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Airport Engineering

Airport engineering involves design and construction of a wide variety of facilities for the landing, takeoff, movement on the ground, and parking of aircraft; maintenance and repair of aircraft; fuel storage; and handling of passengers, baggage, and freight. Thus, at a typical airport, there are terminal buildings and hangars; pavements for aircraft runways, taxiways, and aprons; roads, bridges, and tunnels for automobiles and walks for pedestrians; automobile parking areas; drainage structures; and underground storage tanks. Aircraft include airplanes, helicopters, and the anticipated tilt rotor aircraft. Airport engineers have the responsibility of determining the size and arrangement of these facilities for safe, efficient, low-cost functioning of an airport.

18.1 Functions of Airport Components

A **runway**, the most essential component of an airport, enables landing and takeoff of airplanes. For all but the crudest airports, it is a paved strip. Many airports have more than one runway to accommodate aircraft landing and taking-off at locations where winds vary significantly in both direction and speed. Parallel runways are two runways laid out in the same direction to accommodate operations when the capacity of a single runway is exceeded.

Taxiways provide a convenient means for aircraft to enter and exit a runway. They are usually paved strips connecting runways with each other and with aircraft parking areas.

Parking aprons are typically paved areas adjacent to terminal buildings, storage hangers, aircraft maintenance hangers, and other buildings that pilots use as an approach to the building and to stop to permit passengers and crew to enter or exit the aircraft. Aprons at larger airports usually incorporate fuel systems, electrical power supply, and facilities for servicing aircraft.

A **terminal building usually** is incorporated in an airport layout to provide a transition for passengers and crew from ground to air and vice versa. It houses waiting rooms for passengers and at larger airports include facilities for baggage and cargo handling. Also, at larger airports it generally contains airline ticketing counters and offices. It is served by automobile access roads, and typically parking spaces for autos are provided nearby.

Control towers are built at many busy airports for air-traffic control. They provide a raised area from which traffic controllers can observe runways, taxiways, and aprons.

18.2 Classes of Airports

There are two categories of airports in the United States: civil and military. Civil airports serve the scheduled airlines and all phases of general aviation. They are developed through the local initiative of individual communities, with some assistance from state and Federal sources. Military airports serve as bases for Air Force, Army, Navy, and Marine Corps aviation and are developed, as needed, through the Department of Defense.

Civil airports may be further classified as **air carrier airports** (those that serve the scheduled airlines) and **general aviation airports** (those that serve business and executive flying, air-taxi operations, commercial and industrial aviation, and student instruction). Although all air carrier airports accommodate considerable general aviation activity, the general aviation airports are usually not of a size sufficient to accommodate scheduled airlines. In each instance, the size and type of facility are determined by the existing and anticipated types and volume of air traffic that the facility will serve.

Military airports serve only the nation's defense needs. Only in rare instances is civil aviation activity permitted. There are, however, limited military facilities for Reserve and National Guard purposes at some civil airports. Military development is under the Corps of Engineers, United States Army, or the Facilities Engineering Command, United States Navy. Rigid adherence to standards and specifications for military airports is maintained.

18.3 National Airport Standards

The Federal Aviation Administration (FAA) publishes an advisory circular, AC 150/5300-13, 'Airport Design,' which replaces five previous advisory circulars dealing with site requirements for terminal navigation facilities, design of utility airports, aircraft data for airport design, and design of airport aprons. Airport design, under AC 150/5300-13, is guided by the Airport Reference Code (ARC), which correlates airport design criteria and operational and physical characteristics of the airplanes intended to operate at the airport.

The ARC consists of two components related to the design airplane selected for the airport. A letter depicts one component, the aircraft approach category. This is determined by the aircraft approach speed, which, in general, affects design of runways and runway-related facilities. A Roman numeral designates the second component, the airplane design group. This is related to airplane wing span, which primarily determines aircraft separation requirements and influences the design of taxiways and taxilanes.

The ARC specifies five aircraft approach categories, which are designated A through E, and six wing-span categories, which are labeled I through VI. Category A-I covers small and slow single-engine airplanes, whereas categories such as D-V and C-VI concern larger and faster airplanes (Table 18.1). Category E generally applies to high-speed military airplanes and is not referenced in the design of civil airports.

FAA advisory circulars contain standards for nationwide application to the design and construction of airports. These standards make possible the compatibility of local airports with each other and with the national system of airports. Although the standards are widely accepted, their use by communities is not mandatory unless Federal funds are involved in local airport development. Furthermore, regulations permit some latitude in deviation from the standards, where justified.

Table 18.2 summarizes physical characteristics set by national standards for airports. These are the minimum requirements that the FAA considers acceptable for safe operation. They can be used as a design guide in selection of physical characteristics of an airport to accommodate the aircraft anticipated to use its facilities. Information on how to obtain the standards is available at FAA district offices or one can obtain many of the advisory circulars for airport design by going to the FAA Web Site at http://www.faa.gov/arp/150acs.htm.

18.4 Airport Planning

Safety is the number one priority when designing or operating airports. All airport work must be carefully coordinated with the Federal Aviation Administration (FAA) and must be shown on an FAA (or designated representative) approved airport layout plan (ALP), and receive environmental clearance and air-space clearance to ensure its compatibility with the total airport and airspace system. The Airport Improvement Program (AIP), administered by the FAA, may provide funds for a major part of the development of landing areas including land acquisition. The FAA maintains national airport standards; offers advice on airport planning, design, and construction matters; maintains a national airport systems plan; certifies airports for operation; and conducts a compliance program to ensure adherence to regulations and requirements. The FAA operates

Table 18.1 Airplane Operational Characteristics for FAA Airport Reference Coding System

Approach Category (Speed, Knots)	Airplane Design Group (Wing Span, ft)					
	I Less than 49	II 49 to 78	III 79 to 117	IV 118 to 170	V 171 to 213	VI 214 to 261
A (less than 90)	A-I*	A-II*,†	A-III†	A-IV†		
B (91 to 120)	B-I*,†	B-II*,†	B-III†	B-IV†,‡		
C (121 to 140)	C-I†	C-II*,†	C-III†	C-IV†,‡	C-V‡	C-VI‡
D (141 to 165)	D-I†	D-II†	D-III†,‡	D-IV†,‡	D-V‡	
E (166 or more)		E-II†	E-III†,‡			

*Small airplanes (12,500 lb or less maximum takeoff weight). Examples:

A-I: Cessna 177 Cardinal
A-II: DHC-6 Twin Otter
B-I: Beech 100 King Air
B-II: Beech 200 Super King Air
C-II: Rockwell 980

†Large airplanes (more than 12,500 lb maximum takeoff weight). Examples:

A-II: Dassault 941
A-III: DHC-8 Dash 8-300
A-IV: Lockheed 1649 Constellation
B-I: Mitsubishi 300 Diamond
B-II: Cessna III Citation
B-III: BAe 146
B-IV: MDC DC-7
C-I: Gates 55 Learjet
C-II: Grumman III Gulfstream
C-III: Boeing 737 500
C-IV: Boeing 757
D-I: Gates 36A Learjet
D-II: Grumman IV Gulfstream
D-III: BAC III 500
D-IV: Boeing 707-200
E-II: Lockheed SR-71 Blackbird

‡Heavy airplanes (takeoff weight of 300,000 lb or more). Examples:

B-IV: Ilyushin Il-76
C-IV: Airbus A-300-B4
C-V: Boeing 747-SP
C-VI: Lockheed C-5B Galaxy
D-III: BAC/Aerospatiale Concord
D-IV: Boeing 777
D-V: Boeing 747-400
E-III: Tupolev TU-144

through conveniently located district offices. Liaison should be effected with the appropriate FAA office to ensure full consideration of FAA policies and procedures.

18.4.1 Airport Master Plans

In the event that a full master planning study has not been made for an existing or proposed airport, such a study might well precede the planning of an improvement to that airport. If a master plan study has been undertaken, it can be used as the basis for further planning, or it can be reappraised. The master plan presents the planner's conception of the ultimate development of a specific airport, together with priority phasing, cost estimates, and financial plan. The master plan should be reevaluated periodically to maintain its validity.

To be eligible for Federal funding, an airport must be included in the National Plan of Integrated Airport Systems (NPIAS), described in Art. 18.4.2. It also must have an FAA-approved airport layout plan (ALP). This is a scaled drawing of existing and proposed land and facilities necessary for airport operations and development. All airport development carried out with Federal financial assistance must be done in accordance with the FAA-approved ALP. To the extent practicable, this plan should conform to the FAA airport design standards existing at the time of its approval. See also Arts. 18.3 and 18.4.3.

Table 18.2 Federal Aviation Administration Standards for Airport Design[a]

Item		Airports Serving Aircraft Approach Categories[b] A and B					Airports Serving Aircraft Approach Categories[b] C and D					
		Airplane Design Group[c]					Airplane Design Group[c]					
Length, ft.		I[d]	I	II	III	IV	I	II	III	IV	V	VI
Runway[e]		2,800	3,200	4,370	5,360	6,370	5,490	6,370	7,290	9,580	10,700	12,000
Runway safety area	$<\frac{3}{4}$[f]	600	600	600	800	1,000	1,000	1,000	1,000	1,000	1,000	1,000
(beyond runway end)	$\geq\frac{3}{4}$[g]	240	240	300	600	1,000						
Runway object-free area	$<\frac{3}{4}$[f]	600	600	600	800	1,000	1,000	1,000	1,000	1,000	1,000	1,000
(beyond runway end)	$\geq\frac{3}{4}$[g]	240	240	300	600	1,000						
Width, ft.												
Runway	$<\frac{3}{4}$[f]	75	100	100	100	150	100	100	100	150	150	200
	$\geq\frac{3}{4}$[g]	60	60	75	100	150						
Runway safety area	$<\frac{3}{4}$[f]	300	300	300	400	500	500	500	500	500	500	500
	$\geq\frac{3}{4}$[g]	120	120	150	300	500						
Runway object-free area	$<\frac{3}{4}$[f]	800	800	800	800	800	800	800	800	800	800	800
	$\geq\frac{3}{4}$[g]	250	400	500	800	800						
Taxiway		25	25	35	50	75	25	35	50	75	75	100
Taxiway safety area		49	49	79	118	171	49	79	118	171	214	262
Taxiway object-free area		89	89	131	186	259	89	131	186	259	320	386
Taxilane object-free area		79	79	115	162	225	79	115	162	225	276	334
Minimum distance between, ft.:												
Center lines of parallel[a] runways[h]		See Advisory Circular 150/5300-13, Chapter 2										
Center lines of runway and center line of taxiway	$<\frac{3}{4}$[f]	200	250	300	350	400	400	400	400	400	450	600
	$\geq\frac{3}{4}$[g]	150	225	240	300	400	300	300	400	400	450	600
Center line of runway and aircraft parking area	$<\frac{3}{4}$[f]	400	400	400	400	500	500	500	500	500	500	500
	$\geq\frac{3}{4}$[g]	125	200	250	400	500	400	400	500	500	500	500
Center line of taxiway and aircraft parking apron		45	45	66	93	130	45	66	93	130	160	193
Center line of parallel taxiways		69	69	105	152	215	69	105	152	215	267	324
Center line of runway to building line or obstruction[i]	$<\frac{3}{4}$[f]	875	875	875	875	875	875	875	875	875	875	875
	$\geq\frac{3}{4}$[g]	600	600	600	600	600	713	713	713	713	713	713
Center line of taxiway to obstruction		45	45	66	93	130	45	66	93	130	160	193
Maximum runway grades[j], %:												
Longitudinal		2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5
Transverse[k]		2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5

[a]"Airport Design," FAA Advisory Circular 150/5300-13, Change 6.

[b]Aircraft Approach Categories are described in Art. 18.3.

[c]Airplane Design Group is described in Art. 18.3.

[d]Represents airports serving only small airplanes (an airplane of 12,500 lb or less maximum certificated takeoff weight).

[e]Runway lengths assume an airport elevation of 1000 ft above mean sea level (MSL) and a mean daily maximum temperature of 85 degrees in the hottest month. Actual runway lengths should be based on the selected design airplane adjusted for the local condition of elevation, temperature, and runway gradient. The lengths shown are representative of a runway that can accommodate selected airplanes found in the indicated Airport Reference Code (ARC). Runway length for airplanes over 60,000 lb is usually determined based on the amount of fuel needed to fly a certain distance or haul length and may need to be increased from that determined above.

[f]With approach visibility minimum less than $\frac{3}{4}$mile.

[g]With approach visibility minimum greater than or equal to $\frac{3}{4}$mile.

[h]Dual simultaneous precision instrument approaches normally require parallel runway center-line separartion of 4300 ft. A minimum distance of 3400 ft may be used if special radar and monitoring equipment is used. Simultaneous instrument flight regulation (IFR) operations to parallel runways are not authorized for nonprecision instrument approach procedures. Simultaneous precision instrument approach procedures serving parallel runways spaced 2500 ft require radar controlled approaches and departures. Consult with FAA.

[i]The numbers represent a building restriction line (BRL) that encompasses the runway protection zones and runway object-free area. The BRL should also encompass the runway visibility zone, NAVAID critical areas, areas required for terminal instrument procedures, and airport traffic control tower clear line of sight.

[j]Taxiway grades should be held to the same maximum grades as runways.

[k]Gradient shown is for pavement. To improve runoff, shoulder slopes may be increased to 5.0% for a distance of 10 ft from the edge of pavement, then continue at 5% maximum for approach categories A and B and 3% for approach categories C and D.

18.4.2 National Plan of Integrated Airport Systems (NPIAS)

Through constant research, the Federal Aviation Administration, Department of Transportation, has developed criteria for determining the aeronautical potential of a community and translating that potential into airport requirements. The overall airport needs of a community are summarized in the NPIAS, published by the FAA. For existing and proposed airports, the plan shows the type of activity forecast and the general facilities required to accommodate the activity. A brief text spells out broad items of recommended development.

In the past, communities to receive passenger service were certificated by the Civil Aeronautics Board (CAB). The Airline Deregulation Act of 1978, however, called for the "sunset" of the CAB by the end of 1984. During the final years of the CAB and in the aftermath of deregulation, air carriers were permitted to change routes without government approval. As a result, the carriers dropped many unprofitable routes. With the end of the CAB, the few remaining essential functions performed by the CAB were transferred to the Department of Transportation (DOT). DOT oversees the Deregulation Act "Essential Air Service" provisions, which authorize subsidized passenger air service to some smaller communities. The historic trend of the number of enplaned airline passengers related to other factors can indicate a community's air carrier potential.

The number of based aircraft at an airport is an indication of the general aviation potential. At air carrier airports, the requirements for facilities to serve scheduled operations are greater than those for general aviation. Consequently, the overall needs of general aviation are usually met at airports that are developed to serve scheduled activity. Thus, the requirements of general aviation become a controlling factor only at airports that are not served by, or built for, the scheduled airline service.

The FAA changed the method of classifying airports in 1982. It now lists them in four major categories, which identify the broad functional mission of each airport in the NPIAS by relating the mission to the service level, including commercial service (primary and reliever) and general aviation airports (Table 18.3).

18.4.3 Airport Layout Plan

Every airport should have a layout plan showing ultimate development, even though construction is to be in stages. Such a plan is desirable to ensure an orderly development and an economical and functionally sound airport. All major components should be worked out in advance.

The airport layout plan is the basic element of the airport's master plan and shows all existing and proposed facilities, property lines, topography, utilities, airport approach surfaces, and runway protection zones, in addition to the ultimate runway and taxiway layout. The ultimate plan will provide a basis for acquiring ample land and for determining zoning required to protect future approaches. The plan should be flexible enough to permit modifications between stages of construction to meet the changing demands of air transportation.

18.4.4 Airport Zoning

In the planning of any airport, it is important that sponsors work closely with local communities and their planners to develop and implement sound land use compatibility plans. This also requires that all existing obstructions to air navigation be cleared or marked and lighted and that future obstructions be prevented. Where legally possible, steps should be taken to adopt appropriate airport zoning legislation to prevent the establishment of obstructions to air navigation. Ideally the zoning will be developed concurrently with the layout plan. If comprehensive zoning is in force or can be instituted, height restrictions and land use can both be incorporated.

18.4.5 Environmental Impact

Airport development is subject to state and Federal regulations that require careful consideration of environmental, ecological, and sociological matters in planning and construction. It is likely that preparation of an Environmental Impact Assessment Report will be required for airport development involving airport location, new runways, major runway extensions, runway strengthening if it might result in increased aircraft noise, adverse effects on the capacity of existing roads, certain land acquisitions, establishment or relocation of an instrument landing system or an approach lighting system. Such a statement should include, among other things, a description of the project and a

Table 18.3 National Airport Classification System—Aeronautical Activity Levels for Functional-Role Airport Classification System*

NPIAS† airport category	Classification description
Commercial service	Annual scheduled passenger service
Primary	Percent of total U.S. enplanements
Large hub (L)	1% or more
Medium hub (M)	0.25–1.00%
Small hub (S)	0.05–0.25%
Non-hub (N)	0.01–0.05%
Other	2500 or more but less than 0.01%
Reliever‡	Must have at least:
	50 based aircraft, or
	25,000 annual itinerant operations, or
	35,000 annual local operations
General aviation	All other civil airports

*Established by the Federal Aviation Administration.

†National Plan of Integrated Airport Systems.

‡Intended to reduce congestion at large commercial service airports by providing general aviation pilots with alternative landing areas and by providing more general aviation access to the overall community.

discussion of its purpose, impact on the natural environment, and impact on the human environment. Also, it should include alternatives to the proposed development, unavoidable adverse impact, short-term effects, long-term impact, irreversible or irretrievable commitments of resources, and long-term benefits. The statement should be carefully prepared, thorough and complete, unbiased, and clear, so that its review by many public bodies and agencies will not be unduly protracted.

18.4.6 Airport Construction Plans

Construction plans for airports should include a location and site plan, airport layout plan, grading and clearing plan, borings and soils-exploration plot, grading and drainage plan, runway and taxiway profiles, access-road plans and profiles, drainage-line profiles, pavement cross sections, drainage structures, lighting and conduit plan, landscaping plan, and summary of construction quantities. Plans are also required for development of terminal area and parking lots and for construction of terminal buildings.

18.5 Obstruction and Clearance Criteria for Airport Approaches

The FAA has established standards for determining obstructions to airports in Part 77 of the Federal Aviation Regulations. These standards set up **civil imaginary surfaces** (Fig. 18.1 and Table 18.4). Objects that extend above these surfaces are considered obstructions and should be removed or marked and lighted, depending on the nature of the obstruction and the feasibility of its removal.

The **airport reference point** is a centrally located point that defines the geographic location of the airport. The **primary surface** corresponds to a **landing surface**; it is a surface with a width of 250, 500, or 1000 feet depending upon the weight class of the airplane to be accommodated longitudinally centered on a runway and extending 200 ft beyond each end of the runway. The **horizontal surface** is a horizontal plane 150 ft above the established airport elevation (the highest point on the landing surfaces). It is bounded by a **conical surface**, which has a width of 4000 ft and rises on a 20:1 slope.

