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Doc 9157

Aerodrome Design Manual

Part 1 — Runways
Fourth Edition, 2020



Approved by and published under the authority of the Secretary General

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

Since the publication of the 3rd edition of this Manual in 2006, the Standards and Recommended Practices (SARPs) in Annex 14, *Aerodromes*, Volume I — *Aerodrome Design and Operations* germane to physical characteristics of aerodromes had undergone several cycles of amendments. Much of the guidance material included herein reproduces and is closely associated with the latest SARPs contained in the Annex. They are intended to facilitate the uniform application of those specifications related to the geometric design of runways and associated aerodrome elements, namely, runway shoulders, runway strips, runway end safety areas, clearways and stopways.

Modern and well-equipped aircraft have increased capabilities obtained by advanced technologies, often providing very precise trajectories on landing/take-off. Amendment 14 to Annex 14, Volume I, reduced, among others, the runway width from 60 m to 45 m for aeroplanes with an outer main gear wheel span (OMGWS) from 9 m up to but not including 15 m. This reduction is based on actual landing deviation studies of code F aeroplanes, which have demonstrated that the standard deviation from the centre line of a 45 m wide runway is less than what was assumed previously. Together with improved specifications related to runway shoulders and runway strips, these result in a more efficient use of land surface, particularly at aerodromes where real estate is at a premium.

Another significant milestone in this edition is the revised methodology for determining the aerodrome reference code for determining the numerous specifications concerning the characteristics of aerodromes. Amendment 14 decorrelated the current two code letter components, i.e. wingspan and OMGWS, since it is observed that while wingspan is relevant for aerodrome characteristics related to separation distances (e.g. obstacles, strips), the OMGWS impacts mainly ground-based manoeuvring characteristics (e.g. runway and taxiway widths). It is recognized that the two 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.

Existing Appendices related to aeroplane classification and runway turnpads have been updated, and a new Appendix providing guidance on performance and compatibility requirements for aircraft arresting systems has been added.

It is intended that this manual be kept current. Future editions will improve on this edition on the basis of experience gained, and of comments and suggestions received from users of the manual. Readers are therefore invited to send their views, comments and suggestions on this edition, in writing, to the Secretary General of ICAO.

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Chapter 1

GENERAL

1.1 INTRODUCTION

1.1.1 In view of the vital function of runways in providing for safe and efficient aircraft landings and take-offs, it is imperative that their design take into account the operational and physical characteristics of the aeroplanes expected to use the runway, as well as engineering and economic considerations.

1.1.2 The aerodrome elements associated with runways which are directly related to the landing and take-off of aeroplanes are: runway strips, runway shoulders, stopways, clearways and runway end safety areas. This manual concerns the provision of runways and these associated elements and summarizes specifications and guidance material relating to their geometric design. Pavement strength design aspects are covered in the *Aerodrome Design Manual* (Doc 9157), Part 3 — *Pavements*.

1.2 EXPLANATION OF TERMS

Aerodrome. A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

Aerodrome elevation. The elevation of the highest point of the landing area.

Clearway. A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height.

Displaced threshold. A threshold not located at the extremity of a runway.

Frangible object. An object of low mass designed to break, distort or yield on impact so as to present the minimum hazard to aircraft.

Instrument runway. One of the following types of runways intended for the operation of aircraft using instrument approach procedures:

- a) Non-precision approach runway. A runway served by visual aids and non-visual aid(s) intended for landing operations following an instrument approach operation type A and a visibility not less than 1000 m.
- b) Precision approach runway, category I. A runway served by visual aids and non-visual aid(s) intended for landing operations following an instrument approach operation type B with a decision height (DH) not lower than 60 m (200 ft) and either a visibility not less than 800 m or a runway visual range not less than 550 m.
- c) Precision approach runway, category II. A runway served by visual aids and non-visual aid(s) intended for landing operations following an instrument approach operation type B with a decision height (DH) lower than 60 m (200 ft) but not lower than 30 m (100 ft) and a runway visual range not less than 300 m.

- d) Precision approach runway, category III. A runway served by visual aids and non-visual aid(s) intended for landing operations following an instrument approach operation type B with a decision height (DH) lower than 30 m (100 ft), or no decision height and a runway visual range less than 300 m or no runway visual range limitations.

Landing area. That part of a movement area intended for the landing or take-off of aircraft.

Manoeuvring area. That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, excluding aprons.

Movement area. That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, consisting of the manoeuvring area and the apron(s).

Non-instrument runway. A runway intended for the operation of aircraft using visual approach procedures, or an instrument approach procedure to a point beyond which the approach may continue in visual meteorological conditions.

