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A SunCam online continuing education course

Airport Engineering

Part II: Runway & Taxiway Design

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Introduction

This course focuses on runway and taxiway design with an engineering perspective. As discussed in Part I of this series, airports in the United States are subject to FAA regulations. The basis of the information in this document is generally derived from FAA Advisory Circular 150/5300-13A *Airport Design*. The use of advisory circulars is not mandatory, but they are indispensable when designing to specific criteria. Therefore, we'll go straight to the source of the FAA's standards and recommendations for design and use AC 150/5300-13A as the foundation of this topic. All data, tables, and dimensions in the following course are taken from this document. Hopefully, this course familiarizes you with the federal standards and makes them easier to understand if you've not yet been acquainted. It should also be noted that advisory circulars are regularly updated, and the technical details contained within this course may not reflect the most current revision of the standards.

You will also notice this course only nominally discusses a significant topic regarding runway and taxiway design: pavement strength. Airport pavement involves the standard design components: subgrade, paving materials, loads, climate, traffic volume, etc. In addition, flexible and rigid designs must support aircraft loads and be firm, stable, and skid-resistant in all weather conditions. The FAA even has a software to assist engineers in airport pavement design, called FAARFIELD. AC 150/5320-6F *Airport Pavement Design & Evaluation* focuses on this subject and is worthy to be the focus of an entire course in itself.

Turf runways are low-cost alternatives to paved runways. In locations where traffic volume is low, and wheel loading is light, turf runways are actually preferred by some pilots. Turf runways are not generally compatible with instrument procedures. Distances (landing, takeoff, and accelerated stop) are recommended to be increased by 20% for turf runways. This course concentrates only on paved runways.

Runway Design

FUNDAMENTALS

By definition, a runway is a defined rectangular surface on an airport suitable for the landing or takeoff of aircraft. Runway design first requires selecting a design aircraft, as discussed in the previous course. Next, the **runway design code** (RDC) must be determined that reflects the planned level of service for a runway. A RDC is comprised of three components: Aircraft Approach Category (AAC), Airplane Design Group (ADG), and visibility minimums. AAC and ADG both depend on aircraft and have already been addressed in Part I. Visibility minimums, however, are a measure of how far down the runway a pilot should be able to see during an instrument approach. They do not depend on aircraft and are a function of weather and other conditions. If a runway is categorized as visual only (no instrument approaches), the third component of the RDC will be indicated as "VIS". The general runway visual range (RVR) determines the designated or planned approach visibility minimums:

RVR (ft) *	Instrument Flight Visibility Category (statute mile)
5000	Not lower than 1 mile
4000	Lower than 1 mile but not lower than ¾ mile
2400	Lower than 3/4 mile but not lower than 1/2 mile
1600	Lower than 1/2 mile but not lower than 1/4 mile
1200	Lower than 1/4 mile

* RVR values are not exact equivalents.

An example runway based on general aviation use might have the Runway Design Code (RDC) of **B-II-2400**, indicating AAC B (91 ≤ V_{Ref} ≤ 121 kts), ADG II (Tail Height 20'- < 30' or Wingspan 49'- < 79') and RVR of 2400 feet. A different runway on the same airport could have an RDC of **C-IV-1200**, indicating acceptable use for larger and faster aircraft with less than ¼ mi visibility RVR.

Once the design aircraft and runway design code are selected, airport engineers can begin crafting the infrastructure that satisfy these demands. As always, safety is the highest priority for any airport development. In addition, reduction of noise and delays, increased efficiency, economic viability, and environmental protection should be hallmark characteristics of an airport project.

Declared distances are the maximum distances available for takeoff, aborted takeoff, and landing requirements. Runways may have declared distances specified in the airport directory manual. If they are not specified, the declared distances are equal to the physical length of the runway unless it has a displaced threshold, in which case that length is subtracted from the overall length. Examples of declared distances are:

TORA – Takeoff Runway Available
TODA – Takeoff Distance Available
ASDA – Accelerate Stop Distance Available
LDA – Landing Distance Available

Pilots use these values to ensure a runway is suitable to accommodate their aircraft based on its performance, weather conditions, and operating weight. Determining the values of declared distances and their geometry is not particularly complex, but it does incorporate RSA boundaries, approach and departure surfaces, threshold siting, ROFA, stopways, clearways, and other runway features. Thus, each runway should be carefully evaluated according to the standards.

Runway Approaches

Pilots know that while takeoff is optional, landing is mandatory. Accident statistics indicate that over 45% of all general aviation accidents occur during the approach and landing phases of a flight. So, particular attention to runway landing features is essential. Ideally, a normal landing approach is made into the wind, with no obstacles present, onto a firm landing surface that is long enough to accommodate a gradual stop. Maximum utility is provided when a runway can be used in various weather conditions. Weather affects many aspects of flight but is most critical in affecting visibility. However obvious this is, pilots have to see the runway. If the runway environment (lighting, markings, etc.) cannot be identified at a minimum visibility point on the approach, pilots are not authorized to land. Therefore, the ultimate design of a runway should accommodate one of the following visibility categories:

1) Visual (V) - Runways classified as Visual are not designed to handle, or anticipated to handle, any Instrument Flight Rules (IFR) operations now or in the future, except circling approaches. Lighting is minimal if present.

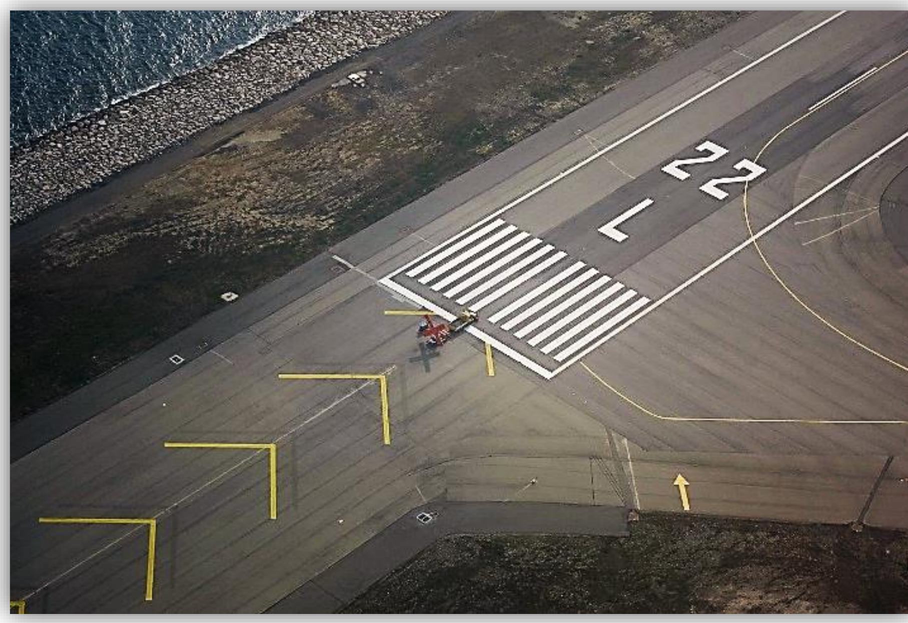
2) Non-Precision Approach (NPA) - Runways classified as NPA are designed to handle straight-in instrument approaches providing only lateral guidance. NPA runways will only support IFR approach operations to visibilities of 3/4 statute mile or greater. These runways are generally at least 3,200 feet long, are lit with at least LIRL or MIRL, and have non-precision runway markings as defined in AC 150/5340-1.

3) Approach Procedure with Vertical Guidance (APV) - Runways classified as APV are designed to handle instrument approach operations where the navigation system provides vertical guidance down to 250 feet HATh (Height Above Threshold) and visibilities to as low as 3/4 statute mile.

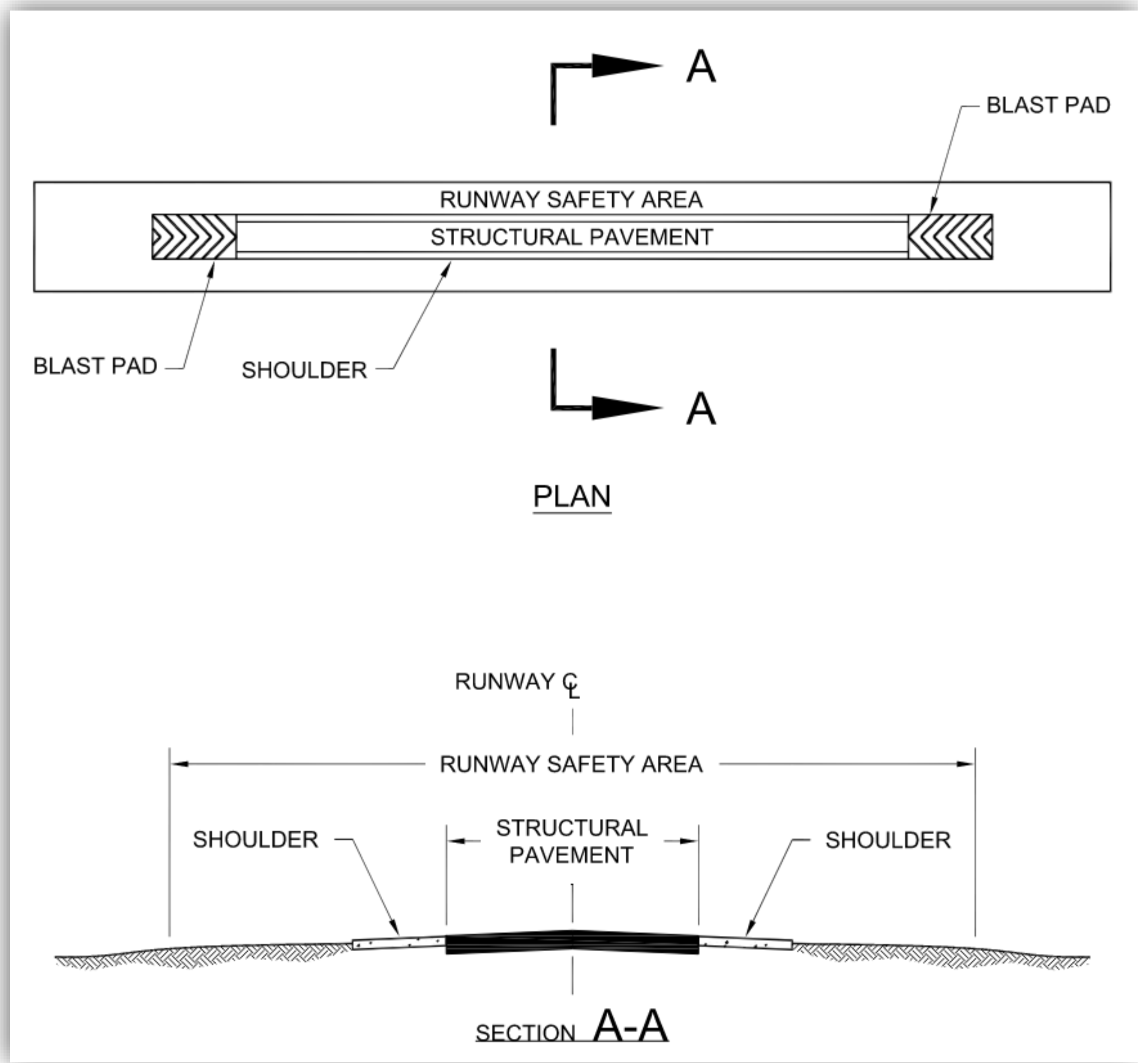
4) Precision Approach (PA) - Runways classified as precision are designed to handle instrument approach operations supporting instrument approach with HATh lower than 250 feet and visibility lower than 3/4 statute mile, down to and including Category (CAT) III. These runways are typically lighted by High Intensity Runway Lights (HIRL) and must have precision runway markings as defined in AC 150/5340-1.