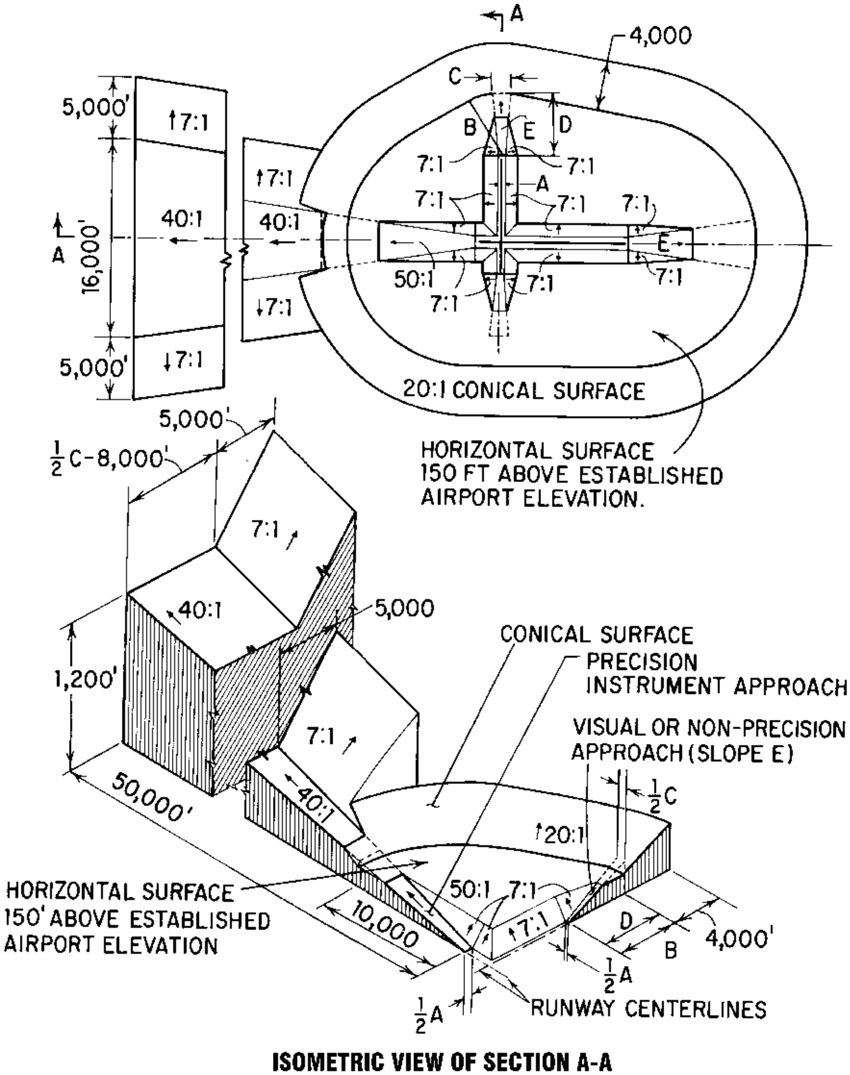


Fig. 18.1 Airport imaginary surfaces for determining obstructions. (*Federal Aviation Administration.*)

Approach surfaces are longitudinally centered on runway center lines extended outward from the primary surface. The dimensions and slopes vary, depending on the nature of the runway involved (Table 18.4). From the sides of the approach surfaces, transitional surfaces extend outward at 7:1 until they intersect the horizontal or conical surfaces. The transitional surface at each end of a precision instrument runway extends beyond the conical surface for the remaining length of the approach surface and has a width of 5000 ft.

All feasible steps should be taken to insure adequate protection of airports from obstructions above these imaginary surfaces.

18.5.1 Runway Protection Zones

These are land areas the function of which is to enhance protection of people or property on the ground from aircraft operation. Runway protec-

Table 18.4 Criteria for Airport Imaginary Surfaces for Determining Obstructions*

		Dimensional standards, ft (see Fig. 18.1)					
		Visual runway		Nonprecision instrument runway			
					Other than utility runways		
Dimension	Item	Utility runaways‡	Other than utility runways	Utility runways	Visibility minimums greater than ¾ mi	Visibility minimums as low as ¾ mi	Precision instrument runway
A	Width of primary surface and width of approach surface at inner end	250	500	500	500	1,000	1,000
B	Radius of horizontal surface	5,000	5,000	5,000	10,000	10,000	10,000
C	Approach surface width at end	1,250	1,500	2,000	3,500	4,000	16,000
D	Approach surface length	5,000	5,000	5,000	10,000	10,000	†
E	Approach slope	20:1	20:1	20:1	34:1	34:1	†

*Federal Aviation Administration.

†Precision instrument approach slope is 50:1 for inner 10,000 ft and 40:1 for an additional 40,000 ft.

‡Runways expected to serve propeller-driven airplanes with maximum certificated takeoff weight of 12,500 lb or less.

tion zones require elimination of objects and activities that are incompatible with airport operations. They also designate areas on which are prohibited land uses such as residences and places of public assembly, including churches, schools, hospitals, office buildings, shopping centers, and theaters.

Runway protection zones lie directly beneath the inner portions of runway approach surfaces (Fig. 18.2 and Table 18.5). The standard configurations of runway protection zones conform to the inner dimensions of approach surfaces. Zone length is a function of the type of aircraft and approach visibility minimums for the runway (Table 18.5).

Airport authorities should control sufficient property in the runway protection zone to provide for unobstructed passage of aircraft landing or taking off. All obstructions should be cleared and creation of future obstructions should be prohibited. Although protected areas should be completely cleared, grading of the areas is not necessary.

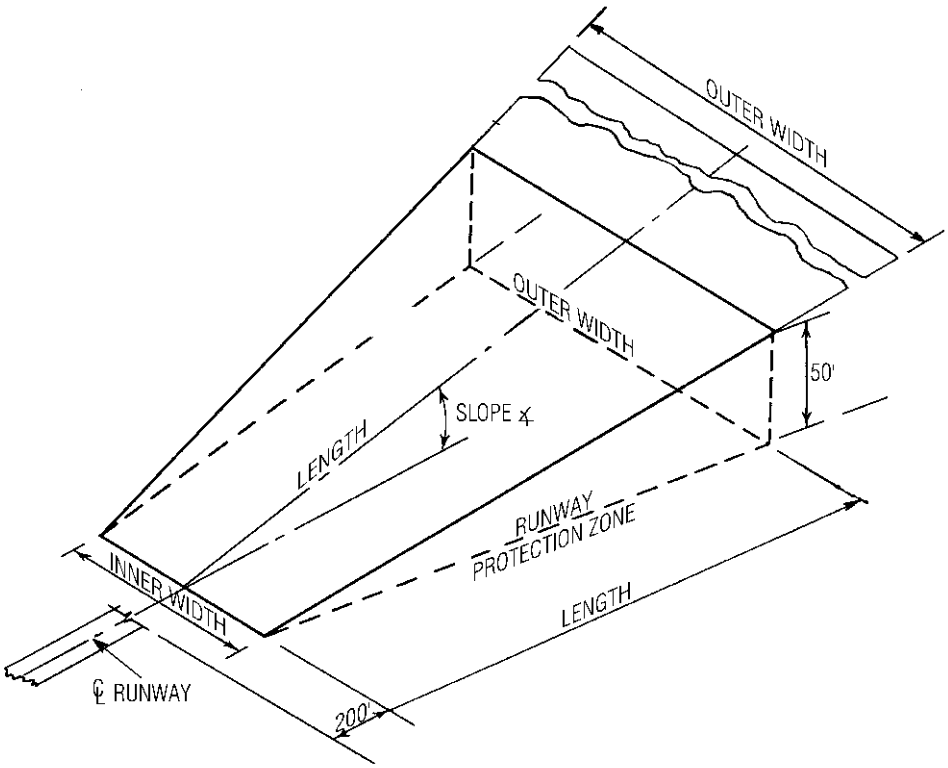


Fig. 18.2 Runway protection zones and approach surfaces. (*Federal Aviation Administration.*)

Also, although ownership of the areas is desirable, zoning or aviation easements give the necessary protection.

18.5.2 Clearance of Obstructions

To test approach zones for clearance of obstructions, a topographic map of the airport site and its environs is required for a radius of at least 4 mi from the airport boundary. A convenient test method is to prepare a transparent template showing the extension of the runway center line, the limits of the runway approach surface, and contour lines representing the elevations of the sloping runway approach surface and 7:1 transition surface. For an instrument-runway approach, the transparent template (Fig. 18.3) is fitted to the end of each runway, and the ground-surface contours are compared with those of the runway approach surface. Any high places or created features on the ground that will protrude into the runway approach surface are noted. The runway layout is adjusted, if necessary, to avoid obstacles with a minimum sacrifice of wind coverage.

The horizontal surface clearances, 150 ft above the airport are examined in a similar manner. All obstructions above the horizontal surface are spotted. Measures should be taken to remove as many obstructions as possible and to mark and light those that cannot be removed.

Detailed plans should be made of critical areas in approach zones. The plans should show heights of trees, poles, buildings, etc. that come near the runway approach surface. Steps should then be taken to obtain control of these areas by easement

Table 18.5 Dimensions for Runway Protection Zones

Approach Visibility Minimums*	Facilities Expected to Serve	Dimensions: Length L, feet (meters)	Dimensions: Inner Width W_1, feet (meters)	Dimensions: Outer Width W_2, feet (meters)	RPZ, acres
Visual and not lower than 1-Mile (1,600 m)	Small aircraft exclusively	1,000 (300)	250 (75)	450 (135)	8.035
	Aircraft approach categories A & B	1,000 (300)	500 (150)	700 (210)	13.770
	Aircraft approach categories C & D	1,700 (510)	500 (150)	1,010 (303)	29.465
Not lower than 3/4 Mile (1,200 m)	All aircraft	1,700 (510)	1,000 (300)	1,510 (453)	48.978
Lower than 3/4 Mile (1,200 m)	All aircraft	2,500 (750)	1,000 (300)	1,750 (525)	78.914

*The RPZ dimensional standards are for the runway end with the specified approach visibility minimums. The departure RPZ dimensional standards are equal to or less than the approach RPZ dimensional standards. When a RPZ begins other than 200 feet (60 m) beyond the runway end, separate approach and departure RPZs should be provided. Refer to appendix 14 for approach and departure RPZs.

Small airplane: Airplanes of 12,500 lb or less maximum certificated takeoff weight.

Large airplane: Airplanes of more than 12,500 lb maximum certificated takeoff weight.

or purchase, so that the obstructions may be removed. Clearances for railroads and highways are shown in Fig. 18.4.

18.6 Airport Site Selection

Before investigating possible sites in detail for an airport, the engineer should assemble certain background data. These include U.S. Geological Survey topographic maps, aerial photographs in stereo-pairs for studying relief and culture, available soils maps and analyses, and overall development plans for the area. Data on winds and weather should be obtained from the most reliable sources possible. It is desirable to get complete weather information for a period of at least 10 years.

The engineer should establish liaison with appropriate representatives of the FAA, the state aviation agency, local and area planning groups, and the aeronautical interests that can be expected to use the airport. Finally, there must be evaluations, projections, and studies to develop forecasts of the volumes and types of anticipated activity and to establish the general size, character, and scope of the airport. With such information, a reconnaissance of the area can be made and the most likely sites identified for further study.

18.6.1 Physical Site Characteristics

Selection of an airport site is influenced by a number of physical factors. These can affect the utility of the airport and the economy of its development.

Adequate area must be provided to accommodate an airport of the type required and oriented for prevailing winds. The area is determined by the runway length and runway layout and by terminal-area requirements. A small airport may be located on 50 to 100 acres.

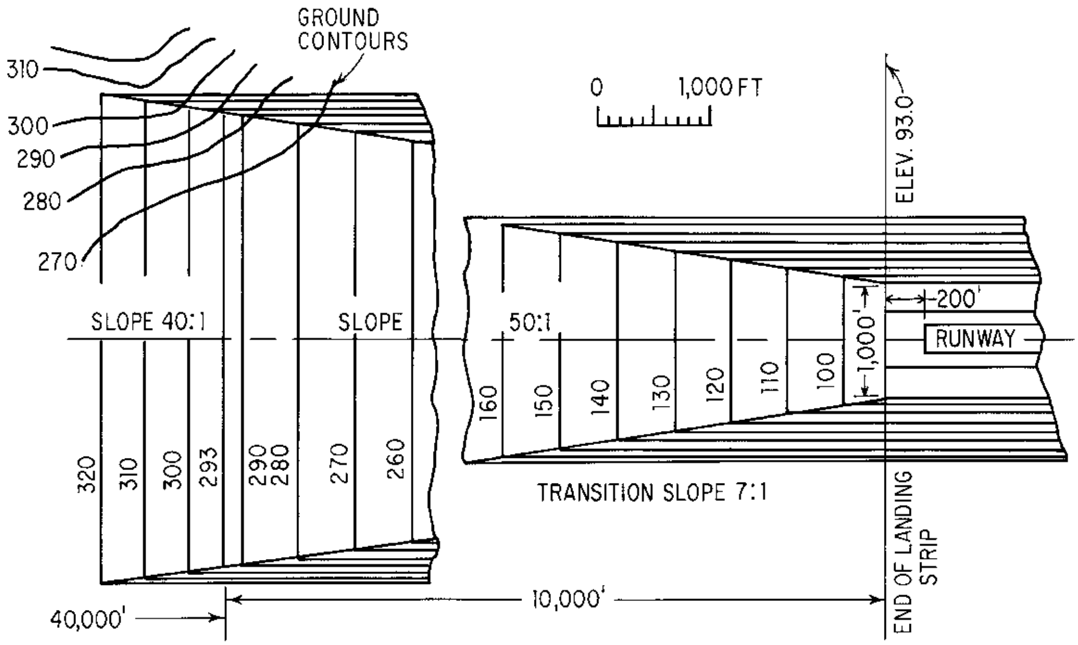


Fig. 18.3 Template for checking approach-zone clearance for instrument runways. Similar templates can be developed for noninstrument runways.

A large international airport may cover as much as 15,000 to 40,000 acres.

Possibility for expansion should be ensured by the selection of a site that is not constrained by built-up property, railroad yards, mountains, rivers, harbors, or other features that prohibit enlargement except at excessive cost. Although initial acquisition should include all land needed for ultimate development, there should be ample undeveloped land available adjacent to the site. This land should be protected by zoning against uncontrolled growth of industrial or residential

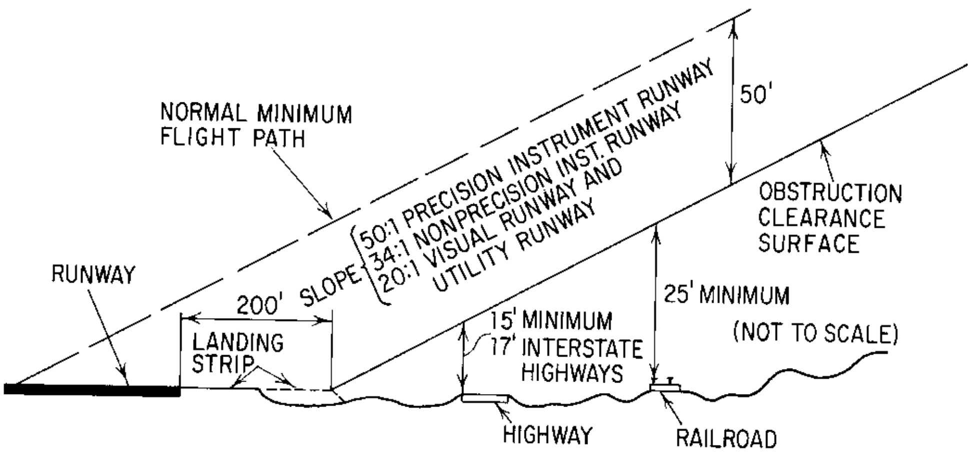


Fig. 18.4 Vertical profile along extended center line of runways shown minimum clearance required by the Federal Aviation Administration over highways and railways.

property that will block runway extensions or terminal-area expansion.

Terrain should be relatively flat to avoid excessive grading costs. Elevated sites are preferable to those in lowlands because they are usually free from obstructions in approach zones, less subject to fog and erratic winds, and easy to drain.

Soils should be studied and evaluated for their effect on grading, drainage, and pavements. The nature of the soil influences the cost of construction. Ideally, the site should be cleared ground that is easily drained and has sandy or gravelly soil that offers a satisfactory foundation for runway pavements without excessively thick subbases and costly subdrainage systems.

Drainage characteristics of the site should be investigated to ascertain the possibility of floods and the existence of high water tables. Natural drainage is most desirable. The ability to dispose of storm water should also be evaluated.

Air approaches to the proposed airport should be free of obstacles, such as mountains, hills, tall buildings, transmission lines, chimneys, and towers.

(A. T. Walls, "Airport Planning and Management," McGraw-Hill, Inc., New York.)

18.6.2 General Site Characteristics

In addition to the physical characteristics of an airport site, factors of a more general nature require consideration.

Accessibility to the community is essential, to preserve the speed advantage of air transportation. In general, accessibility is measured in time rather than distance. Sites near modern express highways are to be sought, and those bounded by traffic-congested streets avoided. On the other hand, the site should not be so remote from the community as to require excessive transportation time.

Availability of utilities, such as electric power, gas, telephone, water, sewers, and public transportation, is an important factor to be investigated. If these utilities are not available, the cost of providing them must be considered.

Control of the site and its surroundings by zoning should be investigated to ensure protection of aerial approaches and possibility of expansion. If the airport is located outside the community to be served, the means of guaranteeing proper control should be determined.

Compatibility with local and area planning is an important characteristic. It should be explored so that the airport and the area can develop without one interfering with the other. The effect on land values and tax assessments may be adverse or beneficial, depending on the nature of the site. If the airport is located near residential property, the value of that property could be affected because of the commercial nature of some types of airports. If located in an undeveloped area, the airport will increase the value of adjacent land for industrial sites and for other uses related to the airport. The possible impact of aircraft noise should be assessed.

Spacing of the airports is a consideration since airports should not be located so that air-traffic patterns interfere. Approval of the FAA is necessary to ensure air-space compatibility. This approval should be obtained before a final commitment is made for a specific airport site.

18.6.3 Site Evaluation

Having identified the most likely sites in an area, the engineer should review them on the basis of physical and general characteristics. It is not likely that any one site will possess all the desirable characteristics. Thus, it is necessary to evaluate the good and bad features of each site to make the best selection.

Preliminary runway patterns should be tested, approaches checked, real estate evaluated, and construction costs analyzed. The more promising sites can be evaluated in the field, and specific soil and topographic data developed. Before final selection is made, the engineer should ascertain that the most favored site will receive FAA air-space clearance, that an acceptable master plan can be developed for that site, and that it offers maximum compatibility with area planning.

18.7 Runway Design

Runways are the focal points of an airport. They must have a length and width adequate to accommodate the aircraft to be served. (See also Table 18.2.)

18.7.1 Runway Lengths

To determine the runway length required for a given airport location, the engineer should take into account the takeoff and landing performance of the most critical aircraft expected to make regular use of the airport. Aircraft performance decreases with increase in distance to be flown from the airport, airport elevation, runway gradient, and air temperature. The runway length chosen should be thoroughly reviewed and validated.

The Federal Aviation Administration (FAA) issues advisory circulars from time to time, giving performance data on aircraft that supplement its engineering data. The safe runway length for transport aircraft is based on Federal Aviation Regulations (Part 25), which specify three requirements for civil air transports, each of which must be met:

1. Runway lengths should be sufficient for airplanes to accelerate to the point of takeoff and then, in case of failure of a critical engine, to be braked and brought to a stop within the limits of the runway (or usable landing strip).
2. If failure of a critical engine occurs at point of takeoff, airplanes should be capable of takeoff with one or more operating engines. Aircraft powered by reciprocating engines should be able to clear the end of the runway at an elevation of 50 ft and those powered by turbine engines, at an elevation of 35 ft.
3. In landing, airplanes should clear the approach end of the runway by 50 ft and be able to touch down and stop within 60% of the available runway length.

Data published on runway requirements for transport aircraft usually incorporate the preceding so that no additional computation is required, except for effective gradient (Art. 18.7.2).

Normal requirements for landing of jet aircraft establish runway lengths that are valid only for normal instrument conditions. For jet airliners to land at lower weather minimums, runways should provide a landing length more than that normally required. Generally, the additional requirement will still be less than the required takeoff length.

Runway length requirements are established for instrument operations for runway visual ranges (RVR) from 2400 ft down to 1200 ft. The equivalent of a 100-ft ceiling and 0.25 mi visibility. With electronic and visual landing aids of greater integrity, weather minimums may be lowered. All-weather operations are the ultimate goal. The corrected landing length should be checked against required takeoff length to ascertain that an adequate length is provided if lower RVR operations can be forecast.

Future needs for a new runway at an existing airport or the need for an entirely new airport should be determined only after thorough study and review of the requirements to meet the anticipated demand. The study process should account for all factors that impact full use of a runway for the design airplane. These include length, width, and specially designated areas free of obstacles to provide an interconnected system of air space and land surfaces for the safe landing and takeoff of aircraft. To control areas off the airport from impacting the air space or approach surfaces, airport owners must have the authority to prohibit potential obstructions and incompatible land uses. The intent of airport planning, in this regard, is to maximize utilization and retention of paved areas on airports. Without proper planning, runways are subject to encroachment by obstructions or incompatible land uses that may restrict or preclude future use of the runways.

To meet obstacle clearance requirements for approaches to existing runways, where control of encroachments has not been possible, the threshold for an affected runway may be displaced or relocated if this is determined to be the only practical alternative. A **displaced threshold** reduces the length of runway available for landings. The portion of the runway behind a displaced threshold is available for takeoffs in either direction and for landings from the opposite direction. A **relocated threshold** is different in that the runway is not available for landings or takeoffs at that end of the runway.

Another way to increase runway utilization at constrained airports is to use *declared distances*. These provide an alternative design procedure in which distances are specified that satisfy requirements for aircraft takeoff run, takeoff distance, accelerate-stop distance, and landing distance. The application of declared distances at a specified location requires prior FAA approval, which is given on a case-by-case basis. Approval must be reflected on the FAA-approved Airport Layout Plan.