Note.— Visual meteorological conditions (VMC) are described in Chapter 3 of Annex 2.

Obstacle. All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that are located on an area intended for the surface movement of aircraft or that extend above a defined surface intended to protect aircraft in flight.

Outer main gear wheel span (OMGWS). The distance between the outside edges of the main gear wheels.

Primary runway(s). Runway(s) used in preference to others whenever conditions permit.

Runway. A defined rectangular area on a land aerodrome prepared for the landing and take-off of aircraft.

Runway end safety area (RESA). An area symmetrical about the extended runway centre line and adjacent to the end of the strip primarily intended to reduce the risk of damage to an aeroplane undershooting or overrunning the runway.

Runway strip. A defined area including the runway and stopway, if provided, intended:

- a) to reduce the risk of damage to aircraft running off a runway; and
- b) to protect aircraft flying over it during take-off or landing operations.

Shoulder. An area adjacent to the edge of a pavement so prepared as to provide a transition between the pavement and the adjacent surface.

Threshold. The beginning of that portion of the runway usable for landing.

1.3 AERODROME REFERENCE CODE

1.3.1 The intent of the reference code is to provide a simple method for interrelating the numerous specifications concerning the characteristics of aerodromes so as to provide a series of aerodrome facilities that are suitable for the aeroplanes that are intended to operate at the aerodrome. The code is composed of two elements which are related to the aeroplane performance characteristics and dimensions. Element 1 is a number based on the aeroplane reference field length and element 2 is a letter based on the aeroplane wing span.

1.3.2 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 Annex 14, Volume I, the aeroplanes which the aerodrome is intended to serve are first identified and then the two elements of the code.

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

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

1.3.5 The code letter for element 2 shall be determined from Table 1-1 by selecting the code letter which corresponds to the greatest wing span of the aeroplanes for which the facility is intended.

1.3.6 The wingspan is relevant for aerodrome characteristics related to separation distances (e.g. obstacles, strips), while OMGWS impacts ground-based manoeuvring characteristics (e.g. runway and taxiway widths). The two 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 and taxiway width, it is referenced directly in the relevant provisions to avoid the complexity of a third code element.

Table 1-1. 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

Note 1.— Guidance on planning for aeroplanes with wingspans greater than 80 m is given in the Aerodrome Design Manual (Doc 9157), Parts 1 and 2.

Note 2.— Procedures on conducting aerodrome compatibility study to accommodate aeroplanes with folding wing tips spanning two code letters are given in the Procedures for Air Navigation Services Aerodromes (PANS-Aerodromes, Doc 9981). Further guidance can be found in the manufacturer's aircraft characteristics for airport planning manual.

Chapter 2

CONFIGURATION CONSIDERATIONS

2.1 FACTORS RELATING TO THE SITING, ORIENTATION AND NUMBER OF RUNWAYS

General

Note.— Flexibility to accommodate any future expansion of the runway infrastructure is fundamental to the planning and design of airports.

2.1.1 Many factors affect the determination of the siting, orientation and number of runways. The more important factors are:

- a) weather, in particular the runway/aerodrome usability factor, as determined by wind distribution, and the occurrence of localized fogs;
- b) topography of the aerodrome site and its surroundings;
- c) type and amount of air traffic to be served, including air traffic control aspects;
- d) aeroplane performance considerations; and
- e) environmental considerations, particularly noise.

2.1.2 The primary runway, to the extent other factors permit, should be oriented in the direction of the prevailing wind. All runways should be oriented so that approach and departure areas are free of obstacles and, preferably, so that aircraft are not directed over populated areas.

2.1.3 The number of runways must be sufficient to meet air traffic demands, which consist of the number of aircraft arrivals and departures, and the mixture of aircraft types, to be accommodated during the busiest periods. The decision as to the total number of runways to be provided should also take into account the aerodrome usability factor and economic considerations. Guidance concerning the airport planning process including traffic forecasting and planning criteria is available in *Airport Planning Manual* (Doc 9184), Part 1 — *Master Planning*.

Type of operation

2.1.4 Particular attention should be paid to whether the aerodrome is to be used in all meteorological conditions or only in visual meteorological conditions, and whether it is intended for use by day and night or only by day.

2.1.5 When a new instrument runway is being located, particular attention needs to be given to areas over which aeroplanes will be required to fly when following instrument approach and missed approach procedures, so as to ensure that obstacles in these areas or other factors will not restrict the operation of the aeroplanes for which the runway is intended.

Wind

2.1.6 The number and orientation of runways at an aerodrome should be such that the usability factor of the aerodrome is not less than 95 per cent for the aeroplane that the aerodrome is intended to serve.