Runway Siting & Safety Zones

Runway location and orientation are paramount to airport safety, efficiency, economics, and environmental impact. There should be enough runways on an airport to meet air traffic demands at peak volume. Runway orientation factors include the direction of prevailing wind, airspace analysis, topography, and wildlife hazards, among other things. Aircraft should be able to operate within limits of crosswind components. Runway intersections should be avoided. Runways also must maintain certain line of sight requirements to ensure safety and visibility for aircraft and vehicles operating on the runway. Consideration to ultimate runway length and visibility minimums is necessary when evaluating new runway locations, with future expansion in mind.

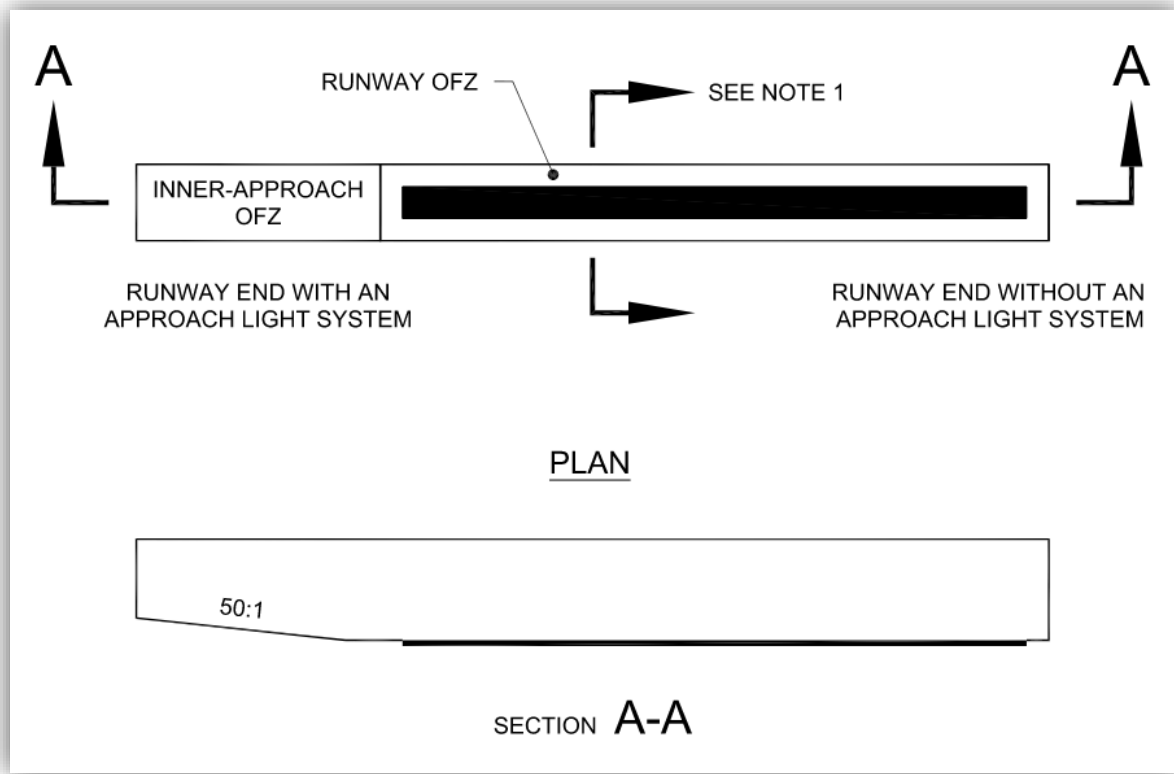


Runway shoulders provide resistance to blast erosion and accommodate the passage of maintenance and emergency equipment and the occasional passage of an aircraft veering from the runway. A stabilized surface, such as turf, normally reduces the possibility of soil erosion and engine ingestion of foreign objects. The shoulders are within the **runway safety area** (RSA) which is a defined surface that surrounds the runway and is intended to reduce risk of damage to an aircraft in the event it leaves the pavement. RSA's must be cleared of debris and graded to avoid projecting objects higher than 3 inches above grade. They also should be well drained and capable of supporting occasional aircraft, airport rescue and firefighting (ARFF) vehicles, and snow removal equipment. NAVAIDs and other critical items that must be within the RSA are required to be mounted with frangible connections. The following figure shows a runway safety area:



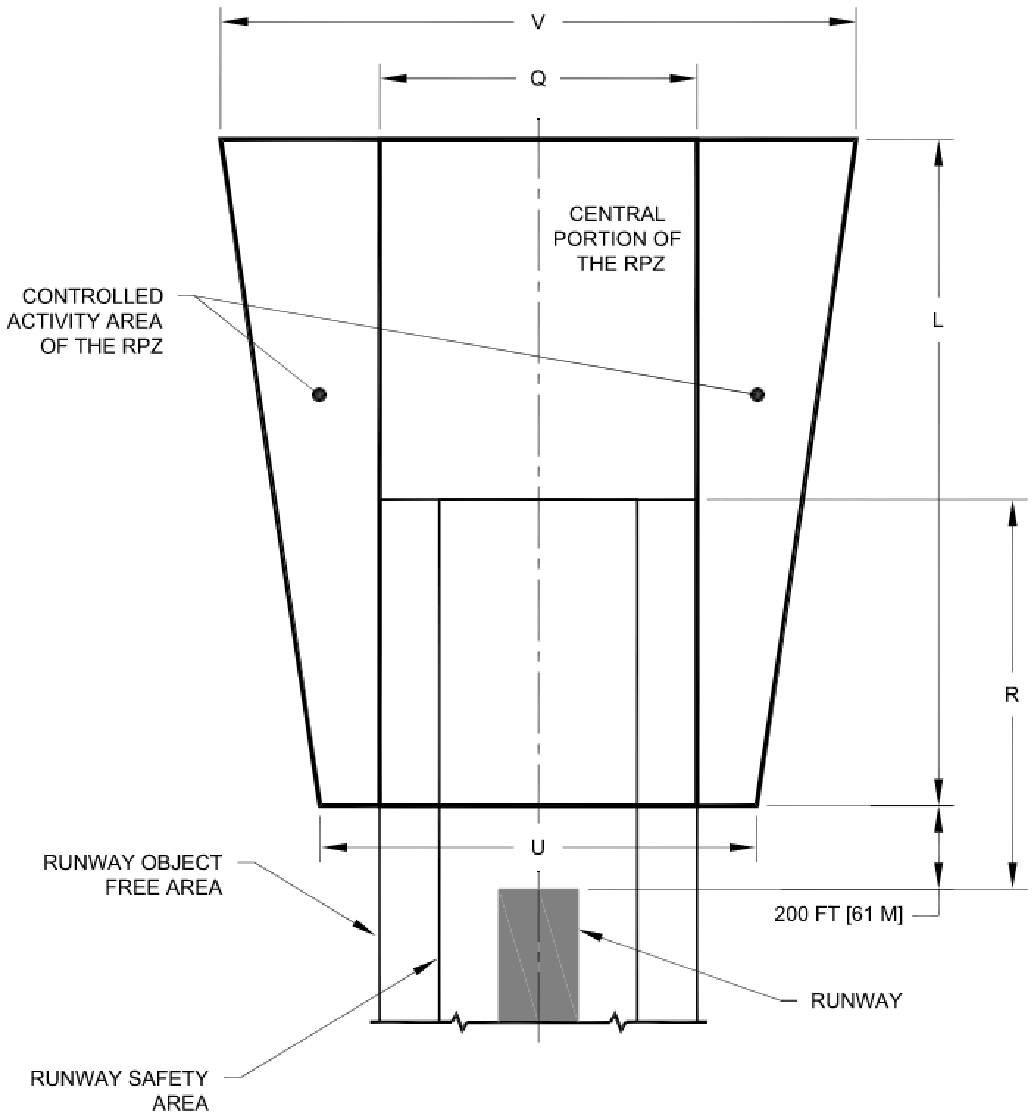
Runway Safety Area Detail

The **obstacle free zone** (OFZ) comprises several volumes of airspace centered above the runway. The **runway object free zone** (ROFZ) is a design surface as well as an operational surface extending 200 feet beyond each end of the runway and must be kept clear of obstacles. Certain allowances are made for NAVAIDs with frangible couplings that are designed to fail on impact. ROFZ width varies between 120 - 400 feet, based on size of aircraft and visibility minimums.



OFZ for Visual Runways and Runways with no less than ¾ mi approach visibility minimums

The **runway protection zone** (RPZ) is intended to enhance the protection of the people and property on the ground. The RPZ is a trapezoidal shape and is centered about the extended runway centerline. The RPZ has three regions: the central portion and the two adjacent controlled activity areas. Where possible, airport owners should own the property to the limits of the RPZ. Having the RPZ clear of all above-ground objects is desirable. This diagram shows the end of the runway with ROFA, RSA, and RPZ boundaries:



Runway Length & Width

A runway should be long enough to accommodate landing and departures for the design aircraft. AC 150/5325-4 describes procedures for planning the appropriate runway length based on aircraft that make up the fleet mix, useful load factor, and other variables. Takeoff distances are often longer than landing distances. All aircraft operational considerations should include takeoff, landing, accelerated stop distances, and obstacle clearance when determining runway length for the aircraft intended to use the runway. Airport elevation, wind & surface temperature, surface conditions, topography, and aircraft performance and weight need to be analyzed.

Runway width depends on three variables: ADG, AAC, and visibility minimums. AC 150/5300-13 has standard runway design matrix tables that specify widths, which vary from 60 feet to 200 feet wide. Each category and class of aircraft have correlating dimensions based on visiblity minimums. The parallel stripes at a threshold correspond to the runway width, as will be discussed in a future course. As an example, the above photo shows eight threshold stripes, indicating 100 foot runway width.

