lights in the high-intensity approach lighting system. The elevation setting angles should always be in accordance with the table given in the figure. These angles vary from 5.5 degrees near the runway threshold to 8 degrees in the outermost parts of the pattern. These angles must be maintained at all times because they are an essential part of the optimized design of the lighting system. They ensure that the segment of lighting seen by the pilot is as large and as consistent as possible in all prevailing conditions. Misalignments as small as 1 degree can be detected, and larger misalignments can result in an incomplete pattern being seen in low visibility conditions.

6.5.5 An adequate approach lighting system is essential for safe and successful precision approaches. Pilots rely on visual references to land the aircraft, and the height at which they can continue the approach (decision height) depends on factors like the approach type, weather conditions, available equipment on the ground and aircraft, and more. To ensure sufficient visual guidance for all these variations, a minimum 900 metre approach lighting system should be provided whenever possible.

6.5.6 However, there are some runway locations where it is impossible to provide the 900 metre length of approach lighting system to support precision approaches.

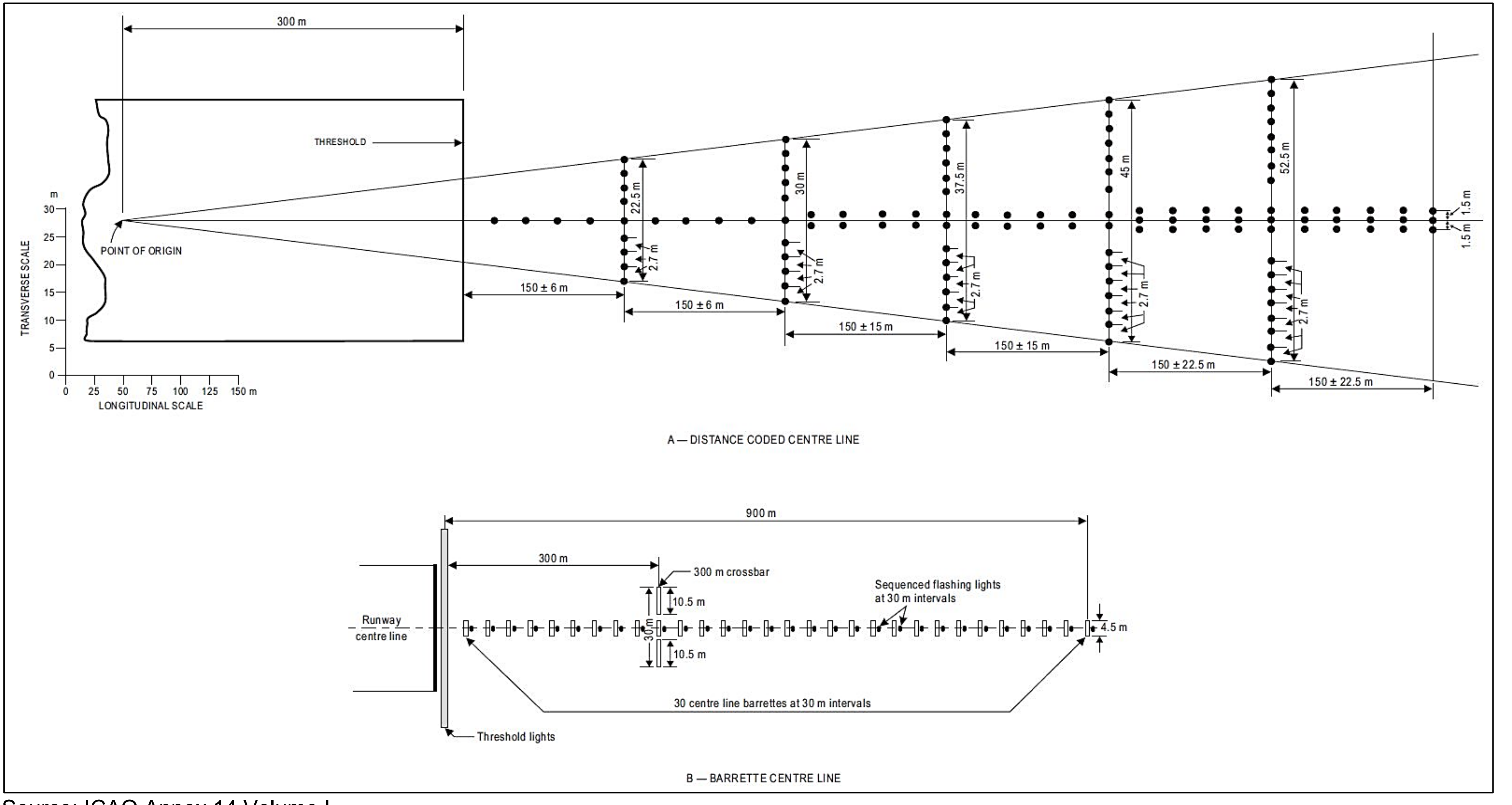
6.5.7 In such cases, every effort should be made to provide as much approach lighting system as possible. The appropriate authority may impose restrictions on operations to runways equipped with reduced lengths of lighting. There are many factors which determine at what height the pilot must have decided to continue the approach to land or execute a missed approach. It must be understood that the pilot does not make an instantaneous judgement upon reaching a specified height. The actual decision to continue the approach and landing sequence is an accumulative process which is only concluded at the specified height. Unless lights are available prior to reaching the decision point, the visual assessment process is impaired and the likelihood of missed approaches will increase substantially. There are many operational considerations which must be taken into account by the appropriate authorities in deciding if any restrictions are necessary to any precision approach and these are detailed in Annex 6.

6.5.8 Flight path envelopes used in designing the lighting for approaches and the ground roll on the runway are shown in Figure 191-34. They are based on 99 per cent isoprobability values from Obstacle Clearance Panel (OCP) data for points at distances of 600 metres and 1200 metres from the runway threshold.

6.5.9 The upper boundaries take into account the height of the pilot’s eyes above the ILS/MLS receiver antenna on the aircraft. The Category I and II boundaries based on these data have been terminated at the respective minimum decision heights, i.e. 60 meters and 30 metres respectively. Below these heights the flight envelopes are defined by the limits of the flight paths which would result in a satisfactory landing in visual conditions. The lower boundary of the Category I envelope has been set at two degrees elevation with an origin at the outermost approach light to cater for non-precision approaches in good visibilities.

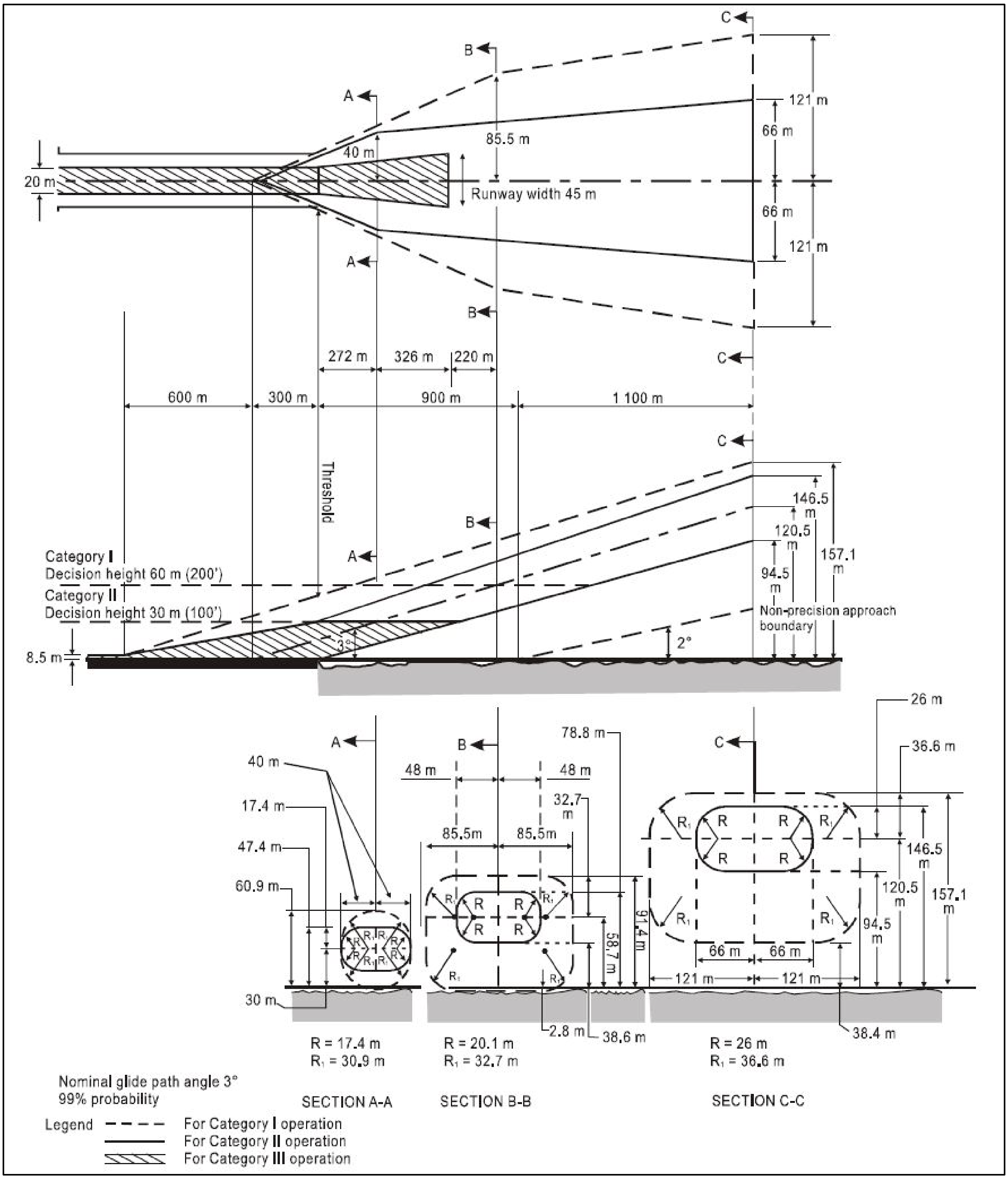
6.5.10 In Category I operating conditions, the runway and approach lighting systems must be effective not only at the limiting RVR of 550 metres but also in intermediate and good visibilities.