2.1.7 In the application of the 95 per cent usability factor it should be assumed that landing or take-off of aeroplanes is, in normal circumstances, precluded when the cross-wind component exceeds:

- a) 37 km/h (20 kt) in the case of aeroplanes whose reference field length is 1 500 m or over, except that when poor runway braking action owing to an insufficient longitudinal coefficient of friction is experienced with some frequency, a cross-wind component not exceeding 24 km/h (13 kt) should be assumed;
- b) 24 km/h (13 kt) in the case of aeroplanes whose reference field length is 1 200 m or up to but not including 1 500 m; and
- c) 19 km/h (10 kt) in the case of aeroplanes whose reference field length is less than 1 200 m.

2.1.8 The selection of data to be used for the calculation of the usability factor should be based on reliable wind distribution statistics that extend over as long a period as possible, preferably of not less than five years. The observations used should be made at least eight times daily and spaced at equal intervals of time, and should take into account the following:

- a) wind statistics used for the calculation of the usability factor are normally available in ranges of speed and direction, and the accuracy of the results obtained depends, to a large extent, on the assumed distribution of observations within these ranges. In the absence of any sure information as to the true distribution, it is usual to assume a uniform distribution since, in relation to the most favourable runway orientations, this generally results in a slightly conservative figure for the usability factor;
- b) the maximum mean cross-wind components given in 2.1.7 refer to normal circumstances. There are some factors which may require that a reduction of those maximum values be taken into account at a particular aerodrome. These include:
 - 1) the wide variations which may exist, in handling characteristics and maximum permissible cross-wind components, among diverse types of aeroplanes (including future types) within each of the three groups given in 2.1.7;
 - 2) prevalence and nature of gusts;
 - 3) prevalence and nature of turbulence;
 - 4) the availability of a secondary runway;
 - 5) the width of runways;
 - 6) the runway surface conditions – water, snow, slush and ice on the runway materially reduce the allowable cross-wind component; and
 - 7) the strength of the wind associated with the limiting cross-wind component.

2.1.9 The 95 per cent criterion recommended by Annex 14, Volume I is applicable to all conditions of weather; nevertheless, it is useful to examine wind speed and direction for different visibility conditions. Weather records can usually

be obtained from government weather bureaus. The velocities are generally grouped into 22.5 degree increments (16 points of the compass). The weather records contain the percentage of time certain combinations of ceiling and visibility occur (e.g. ceiling, 500 to 274 m; visibility, 4.8 to 9.7 km), and the percentage of time winds of a specific velocity occur from different directions; for example NNE, 2.6 to 4.6 kt. The directions are relative to true north. Often wind data for a new location have not been recorded. If that is the case, records of nearby measuring stations should be consulted. If the surrounding area is fairly level, the records of these stations should indicate the winds at the site of the proposed aerodrome. However, if the terrain is hilly, the wind pattern often is dictated by the topography, and it is dangerous to utilize the records of stations some distance from the site. In that event, a study of the topography of the region and consultation with local residents may prove useful but a wind study of the site should be initiated. Such a study would involve the installation of wind gauges and the keeping of wind records. Guidance material on the preparation and analysis of wind data for aerodrome planning purposes is given in the *Airport Planning Manual* (Doc 9184) Part 1 — *Master Planning*.

Visibility conditions

2.1.10 Wind characteristics under poor visibility conditions are often quite different from those experienced under good visibility conditions. Therefore a study should be made of the wind conditions occurring with poor visibility and/or low cloud base at the aerodrome, including the frequency of occurrence and the accompanying wind direction and speed.

Topography of the aerodrome site, its approaches and surroundings

2.1.11 The topographical features of the aerodrome and its surroundings should be examined. In particular the following should be reviewed:

- a) compliance with the obstacle limitation surfaces;
- b) current and future land use. The orientation and layout should be selected so as to protect as far as possible the particularly sensitive areas such as residential, school and hospital zones from the discomfort caused by aircraft noise;
- c) current and future runway lengths to be provided;
- d) construction costs; and
- e) the possibility of installing suitable non-visual and visual aids for approach-to-land.

Air traffic in the vicinity of the aerodrome

2.1.12 When considering the siting of runways the following should be taken into account:

- a) proximity of other aerodromes or ATS routes;
- b) traffic density; and
- c) air traffic control and missed approach procedures.

Environmental factors

2.1.13 The effect of a particular runway alignment on wild life, the general ecology of the area, and noise-sensitive areas of communities should be considered.