Runway Ends

The end of a runway is normally the beginning of the takeoff roll and the end of the landing roll out. Of course, it is not a requirement that an aircraft use the entire runway for takeoff or landing, but it is important to know exactly how much runway is available. The **threshold** is the beginning of a runway that is available for landing (note: threshold always refers to landing, not the start of a takeoff). Threshold locations provide clearance from obstacles for landing aircraft. Sometimes, however, there are objects that the airport owner is unable to remove or relocate which prohibit an aircraft from landing at the beginning of the runway. In this case, the threshold may be moved further down the runway, reducing the available length of runway for landings; this is called a **displaced threshold**.

Displaced Threshold

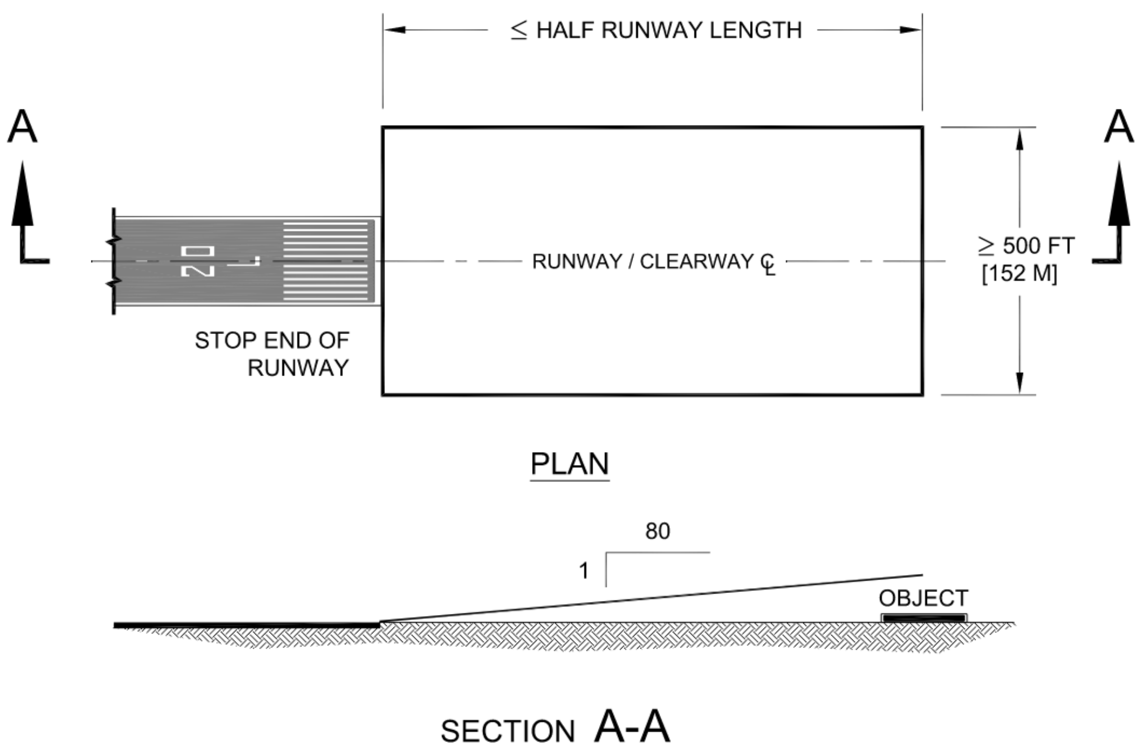
As simple as this is in concept, displacing a threshold often causes disruptions to other aspects of the airport design. Lighting and NAVAIDs need to be moved, taxiways may have to be relocated, and hold lines changed. The FAA advises that although moving a threshold *is* a feasible option, the decision should be carefully weighed and the tradeoffs be thoroughly evaluated.

Blast pads are found at the end of runways to provide erosion protection during operation of jet aircraft. Jet blast produces very high wind velocities and temperature, capable of damaging pavement and airport infrastructure, not to mention injury of personnel. Blast pads must be paved. Standard length and width of blast pads depend on AAC, ADG, and visibility minimums.

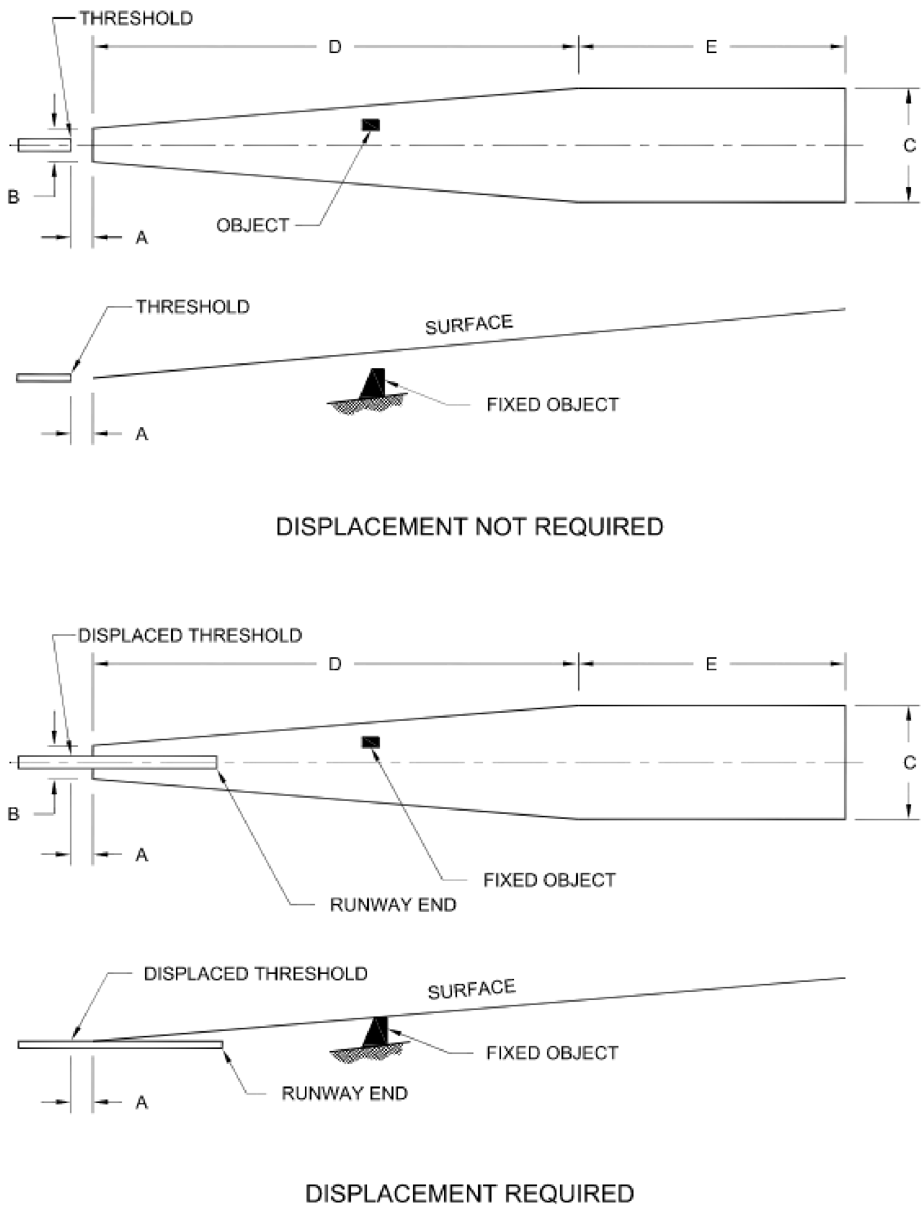
Blast Pad

Stopways, on the other hand, are areas beyond the takeoff runway that are able to support an aircraft during an aborted takeoff. Technically, blast pads are not stopways but stopways may serve as blast pads. Aviation irony. Since a stopway is only intended for one-way traffic with occasional use, their construction is less cost effective than an equivalent length of runway.

Clearways are areas beyond the runway end which allow aircraft to takeoff at high takeoff weight without increasing runway length. Clearways are required to be 500 feet wide and less than half the length of the runway. Clearway plane slopes upward at 80:1 (1.25%) maximum, above which no objects or terrain may penetrate except threshold lights. This area must be under the airport's control, even if indirectly.



Runway ends must also meet approach and departure surface criteria. Approach surfaces have trapezoidal shapes that extend from the runway threshold at a specific slope, which varies based on certain conditions. The following figure and table show the standard geometry of an approach surface:



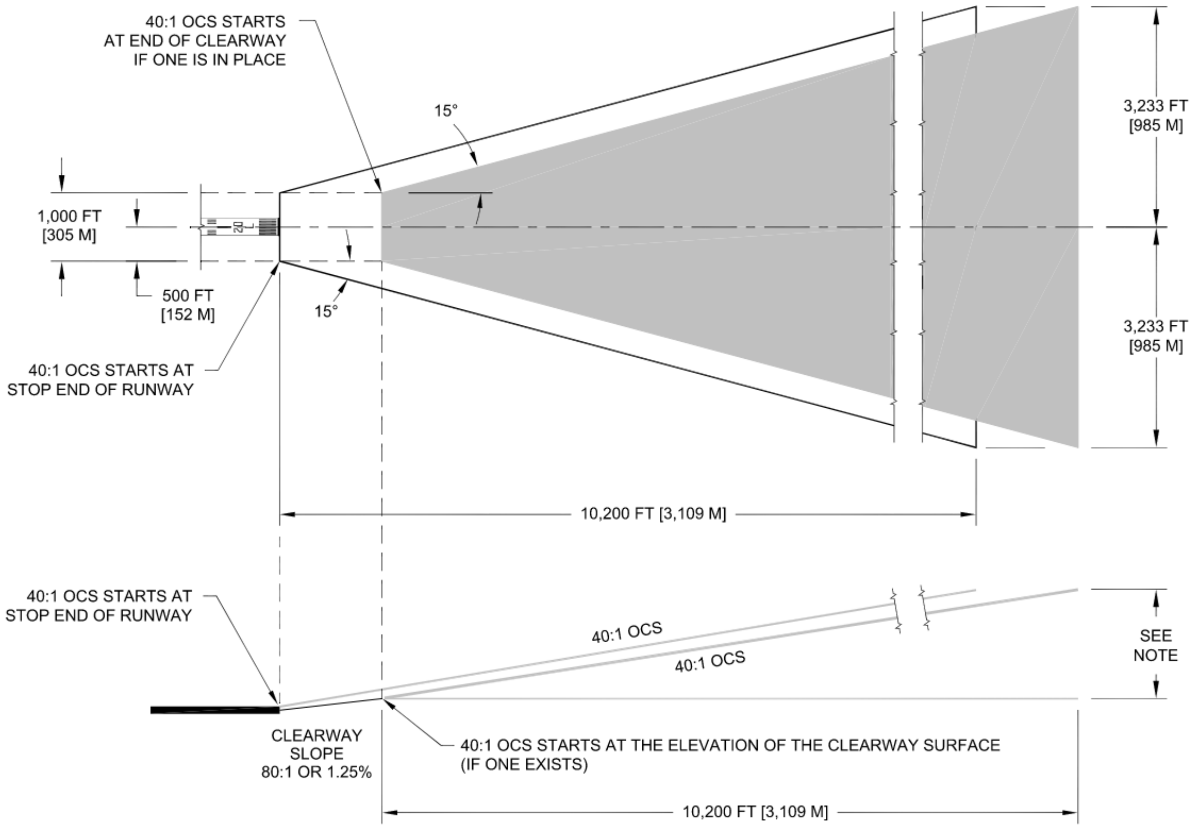
Approach Surface Geometry

	Runway Type	DIMENSIONAL STANDARDS* Feet (Meters)					Slope/ OCS
		A	B	C	D	E	
1	Approach end of runways expected to serve small airplanes with approach speeds less than 50 knots. (Visual runways only, day/night)	0 (0)	120 (37)	300 (91)	500 (152)	2,500 (762)	15:1
2	Approach end of runways expected to serve small airplanes with approach speeds of 50 knots or more. (Visual runways only, day/night)	0 (0)	250 (76)	700 (213)	2,250 (686)	2,750 (838)	20:1
3	Approach end of runways expected to serve large airplanes (Visual day/night); or instrument minimums ≥ 1 statute mile (1.6 km) (day only).	0 (0)	400 (122)	1000 (305)	1,500 (457)	8,500 (2591)	20:1
4	Approach end of runways expected to support instrument night operations, serving approach Category A and B aircraft only. [1]	200 (61)	400 (122)	3,800 (1158)	10,000 [2] (3048)	0 (0)	20:1
5	Approach end of runways expected to support instrument night operations serving greater than approach Category B aircraft. [1]	200 (61)	800 (244)	3,800 (1158)	10,000 [2] (3048)	0 (0)	20:1
6	Approach end of runways expected to accommodate instrument approaches having visibility minimums ≥ 3/4 but <1 statute mile (≥ 1.2 km but < 1.6 km), day or night.	200 (61)	800 (244)	3,800 (1158)	10,000 [2] (3048)	0 (0)	20:1
7	Approach end of runways expected to accommodate instrument approaches having visibility minimums < 3/4 statute mile (1.2 km).	200 (61)	800 (244)	3,800 (1158)	10,000 [2] (3048)	0 (0)	34:1
8[3,5,6,7]	Approach end of runways expected to accommodate approaches with vertical guidance (Glide Path Qualification Surface [GQS]).	0 (0)	Runway width + 200 (61)	1520 (463)	10,000 [2] (3048)	0 (0)	30:1
9	Departure runway ends for all instrument operations.	0 [4] (0)	See Figure 3-4.				40:1

Approach Surface Dimensions

Engineers must also consider effects to the surfaces specified in 14 CFR Part 77 *(Safe, Efficient Use, and Preservation of the Navigable Airspace)* and accordingly report them to the FAA as design and construction progress via form 7460-1 *Notice of Proposed Construction or Alteration*. The finer points of Part 77 airspace analysis and procedures for notification are not addressed in this course.

Departure surfaces start at the Takeoff Distance Available (TODA) extending the length of the runway, at a standard slope of 40:1. Recognize that non-standard climb rates or departure minimums may cause aircraft to penetrate the departure surface. The subsequent image specifies the dimensions of the standard departure surface for instrument runways:



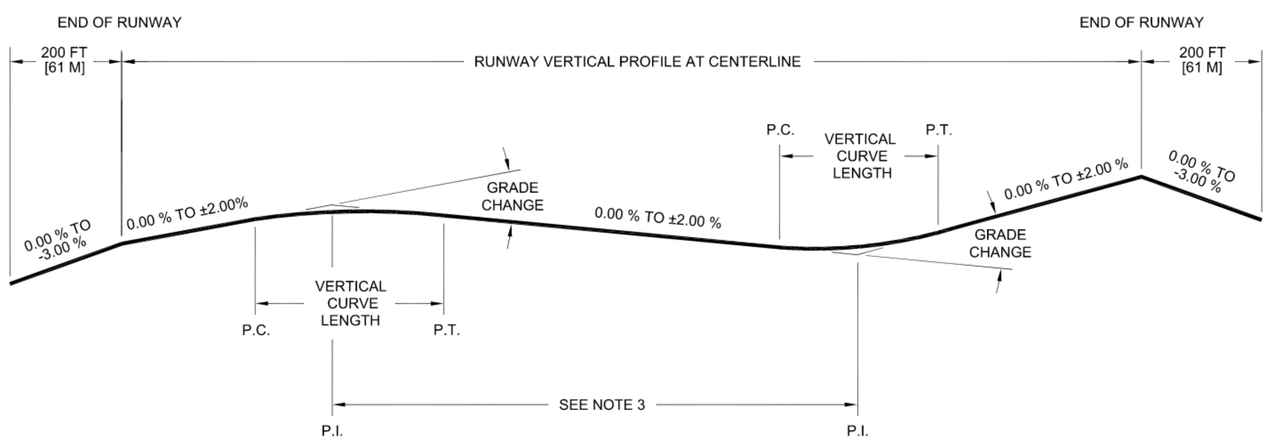
NOTE: THIS IS AN INTERPRETATION OF THE APPLICATION OF THE OCS SURFACE ASSOCIATED WITH A CLEARWAY.

Instrument Runway Departure Surface Geometry

RUNWAY GRADIENTS

Runway surface gradients depend on aircraft approach categories. Standards are grouped into categories A & B, and C, D & E. There are longitudinal and transverse limitations for runway pavement, shoulders, and areas adjacent to the runway. Smooth transitions between intersecting pavement surfaces are desirable. When runways intersect, grades are given precedence to the dominant runway based on whichever is a higher category. Runways have precedence in a runway-taxiway interface. Design grades should also consider future runway extensions or upgrades to accommodate more stringent aircraft approach categories. Transverse grades should be kept to a minimum and consistent with drainage requirements. RSA grades are the same as comparable standards for runways and stopways, although there is an allowance for taxiways or other runways that are within the RSA.

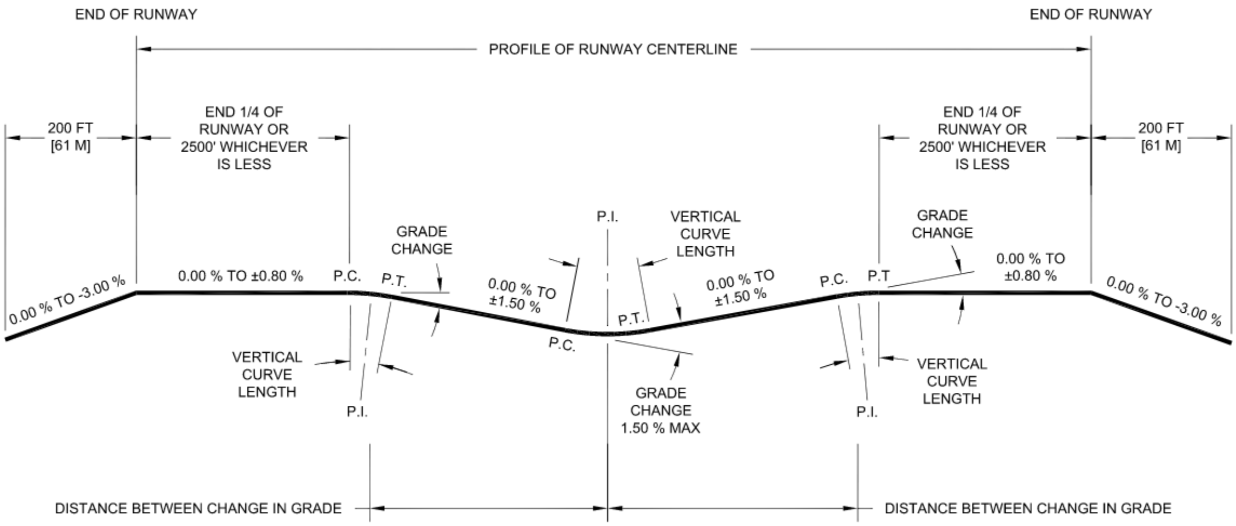
The next two graphics detail the longitudinal standards for runways:



NOTES:

1. LENGTH OF VERTICAL CURVES WILL NOT BE LESS THAN 300 FT [91 M] FOR EACH 1% GRADE CHANGE, EXCEPT THAT NO VERTICAL CURVE WILL BE REQUIRED WHEN GRADE CHANGE IS LESS THAN 0.4%.
2. MAXIMUM GRADE CHANGE AT VERTICAL CURVES SHOULD NOT EXCEED 2.00 %.
3. MINIMUM DISTANCE BETWEEN POINTS OF VERTICAL INTERSECTION SHOULD BE 250 FT [76 M] x SUM OF ABSOLUTE GRADE CHANGES.

Longitudinal grade limitations for AAC A&B

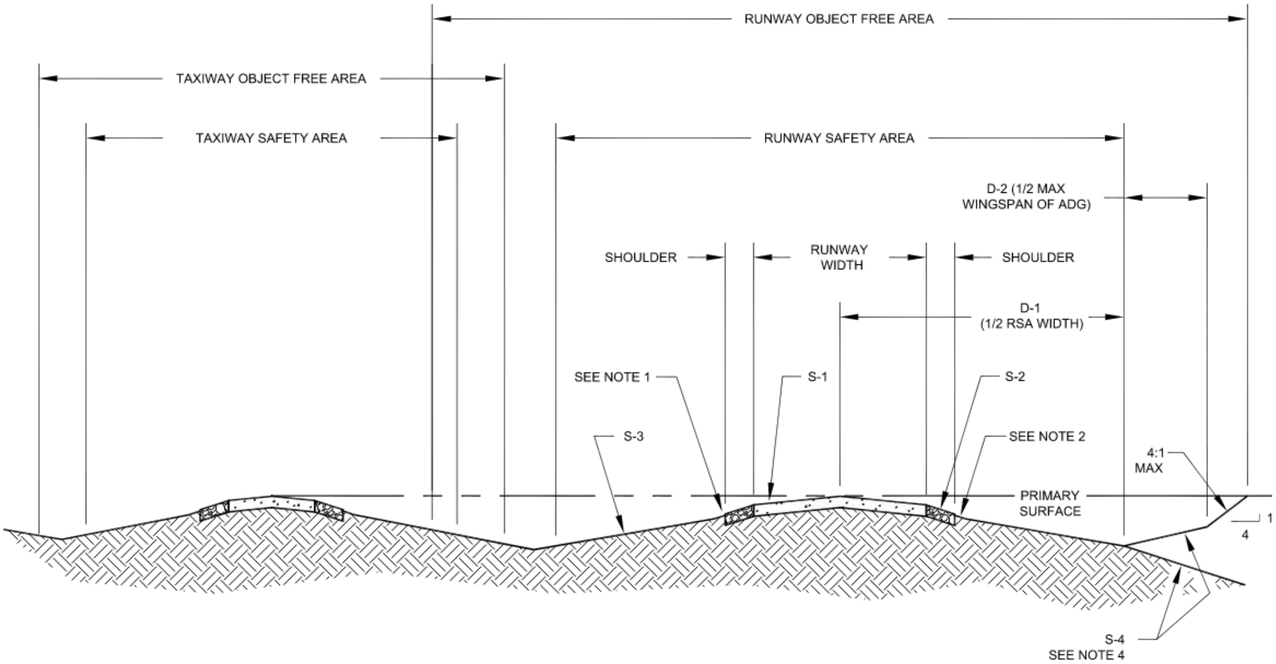


NOTES:

1. MINIMUM LENGTH OF VERTICAL CURVES = 1,000 FT [305 M] x GRADE CHANGE (IN %).
2. THE MINIMUM VERTICAL CURVE LENGTH IS EQUAL TO 1,000 FT [305 M] x GRADE CHANGE.
3. THE MINIMUM DISTANCE BETWEEN POINTS OF VERTICAL INTERSECTION MUST BE 1,000 FT [305 M] x SUM OF THE ABSOLUTE GRADE CHANGES.

