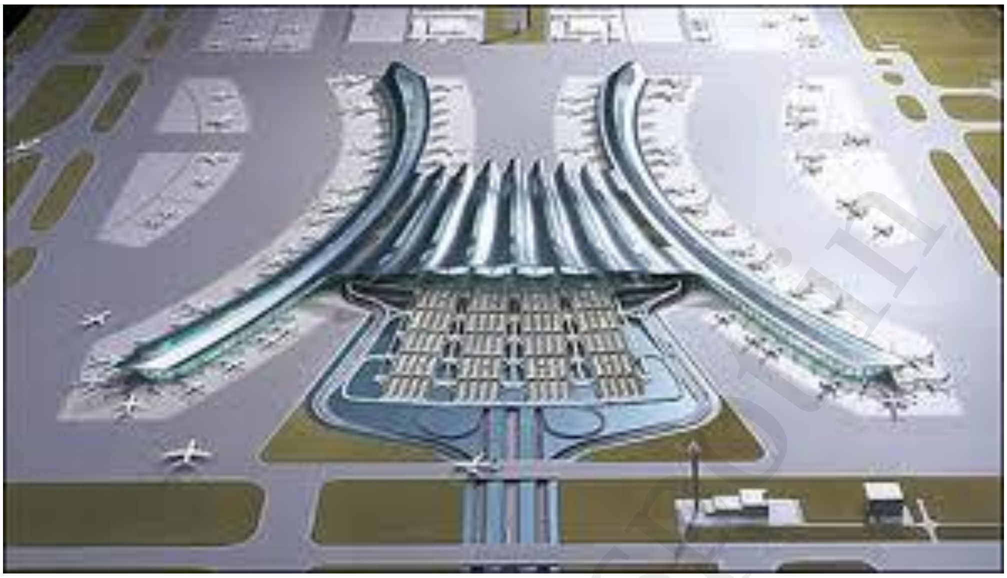
AIRPORT PLANNING AND DESIGN



Introduction

The planning of an airport is such a complex process that the analysis of one activity without regard to the effect on other activities will not provide acceptable solutions. An airport encompasses a wide range of activities which have different and often conflicting requirements. Yet they are interdependent so that a single activity may limit the capacity of the entire complex. In the past airport master plans were developed on the basis of local aviation needs. In more recent times these plans have been integrated into an airport system plan which assessed not only the needs at a specific airport site but also the overall needs of the system of airports which service an area, region, state, or country. If future airport planning efforts are to be successful, they must be founded on guidelines established on the basis of comprehensive airport system and master plans.

The elements of a large airport are shown in Fig.

It is divided into two major components, the airside and the landside. The aircraft gates at the terminal buildings form the division between the two components. Within the system, the characteristics of the vehicles, both ground and air, have a large influence on planning. The passenger and shipper of goods are interested primarily in the overall door to-door travel time and not just the duration of the air journey. For this reason access to airports is an essential consideration in planning. The problems resulting from the incorporation of airport operations into the web of metropolitan life are complex. In the early days of air transport, airports were located at a distance from the city, where inexpensive land and a limited number of obstructions permitted flexibility in airport operations.

Types of Studies

Many different types of studies are performed in airport planning. These include studies related to facility planning, financial planning, traffic and markets, economics, and the environment. However, each of these studies can usually be classified as being performed at one of three levels: the system planning level, the master planning level, or the project planning level.

The Airport System Plan

An airport system plan is a representation of the aviation facilities required to meet the immediate and future needs of a metropolitan area, region, state, or country. The National Plan of Integrated Airport Systems (NPIAS) is an example of a system plan representing the airport development needs of the United States. The Michigan Aviation System Plan [10] is an example of a system plan representing the airport development needs of the state of Michigan, and the Southeast Michigan Regional Aviation System Plan [13] is a system plan representing the airport development needs of a seven county region comprising the Detroit Metropolitan area. The system plan presents the recommendations for the general location and characteristics of new airports and heliports and the nature of expansion for existing ones to meet forecasts of aggregate demand. It identifies the aviation role of existing and recommended new airports and facilities. It includes the timing and estimated costs of development and relates airport system planning to the policy and objectives of the relevant jurisdiction. Its overall purpose is to determine the extent, type, nature, location, and timing of airport development needed to establish a viable, balanced, and integrated system of airports It also provides the basis for detailed airport planning such as that contained in the airport master plan. The airport system plan provides both broad and specific policies, plans, and programs required to establish a viable and integrated system of airports to meet the needs of the region. The objectives of the system plan include

1. The orderly and timely development of a system of airports adequate to meet present and future aviation needs and to promote the desired pattern of regional growth relative to industrial, employment, social, environmental, and recreational goals.
2. The development of aviation to meet its role in a balanced and multimodal transportation system to foster the overall goals of the area as reflected in the transportation system plan and comprehensive development plan.

3. The protection and enhancement of the environment through the location and expansion of aviation facilities in a manner which avoids ecological and environmental impairment.
4. The provision of the framework within which specific airport programs may be developed consistent with the short- and long-range airport system requirements.

5. The implementation of land-use and airspace plans which optimize these resources in an often constrained environment.
6. The development of long-range fiscal plans and the establishment of priorities for airport financing within the governmental budgeting process.
7. The establishment of the mechanism for the implementation of the system plan through the normal political framework, including the necessary coordination between governmental agencies, the involvement of both public and private aviation and nonaviation interests, and compatibility with the content, standards, and criteria of existing legislation. The airport system planning process must be consistent with state, regional, or national goals for transportation, land use, and the environment. The elements in a typical airport system planning process include the following:
1. Exploration of issues that impact aviation in the study area
2. Inventory of the current system
3. Identification of air transportation needs
4. Forecast of system demand
5. Consideration of alternative airport systems
6. Definition of airport roles and policy strategies
7. Recommendation of system changes, funding strategies, and airport development
8. Preparation of an implementation plan
Although the process involves many varied elements, the final product will result in the identification, preservation, and enhancement of the aviation system to meet current and future demand. The ultimate result of the process will be the establishment of a viable, balanced, and integrated system of airports.

Airport Site Selection

The emphasis in airport planning is normally on the expansion and improvement of existing airports. However if an existing airport cannot be expanded to meet the future demand or the need for a new airport is identified in an airport system plan, a process to select a new airport site may be required. The scope of the site selection process will vary with size, complexity, and role of the new airport, but there are basically three steps—identification, screening, and selection.

Identification—criteria is developed that will be used to evaluate different sites and determine if a site can function as an airport and meets the needs of the community and users. One criterion will be to identify the land area and basic facility requirements for the new airport. Part of this analysis will be a definition of airport roles if more than two airports serve the region. Other criteria might be that sites are within a certain radius or distance from the existing airport or community, or that sites should be relatively flat. Several potential sites that meet the criteria are identified.

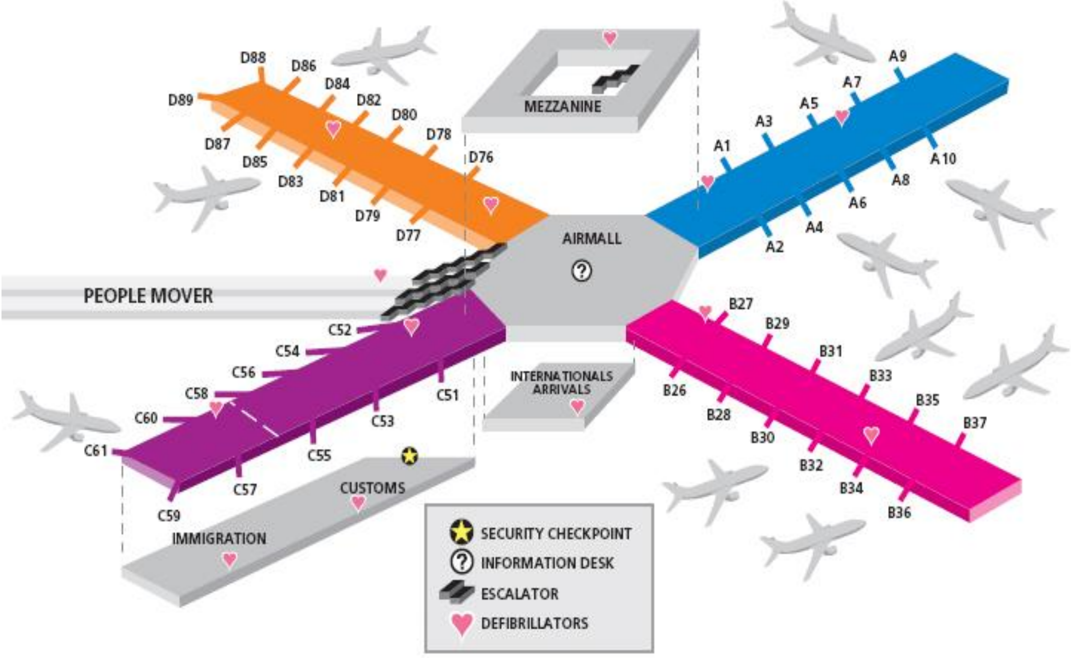
Screening—once sites are identified, a screening process can be applied to each site. An evaluation of all potential sites that meet the initial criteria should be conducted, screening out those with the most obvious shortcomings. Screening factors might include topography, natural and man-made obstructions, airspace, access, environmental impacts, and development costs. If any sites are eliminated from further consideration, thorough documentation of the reasons for that decision is recommended. The remaining potential sites should then undergo a detailed comparison using comprehensive evaluation criteria. While the criteria will vary, the following is typically considered:

O*perational capability*—airspace considerations, obstructions, weather

Capacity potential—available land, suitability for construction, Weather

Ground access—distance from the demand for aviation services, regional highway infrastructure, available public transportation modes
Development costs—terrain, land costs, land values, soil conditions, availability of utilities
Environmental consequences—aircraft noise, air quality, groundwater runoff, impact on flora and fauna, existence of endangered species or cultural artifacts, historical features, changes in local land use, relocation of families and businesses, changes in socioeconomic characteristics
Compatibility with area-wide planning—impact on land use, effect on comprehensive land-use plans and transportation plans at the local and regional levels
Selection—the fi nal step is selecting and recommending a preferred site. While a weighting of the evaluation criteria and weighted ratings or ranking of the alternative sites is often used in selecting a site, caution must be used in applying this technique since it introduces an element of sensitivity into the analysis. The process nshould focus on providing decision makers with information on the various sites in a manner that is understandable and unbiased.

The Airport Master Plan
An airport master plan is a concept of the ultimate development of a specific airport. The term development includes the entire airport area, both for aviation and non aviation uses, and the use of land adjacent to the airport. It presents the development concept graphically and contains the data and rationale upon which the plan is based. Figure 4-2 shows a simple flowchart of the steps for preparing an airport master plan. Master plans are prepared to support expansion and modernization of existing airports and guide the development of new airports. The overall objective of the airport master plan is to provide guidelines for future development which will satisfy aviation demand in a financially feasible manner and be compatible with the environment, community development, and other modes of transportation.



More specifically it is a guide for
1. Developing the physical facilities of an airport
2. Developing land on and adjacent to the airport
3. Determining the environmental effects of airport construction and operations
4. Establishing access requirements

5. Establishing the technical, economic and financial feasibility of proposed developments through a thorough investigation of alternative concepts
6. Establishing a schedule of priorities and phasing for the improvements proposed in the plan
7. Establishing an achievable financial plan to support the implementation schedule
8. Establishing a continuing planning process which will monitor conditions and adjust plan recommendations as circumstances warrant

Guidelines for completing an airport master plan are described by ICAO [4] and in the United States by the FAA [1]. A master plan report is typically organized as follows:

Master plan vision, goals, and objectives—establishes the vision and overarching goals for the master plan as well as objectives that will guide the planning process and help ensure that the goals are achieved and the vision is realized.

Inventory of existing conditions—provides an overview of the airport's history, role in the region and nation, growth and development over time, description of its physical assets (airfield and airspace, terminal, ground access, and support facilities), and key industry trends.

Forecast of aviation demand—future levels of aircraft operations, number of passengers, and volume of cargo are forecasted for short, intermediate, and long-range time periods. Typically forecasts are made for 5, 10, and 20 years on both annual as well daily and busiest hours of the day.

Demand/capacity analysis and facility requirements—compares the future demand with the existing capacity of each airport component and identifies the facility requirements necessary to accommodate the demand.

Alternatives development—identifies, refines, and evaluates a range of alternatives for accommodating facility requirements. If the existing site cannot accommodate the anticipated growth, a selection process to find a new site may be necessary.

Preferred development plan—identifies, describes, and defines the alternative that best achieves the master plan goals and objectives.

Implementation plan—provides a comprehensive plan for the implementation of the preferred development plan, including the definition f projects, construction sequence and timeline, cost estimates, and financial plan.

Environmental overview—provides an overview of the anticipated environmental impacts associated with the preferred development plan in order to understand the severity and to help expedite subsequent environmental processing at the project specific stage.

Airport plans package—documents that show the existing as well as planned modifications are prepared and the more notable is the airport layout plan (ALP). It comprises drawings that include the airfi eld's physical facilities, obstruction clearance and runway approach profiles, land-use plans, terminal area and ground access plans, and a property map. Specific guidelines for the airport layout plan in the United States are identified by FAA [1].

Stakeholder and public involvement—documents the coordination efforts that occur among the stakeholders throughout the study.

The Airport Project Plan

A project plan focuses on a specific element of the airport master plan which is to be implemented in the short term and may include such items as the addition of a new runway, the modification of existing of runways, the provision of taxiways or taxiway exits, the addition of gates, the addition to or the renovation of terminal building facilities, or the modification of ground access facilities The overall objective of the airport project plan is to provide the specific details of the development which will satisfy immediate aviation needs and be consistent with the objectives and constraints identified in the airport master plan. More specifically it is a detailed plan for

1. Developing the specific physical facilities at an airport including the architectural and engineering design for these facilities
2. Determining the environmental effects of this development through the construction and operational phases
3. Determining the detailed costs and financial planning for the development
4. Establishing a schedule for the construction and phasing of the specific items of development in the plan

Land-Use Planning

A land-use plan for property within the airport boundary and in areas adjacent to the airport is an essential part of an airport master plan. The land-use plan on and off the airport is an integral part of an area wide comprehensive planning program, and therefore it must be coordinated with the objectives, policies, and programs for the area which the airport is to serve. Incompatibility of the airport with its neighbors stems primarily from the objections of people to aircraft noise. A land-use plan must therefore project the extent of aircraft noise that will be generated by airport operations in the future. Contours of equal intensity of noise can be drawn and overlaid on a land-use map and from these contours an estimate can be made of the compatibility of existing land use with airport operations. If the land outside the airport is underdeveloped, the contours are the basis for establishing comprehensive land-use zoning requirements. Although zoning is used as a method for controlling land use adjacent to an airport, it is not effective in areas which are already built-up because it is usually not retroactive. Furthermore jurisdictions having zoning powers may not take effective zoning action. Aircraft operations into and out of the airport may be made unnecessarily complex to minimize noise encroachment on incompatible land uses. Despite these shortcomings the planner should utilize zoning as a vehicle to achieve compatibility wherever this approach is feasible. Airports become involved in two types of zoning. One type is height and hazard zoning, which is mainly to protect the approaches to the airport from obstructions. The other type is land-use zoning. The extent of land use in the airport depends a great deal on the amount of acreage available. Land uses can be classified as eitherclosely related to aviation or remotely related to aviation. Those closely related to aviation use include the runways, taxiways, aprons, terminal buildings, parking, and maintenance facilities. Nonaviation uses include space for recreational, industrial, and commercial activities. When considering commercial or industrial activities, care should be taken to ensure that they will not interfere with aircraft operations, communications equipment, and aids to navigation on the ground. Recreational facilities such as golf courses may be suitable within the immediate proximity of the airport boundary or certain agricultural uses are also appropriate as long as they do not attract birds. When there is acreage within the airport boundary in excess of aviation needs, it is sound fiscal planning to provide the greatest financial return from leases of the excess property. Thus the land-use plan within the airport is a very effective tool in helping airport management make decisions concerning requests for land use by various interests and often airports delineate areas on the airport property for the development of industrial parks.

The principal objective of the land-use plan for areas outside the airport boundary is to minimize the disturbing effects of noise. As stated earlier the delineation of noise contours is the most promising approach for establishing noise-sensitive areas. The contours define the areas which are or are not suitable for residential use or other use and, likewise, those which are suitable for light industrial, commercial, or recreational activity. Although the responsibility for developing land uses adjacent to the airport lies with the governing bodies of adjacent communities, the land-use plan provided by the airport authority will greatly influence and assist the governing bodies in their task of establishing comprehensive land-use zoning.

Environmental Impact Assessment

Environmental factors must be considered carefully in the development of a new airport or the expansion of an existing one. In the United States, this is a requirement of the Airport and Airway Improvement Act of 1982 and the Environmental Policy Act of 1969. Studies of the impact of the construction and operation of a new airport or the expansion of an existing one upon acceptable levels of air and water quality, noise levels, ecological processes, and demographic development of the region must be conducted to determine how the airport requirements can best be met with minimal adverse environmental and social consequences.

Aircraft noise is the severest environmental problem to be considered in the development of airport facilities. Much has been done to quiet engines and modify flight procedures, resulting in substantial reductions in noise. Another effective means for reducing noise is through proper planning of land use for areas adjacent to the airport. For an existing airport this may be difficult as the land may have already been built up. Every effort should be made to orient air traffic away from noise-sensitive land development.

Other important environmental factors include air and water pollution, industrial wastes and domestic sewage originating at the airport, and the disturbance of natural environmental values. In regard to air pollution, the federal government and industry have worked jointly toward alleviating the problem, and there is a reason to believe that it will probably be eliminated in the near future as an environmental factor. An airport can be a major contributor to water pollution if suitable treatment facilities for airport wastes are not provided. Chemicals used to deice aircraft are a major source of potential ground water pollution and provisions need to be made to safely dispose of this waste product. The environmental study must include a statement detailing the methods for handling sources of water pollution.

The construction of a new airport or the expansion of an existing one may have major impacts on the natural environment. This is particularly true for large developments where streams and major drainage courses may be changed, the habitats of wildlife may be disrupted, and wilderness and recreational areas may be reshaped.