2.1.14 The noise level produced by aircraft operations at and around the aerodrome is generally considered a primary environmental cost associated with the facility. Most noise exposure lies within the land area immediately beneath and adjacent to the aircraft approach and departure paths. Noise levels are generally measured through some formulation of decibel level, duration and number of occurrences. A large number of noise measuring techniques exist (see Annex 16 — *Environmental Protection and Recommended Method for Computing Noise Contours around Airports* (Cir 205)). Proper site selection and adjacent land use planning can serve to greatly reduce and possibly eliminate the noise problem associated with the aerodrome.

Parallel runways

2.1.15 The number of runways to be provided in each direction depends on the forecast of aircraft movements (see the *Airport Planning Manual* (Doc 9184), Part 1).

2.1.16 *VMC operations.* Where parallel runways are provided for simultaneous use under visual meteorological conditions only, the minimum distance between their centre lines should be:

- a) 210 m where the higher code number is 3 or 4;
- b) 150 m where the higher code number is 2; and
- c) 120 m where the higher code number is 1.

2.1.17 *IMC operations.* Where parallel runways are provided for simultaneous operations under instrument meteorological conditions (IMC), the minimum separation distance between their centre lines should be:

- a) 1 035 m for independent parallel approaches;
- b) 915 m for dependent parallel approaches;
- c) 760 m for independent parallel departures;
- d) 760 m for segregated parallel operations;

except that:

- a) for segregated parallel operations the specified separation distance:
 - 1) may be decreased by 30 m for each 150 m that the arrival runway is staggered toward the arriving aircraft, to a minimum of 300 m; and
 - 2) should be increased by 30 m for each 150 m that the arrival runway is staggered away from the arriving aircraft;
- b) lower separation distances than those specified above may be applied if, after aeronautical study, it is determined that such lower separation distances would not affect the safety of operations of aircraft.

2.1.18 Guidance on planning and conducting simultaneous operations on parallel or near-parallel instrument runways is contained in the *Manual on Simultaneous Operations on Parallel or Near-Parallel Instrument Runways (SOIR)* (Doc 9643).

Terminal area between parallel runways

2.1.19 To minimize taxi operations across active runways and to better utilize the area between the parallel runways, the terminal area and other operational areas may be placed between parallel runways. To accommodate these areas, greater separation distances than those recommended in the preceding paragraph may be required.

2.2 LOCATION OF THRESHOLD

2.2.1 The threshold is normally located at the extremity of a runway, if there are no obstacles penetrating above the approach surface. In some cases, however, due to local conditions it may be desirable to displace the threshold permanently (see 2.2.3). When studying the location of a threshold, consideration should also be given to the height of the ILS reference datum and the determination of the obstacle clearance limits. (Specifications concerning the height of the ILS reference datum are given in Annex 10, Volume I.)

2.2.2 In determining that no obstacle penetrates above the approach surface, account should be taken of the presence of mobile objects (vehicles on roads, trains, etc.).

2.2.3 If an object extends above the approach surface and the object cannot be removed, consideration should be given to displacing the threshold permanently.

2.2.4 To meet the obstacle limitation objectives of Annex 14, Volume I, Chapter 4, the threshold should ideally be displaced down the runway for the distance necessary to ensure that the approach surface is clear of obstacles.

2.2.5 However, displacement of the threshold from the runway extremity will inevitably cause reduction of the landing distance available, and this may be of greater operational significance than penetration of the approach surface by marked and lighted obstacles. A decision to displace the threshold, and the extent of such displacement, should therefore have regard to an optimum balance between the considerations of clear approach surfaces and adequate landing distance. In deciding this question, account will need to be taken of the types of aeroplanes which the runway is intended to serve, the limiting visibility and cloud base conditions under which the runway will be used, the position of the obstacles in relation to the threshold and extended centre line and, in the case of a precision approach runway, the significance of the obstacles to the determination of the obstacle clearance limit.

2.2.6 Notwithstanding the consideration of landing distance available, the selected position for the threshold should not be such that the obstacle-free surface to the threshold is steeper than 3.3 per cent where the code number is 4 or steeper than 5 per cent where the code number is 3.

Chapter 3

RUNWAY LENGTH CONSIDERATIONS

3.1 FACTORS AFFECTING THE LENGTH OF RUNWAYS

3.1.1 Factors which have a bearing on the runway length to be provided are:

- a) performance characteristics and operating masses of the aeroplanes to be served;
- b) weather, particularly surface wind and temperature;
- c) runway characteristics such as slope and surface condition; and
- d) aerodrome location factors, for example, aerodrome elevation which affects the barometric pressure and topographical constraints.

3.1.2 The relationship between runway length and aeroplane performance characteristics is discussed in Chapter 4. The greater the head wind down a runway, the shorter the runway length required by an aeroplane taking off or landing. Conversely, a tail wind 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. 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. 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.