18.7.2 Runway Grades

Aircraft performance is influenced by the gradient of the runway. Ascending grades increase power required for takeoff. Descending grades increase braking distance. Not only is the gradient at any point along the runway of concern, but also the effective gradient of the overall runway. Other factors that influence grades are the sight distance and the transverse slopes of graded areas.

Longitudinal grades for airports serving aircraft in approach categories C and D should not exceed 1.50% at any point on the runway profile, but a 2.0% maximum is allowable for airports serving aircraft in categories A and B (Table 18.2).

Runway length determined for the critical aircraft at the elevation and mean temperature of the airport site is further increased at the rate of 20% for each 1.0% of effective gradient.

Longitudinal grade changes should be avoided. If changes are necessary, they should be in accordance with Table 18.6, which shows maximum grade changes and minimum length of vertical curves.

Minimum runway sight distances are necessary to permit safe visual aircraft operations. At noncontrolled airports, runway grade changes should be such that there will be an unobstructed line of sight from any point 5 ft above the center line of the runway to any other point 5 ft above the runway. If the airport has an operating control tower, adherence to longitudinal gradient standards for runways will provide an adequate line of sight from the tower to the runways.

A graded safety area 240 to 1000 ft long is required at each runway end, depending on aircraft approach category and design group (Table 18.2). The associated width required, also shown in

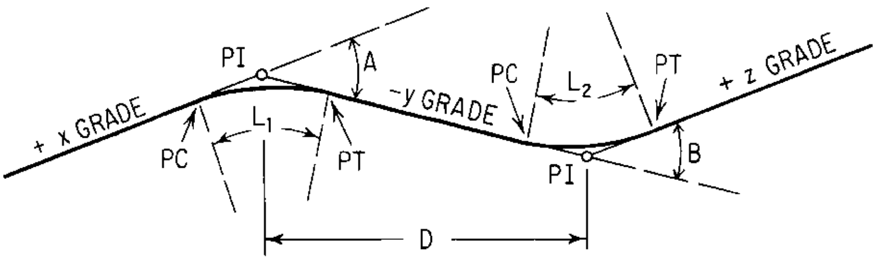


Fig. 18.5 Vertical profile around runway center line shows changes in longitudinal grades. (*Federal Aviation Administration.*)

Table 18.6 Vertical Curve Data and Maximum Grade Changes for Runways

	Runways serving categories A and B airplanes	Runways serving categories C and D airplanes
Maximum gradient at ends of runaway, such as x grade or z grade (Fig. 18.5)	0 to 2.0%	0 to 0.8%, first and last quarter of runway length
Maximum gradient in middle portion of runway, such as y grade (Fig. 18.5)	0 to 2.0%	0 to 1.5%
Maximum grade change, such as A or B (Fig. 18.5)	2.0%	1.5%
Minimum length of vertical curve L_1 or L_2 (Fig. 18.5) for each 1.0% grade change	300 ft*	1000 ft
Minimum distance between points of intersection for vertical curves, D (Fig. 18.5)	$250(A + B)$ ft†	$1000(A + B)$ ft†

*Vertical curves not required at utility airports for grade changes less than 0.4%.

†A% and B% are successive changes in grade.

Table 18.2, varies from 120 to 500 ft. For the first 200 ft, measured from the runway ends, the safety area should slope between 0 and 3% downward along the longitudinal axis of the runway. For the rest of the safety area, the maximum longitudinal grade should be selected to prevent any part of the runway area from penetrating the approach surface or clearway plane. The maximum downward slope permitted in the safety area is 5%. Longitudinal grade changes are limited to 2% per 100 ft up or down.

Transverse grades on runways should not exceed 2% for approach categories A and B and 1.5% for categories C and D (Table 18.2).

Unpaved shoulders may have a steeper slope to improve runoff. The first 10 ft of shoulder adjoining the pavement may be as steep as 5%. The transverse grade of shoulder beyond the 10-ft distance may be as steep as 5% for approach categories A and B and not more than 3% for categories C and D.

Graded shoulders should be set $1\frac{1}{2}$ in below the adjoining pavement edge to preclude future turf from developing a gutter that would impound water at the pavement.

18.7.3 Runway Numbering System

The runways at each airport are designated by numbers related to azimuth, measured clockwise from magnetic north. For simplicity, the numbers are expressed in 10° units of azimuth.

For example, if a runway has an azimuth measured from magnetic south of 32°, the southerly end is numbered 21 since $(32^\circ + 180^\circ)/10^\circ = 21.2$. The other end is numbered 3 since $32^\circ/10^\circ = 3.2$. The runway is referred to as 3-21.

The object of the system is to have the number facing a landing airplane correspond (in 10° units) to the compass course of the airplane. Where there are parallel runways, the runway on the right of the landing airplane is designated with an R (right); the other is designated L (left). For example, if there were a runway parallel to 3-21, the runway would be 3R-21L or 3L-21R.

18.7.4 Runway Layout

Choice of runway pattern is influenced by the necessity of obtaining clear approaches, the desirability of providing maximum wind coverage, and the necessity for fitting the layout to the topography so as to secure low grading and drainage costs. Shape and location of the terminal area also influence the layout. Furthermore, short and direct taxiing distances are desired between runways and the airport terminal.

The number of runways will depend on wind coverage and traffic volume to be handled. To increase capacity, the layout should permit simultaneous use of two or more runways.

Orientation of the runways depends on obstacle clearance requirements and prevailing wind directions. The instrument runway should, if possible, be aligned with the winds that prevail during instrument-flying conditions. Ideally, runway approaches should, if possible, be over sparsely settled or nonresidential areas where the public will be the least inconvenienced by aircraft operations.

18.7.5 Wind Coverage

The Federal Aviation Administration (FAA) specifies that runways be oriented with the prevailing winds. The intent is to ensure that aircraft may be landed at least 95% of the time without exceeding the cross-wind capability of aircraft forecast to use the airport on a regular basis. If the runway does not provide 95% wind coverage for the forecast aircraft, then a cross-wind runway may be necessary. Inasmuch as light airplanes are more susceptible to cross winds than heavy airplanes, allowable cross-wind components are specified for runways designed to serve the aircraft of different Airport Reference Codes, as indicated in Table 18.7.

The trend is toward one- or possibly two-directional layouts. In some localities, where the prevailing winds are consistently in one direction

Table 18.7 Allowable Cross-Wind Components for Aircrafts

Aircraft Reference Code	Cross-wind component, knots
A-I and B-I	10.5
A-II and B-II	13
A-III and B-III	16
C-I through D-III	16
A-IV through D-VI	20

or the reverse, a single runway will meet FAA requirements. One-runway layouts are sometimes adopted when wind-coverage requirements are not fully met but the approaches are excellent and other factors are satisfied.

18.7.6 Wind Rose

To determine the orientation of a runway that will offer the greatest wind coverage, a wind rose may be used. A simple type consists of bars radiating in several compass directions, each representing, to scale, the percentage of time that the wind blows from the direction in which that bar points.

For mathematical computation of wind coverage on the basis of cross-wind component, a wind rose similar to that shown in Fig. 18.6 is helpful. This wind rose gives the percentage of time the wind blows in specified speed ranges as well as in specified directions. The small numbers on the diagram represent the percentages of time the wind blows from the several compass directions between specified velocities. For the wind rose in Fig. 18.6, the percentages of winds were known for velocity ranges of 0 to 3.5 knots (calm), 3.5 to 13 knots, 14 to 27 knots, 28 to 41 knots, and over 41 knots. Winds over 41 knots accounted for less than 0.1% and were neglected.

This wind rose may be used to determine the maximum wind coverage for a one-, two-, or three-directional runway layout. It may also be used to check the wind coverage for a layout adopted after a study of obstacles in approaches and other factors.

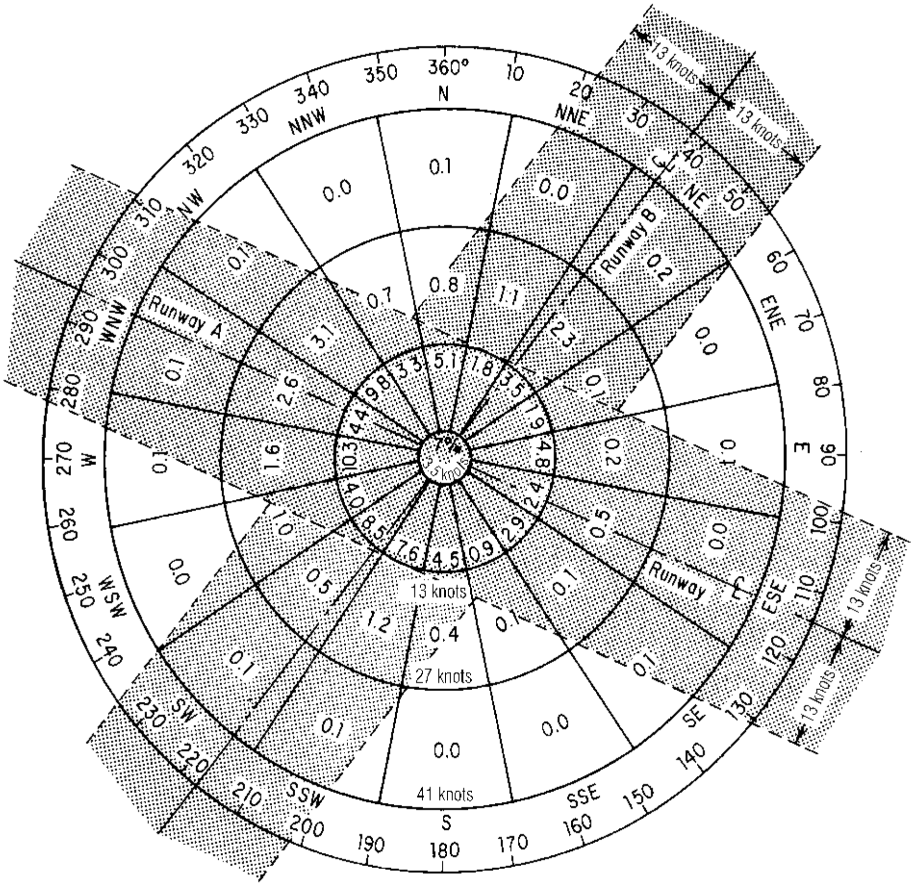


Fig. 18.6 Template aids determination of wind coverage for a cross-wind component of 13 knots.

For finding the maximum wind coverage possible for a given runway, a transparent template is made. On it are drawn the runway center line and parallel lines representing the limits of 13-knot cross-wind components on each side of the center line. This template is then superimposed on the wind rose, with the center line passing through the center of the rose. Next, the template is rotated until a direction is found in which the greatest percentage of wind is included within the 26-knot-wide band.

If the layout has more than one runway, templates are plotted for each runway and shifted about the center of the wind rose until the direction for each runway is found such that the total percentage of wind coverage by all runways is a maximum.

With Fig. 18.6, for example, a two-runway layout is to be checked for wind coverage; first for Runway *A* alone and then for both Runways *A* and *B*. The runway center lines are plotted on the wind rose in their proper compass directions. Lines are drawn parallel to each center line, to represent, to the scale of the wind rose, the limits of all cross-wind components of 13 knots. For simplicity, the percentage of winds not covered is computed and deducted from 100. The percentages and fractions of percentages outside the limits of coverage (dashed lines in Fig. 18.6) for Runway *A* are as follows: in directions NW to E, $0.4 \times 0.1 + 0.0 + 0.6 \times 0.7 + 0.1 + 0.9 \times 0.8 + 0.0 + 1.1 + 0.2 + 2.3 + 0.0 + 0.8 \times 0.1 + 0.6 \times 0.1 + 0.1 \times 0.2$; from SE to W, $0.4 \times 0.1 + 0.0 + 0.5 \times 0.1 + 0.0 + 0.9 \times 0.4 + 0.1 + 1.2 + 0.1 + 0.9 \times 0.5 + 0.0 + 0.6 \times 1.0 + 0.6 \times 0.1 + 0.1 \times 1.6 = 8.16$ or 91.84% coverage. The addition of Runway *B* will add the following coverage: from N to ENE, $0.5 \times 0.8 + 0.0 + 1.1 + 0.2 + 2.3 + 0.0 + 0.6 \times 0.1$ and from S to WSW $0.5 \times 0.4 + 0.8 \times 0.1 + 1.2 + 0.1 + 0.9 \times 0.5 + 0.0 + 0.4 \times 1.0 = 6.49$, giving total coverage for two runways of 98.33%.

The analysis may be refined by using more wind-velocity groups if they are available. It may also be applied for other cross-wind components.

The wind rose usually employed for study purposes is plotted for annual data. In locations where the wind distribution varies during the year, roses should be plotted for the different seasons and the fluctuations taken into account in design, particularly if the airport is used mostly in certain seasons.

For selecting the instrument-runway orientation, a wind rose for low-visibility conditions is useful and can be developed from special studies undertaken by the U.S. Weather Bureau.

18.7.7 Runway Configurations

The simplest layout is a single runway with parallel taxiway and centrally located terminal area as shown by full lines in Fig. 18.7*a*. Two directions of operation are possible, 6-24 or 24-6 (Art. 18.7.3). Only one landing or takeoff can be made at a time.

Under these conditions, the capacity of the runway is about 50 movements per hour (including both landings and takeoffs). When more capacity is needed, a second parallel runway may be built as shown by dashed lines in Fig. 18.7*a*.

In this design, the original runway can be used for takeoffs, while the "future" runway is used for landings. The capacity under visual flight rules will be raised to about 70 movements per hour. Landing traffic will have to cross the takeoff runway under control from the tower.

Figure 18.7*b* shows parallel runways 5000 ft apart. The terminal area lies between the runways. This arrangement has definite operational advantages over the layout in Fig. 18.7*a*. Taxiways do not cross runways, the terminal area is centrally located with ample room for expansion, and the wide separation of runway approaches will increase capacity under conditions of low visibility since the 5000-ft separation is adequate for simultaneous operations. But the layout in Fig. 18.7*b* requires a larger area than the one in Fig. 18.7*a*. The two parallel runways, however, need not be opposite each other. Increasing the offset from the terminal area will decrease taxiing distance but may increase land and construction costs.

Taxiways may be extended to the runway ends to provide exits for incompleted takeoffs, to facilitate landings and takeoffs on the same runway, and to permit simultaneous use of both runways for takeoff or for landing. During peak-hour operations, arrivals and departures are not usually equal, so simultaneous use of both runways for the same type of operation is often desirable.

In Fig. 18.8 an open V-type layout is shown. This layout gives four directions of wind coverage and also allows simultaneous operation of runways in most directions when wind velocities are not unusually high. The traffic diagrams indicate a

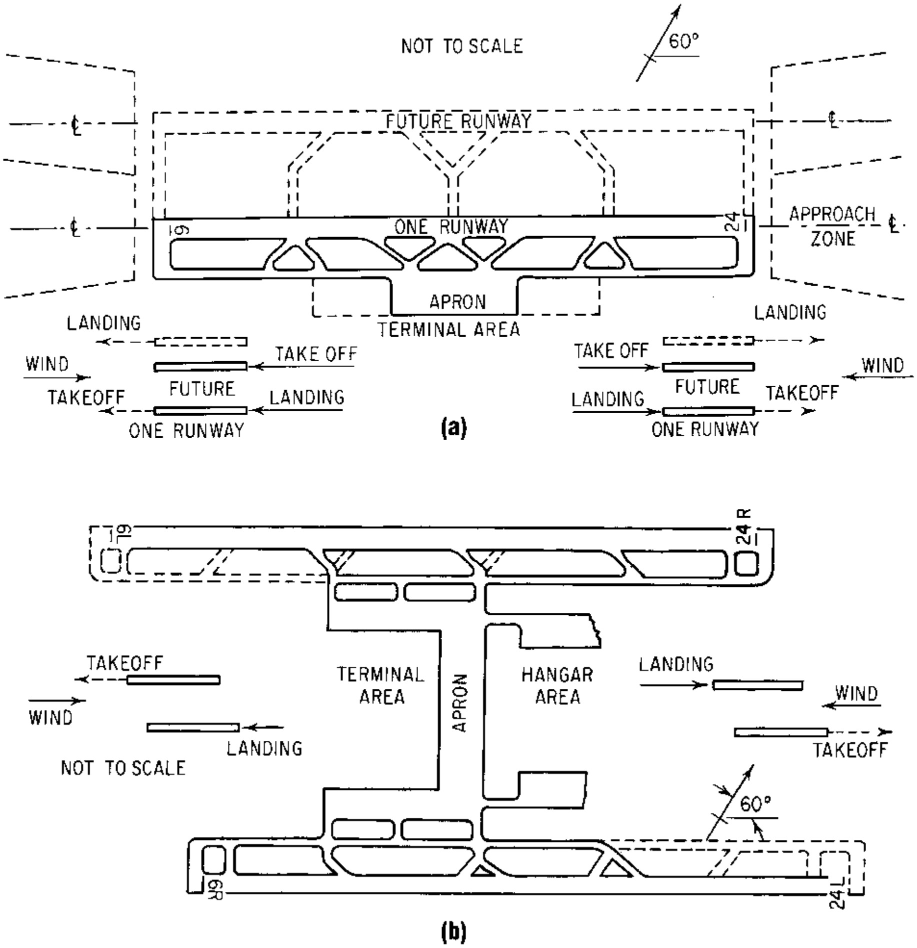


Fig. 18.7 Plan of simple runway layouts: (*a*) Single runway with future parallel runway. (*b*) Two parallel runways.

separation of landings and takeoffs in three or four wind directions. In the one situation where the landing go-around path intersects the takeoff path, the landings and takeoffs will have to be rigidly coordinated.

The V shape permits a centrally located terminal area with room for expansion. In some designs the angle of the V is made about 90°.

When additional capacity is required, the designs in Figs. 18.7*b* and 18.8 may be expanded by building a runway parallel to each of the original runways but 1000 to 3500 ft farther out. Two runways would then be available for landings and two for takeoffs at all times for the layout in Fig. 18.7*b*, and for most of the time for the layout in Fig. 18.8. The greatest capacity can be obtained from the two sets of parallels for the configuration shown in Fig. 18.7*b*, with a third runway at a divergent angle on each side.

Most existing airports have intersecting runways. At some locations, it is impractical to build nonintersecting runways. When winds are not critical, the capacity of these designs can be improved over single-runway operations by using

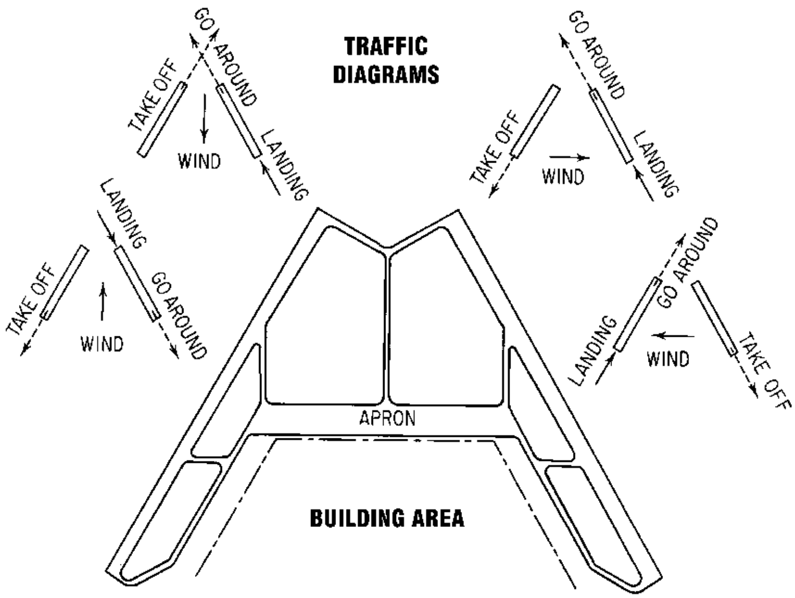


Fig. 18.8 V-type runway layout permits two-directional operation of aircraft. (*Federal Aviation Administration.*)

one runway for takeoffs and another for landings. The movements are alternated under rigid coordination from the air-traffic control tower.

Airport capacity is reduced under instrument-landing procedures, and delays to landings occur. Improvements in air-traffic control, however, have increased landing rates in overcast weather so they nearly equal those in good weather.

18.8 Taxiway Systems

Taxiways are laid out to connect the terminal area with ends of runways for takeoffs and to tap the runways at several points to provide exits for landing aircraft. Landings usually do not require the full length of the runway.