The environmental study should indicate how these disruptions might be alleviated. In the preparation of an environmental study, or an environmental impact statement, the findings must include the following items:

1. The environmental impact of the proposed development
2. Any adverse environmental effects which cannot be avoided should the development be implemented
3. Alternatives to the proposed development
4. The relationship between local short-term uses of the environment and the maintenance and enhancement of long-term productivity
5. Any irreversible environmental and irretrievable commitments of resources which would be involved in the proposed development should it be implemented
6. Growth inducing impact
7. Mitigation measures to minimize impact

In the application of these guidelines attention must be directed to the following questions. Will the proposed development

1. Cause controversy
2. Noticeably affect the ambient noise level for a significant number of people

3. Displace a significant number of people
4. Have a significant aesthetic or visual effect
5. Divide or disrupt an established community or divide existing uses
6. Have any effect on areas of unique interest or scenic beauty
7. Destroy or derogate important recreational areas
8. Substantially alter the pattern of behavior for a species
9. Interfere with important wildlife breeding, nesting, or feeding grounds
10. Significantly increase air or water pollution
11. Adversely affect the water table of an area
12. Cause excessive congestion on existing ground transportation facilities
13. Adversely affect the land-use plan for the region

The preparation of an environmental impact statement based upon an environmental assessment study is an extremely important part of the airport planning process. The statement should clearly identify the problems that will affect environmental quality and the proposed actions to alleviate them. Unless the statement is sufficiently comprehensive, the entire airport development may be in jeopardy.

Economic and Financial Feasibility

The economic and financial feasibility of alternative plans for a new airport or expansion of an existing site must be clearly demonstrated by the planner. Even if the selected alternative is shown to be economically feasible, then also it is necessary to show that the plan will generate sufficient revenues to cover annual costs of capital investment, administration, operations, and maintenance. This must be determined for each stage or phase of development detailed in the airport master plan.

An evaluation of economic feasibility requires an analysis of benefits and costs. A comparison of benefits and costs of potential capital investment programs indicates the desirability of a project from an economic point of view. The economic criterion used in evaluating an aviation investment is the total cost of facilities, including quantifiable social costs, compared with the value of the increased effectiveness measured in terms of total benefits. The costs include capital investment, administration, operation, maintenance, and any other costs that can be quantified. The benefits include a reduction in aircraft and passenger delays, improved operating efficiency, and other benefits. The costs and benefits are usually determined on an annual basis.

Airport Classification

For the purpose of stipulating geometric design standards for the various types of airports and the functions which they serve, letter and numerical codes and other descriptors have been adopted to classify airports.

For design purposes, airports are classified based on the aircraft they accommodate. While at any airport, a wide variety of aircraft, from small general aviation piston-engine aircraft to heavy air transport aircraft, will use the airfield, airports are designed based on a series of “critical” or “design” aircraft. These aircraft are selected from the fleet using the airport as those most critical to airfield design. The FAA defines the term *critical aircraft* as the aircraft most demanding on airport design that operates at least 500 annual itinerant operations at a given airport. In many cases, more than one critical aircraft will be selected at an airport for design purposes. For example, it is often the smallest aircraft that is critical to the orientation of runways, while the largest aircraft determines most of the other dimensional specifications of an airfield. The airport reference code is a coding system used to relate the airport design criteria to the operational and physical characteristics of the aircraft intended to operate at the airport. It is based upon the *aircraft approach category* and the *airplane design group* to which the aircraft is assigned. The aircraft approach category, is determined by the aircraft approach speed, which is defined as 1.3 times the stall speed in the landing configuration of aircraft at maximum certified landing weight.

The airplane design group (ADG) is a grouping of aircraft based upon wingspan or tail height, An airplane design group for a particular aircraft is assigned based on the greater (higher Roman numeral) of that associated with the aircraft's wingspan or tail height. The airport reference code is a two designator code referring to the aircraft approach category and the airplane design group for which the airport has been designed. For example, an airport reference code of B-III is an airport designed to accommodate aircraft with approach speeds from 91 to less than 121 kn (aircraft approach category B) with wingspans from 79 to less than 118 ft or tail heights from 30 to less than 45 ft (airplane design group III). The FAA publishes a list of the airport reference codes for various aircraft in Advisory Circular 150/5300-13 "Airport Design". As an example, an airport designed to accommodate the Boeing 767-200 which has an approach speed of 130 kn (aircraft approach category C) and a wingspan of 156 ft 1 in (airplane design group IV) would be classified with an airport reference code C-IV. The ICAO uses a two-element code, *the aerodrome reference code*, to classify the geometric design standards at an airport. The code elements consist of a numeric and alphabetic designator. The aerodrome code numbers 1 through 4 classify the length of the runway available, the *reference field length*, which includes the runway length and, if present, the stopway and clearway. The reference field length is the approximate required runway takeoff length converted to an equivalent length at mean sea level, 15°C, and zero percent gradient. The aerodrome code letters A through E classify the wingspan and outer main gear wheel span for the aircraft for which the airport has been designed. 1 kn is approximately 1.15 mi/h

Utility Airports

A *utility airport* is defined as one which has been designed, constructed, and maintained to accommodate approach category A and B aircraft. The specifications for utility airports are grouped for *small aircraft*, those of maximum certified takeoff weights of 12,500 lb or less, and *large aircraft*, those with maximum certified takeoff weight in excess of 12,500 lb. Design specifications for utility airports are governed by the airplane design group and the types of approaches authorized for the airport runway, that is, visual, nonprecision instrument or precision instrument approaches.

Utility airports for small aircraft are called *basic utility stage I*, *basic utility stage II*, and *general utility stage I*. Utility airports for large aircraft are called *general utility stage II*. Utility airports are further grouped for either visual and nonprecision instrument operations or precision instrument operations. The visual and nonprecision instrument operation utility airports are the basic utility stage I, basic utility stage II, or general utility stage I airports. The precision instrument operation utility airport is the general utility stage II airport. A basic utility stage I airport has the capability of accommodating about 75 percent of the single engine and small twin engine aircraft used for personal and business purposes. This generally means aircraft weighing on the order of 3000 lb or less is given the airport reference code B-I, which indicates that it accommodates aircraft in aircraft approach categories A and B and aircraft in airplane design group I. A basic utility stage II airport has the capability of accommodating all of the airplanes of a basic utility stage I airport plus some small business and air taxi-type airplanes. This generally means aircraft weighing on the order of 8000 lb or less is also given the airport reference code B-I. A general utility stage I airport accommodates all small aircraft. It is assigned the airport reference code of B-II. A general utility stage II airport serves large airplanes in aircraft approach categories A and B and usually has the capability for precision instrument operations. It is assigned the airport reference code of B-III.

Transport Airports

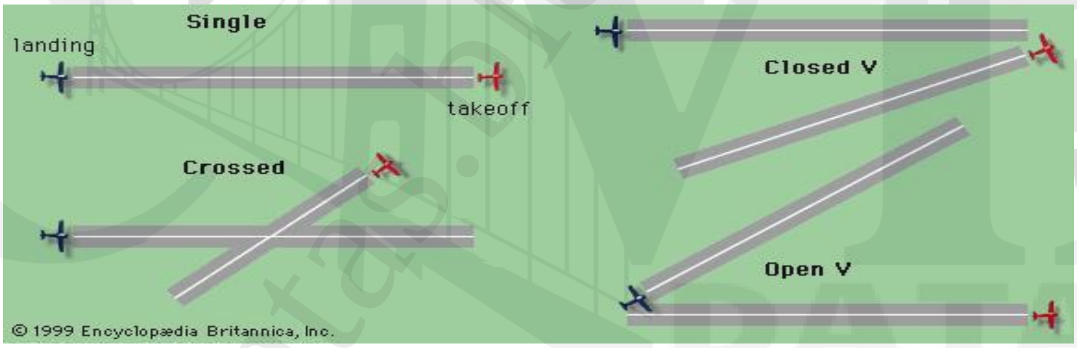
A *transport airport* is defined as an airport which is designed, constructed, and maintained to accommodate aircraft in approach categories C, D, and E. The design specifications of transport airports are based upon the airplane design group.

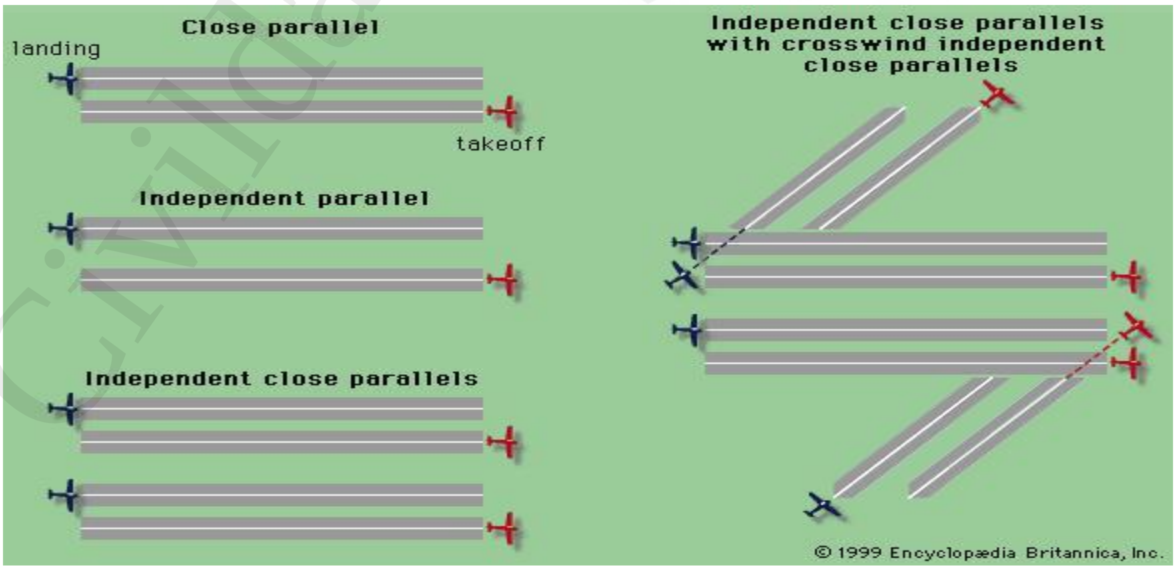
Runways

A runway is a rectangular area on the airport surface prepared for the takeoff and landing of aircraft. An airport may have one runway or several runways which are sited, oriented, and configured in a manner to provide for the safe and efficient use of the airport under a variety of conditions. Several of the factors which affect the location, orientation, and number of runways at an airport include local weather conditions, particularly wind distribution and visibility, the topography of the airport and surrounding area, the type and amount of air traffic to be serviced at the airport, aircraft performance requirements, and aircraft noise.

Runway Configurations

The term “runway configuration” refers to the number and relative orientations of one or more runways on an airfield. Many runway configurations exist. Most configurations are combinations of several basic configurations. The basic configurations are (1) single runways, (2) parallel runways, (3) intersecting runways, and (4) open-V runways.





Single Runway

It has been estimated that the hourly capacity of a single runway in VFR conditions is somewhere between 50 and 100 operations per hour, while in IFR conditions this capacity is reduced to 50 to 70 operations per hour, depending on the composition of the aircraft mix and navigational aids available.

Parallel Runways

The capacities of parallel runway systems depend on the number of runways and on the spacing between the runways. Two, three, and four parallel runways are common. The spacing between parallel runways varies widely. For the purpose of this discussion, the spacing is classified as close, intermediate, and far, depending on the centerline separation between two parallel runways. Close parallel runways are spaced from a minimum of 700 ft (for air carrier airports) to less than 2500 ft. In IFR conditions an operation of one runway is dependent on the operation of other runway. Intermediate parallel runways are spaced between 2500 ft to less than 4300 ft [5]. In IFR conditions an arrival on one runway is independent of a departure on the other runway. Far parallel runways are spaced at least 4300 ft apart [5]. In IFR conditions the two runways can be operated independently for both arrivals and departures. Therefore, as noted earlier, the centerline separation of parallel runways determines the degree of interdependence between operations on each of the parallel runways. It should be recognized that in future the spacing requirements for simultaneous operations on parallel runways may be reduced. If this occurs, new spacing can be applied to the same classifications. If the terminal buildings are placed between parallel runways, runways are always spaced far enough apart to allow room for the buildings, the adjoining apron, and the appropriate taxiways. When there are four parallel runways, each pair is spaced close, but the pairs are spaced far apart to provide space for terminal buildings.

In VFR conditions, close parallel runways allow simultaneous arrivals and departures, that is, arrivals may occur on one runway while departures are occurring on the other runway. Aircraft operating on the runways must have wingspans less than 171 ft (airplane design groups I through IV, see Table 6-2) for centerline spacing at the minimum of 700 ft [5]. If larger wingspan aircraft are operating on these runways (airplane design groups V and VI), the centerline spacing must be at least 1200 ft for such simultaneous operations [5]. In either case, wake vortex avoidance procedures must be used for simultaneous operations on closely spaced parallel runways. Furthermore, simultaneous arrivals to both runways or simultaneous departures from both runways are not allowed in VFR conditions for closely spaced parallel runways. In IFR conditions, closely spaced parallel runways cannot be used simultaneously but may be operated as dual-lane runways. Intermediate parallel runways may be operated with simultaneous arrivals in VFR conditions. Intermediate parallel runways may be operated in IFR conditions with simultaneous departures in a non radar environment if the centerline spacing is at least 3500 ft and in a radar environment if the centerline spacing is at least 2500 ft [5]. Simultaneous arrivals and departures are also permitted if the centerline spacing is at least 2500 ft if the thresholds of the runways are not staggered [5]. There are times when it may be desirable to stagger the thresholds of parallel runways. The staggering may be necessary because of the shape of the acreage available for runway construction, or it may be desirable for reducing the taxiing distance of takeoff and landing aircraft. The reduction in taxiing distance, however, is based on the premise that one runway is to be used exclusively for takeoff and the other for landing. In this case the terminal buildings are located between the runways so that the taxiing distance for each type of operation (takeoff or landing) is minimized. If the runway thresholds are staggered, adjustments to the centerline spacing requirement are allowed for simultaneous arrivals and departures [5]. If the arrivals are on the near threshold then the centerline spacing may be reduced by 100 ft for each 500 ft of threshold stagger down to a minimum centerline separation of 1000 ft for aircraft with wingspans up to 171 ft and a minimum of 1200 ft for larger wingspan aircraft. If the arrivals are on the far threshold the centerline spacing must be increased by 100 ft for each 500 ft of threshold stagger.

Simultaneous arrivals in IFR conditions are not permitted on intermediate parallel runways but are permitted on far parallel runways with centerline spacings of at least 4300 ft [5]. The hourly capacity of a pair of parallel runways in VFR conditions varies greatly from 60 to 200 operations per hour depending on the aircraft mix and the manner in which arrivals and departures are processed on these runways [4].

Similarly, in IFR conditions the hourly capacity of a pair of closely spaced parallel runways ranges from 50 to 60 operations per hour, of a pair of intermediate parallel runways from 60 to 75 operations per hour, and for a pair of far parallel runways from 100 to 125 operations per hour [4]. A dual-lane parallel runway consists of two closely spaced parallel runways with appropriate exit taxiways. Although both runways can be used for mixed operations subject to the conditions noted above, the desirable mode of operation is to dedicate the runway farthest from the terminal building (outer) for arrivals and the runway closest to the terminal building (inner) for departures.

It is estimated that a dual-lane runway can handle at least 70 percent more traffic than a single runway in VFR conditions and about 60 percent more traffic than a single runway in IFR conditions. It is recommended that the two runways be spaced not less than 1000 ft apart (1200 ft, where particularly larger wingspan aircraft are involved). This spacing also provides sufficient distance for an arrival to stop between the two runways. A parallel taxiway between the runways will provide for a nominal increase in capacity, but is not essential. The major benefit of a dual-lane runway is to provide an increase in IFR capacity with minimal acquisition of land [7, 14].

Intersecting Runways

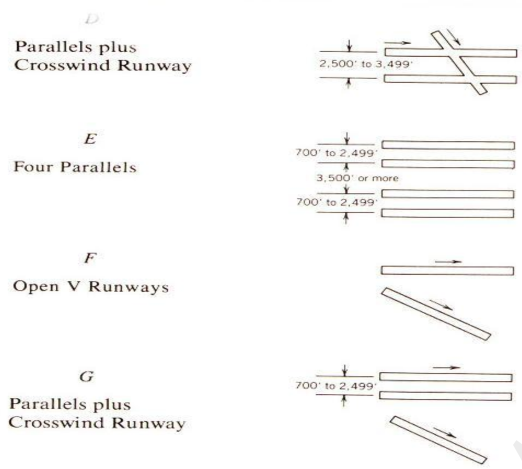
Many airports have two or more runways in different directions crossing each other. These are referred to as intersecting runways. Intersecting runways are necessary when relatively strong winds occur from more than one direction, resulting in excessive crosswinds when only one runway is provided. When the winds are strong, only one runway of a pair of intersecting runways can be used, reducing the capacity of the airfield substantially. If the winds are relatively light, both runways can be used simultaneously.

The capacity of two intersecting runways depends on the location of the intersection (i.e., midway or near the ends), the manner in which the runways are operated for takeoffs and landings, referred to as the runway use strategy, and the aircraft mix.

The farther the intersection is from the takeoff end of the runway and the landing threshold, the lower is the capacity. The highest capacity is achieved when the intersection is close to the takeoff and landing threshold.

Open-V Runways

Runways in different directions which do not intersect are referred to as open-V runways. This configuration is shown in Fig.. Like intersecting runways, open-V runways revert to a single runway when winds are strong from one direction. When the winds are light, both runways may be used simultaneously.



The strategy which yields the highest capacity is when operations are away from the V and this is referred to as a diverging pattern.

In VFR the hourly capacity for this strategy ranges from 60 to 180 operations per hour, and in IFR the corresponding capacity is from 50 to 80 operations per hour [4]. When operations are toward the V it is referred to as a converging pattern and the capacity is reduced to 50 to 100 operations per hour in VFR and to between 50 and 60 operations per hour in IFR.

Combinations of Runway Configurations

From the standpoint of capacity and air traffic control, a single-direction runway configuration is most desirable. All other things being equal, this configuration will yield the highest capacity compared with other configurations.

For air traffic control the routing of aircraft in a single direction is less complex than routing in multiple directions. Comparing the divergent configurations, the open-V runway pattern is more desirable than an intersecting runway configuration. In the open-V configuration an operating strategy that routes aircraft away from the V will yield higher capacities than if the operations are reversed.