3.2 ACTUAL LENGTH OF RUNWAYS

Primary runways

3.2.1 Except where a runway is associated with a stopway and/or clearway, the actual runway length to be provided for a primary runway should be adequate to meet the operational requirements of the aeroplanes for which the runway is intended and should be not less than the longest length determined by applying the corrections for local conditions to the operations and performance characteristics of the relevant aeroplanes.

3.2.2 Both take-off and landing requirements need to be considered when determining the length of runway to be provided and the need for operations to be conducted in both directions of the runway. Local conditions that may need to be considered include elevation, temperature, runway slope, humidity and the runway surface characteristics.

3.2.3 When performance data on aeroplanes for which the runway is intended are not known, the actual length of a primary runway may be determined by application of general correction factors as described in 3.5. However, it is advisable that the aeroplane manufacturer's document entitled Aeroplane Characteristics for Airport Planning be consulted for the most up-to-date information.

Secondary runways

3.2.4 The length of a secondary runway should be determined similarly to primary runways except that it needs only to be adequate for those aeroplanes which require to use that secondary runway in addition to the other runway or runways in order to obtain a usability factor of at least 95 per cent.

3.2.5 Flight manuals providing data on aeroplane operational requirements and performance characteristics are available for most modern aeroplanes. Aeroplane performance curves and tables for landing and take-off operations have also been developed for basic runway length planning purposes. Information on these aeroplane performance curves and tables is given in Appendix 3.

3.3 RUNWAYS WITH STOPWAYS AND/OR CLEARWAYS

3.3.1 Where a runway is associated with a stopway or clearway, an actual runway length less than that resulting from application of 3.2.2 or 3.2.3, as appropriate, may be considered satisfactory, but in such a case any combination of runway, stopway and/or clearway provided should permit compliance with the operational requirements for take-off and landing of the aeroplanes the runway is intended to serve.

3.3.2 The decision to provide a stopway and/or a clearway as an alternative to an increased length of runway will depend on the physical characteristics of the area beyond the runway end, and on the operating performance requirements of the prospective aeroplanes. The runway, stopway and clearway lengths to be provided are determined by the aeroplane take-off performance, but a check should also be made of the landing distance required by the aeroplanes using the runway to ensure that adequate runway length is provided for landing. The length of a clearway, however, cannot exceed half the length of take-off run available.

3.4 CALCULATION OF DECLARED DISTANCES

3.4.1 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:

- a) Take-off run available (TORA), i.e. the length of runway declared available and suitable for the ground run of an aeroplane taking off.
- b) Take-off distance available (TODA), i.e. the length of the take-off run available plus the length of the clearway, if provided.
- c) Accelerate-stop distance available (ASDA), i.e. the length of the take-off run available plus the length of the stopway, if provided.
- d) Landing distance available (LDA), i.e. the length of runway which is declared available and suitable for the ground run of an aeroplane landing.

3.4.2 Annex 14, Volume I, calls for the calculation of declared distances for a runway intended for use by international commercial air transport, and Annex 15 calls for the reporting of declared distances for each direction of the runway in the State Aeronautical Information Publication (AIP). Figure 3-1 illustrates typical cases, and Figure 3-2 shows a tabulation of declared distances.

3.4.3 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 3-1(A).

3.4.4 Where a runway is provided with a clearway (CWY), then the TODA will include the length of clearway as shown in Figure 3-1(B).

3.4.5 Where a runway is provided with a stopway (SWY), then the ASDA will include the length of stopway as shown in Figure 3-1(C).

3.4.6 Where a runway has a displaced threshold, then the LDA will be reduced by the distance the threshold is displaced as shown in Figure 3-1(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.

3.4.7 Figures 3-1B through 3-1(D) illustrate 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 3-1(E) illustrates the situation where all these features exist.

3.4.8 A suggested format for providing information on declared distances is given in Figure 3-2. 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.

3.4.9 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.