To clear a runway of landing planes as rapidly as possible, easy turns are introduced at exit taxiways (Fig. 18.7). Even faster aircraft exits are obtained when the runway is equipped with the taxiway illustrated in Fig. 18.9. These exit taxiways best serve a variety of aircraft when placed about 2500, 4000, and 6000 ft from the runway threshold.

Where there is a taxiway parallel to the runway, the exit taxiways can lead into the parallel taxiway with a reverse curve that permits the maintenance of high-speed taxi operations. When applied bidirectionally to the same runway, the effect can be that in Fig. 18.7*a*. At the ends of a runway, the taxiways join the runway at about 90° to give the pilot a view of the runway and its extension in both directions. Additional pavement is added to make room for waiting airplanes and to allow one airplane to pass another in the takeoff sequence. Taxiway widths and clearances are given in Table 18.2. Figure 18.10 shows taxiway intersection details, and Table 18.8 lists standard dimensions.

18.9 Aprons

The apron or "ramp" adjacent to a terminal is used for loading and unloading airplanes, fueling, and minor servicing and checkup. The dimensions of the apron depend on the number of loading positions required and the size and turning characteristics of aircraft. The number of spaces depends on the time of occupancy per aircraft, the time being longer at terminal airports than at en-route stops. In most instances, airlines desire exclusive use of apron positions because of the complex equipment required to service transport aircraft. The resulting need is for a greater number

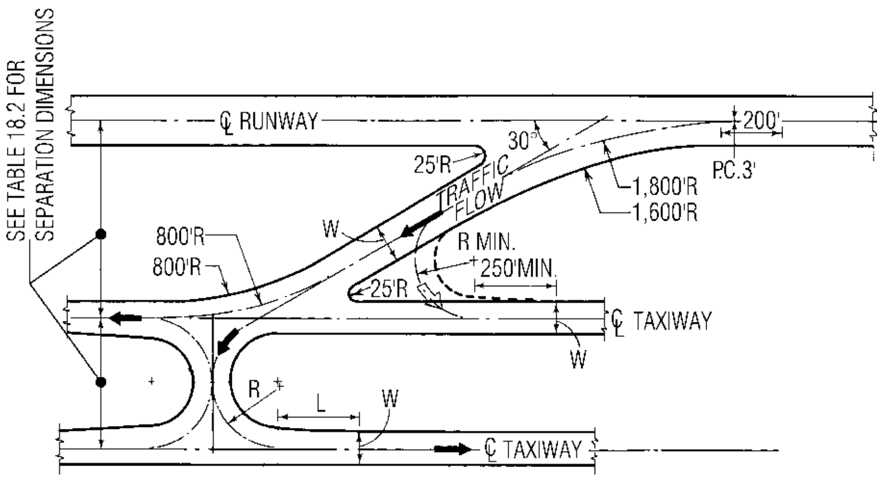


Fig. 18.9 Angled-exit taxiway design with dual parallel and crossover. (*Federal Aviation Administration.*)

of loading positions than would be required if positions were shared.

When determining area requirements for aprons, various methods of aircraft positioning should be explored. The size of airline loading aprons depends on the number and size of aircraft to be accommodated, as determined from a forecast of peak-hour aircraft movements. Aircraft loading positions are designated by circles of varying diameters, depending on wing span, length, and turning radius of the aircraft that will use the airport.

Provision of underground facilities in the apron is a requirement at some airports. At others, services such as fuel, air, power, and telephone are available at the edge of the apron or from the terminal building. Grounding connections should be provided.

18.10 Automobile Parking Areas

Ample parking facilities are required for airport patrons, passengers, employees, and spectators. Public parking should be developed as near the airline terminal as feasible, to minimize walking distance. Most visitors will come on Sundays and when special events occur at the airport.

The parking lot should be designed to handle overflow traffic, or a supplemental lot should be developed for intermittent use. A design criterion of 150 parked automobiles per acre may be used when estimating the size of parking lot required.

To minimize walking distances, some airports have multilevel parking structures adjoining the terminal. Employee parking facilities are usually separate and more distant.

At busy terminals, temporary storage areas will be needed to park taxicabs, buses, and limousines waiting for turns or for scheduling. Parking might be required for service vehicles such as fuel trucks. There should be adequate truck-parking areas at the terminal for delivery of commodities and supplies.

18.11 Airport Grading and Drainage

A thorough analysis of the soils on an airport site is required for planning of grading and drainage and subdrainage systems and for designing pavements and base courses. Soils testing is also required for the control of compaction of fills and base courses so that there will be no detrimental settlement under heavy airplane loads.

Procedures for soil sampling and testing are much the same as for highways. Samples should be taken at 200-ft intervals along the center lines of planned runways and taxiways, one boring per

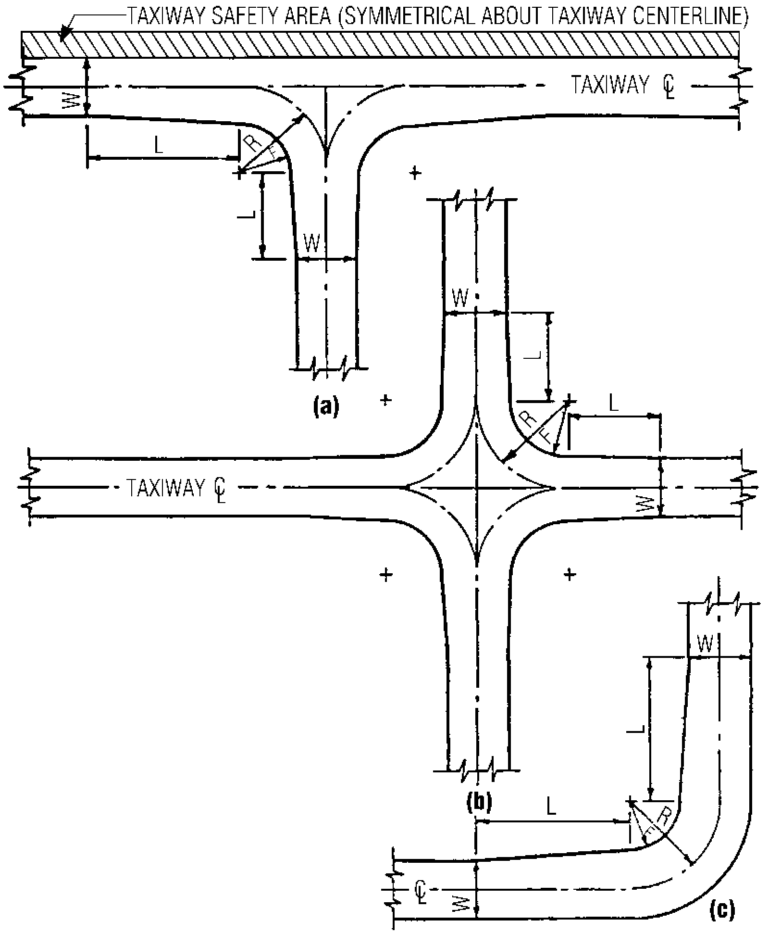


Fig. 18.10 Taxiway intersection details. The taxiway safety area shown in (*a*) has been omitted from (*b*) and (*c*) for clarity. Dimensions *W*, *R*, *L*, and *F* are given in Table 18.8. (*a*) T-shape intersection. (*b*) Crossover. (*c*) Turn.

10,000 ft^2 for other areas of pavement. Borrow areas should be tested sufficiently to define the borrow material clearly. Results of such tests are plotted on soils profiles or on a boring plan. This plan shows locations of borings with respect to proposed runway layout and individual profiles of the soil layers at each location, with a description of each soil type.

The FAA has adopted the Unified System of soil classification (ASTM D2487). Table 18.9 lists recommended spacings and depths for borings for soil investigations for airport construction. A typical graphic soil log is shown in Fig. 18.11. FAA Advisory Circular "Airport Paving," AC 150/5230-6, discusses soils and paving topics.

18.11.1 Airport Grading

The surface of an airport should be relatively smooth but well-drained. Few natural sites provide these ideals; hence, proper grading is important. Grading plans and drainage plans must be carefully coordinated.

The grading plans should consist of runway and taxiway center-line profiles, cross sections showing areas of cut and fill, and a topographic map

Table 18.8 Taxiway Dimensional Standards

		Airplane Design Group					
Design item	Symbol[a]	I	II	III	IV	V	VI
Taxiway width	*W*	25	35	50[b]	75	75	100
Taxiway edge safety margin[c]		5	7.5	10[d]	15	15	20
Taxiway pavement fillet configuration:							
Radius of taxiway turn[e]	*R*	75	75	100[f]	150	150	170
Length of lead-in to fillet	*L*	50	50	150[f]	250	250	250
Fillet radius for center line	*F*	60	55	55[f]	85	85	85
Fillet radius for judgmental oversteering, symmetrical widening[g]	*F*	62.5	57.5	68[f]	105	105	110
Fillet radius for judgmental oversteering, symmetrical widening[h]	*F*	62.5	57.5	60[f]	97	97	100
Taxiway shoulder width		10	10	20	25	35[i]	40[i]
Taxiway safety area width		49	79	118	171	214	262
Taxiway object-free area width		89	131	186	259	320	386
Taxilane object-free area width		79	115	162	225	276	334

[a]Letters correspond to the dimensions in Fig. 18.10.

[b]For airplanes in Airplane Design Group III with wheelbase equal to or greater than 60 ft, the standard taxiway width is 60 ft.

[c]The taxiway edge safety margin is the minimum acceptable distance between the outside of the airplane wheels and the pavement edge.

[d]For airplanes in Airplane Design Group III with a wheelbase equal to or greater than 60 ft, the taxiway edge safety margin is 15 ft.

[e]Dimensions for taxiway fillet designs relate to the radius of taxiway turn specified. Additional design data can be found in "Airport Design," AC 150/5200-13.

[f]Airplanes in Airplane Design Group II with a wheelbase equal to or greater than 60 ft should use a fillet radius of 50 ft.

[g]Figure 18.10*b* displays pavement fillets with symmetrical taxiway widening.

[h]Figure 18.10*c* displays a pavement fillet with taxiway widening on one side.

[i]Airplanes in Airplane Design Groups V and VI normally require stabilized or paved taxiway shoulder surfaces.

Table 18.9 Recommended Spacings and Depths for Borings for Soil Investigations for Airport Construction

Area	Spacing	Depth
Runways and taxiways	Along center line, 200 ft c to c	Cut areas: 10 ft below finished grade Fill areas: 10 ft below existing ground surface*
Other areas of pavement	One boring per 10,000 ft^2 of area	Cut areas: 10 ft below finished grade Fill areas: 10 ft below existing ground surface*
Borrow areas	Sufficient tests to define borrow material clearly	To depth of proposed excavation of borrow

*For deep fills, boring depths should be used as necessary to determine the extent of consolidation and slippage that the fill to be placed may cause.

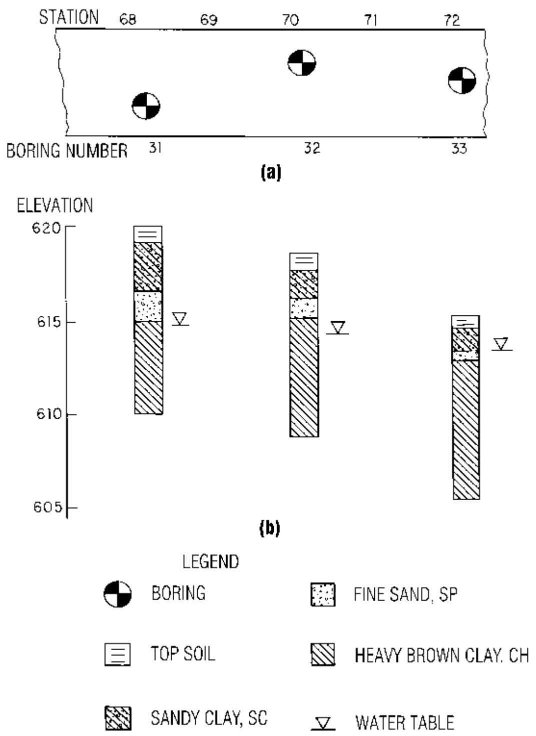


Fig. 18.11 Boring for subgrade investigation. (*a*) Plan of runway showing locations of borings. (*b*) Typical graphic boring log. (*Federal Aviation Administration.*)

showing initial and final contours. This latter map becomes the basis of the drainage-layout plan.

Cross sections of runways and taxiways should slope transversely each way from the center line to provide for surface drainage. Paved surfaces should slope 1 to 1½% for those serving approach categories C and D airplanes and 1 to 2% for those serving categories A and B.

Side slopes of cuts and fills should be as flat as possible. In cuts, the sides should not encroach on a lateral clearance ratio of 7:1 measured normal to the edge of the landing strip.

Properly designed grades can develop low areas that may be used for temporary ponding of storm runoff in the interest of a more economical storm-sewer system. Typical cross sections of runways are shown in Fig. 18.12.

(See "Airport Pavement Design and Evaluation" (www.faa.gov/arp/).)

18.11.2 Airport Drainage

With proper grading, the surface runoff is drained into collector sewers or ditches. Runoff is usually collected along the edges of runways in shallow ditches leading to inlets piped to storm sewers (Fig. 18.12*a*). At some airports in northern climates, where snowbanks along the edges of the runway block drainage across the runway, the surface water is also collected along the edges of the runway (Fig. 18.12*b*). Surface drainage inlets may be placed just outside the edges of runways, or they may be set in a shallow depression built in the outer edge of the pavement (Fig. 18.13). Inlets are usually spaced from 200 to 300 ft apart along the runway or taxiway.

Subsurface drainage is obtained by the use of interceptor drains and pervious base-course layers, in much the same way that highways are drained. Some of the smaller, turfed fields are drained by a network of subdrains covering the entire area. At airports with paved runways, subdrains are usually placed along the edges of the runways where soil conditions indicate that drainage is needed to lower the groundwater level. A combined interceptor and base drain is often used (Fig. 18.14).

Surface drainage is accomplished by the collection of surface water into inlets. A system of underground pipes is required to carry runoff from inlets and subdrains to outlets into waterways. In low areas, surface waters are sometimes drained into ditches or canals running around the perimeter of the airport.

For design of the drainage system, a topographic map is required, on which is plotted the proposed layout of runways, taxiways, aprons, and the terminal plan. The proposed surface grades of these features are shown by contours of small interval: 0.1 or 0.2 ft for paved areas and 0.5 or 1.0 ft for turfed areas. Inlet locations and subdrains are plotted, and storm-drain lines laid out to collect the discharge from them. The system should be as direct as possible to avoid excessive lengths of pipe; frequent changes in pipe size should also be avoided. Crossings of pipes under runways should be held to a minimum.

Figure 18.15 shows a portion of an airport drainage system. The pipe sizes are computed to accommodate the discharge from the design storm, which may be taken as that expected once in every 2 to 10 years, depending on how serious an effect

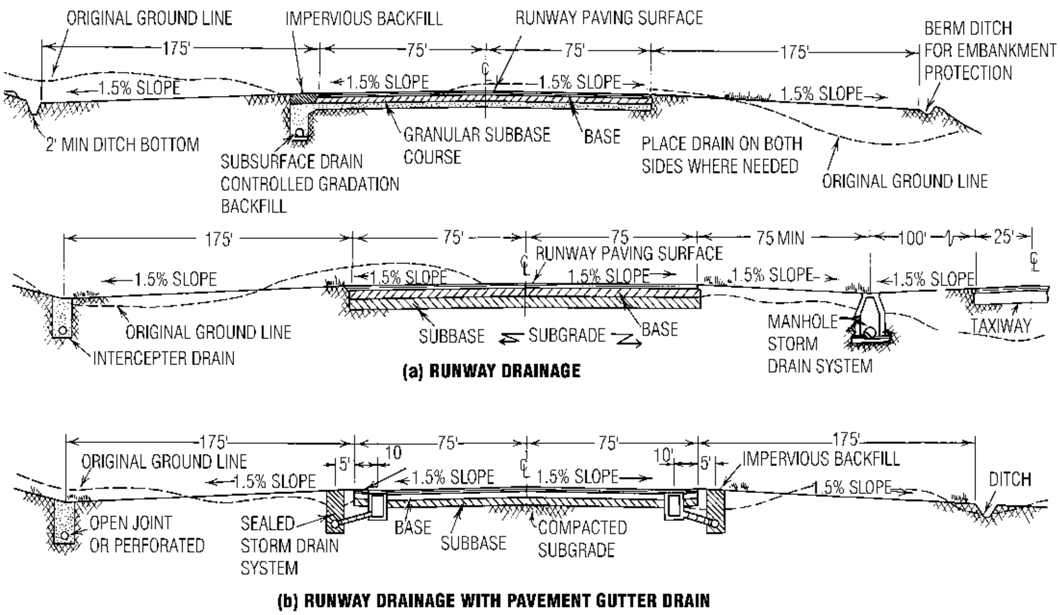


Fig. 18.12 Runway cross sections showing typical provisions for drainage.

an occasional flooding may have on airplane operations. In some designs, a certain amount of ponding is permitted in areas outside the runways.

The rational method (Art. 21.39) of calculating runoff is universally used in airport-drainage design.

The engineer should prepare studies of intersections to ensure good drainage. Center-line grades are held constant, and the grades of the outer portion of the runway or taxiway warped or adjusted so that there will be no abrupt changes in grade in the path of airplanes. The surface should have sufficient slope to drain properly. Intersection studies should be made at a scale of 1 in equals 50 ft. A contour interval of 0.10 ft will permit positive surface drainage to be designed. The

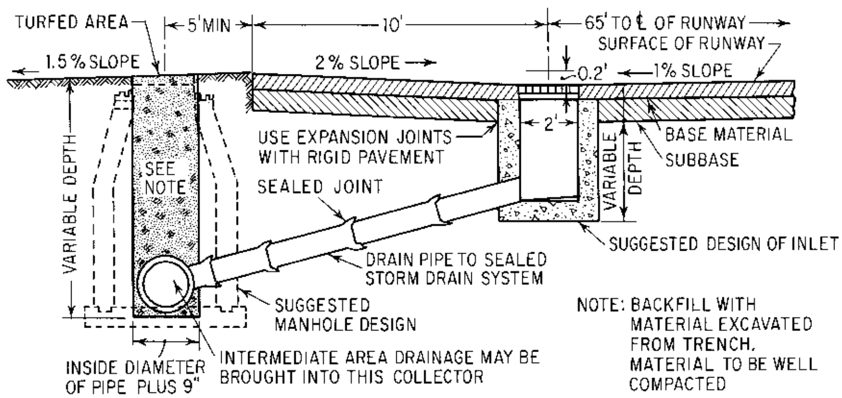


Fig. 18.13 Drainage inlet at outer edge of runway in northern climates. (*Federal Aviation Administration.*)

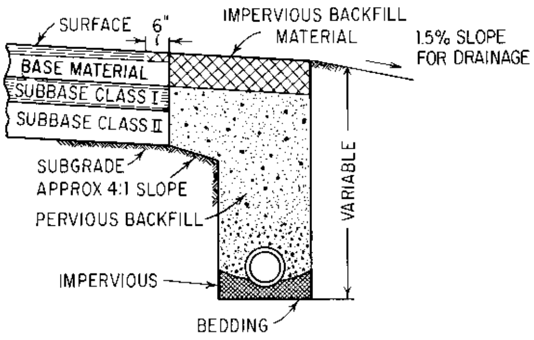


Fig. 18.14 Combined interceptor and base drain. (*Federal Aviation Administration.*)

studies will also be useful in establishing pavement grades.

("Airport Drainage," Federal Aviation Administration Advisory Circular AC150/5320-5.)