Longitudinal grade limitations for AAC C, D, and E

Transverse runway grade limits are shown here:



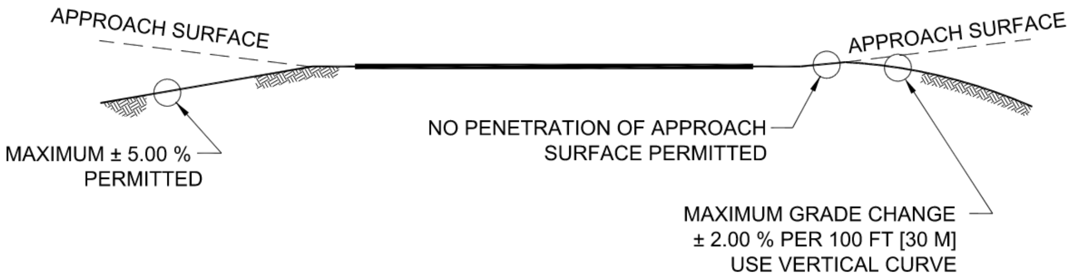
NOTES:

1. CONSTRUCT A 1.5 IN [4 cm] DROP BETWEEN PAVED AND UNPAVED SURFACES.
2. MAINTAIN A -5.0 % GRADE FOR 10 FEET OF UNPAVED SURFACE ADJACENT TO THE PAVED SURFACE.
3. S-2 APPLIES WHEN SHOULDERS ARE PROVIDED.
4. S-4 SHOULD BE 0% OR NEGATIVE (UNLIMITED) TO THE EDGE OF THE RUNWAY OFA IF PRACTICABLE. ALLOWABLE POSITIVE SLOPE BASED ON AIRPLANE DESIGN GROUP.
5. REFER TO FIGURE 4-33 FOR TAXIWAY TRANSVERSE GRADES.

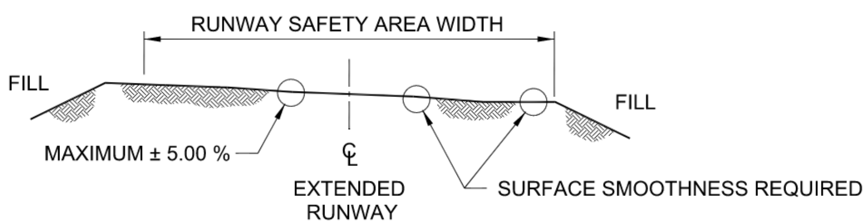
APPROACH CATEGORY	A & B	C, D, AND E
S-1	1.0% TO 2.0%	1.0% TO 1.5%
S-2 (≥S-1)	1.5% TO 5.0%	1.5% TO 5.0%
S-3	1.5% TO 5.0%	1.5% TO 3.0%

ADG	I	II	III	IV	V	VI
D-1	D-1 IS 1/2 OF C (RUNWAY SAFETY AREA WIDTH). SEE INTERACTIVE TABLE 3-5.					
D-2	25	40	59	86	107	131
S-4 (MAXIMUM)	8:1		10:1		16:1	

Beyond the ends of the RSA, grade limitations are presented here:



LONGITUDINAL GRADE



NOTE: TRANSITIONS BETWEEN DIFFERENT GRADIENTS SHOULD BE WARPED SMOOTHLY.

TRANSVERSE GRADE

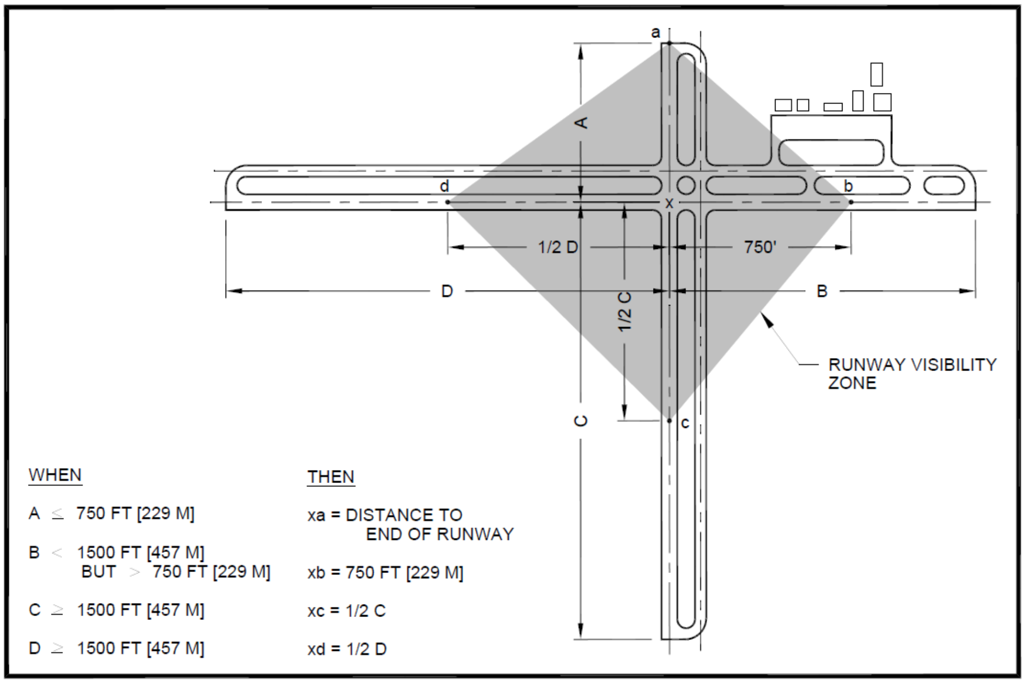
Line of Sight Requirements

Line of sight requirements provide aircraft and ground vehicles the ability to verify location and movements of other aircraft or vehicles. Essentially, it's a system to avoid hazards and collisions on an airport. For runways without parallel taxiways, the condition is that any point 5 feet above the runway centerline must be mutually visible with any other point 5 feet above the runway centerline. Runways with full parallel taxiways are under the same constraint except any point 5 feet above the centerline must be mutually visible with any other point 5 feet above the centerline that is located at a distance that is less than one half the length of the runway.

When runways intersect, the polygon formed between points connecting the runways' line of sight points is called the **runway visibility zone**. The runway line of sight points have three potential locations:

1. The end of the runway if located within 750 feet of the crossing runway centerline
2. A point 750 feet from the runway intersection if the end of the runway is located within 1,500 feet of the crossing runway centerline
3. A point one-half of the distance from the intersecting runway centerline, if the end of the runway is located at least 1,500 feet from the crossing runway centerline.

Thus, any point 5 feet above the runway centerline and in the runway visibility zone must be mutually visible with any other point 5 feet above the centerline of the crossing runway and inside the runway visibility zone.



Runway Visibility Zone Diagram

These dimensions may not be modified unless the FAA approves under the condition that the airport has a 24-hour control tower which will continue to operate based on airport use forecasts.

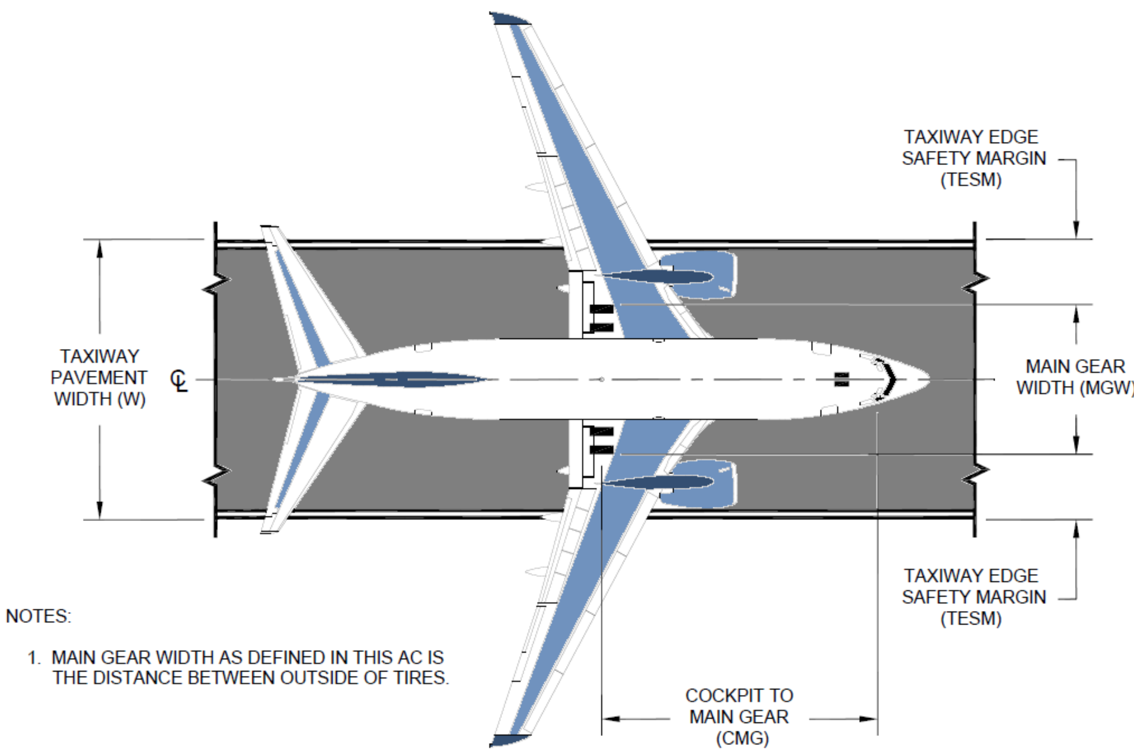
Runway Markings & Lighting

Runway markings and lighting are not addressed in this course. A following course in this series will detail these subjects.