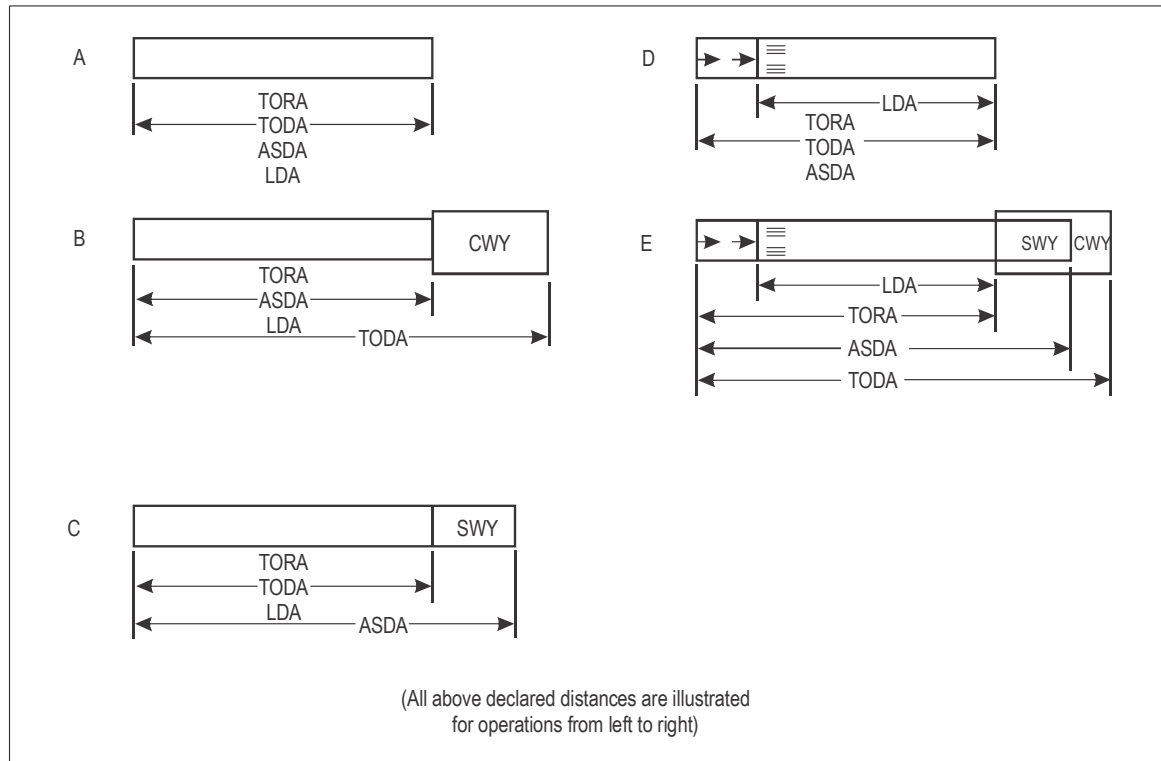


Figure 3-1. Illustration of declared distances

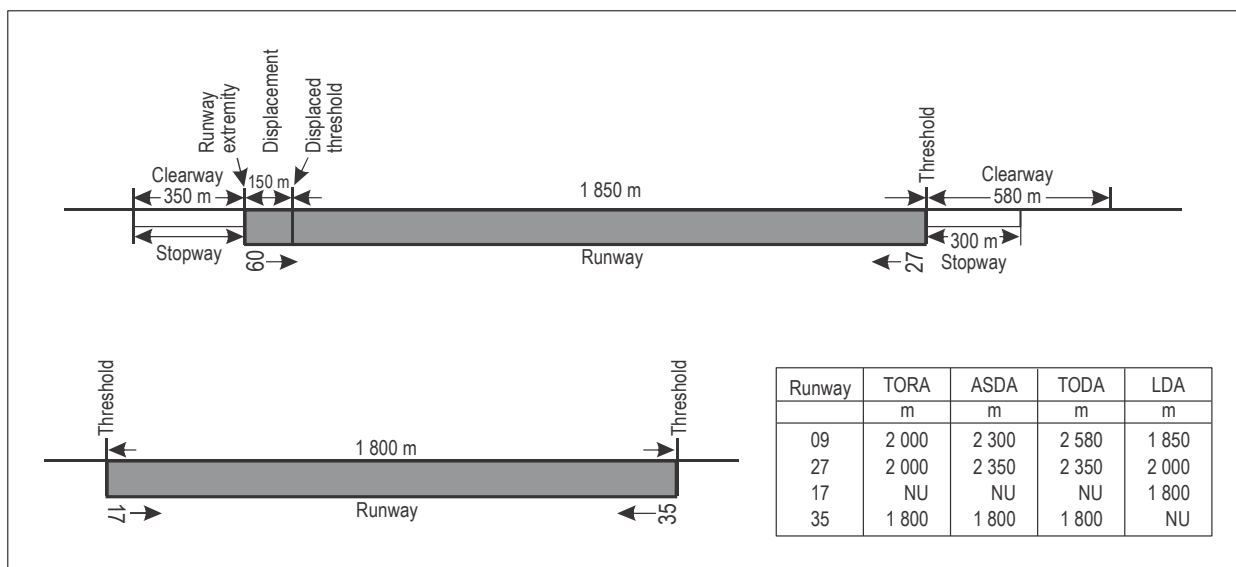


Figure 3-2. Determination of declared distances

3.5 RUNWAY LENGTH CORRECTIONS FOR ELEVATION, TEMPERATURE AND SLOPE

3.5.1 As stated in 3.2.3, when the appropriate flight manual is not available the runway length must be determined by applying general correction factors. As a first step, a basic length should be selected for the runway adequate to meet the operational requirements of the aeroplanes for which the runway is intended. This basic length is a runway length selected for aerodrome planning purposes which is required for take-off or landing under standard atmospheric conditions for zero elevation, zero wind and zero runway slope.