18.12 Airport Pavements

Airport pavements are constructed to support the loads imposed by aircraft using the airport and to produce a smooth, all-weather surface. Pavements are divided into two general types: *flexible* and *rigid*. Properly designed and constructed, either type will provide a satisfactory airport pavement. Specific types have, however, proved beneficial in

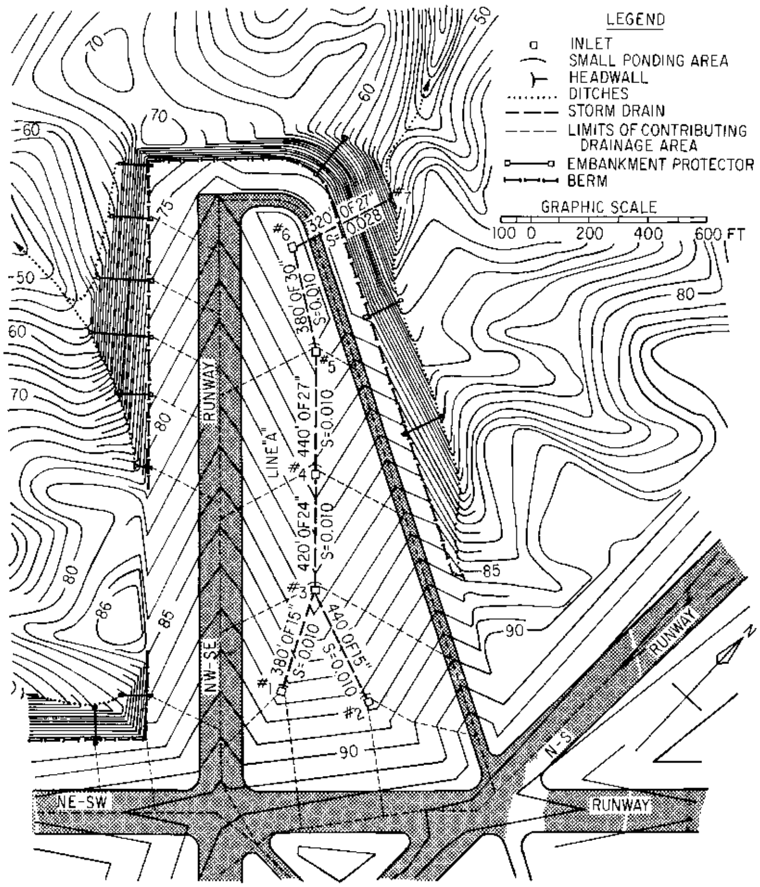


Fig. 18.15 Plan of a portion of an airport drainage system. (*Federal Aviation Administration Advisory Circular AC 150/5320-5.*)

specific applications: Rigid pavements are recommended for areas subjected to appreciable fuel spillage at aircraft gate positions or maintenance positions on the apron; a low-cost flexible pavement is adequate to stabilize an area subject to jet-blast erosion.

The "Airport Paving Manual," published by the Federal Aviation Administration, is the usually accepted guide for design of civil airport pavements. It contains methods and requirements to be used in designing projects involving Federal funds.

Subgrade is the foundation for airport pavements (Fig. 18.12). Its bearing capacity affects the thickness required in flexible and rigid pavements. Depth of frost penetration and influence of drainage conditions can affect the supporting value of the subgrade. Through selective grading, it might be economical to replace inferior subgrade material with superior material so as to reduce the subbase thickness requirement. Subgrades should be thoroughly compacted to provide the highest possible bearing capacity.

Subbase is a granular material placed on the compacted subgrade (Fig. 18.12). It usually is required under flexible and rigid pavements, except for the better soils groups. Thorough compaction is mandatory.

Figure 18.16 shows cross sections of typical runway pavements. The transverse slope of pavements usually is 1.50%, to minimize water ponding on the surface. The Federal Aviation Administration maintains "Standards for Specifying Construction of Airports," AC 150/5370-10, which cover most elements of airport development.

Critical areas are those requiring the thickest pavement. They include sections of runways, all taxiways, and aprons (Fig. 18.17). These are the areas subject to the most adverse aircraft loadings. Pavement thickness in noncritical areas may be reduced from the thickness required in critical areas (Fig. 18.16).

18.12.1 Flexible Pavements

These consist of a bituminous surface course, a base course of suitable material, and usually a granular subbase course (Fig. 18.16). Design of flexible pavements is based on the results of subgrade soils tests. The FAA has developed a relationship

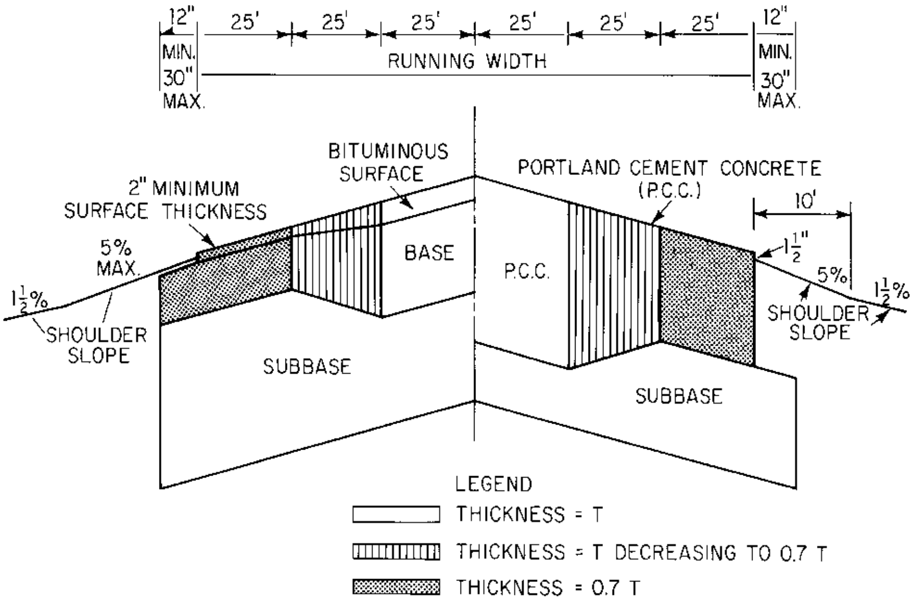


Fig. 18.16 Cross section shows typical bituminous pavement (left of center line) and portland cement–concrete pavement construction (right of center line) for critical areas of runways (Fig. 18.17).

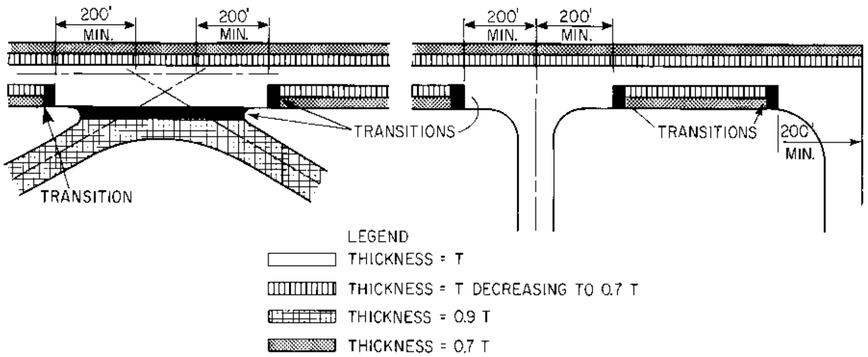


Fig. 18.17 Critical areas of airport pavement. T = total thickness of flexible pavement or concrete thickness for rigid pavement. See also Fig. 18.16.

between soil classes and thickness of surface course, base course, and subbase course required for various gross weights of aircraft, based on different conditions of drainage and frost action.

Design curves for flexible pavements are shown in Fig. 18.18, applicable to single-wheel landing gear, Fig. 18.19, applicable to dual-wheel landing gear; and Fig. 18.20, applicable to dual-tandem landing gear.

Curves are based on the assumption of a 20-year pavement life. Bituminous surfaces should be at least 4 in thick in critical areas, 3 in in noncritical areas, except for light aircraft. Use of the design curves for flexible pavements requires a California bearing ratio (CBR) value for the subgrade material and a CBR value for the subbase material. Also required are the gross weight of the design aircraft and the equivalent number of annual departures of the design aircraft. When the proper curve has been selected based on the landing-gear configuration of the design aircraft, the chart is entered at the appropriate CBR value at the top. A line is drawn vertically down to the gross weight of the design aircraft. From this point of intersection, a line is drawn horizontally to the number of annual departures. From this point of intersection, a vertical line is drawn to the base of the chart and the thickness read on the lower scale. The indicated thickness is for the surface and base courses combined, bearing on a subbase with the indicated CBR value.

Surface-course requirements are established to protect the base from surface water, provide a smooth running surface for aircraft, accommodate traffic loads, and resist skidding, traffic abrasion, and weathering. The surface course generally consists of two bituminous layers—a wearing course and a binder course. The binder course

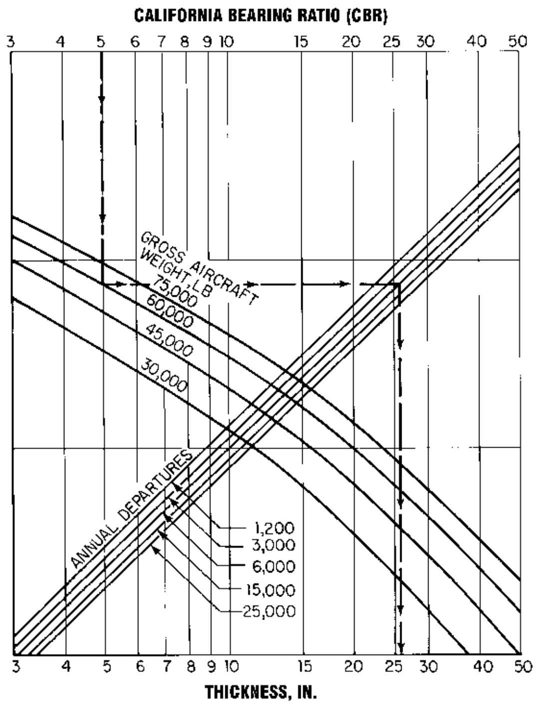


Fig. 18.18 Flexible-pavement design curves for critical areas—single-wheel gear. (*"Airport Pavement," Federal Aviation Administration.*)

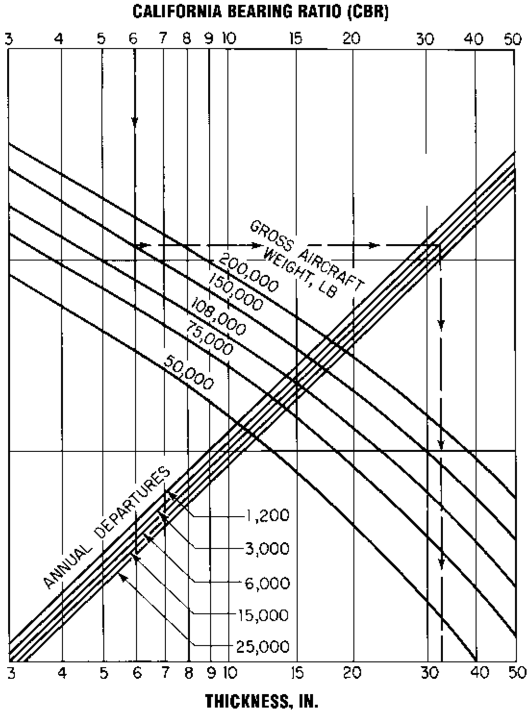


Fig. 18.19 Flexible-pavement design curves for critical areas—dual-wheel gear. (*"Airport Pavement," Federal Aviation Administration*.)

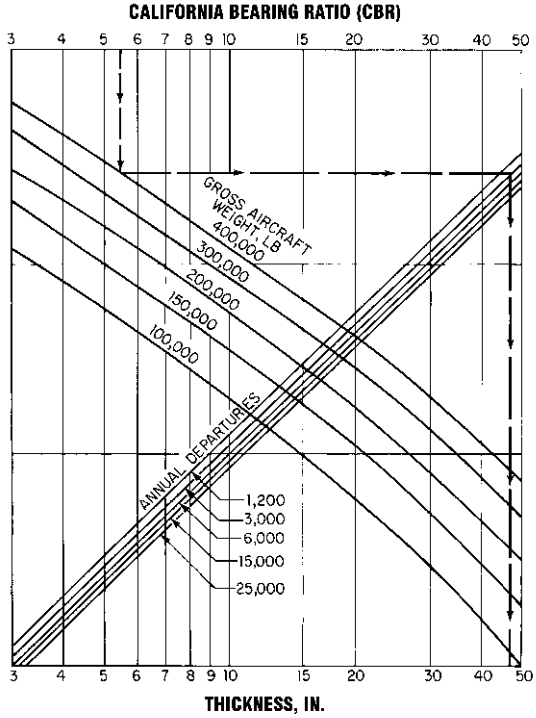


Fig. 18.20 Flexible-pavement design curves for critical areas—dual-tandem gear. (*"Airport Pavement," Federal Aviation Administration*.)

typically contains larger aggregate and less asphalt. Bonding of the two courses may be enhanced by a tack coat of asphalt emulsion. The FAA recommends a dense-graded, hot-laid bituminous concrete produced in a central mixing plant for the wearing course of flexible pavements.

Base-course materials include a wide variety, to take maximum advantage of local materials and construction practices. When high-quality aggregates are used, asphalt or portland cement treatments produce bases that are more effective than untreated bases. Accordingly, the FAA credits 1.0 in of certain treated base materials as being equivalent to 1.5 in of untreated base material.

Subbase is usually an integral part of the flexible-pavement structure. It is protected by the base and surface courses, and so the material requirements are not so strict as for the base course.

Pavements for light aircraft do not need to be so thick as for heavy aircraft. At airports that will not be required to accommodate aircraft in excess of 30,000 lb gross weight, the design curves in Fig. 18.21 should be used. The procedure is the same as with the design curves for heavier aircraft, except there is no reduction for noncritical areas.

18.12.2 Rigid Pavements

These are made of portland cement-concrete, usually placed on a suitable subbase course, which rests on a compacted subgrade (Fig. 18.16). Design curves for rigid pavements are shown in Fig. 18.22, applicable to single-wheel landing gear, Fig. 18.23, applicable to dual-wheel landing gear, and Fig. 18.24, applicable to dual-tandem landing gear.

Use of the design curves for rigid pavements requires the flexural strength of the concrete, the *k* value of the subbase, the gross weight of the design aircraft, and the equivalent number of annual departures of the design aircraft. When the proper curve has been selected based on the landing-gear configuration of the design aircraft, the chart

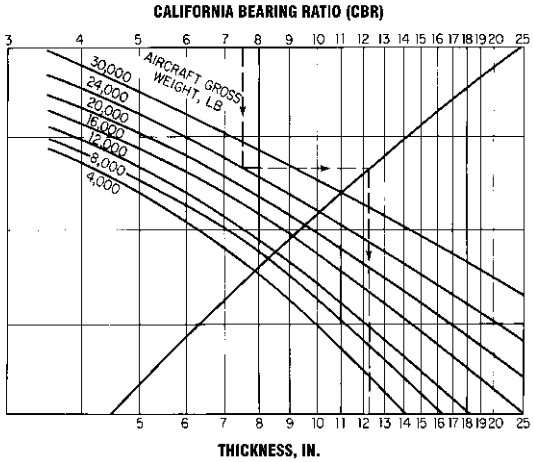


Fig. 18.21 Flexible-pavement design curves—light aircraft. A minimum of 2 in is required for the surface course. (*Federal Aviation Administration*.)

containing the appropriate design curve is entered, from the left, with the concrete flexural strength. A horizontal projection is made until it intersects the appropriate foundation modulus (the k value). A vertical projection is made from this point of intersection to the appropriate gross weight of the design aircraft. A horizontal projection is then made to the scale on the right that corresponds with the annual departures. The pavement thickness is read from that scale. The pavement thickness shown refers to the thickness of the concrete pavement only, exclusive of the subbase, and is that shown in Fig. 18.16 as T, referred to as the critical thickness.

The k value is based on the material directly beneath the concrete pavement. (See p. 16.42) A k value should be established for the subgrade and then corrected to account for the effects of the subbase.

Joints and reinforcing used in airport pavements are similar to those used in highway pavements, except that wider slabs and larger dowels are used for thick pavements. Longitudinal construction joints are doweled, keyed, or hinged (butt or keyed).

Longitudinal expansion joints are advisable at runway and taxiway intersections and next to structures. Where dowels are not suitable, a thickened edge may be introduced.

Transverse contraction joints are spaced 15 to 25 ft apart in unreinforced pavement. Transverse expansion joints are not generally used except at intersections.

Dowels are used across expansion joints and also across construction joints in some designs. The bars or bonded reinforcing are carried across certain longitudinal contraction joints and keyed construction joints to hold the slab faces in close contact.

Construction joints between runs of pavement are keyed, doweled, or hinged. The diameters of dowels vary from ¾ in for 6- to 7-in-thick slabs, to

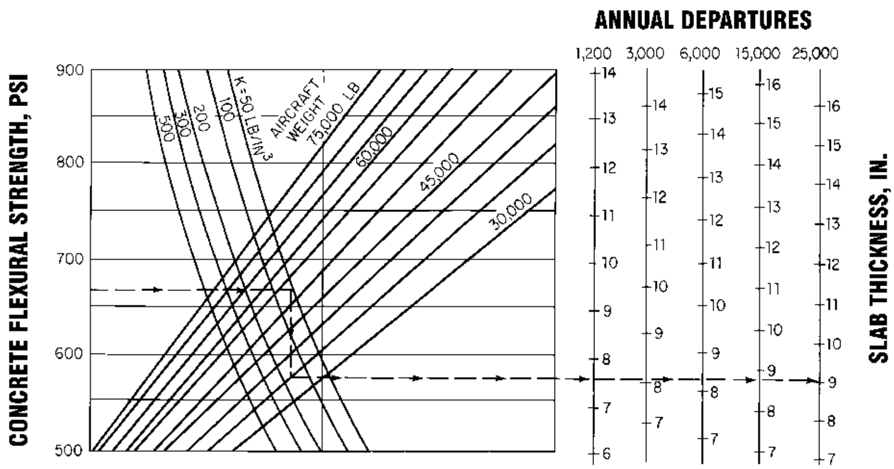


Fig. 18.22 Rigid-pavement design curves—single-wheel gear. ("*Airport Pavement*," *Federal Aviation Administration*.)

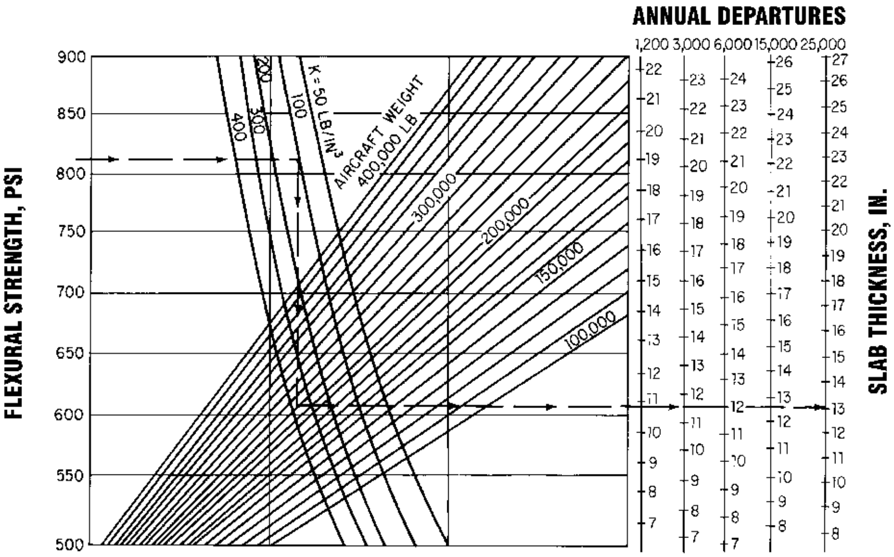


Fig. 18.23 Rigid-pavement design curves—dual-wheel gear. (*"Airport Pavement," Federal Aviation Administration*.)

2 in for 21- to 24-in slabs. Standard length of dowels is 18 to 24 in and spacing is 12 to 18 in c to c.

Reinforcing of the pavement is desirable to control cracks. Its installation should follow the latest design and construction practices.

Rigid pavement for small aircraft (weighing 12,500 lb or less) should be at least 5 in thick. For aircraft between 12,500 and 30,000 lb, the rigid pavement should be at least 6 in thick. All paved areas should be considered as critical areas (Fig. 18.16).

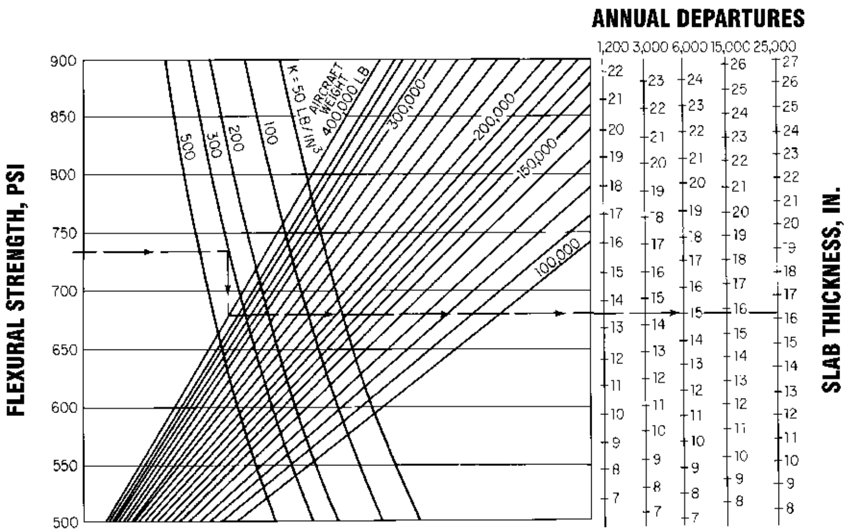


Fig. 18.24 Rigid-pavement design curves—dual-tandem-wheel gear. (*"Airport Pavement," Federal Aviation Administration*.)