Figure 191-33 Precision approach category I lighting systems



Source: ICAO Annex 14 Volume I

Figure 191-34 Flight path envelopes to be used for lighting design for category I, II and III operations



Source ICAO Annex 14 Volume I

6.5.11 In deriving the light characteristics shown in OTAR Part 191, the following principles and procedures have been applied:

1) The fog is of uniform density;

2) the overall lighting system should be balanced in the sense that the visual segment seen by the pilot generally increases continuously;

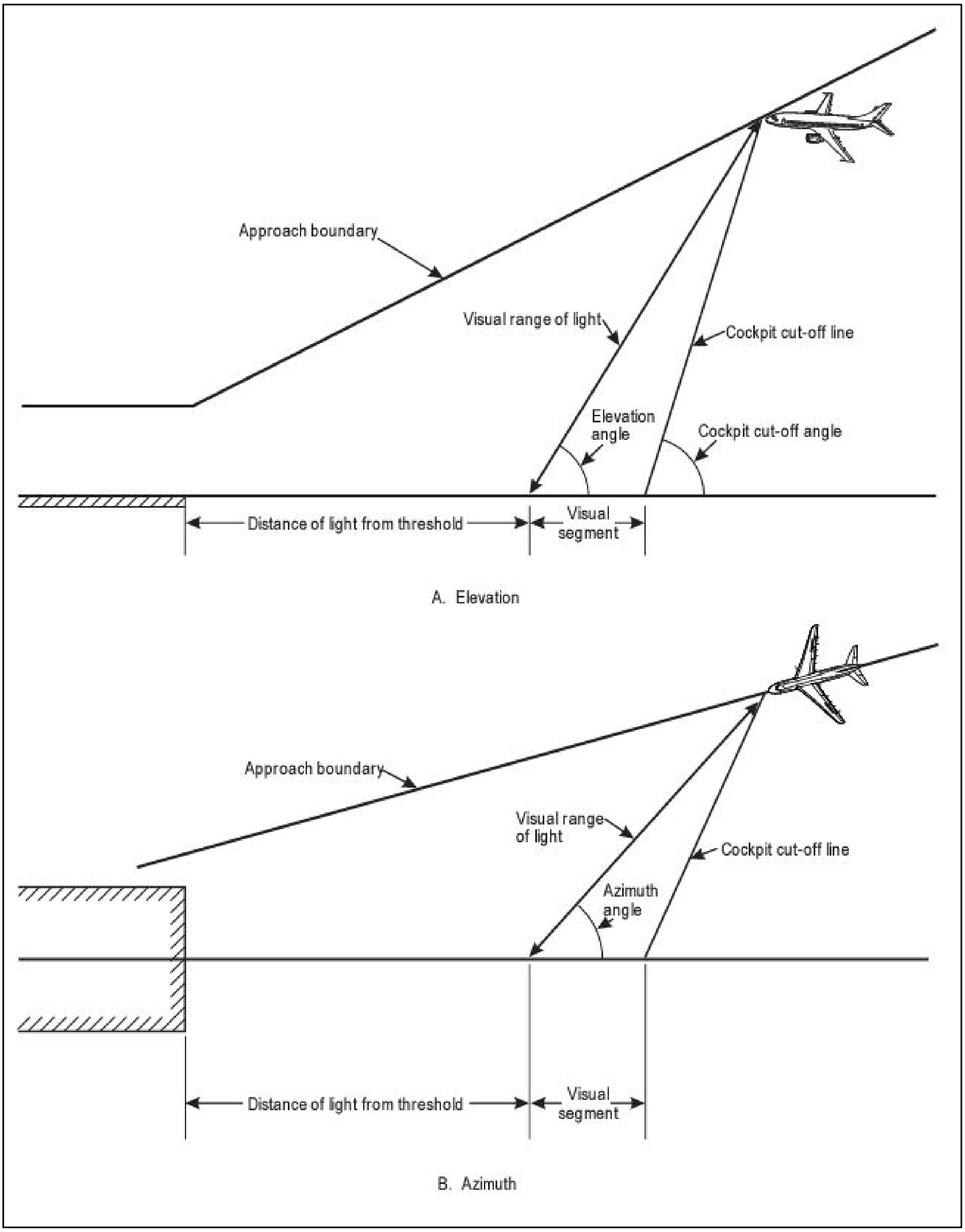
3) for a given meteorological visibility, the length of the visual segment seen after initial contact should be the same for all approach paths within the approach envelopes.

6.5.12 Aircraft are assumed to follow the boundaries defined in OTAR Part 191. The visual range, the elevation angles and the azimuth angle between the aircraft and representative light positions in the approach and runway lighting patterns at positions along the boundaries are calculated for a number of values of visual segment.

6.5.13 The corresponding values of the intensity needed to meet the visual range requirement are calculated for each case, using Allard’s Law, for a range of values of the equivalent meteorological visibility appropriate to the three ICAO categories of low visibility operation for daylight values of the pilot’s illuminance threshold (10–4 to 10–3 lux).

6.5.14 The above calculations are repeated for various aircraft types using appropriate values of the cockpit cut-off angle (the distance ahead of the aircraft that is obscured from the pilot by the cockpit and nose of the aircraft; Figure 191-35 refers) and aircraft dimensions pertaining to the ILS/MLS receiver aerial-to-eye height during the approach and the wheel-to-eye height during the ground-roll. The resulting information is then plotted to give the theoretical angular distribution of luminous intensity required for that light in the pattern. Computer modelling techniques are the best means of developing these specifications.

Figure 191-35 Visual segment geometry



Source: ICAO Doc 9157 Part 4

6.6 Visual approach slope indicators

6.6.1 The visual approach slope indicator systems defined in OTAR Part 191 are designed to give visual indications of the desired approach slope. There are four standard systems, i.e. T visual approach slope indicator system (T-VASIS), abbreviated T visual approach slope indicator system (AT-VASIS), precision approach path indicator (PAPI) and abbreviated precision approach path indicator (APAPI). These systems have been proven by operational experience.

6.6.2 This section provides guidance in the application of requirements defined in OTAR Part 191 considering that:

1) Light units of different design are in use;

2) systems are installed on airports of widely divergent physical characteristics;

3) systems are used by both the large and the small aircraft types.

6.6.3 OTAR Part 1919 details the characteristics (viz. the origin, dimensions and slope) of the obstacle protection surfaces of T-VASIS, AT-VASIS, PAPI and APAPI. Since these surfaces have been patterned generally on the lines of the approach surface of the runway, the data collected during the obstacle survey of the latter surface will be useful in determining whether or not objects extend above an obstacle protection surface. Where an aeronautical study indicates that an object extending above the obstacle protection surface could affect the safety of operations of aeroplanes, then one or more of the following measures shall be taken to eliminate the problem:

1) raise the approach slope of the system;

2) reduce the azimuth spread of the system so that the object is outside the confines of the beam;

3) displace the axis of the system and its associated obstacle protection surface by no more than 5 degrees;

4) displace the threshold;

5) where 4) is found to be impracticable, displace the system upwind of the threshold to provide an increase in the threshold crossing height equal to the amount by which the obstacle penetrates the obstacle protection surface.