If intersecting runways cannot be avoided, every effort should be made to place the intersections of both runways as close as possible to their thresholds and to operate the aircraft away from the intersection rather than toward the intersection.

The complex runway configuration of Chicago’s O’Hare Field, with multiple parallel, intersecting, and nonintersecting runways.

It should be noted that a large capital improvement program is being undertaken to simplify the runway configuration, by adding additional parallel runways and removing many intersecting runways. This runway redesign is being done with the intention of improving the capacity and efficiency of airport operations at the airport.

Runway Orientation

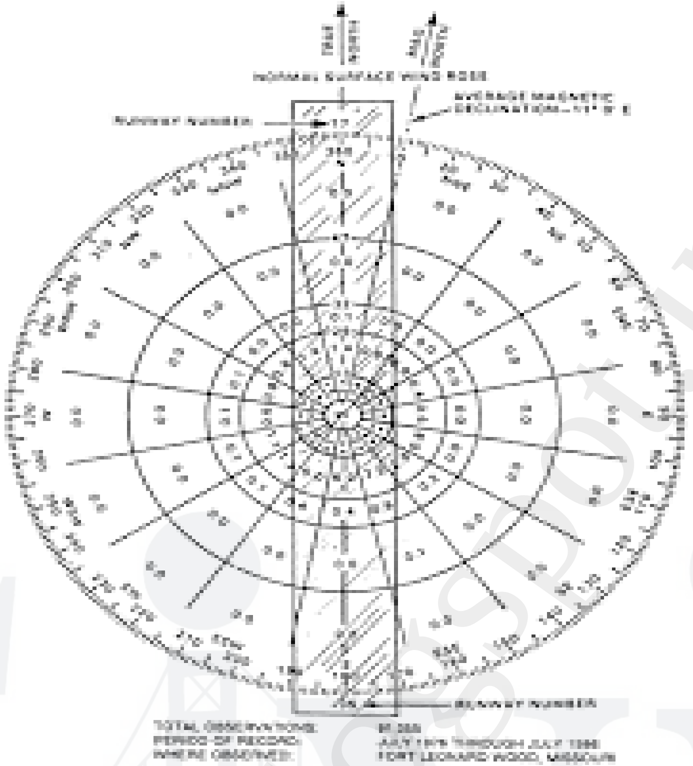


Figure 11-13. Determination of runway alignment by wind-rose analysis

The orientation of a runway is defined by the direction, relative to magnetic north, of the operations performed by aircraft on the runway. Typically, but not always, runways are oriented in such a manner that they may be used in either direction. It is less preferred to orient a runway in such a way that operating in one direction is precluded, normally due to nearby obstacles. In addition to obstacle clearance considerations, which will be discussed later in this chapter, runways are typically oriented based on the area's wind conditions. As such, an analysis of wind is essential for planning runways. As a general rule, the primary runway at an airport should be oriented as closely as practicable in the direction of the prevailing winds. When landing and taking off, aircraft are able to maneuver on a runway as long as the wind component at right angles to the direction of travel, the crosswind component, is not excessive. The FAA recommends that runways should be oriented so that aircraft may be landed at least 95 percent of the time with allowable crosswind components not exceeding specified limits based upon the airport reference code associated with the critical aircraft that has the shortest wingspan or slowest approach speed. When the wind coverage is less than 95 percent a crosswind runway is recommended.

The allowable crosswind is 10.5 kn (12 mi/h) for Airport Reference Codes A-I and B-I, 13 kn (15 mi/h) for Airport Reference Codes A-II and B-II, 16 kn (18.5 mi/h) for Airport Reference Codes A-III, B-III, C-I, C-II, C-III and C-IV, and 20 knots (23 mph) for Airport Reference Codes A-IV through D-VI [5].

ICAO also specifies that runways should be oriented so that aircraft may be landed at least 95 percent of the time with crosswind components of 20 kn (23 mph) for runway lengths of 1500 m more, 13 kn (15 mi/h) for runway lengths between 1200 and 1500 m, and 10 kn (11.5 mi/h) for runway lengths less than 1200 m [1, 2].

Once the maximum permissible crosswind component is selected, the most desirable direction of runways for wind coverage can be determined by examination of the average wind characteristics at the airport under the following conditions:

1. The entire wind coverage regardless of visibility or cloud ceiling
2. Wind conditions when the ceiling is at least 1000 ft and the visibility is at least 3 miles.
3. Wind conditions when ceiling is between 200 and 1000 ft and/or the visibility is between and 3 mi.

The first condition represents the entire range of visibility, from excellent to very poor, and is termed the all weather condition. The next condition represents the range of good visibility conditions not requiring the use of instruments for landing, termed visual meteorological condition (VMC).

The last condition represents various degrees of poor visibility requiring the use of instruments for landing, termed instrument meteorological conditions (IMC).

The 95 percent criterion suggested by the FAA and ICAO is applicable to all conditions of weather; nevertheless it is still useful to examine the data in parts whenever this is possible.

In the United States, weather records can be obtained from the Environmental Data and Information Service of the National Climatic Center at the National Oceanic and Atmospheric Administration located in Ashville, N.C., or from various locations found on the Internet.

Weather data are collected from weather stations throughout the United States on an hourly basis and recorded for analysis. The data collected include ceiling, visibility, wind speed, wind direction, storms, barometric pressure, the amount and type of liquid and frozen precipitation, temperature, and relative humidity.

A report illustrating the tabulation and representation of some of the data of use in airport studies was prepared for the FAA [15]. The weather records contain the percentage of time certain combinations of ceiling and visibility occur (e.g., ceiling, 500 to 900 ft; visibility, 3 to 6 mi), and the percentage of time winds of specified velocity ranges occur from different directions (e.g., from NNE, 4 to 7 mi/h). The directions are referenced to true north.

The Wind Rose

The appropriate orientation of the runway or runways at an airport can be determined through graphical vector analysis using a wind rose. A standard wind rose consists of a series of concentric circles cut by radial lines using polar coordinate graph paper.

The radial lines are drawn to the scale of the wind magnitude such that the area between each pair of successive lines is centered on the wind direction.

The shaded area indicates that the wind comes from the southeast (SE) with a magnitude between 20 and 25 mi/h. A template is also drawn to the same radial scale representing the crosswind component limits.

Fig 17.3. A typical wind rose

By overlaying the template on the wind rose and rotating the centerline of the template through the origin of the wind rose one may determine the percentage of time a runway in the direction of the centerline of the template can be used such that the crosswind component does not exceed 15 mi/h. Optimum runway directions can be determined from this wind rose by the use of the template, typically made on a transparent strip of material. With the center of the wind rose as a pivot point, the template is rotated until the sum of the percentages included between the outer lines is a maximum. If a wind vector from a segment lies outside either outer line on the template for the given direction of the runway, that wind vector must have a crosswind component which exceeds the allowable crosswind component plotted on the template. When one of the outer lines on the template divides a segment of wind direction, the fractional part is estimated visually to the nearest 0.1 percent. This procedure is consistent with the accuracy of the wind data and assumes that the wind percentage within the sector is uniformly distributed within that sector. In practice, it is usually easier to add the percentages contained in the sectors outside of the two outer parallel lines and subtract these from 100 percent to find the percentage of wind coverage.

Estimating Runway Length

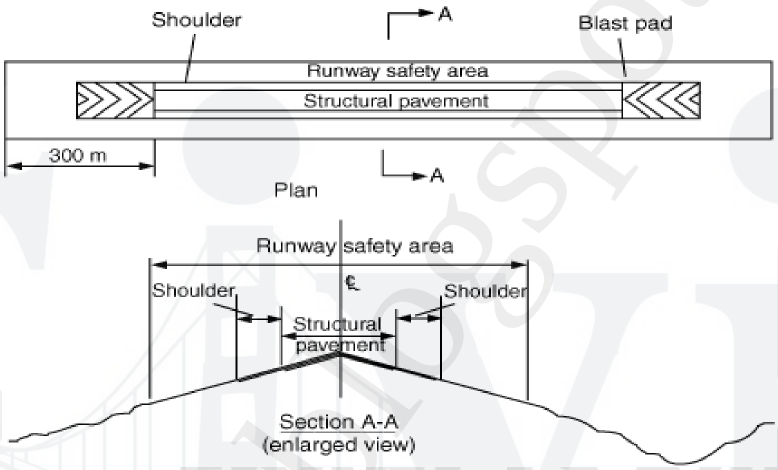
Other than orientation, planning and designing the length of a runway is critical to whether or not a particular aircraft can safely use the runway for takeoff or landing. Furthermore, designing a runway to accommodate a given aircraft is a difficult task, given the fact that an aircraft's required runway length will vary based on aircraft weight, as well as on several ambient conditions.

As a guide to airport planners, the FAA has published Advisory Circular 150/5325-4b, "Runway Length Requirements for Airport Design" [17]. In this publication, procedures are defined for estimating the design runway length of aircraft, based on their maximum takeoff weights (MTOW), certain aircraft performance specifications, and the airport's field elevation and temperature. The airport design runway length is found for the critical aircraft, defined as the aircraft which flies the greatest nonstop route segment from the airports at least 500 operations per year and requires the longest runway. The FAA's procedure for estimating runway length is based on the following data:

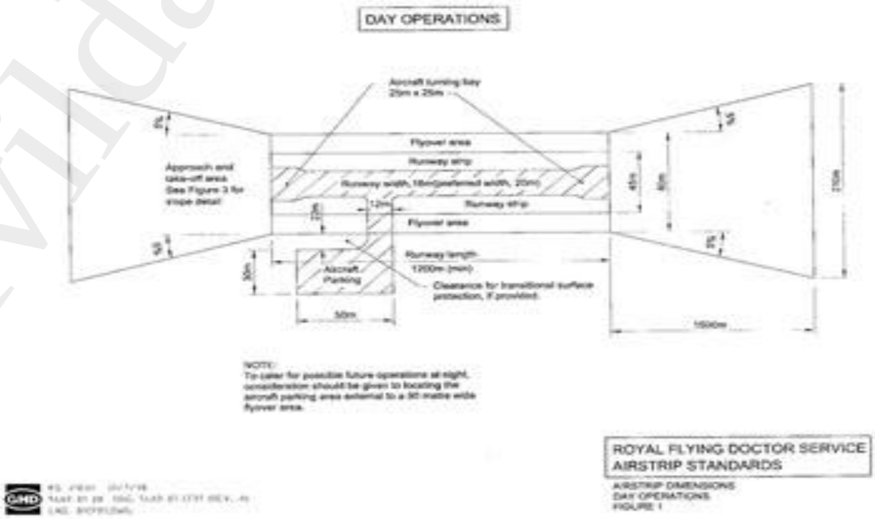
1. Designation of a critical aircraft
2. The maximum takeoff weight of the critical aircraft at the airport
3. The airport elevation
4. The mean daily maximum temperature for the hottest month at the airport
5. The maximum different in elevation along the runway centerline.

Runway System Geometric Specifications

The runway system at an airport consists of the structural pavement, the shoulders, the blast pad, the runway safety area, various obstruction-free surfaces, and the runway protection zone,



1. The runway *structural pavement* supports the aircraft with respect to structural load, maneuverability, control, stability, and other operational and dimensional criteria.
2. The *shoulder* adjacent to the edges of the structural pavement resists jet blast erosion and accommodates maintenance and emergency equipment.
3. The *blast pad* is an area designed to prevent erosion of the surfaces adjacent to the ends of runways due to jet blast or propeller wash.



4. The *runway safety area* (RSA) is an area surrounding the runway prepared or suitable for reducing the risk of damage to aircraft in the event of an undershoot, overshoot, or excursion from the runway. ICAO refers to an area similar to the runway safety area as the *runway strip* and the *runway end safety area*. The runway safety area includes the structural pavement, shoulders, blast pad, and stopway, if provided. This area should be capable of supporting emergency and maintenance equipment as well as providing support for aircraft. The runway safety area is cleared, drained, and graded and should have no potentially hazardous ruts, humps, depressions, or other surface variations. It should be free of objects except for objects that are required to be located in the runway safety area because of their function. These objects are required to be constructed on frangible mounted structures at the lowest possible height with the frangible point no higher than 3 in above grade.

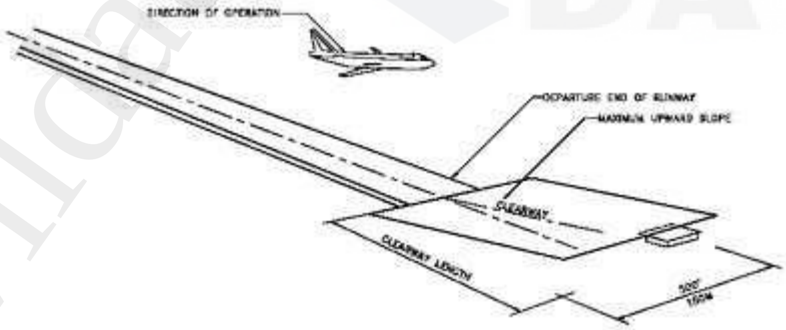
5. The runway *object-free area* (OFA) is defined by the FAA as a two-dimensional ground area surrounding the runway which must be clear of parked aircraft and objects other than those whose location is fixed by function.

6. The runway *obstacle-free zone* (OFZ) is a defined volume of airspace centered above the runway which supports the transition between ground and airborne operations. The FAA specifies this as the airspace above a surface whose elevation is the same as that of the nearest point on the runway centerline and extending 200 ft beyond each end of the runway.

7. The *inner approach obstacle-free zone*, which applies only to runways with approach lighting systems, is the airspace above a surface centered on the extended runway centerline beginning 200 ft beyond the runway threshold at the same elevation as the runway threshold and extending 200 ft beyond the last light unit on the approach lighting system. Its width is the same as the runway obstacle-free zone and it slopes upward at the rate of 50 horizontal to 1 vertical.

8. The *inner transitional obstacle-free zone,* which applies only to precision instrument runways, is defined by the FAA as the volume of airspace along the sides of the runway and the inner approach obstacle-free zone. The surface slopes at the rate of 3 horizontal to 1 vertical out from the edge of the runway obstacle-free zone and the inner approach obstacle-free zone until it reaches a height of 150 ft above the established airport elevation.

9. The *runway protection zone* (RPZ) is an area on the ground used to enhance the protection of people and objects near the runway approach.



Parallel Runway System Spacing

The spacing of parallel runways depends on a number of factors such as whether the operations are in VMC or IMC and, if in IMC, whether it is desired to have the capability of accommodating simultaneous arrivals or simultaneous arrivals and departures. At those

airports serving both heavy and light aircraft simultaneous use of runways even in VMC conditions may be dictated by separation requirements to safeguard against wake vortices.
For airplane design group III serving aircraft with maximum certified takeoff weight greater than 150,000 lb, the standard runway width is 150 ft, the shoulder width is 25 ft, and the blast pad width is 200 ft.
Airplane design groups V and VI normally require stabilized or paved shoulder surfaces.
For Airport Reference Code C-I and C-II, a runway safety area width of 400 ft is permissible.
For runways designed after 2/28/83 to serve aircraft approach category D aircraft, the runway safety area width increases 20 ft for each 1000 ft of airport elevation above mean sea level.
From end of runway; with the declared distance concept, these lengths begin at the stop end of each ASDA and both ends of the LDA, whichever is greater.
For large aircraft the greater of 400 ft or 180 ft plus the wingspan of the most demanding aircraft plus 20 ft for each 1000 ft of airport elevation; for small aircraft 300 ft for precision instrument runways, 250 ft for all other runways serving small aircraft with approach speeds of 50 kn or more, and 120 ft for all other runways serving small aircraft with approach speeds less than 50 kn.
Beyond the end of each runway. Under VMC, the FAA requires parallel runway centerline separations of 700 ft for all aircraft when the operations are in the same direction and wake vortices are not prevalent. It also recommends increasing the separation to 1200 ft for airplane design group V and VI runways. If wake vortices are generated by heavy jets and it is desired to operate on two runways simultaneously in VMC when little or no crosswind is present, the minimum distance specified by the FAA is 2500 ft. For operations under VMC, the ICAO recommends that the minimum separations between the centerlines of parallel runways for simultaneous use disregarding wake vortices be 120 m (400 ft) for aerodrome code number 1, 150 m (500 ft) for aerodrome code number 2, and 210 m (700 ft) for aerodrome code number 3 or 4 runways. In IMC conditions, the FAA specifies 4300 ft and ICAO specifies 1525 m (5000 ft) as the minimum separation between centerlines of *The width of a precision approach runway should not be less than 30 m where the aerodrome code number is 1 or 2.
Minimum width of pavement and shoulders when pavement width is less than 60 m.
Symmetrical about the runway centerline.
It is recommended that this be provided for the first 150 m from each end of the runway and that it should be increased linearly from this point to a width of 210 m at a point 300 m from each end of the runway and remain at this width for the remainder of the runway parallel runways for simultaneous instrument approaches. However, there is evidence that these distances are conservative and steps are being taken to reduce it. The ultimate goal is to reduce this distance by about one-half. For dependent instrument approaches both the FAA and ICAO recommend centerline separations of 3000 ft (915 m). For triple and quadruple simultaneous instrument approaches, the FAA requires 5000-ft separation between runway centerlines, although will allow 4300 ft separations on a case-by-case basis. Both the FAA and ICAO specify that two parallel runways may be used simultaneously for radar departures in IMC if the centerlines are separated by at least 2500 ft (760 m). The FAA requires a 3500-ft centerline separation for simultaneous non radar departures. If two parallel runways are to be operated independently of each other in IMC under radar control, one for arrivals and the other for departures, both the FAA and ICAO specify that the minimum separation between the centerlines is 2500 ft (760 m) when the thresholds are even. If the thresholds are staggered, the runways can be brought closer together or must be separated farther depending on the amount of the stagger and which runways are used for arrivals and departures. If approaches are to the nearest runway, then the spacing may be reduced by 100 ft (30 m) for

each 500 ft (150 m) of stagger down to a minimum of 1200 ft (360 m) for airplane design groups V and VI and 1000 ft (300 m) for all other aircraft. However, if the approaches are to the farthest runway, then the runway spacing must be increased by 100 ft (30 m) for each 500 ft (150 m) of stagger.