Taxiway Design

FUNDAMENTALS

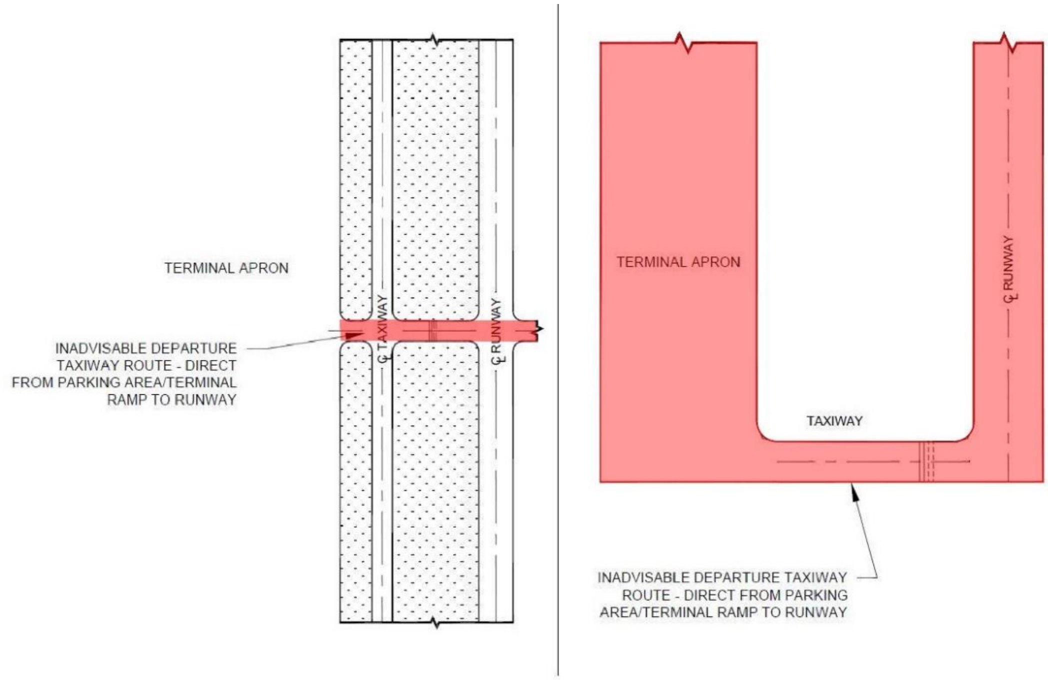
As defined in Part I of this course, a taxiway is a defined path established for the taxiing of aircraft from one part of an airport to another. Taxiway design incorporates low speed and precise maneuvering, integrating safety as the basis of design. Taxiways are generally hard surfaces, although some airports may use gravel or grass. Airport guidance signs provide directions and information to taxiing aircraft and airport vehicles. Taxilanes, on the other hand, provide access from taxiways to aircraft parking positions and other terminal areas which are usually located outside the movement area on an airport. Both taxiways and taxilanes are considered in this section. Design is based on **taxiway design group** (TDG), which considers the geometry of the landing gear. The **main gear width** (MGW) and **cockpit to main gear** (CMG) are both critical dimensions for taxiway design. TDG is unique to each aircraft and is easily found in an aircraft characteristic database.



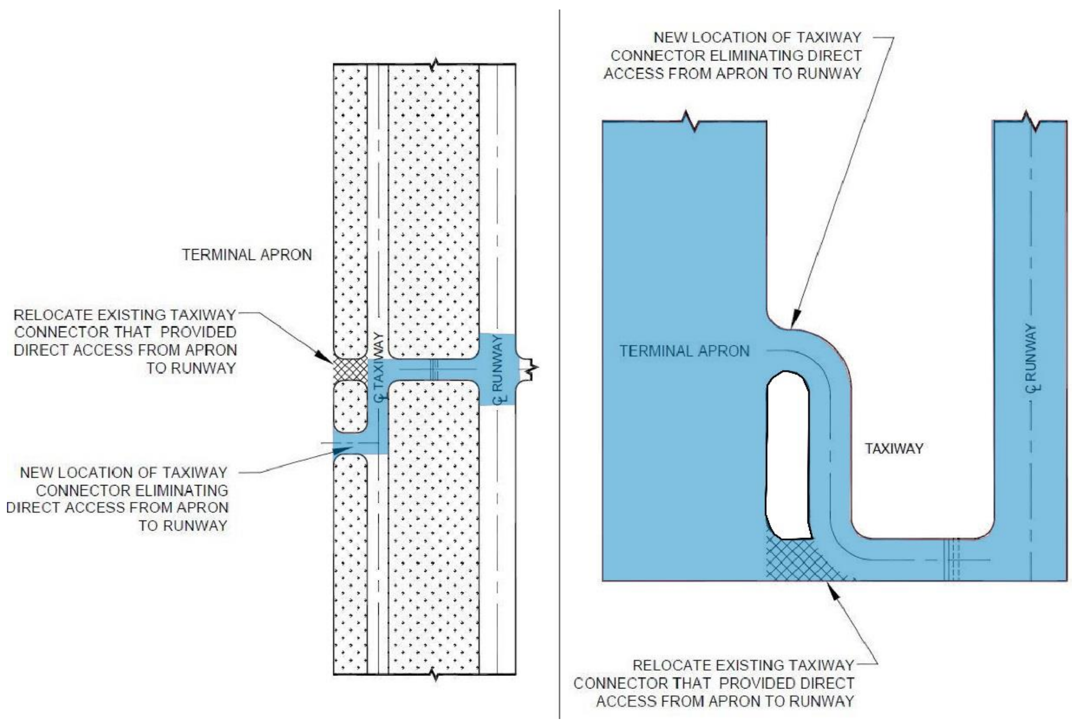
Design of taxiways and taxilanes should always reflect sound safety measures to avoid runway incursions and collisions with other aircraft, vehicles, or infrastructure. The FAA specifies several techniques to accomplish suitable taxiway design:

i. Design for an aircraft to taxi cockpit-over-centerline with a sufficient margin of width for an aircraft to drift to one side or the other.
ii. Engineers should not design a taxiway to accommodate "judgmental oversteering" (when a large aircraft steers past the centerline to turn on a taxiway that is designed for small aircraft) for the reason of lowering the paving cost; the taxiway should be designed for the design aircraft and expected fleet mix.
iii. Limit the nose gear steering angle to less than 50° to the left or right, when possible. Angles greater than this can cause tires to scrub and wear prematurely.
iv. Keep intersections simple. Present no more than three options for a pilot: ideally left, right, or straight ahead. This reduces pilot error and increases the pilot's awareness.
v. Use standard intersection angles, with 90° being preferred: 30°/45°/60°/90°/120°/135°/150°.
vi. Avoid wide expanses of pavement which require signs to be located farther away and are therefore less visible.
vii. Reduce the need for runway crossings; limit hazardous errors by reducing occurrences and also ease the air traffic controller's responsibility.

viii. The middle third of a runway is considered "high energy" because aircraft are moving the fastest in that section and can maneuver the least. Taxiing over a runway in this area increases risk and should be averted.
ix. Improve visibility at intersections by using 90° turns. High speed runway exits with acute steering angles allow faster and more efficient use of the runway, but should not be used as a path to enter or cross a runway.
x. Prevent confusion by avoiding dual purpose pavement. Any given section should either be a runway or a taxiway, not both.
xi. Watch out for hot spots! These areas are especially prone to collisions. Redesign where possible to prevent accidents before they happen.
xii. Request and confirm ATC operational procedures and recommendations to design an airport system that is functional and efficient.
xiii. An aligned taxiway is one whose centerlines coincide with a runway centerline, and are prohibited for safety reasons. Existing aligned taxiways should be removed.
xiv. Taxiway shoulders should be protected from erosion. Pavement is required for large aircraft (ADG-IV and up) and recommended for ADG-III aircraft. Turf and other stable options are acceptable for smaller aircraft.
xv. Paved shoulders should join a taxiway with a flush joint. A 1.5 inch step is the standard at the edge of paved shoulders.
xvi. Create indirect access to runways by implementing a turn before entering a runway. This inhibits accidental access to an active runway, as shown here:



Unacceptable Taxiway Design Examples



Acceptable Taxiway Design Examples

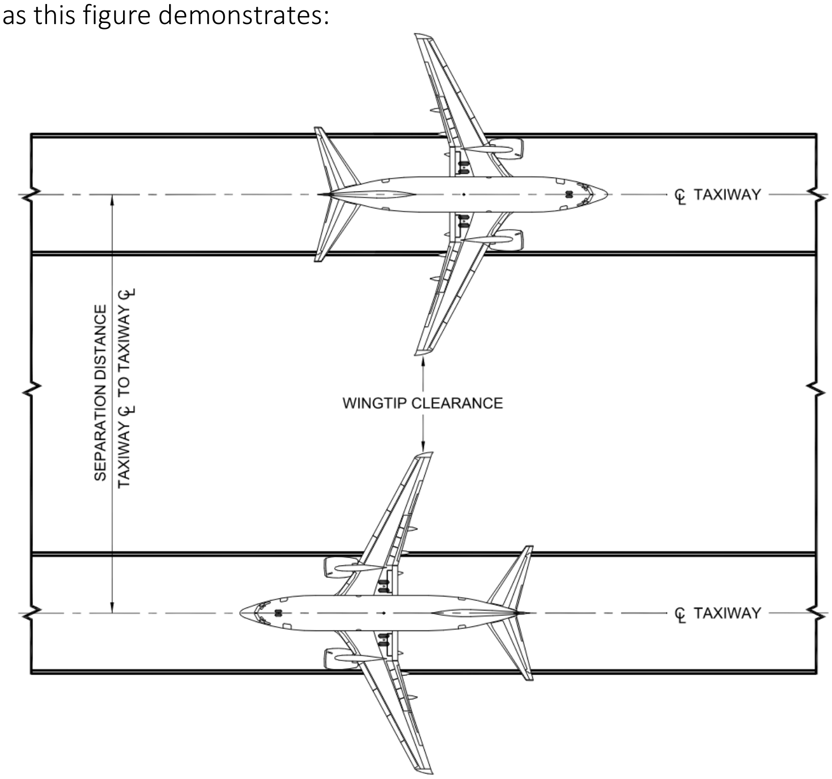
Taxiway Width

Determining the correct taxiway pavement width is a simple matter once the TDG is known. Table 4-2 in AC 150/5300-13A is the go-to source for this data:

ITEM	DIM (See Figure 4-6)	TDG							
		1A	1B	2	3	4	5	6	7
Taxiway Width	W	25 ft (7.5 m)	25 ft (7.5 m)	35 ft (10.5 m)	50 ft (15 m)	50 ft (15 m)	75 ft (23 m)	75 ft (23 m)	82 ft (25 m)
Taxiway Edge Safety Margin	TESM	5 ft (1.5 m)	5 ft (1.5 m)	7.5 ft (2 m)	10 ft (3 m)	10 ft (3 m)	15 ft (4.6m)	15 ft (4.6m)	15 ft (4.6m)
Taxiway Shoulder Width		10 ft (3 m)	10 ft (3 m)	15 ft (3 m)	20 ft (6 m)	20 ft (6 m)	30 ft (9 m)	30 ft (9 m)	40 ft (12 m)
Taxiway/Taxilane Centerline to Parallel Taxiway/Taxilane Centerline w/ 180 Degree Turn	J	See Table 4-14							
TAXIWAY FILLET DIMENSIONS		Table 4-3	Table 4-4	Table 4-5	Table 4-6	Table 4-7	Table 4-8	Table 4-9	Table 4-10