6.6.4 The system's extensive azimuth coverage offers valuable information to aircraft on the base leg, but this data alone should not be used for descent unless a dedicated aeronautical study verifies there are no obstacles within the system's range. If such a study identifies an object outside the system's protected surface but within its lateral light beam that could endanger operations due to its height, then the azimuth spread of the light beam on the affected side should be restricted to exclude the object from the beam's reach.

6.6.5 Although the normal approach slope is 3 degrees, a different approach slope may be selected to achieve a visual approach slope angle which equals the approach slope angle of a non-visual glide path, when provided. If obstacles are present in the approach area, a higher approach slope angle may be selected.

6.6.6 The indications provided define one normal approach path plus seven discrete deviation indications in the case of T-VASIS, one normal approach path and four discrete deviation indications in the case of PAPI, and one normal approach path and two discrete deviation indications in the case of APAPI.

Note: In this chapter, PAPI is meant to imply also AT-VASIS and T-VASIS to imply also APAPI.

6.6.7 In preparing a design for the installation of a system, it may be necessary to change the dimensions stated in the ideal layout due to the location of taxiways or other features alongside the runway. It has been found that these dimensions may be changed by up to 10 per cent without impairing the operation of the system.

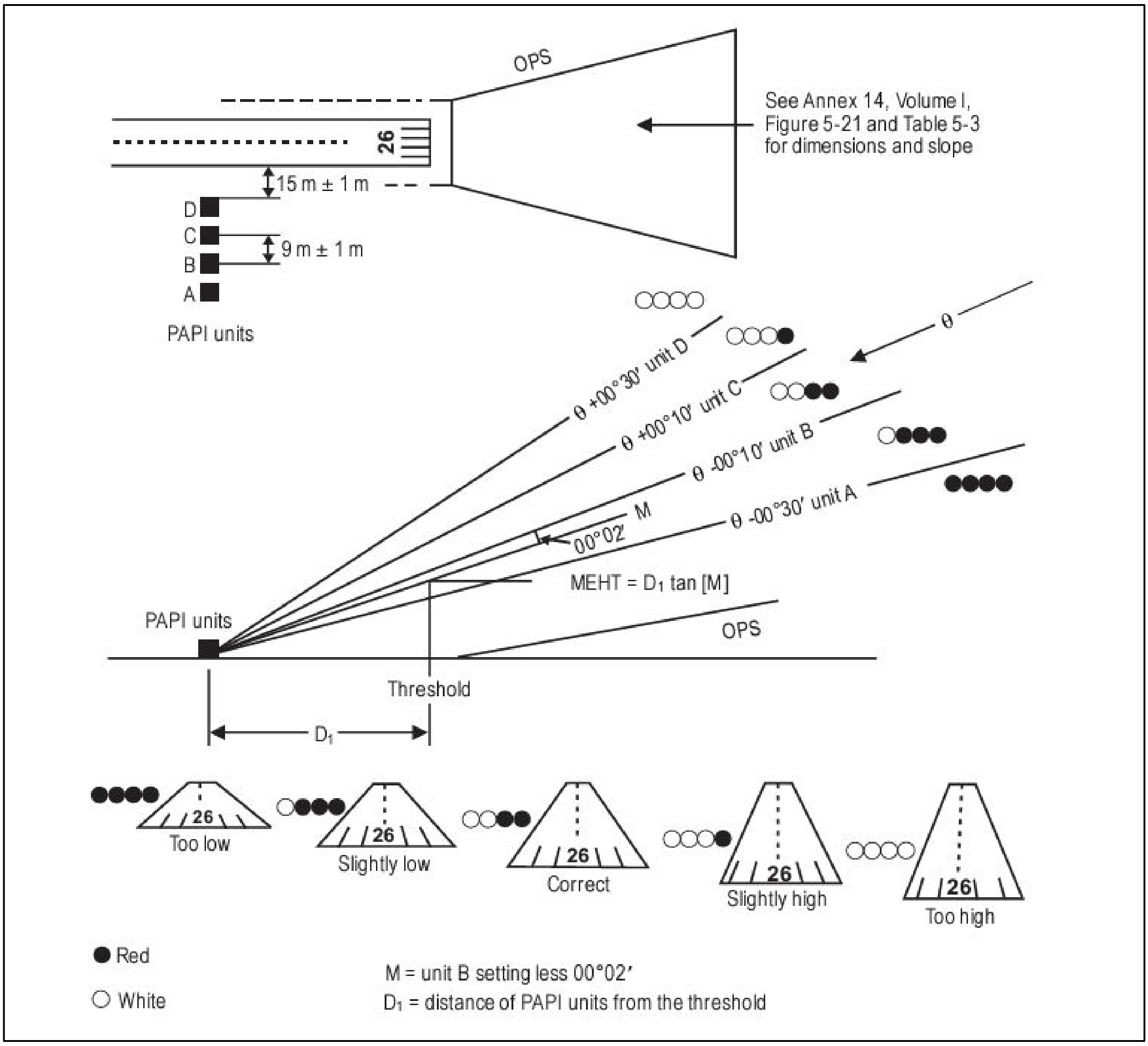
6.6.8 While the runway strip's contours should not create any perceived distortion for pilots on the proper approach slope, the light units are physically moved to compensate for the elevation difference between the runway threshold and their final position. This adjustment requires a longitudinal movement of 19 times the level difference to ensure proper functionality at a 3-degree approach slope.

6.6.9 For PAPI, when viewed along the approach slope, a light unit should appear to be at the same level as any equivalent light on the other side of the runway. After having allowed for the difference in height between the opposite sides of the runway, the difference between the longitudinal location of each of the light units of a matching pair should be less than 1.5 metres.

6.6.10 To safeguard against damage from aircraft overruns, the concrete foundation supporting the light units requires special design considerations. Either the slab can be depressed below ground level, creating a backfilled cavity, or the sides can be sloped to allow the aircraft to pass over with minimal damage. In both cases, the frangible (easily breakable) nature of the units and their supports minimizes harm. Additionally, for light units not designed to withstand jet efflux from aircraft operations, baffles to deflect the blast and measures to secure the units themselves may be necessary.

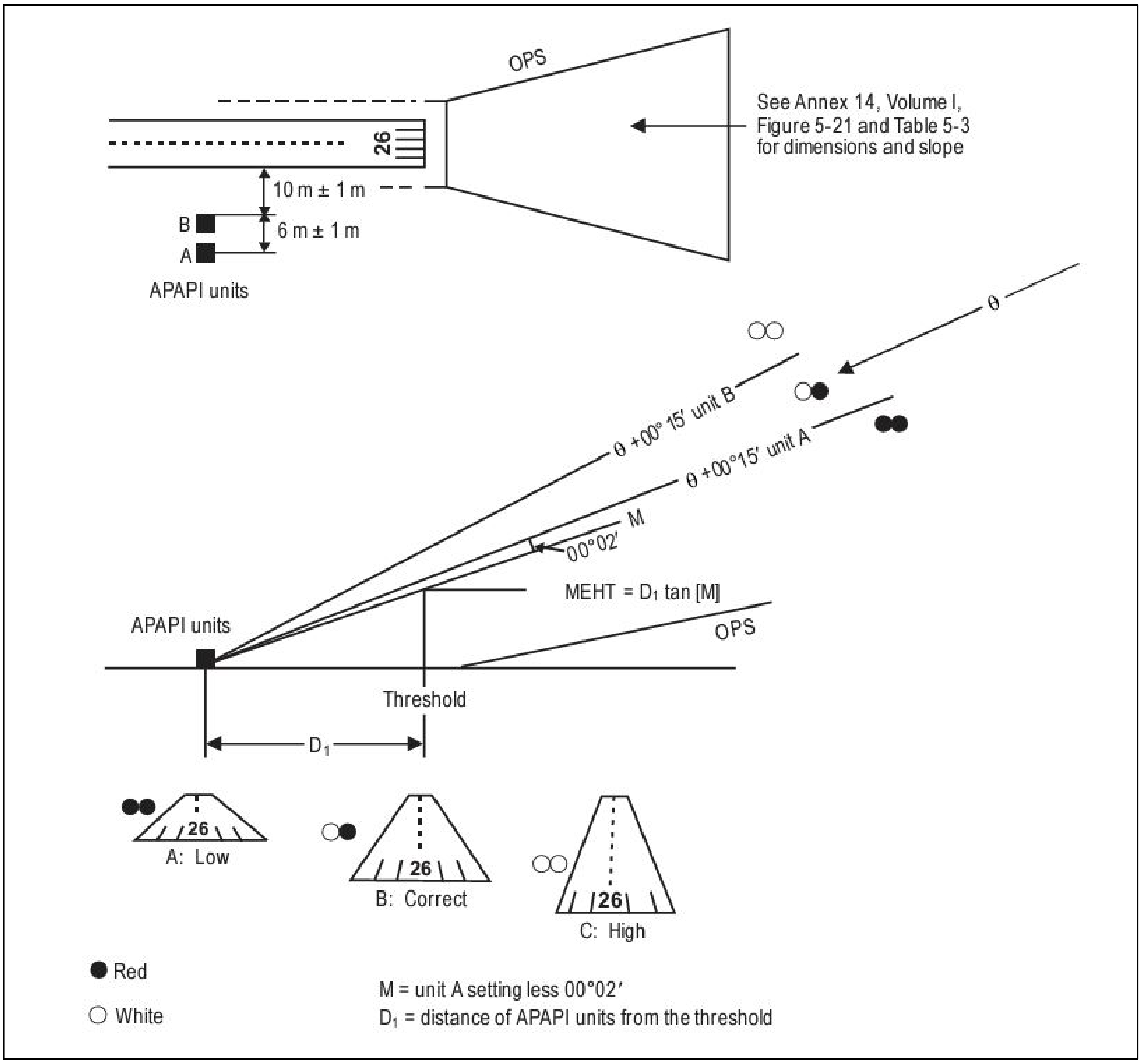
6.6.11 Where a PAPI or APAPI is installed on a runway equipped with an ILS and/or MLS, the distance (D1) (as shown in Figures 191-36 and 191-37) is calculated to provide the optimum compatibility between the visual and non-visual aids for the range of eye-to-antenna heights of aeroplanes that regularly use the runway.