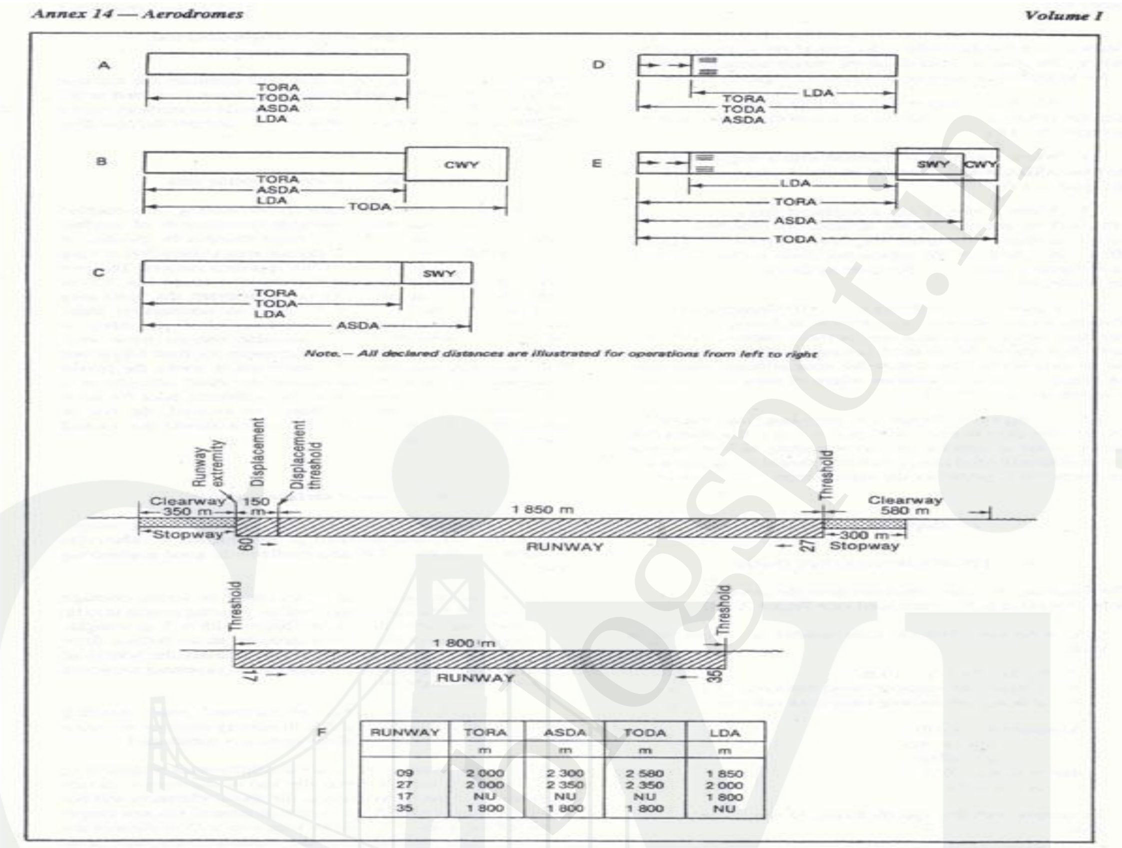


Figure A-1. Illustration of declared distances

Sight Distance and Longitudinal Profile

The FAA requirement for sight distance on individual runways requires that the runway profile permit any two points 5 ft above the runway centerline to be mutually visible for the entire runway length.

If, however, the runway has a full length parallel taxiway, the runway profile may be such that an unobstructed line of sight will exist from any point 5 ft above the runway centerline to any other point 5 ft above the runway centerline for one-half the runway length. The FAA recommends a clear line of sight between the ends of intersecting runways.

The terrain must be graded and permanent objects designed and sited so that there will be an unobstructed line of sight from any point 5 ft above one runway centerline to any point 5 ft above an intersecting runway centerline within the runway visibility zone.

The runway visibility zone is the area formed by imaginary lines connecting the visibility points of the two intersecting runways.

The runway visibility zone for intersecting runways is shown in Fig.

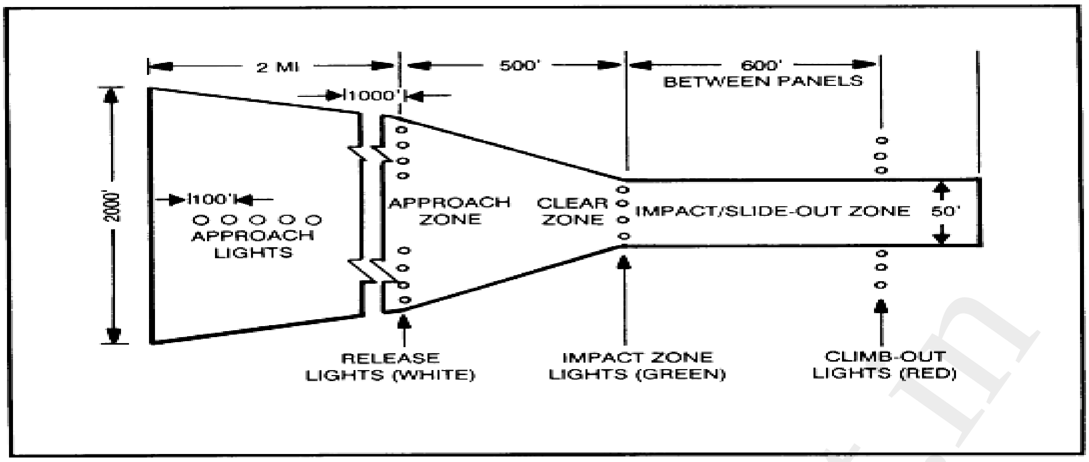
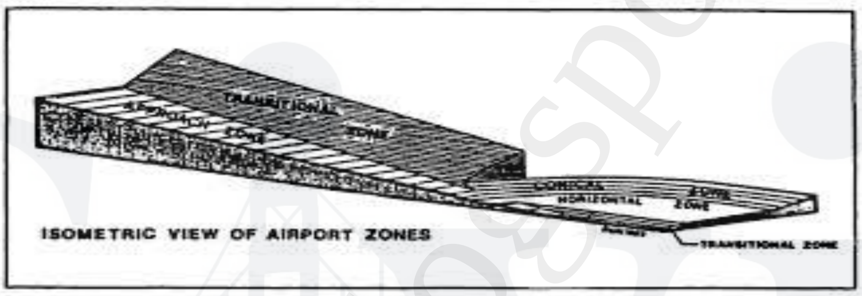
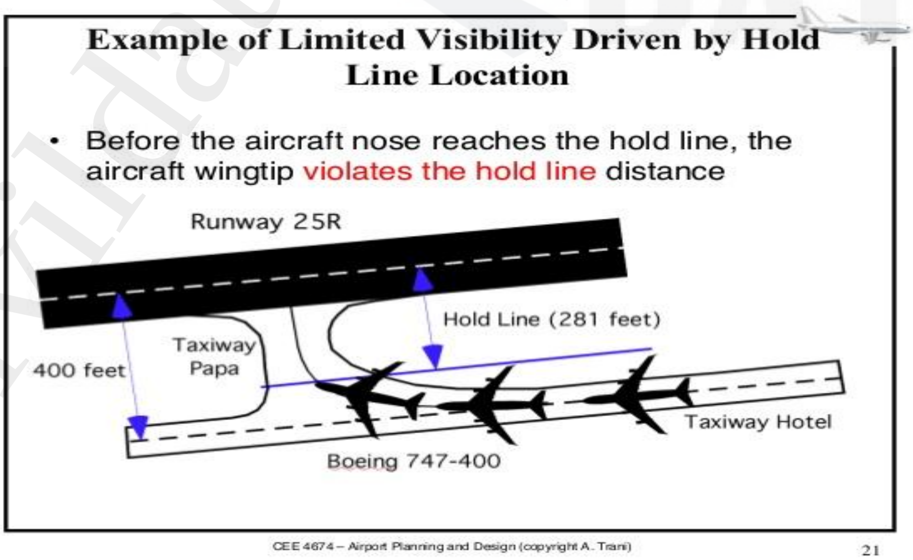


Figure A-6. LAPES night zone marking.



The visibility points are defined as follows:

1. If the distance from the intersection of the two runway centerlines is 750 ft or less, the visibility point is on the centerline at the runway end designated by point.
2. If the distance from the intersection of the two runway centerlines is greater than 750 ft but less than 1500 ft, the visibility point is on the centerline 750 ft from the intersection of the centerlines designated by point b.



3. If the distance from the intersection of the two runway centerlines is equal to or greater than 1500 ft, the visibility point is on the centerline equidistant from the runway end and the intersection of the centerlines designated by points c and d.

The ICAO requirement for sight distance on individual runways requires that the runway profile permit an unobstructed view between any two points at a specified height above the runway centerline to be mutually visible for a distance equal to at least one-half the runway length. ICAO specifies that the height of these two points be 1.5 m (5 ft) above the runway for aerodrome code letter A runways, 2 m (7 ft) above the runway for aerodrome code letter B runways, and 3 m (10 ft) above the runway for aerodrome code letter C, D, or E runways.

It is desirable to minimize longitudinal grade changes as much as possible. However, it is recognized that this may not be possible for reasons of economy. Therefore both the ICAO and FAA allow changes

- Applies also to runway safety area adjacent to sides of the runway.
- May not exceed 0.8 percent in the first and last quarter of runway.
- A minimum of 3 percent for turf.
- A slope of 5 percent is recommended for a 10 ft width adjacent to the pavement areas to promote drainage.
- For the first 200 ft from the end of the runway and if it slopes it must be downward.
- For the remainder of the runway safety area the slope must be such that any upward slope does not penetrate the approach surface or clearway plane and any downward slope does not exceed 5 percent.
- For each 1 percent change in grade.
- No vertical curve is required if the grade change is less than 0.4 percent.
- Distance is multiplied by the sum of the absolute grade grade changes in percent.

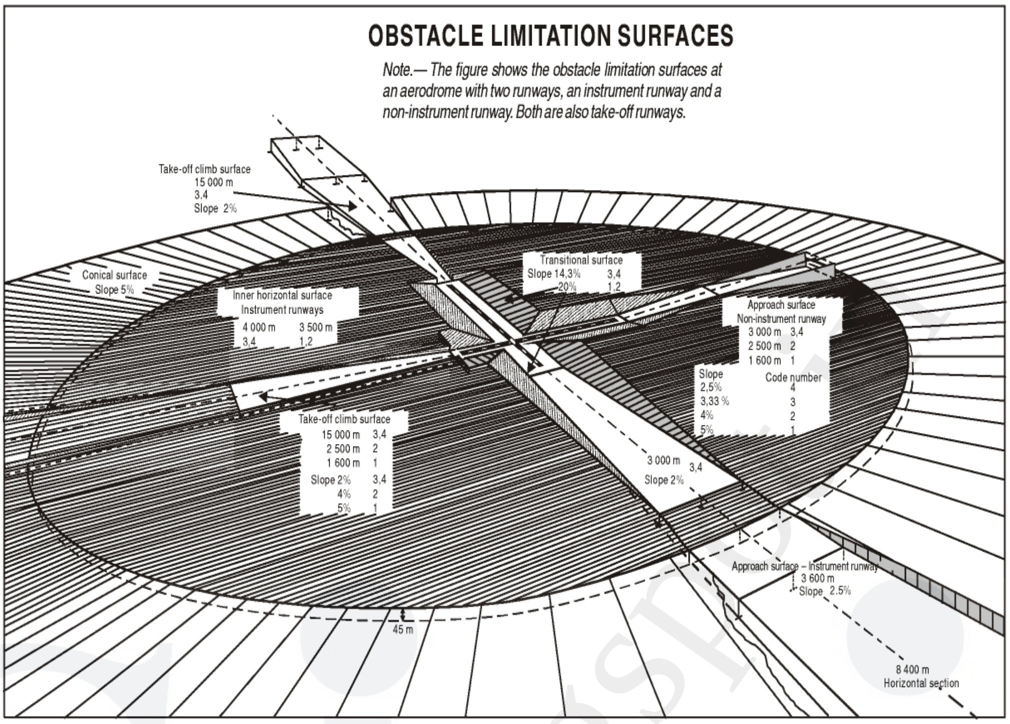
Source: Federal Aviation Administration [6]. longitudinal gradient and longitudinal grade changes to 2 percent for runways serving approach category A and B aircraft and 1.5 percent for runways serving approach category C, D, and E aircraft. ICAO limits both longitudinal gradient and longitudinal grade changes to 2 percent for aerodrome code number 1 and 2 runways and 1.5 percent for aerodrome code number 3 runways. For aerodrome code number 4 runways the maximum longitudinal gradient is 1.25 percent and the maximum change in longitudinal gradient is 1.5 percent. In addition, for runways that are equipped to be used in bad weather, the gradient of the first and last quarter of the length of the runway must be very flat for reasons of safety. Both the ICAO and the FAA require that this gradient not exceed 0.8 percent. In all cases it is desirable to keep both longitudinal grades and grade changes to a minimum. Longitudinal slope changes are accomplished by means of vertical curves. The length of a vertical curve is determined by the magnitude of the changes in slope and the maximum allowable change in the slope of the runway.

*May not exceed 0.8 percent in the first and last quarter of runway for aerodrome code number 4 or for a category II or III precision instrument runway for aerodrome code number 3.

†Difference in elevation between high and low point divided by runway length

‡For each 1 percent change in grade.

§Distance is multiplied by sum of absolute grade changes in percent minimum length is 45 m.

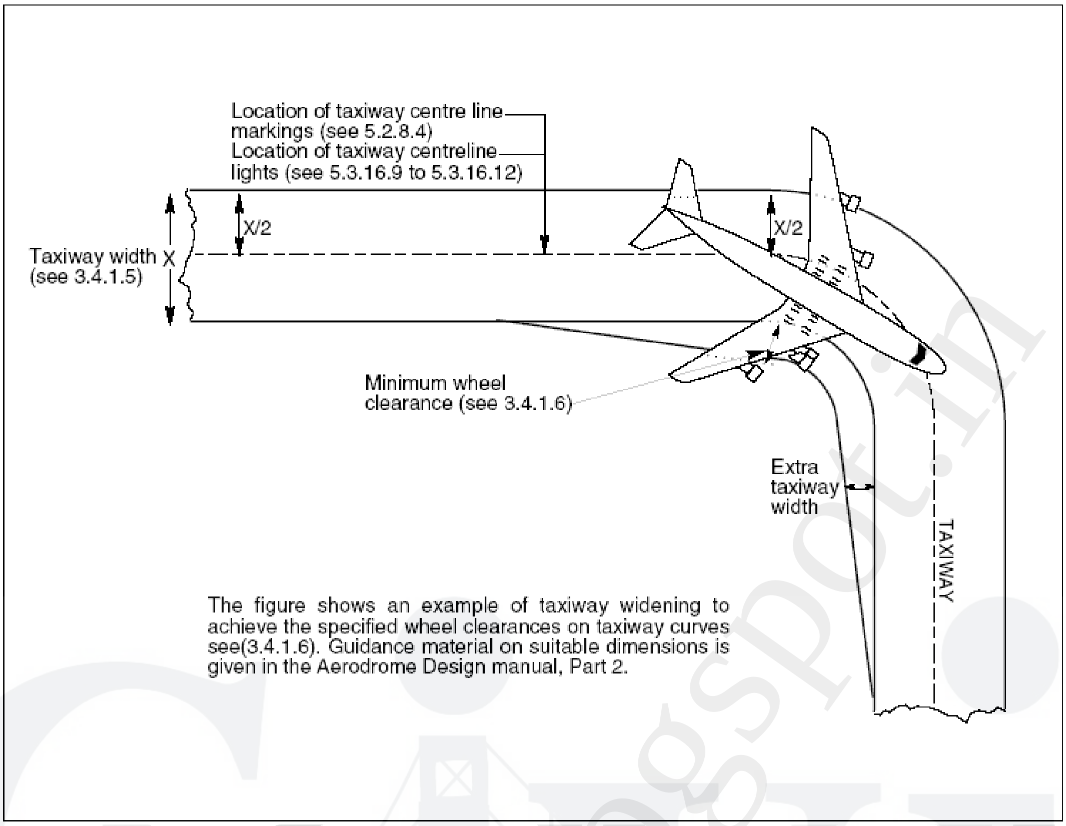


The number of slope changes along the runway is also limited. The FAA requires that the distance between the points of intersection of two successive curves should not be less than the sum of the absolute percentage values of change in slope multiplied by the 250 ft for airports serving aircraft approach category A and B aircraft and 1000 ft for airports serving aircraft approach category C, D, and E aircraft. The ICAO requires that the distance between the points of intersection of two successive curves should not be less than the sum of the absolute percentage values of change in slope multiplied by 50 m (165 ft) for aerodrome code number 1 and 2 runways, 150 m (500 ft) for aerodrome code number 3 runways, and 300 m (1000 ft) for aerodrome code number 4 runways. ICAO also specifies that the minimum distance in all cases is 45 m (150 ft). For example, for an FAA runway serving transport aircraft, that is, approach category C, D, or E aircraft, if the change in slope was 1.5 percent, the required length of vertical curve would be 1500 ft. Vertical curves are normally not necessary if the change in slope is not more than 0.4 percent. The FAA specifies a minimum length of vertical transition curve of 300 for each 1 percent change in grade for runways

*For facilities for small aircraft only.
†Satisfies the requirement that no part of an aircraft at a holding an increase to these separations may be needed to achieve this result.
‡For sea level up to elevation 6000 ft. Increase by 1 ft for each 100 ft of airport elevation above 6000 ft. serving approach category A and B aircraft and 1000 ft for each 1 percent change in grade for airport serving approach category C, D, and E aircraft. ICAO specifies a minimum length of vertical transition curve of 75 m for each 1 percent change in grade for aerodrome code number 1 runways, 150 m for each 1 percent change in grade aerodrome code number 2 runways, and 300 m for each 1 percent change in grade for aerodrome code number 4 runways.

Transverse Gradient

A typical cross section of a runway is shown in Fig.



The FAA and ICAO specifications for transverse slope on the runways are given in Tables 6-10 and 6-11, respectively. It is recommended that a 5 percent transverse slope be provided for the first 10 ft of shoulder adjacent to a pavement edge to ensure proper drainage.