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

3.5.3 The length of runway determined under 3.5.2 should be further increased at the rate of 1 per cent for every 1°C by which the aerodrome reference temperature exceeds the temperature in the standard atmosphere for the aerodrome elevation (see Table 3-1). If, however, the total correction for elevation and temperature exceeds 35 per cent, the required corrections should be obtained by means of a specific study. The operational characteristics of certain aeroplanes may indicate that these correction constants for elevation and temperature are not appropriate, and that they may need to be modified by results of aeronautical study based upon conditions existing at the particular site and the operating requirements of such aeroplanes.

Table 3-1. Table of 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

3.5.4 The aerodrome reference temperature is the monthly mean of the average daily temperature for the hottest month of the year plus one-third of the difference between this temperature and the monthly mean of the maximum daily temperature for the same month of the year.

$$\text{Aerodrome reference temperature} = T_1 + \frac{T_2 - T_1}{3}$$

where T_1 = the monthly mean of the average daily temperature for the hottest month of the year.

where T_2 = the monthly mean of the maximum daily temperature for the same month.

The values of T_1 and T_2 are determined over a period of years. On any day, it is easy to observe the maximum and minimum temperature, t_2 and t_1 , respectively.

$$\text{Average daily temperature} = \frac{t_1 + t_2}{2}$$

$$\text{Maximum daily temperature} = t_2$$

For a thirty-day month, therefore, the monthly mean of the average daily temperature, $T_1 = \frac{1}{30}$ of the thirty values of $\frac{t_1 + t_2}{2}$

obtained once every day in the hottest month, all added together. Similarly, the monthly mean of the maximum daily

temperature $T_2 = \frac{1}{30}$ of the thirty values of t_2 obtained once every day in the hottest month, all added together.

3.5.5 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 per cent for each 1 per cent of the runway slope as defined in 5.1.4.

3.5.6 At aerodromes where temperature and humidity are both high, some addition to the runway length determined under 3.5.5 may be necessary, even though it is not possible to give exact figures for the increased length required.

Examples of the application of runway length corrections

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

Example 1:

a) Data:

- | | |
|--|----------|
| 1) runway length required for landing at sea level in standard atmospheric conditions | 2 100 m |
| 2) runway length required for take-off at a level site at sea level in standard atmospheric conditions | 1 700 m |
| 3) aerodrome elevation | 150 m |
| 4) aerodrome reference temperature | 24°C |
| 5) temperature in the standard atmosphere for 150 m | 14.025°C |
| 6) runway slope | 0.5% |

b) Corrections to runway take-off length:

- | | |
|---|---------|
| 1) runway take-off length corrected for elevation =
$\left[1700 \times 0.07 \times \frac{150}{300} \right] + 1700 =$ | 1 760 m |
| 2) runway take-off length corrected for elevation and temperature =
$[1760 \times (24 - 14.025) \times 0.01] + 1760 =$ | 1 936 m |
| 3) runway take-off length corrected for elevation, temperature and slope =
$[1936 \times 0.5 \times 0.10] + 1936 =$ | 2 033 m |

c) Correction to runway landing length:

- | | |
|--|---------|
| runway landing length corrected for elevation =
$\left[2100 \times 0.07 \times \frac{150}{300} \right] + 2100 =$ | 2 174 m |
|--|---------|

d) Actual runway length = 2 175 m

Example 2:

a) Data:

- | | |
|--|----------|
| 1) runway length required for landing at sea level in standard atmospheric conditions | 2 100 m |
| 2) runway length required for take-off at a level site at sea level in standard atmospheric conditions | 2 500 m |
| 3) aerodrome elevation | 150 m |
| 4) aerodrome reference temperature | 24°C |
| 5) temperature in the standard atmosphere for 150 m | 14.025°C |
| 6) runway slope | 0.5% |

b) Correction to runway take-off length:

- | | |
|---|---------|
| 1) runway take-off length corrected for elevation =
$\left[2500 \times 0.07 \times \frac{150}{300} \right] + 2500 =$ | 2 588 m |
| 2) runway take-off length corrected for elevation and temperature =
$[2588 \times (24 - 14.025) \times 0.01] + 2588 =$ | 2 846 m |
| 3) runway take-off length corrected for elevation, temperature and slope =
$[2846 \times 0.5 \times 0.10] + 2546 =$ | 2 988 m |

c) Correction to runway landing length:

runway landing length corrected for elevation = $\left[2100 \times 0.07 \times \frac{150}{300} \right] + 2100 =$	2 174 m
--	---------

d) Actual runway length = 2 988 m

Chapter 4

AEROPLANE PERFORMANCE PARAMETERS AFFECTING RUNWAY LENGTH

4.1 OPERATIONAL TERMS

Before discussing the relationship between aeroplane performance parameters and runway length requirements it is necessary to explain the following operational terms:

- a) *Decision speed* (V_1) is the speed chosen by the operator at which the pilot, having recognized 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 (V_2). 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.
- b) *Take-off safety speed* (V_2) 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.
- c) *Rotation speed* (V_R) is the speed at which the pilot initiates rotation of the aeroplane to cause raising of the landing gear.
- d) *Lift-off speed* (V_{LOF}) in terms of calibrated airspeed, is the speed at which the aeroplane first becomes airborne.

4.2 TAKE-OFF LENGTH REQUIREMENT

4.2.1 The aeroplane performance operating limitations require a length which is enough to ensure that the aeroplane can, after starting a take-off, either be brought safely to a stop or complete the take-off safely. For the purpose of discussion it is supposed that the runway, stopway and clearway lengths provided at the aerodrome are only just adequate for the aeroplane requiring the longest take-off and accelerate-stop distances, taking into account its take-off mass, runway characteristics and ambient atmospheric conditions. Under these circumstances, there is for each take-off, a speed, called the decision speed (V_1); below this speed, the take-off must be abandoned if an engine fails, while above it the take-off must be completed. A very long take-off run and take-off distance would be required to complete a take-off when an engine fails before the decision speed is reached because of the insufficient speed and the reduced power available. There would be no difficulty in stopping in the remaining accelerate-stop distance available provided action is taken immediately. In these circumstances the correct course of action would be to abandon the take-off.

4.2.2 On the other hand, if an engine fails after the decision speed is reached, the aeroplane will have sufficient speed and power available to complete the take-off safely in the remaining take-off distance available. However, because of the high speed, there would be difficulty in stopping the aeroplane in the remaining accelerate-stop distance available.

4.2.3 The decision speed is not a fixed speed for any aeroplane, but can be selected by the pilot within limits to suit the accelerate-stop and take-off distance available, aeroplane take-off mass, runway characteristics, and ambient atmospheric conditions at the aerodrome. Normally, a higher decision speed is selected as the accelerate-stop distance available increases.

4.2.4 A variety of combinations of accelerate-stop distances required and take-off distances required can be obtained to accommodate a particular aeroplane, taking into account the aeroplane take-off mass, runway characteristics, and ambient atmospheric conditions. Each combination requires its particular length of take-off run.

4.2.5 The most familiar case is where the decision speed is such that the take-off distance required is equal to the accelerate-stop distance required; this value is known as the balanced field length. Where stopway and clearway are not provided, these distances are both equal to the runway length. However, if landing distance is for the moment ignored, runway is not essential for the whole of the balanced field length, as the take-off run required is, of course, less than the balanced field length. The balanced field length can, therefore, be provided by a runway supplemented by an equal length of clearway and stopway, instead of wholly as a runway. If the runway is used for take-off in both directions, an equal length of clearway and stopway has to be provided at each runway end. The saving in runway length is, therefore, bought at the cost of a greater overall length.

4.2.6 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.

4.2.7 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:

- a) if a stopway is economically possible, the lengths to be provided are those for the balanced field length. The runway length is the take-off run required or the landing distance required, whichever is the greater. If the accelerate-stop distance required is greater than the runway length so determined, the excess may be provided as stopway, usually at each end of the runway. In addition, a clearway of the same length as the stopway must also be provided;
- b) if a stopway is not to be provided, the runway length is the landing distance required, or if it is greater, the accelerate-stop distance required which corresponds to the lowest practical value of the decision speed. The excess of the take-off distance required over the runway length may be provided as clearway, usually at each end of the runway.

4.2.8 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.

4.2.9 The economy of a stopway can be entirely lost if, after each usage, it must be regraded and compacted. Therefore, it should be designed to withstand at least a certain number of loadings of the aeroplane which the stopway is intended to serve without inducing structural damage to the aeroplane.

4.2.10 Taking as a schematic illustration (Figure 4-1 (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 (V_1) point B. A sudden and complete failure of an engine is assumed to occur and is recognized by the pilot as the decision speed (V_1) is attained. The pilot can either:

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