18.12.3 Pavement Overlays

Pavement overlays restore a pavement. An overlay may be applied over a pavement that no longer can be maintained satisfactorily. Or an overlay may be used to increase the load-bearing qualities of a satisfactory pavement that must accommodate aircraft heavier than those for which the pavement was designed.

Flexible overlays involve a combination of a base course and a bituminous surface course. *Rigid overlays* involve the use of a layer of portland cement-concrete. *Bituminous overlays* consist entirely of bituminous concrete. In each instance, the qualities of the existing pavement must be fully ascertained and the overlay designed to make the resultant pavement capable of handling the required traffic, following procedures outlined in "Airport Paving," Federal Aviation Administration.

18.13 Unpaved Surfaces at Airports

Some airports do not require paved surfaces because of a low volume of traffic and use by only light aircraft. In some instances, turf surfaces are used for landings and takeoffs at small airports and on the unpaved areas of runways at larger airports.

A tough, thickly matted grass is required in these areas. The type of grass to use depends on soil characteristics and climate at the site. If tests show the soil deficient in nutrient elements, these may be supplied by appropriate fertilizers. When a fertile topsoil must be removed during grading operations, it should be stockpiled and later spread on the areas to be turfed. A vegetative cover is also desirable on embankment, cut slopes, and other interior areas of the airport to prevent dusting and erosion.

When turf is not adequate by itself, it may be possible to add to stability by adding coarse aggregate to the soil prior to the development of the turf. This will permit the soil to retain sufficient moisture to promote the growth of grass, yet provide a surface that will not become too soft in wet weather.

18.14 Soil Stabilization at Airports

Granular material, portland cement, tar, cut-back asphalt, or emulsified asphalt may be used to improve the qualities of a soil so that it can serve as a base or subbase. Such stabilized soils are not intended to serve as a surface course; a separate wearing surface must be provided. The same general procedures are followed in stabilizing airport soils as are followed in highway practice. (See Art. 16.19.)

18.15 Airport Terminal Buildings

Transition of passengers from ground to air occurs in the terminal area. Various methods are used to accommodate and transfer the public and its goods, arriving either by air or by ground, and to provide for parking, servicing, and storage of aircraft and vehicles used in ground transportation. The degree of development in the terminal area varies with the volume of airport operations, the type of traffic using the airport, the number of people to be served, and the manner in which they are to be accommodated.

18.15.1 Airplane Parking

The concept of a very small airport might involve only a hangar with simple office facilities, adequate for limited aeronautical activity. At larger airline terminals, demands are greater. The concept can involve bilevel terminal operations, auto parking in buildings, and elaborate passenger-loading devices. Various concepts of terminal systems are shown in Figs. 18.25 and 18.26.

Frontal layout of facilities is usual at airports of low activity. In the small-airport layout (Fig. 18.25*a*), the facilities required to serve a moderate volume of general aviation are in a row along the boundary road. At many small airports, the terminal is eliminated and its functions housed in a lean-to of a service hangar. At such an airport, the terminal (or lean-to) would usually have a waiting room, rest rooms, office for the airport manager or flight service operator, and perhaps a restaurant, snack bar, or vending machines.

At airline terminals of low activity, a frontal loading system as shown in Fig. 18.25*b* is usually preferred. Expansion possibilities are indicated. As the fingers are extended, however, the passenger walking distances increase. Likewise, the finger structure becomes less economical, since loading positions are on only one side.

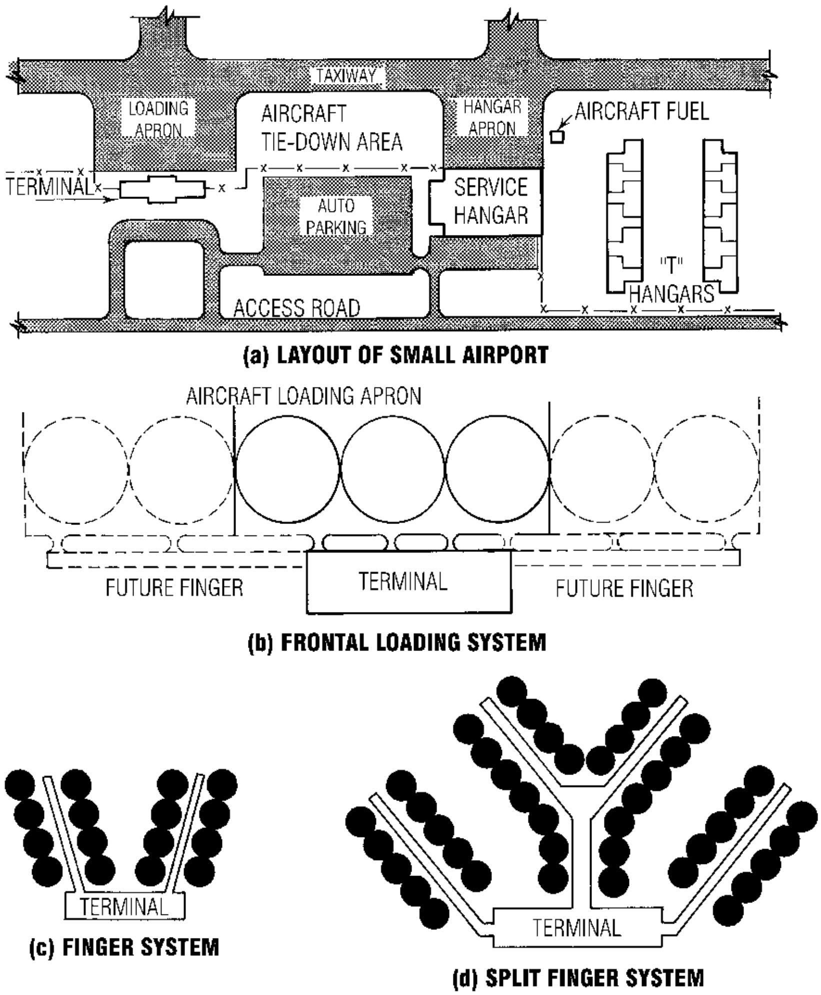


Fig. 18.25 Simple terminal systems. Fingers are added to increase aircraft parking capacity.

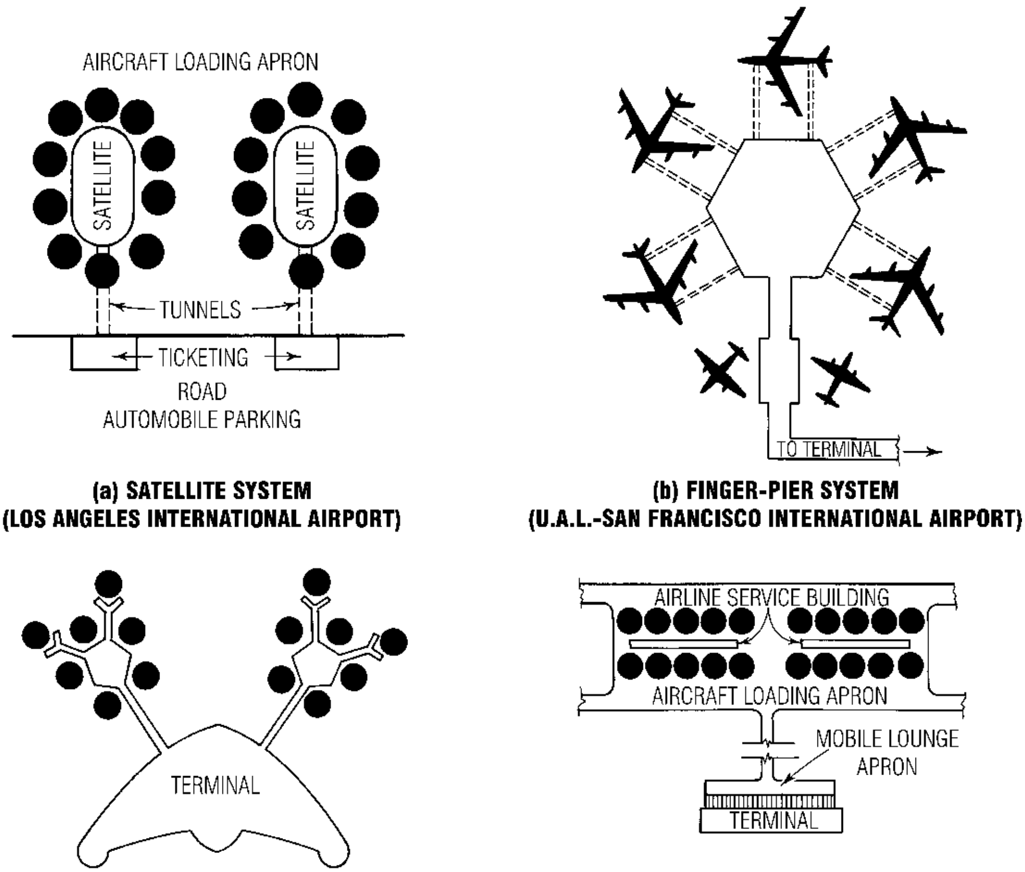
Finger systems project onto the parking apron and permit aircraft to park closer to the terminal. This arrangement reduces structural cost since loading is accomplished on both sides.

The finger system shown in Fig. 18.25*c* is a simple solution for a hub airport. Walking distances to the extreme end positions, however, could be rather long.

A more elaborate finger layout is the split-finger system (Fig. 18.25*d*). Here the passenger walking distances become quite long. A passenger transferring from the end-loading position of one finger to the end-loading position of another finger would walk more than ½ mi, assuming the aircraft parking positions to be 200 ft in diameter. Walking distances are inevitably long at centralized terminals that serve large numbers of gates, unless mechanical transfer of passengers is employed.

Unit terminals concentrate aircraft parking positions and minimize passenger walking distance except where interunit transfers are required. The movement from one unit terminal to another can involve excessive time and distance. Unit terminals are generally designed so that each unit is a self-contained entity.

Satellite terminals also concentrate aircraft parking positions in an effort to minimize walking distances. The satellites shown in Fig. 18.26*a* are fed



(a) SATELLITE SYSTEM (LOS ANGELES INTERNATIONAL AIRPORT)

(b) FINGER-PIER SYSTEM (U.A.L.-SAN FRANCISCO INTERNATIONAL AIRPORT)

(c) FINGER-PIER SYSTEM (T.W.A.-J.F. KENNEDY INTERNATIONAL AIRPORT)

(d) REMOTE PARKING SYSTEM (DULLES INTERNATIONAL AIRPORT)

Fig. 18.26 Terminal systems used at some international airports.

by tunnels from the ticketing area and provide a number of aircraft parking positions without excessive walking distances.

In Fig. 18.26*b* the satellite is a pier at the end of a finger and concentrates parking positions, with a resultant saving in walking distance. The terminal layout shown in Fig. 18.26*c* has two piers to serve 14 loading positions with relatively short walking distances. The pier-satellite approach offers minimum passenger walking distances for a large number of gate positions.

Remote parking of aircraft minimizes walking distances by using a vehicle to transport passengers from terminal to airplane. At some European airports, buses accomplish the transfer.

In an elaborate scheme under the remote concept, a mobile lounge moves passengers to and from aircraft parked some distance from the terminal (Fig. 18.26*d*). The mobile lounge is in use in several countries. At flight time, passengers are driven to the aircraft, or are met on arrival. Thus, the long walk between plane and terminal is eliminated.

18.15.2 Passenger Loading and Unloading

Passenger-loading devices permit weatherproof transfer from terminal to aircraft, usually with no change in level required. The *mobile lounge* is one type of loading device. Figure 18.27*a* shows the type of lounge vehicle used at Dulles Airport. Figure 18.27*b* shows passengers transferring from lounge to aircraft. Local-service airlines using small transport aircraft can be accommodated directly at the terminal.

The *telescoping gangplank*, shown in Fig. 18.27*c* and *d*, is the loading device in most general use. The telescoping passage has a swivel connection at the terminal. The aircraft end rides on a full-swivel gear that is electric-powered. Parallel parking is shown in Fig. 18.27*c*, with gangplanks serving front and rear doors of the aircraft. Airplanes that park at an angle may use a single gangplank, as shown in Fig. 18.27*d*. In both instances the aircraft can taxi into and out of gate positions. (Wide-body aircraft are normally towed away from parking positions.)

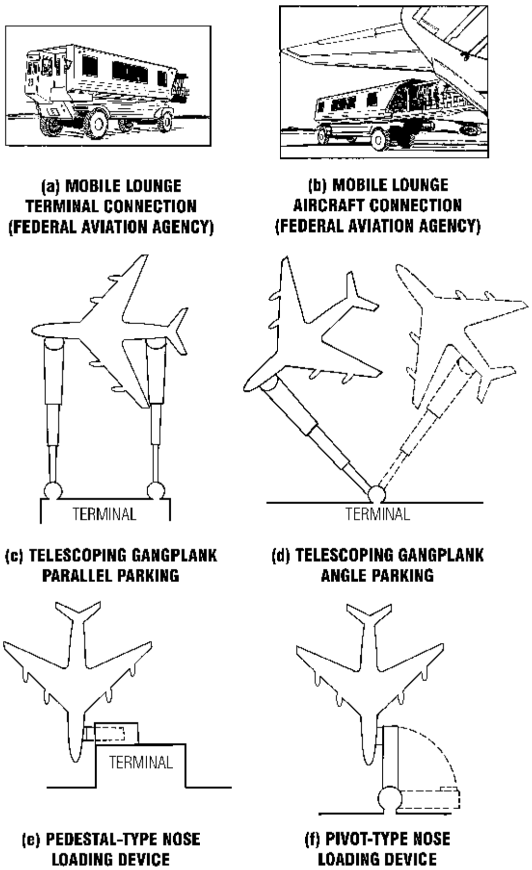


Fig. 18.27 Devices used for passenger loading on and unloading from aircraft at airports.

The *nose devices* shown in Fig. 18.27*e* and *f* permit aircraft to taxi into the parking position, but aircraft must be towed away from the gate. Deplaning the passengers is faster with nose loading devices, but the departure from the gate is slower.

In Fig. 18.27*e*, an adjustable transfer device suspended from a canopy on the outside of the terminal moves only a few feet to the aircraft door. The nose loading device in Fig. 18.27*f* is pivoted at the terminal and supported on fixed, powered wheels at the aircraft end. When not in use, the device is stored against the wall of the terminal and swings into position to connect to the doorway of the aircraft. Experience has shown that aircraft can be precisely taxied into parking positions so that elaborate adjustments are not required.

The pedestal device (Fig. 18.27*e*) is the least expensive, but the swivel type (Fig. 18.27*f*) can serve a greater variety of aircraft since it can serve a wider span of aircraft heights because of the longer ramp.

Other types of passenger-transfer devices include moving sidewalks in fingers and other places where feasible, horizontal transportation systems that connect unit terminals and satellites, and similar systems that can serve individual loading positions, to keep walking distances to a minimum.

18.15.3 Terminal-Building Layout

The key feature of any terminal-area layout is the terminal building. In size, it can be small for airports with low activity, or large and complex at primary-system terminals.

The terminal should be planned to serve the number of peak-hour passengers forecast for 10 years in the future. Flexibility and expandability are paramount requirements.

The terminal building should provide a smooth flow of passengers from parking lot to aircraft. The passenger should be able to park, or get out of a taxi, bus, or limousine, at a point near the ticket counter. Baggage is checked at this point. Then the passenger proceeds to the aircraft via a waiting room where rest rooms, telephones, concessions, and restaurant facilities should be available. At the loading position, there should be a hold room where the passenger may be processed for boarding the scheduled flight.

Deplaning passengers go directly from the aircraft to the baggage pickup area, then proceed to taxicab, bus, limousine, or parked automobile. Automobile rental counters should be near the baggage-pickup areas, and there should be telephones and rest rooms nearby.

Visitors should be provided with observation decks. The need for concession, restaurant, and office space will vary at each location. A greater variety of concession potential will obviously develop at the larger airports.

Airline facilities include ticket counters, ticket offices, baggage-processing areas (with baggage usually mechanically conveyed from the ticket counters), and operational space at the loading position. Inbound baggage should be available to the passenger at a convenient location, either placed by hand on a claim counter or mechanically conveyed by belt with spacers, diverters, or carousels for delivery to the arriving passenger.

At small airline terminals, the entire operation is at a single level. Larger terminals tend to have elevated roadways so that departing passengers enter the terminal at the second level and enter the aircraft at the same general elevation by means of a loading device. Deplaning passengers leave the aircraft at the second level and escalate down to the ground floor for baggage pickup and ground transportation. There are many variations of this scheme, but the pattern is the same.

The accommodation of FAA air-traffic-control quarters, as well as weather facilities, will vary from one location to another. There is a trend toward locating these government facilities in separate structures, away from the terminal but nearer to the general aviation activity. There is no fixed pattern. The need for such space in the terminal building varies from location to location.

18.16 Access Roads

In preparing a terminal-area layout, the engineer should recognize the importance of vehicular access. The area should be located so that full advantage is gained from freeways and other roads, planned or existing, that will expedite ground transportation to the airport.

Within the airport, the access-roadway system should provide a connection between the terminal area and the best routes to town. The system also should include roads for intercommunication between the separate facilities. Separation of passenger and commercial traffic is desirable, as well as separation of patron, spectator, and employee traffic.

18.17 Hangars

The size of hangars depends on the dimensions and numbers of aircraft to be serviced. Airports for general aviation usually have one or more service hangars that hold several aircraft, for which repair and maintenance operations are conducted. These hangars are supplemented by nests of T hangars, which provide individual stalls for aircraft storage. At larger airports, the trend is toward cantilever hangars, capable of accommodating the largest aircraft.

Table 18.10 gives the gross weight, wing span, length, and height of typical aircraft. Jet transport aircraft are being produced in short-, medium-, and long-haul versions. The larger jets have become even larger, with fuselage increases in excess of 30 ft and with gross weights exceeding 350,000 lb. Supersonic aircraft exceed the length and weight of a stretched-out jet aircraft. One model has a length of about 300 ft, a wing span of about 120 ft, and a gross weight of nearly 500,000 lb. Hangars to serve such aircraft must have built-in flexibility.

18.18 Cargo and Service Buildings

At many airports, air cargo is handled through the terminal building. Where separate cargo facilities have been developed, they usually have been located adjacent to terminal areas. Size and type of cargo facilities vary, depending on local need. Most are long, low structures with truck docks on one side and aircraft parking on the other. The roadway level on the truck side should be depressed to provide a truck-high floor for easy loading and unloading.

These separate cargo buildings not only provide facilities to load cargo directly into aircraft on the adjacent apron but contain facilities for sorting out small freight shipments to be taken to the terminal area on small carts and placed aboard passenger aircraft.

Table 18.10 Physical Data for Selected Aircraft

Name and model	Gross weight, lb	Wing span	Length	Height
Single Engine, Prop.				
Beech Bonanza	3,125	33 ft 5 in	25 ft 2 in	7 ft 7 in
Cessna 210	2,900	36 ft 7 in	27 ft 9 in	8 ft 8 in
Piper Saratoga	2,900	36 ft 0 in	24 ft 11 in	7 ft 3 in
Multiengine, Prop.				
Aero Commander	8,000	49 ft 0 in	35 ft 1 in	14 ft 6 in
Beech Super King Air	12,500	54 ft 6 in	43 ft 10 in	15 ft 0 in
Cessna Conquest	9,925	49 ft 4 in	39 ft 0 in	13 ft 1 in
Piper Cheyenne	12,050	47 ft 8 in	43 ft 5 in	17 ft 0 in
Executive Jets				
Lockheed Jetstar	35,000	54 ft 5 in	60 ft 5 in	20 ft 5 in
Grumman Gulfstream II	51,340	68 ft 10 in	79 ft 11 in	24 ft 6 in
Learjet 25	13,300	35 ft 7 in	47 ft 7 in	12 ft 7 in
Rockwell Sabreliner	17,500	44 ft 5 in	43 ft 9 in	16 ft 0 in
Airline Transports				
Airbus A-300	330,700	147 ft 1 in	175 ft 6 in	55 ft 6 in
B-737-200	100,800	93 ft 0 in	100 ft 0 in	36 ft 9 in
B-727-200	173,000	108 ft 0 in	153 ft 2 in	34 ft 0 in
DC-9-30	109,000	93 ft 4 in	107 ft 0 in	27 ft 6 in
DC-8-63	358,000	148 ft 5 in	187 ft 5 in	43 ft 0 in
B-747	775,000	195 ft 8 in	229 ft 2 in	64 ft 8 in
B-757	225,000	124 ft 10 in	155 ft 4 in	45 ft 1 in
B-767	350,000	156 ft 1 in	180 ft 4 in	52 ft 7 in
L-1011	432,000	155 ft 4 in	178 ft 8 in	55 ft 10 in
DC-10-30	555,000	161 ft 4 in	181 ft 11 in	59 ft 7 in
MOC-MD-11	602,500	169 ft 10 in	201 ft 4 in	57 ft 10 in

At smaller airports, the cargo is handled at the terminal building and carried only by passenger planes.