Figure 191-36 The arrangement of the PAPI units and the resulting display



Source: ICAO Doc 9157 Part 4

Figure 191-37 The arrangement of the APAPI units and resulting display



Source: ICAO Doc 9157 Part 4

6.7 Circling guidance lights

6.7.1 The following guidance should be provided for circling approaches:

1) adequate indication of the direction or location of the runway. This would enable a pilot to join the downwind leg or align and adjust the track to the runway;

2) a distinct indication of the threshold so that a pilot can distinguish the threshold in passing;

3) adequate indication of the extended runway centre line in the direction of the approach and compatible with the threshold indication to enable a pilot to judge the turn onto base leg and final approach.

6.7.2 The need for, and design of, circling guidance lights vary from location to location depending on such factors as the circling approach procedure used, the types of aircraft using the runway, meteorological conditions, and types of lights available. At most airports, runway edge lights and approach lighting systems provide all the guidance that is required. Consequently, special lights for circling guidance would be needed only where these systems do not satisfactorily provide the guidance identified in 6.7.1. The provision of additional lights for circling guidance is not usually a major problem. In general, the lights should be designed and installed in such a manner that they will be visible from the downwind leg but will not dazzle or confuse a pilot when approaching to land, taking off or taxiing.

6.7.3 OTAR Part 191 incorporates specifications for runway edge lights. These lights are primarily intended to define the lateral limits of the runway to aircraft on final approach. However, OTAR Part 191 particularly emphasizes that the runway edge lights shall show at all angles in azimuth when they are intended to provide circling guidance. Low-intensity lights which are used for operations on clear nights are generally, omni-directional and therefore comply with this requirement. High-intensity lights which are used for operations under poor visibility conditions are bidirectional but may also be designed to emit a low-intensity omnidirectional light capable of providing circling guidance.

6.7.4 If circling guidance is to be provided by this type of light fitting, it is necessary to ensure that the required low-intensity output can be achieved when the high-intensity lighting is operated at the low outputs normally used on clear nights. This is normal practice in order to avoid glare problems during the final approach and landing. An output of 50 cd at maximum brilliancy will reduce to less than 0.5 cd when a night setting is used for the high-intensity lighting. Where a low-intensity omnidirectional light is not included with the high-intensity lights, additional lights should be installed along the runway edges to provide circling guidance. If these additional lights are high-intensity lights, they should be unidirectional with their beams at right angles to the runway centre line and directed away from the runway. The colour of these lights should preferably be white, but yellow light such as is emitted by some forms of gas discharge may be used.

6.7.5 OTAR Part 191 requires the installation of two white flashing lights at the threshold of a non-precision approach runway when additional threshold conspicuity is required or where it is not possible to install other approach lighting aids. Additional conspicuity may also be necessary when the runway threshold is permanently or temporarily displaced. These lights can also be used on other runways to facilitate identification of the threshold, particularly in areas having a preponderance of lighting or where featureless terrain exists. If the lights have a wide or omnidirectional beam spread or are oriented at right angles to the runway, they will provide circling guidance.

6.7.6 The centre line lights of all the approach lighting systems specified in OTAR Part 191 are intended to define the extended centre line of the runway. Low-intensity systems are normally designed with omnidirectional lights, and thus they will provide circling guidance as well. High-intensity systems employ unidirectional lights which will not be visible to a pilot on the downwind leg. Such systems can be improved by installing additional lights either adjacent to the existing lights or beyond the outer end of the approach lighting system (along the extended centre line). These lights should be steady burning or flashing. Where lights are installed beyond the outer end of an approach lighting system, the intensity and beam spread of the lighting should be adequate to be visible from the downwind leg. Where flashing lights are used, they should flash in sequence at the rate of one per second, starting at the outermost light and proceeding towards the threshold.

6.8 Taxiway and runway guard lights

6.8.1 At many aerodromes, the concentration of taxiway edge lights in the operational area often results in a confusing mass of blue lights commonly referred to as a “sea of blue”. In some cases, this can result in pilots finding it difficult to correctly identify the taxiway boundaries. This problem particularly occurs in complex taxiway layouts with small radius curves.

6.8.2 The provision of runway guard lights is an effective way of increasing the conspicuity of the location of the runway-holding position in visibility conditions above, as well as below, a runway visual range of 1 200 m. There are two standard configurations of runway guard lights, elevated and in-pavement lights, as illustrated in OTAR Part 191.

6.8.3 Recognizing the rising number of aircraft operations and the corresponding growth in potential runway incursions globally, OTAR Part 191 advocates for the use of runway guard lights, either Configuration A or B, at taxiway-runway intersections identified as high-risk areas. These lights should be operational under all weather conditions, day and night.

6.8.4 Where runway guard lights are intended for use during the day, it is recommended that high-intensity runway guard lights be used, in accordance with OTAR Part 191.

6.8.5 Runway guard lights, Configuration A, shall consist of two pairs of elevated flashing-yellow lights, and runway guard lights, Configuration B, shall consist of in-pavement flashing-yellow lights spaced at intervals of 3 m across the taxiway. The light beam shall be unidirectional in the direction of approach to the runway-holding position.

6.8.6 The installation of runway guard lights, Configuration A, has been found useful to increase the conspicuity of stop bars installed at runway-holding positions associated with precision approach runways.

6.9 Frangibility of visual aids

6.9.1 To minimize damage from accidental aircraft impact during landing, take-off, or ground manoeuvres near runways, taxiways, and aprons, all visual and non-visual navigational aids and their supports must be frangible. This means they are designed to break, deform, or give way upon impact. To achieve this frangibility, lightweight materials and breakaway mechanisms are employed, ensuring minimal impact on aircraft control.

6.9.2 All fixed objects, or parts thereof, that are located on an area intended for the surface movement of aircraft, or that extend above a surface intended to protect an aircraft in flight are, by definition, obstacles. The first objective should be to site objects so that they are not obstacles. Nevertheless, certain airport equipment and installations, because of their function, must inevitably be located so that they are obstacles. All such equipment and installations as well as their supports shall be of minimum mass and frangible to ensure that impact will not result in loss of control of the aircraft.

6.9.3 Signs and markers need to be located as near to the edge of the pavement as their construction will permit for easier visibility by the pilot of an aircraft. Those located near a runway or taxiway need to be sufficiently low to preserve clearance for propellers and for the engine pods of jet aeroplanes. Those farther from the runway or taxiway need to be larger to provide for inscriptions large enough to be read by the pilot.

6.9.4 The design of breakaway or failure mechanisms in navigational aids, and the selection of materials used, significantly affect the energy required for their activation. This energy depends on two key factors: mechanism efficiency and object mass. The energy absorbed through plastic or elastic deformation of the structure is highly dependent on the chosen material. Ductile materials with high yield strains will absorb more energy. Additionally, the kinetic energy required to accelerate the entire obstacle, or a part of it, depends on the aircraft's velocity (which cannot be controlled through design) and the mass to be accelerated. Therefore, minimizing mass is crucial. This can be achieved by using low-mass materials and by limiting the amount of structure that needs to accelerate. This limitation can be accomplished by incorporating strategically located breakaway or failure mechanisms within the structure itself.