Taxiway Separation & Clearances

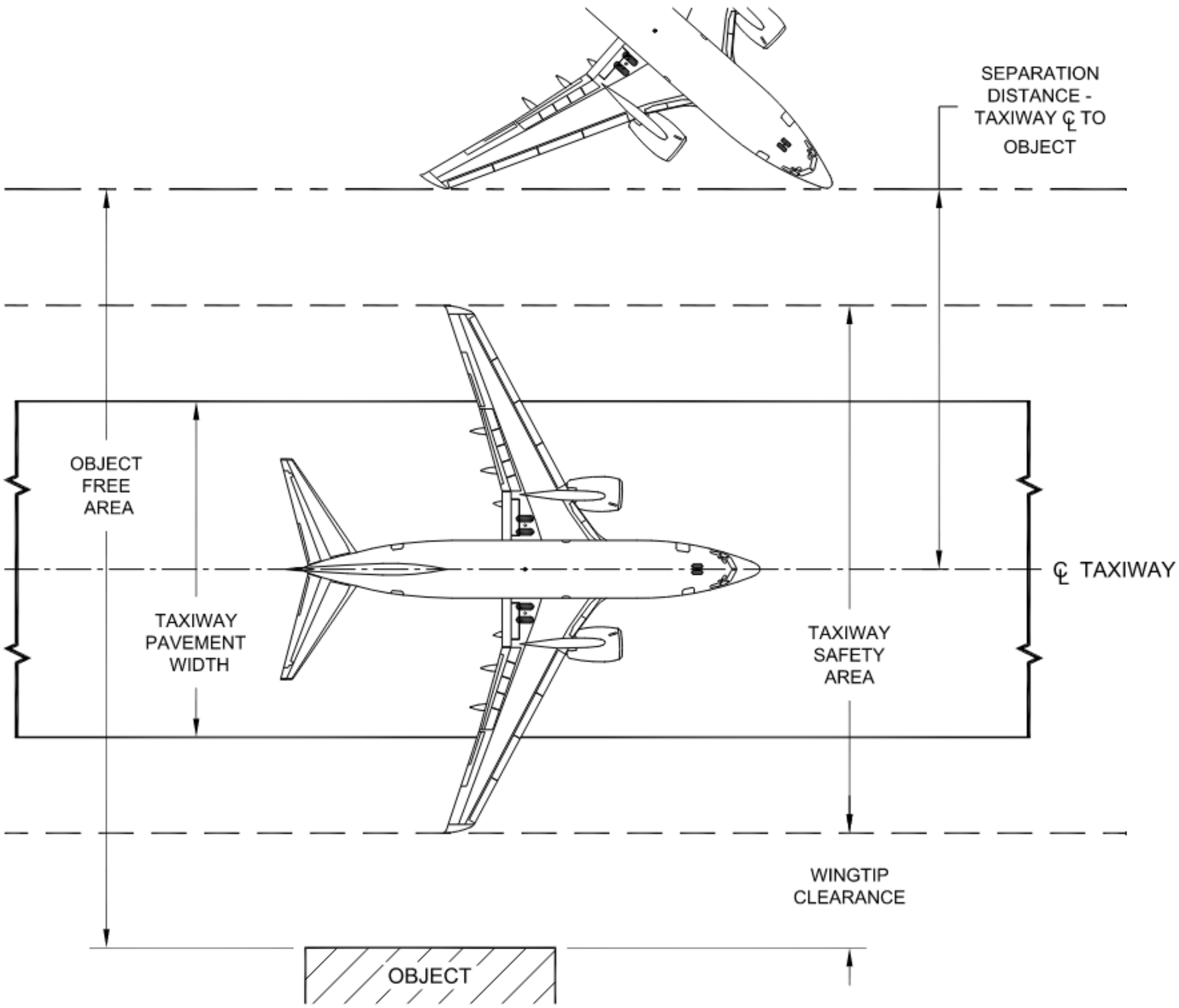
Taxiway separation is more complex. Taxiways must have enough separation maintain clearance between aircraft wingtips as this figure demonstrates:



Taxiway clearance is largely due to the fact that the pilots of many modern jets cannot see their wingtips from the cockpit. There also must be sufficient separation between taxiing aircraft and other obstacles, such as parked aircraft, buildings, etc. There are five different forms of separation requirements:

i. T/W to T/W Centerline Separation = (1.2) x (max ADG wingspan) + 10 ft.
ii. T/W to Object Separation = (0.7) x (max ADG wingspan) + 10 ft.
iii. Parallel T/L to T/L Centerline Separation = (1.1) x (max ADG wingspan) + 10 ft.
iv. T/L Centerline to Object Separation = (0.6) x (max ADG wingspan) + 10 ft.
v. Parallel T/L or T/W for Dissimilar ADG = use larger ADG or higher use

These different forms of separation requirements are visually demonstrated in this figure:

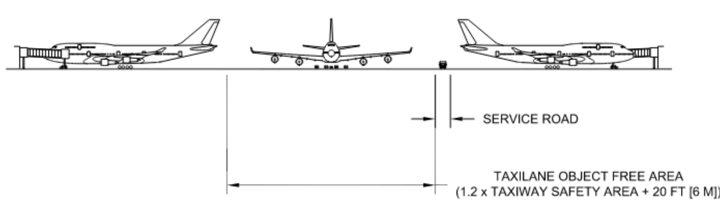


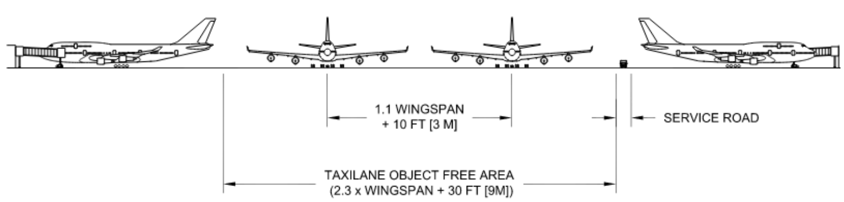
Once the correct separation type is selected, dimensional values may be calculated using the above equations, or selected from the following table:

ITEM	DIM (See Figure 3-26)	ADG					
		I	II	III	IV	V	VI
TAXIWAY PROTECTION							
TSA	E	49 ft (15 m)	79 ft (24 m)	118 ft (36 m)	171 ft (52 m)	214 ft (65 m)	262 ft (80 m)
Taxiway OFA		89 ft (27 m)	131 ft (40 m)	186 ft (57 m)	259 ft (79 m)	320 ft (98 m)	386 ft (118 m)
Taxilane OFA		79 ft (24 m)	115 ft (35 m)	162 ft (49 m)	225 ft (69 m)	276 ft (84 m)	334 ft (102 m)
TAXIWAY SEPARATION							
Taxiway Centerline to Parallel Taxiway/Taxilane Centerline [1]	J	70 ft (21 m)	105 ft (32 m)	152 ft (46.5 m)	215 ft (65.5 m)	267 ft (81 m)	324 ft (99 m)
Taxiway Centerline to Fixed or Movable Object	K	44.5 ft (13.5 m)	65.5 ft (20 m)	93 ft (28.5 m)	129.5 ft (39.5 m)	160 ft (48.5 m)	193 ft (59 m)
Taxilane Centerline to Parallel Taxilane Centerline [1]		64 ft (19.5 m)	97 ft (29.5 m)	140 ft (42.5 m)	198 ft (60 m)	245 ft (74.5 m)	298 ft (91 m)
Taxilane Centerline to Fixed or Movable Object		39.5 ft (12 m)	57.5 ft (17.5 m)	81 ft (24.5 m)	112.5 ft (34 m)	138 ft (42 m)	167 ft (51 m)
WINGTIP CLEARANCE							
Taxiway Wingtip Clearance		20 ft (6 m)	26 ft (8 m)	34 ft (10.5 m)	44 ft (13.5 m)	53 ft (16 m)	62 ft (19 m)
Taxilane Wingtip Clearance		15 ft (4.5 m)	18 ft (5.5 m)	22 ft (6.5 m)	27 ft (8 m)	31 ft (9.5 m)	36 ft (11 m)

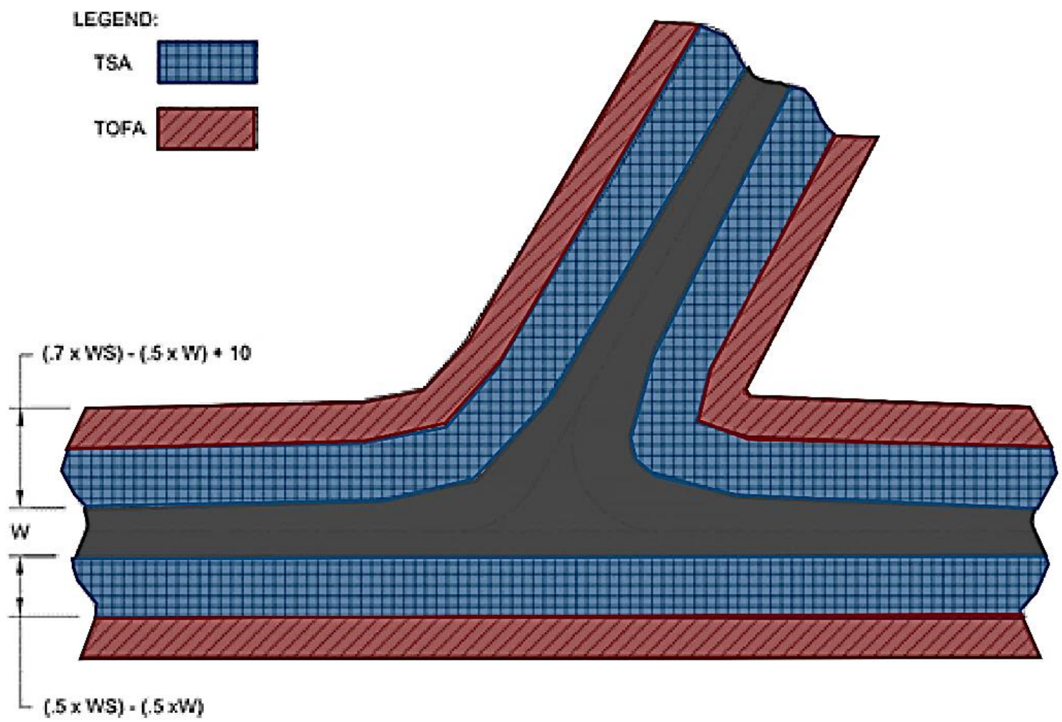
Note: 1. These values are based on wingtip clearances. If direction reversal between parallel taxiways is needed, use this dimension or the dimension specified in Table 4-14 or Table 4-15, whichever is largest.