At most airports with scheduled passenger service some form of aircraft rescue and fire-fighting facilities is required. They should be provided at a location having ready access to all parts of the airport. Other buildings that might be required are heating plant, utility buildings, maintenance buildings, equipment-storage buildings, electrical equipment, and transformer vaults.

18.19 Airport Lighting

Airport lighting provides illumination to keep the facilities available around the clock. Lighting, usually kept on from dusk to dawn, assists in location and identification of the airport, outlines the usable areas, and furnishes guidance to moving aircraft.

Basic lighting consists of beacons, lighted wind indicator, runway or trip lights, and such obstruction lights as are required. Figure 18.28 illustrates the basic lighting at a small airport. Airport-lighting equipment and systems are subject to considerable modification in concept and design. The latest FAA recommendations and practices should be followed.

Airport Beacon ▪ This is a double-end, rotating light situated on or near the airport and visible from considerable distances. Appropriate color coding of the two beacon lenses will identify the airport as an unlighted facility (both lenses clear), or equipped with runway lights, burning or readily available (clear-green).

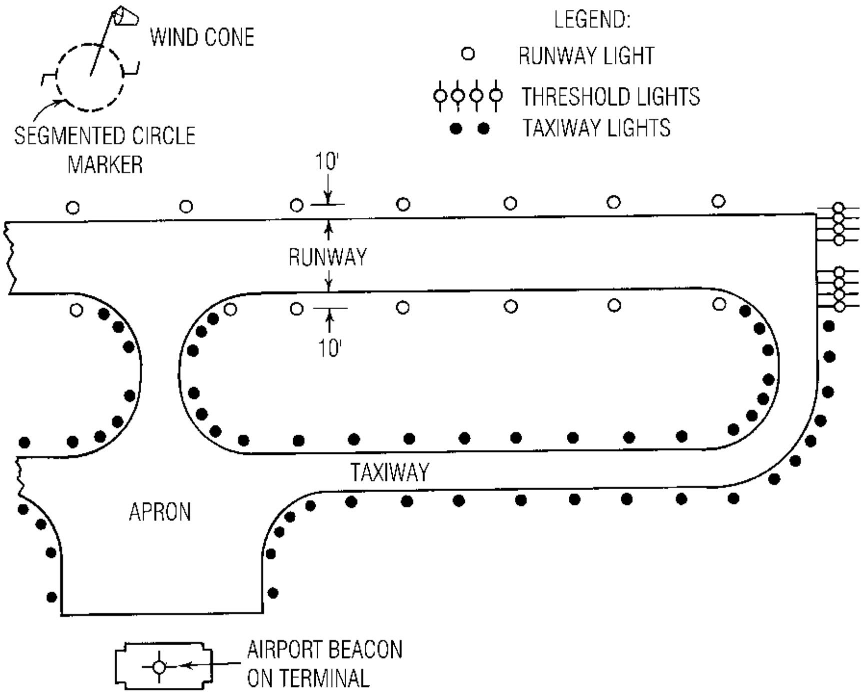


Fig. 18.28 Basic layout for airport lighting.

The beacon may be placed atop a structure or on a standard beacon tower. The beams of the beacon are set slightly above the horizontal and should clear all trees and obstructions in the vicinity.

Obstruction Lights ▪ These red lights mark objects that penetrate approach, horizontal, or conical surfaces (Fig. 18.1). Both steady-running and flashing obstruction lights are available for use according to requirements. The positions of lights will depend on the obstruction and its location with respect to the airport.

Wind Indicator ▪ Wind information is required at all times to permit aircraft to select the most favorable runway or landing strip for takeoff or landing. The simplest indicator is a wind cone, a free-swinging cloth cylinder which gives information as to wind direction and velocity. At larger airports, landing information is furnished by a wind tee. The cone and tee should be illuminated to provide information during hours of darkness.

18.19.1 Runway Lighting

These are low, elevated lights used to outline the edges of paved runways or to define unpaved runways. The smallest airports have lights mounted on driven stakes. At larger airports, the lights are mounted on heavy bases or small vaults of metal or concrete. The vault contains the isolating transformer for each fixture; otherwise, the transformer is buried alongside the runway light. The tops of bases and vaults are flush with the airport surface.

The lights are spaced 200 ft apart longitudinally and are usually 10 ft off the edge of the pavement (Fig. 18.28). They are fed from underground cables, either direct-burial or in ducts.

Medium-intensity runway lights are used on noninstrument runways and are adequate for visual operations. The intensity is controlled through a five-step regulator so that minimum intensity can be used in good weather. The lights have a Fresnel lens for optimum light distribution.

High-intensity runway lights are used on runways equipped for instrument landings or designated as instrument-landing runways by the FAA. These lights concentrate powerful beams down the longitudinal axis of the runway, in both directions. Intensity is controlled so that there is adequate guidance without undue glare.

Threshold Lights ▪ The effective end of each runway is indicated by runway lights (medium- or high-intensity) with green lenses. These lights are placed athwart the runway to mark its actual end, or outboarded beyond the edges of the runway for displaced thresholds. It is usual to place threshold lights at the actual runway ends (Fig. 18.28), except where clearance of obstructions in the approach dictates locating the threshold inward from the actual end.

In-Runway Lights ▪ Use of precision approach facilities to achieve lower weather minimums requires extensive electronic equipment in the aircraft, improved FAA navigation aids on the airport, and high-intensity runway lights, plus "in-runway" lighting. The last consists of center-line runway lights and touchdown-zone lighting. The lighting of the center line of taxiway turnoffs is desirable since it assists aircraft in clearing the runway during inclement weather.

Runway center-line lighting (Fig. 18.29) consists of fixtures installed at uniform intervals along the center line of a runway to give a continuous lighting reference from threshold to threshold. The lights are spaced at 50-ft intervals. Fixtures are installed in shallow holes drilled into the pavement. The lights are fed by cables installed in $\frac{1}{4}$in slots sawed 1 in deep. Isolating transformers are located at the sides of the runway.

Touchdown-zone lighting (Fig. 18.29) consists of 30 rows of transverse light bars at 100-ft intervals. Each row contains two bars. Set 30 ft on

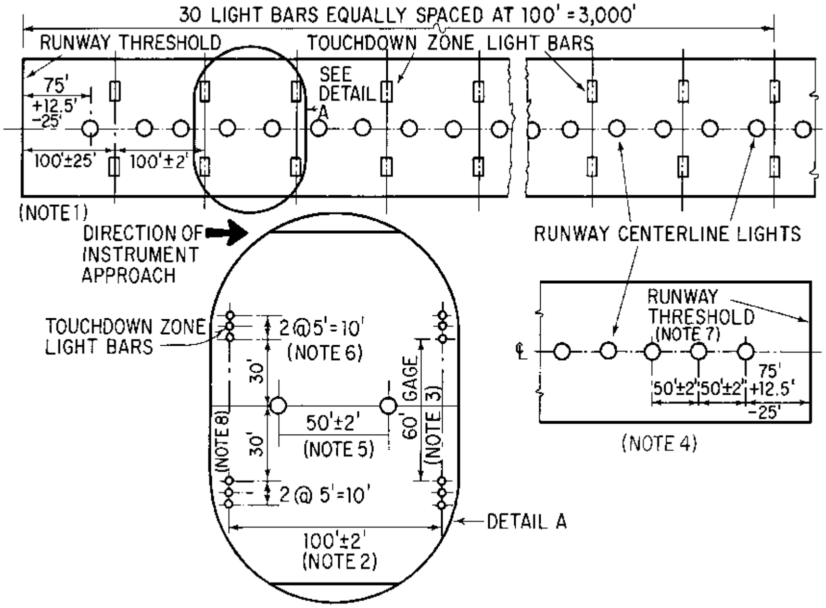


Fig. 18.29 Lighting layout for runway touchdown zone and center-line runway lights. NOTES: (1) In case of unusual joint location in concrete pavement, the first pair of light bars may be located 75 to 125 ft from the threshold. (2) Longitudinal tolerance should not exceed 2 ft. (3) Gage may be reduced to 55 ft to meet construction requirements. (4) Longitudinal installation tolerance for individual lights should not exceed 2 ft. (5) Center-line lights need not be aligned with transverse light bars. (6) Maximum uniform spacing of lights is 5 ft c to c. (7) Center-line lights may be located up to 2 ft from the runway center line to avoid joints. (8) Corresponding pairs of transverse light bars should lie along a line perpendicular to the runway center line. (*Federal Aviation Administration.*)

each side of the runway center line, each bar consists of three lights 5 ft apart, flush with the surface of the pavement, and aligned normal to the axis of the runway.

The fixtures are high-intensity lights installed in the pavement and fed through ducts or cemented into shallow holes drilled into the pavement and fed through cable installed in sawed joints. A variety of fixtures is available.

18.19.2 Taxiway Lighting

An airport with paved taxiways should have guidance lights if there is significant traffic at night. Taxiway lights are similar to medium-intensity runway edge lights, except that they are equipped with blue lenses. They are placed along the edges of taxiways to outline usable paved areas (Fig. 18.28). The longitudinal spacing varies with the taxiway configuration.

Taxiway Guidance Signs ▪ These are internally illuminated directional indicators placed low above the ground surface. They give abbreviated guidance to the ends of runways, terminal aprons, hangar areas, and other airport locations. Need for them depends on the volume of traffic and the complexity of airport layout and development.

Taxiway-turnoff lighting (Fig. 18.30) consists of lights installed, for relatively high-speed performance, along the center of a turnoff taxiway to indicate the exit path. The lights are spaced 50 ft apart. The fixtures are similar to those used in the runway center line.

18.19.3 Airport-Lighting Control

All airport lights should be controlled from a single panel, readily accessible to an operator. At small airports, a regulator assembly with controls built into the same cabinet provides a simple solution for basic lighting. Automatic controls (photoelectric or astronomic time switches) may be used where it is not feasible to have an operator on duty, or for remote beacons, obstruction lights, or other equipment, where direct control lines would not be economically feasible.

At airports with more complex installations, relay control equipment is placed in a transformer vault and lights are remotely controlled from the airport traffic-control tower or other central source. The remote-control source should have an adequate control panel, usually mounted on the control-tower console, and should contain circuit-control and brightness-control switches.

18.20 Airport Electric Power Supply

Provision of electric power to an airport for general purposes, as well as for airport lighting, requires a determination of power requirements and study of power availability. Usually, a second source of power is desirable to ensure reliability of the

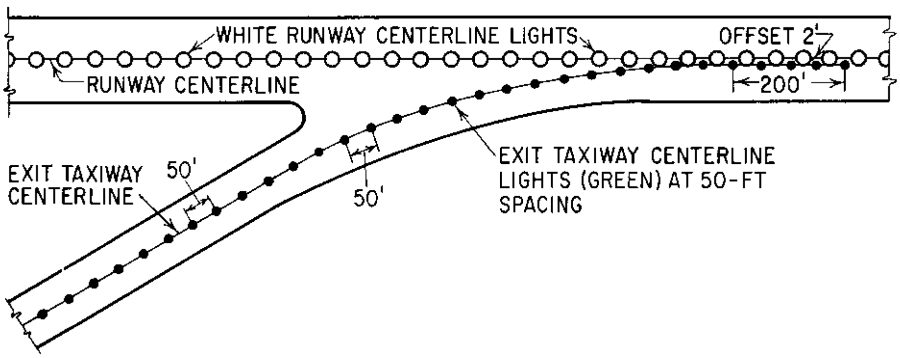


Fig. 18.30 Long-radius taxiway-turnoff lighting. A longitudinal tolerance may be necessary to avoid joints in rigid pavements. (*Federal Aviation Administration.*)

lighting system. The overall reliability of power from commercial sources will determine the possible need for standby service or equipment.

Electrical Ducts ▪ In the preparation of a master plan for an airport, provision of electrical ducts for all cable crossings under paved areas should be carefully studied. The various systems of lighting should be laid out in sufficient detail to permit cable runs to be determined. All lighting that can be contemplated as an ultimate requirement should be studied.

The FAA should be requested to furnish details of all installations that it might make so its cable requirements can be incorporated into the duct plan.

When runways, taxiways, or aprons are paved, care should be taken to ensure that adequate electrical ducts are provided to preclude costly jacking or cutting of pavements at some future date. A number of spare ducts might well be provided in all instances.

18.21 Airport Marking

In addition to airport lighting, marking of facilities assists in guidance day and night and enhances operations in periods of restricted visibility. Federal Aviation Administration national standards should be followed.

The basic marking at an airport consists of a segmented circle marker (Fig. 18.28) and a wind indicator. The segmented circle marker is placed just outside the usable landing area. It identifies an airport and provides a central location for such indicators as exist at that airport.

The marker is a broken circle 100 ft in diameter. At the center is a conventional wind cone. A tee, however, may be used as a landing direction indicator.

Radial extensions beyond the 100 ft circle show the orientation of landing strips or runways. Extensions of the radials to the left or right indicate the airport traffic pattern.

Obstructions should be day-marked for maximum visibility. Other marking includes the numbering and striping of runways for normal identification, striping of taxiways, marking of unusable areas, and special runway marking to facilitate operations during low-visibility weather.

18.22 Fuel Systems

Regardless of the volume of traffic at an airport, some system of supplying fuel to aircraft must be provided. The simplest system at a small airport is an underground tank and an elevated dispenser, not unlike a regular service station pump. Usually provided by a petroleum company, this system requires aircraft to taxi to a central location for service (Fig. 18.25*a*).

Generally, a single grade of fuel is available. Each additional grade and type of fuel requires a separate installation.

Airports with a medium volume of traffic normally use fuel-truck dispensers. These are serviced from local bulk stations if traffic is low and from airport storage if there is a sufficient volume of traffic to warrant. The busiest primary-system airports require fuel in such quantities that supply, storage, and distribution become special and complex problems.

Fuel Supply ▪ Depending on overall fuel requirements coupled with local conditions, fuel will be supplied to the airport by truck delivery from local sources; tank truck, rail, or barge deliveries from refineries or bulk-storage sources; direct pipeline delivery; or various combinations of these. The heavier the volume of traffic, the more varied the types of fuel required.

Even at some airports where large quantities of certain varieties of fuels come by pipeline, the demand for other varieties is so low that truck delivery is employed for them. It is necessary to make a forecast of the demand for various grades of fuel, to determine long-range sources of availability, and to study all possible methods of delivery as a prerequisite to the design of an airport fuel system.

Fuel Storage ▪ The bulk-storage system at the airport should provide for each type of fuel to be handled. Normal practice is also to maintain brand segregation. The capacity for each type should be adequate to accommodate fueling requirements for several days.

Delivery provisions should be flexible. There should be truck stands so that fuel can be unloaded from trucks and pumped into storage. Even where trucks are not the major source of supply to the airport, truck stands should be adequate to supply the entire fuel demand in an emergency, with pumping capacity sized accordingly. The same pumping capacity can be used for rail or barge supply.

Pipeline delivery will normally not require pumping capacity, inasmuch as fuel can be transferred under pressure to storage tanks. A waste tank should be provided for changing types of fuel without affecting type integrity.

The storage tanks should be interconnected to provide for interchange or transfer of fuel within the storage area. Tanks should be adequate to handle modern jet fuels. Usually, inert-gas explosion suppression is provided, or the tanks have floating roofs. The storage system should be capable of easy expansion or modification.

Fuel Transfer ▪ Fuel is pumped from storage tanks through filter separators to pits, hydrants, or truck-loading stands, either directly or through satellite storage areas. If the distance is great, the size and number of transfer pipes may be reduced by introducing one or more satellite storage areas.

It is usual to have a separate satellite area for each user or group of users. Pumps take fuel from satellite storage through filter separators and to pits, hydrants, or truck stands.

Fuel Delivery ▪ Trucks and pits are used for low-capacity delivery of fuel. High-capacity fuel delivery is accomplished by hydrants and hose carts.

Truck stands serve as loading points for fuel trucks, which deliver from the trucks directly into aircraft fuel tanks, through filter separators.

Pits contain booster pumps, filter separators, and coiled hose to deliver fuel directly into aircraft tanks similar to truck delivery.

Hydrants provide for quick connection to hose carts. These are powered vehicles equipped with filter separators and pressure regulators to deliver fuel at high rates, under pressure, through underwing loading.

18.23 Air-Traffic Control

Airports are developed through the initiative of local communities, but the control of air traffic is a function of the Federal government. It is usual for air-traffic-control facilities to be installed and operated wholly with Federal funds.

Some auxiliary facilities, such as high-intensity runway lights and in-runway lighting, are the responsibility of the local community owning the airport. Facilities that furnish guidance along the airways and assist in the transition from airway to airport are usually installed without local participation. The FAA has criteria based on volumes of traffic that are used to locate specific control facilities at an airport. Articles 18.23.1 to 18.23.3 provide general information concerning location and installation, but the FAA should be contacted for the latest revisions.

(“Airport Design Requirements for Terminal Navigation Aids,” Federal Aviation Administration.)

18.23.1 Instrument Landing System (ILS)

The ILS is an electronic facility that furnishes three-dimensional information in the final portion of an airport approach, to permit an aircraft to fly to the landing runway in inclement weather. The system consists of localized glide slope, outer marker, and middle marker.

Localizer equipment provides an electronic course down the projected center line of the runway for lateral guidance. The equipment is normally installed 1000 ft beyond the end of the runway opposite the approach direction. The area between the end of the runway and the localizer should be smooth, and within a circular area 500 ft from the localizer there should be no trees, buildings, roads, or fences.

Glide-slope reference is transmitted from equipment located 400 to 600 ft off the center line of the runway and 750 to 1250 ft in from the approach end. A smooth area is necessary for a considerable distance in front of the glide-slope unit to ensure the stability and accuracy of the electronic emissions.

Outer-marker equipment is located 4 to 7 mi from the airport on the projected center line of runway. The signals from the outer marker indicate distance from the runway end.

Middle-marker signals indicate a point about 3500 ft from the runway end.

(“Airport Design Requirements for Terminal Navigation Aids,” Federal Aviation Administration.)

18.23.2 Approach-Light Systems

This is a system of high-intensity lights that extend outward from the approach end along the projected center line of the runway. They provide visual reference to the instrument runway during the transition from instrument flight to visual flight.

The system consists of horizontal 12-ft bars of high-intensity lights spaced 100 ft apart longitudinally for a distance of 1400 to 3000 ft. Each bar contains, in addition, a condenser discharge light. These flash in sequence toward the runway.

An area 400 × 3200 ft is desirable for the installation of the approach-light system. The lights are placed on piers or towers as required to provide a uniform light line at a slope not exceeding 2% upward from the end of the runway or a slope of 1% downward.

Runway-End Identifier Lights ▪ This system consists of a pair of synchronized flashing lights. One is located on each side of the runway-landing threshold facing into the approach area. The lights are placed 40 ft outward from the runway edge lights. The flashing lights provide rapid and positive identification of the approach end of a particular runway.

Precision-Approach-Path Indicator ▪ This is a system of visual-approach indication, designed to provide visually the same information that a glide-slope unit provides electronically. Normally, four light units in one row are placed 1000 ft in from the runway threshold. The lights are placed 50 ft from the runway edges.

The light units have beams elevated so that a specific approach slope is indicated through the proper combination of red and white lights; for example, two red and two white. The approach slope may be set to clear a specific obstruction or to enhance noise-abatement procedures.

("Airport Design Requirements for Terminal Navigation Aids," Federal Aviation Administration.)