6.9.5 A modular design offers distinct advantages for frangible navigational aids. By incorporating breakaway or failure mechanisms within individual modules, the total energy needed for activation is minimized, both for each mechanism and overall. This approach allows for the movement of the least possible mass away from the path of a colliding aircraft. The predictable behaviour of a modular, brittle design simplifies impact analysis. Preferably, these breakages occur with minimal deflection, further reducing the risk of an aircraft component "wrapping around" the broken structure. However, a potential drawback exists: detached fragments from the broken modules could be struck by other parts of the aircraft following closely behind the initial impact zone.

6.9.6 In a frangible connection design, frangibility is incorporated in the connection, which carries the design load but fractures at impact. The structural member is not designed to break but rather to transfer the impact force to the connection. A stiff, lightweight member provides efficient load transfer to the connection and minimizes the energy absorbed from bending and mass acceleration. The connection should break at low energy levels, as determined by impact tests. Types of frangible connections include neck-down or fuse bolts, special material or alloy bolts, countersunk rivets or tear-through fasteners, and gusset plates with tear-out sections. Some of these are described as follows:

1) Fuse bolts. Failure of this type of connection is induced by providing a “stress raiser”, due to removal of material from the bolt shank. One method used to achieve this is to machine a groove to reduce the bolt diameter or to machine flats in the sides of the bolt, making it weaker in a specific direction. Shear strength is maintained and tensile strength is reduced by machining a hole through the bolt diameter and locating it out of the shear plane. Fuse bolts must be carefully installed to ensure they are not damaged or overstressed when tightened. The problem with fuse bolts is that the stress raiser may shorten the fatigue life of the bolt or may propagate under service loads and fail prematurely. Fuse bolts with machine grooves are commercially available.

2) Special material bolts. Use of fasteners manufactured from special materials eliminates the need for extensive machining or fabricating and allows the basic design to consist of conventional cost-effective techniques.

The fasteners are sized to carry the design loads but are made from material with low-impact resistance. Materials such as steel, aluminium and plastic should be selected based on strength and minimum elongation to failure. Aluminium bolts of ANSI alloy designation 2024-T4 are recommended because they are as strong as stainless-steel bolts but have only 10 per cent ultimate elongation compared to 50 per cent for stainless steel. Plastic bolts may have low elongation values, but their strength would have to be established by testing. Since frangibility is based on material selection, it is extremely important to purchase hardware with guaranteed compliance of physical properties.

3) Tear-through fasteners. Fasteners such as countersunk rivets can be used to sustain shear loads but tear through the base material if the impact force creates a tension load. The hole in the base material is accurately machined to grip a minimum amount of the area under the head of the fastener. The taper of the countersunk head also helps initiate the pull-through. This technique relies heavily on the manufacturing process and requires extensive quality inspection.

4) Tear-out sections. Connecting gusset plates can be designed with notches that will tear out with the member. In this type of connection the fastener does not break but instead is used to pull out a section of the gusset plate. Fatigue life and manufacturing quality are the primary design considerations.

6.10 Lighting of unserviceable areas

6.10.1 To effectively mark temporarily unusable areas, fixed red lights are recommended. These lights should prioritize highlighting the most hazardous edges of the zone. A minimum of four lights are required, with a reduction to three allowed only for triangular areas. The number of lights should be increased for larger or oddly shaped zones. Ideally, one light should be positioned for every 7.5 meters along the perimeter. If the lights are directional, they should be aimed to face approaching aircraft or vehicles. In situations where approaches occur from multiple directions, consider adding more lights or using omnidirectional lights for better visibility. Importantly, all unserviceable area lights must be frangible (easily breakable) and remain low enough to ensure safe clearance for aircraft propellers and jet engine pods.

6.11 Runway lead-in lighting system

6.11.1 A runway lead-in lighting system may be required to provide positive visual guidance along a specific approach path, (generally) segmented, where special problems exist with hazardous terrain, obstructions and noise abatement procedures. Such a system consists of a series of flashing lights installed at or near ground level to indicate the desired course to a runway or final approach. Each group of lights is positioned and aimed so as to be conveniently sighted from the preceding group. The approaching aircraft follows the lights under conditions at or above approach minima. The path may be segmented, straight or a combination thereof, as required. The runway lead-in lighting system may be terminated at any approved approach lighting system, or it may be terminated at a distance from the landing threshold which is compatible with authorized visibility minima permitting visual reference to the runway environment. The outer portion uses groups of lights to mark segments of the approach path beginning at a point within easy visual range of a final approach fix. These groups may be spaced close enough together (approximately 1 600

m) to give continuous lead-in guidance. A group consists of at least three flashing lights in a linear or cluster configuration and may be augmented by steady burning lights where required. When practicable, groups should flash in sequence toward runways. Each system must be designed to suit local conditions and to provide the visual guidance intended.

6.11.2 In some locations there may be a need for very accurate horizontal guidance due to the presence of obstacles or residences located near the normal approach path. In such cases, the system needs to be augmented at each group by a light that accurately provides alignment information.

Appendix A – Arresting Systems

Note: This appendix sets out performance and compatibility standards for widely used aircraft arresting systems like Engineered Materials Arresting System (EMAS), primarily for commercial aircraft. These standards can be adapted for other similar systems with adjustments.

An Aircraft Arresting System (AAS) is a system designed to decelerate an aeroplane overrunning the runway. In accordance with Annex 14, Volume I, if an arresting system is installed, the length of the standard or recommended RESA may be reduced, based on the design specification of the system, subject to acceptance by the State. AASs provide predictable and effective performance in arresting aircraft overruns, independent of the weather.

The EMAS acts as a safety net for aircraft overruns, relying on specifically designed materials to dissipate the plane's kinetic energy through a controlled and predictable process. These engineered materials possess carefully calibrated strength properties that guarantee reliable crushing under the weight of an aeroplane's landing gear. Imagine them as specialised shock absorbers built into the runway, each strategically chosen block yielding and fragmenting in a predetermined manner. As the aircraft engages the EMAS, these engineered materials undergo progressive fracture, absorbing tremendous amounts of energy through the breaking and shearing of their internal structures. This controlled destruction creates a friction-laden path, decelerating the aircraft without causing sudden jolts or uncontrolled skidding. The extent of this sacrificial crushing directly translates into the EMAS's stopping power. The more material that surrenders to the aircraft's weight, the greater the energy dissipation and the quicker the deceleration. Ultimately, EMAS stands as a testament to the power of engineered materials, transforming what could be a disastrous overrun into a controlled and manageable event.

Research programmes, as well as the evaluation of actual aeroplane overruns into an EMAS installation, have demonstrated that these systems are effective in arresting aeroplane overruns. The documents listed below provide guidance on the requirements and evaluation process used by the following States for EMAS systems:

1) China: MH/T 5111 — 2015 Engineered Materials Arresting System (EMAS). (Issued by Civil Aviation Administration of China).

2) France: Provisions concerning arresting systems installed in runway-end safety areas (Direction générale de l'aviation civile (DGAC)).

3) Japan: Design Standards for Airport Civil Engineering Facilities (Ministry of Land, Infrastructure, Transport & Tourism Civil Aviation Bureau).

4) Japan: Airport Civil Engineering Facility Structure Design Manual (Ministry of Land, Infrastructure, Transport & Tourism Civil Aviation Bureau).
5) USA: FAA Advisory Circular 150/5300-13: Airport Design

6) USA: FAA Advisory Circular 150/5220-22B: Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns

7) USA: FAA Order 5200.8: Runway Safety Area Program

8) USA: FAA Order 5200.9: Financial Feasibility and Equivalency of Runway Safety Area Improvements and Engineered Material Arresting Systems

The EMAS is a passive system which requires no external means to initiate/trigger the operation of arresting an aircraft, nor does it require any special actions or procedures of the flight crew.
While EMAS functions passively, familiarising crews with its capabilities can prevent unnecessary manoeuvres that might jeopardise a safe stop. Ideally, engage EMAS head-on, utilising your full braking and thrust reversal potential.

The EMAS is not intended to meet the definition of a stopway, and its availability is not to be used for flight planning purposes. An EMAS is located beyond the end of the runway (or stopway, if provided) at enough setback distance in order to avoid damage due to jet blast.

Note: The setback is defined as the distance between runway end or stopway and the beginning of the EMAS. The minimum setback distance required for jet blast protection may differ depending on the manufacturer and the operational conditions.

The calculation of the setback distance balances the risk objectives of:

1) providing enough area for arresting purposes;

2) providing enough separation to protect the bed from jet blast;

3) providing separation from the threshold to reduce the probability of undershoot in the EMAS; and

4) decreasing the probability of aircraft overruns passing by one side of the EMAS due to lateral dispersion.