- Lighting of obstacle penetrations to this surface or the use of a VGSI, as defined by the TERPS order, may avoid displacing the threshold.
- 10,000 ft is a nominal value for planning purposes. The actual length of these areas is dependent upon the visual descent point position for 20:1 and 34:1 and decision altitude point for the 30:1.
- Any penetration to this surface will limit the runway end to nonprecision approaches. No vertical approaches will be authorized until the penetration(s) is/are removed except obstacles fixed by function and/or allowable grading.
- Dimension A is measured relative to departure end of runway (DER) or TODA (to include clearway).
- Data collected regarding penetrations to this surface are provided for information and use by the air carriers operating from the airport. These requirements do not take effect until January 1, 2009.
- Surface dimensions/obstacle clearance surface (OCS) slope represent a nominal approach with 3° GPA, 50̣′TCH, 500̣′HAT. For specific cases refer to TERPS. The obstacle clearance surface slope (30:1) represents a nominal approach of 3° (also known as the glide path angle). This assumes a threshold crossing height of 50 ft. Three degrees is commonly used for ILS systems and VGSI aiming angles. This approximates a 30:1 approach angle that is between the 34:1 and the 20:1 notice surfaces of Part 77. Surfaces cleared to 34:1 should accommodate a 30:1 approach without any obstacle clearance problems.

- For runways with vertically guided approaches the criteria in Row 7 is in addition to the basic criteria established within the table, to ensure the protection of the glide path qualification surface.
- For planning purposes, sponsors and consultants determine a tentative decision altitude based on a 3° glide path angle and a 50-ft threshold crossing height.

These specifications are used to site the location of a runway's threshold so that approach and departure procedures associated with that runway are not adversely affected by existing obstacles or terrain. The siting specifications vary depending on a number of runway use conditions, including

- The approach speed of arriving aircraft
- The approach category of arriving aircraft
- Day versus night operations
- Types of instrument approaches
- The presence of published instrument departure procedures
- The use of the runway by air carriers

Runway end siting requirements are often the most confusing as well as overlooked element of runway planning. Care should be given to fully understand the purpose of the planned runway, the type of aircraft that will be using the runway, the current and future instrument approach procedures associated with the runway, and of course any terrain or obstacles in the vicinity. Should an object penetrate any of the surfaces at the site of a runway, Displacing the threshold allows the airport planner to design runways with sufficient lengths to accommodate aircraft departures, while also allowing arrivals to safely approach the runway by maintaining sufficient clearance from upstream obstacles. Displacing the threshold does carry the penalty of reducing available runway lengths for landing. The FAA recommends avoiding the need for displaced thresholds when possible, but recognizes their benefits in the wake of no other alternatives.

Taxiways and Taxilanes

Taxiways are defined paths on the airfield surface which are established for the taxiing of aircraft and are intended to provide a linkage between one part of the airfield and another. The term "dual parallel taxiways" refers to two taxiways parallel to each other on which airplanes can taxi in opposite directions. An apron taxiway is a taxiway located usually on the periphery of an apron intended to provide a through taxi route across the apron. A taxilane is a portion of the aircraft parking area used for access between the taxiways and the aircraft parking positions. ICAO defines an aircraft stand taxilane as a portion of the apron intended to provide access to the aircraft stands only. In order to provide a margin of safety in the airport operating areas, the trafficways must be separated sufficiently from each other and from adjacent obstructions. Minimum separations between the centerlines of taxiways, between the centerlines of taxiways and taxilanes, and between taxiways and taxilanes and objects are specified in order that aircraft may safely maneuver on the airfield.

Widths and Slopes

Since the speeds of aircraft on taxiways are considerably less than on runways, criteria governing longitudinal slopes, vertical curves, and sight distance are not as stringent as for runways. Also the lower speeds permit the width of the taxiway to be less than that of the runway.

- For airplanes in airplane design group III with a wheelbase equal to or greater than 60 ft, the standard taxiway width is 60 ft.
- The taxiway edge safety margin is the minimum acceptable between the outside of the airplane wheels and the pavement edge.
- For airplanes in airplane design group III with a wheelbase equal or greater than 60 ft, the taxiway edge safety margin is 15 ft.
- Airplanes in airplane design groups V and VI normally stabilized or paved taxiway shoulder surfaces.
- May use aircraft wingspan in lieu of these values.
- May use 1.4 wingspan plus 20 ft in lieu of these values.
- May use 1.2 wingspan plus 20 ft in lieu of these values.
- May use 1.2 wingspan plus 10 ft in lieu of these values.
- May use 0.7 wingspan plus 10 ft in lieu of these values.
- May use 1.1 wingspan plus 10 ft in lieu of these values.
- May use 0.6 wingspan plus 10 ft in lieu of these values.

Taxiway and Taxilane Separation Requirements

FAA Separation Criteria

The separation criteria adopted by the FAA are predicated upon the wingtips of the aircraft for which the taxiway and taxilane system have been designed and provide a minimum wingtip clearance on these facilities. The required separation between taxiways, between a taxiway and a taxilane, or between a taxiway and a fixed or movable object requires a minimum wingtip clearance of 0.2 times the wingspan of the most demanding aircraft in the airplane design group plus 10 ft. This clearance provides a minimum taxiway centerline to a parallel taxiway centerline or taxilane centerline separation of 1.2 times the wingspan of the most demanding aircraft plus 10 ft, and between a taxiway centerline and a fixed or movable object of 0.7 times the wingspan of the most demanding aircraft plus 10 ft.

*A minimum of 3 percent for turf.

†A slope of 5 percent is recommended for a 10-ft width adjacent to the pavement areas to promote drainage.

‡For each 1 percent of grade change.

§Distance is multiplied by the sum of the absolute grade changes in percent.

*18 m if used by aircraft with a wheelbase equal to or greater than 18 m.

†23 m is used by aircraft with an outer main gear wheel span equal to or greater than 9 m.

‡4.5 m. if intended to be used by airplane with a wheelbase equal to or greater than 18 m.

separation is also applicable to aircraft traversing through a taxiway on an apron or ramp. This separation may have to be increased to accommodate pavement widening on taxiway curves. It is recommended that a separation of at least 2.6 times the wheelbase of the most demanding aircraft be provided to accommodate a 180°turn when the pavement width is designed for tracking the nose wheel on the centerline.

The taxilane centerline to a parallel taxilane centerline or fixed or movable object separation in the terminal area is predicated on a wingtip clearance of approximately half of that required for an apron taxiway. This reduction in clearance is based on the consideration that taxiing speed is low in this area, taxiing is precise, and special guidance techniques and devices are provided. This requires a wingtip clearance or wingtip-to-object clearance of 0.1 times the wingspan of the most demanding aircraft plus 10 ft. Therefore, this establishes a minimum separation between the taxilane centerlines of 1.1 times the wingspan of the most demanding aircraft plus 10 ft, and between a taxilane centerline and a fixed or movable object of 0.6 times the wingspan of the most demanding aircraft plus 10 ft [6]. Therefore, when dual parallel taxilanes are provided in the terminal apron area, the taxilane object-free area becomes 2.3 the wingspan of the most demanding aircraft plus 30 ft. The separation criteria adopted by ICAO are also predicated upon the wingtips of the aircraft for which the taxiway and taxilane system have been designed and providing a minimum wingtip clearance on these facilities, but also consider a minimum clearance between the outer main gear wheel and the taxiway edge. The required separation between taxiways or between a taxiway and a taxilane requires a minimum wingtip clearance, *C*1, of 3 m for aerodrome code letter A and B runways, 4.5 m for aerodrome code letter C runways, and

*For each 1 percent of grade change.

7.5 m for aerodrome code letter D and E runways. The minimum clearance between the edge of each taxiway and the outer main gear wheels, the taxiway edge safety margin *U*1, is given in Table 6-20. This clearance provides a minimum taxiway centerline to a parallel taxiway centerline or taxilane centerline separation given by Eq. (6-1).

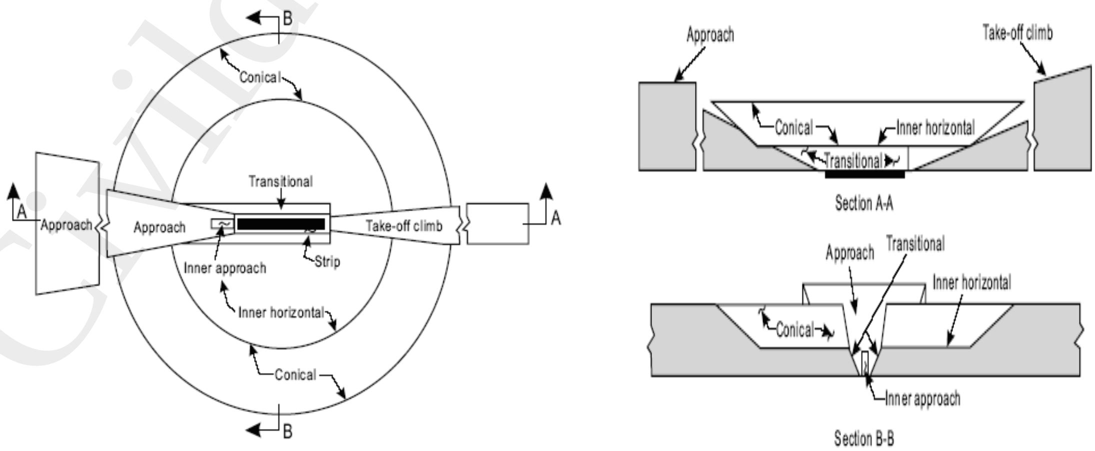
Therefore, for example, an ICAO aerodrome code letter E runway, which accommodates aircraft with wingspans up to 65 m, requires a taxiway centerline to a taxiway centerline or a taxilane centerline separation from Eq. (6-1) of 65 2(4.5) 7.5 81.5 m.

The required separation between a taxiway centerline or an apron taxiway centerline and a fixed or movable object is found from Eq. (6-2). *S*TO 0.5 WS *U*1 *C*2 (6-2)

where *S*TO is the minimum taxiway or apron taxiway to a fixed or movable object separation and *C*2 is the required clearance between a wingtip and an object. The required clearance between a wingtip and an object *C*2 is 4.5 m for aerodrome code letter A runways, 5.25 m for aerodrome code letter B runways, 7.5 m for aerodrome code letter C runways, and 12 m for aerodrome code letter D and E runways.

The required separation between an aircraft stand taxilane centerline and a fixed or movable object is found from Eq. (6-3). *S*ATO 0.5 WS *U*2 *C*1 (6-3) where *S*ATO is the minimum aircraft stand taxilane to fixed or movable object separation and *U*2 is the aircraft stand safety margin.

Since aircraft moving on the aircraft stand taxilane are moving at low speed and are often under positive ground guidance, the aircraft stand safety margin is less than on the taxiway system. The value for this safety margin *U*2 is 1.5 m for aerodrome code letter A and B airports, 2 m for aerodrome code letter C airports, and 2.5 m for aerodrome code letter D or E airports.



Sight Distance and Longitudinal Profile

As in the case of runways, the number of changes in longitudinal profile for taxiways is limited by sight distance and minimum distance between vertical curves. The FAA does not specify line of sight requirements for taxiways other than those discussed earlier related to runway and taxiway intersections. However, the sight distance along a runway from an intersecting taxiway needs to be sufficient to allow a taxiing aircraft to enter or cross the runway safely. The FAA specifies that from any point on the taxiway centerline the difference in elevation between that point and the corresponding point on a parallel runway, taxiway, or apron edge is 1.5 percent of the shortest distance between the points.

ICAO requires that the surface of the taxiway should be seen for a distance of 150 m from a point 1.5 m above the taxiway for aerodrome code letter A runways, for a distance of 200 m from a point 2 m above the taxiway for aerodrome code letter B runways, and for a distance of 300 m from a point 3 m above the taxiway for aerodrome code letter C, D, or E runways.

In regard to longitudinal profile of taxiways, the ICAO does not specify the minimum distance between the points of intersection of vertical curves. The FAA specifies that the minimum distance for both utility and transport category airports should be not less than the product of 100 ft multiplied by the sum of the absolute percentage values of change in slope.

Exit Taxiway Geometry

The function of exit taxiways, or runway turnoffs as they are sometimes called, is to minimize runway occupancy by landing aircraft.Exit taxiways can be placed at right angles to the runway or someother angle to the runway. When the angle is on the order of 30°, the term high-speed exit is often used to denote that it is designed forhigher speeds than other exit taxiway configurations. In this chapter,specific dimensions for high-speed exit, right-angle exit (low-speed) taxiways are presented. The dimensions presented here are the results obtained from research conducted many years ago [13] and subsequent research conducted by the FAA.The earlier tests [13] were conducted on wet and dry concrete and asphalt pavement with various types of civil and military aircraft in order to determine the proper relationship between exit speed and radii of curvature and the general configuration of the taxiway. A significant finding of the tests was that at high speeds a compound curve was necessary to minimize tire wear on the nose gear and, therefore, the central or main curve radius $R2$ should be preceded by a much larger radius curve $R1$. Aircraft paths in the test approximated a spiral. A compound curve is relatively easy to establish in the field and begins to approach the shape of a spiral, thus the reason for suggesting a compound curve. The following pertinent conclusions were reached as a result of the tests [13]:

1. Transport category and military aircraft can safely and comfortably turn off runways at speeds on the order of 60 to 65 mi/h on wet and dry pavements.
2. The most significant factor affecting the turning radius is speed, not the total angle of turn or passenger comfort.
3. Passenger comfort was not critical in any of the turning movements.
4. The computed lateral forces developed in the tests were substantially below the maximum lateral forces for which the landing gear was designed.
5. Insofar as the shape of the taxiway is concerned, a slightly widened entrance gradually tapering to the normal width of taxiway is preferred. The widened entrance gives the pilot more latitude in using the exit taxiway.
6. Total angles of turn of 30° to 45° can be negotiated satisfactorily. The smaller angle seems to be preferable because the length of the curved path is reduced, sight distance is improved, and less concentration is required on the part of the pilots.

7. The relation of turning radius versus speed expressed by the formula below will yield a smooth, comfortable turn on a wet or dry pavement when *f* is made equal to 0.13.
8. The curve expressed by the equation for *R*2 should be preceded by a larger radius curve *R*1 at exit speeds of 50 to 60 mi/h. The larger radius curve is necessary to provide a gradual transition from a straight tangent direction section to a curved path section. If the transition curve is not provided tire wear on large jet transports can be excessive.
9. Sufficient distance must be provided to comfortably decelerate an aircraft after it leaves the runway. It is suggested that for the present this distance be based on an average rate of deceleration of 3.3 ft/s2. This applies only to transport category aircraft. Until more experience is gained with this type of operation the stopping distance should be measured from the edge of the runway. A chart showing the relationship of exit speed to radii *R*1 and *R*2, and length of transition curve *L*1 ICAO has indicated the relationship between aircraft speed and the radius of curvature of taxiway curves For high-speed exit taxiways ICAO recommends a minimum radius of curvature for the taxiway centerline of 275 m (900 ft) for aerodrome code number 1 and 2 runways and 550 m (1800 ft) for aerodrome code number 3 and 4 runways. This will allow exit speeds under wet conditions of 65 km/h (40 mi/h) for aerodrome code number 1 and 2 runways and 93 km/h (60 mi/h) for aerodrome code number 3 and 4 runways. It also recommends a straight tangent section after the turnoff curve to allow exiting aircraft to come to a full stop clear of the intersecting taxiway when the intersection is 30°. This tangent distance should be 35 m (115 ft) for aerodrome code number 1 and 2 runways and 75 m (250 ft) for aerodrome code number 3 and 4 runways[2, 4]. A configuration for an exit speed of 60 mi/h and a turnoff angle of 30° is shown in Fig. 6-34. The FAA recommends that the taxiway centerline circular curve be preceded by a 1400-ft spiral to smooth the transition from the runway centerline to the taxiway exit circular curve. ICAO recommends the same geometry for both of these highspeed exits. Right-angle or 90° exit taxiways, although not desirable from the standpoint of minimizing runway occupancy, are often constructed for other reasons. The configurations for a 90° exit and other common taxiway intersection configurations are illustrated in Fig. 6-35. The dimensions labeled in Fig. 6-35 are determined by the aircraft design group of the design aircraft. These dimensional standards are provide.

Location of Exit Taxiways

The location of exit taxiways depends on the mix of aircraft, the approach and touchdown speeds, the point of touchdown, the exit speed, the rate of deceleration, which in turn depends on the condition of the pavement surface, that is, dry or wet, and the number of exits.