18.23.3 Other Airport Traffic Controls

Surveillance radar controls traffic within a considerable distance from the airport, about the same range as covered by the airport approach-service control. No unusual siting problems are involved.

Precision-approach radar system is used to monitor or control traffic approaching the instrument runway. It is located alongside the instrument runway 400 to 750 ft from the center line.

Terminal VOR omnirange is a terminal facility similar to the standard VOR (VHF omnirange) navigation device. When it is sited on an airport, there should be a clearance of 1200 ft in all directions to ensure true azimuth course indication.

Transmissometer is a device that furnishes visibility-measurement information for the runway touchdown area. The installation is located slightly more than 400 ft from the center line of the instrument landing system runway.

Airport traffic-control towers are provided by the FAA at those locations where new towers are required. The control tower should be located at a point from which all portions of the runways, taxiways, and aprons are visible. Requirements for each airport will vary; hence, they should be checked with the FAA.

Airport surface-detection equipment comprises a radar system that permits the observation of aircraft ground traffic on the airport. It is usually located on top of airport traffic-control towers.

("Airport Design Requirements for Terminal Navigation Aids," Federal Aviation Administration.)

18.24 Heliports

Helicopters in civil use vary in size, number of rotors, number of engines, and overall weight. Small helicopters usually employ a single rotor for lift and lateral control and a vertical tail rotor for pivotal or yaw control. Large civil helicopters have a single main rotor and vertical tail rotor or two main rotors located in tandem along the longitudinal axis of the helicopter. There are other potential configurations, including intermeshing main rotors placed normal to the main axis, and various models of vertical-lift devices and convertible aircraft that can take off vertically and, through variable aircraft geometry, fly horizontally at speeds greater than those possible for helicopters.

Helicopters rise vertically a few feet above the heliport surface when taking off. Then they accelerate upward and forward on a sloping path to climb-out speed and continue to en-route altitude.

Landing involves an approach on a sloping path to a hovering position a few feet above the heliport surface. Then, the craft descends vertically to a selected landing point. Sideward flight may be performed easily during the landing maneuver, so the helicopter will land in a precise position. Ability to operate vertically permits the helicopter to land and take off using areas only slightly larger than its own dimensions.

18.24.1 Heliport Classifications

Heliports, as described in FAA Advisory Circular 150/5390-2A, are classified by use as private, public—general aviation, public—transport, and hospital. Private-use heliports are developed for the exclusive use of the owner and person representing the owner. General aviation heliports are intended to accommodate individuals, corporations, and helicopter air-taxi operators. Scheduled passenger services may be available. Transport heliports are intended to accommodate air-carrier operators who provide service with large helicopters. Hospital heliports are limited to serving helicopters engaged in air ambulance or other hospital-related functions. Helistops are heliports with minimum support facilities; that is, no shelter, maintenance, or fueling.

Heliports are developed around a *design helicopter*, the largest helicopter expected to use the heliport during future years. For heliports located on airports, helicopters are classified as small, medium, or heavy for determining the distance between landing facilities.

Small helicopters (up to 4 passengers) generally weigh up to 6000 lb, are 30 to 40 ft long, 9 to 10 ft high, and have rotor diameters up to 35 ft. Medium helicopters have a takeoff weight between 6000 and 12,000 lb. Larger helicopters in general use weigh up to 20,000 lb, carry as many as 30 passengers, are 65 to 85 ft long, up to 17 ft high, and have rotor diameters up to 55 ft. Most small helicopters use a skid-type landing gear, but large helicopters use wheel landing gear with a three- or four-wheel configuration.

18.24.2 Final Approach and Takeoff Area

Although planning considerations are the same for the various classifications of heliports, requirements for physical characteristics differ slightly. Heliports have in common the final approach and takeoff area (FATO), which is an object-free area available for helicopter landings and takeoffs. The FATO may be at ground or water level or elevated, on a pier or rooftop. At least one clear path from the FATO aligned with the prevailing wind should permit approach and takeoff of a helicopter clear of all objects (Fig. 18.31.) A FATO should have a minimum dimension (length, width, or diameter) 1.5 times the overall length of the design helicopter. If a heliport is 1000 ft or more above mean sea level, consideration should be given to elongating the FATO in the direction of takeoff. The FATO should be smooth. Grades may range from 0.5% to a maximum of 5.0% to ensure good drainage, but they should not exceed 2% in any area where a helicopter is expected to land.

A safety area, free and clear of objects that could be struck by the main or tail rotor or that could catch the skids of an arriving or departing helicopter, should surround the FATO. The width of this area, measured outward from the FATO, should be at least one-third the rotor diameter but not less than 20 ft.

18.24.3 Touchdown and Liftoff Area

A FATO should have a touchdown and liftoff area (TLOF) with a paved or other hard surface, preferably centered in the FATO. The diameter of the TLOF should be at least that of the rotor of the design helicopter. (When the entire FATO is load-bearing, however, an identifiable TLOF may not be required.)

For ground-level heliports, the surface of the TLOF should be portland cement-concrete. An asphaltic concrete surface may also be used, but provision should be made for the possibility that ruts may form under wheels or skids due to hot climatic conditions or the repeated loads of landing and parking helicopters. (Ruts are suspected of being possible factors in some rollover incidents.) Pavements should be designed to support 1.5 times the maximum weight of the design helicopter. They should have a broomed finish to enhance safety of persons and helicopters on the TLOF.

An elevated TLOF also should be designed to support 1.5 times the maximum takeoff

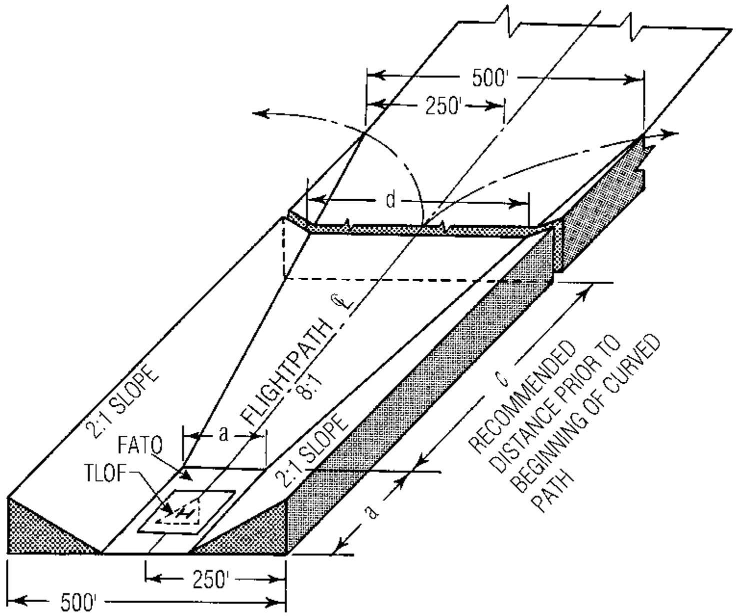


Fig. 18.31 Standard dimensions for heliports and approaches. FATO length and width *a* should be at least 1.5 times the overall length of the design helicopter. Straightway approach-departure length *c*, width *d* of the flight path at the wide end of the straightway, and the radius of the curved path should each be at least 300 ft.

weight of the design helicopter. The TLOF may be constructed of wood, metal, or concrete, but usually, a combination of steel and concrete is used. The gradient of an elevated TLOF should be about the same as that for a ground-based TLOF.

When a TLOF is elevated more than 30 in above its surroundings, a 5-ft-wide safety net or shelf should be provided in lieu of a railing. The safety net should have a load-carrying capacity of at least 25 lb/ft^2. Normally, it is installed with a slight slope upward and outward from the TLOF with the outer edge projecting above the TLOF 2 in or less.

Engineers should obtain information from local building officials on design loads for elevated heliports; fire-extinguishment requirements; and storage, handling, and dispensing of aircraft fuels. Information also should be obtained from the nearest FAA Airports District Office on requirements for heliport markers and markings, wind indicators, heliport lighting, and approach and navigational aids applicable to the type of heliport being designed. The FAA should also review environmental impacts and compatibility of land uses in the vicinity of the proposed heliport.

18.24.4 Approach and Takeoff Paths

All public-use heliports should have more than one approach and takeoff path. One path should be aligned with the predominant wind during operations in visual meteorological conditions (VMC). Another path, if practicable, should be aligned with the prevailing winds for operations in instrument meteorological conditions (IMC). Visual approach and takeoff paths may curve to avoid objects or noise-sensitive areas or to utilize the airspace above public ways, such as freeways and rivers (Fig. 18.31).

A visual approach and takeoff surface should be centered on each approach and takeoff path. This surface should conform to the dimensions specified in the FAR Part 77 heliport approach surface.

Approach-departure paths should be laid out to offer the best lines of flight. It generally is necessary to have at least two flight paths, usually 180° apart, but the paths may be as little as 90° apart.

Curved paths are practicable but should be used with a minimum straightway approach-departure length of 300 ft (Fig. 18.31). The center-line radius of a curved path will vary, depending on local conditions and type of helicopter used. In general, however, the radius of the curved path should be at least 300 ft.

The approach-departure path has the same width as the contiguous edge of the landing and takeoff area and flares uniformly on each side of the center line to a width of 500 ft at the en route altitude. The slope of the path is 1 ft vertical for each 8 ft longitudinally (8:1). Objects that extend above this sloping plane are obstructions.

Transition areas are surfaces along the lateral boundaries of the landing and takeoff area and the approach-departure areas. The surfaces, or "side slopes," extend outward and upward from the edges of the heliport and approach-departure areas for a distance of 250 ft from the center line. The slope is 2:1 upward from the edge of the landing and takeoff area or from the edge of the sloping approach-departure plane.

Heliport proponents or owners should own or control property underlying the approach and takeoff surface outward to a distance where the surface is 35 ft above the heliport.

18.24.5 Helicopter Parking

Public heliports, not designed as helistops, should have an area designated for parking helicopters. The size required for this area, or apron, depends on the number of helicopters to be accommodated. The clear distance from any part of a helicopter on its intended path to another helicopter or any object should be at least one-third the rotor diameter, but not less than 10 ft. If a helicopter must turn more than 30° within a parking position, clearance of the tail rotor beyond one-third the rotor diameter or 10 ft. whichever is larger, may control location of parking positions. Parking pads should have a minimum dimension of 1.5 times the undercarriage length or width of the design helicopter.

Taxi routes or taxiways should connect the FATO to the area designated for helicopter parking. They should be designed to provide 20 ft of rotor tip clearance to objects and parked helicopters for hover taxiing and 10 ft of clearance for ground taxiing. Paved surfaces of taxiways should have at least twice the undercarriage width of the design helicopter. If the surface is unpaved, it should be treated in some manner to prevent dirt and debris from being raised by the rotor wash of a taxiing helicopter.

18.24.6 Heliport Layout and Design

A heliport may be sited on the ground or on top of a building. For greatest utility to helicopters, the site should be as close as possible to the locale it serves. It should provide operational safety, have clear approaches, and be compatible with air traffic in the vicinity. It should fit in with area planning and not have an adverse impact on the community.

The small heliport may consist of only a designated area containing an unsurfaced landing and takeoff area (Fig. 18.32) or of an elaborate facility with a paved landing area, parking and service aprons, heliport terminal, and automobile parking (Fig. 18.33).

Standard grading and drainage practices should be employed. The rotor downwash of helicopter operations usually requires a stabilized landing and takeoff area at a minimum. A paved touch-down pad is desirable.

Ground locations for heliports usually permit less expensive construction than rooftop sites but are seldom available in congested areas. Rooftop locations usually have advantages of accessibility and clear approaches to counter the disadvantages of limited space, difficulty of locating emergency-landing areas, and the probable need to strengthen the structure. It is necessary to consider wind effects as well as local building codes, zoning, and fire regulations.

If the structure requires reinforcing, a load-distribution pad might be satisfactory. The pad need not be so large as the landing and takeoff area, but the full area should be a clear area. The pad can be as small as 20 × 20 ft for smaller helicopters, up to 50 × 50 ft for larger vehicles. The rooftop heliport should be of sufficient strength that it will not fail under unusual, high-impact landings. The landing surface should be designed for a concentrated load equal to 75% of the gross weight of the helicopter on any 1 ft^2 of the surface.

Wind conditions might require baffles to eliminate turbulence across the surface of the heliport.

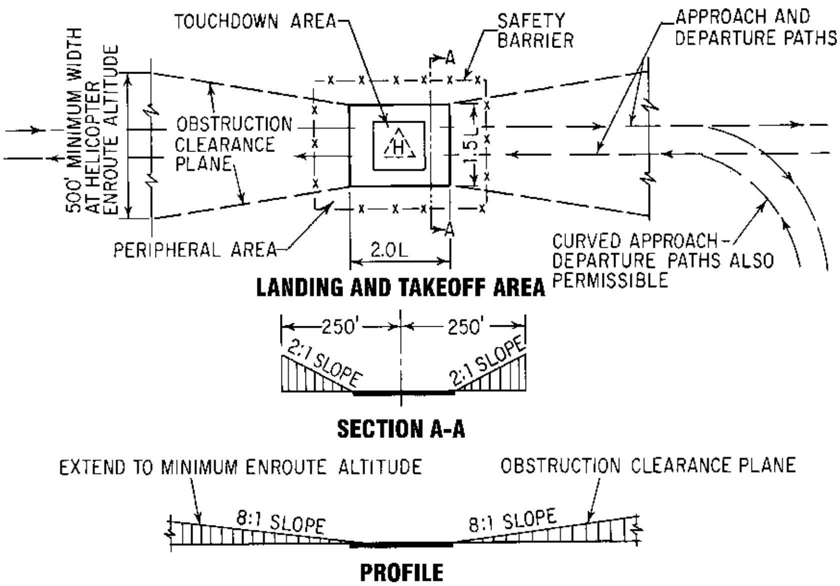


Fig. 18.32 Layout for a small heliport. L = overall length of design helicopter. (*"Heliport Design," Federal Aviation Administration.*)

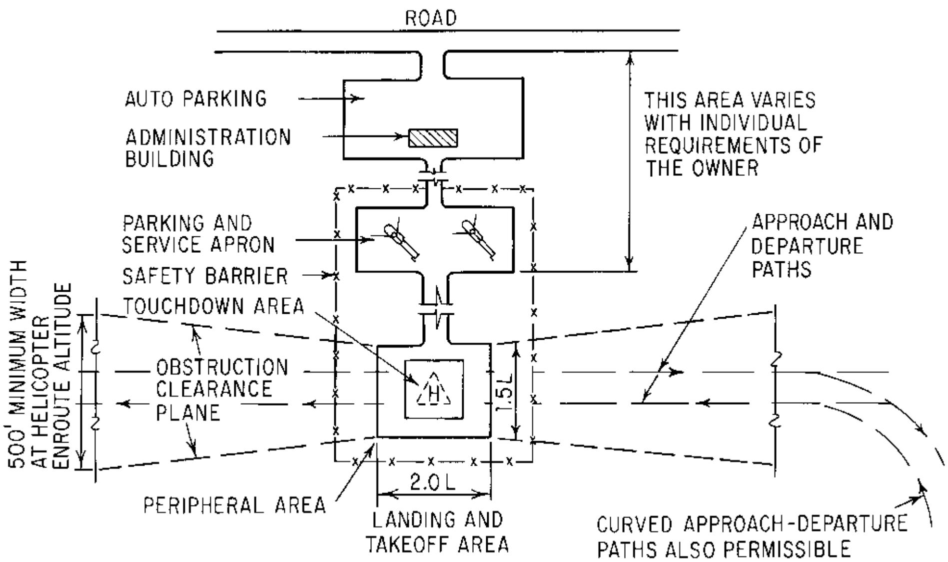


Fig. 18.33 Layout for a large heliport. L = overall length of design helicopter. (*Federal Aviation Administration.*)

Also, a safety device should be provided around elevated touchdown areas or landing pads. This should extend outward from the touchdown area.

18.24.7 Heliport Marking and Lighting

Standard heliport markers, placed near the center of the touchdown area, are shown in Fig. 18.34.

The touchdown area should be marked with a border at least 1 ft wide. The boundary of the landing and takeoff area should be made conspicuous by low markers spaced 25 ft apart. A wind indicator should be adjacent to the landing and takeoff area, located to provide true wind information.

Obstructions should be marked and lighted. Yellow boundary lights may be used to outline the

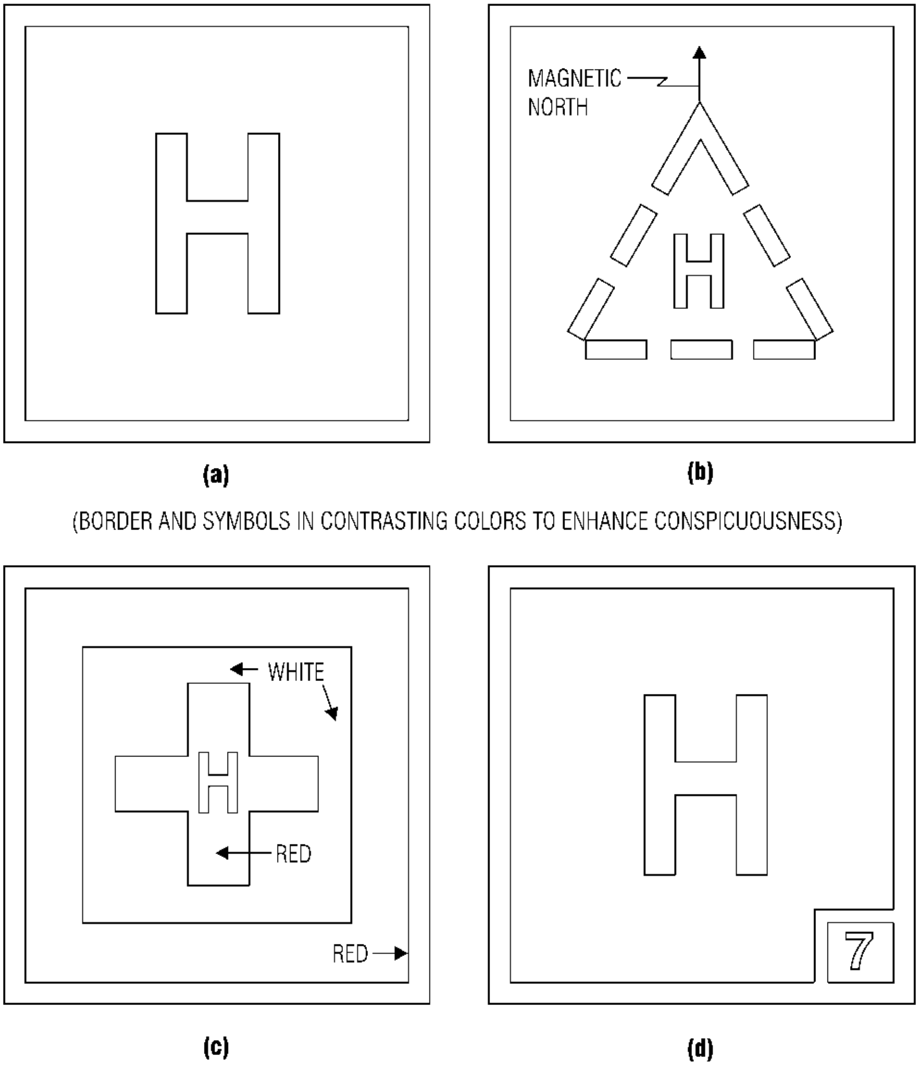


Fig. 18.34 Heliport markers: (*a*) Standard public heliport markers; (*b*) example of marker for private-use ports; (*c*) marker for hospital heliport; (*d*) weight-limiting marker (7000 lb indicated) for elevated heliports. (*"Heliport Design," Federal Aviation Administration.*)

landing and takeoff area. Floodlighting will be effective. One method is to place low Fresnel-lens lights around the landing and takeoff area, with a sharp cutoff that will not bother the pilot.

("Heliport Design," Federal Aviation Administration.)

18.25 STOL Ports

There is a great potential for STOL (short take-off and landing) aircraft in short-haul transportation, serving stage distances of up to 500 mi. There is considerable advantage for city-center-to-city-center and intracity air-passenger carriers that can provide better service to passengers and relieve both air-space and ground congestion at large airports.

Criteria for STOL ports are tentative and subject to change as evaluation of proposed STOL aircraft and operational experience dictate. Significant future changes may be incorporated into revisions to the Federal Aviation Administration publication, "Planning and Design Criteria for Metropolitan STOL Ports." The STOL vehicle promises shorter runways, steeper approach paths, lesser real estate requirements, and the prospect of in-town airport locations, but more research and testing are needed.