The relevance of each individual risk objective for a particular runway can be established through a safety assessment that factors in operational details such as runway utilisation, approach types, weather variability, fleet composition, historical incidents, and any other relevant safety issues. In order to reduce the probability of an aircraft undershooting in an EMAS, it is recommended to provide a minimum setback distance of at least 60 metres from the threshold or the runway end. However, this separation may be reduced if, after an aeronautical study, it is determined that it is the best alternative for both overrun and undershoot protection. The EMAS functional length is designed based on the operating conditions of the associated runway with its centre line coincidental with the extended centre line of the runway. The EMAS functional width may not be less than the runway width. Where possible, this width is provided throughout the whole length of the bed.

Note: Considering the surface of a RESA may vary depending on the type of soil or pavement, resulting in diversity in the decelerating performance and characteristics of overrunning aircraft, it is not easy to establish a correlation between the performances of a RESA and an EMAS, the latter of which is designed to provide the optimal arresting response achievable with the distances available.

Exit speed is defined as the speed of the nose gear of the aeroplane as it passes the physical end of the runway or stopway if provided. Critical aircraft is defined as an aircraft regularly using the associated runway that imposes the greatest demand on the EMAS.
The "critical aircraft" concept identifies the specific plane type utilising the associated runway that sets the highest requirements for the EMAS design, due to its demanding operational characteristics. In contrast, the "design aircraft list" encompasses all aircraft types anticipated for regular operation on the runway, informing the overall design and performance considerations.

Note: While Operational Maximum Take-off Weight (MTOW) often defines the critical aircraft, other factors like landing gear and tire pressure can impact EMAS performance. Therefore, the design considers both the single most demanding aircraft and the entire expected traffic mix, including available runway space and cargo operations. In some cases, a combination of design aircraft might be optimal. Consultation with the airport operator, manufacturer, and State ensures the most effective EMAS for each specific runway.

To increase confidence in the EMAS design's predictive capabilities, we go beyond theoretical validation and conduct practical tests, ideally under real-world conditions. While validating the EMAS design's ability to predict system performance is crucial, further validation through laboratory or, ideally, in situ testing strengthens the design methodology.

Note: EMAS testing is based either on passage of an actual aircraft or a single wheel bearing an equivalent load through a test bed. The design considers multiple aircraft parameters, including but not limited to allowable aircraft gear loads, gear configuration, tire contact pressure, weight, centre of gravity and speed.

EMAS prioritises controlled deceleration of the designated aircraft at an exit speed of 70 knots for both MTOW and 80% Maximum Landing Weight (MLW). This target minimises the likelihood of exceeding the aircraft's structural design limits and protects occupants from excessive deceleration forces. In cases where runway length restricts achieving 70 knots, EMAS adapts its performance to maximise the arresting capability for the most critical aircraft type within the available distance.

The 70 knot exit speed requirement for EMAS arises from both advanced design practices and analysis of historical overrun data. Since RESA and EMAS utilise distinct metrics (stopping distance vs. exit speed), direct equivalence isn't achievable. Consequently, some states consider a 70 knot EMAS performance as equivalent (or preferable due to its predictability) to a recommended RESA. Nevertheless, documented overruns exceed both 70 knots and 300 metres, demonstrating the potential for exceeding design parameters. Significantly, achieving 70 knots with the critical aircraft in the design list generally translates to superior stopping performance for the aircraft.

The design method for EMAS excludes the use of reverse thrust of the aeroplane, using a 0.25 braking friction coefficient for the runway and length of pavement prior to the arrester bed (also known as the setback). The design method for the EMAS assumes no braking friction coefficient (0.00) within the EMAS arrester bed itself unless the EMAS manufacturer can provide documentation of field or laboratory testing which demonstrates the minimum actual braking friction coefficient that can be achieved as an aeroplane passes through the arrester bed material. The designed arresting bed distance is the theoretically calculated distance with a margin that could cover the calculation error.

Adjacent to the Engineered Material Arresting System (EMAS), the runway safety requirements outlined in Annex 14, Volume I, Chapter 3, Section 3.5 of the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) apply to the Runway End Safety Area (RESA). This ensures consistent safety provisions throughout the extended arrestor system. Dedicated service roads flank both sides and the end of the EMAS, facilitating essential maintenance and emergency response operations. These roads are designed with sufficient width to accommodate the ingress and egress of fully loaded Rescue and Fire Fighting Service (RFFS) vehicles, including heavy fire trucks and specialised rescue equipment. To optimise accessibility and prevent potential delays, the service roads are graded to promote efficient drainage and prevent water accumulation, even during heavy precipitation events. This ensures unimpeded passage for RFFS vehicles regardless of weather conditions.

The EMAS is designed so as not to increase the potential for damage in case of an undershoot, and so it does not cause more control problems for or damage to aircraft for undershoots that touch down on it compared with a RESA. Compliance with this requirement is commonly accepted to be difficult to justify, particularly concerning the numerous undershoot scenarios. Consequently, compliance with this requirement could be justified through experience of real cases of undershoot in EMAS, flight simulator tests, other types of studies or a combination thereof. The objectives of reducing the risk of damage to an aeroplane undershooting or overrunning the runway are included in the RESA definition. However, different studies[1] developed in the United States and in the European Union with worldwide data show that undershoots occur normally in close proximity to the runway, and the probability of undershoot decreases when instrumental or visual vertical guidance is provided to pilots. According to the studies, approximately 50 per cent of undershoots occur in the first 60 metres before the runway threshold, and the ratio of undershoots/overruns is reported to be 1:4. This information needs to be taken into account in the safety assessment developed to find the best solution for enhancing runway safety. EMAS is not intended to reduce the risk of damage to an aeroplane undershooting the runway. However, the presence of an AAS does not increase the potential for damage in the case of an undershoot more than the risk associated with an undershoot in a RESA.

[1] ACRP Report 50. Improved Models for Risk Assessment of Runway Safety Areas EASA_REP_RESEA_2011_12. Study on models and methodology for safety assessment of Runway End Safety Areas (RESA).

Although the EMAS is not regarded as an obstacle on the runway strip or in the RESA for clearing and grading requirements, it must be frangible and mounted as low as possible, with ramps provided to avoid vertical surfaces, wherever feasible. The arrester bed is prepared in such a manner so as not to be damaged by jet blast or projected debris during normal aircraft operations.

The mechanical property of the arrester bed is required to be sufficiently adequate to avoid damage resulting from personnel walking on it for routine maintenance. However, the bed is not intended to support vehicular traffic for maintenance or normal operating purposes. The presence of the arrester bed will not hinder the movement of the Rescue and Fire-Fighting Service (RFFS) vehicles during an emergency. Adequate slopes or steps are to be provided to allow these vehicles to enter from the front and sides. To optimise evacuation times in emergency situations, the arrester bed must not impede the movement of passengers and crew. The use of strategically placed slopes or steps around the perimeter can significantly improve evacuation efficiency. The arrester bed's material composition prioritises the suppression of potential fire hazards for incoming aircraft. Key characteristics include resistance to sparking and ignition, minimal combustion propagation, and the absence of significant or noxious fume emission in post-installation fire scenarios.

The following are additional requirements of an EMAS system:

1) will not impede aircraft removal

2) will not cause visual or electromagnetic interference with air navigation aids

3) compatible with the installation of an approach lighting system

4) compatible with the radio altimeter area

5) does not have a reflective surface, which could cause a dazzling effect

6) does not increase wildlife activity

7) the bed and its surrounding area is designed to prevent water from accumulating or pooling.

The EMAS is required to be compatible with meteorological conditions and the aerodrome environment, including water, temperature, ice, snow, hail, salt, UV radiation, de-icing and anti-icing products, aircraft fuels, hydraulic fluids and lubricating oils, paint and herbicides. These factors need to be considered when estimating the service life of the system.

An EMAS maintenance programme is required to be established, including preventive and corrective actions where appropriate, to preserve the system in adequate service condition. Preventive maintenance of the EMAS normally includes visual and waterproof (moisture content tests) inspections. The frequency and the type of preventive actions may differ depending on the manufacturer and the type of system. Maintenance personnel are required to have received adequate training to perform their duties. Maintenance personnel may be part of the aerodrome operator staff or could be sub-contracted to the EMAS manufacturer or other third parties. It is essential that the maintenance personnel are fully conversant with the maintenance programme activities to preserve the system's functionality.

The maintenance programme includes tests to periodically assess the system's service level and to schedule reparation or replacement actions before the end of the service life is reached. The EMAS is designed for repair to a usable condition (conforming to the original specifications) after an overrun or other type of physical damage. The maintenance programme includes procedures and agreements for reparation, including materials in stock, materials production and supply, reparation methodologies, and quality control to maintain the system's required level. The repair period needs to be as short as possible to meet the aerodrome's operational and safety requirements.

Appendix B – Rapid Exit Taxiway

Process of determination of the optimal location of the turn-off point.