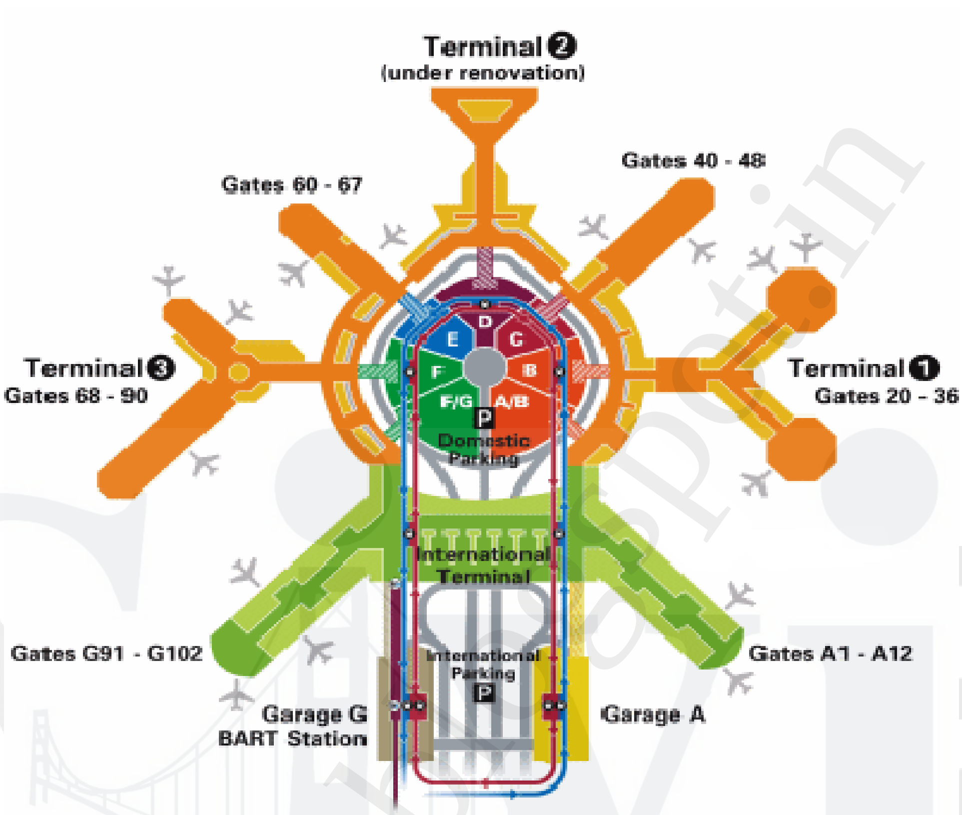
While the rules for flying transport aircraft are relatively precise, certain amount of variability among pilots is bound to occur especially in respect to braking force applied on the runway and the distance from runway threshold to touchdown. The rapidity and the manner in which air traffic control can process arrivals is an extremely important factor in establishing the location of exit taxiways. The location of exit taxiways is also influenced by the location of the runways relative to the terminal area.Several mathematical analyses or models have been developed for optimizing exit locations. While these analyses have been useful in providing an understanding of the significant parameters affecting location, their usefulness to planners has been limited because of the complexity of the analyses and a lack of knowledge of the inputs required for the application of the models. As a result greater use is made of much more simplified methods. The landing process can be described as follows. The aircraft crosses the runway threshold and decelerates in the air until the main landing gear touches the surface of the pavement. At this point the nose gear has not made contact with the runway. It may take as long as 3 s to do so. When it does, reverse thrust or wheel brakes or a combination of both are used to reduce the forward speed of the aircraft to exit velocity. Empirical analysis has revealed that the average deceleration of air-carrier aircraft on the runway is about 5 ft/s2. In the simplified procedure, an aircraft is assumed to touch down at 1.3 times the stall speed for a landing weight corresponding to 85 percent of the maximum structural landing weight. In lieu of computing the distance from threshold to touchdown, touchdown distances are assumed as fixed values for certain classes of aircraft. Typically these values range from 500 to 1500 ft from the runway threshold. To these distances are added the distances to decelerate to exit speed. These locations are derived using standard sea-level conditions. Altitude and temperature can affect the location of exit taxiways. Altitude increases distance on the order of 3 percent for each 1000 ft above sea level and temperature increases the distance 1.5 percent for each 10°F above 59°F. During runway capacity studies conducted for the FAA, data were collected on exit utilization at various large airports in the United States [18]. T indicate the cumulative percentage of each class of aircraft which have exited the runway at exits located at various distances from the arrival threshold. It is recommended that the point of intersection of the centerlines of taxiway exits and runways, which are up to 7000 ft in length and accommodate aircraft approach category C, D, and E aircraft, should be located about 3000 ft from the arrival threshold and 2000 ft from the stop end of the runway. To accommodate the average mix of aircraft on runways longer than 7000 ft, intermediate exits should be located at intervals of about 1500 ft. At airports where there are extensive operations with aircraft approach category A and B aircraft, an exit located between 1500 and 2000 ft from the landing threshold is recommended.

Planners often find that the runway configuration and the location of the terminal at the airport often preclude placing the exits at locations based on the foregoing analysis. This is nothing to be alarmed about since it is far better to achieve good utilization of the exits than to be too concerned about a few seconds lost in occupancy time. When locating exits it is important to recognize local conditions such as frequency of wet pavement or gusty winds. It is far better to place the exits several hundred feet farther from the threshold than to have aircraft overshoot the exits a large amount of time. The standard deviation in time required to reach exit speed is on the order of 2 or 3 s. Therefore, if the exits were placed down the runway as much as two standard deviations from the mean, the loss in occupancy time would only be 4 to 6 s. In planning exit locations at specific airports, one needs to consult with the airlines relative to the specific performance characteristics of the aircraft intended for use at the airport. The total occupancy time of an aircraft can be roughly estimated using the following procedure. The runway is divided into four components, namely, flight from threshold to touchdown of main gear, time required for nose gear to make contact with the pavement after the main gear has made contact, time required to reach exit velocity from the time the nose gear has made contact with the pavement and brakes have been applied, and time required for the aircraft to turn

Mix Index*	Exit Range from Arrival Threshold
0–20	2000–4000
21–50	3000–5500
51–80	3500–6500
81–120	5000–7000
121–180	5500–7500

Mix Index is equal to the percentage of Class C aircraft plus three an aircraft with a maximum certified takeoff weight in excess of class D aircraft, where a class C aircraft is an aircraft with a maximum certified takeoff weight greater than 12,500 lb and up to 300,000 lb and a class D aircraft is an aircraft with a maximum certified takeoff weight in excess of 300,000 lb. off on to the taxiway and clear the runway. For the first component it can be assumed that the touchdown speed is 5 to 8 kn less than the speed over the threshold. The rate of deceleration in the air is about 2.5 ft/s2. The second component is about 3 s and the third component depends upon exit speed. Time to turnoff from the runway will be on the order of 10 s. As may be observed in this table, typical runway occupancy times for 60 mi/h high-speed exits are 35 to 45 s. The corresponding time for a 15 mi/h regular exit is 45 to 60 s for air carrier aircraft.

AIRPORT LAYOUTS, VISUAL AIDS AND AIR TRAFFIC CONTROL



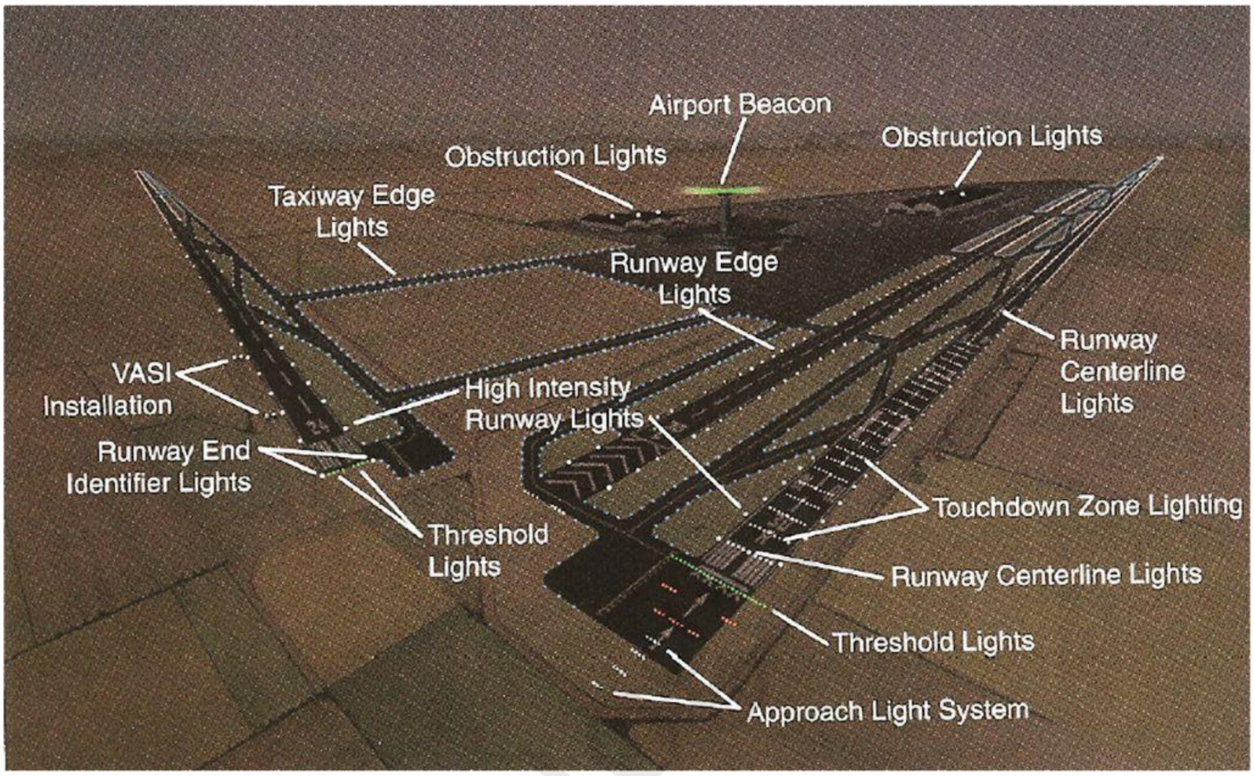
Introduction

Visual aids assist the pilot on approach to an airport, as well as navigating around an airfield and are essential elements of airport infrastructure. As such, these facilities require proper planning and precise design. These facilities may be divided into three categories: lighting, marking, and signage. Lighting is further categorized as either approach lighting or surface lighting.

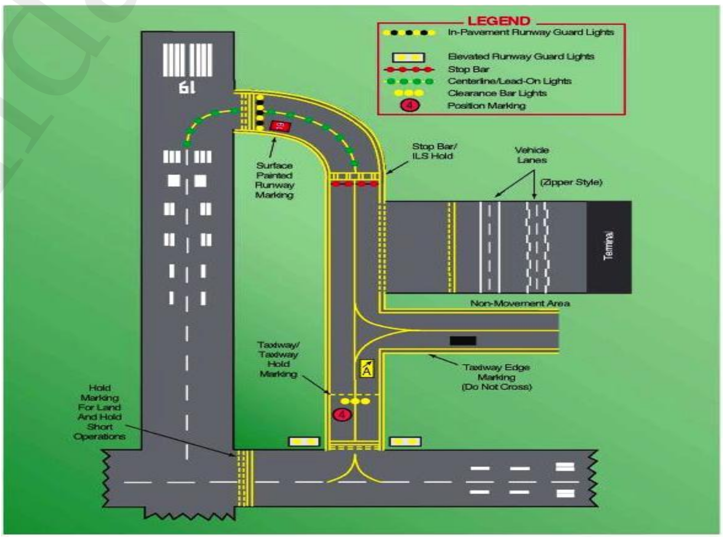
Specific lighting systems described in this chapter include

1. Approach lighting
2. Runway threshold lighting
3. Runway edge lighting
4. Runway centerline and touchdown zone lights

5. Runway approach slope indicators
6. Taxiway edge and centerline lighting



The proper placement of these systems is described in this chapter but no attempt has been made to describe in detail the hardware or its installation. Airfield marking and signage includes
1. Runway and taxiway pavement markings
2. Runway and taxiway guidance sign systems
Airfield lighting, marking, and signage facilities provide the following functions:
1. Ground to air visual information required during landing
2. The visual requirements for takeoff and landing
3. The visual guidance for taxiing



The Requirements for Visual Aids

Since the earliest days of flying, pilots have used ground references for navigation when approaching an airport, just as officers on ships at sea have used landmarks on shore when approaching a harbor. Pilots need visual aids in good weather as well as in bad weather and during the day as well as at night. In the daytime there is adequate light from the sun, so artificial lighting is not usually required but it is necessary to have adequate contrast in the field of view and to have a suitable pattern of brightness so that the important features of the airport can be identified and oriented with respect to the position of the aircraft in space. These requirements are almost automatically met during the day when the weather is clear.

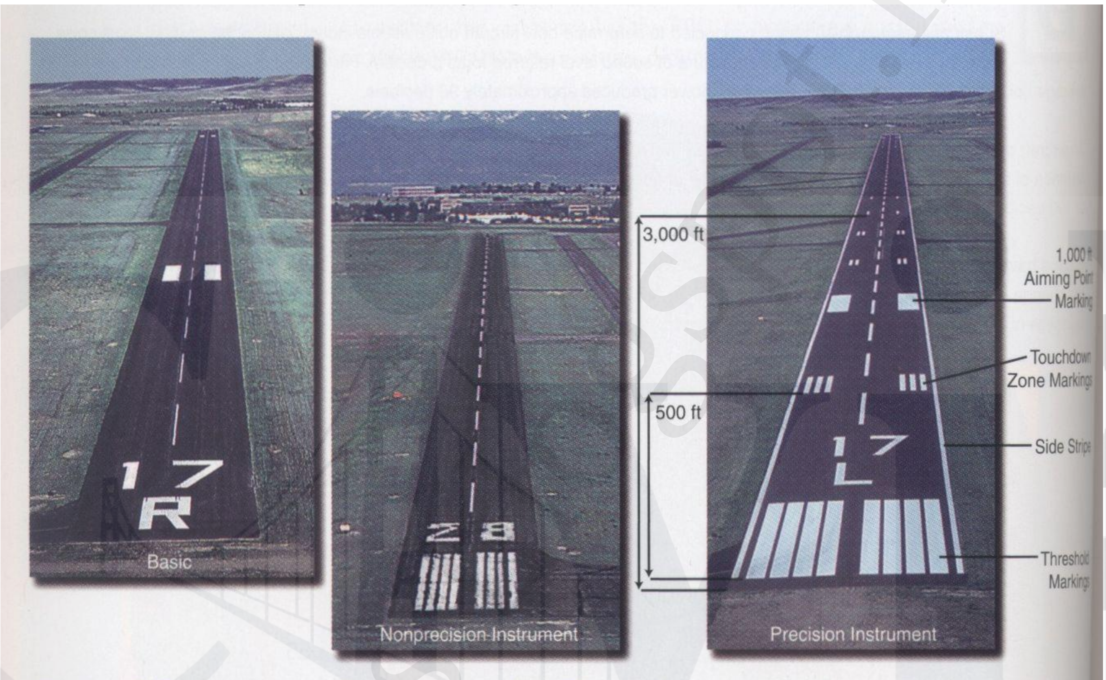


Figure 4-17. The common types of runway markings for VFR, precision, and nonprecision runways are shown here.

The runway for conventional aircraft always appears as a long narrow strip with straight sides and is free of obstacles. It can therefore be easily identified from a distance or by flying over the field. Therefore ,the perspective view of the runway and other identifying reference landmarks are used by pilots as visual aids for orientation when they are approaching the airport to land. Experience has demonstrated that the horizon, the runway edges, the runway threshold, and the centerline of the runway are the most important elements for pilots to see .In order to enhance the visual information during the day, the runway is painted with standard marking patterns. The key elements in these patterns are the threshold, the centerline, the edges, plus multiple parallel lines to increase the perspective and to define the plane of the surface. During the day when visibility is poor and at night, the visual information is reduced by a significant amount over the clear weather daytime scene. It is therefore essential to provide visual aids which will be as meaningful to pilots as possible.

The Airport Beacon

Beacons are lighted to mark an airport. They are designed to produce a narrow horizontal and vertical beam of high-intensity light which is rotated about a vertical axis so as to produce approximately 12 flashes per minute for civil airports and 18 flashes per minute for military airports [28]. The flashes with a clearly visible duration of at least 0.15 s are arranged in a white-green sequence for land airports and a white yellow sequence for landing areas on water. Military airports use a double white flash followed by a longer green or yellow flash to differentiate them from civil airfields. The beacons are mounted on top of the control tower or similar high structure in the immediate vicinity of the airport.

Obstruction Lighting

Obstructions are identified by fixed, flashing, or rotating red lights or beacons. All structures that constitute a hazard to aircraft in flight or during landing or takeoff are marked by obstruction lights having a horizontally uniform intensity duration and a vertical distribution design to give maximum range at the lower angles (1.5° to 8°) from which a colliding approach would most likely come.

The Aircraft Landing Operation

An aircraft approaching a runway in a landing operation may be visualized as a sequence of operations involving a transient body suspended in a three-dimensional grid that is approaching a fixed two-dimensional grid. While in the air, the aircraft can be considered as a point mass in a three-dimensional orthogonal coordinate system in which it may have translation along three coordinate directions and rotation about three axes. If the three coordinate axes are aligned horizontal, vertical, and parallel to the end of the runway, the directions of motion can be described as lateral, vertical, and forward. The rotations are normally called pitch, yaw, and roll, for the horizontal, vertical, and parallel axes, respectively. During a landing operation, pilots must control and coordinate all six degrees of freedom of the aircraft so as to bring the aircraft into coincidence with the desired approach or reference path to the touchdown point on the runway. In order to do this, pilots need translation information regarding the aircraft's alignment, height, and distance, rotation information regarding pitch, yaw, and roll, and information concerning the rate of descent and the rate of closure with the desired path.

Alignment Guidance

Pilots must know where their aircraft is with respect to lateral displacement from the centerline of the runway. Most runways are from 75 to 200 ft wide and from 3000 to 12,000 ft long. Thus any runway is a long narrow ribbon when first seen from several thousand feet above. The predominant alignment guidance comes from longitudinal lines that constitute the centerline and edges of the runway. All techniques, such as painting, lighting, or surface treatment that develop contrast and emphasize these linear elements are helpful in providing alignment information.

Height Information

The estimation of the height above ground from visual cues is one of the most difficult judgments for pilots. It is simply not possible to provide good height information from an approach lighting system. Consequently the best source of height information is the instrumentation in the aircraft. However, use of these instruments often requires the availability of precision ground or satellite based navigation technologies. Many airports have no such technologies, and at others only provide lateral approach guidance to certain runways. Consequently two types of ground-based visual aids defining the desired glide path have been developed. These are known as the visual approach slope indicator (VASI) and the precision approach path indicator (PAPI) which are discussed later in this chapter. Several parameters influence how much a pilot can see on the ground. One of these is the *cockpit cutoff angle*. This is the angle between the longitudinal axis of the fuselage and an inclined plane below which the view of the pilot is blocked by some part of the aircraft

Approach Lighting

Approach lighting systems (ALS) are designed specifically to provide guidance for aircraft approaching a particular runway under nighttime or other low-visibility conditions. While under nighttime conditions it may be possible to view approach lighting systems from several miles away, under other low-visibility conditions, such as fog, even the most intense ALS systems may only be visible from as little as 2500 ft from the runway threshold.

Studies of the visibility in fog [3] have shown that for a visual range of 2000 to 2500 ft it would be desirable to have as much as 200,000 candelas (cd) available in the outermost approach lights where the slant range is relatively long. Under these same conditions the optimum intensity of the approach lights near the threshold should be on the order of 100 to 500 cd. A transition in the intensity of the light that is directed toward the pilot is highly desirable in order to provide the best visibility at the greatest possible range and to avoid glare and the loss of contrast sensitivity and visual acuity at short range.

System Configurations

The configurations which have been adopted are the Calvert system [3] shown in Fig. 8-3 which has been widely used in Europe and other parts of the world, the ICAO category II and category III system shown in Fig. 8-4, and the four system configurations which have been adopted by the FAA in the United States shown in Fig. 8-5. The FAA publishes criteria for the establishment of the approach lighting systems [13] and other navigation facilities at airports [6]. Approach lights are normally mounted on frangible pedestals of varying height to improve the perspective of the pilot in approaching a runway.

The first approach lighting system was known as the Calvert system. In this system, developed by E. S. Calvert in Great Britain in 1949, includes a line of single bulb lights spaced on 100-ft centers along the extended runway centerline and six transverse crossbars of lights of variable length spaced on 500-ft centers, for a total length of 3000 ft. For operations in very poor visibility, ICAO has certified a modification of the Calvert system, known as the ICAO category II system. The variation calls for a higher lighting intensity to the inner 300 m of the system closest to the runway threshold. The category II and category III system adopted by ICAO consists of two lines of red bars on each side of the runway centerline and a single line of white bars on the runway centerline both at 30 m intervals and both extending out 300 m from the runway threshold. In addition, there are two longer bars of white light at a distance of 150 and 300 m from the runway threshold, and a long threshold bar of green light at the runway threshold. ICAO also recommends that the longer bars of white light also be placed at distances of 450, 500, and 750 m from the runway threshold if the runway centerline lights extend out that distance The ALSs currently certified by the FAA for installation in the United States consist of a high-intensity ALS with sequenced flashing lights (ALSF-2), which is required for category II and category III precision approaches, a high-intensity approach lighting system with sequenced flashing lights (ALSF-1), and three medium-intensity ALSs (MALSR, MALS, MALSF). In each of these systems there is a long transverse crossbar located 1000 ft from the runway threshold to indicate the distance from the runway threshold. In these systems roll guidance is provided by crossbars of white light 14 ft in length, placed at either 100- or 200-ft centers on the extended runway centerline. The 14-ft crossbars consist of closely spaced five-bulb white lights to give the effect of a continuous bar of light.

The high-intensity ALS is 2400 ft long (some are 3000 ft long) with various patterns of light located symmetrically about the extended runway centerline and a series of sequenced high-intensity flashing lights located every 100 ft on the extended runway centerline for the outermost 1400 ft. In the high-intensity ALSs the 14-ft crossbars of five-bulb white light are placed at 100-ft intervals and in the mediumintensity ALSs these crossbars of white light are placed at 200-ft intervals both for a distance of 2400 ft from the runway threshold on the extended runway centerline. The high-intensity ALSs have a long crossbar of green lights at the edge of the runway threshold. The ALSF-2 system, shown in Fig. 8-5*a*, has two additional crossbars consisting of three-bulb white light crossbars which are placed symmetrically about the runway centerline at a distance of 500 ft from the runway threshold and two additional three-bulb red light crossbars are placed symmetrically about the extended runway centerline at 100-ft intervals for the inner 1000 ft to delineate the edges of the runway surface.

The ALSF-1 system, shown in Fig. 8-5*b*, has two additional crossbars consisting of five-bulb red light crossbars which are placed symmetrically about the runway centerline at a distance of 100 ft from the runway threshold to delineate the edge of the runway and two additional three-bulb red light crossbars placed symmetrically about the extendedrunway centerline at 200 ft from the runway threshold.

The MALSR system, shown in Fig. 8-5*c*, is a 2400-ft medium intensity ALS with runway alignment indicator lights (RAILs). The inner 1000 ft of the MALSR is the MALS portion of the system and the outer 1400 ft is the RAIL portion of the system. The system has sequential flashing lights for the outer 1000 ft of the system. It is recommended for category I precision approaches. The simplified short approach lighting system (SSALR) has the same configuration as the MALSR system.
At smaller airports where precision approaches are not required, a medium ALS with sequential flashers (MALSF) or with sequenced flashers (MALS) is adequate. The system is only 1400 ft long compared to a length of 2400 ft for a precision approach system. It is therefore much more economical, an important factor at small airports. the runway alignment indicator lights and these are only provided in the outermost 400 ft of the 1400-ft system to improve pilot recognition of the runway approach in areas where there are distracting lights in the vicinity of the airport. The MALS system does not have the runway alignment indicator lights or the sequential flashers. At international airports in the United States, the 2400-ft ALSs are often extended to a distance of 3000 ft to conform to international specifications.

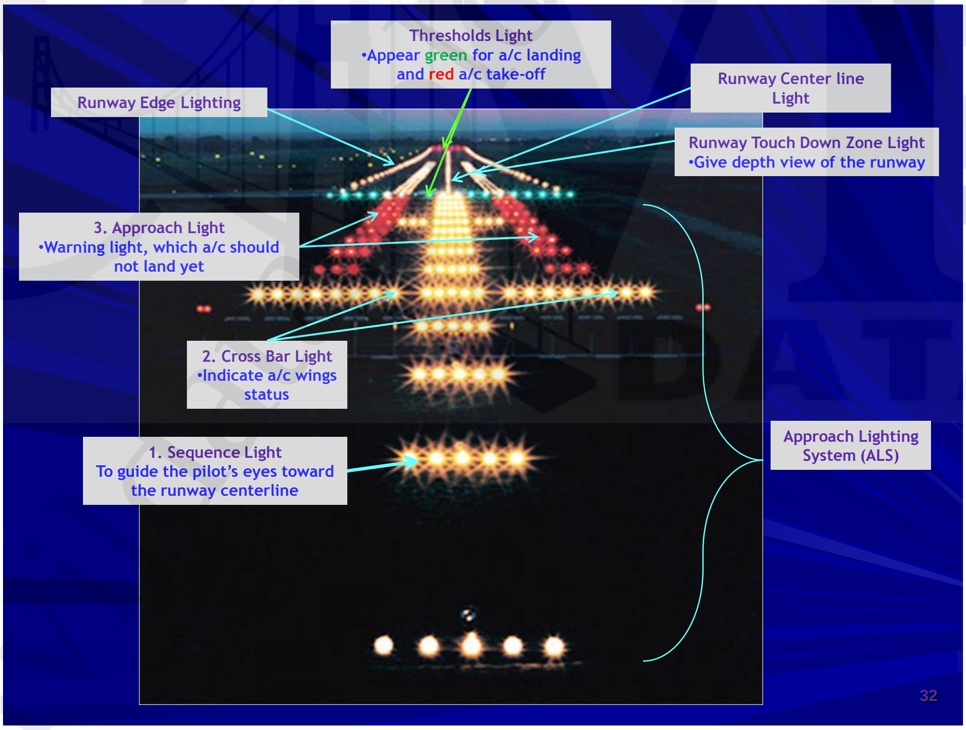
Sequenced-flashing high-intensity lights are available for airport use and are installed as supplements to the standard approach lighting system at those airports where very low visibilities occur frequently. These lights operate from the stored energy in a capacitor which is discharged through the lamp in approximately 5 ms and may develop as much as 30 million cd of light. They are mounted in the same pedestals as the light bars. The lights are sequence-fired, beginning with the unit farthest from the runway. The complete cycle is repeated every 2 s. This results in a brilliant ball of light continuously moving toward the runway. Since the very bright light can interfere with the eye adaptation of the pilot, condenser discharge lamps are usually omitted in the 1000 ft of the approach lighting system nearest the runway.

Visual Approach Slope Aids

Visual approach slope aids are lighting systems designed to provide a measure of vertical guidance to aircraft approaching a particular runway. The principle of these aids is to provide color-based identification to the pilot indicating their variation from a desired altitude and descent rate while on approach. The two most common visual approach slope aids are the visual approach slope indicator (VASI), and the precision approach path indicator (PAPI).

Visual Approach Slope Indicator

The visual approach slope indicator (VASI) is a system of lights which acts as an aid in defining the desired glide path in relatively good weather conditions. VASI lighting intensities are designed to be visible from 3 to 5 mi during the day and up to 20 mi at night. There are a number of different VASI configurations depending on the desired visual range, the type of aircraft, and whether large wide bodied aircraft will be using the runway. Each group of lights transverse to the direction of the runway is referred to as a *bar*. The downwind bar is typically located between 125 and 800 ft from the runway threshold, each subsequent bar is located between 500 and 1000 ft from the previous bar. A bar is made up of one, two, or three light units, referred to as *boxes*. The basic VASI-2 system, illustrated in Fig. 8-6, is a two-bar system consisting of four boxes. The bar that is nearest to the runway threshold is referred to as the *downwind bar*, and the bar that is farthest from the runway threshold is referred to as the *upwind bar*. As illustrated in Fig. 8-6, if pilots are on the proper glide path, the downwind bar appears white and the upwind bar appears red; if pilots are too low, both bars appear red; and if they are too high both bars appear white.



In order to accommodate large wide bodied aircraft where the height of the eye of the pilot is much greater than in smaller jets, a third upwind bar is added. For wide bodied aircraft the middle bar becomes the downwind bar and the third bar is the upwind bar. In other words, pilots of large wide bodied aircraft ignore the bar closest to the runway threshold and use the other two bars for visual reference..

The more common systems in use in the United States are the VASI-2, VASI-4, VASI-12, and VASI-16. VASI systems are particularly useful on runways that do not have an instrument landing system or for aircraft not equipped to use an instrument landing system.

Precision Approach Path Indicator

The FAA presently prefers the use of another type of visual approach indicator called the *precision approach path indicator* (PAPI) [20].

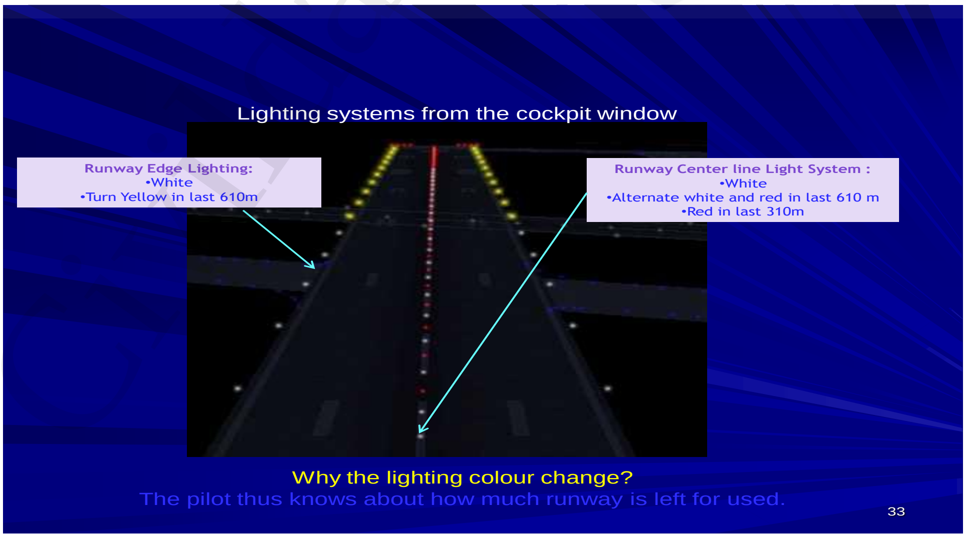
This system gives more precise indications to the pilot of the approach path of the aircraft and utilizes only one bar as opposed to the minimum of two required by the VASI system. The system consists of a unit with four lights on either side of the approach runway.

Threshold Lighting

During the final approach for landing, pilots must make a decision to complete the landing or "execute a missed approach." The identification of the threshold is a major factor in pilot decisions to land or not to land. For this reason, the region near the threshold is given special lighting consideration. The threshold is identified at large airports by a complete line of green lights extending across the entire width of the runway, and at small airports by four green lights on each side of the threshold. The lights on either side of the runway threshold may be elevated. Threshold lights in the direction of landing are green but in the opposite direction these lights are red to indicate the end of the runway.

Runway Lighting

After crossing the threshold, pilots must complete a touchdown and roll out on the runway. The runway visual aids for this phase of landing are be designed to give pilots information on alignment, lateral displacement, roll, and distance. The lights are arranged to form a visual pattern that pilots can easily interpret. At first, night landings were made by floodlighting the general area. Various types of lighting devices were used, including automobile headlights, arc lights, and search lights. Boundary lights were added to outline the field and to mark hazards such as ditches and fences. Gradually, preferred landing directions were developed, and special lights were used to indicate these directions. Floodlighting was then restricted to the preferred landing directions, and runway edge lights were added along the landing strips. As experience was developed, the runway edge lights were adopted as visual aids on a runway. This was followed by the use of runway centerline and touchdown zone lights for operations in very poor visibility. FAA Advisory Circular 150/5340-30C provides guidance for the design and installation of runway and taxiway lighting systems.



Runway Edge Lights
Runway edge lighting systems outline the edge of runways during nighttime and reduced visibility conditions. Runway edge lights are classified by intensity, high intensity (HIRL), medium intensity (MIRL), and low intensity (LIRL). LIRLs are typically installed on visual runways and at rural airports. MIRLs are typically installed on visual runways at larger airports and on non precision instrument runways, HIRLs are installed on precision-instrument runways. Elevated runway lights are mounted on frangible fittings and project no more than 30 in above the surface on which they are installed. They are located along the edge of the runway not more than 10 ft from the edge of the full-strength pavement surface. The longitudinal spacing is not more than 200 ft. Runway edge lights are white, except that the last 2000 ft of an instrument runway in the direction of aircraft operations these lights are yellow to indicate a caution zone.

Runway Centerline and Touchdown Zone Lights
As an aircraft traverses over the approach lights, pilots are looking at relatively bright light sources on the extended runway centerline. Over the runway threshold, pilots continue to look along the centerline, but the principal source of guidance, namely, the runway edge lights, has moved far to each side in their peripheral vision. The result is that the central area appears excessively black, and pilots are virtually flying blind, except for the peripheral reference information, and any reflection of the runway pavement from the aircraft's landing lights. Attempts to eliminate this "black hole" by increasing the intensity of runway edge lights have proven ineffective. In order to reduce the black hole effect and provide adequate guidance during very poor visibility conditions, runway centerline and touchdown zone lights are typically installed in the pavement. These lights are usually installed only at those airports which are equipped for instrument operations. These lights are required for ILS category II and category III runways and for category I runways used for landing operations below 2400 ft runway visual range. Runway centerline lights are required on runways used for takeoff operations below 1600 ft runway visual range. Although not required, runway centerline lights are recommended for category I runways greater than 170 ft in width or when used by aircraft with approach speeds over 140 kn. When there are displaced thresholds, the centerline lights are extended into the displaced threshold area. If the displaced area is not used for takeoff operations, or if the displaced area is used for takeoff operations and is less than 700 ft in length, the centerline lights are blanked out in the direction of landing. For displaced thresholds greater than 700 ft in length or for displaced areas used for takeoffs, the centerline lights in the displaced area must be capable of being shut off during landing operations.

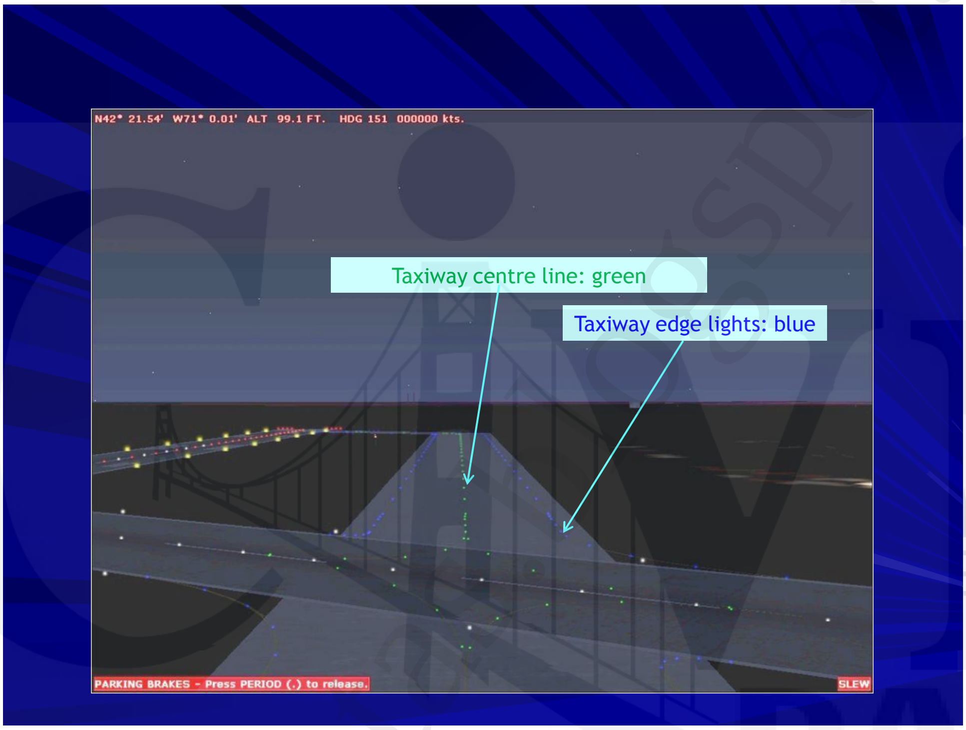
Runway touchdown zone lights are white, consist of a three-bulb bar on either side of the runway centerline, and extend 3000 ft from the runway threshold or one-half the runway length if the runway is less than 6000 ft long. They are spaced at intervals of 100 ft, with the first light bar 100 ft from the runway threshold, and are located 36 ft on either side of the runway centerline, as shown in Fig. 8-13. The centerline lights are spaced at intervals of 50 ft. They are normally offset a maximum of 2 ft from the centerline to avoid the centerline paint line and the nose gear of the aircraft riding over the light fixtures. These lights are also white, except for the last 3000 ft of runway in the direction of aircraft operations, where they are color coded. The last 1000 ft of centerline lights are red, and the next 2000 ft are alternated red and white.

Runway End Identifier Lights

Runway end identifier lights (REIL) are installed at airports where there are no approach lights to provide pilots with positive visual identification of the approach end of the runway. The system consists of a pair of synchronized white flashing lights located on each side of the runway threshold and is intended for use when there is adequate visibility.

Taxiway Lighting

Either after a landing or on the way to takeoff, pilots must maneuver the aircraft on the ground on a system of taxiways to and from the terminal and hangar areas. Taxiway lighting systems are provided for taxiing at night and also during the day when visibility is very poor, particularly at commercial service airports.



The following overall guidance should be applied in determining the lighting, marking, and signing visual aid requirements for taxiways:

- In order to avoid confusion with runways, taxiways must be clearly identified.
- Runway exits need to be readily identified. This is particularly true for high-speed runway exits so that pilots can be able to locate these exits 1200 to 1500 ft before the turnoff point.
- Adequate visual guidance along the taxiway must be provided.
- Specific taxiways must be readily identified.
- The intersections between taxiways, the intersections between runways and taxiways, and runway-taxiway crossings need to be clearly marked.
- The complete taxiway route from the runway to the apron and from the apron to the runway should be easily identified.