Step 1: Specify for which operational conditions runway capacity should be enhanced. Depending on the intended purpose of the runway, specific conditions could consist of:

1) peak period
2) special weather conditions
3) particular group of aircraft
4) alternating landings and departures

Step 2: Determine the representative fleet-mix for the scenario the exit is intended to serve. Future types of aircraft should be taken into account. If only a particular group of aircraft is supposed to use the exit, take only these into consideration. Eliminate the types of aircraft with a share less than a certain percentage (e.g. 5% or 10%).

Step 3: Decide if the runway/taxiway separation is sufficient to permit the design of a standard rapid exit taxiway (RET). Standard RETs are designed according to Figures 191-15 and 191-16 in Section 4.6.

If the runway and taxiway system does not permit construction of a standard RET, the construction of a spiral-shaped exit is recommended to achieve a higher turn-off speed as compared to a 90° exit. This option would (in particular) apply to non-instrument runways.

Step 4: Calculate the distances for flare, transition and braking for each type of aircraft by using the Three Segment Method. For the turn-off speed V_{ex} use 33 kt for a standard rapid exit, or values given in Section 4.6, Table 191-8 and Figure 191-18.

Step 5: The calculations must be repeated for different typical wind conditions using the following formula:

$$V_{th,ground} = V_{th} - V_{wind}$$

V_{wind} = Headwind component

Insert $V_{th,ground}$ instead of V_{th} in respective formulas.

Step 6: These calculations lead to an Optimal Turn-Off point (OTP) for each type of aircraft for different wind conditions.

Step 7: Since the position of the touchdown point as well as the transition and braking distance show a certain scatter, a stretch of 100 metres before and 200 metres after the OTP is designated as the 'Optimal Turn-off Segment' (OTS). This also acknowledges the fact that pilots can minimize runway occupancy time by adjusting their braking technique accordingly.

Step 8: Find the OTS with the highest percentage of aircraft being served (OTS_{max}) by adding the percentage of those aircraft types for which the OTP lies within a particular OTS. The probability of the differing wind conditions should also be considered.

Step 9: Determine the turn-off point belonging to OTS_{max}. This is the optimal location for a rapid exit taxiway, according to the requirements of the selected scenario.

Step 10: If there is more than one OTS showing clearly a higher percentage than others, it may be necessary to consider the construction of two or more rapid exits.

Step 11: Compare the determined turn-off point with the turn-off points which are considered optimal relative to the existing configuration of the runway/taxiway system. Note that a distance between exits of approximately 450 metres is recommended and should be observed.

Example for the use of the method described in Section 4.6.

This example shows how to use the method explained in section 1.3 of Chapter 1. To understand the example, we need to consider the following things that are assumed to be true:

1) Aerodrome Reference Code 4.

2) In order to enhance runway capacity under specified conditions, a new exit should be located between 1800 metres and 2500 metres from threshold on a non-instrument runway with a length of 2500 metres. In the touch down area the runway slope is -0.75%.

3) The runway should provide its full capacity in strong headwind conditions (headwind > 15 kt). In this situation it is the only runway available for landing as well as for take-off at this airport, and it has to serve all types of aircraft.

4) In light wind conditions the runway is used exclusively for landing by commuter aircraft; for take-off, however, it is used by all types of aircraft, subject to the performance capabilities of the aircraft.

Step 1: The specific operational scenario involves the peak traffic period in strong headwind conditions and alternating landing and take-off operations for all aircraft types.

Step 2: The fleet-mix anticipated for the year 2020 till 2030 is displayed in Table 191-D1. For the calculation of the optimal location of the exit, only types of aircraft with a share higher than 10% are taken into account (marked with *).

Step 3: A parallel taxiway exists at a distance of 120 metres (centre line to centre line). A 180° turn is necessary for landing aircraft to reach the apron. The design of a standard rapid exit taxiway is not possible. See 4.6.9 for an alternative design of the exit. The turn-off speed for this type of exit would be 24 kts according to Figure 191-18.

Step 4: As all the relevant types of aircraft are part of category C and D, the touchdown point is located at a common position. According to the Three Segment Method it can be calculated for a runway slope of -0.75% with no tailwind as:

Aircraft category C and D: S_1 = 150m

+ Correction for slope (-0.75%): + 150m

S_1 = 600m

The speed over threshold can be found for each type of aircraft in the aircraft operating manual of the airlines and it leads to the transition distance:

V_{th} in kt

Aircraft	V_{th}	S_2
B737	128	590m
A320	133	615m
RJ	121	555m

Based on a turn-off speed of 24 kt and a deceleration rate of 1.5m/s^2 the braking distance can be computed:

V in kt, a in m/s^2

Aircraft	V_{th}	S_3
B737	128	1016m
A320	133	1112m
RJ	121	888m

Step 5: As the decisive factor is a strong headwind, the calculations for S2 and S3 are repeated for headwinds of 15, 20 and 25 kt with:

$$V_{th,ground} = V_{th} - V_{wind}$$

V_{wind} = 15kt

Aircraft	V_{th}	$V_{th,ground}$	S_2	S_3
B737	128	113	515	752m
A320	133	118	540	836m
RJ	121	106	480	642m

V_{wind} = 20kt

Aircraft	V_{th}	$V_{th,ground}$	S_2	S_3
B737	128	108	490	673m
A320	133	113	515	752m
RJ	121	101	455	568m

Step 6: The sum of S_1, S_2 and S_3 gives the OTP for each type of aircraft and each wind condition (values rounded to 10m):

Aircraft	Vwind = 0kt	Vwind = 15kt	Vwind = 20kt	Vwind = 25kt
B737	2210m	1870m	1760m	1660m
A320	2330m	1980m	1870m	1760m
RJ	2040m	1800m	1620m	1530m

Step 7: The OTS can be determined for each turn-off point. It reaches from 100m before the OTP to 200m after. All types of aircraft being served within this segment are added. The maximum possible value for the four different wind conditions is 4 × 100% = 400%. Figure 191-D1 shows the determination of the OTS for the A320 with a 20kt headwind.

Step 8: Table 191-D2 shows that the highest percentage of aircraft can be served with an OTS_{max} from 1660 to 1960 m or 1700 to 2000 m from threshold. The probability of different wind conditions is not considered, as the exit is required only in strong wind conditions. In normal weather conditions the traffic volume for this runway is far below the maximum runway capacity even without additional exit.

Step 9: As shown in Table 191-D2 and Figure 191-D2, the optimal turn-off point for OTS_{max} is located at a position of 1 760 m or 1 800 m from threshold.

Step 10: In this scenario, there is no need to consider the location of a second exit as no other peak for a different aircraft mix has been identified.

Step 11: If the runway/taxiway system does not dictate a different position, it is suggested that the turn-off point be located at a distance of (S)1800m from threshold

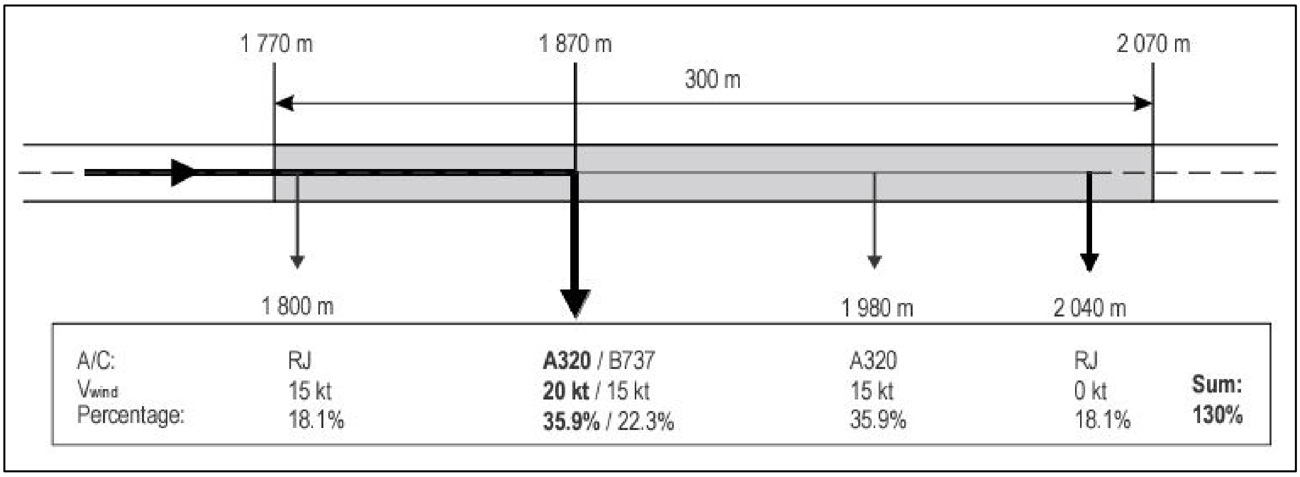
Note: ICAO Doc 9157 Part 2 contains details for the design of a non-standard RET.