There are two primary types of lights used for the designation of taxiways. One type delineates the edges of taxiways [21] and the other type delineates the centerline of the taxiway [27]. In addition, there is an increasing use of lighting systems on taxiways, such as runway guard lights (RGLs) and stop bars, to identify intersections with runways, in an effort to reduce accidental incursions on to active runway environments.

Taxiway Edge Lights

Taxiway edge lights are elevated blue colored bidirectional lights usually located at intervals of not more than 200 ft on either side of the taxiway. The exact spacing is influenced by the physical layout of the taxiways. Straight sections of taxiways generally require edge light spacing in 200-ft intervals, or at least three lights equally spaced for taxiway straight line sections less than 200 ft in length.

Closer spacing is required on curves. Light fixtures are located not more than 10 ft from the edge of full strength pavement surfaces. Taxiway centerline lights are in-pavement bidirectional lights placed in equal intervals over taxiway centerline markings. Taxiway centerline lights are green, except in areas where the taxiway intersects with a runway, where the green and yellow lights are placed alternatively. Research and experience have demonstrated that guidance from centerline lights is superior to that from edge lights, particularly in low visibility conditions. For normal exits, the centerline lights are terminated at the edge of the runway. At taxiway intersections the lights continue across the intersection.

For long-radius high-speed exit taxiways, the taxiway lights are extended onto the runway from a point 200 ft back from the point of curvature (PC) of the taxiway to the point of tangency of the central curve of the taxiway. Within these limits the spacing of lights is 50 ft. These lights are offset 2 ft from the runway centerline lights and are gradually brought into alignment with the centerline of the taxiway. Where the taxiways intersect with runways and aircraft are required to hold short of the runway, several yellow lights spaced at 5-ft intervals are placed transversely across the taxiway.

Runway Guard Lights

Runway guard lights (RGLs) are in-pavement lights located on taxiways at intersections of runways to alert pilots and operators of airfield ground vehicles that they are about to enter onto an active runway. RGLs are located across the width of the taxiway, approximately 2 ft from the entrance to a runway, spaced at approximately 10-ft intervals,

Runway Stop Bar

Similar to runway guard lights, runway stop bar lights are in-pavement lights on taxiways at intersections with runways. As opposed to RGLs that provide warning to pilots approaching a runway, runway stop bar lights are designed to act as “stop” lights, directing aircraft and vehicles on the taxiway not to enter the runway environment. Runway stop bar lights are activated with red illuminations during periods of runway occupancy or other instances where entrance from the taxiway to the runway is prohibited. In-pavement runway stop bar lighting is typically installed in conjunction with elevated runway guard lights located outside the width of the pavement.

Runway and Taxiway Marking

In order to aid pilots in guiding the aircraft on runways and taxiways, pavements are marked with lines and numbers. These markings are of benefit primarily during the day and dusk. At night, lights are used to guide pilots in landing and maneuvering at the airport. White is used for all markings on runways and yellow is used on taxiways and aprons.

Runways

The FAA has grouped runways for marking purposes into three classes: (1) visual, or "basic" runways, (2) nonprecision instrument runways, and (3) precision instrument runways. The visual runway is a runway with no straight-in instrument approach procedure and is intended solely for the operation of aircraft using visual approach procedures. The non precision instrument runway is one having an existing instrument approach procedure utilizing air navigation facilities with only horizontal guidance (typically VOR or GPS-based RNAV approaches without vertical guidance) for which a straight-in non precision approach procedure has been approved. A precision instrument runway is one having an existing instrument approach procedure utilizing a precision instrument landing system or approved GPS-based RNAV (area navigation) or RNP (required navigation performance) precision approach. Runways that have a published approach based solely on GPS-based technologies are known as GPS runways.

Runway markings include runway designators, centerlines, threshold markings, aiming points, touchdown zone markings, and side stripes. Depending on the length and class of runway and the type of aircraft operations intended for use on the runway, all or some of the above markings are required.

Runway Designators

The end of each runway is marked with a number, known as a runway designator, which indicates the approximate magnetic azimuth (clockwise from magnetic north) of the runway in the direction of operations. The marking is given to the nearest 10° with the last digit omitted. Thus a runway in the direction of an azimuth of 163° would be marked as runway 16 and this runway would be in the approximate direction of south-south-east. Therefore, the east end of an east-west runway would be marked 27 (for 270° azimuth) and the west end of an east-west runway would be marked 9 (for a 90° azimuth). If there are two parallel runways in the east-west direction, for example, these runways would be given the designation 9L-27R and 9R-27L to indicate the direction of each runway and their position (L for left and R or right) relative to each other in the direction of aircraft operations. If a third parallel runway existed in this situation it has traditionally been given the designation 9C-27C to indicate its direction and position relative (C for center) to the other runways in the direction of aircraft operations. When there are four parallel runways, one pair is marked with the magnetic azimuth to the nearest 10° while the other pair is marked with the magnetic azimuth to the next nearest 10°. Therefore, if there were four parallel runways in the east-west direction, one pair would be designated as 9L-27R and 9R-27L and the other pair could be designated as either 10L-28R and 10R-28L or 8L-26R and 8R-26L. This type of designation policy is increasingly being applied to three parallel runway configurations, as well. For example, one pair would be designated as 9L-27R and 9R-27L and the third runway may be designated 10-28. Runway designation markings are white, have a height of 60 ft and a width, depending upon the number or letter used, varying from 5 ft for the numeral 1 to 23 ft for the numeral 7. When more than one number or letter is required to designate the runway the spacing between the designators is normally 15 ft. The sizes of the runway designator markings are proportionally reduced only when necessary due to space limitations on narrow runways and these designation markings should be no closer than 2 ft from the edge of the runway or the runway edge stripes.

Runway Threshold Markings
Runway threshold markings identify to the pilot the beginning of the runway that is safe and available for landing. Runway threshold markings begin 20 ft from the runway threshold itself. Runway threshold markings consist of two series of white stripes, each stripe 150 ft in length and 5.75 ft in width, separated about the centerline of the runway. On each side of the runway centerline, a number of threshold marking stripes are placed, For example, for a 100-ft runway, eight stripes are required, in two groups of four are placed about the centerline. Stripes within each set are separated by 5.75 ft. Each set of stripes is separated by 11.5 ft about the runway centerline. The above specifications for runway threshold markings were adapted by the FAA from ICAO international standards and made mandatory for United States civil use airports in 2008.

Centerline Markings
Runway centerline markings are white, located on the centerline of the runway, and consist of a line of uniformly spaced stripes and gaps. The stripes are 120 ft long and the gaps are 80 ft long. Adjustments to the lengths of stripes and gaps, where necessary to accommodate runway length, are made near the runway midpoint. The minimum width of stripes is 12 in for visual runways, 18 in for non precision instrument runways, and 36 in for precision instrument runways. The purpose of the runway centerline markings is to indicate to the pilot the center of the runway and to provide alignment guidance on landing and takeoff.

Aiming Points
Aiming points are placed on runways of at least 4000 ft in length to provide enhanced visual guidance for landing aircraft. Aiming point markings consist of two bold stripes, 150 ft long, 30 ft wide, spaced 72 ft apart symmetrically about the runway centerline, and beginning 1020 ft from the threshold.

Touchdown Zone Markings
Runway touchdown zone markings are white and consist of groups of one, two, and three rectangular bars symmetrically arranged in pairs about the runway centerline. These markings begin 500 ft from the runway threshold. The bars are 75 ft long, 6 ft wide, with 5 ft spaces between the bars, and are longitudinally spaced at distances of 500 ft along the runway. The inner stripes are placed 36 ft on either side of the runway centerline. For runways less than 150 ft in width, the width and spacing of stripes may be proportionally reduced. Where touchdown zone markings are installed on both runway ends on shorter runways, those pairs of markings which would extend to within 900 ft of the runway midpoint are eliminated.

Side Stripes
Runway side stripes consist of continuous white lines along each side of the runway to provide contrast with the surrounding terrain or to delineate the edges of the full strength pavement. The maximum distance between the outer edges of these markings is 200 ft and these markings have a minimum width of 3 ft for precision instrument runways and are at least as wide as the width of the centerline stripes on other runways.

Displaced Threshold Markings
At some airports it is desirable or necessary to “displace” the runway threshold on a permanent basis. A displaced threshold is one which has been moved a certain distance from

the end of the runway. Most often this is necessary to clear obstructions in the flight path on landing. The displacement reduces the length of the runway available for landings, but takeoffs can use the entire length of the runway. T. These markings consist of arrows and arrow heads to identify the displaced threshold and a threshold bar to identify the beginning of the runway threshold itself. Displaced threshold arrows are 120 ft in length, separated longitudinally by 80 ft for the length of the displaced threshold. Arrow heads are 45 ft in length, placed 5 ft from the threshold bar. The threshold bar is 5 ft in width and extends the width of the runway at the threshold.

Blast Pad Markings

In order to prevent erosion of the soil, many airports provide a paved *blast pad* 150 to 200 ft in length adjacent to the runway end. Similarly, some airport runways have a *stopway* which is only designed to support aircraft during rare aborted takeoffs or landing overruns and is not designed as a full strength pavement. Since these paved areas are not designed to support aircraft and yet may have the appearance of being so designed, markings are required to indicate this.

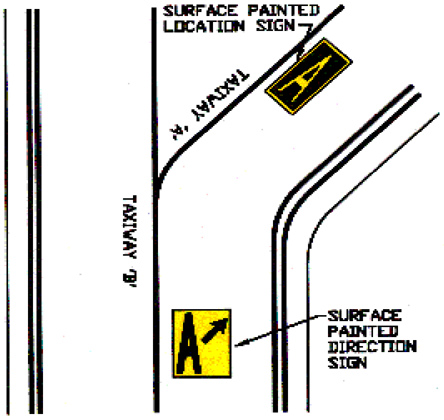
Centerline and Edge Markings

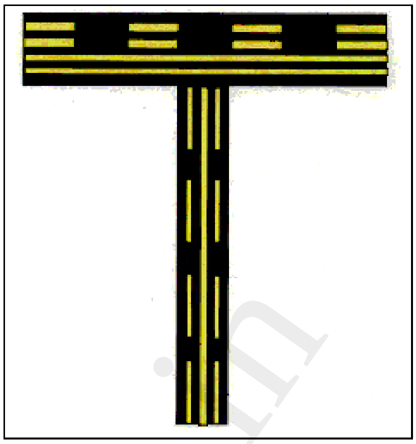
The centerline of the taxiway is marked with a single continuous 6-in yellow line. On taxiway curves, the taxiway centerline marking continues from the straight portion of the taxiway at a constant distance from the outside edge of the curve. At taxiway intersections which are designed for aircraft to travel straight through the intersection, the centerline markings continue straight through the intersection. At the intersection of a taxiway with a runway end, the centerline stripe of the taxiway terminates at the edge of the runway. At the intersection between a taxiway and a runway, where the taxiway serves as an exit from the runway, the taxiway marking is usually extended on to the runway in the vicinity of the runway centerline marking. The taxiway centerline marking is extended parallel to the runway centerline marking a distance of 200 ft beyond the point of tangency. The taxiway curve radius should be large enough to provide a clearance to the taxiway edge and the runway edge of at least one-half the width of the taxiway. For a taxiway crossing a runway, the taxiway centerline marking may continue across the runway but it must be interrupted for the runway markings.

When the edge of the full strength pavement of the taxiway is not readily apparent, or when a taxiway must be outlined when it is established on a large paved area such as an apron, the edge of the taxiway is marked with two continuous 6-in wide yellow stripes that are 6 in apart.

Taxiway Hold Markings

For taxiway intersections where there is an operational need to hold aircraft, a dashed yellow holding line is placed perpendicular to and across the centerline of both taxiways. When a taxiway intersects a runway or a taxiway enters an instrument landing system critical area, a holding line is placed across the taxiway. The holding line for a taxiway intersecting a runway consists of two solid lines of yellow stripes and two broken lines of yellow stripes placed perpendicular to the centerline of the taxiway and across the width of the taxiway. The solid lines are always placed on the side where the aircraft is to hold. The holding line for an instrument landing system critical area consists of two solid lines placed perpendicular to the taxiway centerline and across the width of the taxiway joined with three sets of two solid lines symmetrical about and parallel to the taxiway centerline.





Taxiway Shoulders

In some areas on the airfield, the edges of taxiways may not be well defined due to their adjacency to other paved areas such as aprons and holding bays. In these areas, it is prudent to mark the edges of taxiways with shoulder markings. Taxiway shoulder markings are yellow in color, and are often painted on top of a green background. The shoulder markings consist of 3-ft-long yellow stripes placed perpendicular to the taxiway edge stripes, On straight sections of the taxiway, the marks are placed at a maximum spacing of 100 ft. On curves, the marks are placed on a maximum of 50 ft apart between the curve tangents.

Distances shown above are for planning purposes only. “Hold position markings” must be placed in order to restrict the largest aircraft (tail or body) expected to use the runway from penetrating the obstacle-free zone. For aircraft approach categories A and B, airplane design group III, this distance is increased 1 ft for each 100 ft above 5100 ft above sea level. For airplane design group IV, precision instrument runways, this distance is increased 1 ft for each 100 ft above sea level. For aircraft approach category C, airport design group IV, precision instrument runways. This distance is increased 1 ft for each 100 ft above sea level. For airplane design group V, this distance is increased 1 ft for each 100 ft above sea level. For aircraft approach category D, this distance is increased 1 ft for each 100 ft above sea level.

Enhanced Taxiway Markings

Beginning in 2008, all airports serving commercial air carriers are required to mark certain critical areas of the airfield with enhanced taxiway markings. These markings are designed to provide additional guidance and warning to pilots of runway intersections. Enhanced markings consist primarily of yellow-painted lines, using paint mixtures with imbedded glass beads to enhance visibility. In addition, yellow markings must be marked on top of a darkened black background. Taxiway centerlines are enhanced for 150 ft from the runway hold-short markings. The centerline enhancements include dashed yellow lines 9 ft in length, separated longitudinally by 3 ft. These yellow lines are placed 6 in from each end of the existing centerline.

Closed Runway and Taxiway Markings

When runways or taxiways are permanently or temporarily closed to aircraft, yellow crosses are placed on these trafficways. For permanently closed runways, the threshold, runway designation, and touchdown markings are obliterated and crosses are placed at each end and at 1000 ft intervals. For temporarily closed runways, the runway markings are not obliterated, the crosses are usually of a temporary type and are only placed at the runway ends. For permanently closed taxiways, a cross is placed on the closed taxiway at each entrance to the taxiway. For temporarily closed taxiways barricades with orange and white markings are normally erected at the entrances.

Airfield Signage

In addition to markings, signage is placed on the airfield to guide and direct pilots and ground vehicle operators to points on the airport. In addition some signage exists to provide the pilots with information regarding their position on the airfield, the distance remaining on a runway, the location of key facilities at the airport, and often informative signage ranging from voluntary procedures to mitigate noise impacts to warnings about nearby security sensitive areas

Runway Distance Remaining Signs

Runway distance remaining signs are placed on the side of a runway and provide the pilot with information on how much runway is left during takeoff or landing operations. These signs are placed at 1000 ft intervals along the runway is a descending sequential order. In this configuration it is recommended that the signs be placed on the left side of the most frequently used direction of the runway. The signs may be placed on the right side of the runway when necessary due to required runway-taxiway separations or due to conflicts between intersecting runways or taxiways. An alternative method is to provide a set of single-faced signs on either side of the runway to indicate the distance remaining when the runway is used in both directions. The advantage of this configuration is that the distance remaining is more accurately reflected when the runway length is not an even multiple of 1000 ft. Another alternative uses double-faced signs on both sides of the runway. The advantage of this method is that the runway distance is displayed on both sides of the runway in each direction which is an advantage when a sign on one side needs to be omitted because of a clearance conflict. When the runway distance is not an even multiple of 1000 ft, one half of the excess distance is added to the distance on each sign on each runway end.

Taxiway Guidance Sign System

The primary purpose of a taxiway guidance sign system is to aid pilots in taxiing on an airport. At controlled airports, the signs supplement the instructions of the air traffic controllers and aid the pilot in complying with those instructions. The sign system also aids the air traffic controller by simplifying instructions for taxiing clearances, and the routing and holding of aircraft. At locations not served by air traffic control towers, or for aircraft without radio contact, the sign system provides guidance to the pilot to major destinations areas in the airport. The efficient and safe movement of aircraft on the surface of an airport requires that a well-designed, properly thought-out, and standardized taxiway guidance sign system is provided at the airport. The system must provide the pilot with the ability to readily determine the designation of any taxiway on which the aircraft is located, readily identify routings to a desired destination on the airport property, indicate mandatory aircraft holding positions, and identify the boundaries for aircraft approach areas, instrument landing system critical areas, runway safety areas and obstacle free zones. It is virtually impossible, except for holding position signs, to completely specify the locations and types of signs that are required on a taxiway system at a particular airport due to the wide variation in the types of functional layouts for airports.

Taxiway Designations

Taxiway guidance sign systems are in a large part based on a system of taxiway designators which identify the individual taxiway components. While runway designators are based on the magnetic heading of the runway, taxiway designators are assigned based on an alphabetic ordering system, independent of the taxiways direction of movement. Taxiways are typically identified in alphabetic order from east to west or north to south (i.e., the northern or easternmost taxiway would be designated “A”, the next southern or western taxiway would be designated “B,” and so forth). Entrance and exit taxiways perpendicular to main parallel taxiways are designated by the letter of the main parallel taxiway from which they spur, followed by a numeric sequence. For instance, the northernmost entrance taxiway off of taxiway “A” would be designated “A1,” and so forth. The letters “I” and “O” are not used as taxiway designators due to their similarity in form to the numbers “1” and “0.” In addition the letter “X” is not used as a taxiway designator due to its similarity to a closed runway marking. An example taxiway designation scheme is illustrated in Fig. 8-30. The taxiway guidance sign system consists of four basic types of signs: *mandatory instruction* signs, which indicate that aircraft should ot proceed beyond a point without positive clearance, *location* signs, which indicate the location of an aircraft on the taxiway or runway system and the boundaries of critical airfield surfaces, *direction* signs, which identify the paths available to aircraft at intersections, and *destination* signs, which indicate the direction to a particular destination.