Table 191-B1 Anticipated fleet mix, 2020-2030

Aircraft	Share
B747	**1.2%**
B777	**1.2%**
A340	**6.7%**
A3xx	**0.2%**
B757	**1.4%**
B767	**1.7%**
B737*	**22.3%**
A330	**6.4%**
A320*	**35.9%**
RJ*	**18.1%**
Misc	**4.9%**
Total	**100.0%**

Source: ICAO Doc 9157 Part 2

Figure 191-B1 Optimal turn-off segment – A320



Source: ICAO Doc 9157 Part 2

Calculation of the turn of curve
The coordinates of the basic points of the turn-off curve were determined as shown in Figure 191-D3 and in the following calculations (all values in metres).

R_1 = 160m

R_2 = 100m

R_3 = 40m

The calculations are valid for: 112m ≤ S ≤ 127m

Where S is the distance from the centre line runway to centre line taxiway.

P_0: $x_0 = 0$
$y_0 = 0$

M_1: $x_{M1} = 0$
$y_{M1} = R_1$

P_1: $x_1 = R_1 \times \sin(\psi_1)$

$$\psi 1 - 90° - \arctan\left(\frac{a}{\sqrt{R_2^2 - a^2}}\right)$$

$$a = \frac{R_2 \times b}{R_1 - R_2}$$

$b = R_1 + 10 - S$

$y_1 = R_1 - (a + b)$

M_2: $x_{M2} = b \times \tan(\psi_1)$

$y_{M2} = S - 10$

P2: $x_2 = b \times \tan(\psi_1) + R_2 \times \frac{\sqrt{3}}{2}$

$y_2 = S - 60$

$(\psi_1) = 60°$

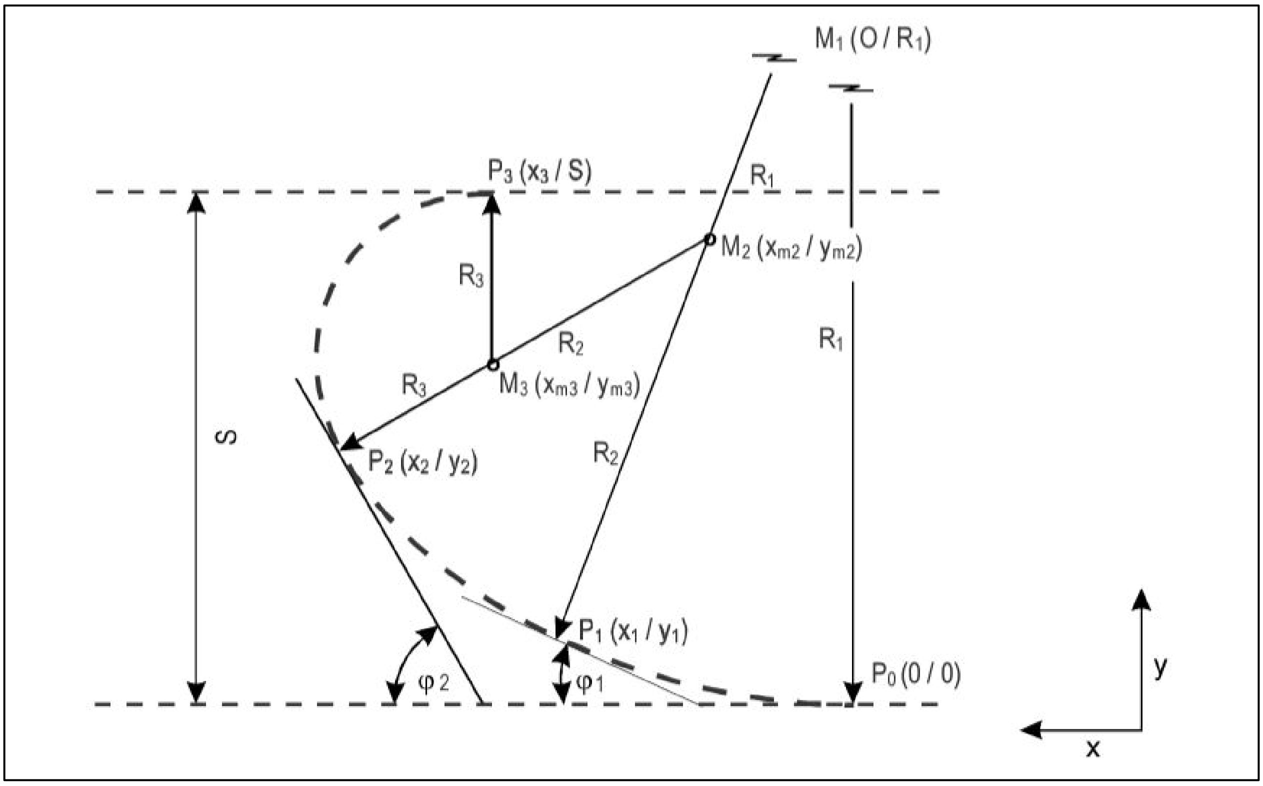
M_3: $x_{M3} = b \times \tan(\psi_1) + (R2 - 40) \times \frac{\sqrt{3}}{2}$

$y_{M3} = S - 40$

P_3: $x_3 = x_{M3}$

$y_3 = S$

Figure 191-B3 Calculation of the turn-off curve



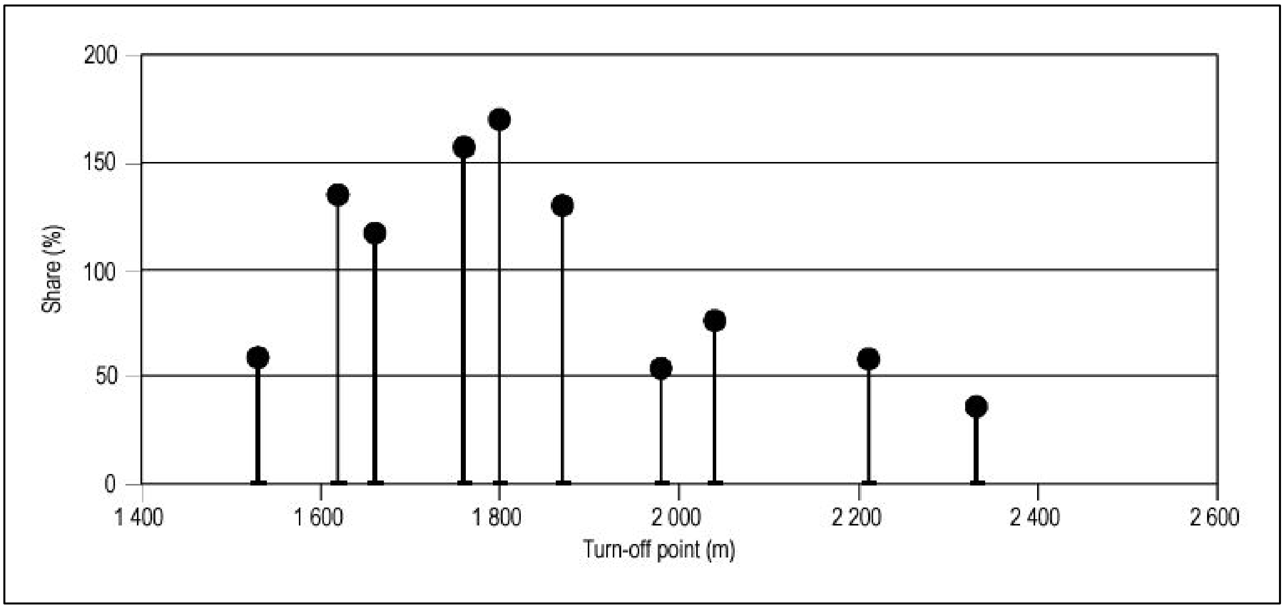
Source: ICAO Doc 9157 Part 2

Table 191-B2 Optimal turn-off points and segments

Turn-off point (m)	Turn-off segment (m)	A/C served at Vwind (kt)			Sum of share (%)
		B737	A320	RJ	
1530	1430 - 1730	25		20, 25	59
1620	1520 - 1820	20, 25	25	15, 20, 25	135
1660	1560 – 1860	20, 25	25	15, 20	117
1760	1660 – 1960	15, 20, 25	20, 25	15	157
1800	1700 – 2000	15, 20	15, 20, 25	15	170
1870	1770 – 2070	15	15, 20	0, 15	130
1980	1880 – 2180	-	15	-	54
2040	1940 – 2240	-	15	-	76
2210	2110 – 2410	-	-	-	58
2330	2230 – 2530	-	-	-	36

Source: ICAO Doc 9157 Part 2

Figure 191-B4 Optimal turn-off point



Source: ICAO Doc 9157 Part 2