Separations for a taxilane between parked aircraft (such as an airport terminal with parallel gates) depends on the TSA and aircraft wingspan. Service roads for ground vehicles may be present in an airport layout and must be considered during design to maintain safe traffic configuration. It is important to know that ground vehicles may operate within the OFA as long as they give right of way to taxiing aircraft. Vehicle exiting areas may be necessary for certain taxiway geometries.

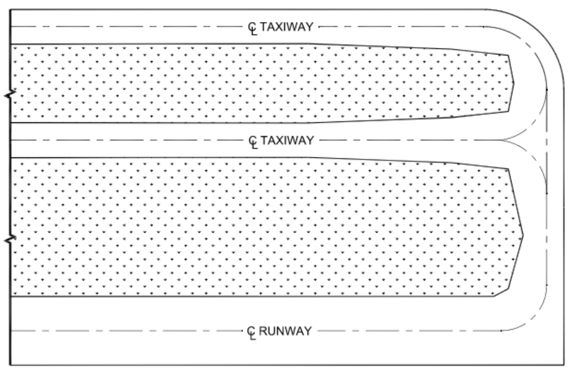


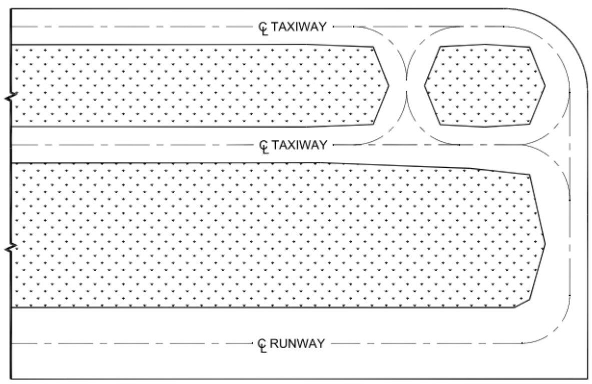


The **taxiway/taxilane safety area** (TSA) is a defined surface, centered on the taxiway or taxilane, intended to reduce the risk of damage to an aircraft that departs the paved surface. The TSA must be free from hazards, including ruts, depressions, or rough surfaces and must have proper drainage to prevent water from ponding. It also must support ground vehicles in dry conditions, such as SRE, ARFF equipment, and the occasional aircraft that veers off the pavement. All objects must be removed from the TSA unless they must be there because of their function (i.e., taxiway lights, signs, etc.). If these critical objects are taller than 3 inches, they must be mounted on frangible supports, which are designed to fail upon impact. Manholes, hand holes, access structures, and foundations should be flush with surrounding the grade. The TSA is within the boundary of the TOFA, as previously seen. This figure illustrates a plan view of a typical TSA/TOFA layout:



The use of parallel taxiways can improve airport efficiency and safety by creating extra capacity for taxiing aircraft and removing the need for aircraft to taxi on the runway. Even better, a dual parallel taxiway allows an aircraft to taxi past a lineup of aircraft waiting at a runway hold line:

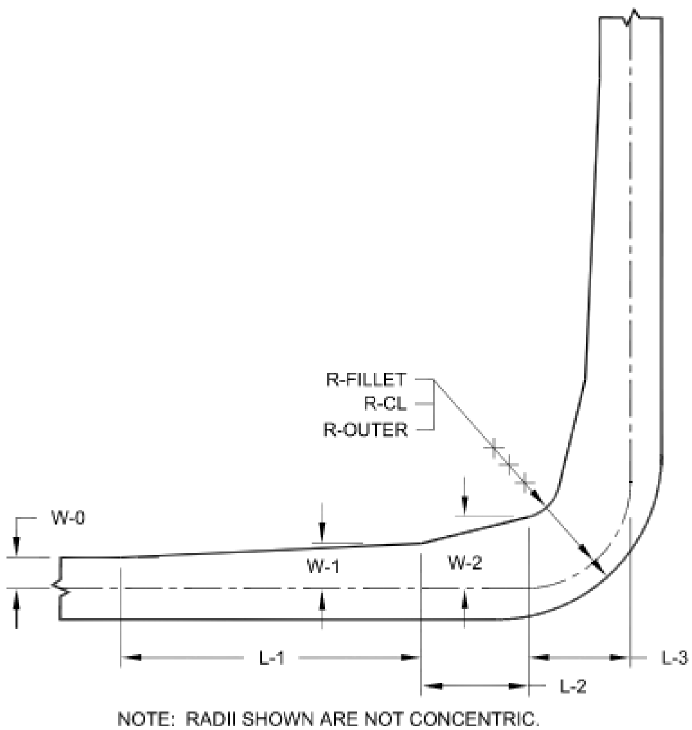


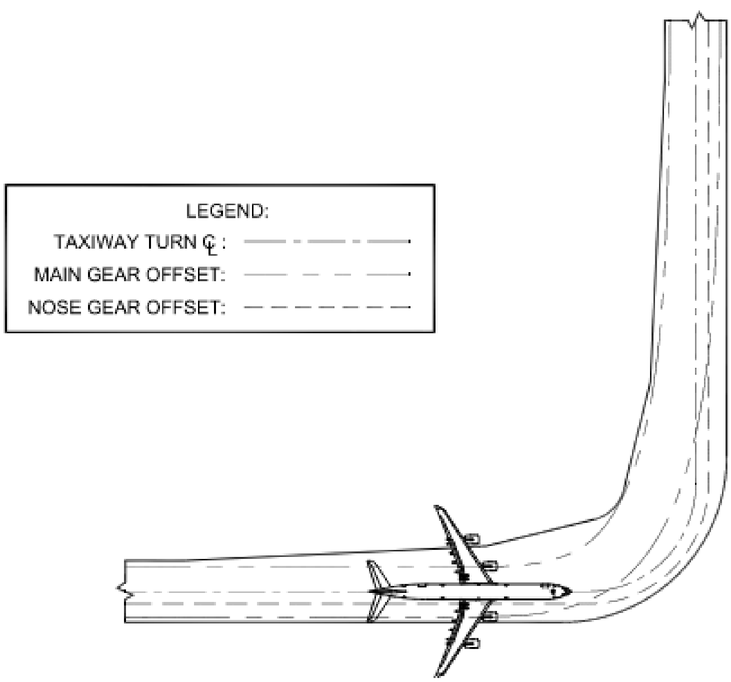


Example Parallel Taxiway Configurations

Fillet Design

Taxiway intersections and turns require fillet design to ensure the proper taxiway edge safety margin (TESM) is maintained while an aircraft follows the centerline around a corner. Obsolete design methods used inefficient constant radii at intersections or turns. The improved method tapers the approach and optimizes the geometry to meet dimensional requirements for the selected TDG. Standard turn angles are desirable, although not always possible. Obtuse angles should be avoided; limit turns to 90 degrees whenever possible. Design software facilitates turning pattern layouts based on aircraft type and will automatically generate the necessary dimensions. AC 150-5300-13A includes dimensional tables for angles less than, greater than, and exactly 90-degree taxiway turns. This course only demonstrates values of exactly a 90 degree turn for a TDG 1A aircraft:

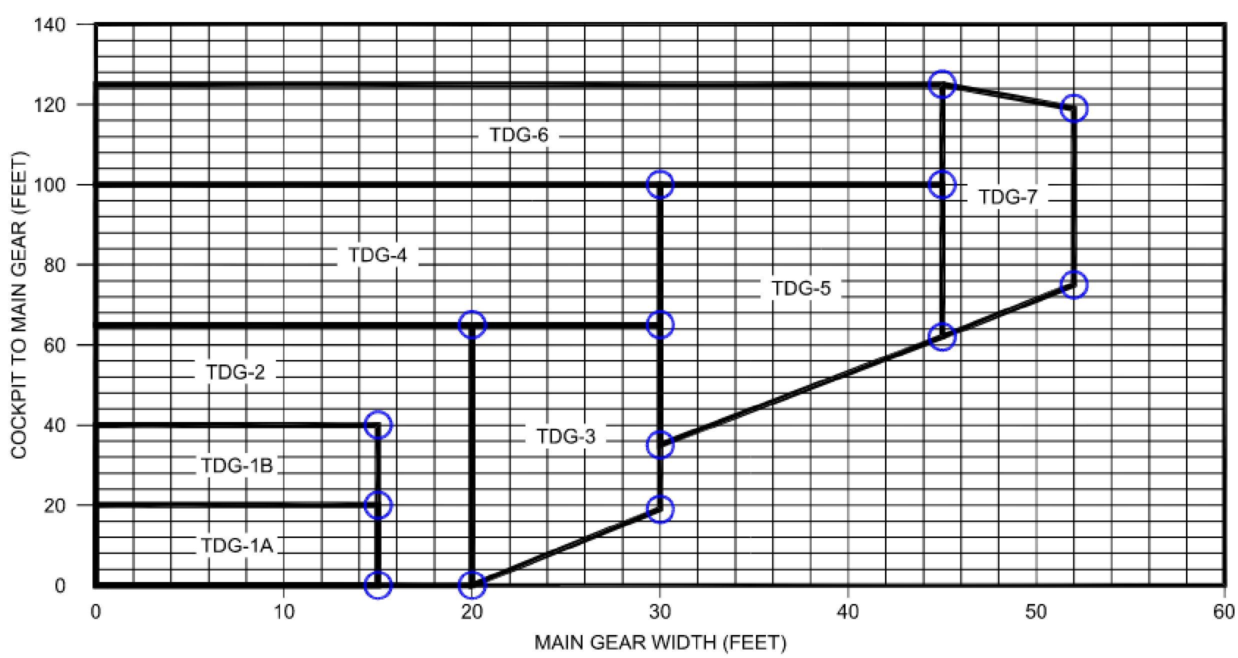

R-FILLET
R-CL
R-OUTER
W-0
W-1
W-2
L-1
L-2
L-3
NOTE: RADII SHOWN ARE NOT CONCENTRIC.


LEGEND:
TAXIWAY TURN ℄ :
MAIN GEAR OFFSET:
NOSE GEAR OFFSET:

TDG 1A							
Dimension (See Figure 4-13, Figure 4-14, and Figure 4-15)							
Δ (degrees)	30	45	60	90	120	135	150
W-0 (ft)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
W-1 (ft)	16	18	20	21	22	23	24
W-2 (ft)	16	18	20	21	22	23	24
L-1 (ft)	39	46	52	53	55	56	56
L-2 (ft)	0	0	0	0	0	0	0
L-3 (ft)	4	8	12	21	39	56	89
R-Fillet (ft)	0	0	0	0	0	0	0
R-CL (ft)	50	50	50	25	25	25	25
R-Outer (ft)	62	62	62	37	37	37	37

Note: Values in the table are rounded to the nearest foot. 1 foot = 0.305 meters.

This chart illustrates MGW/CMG combinations and is very useful when modeling aircraft movements:

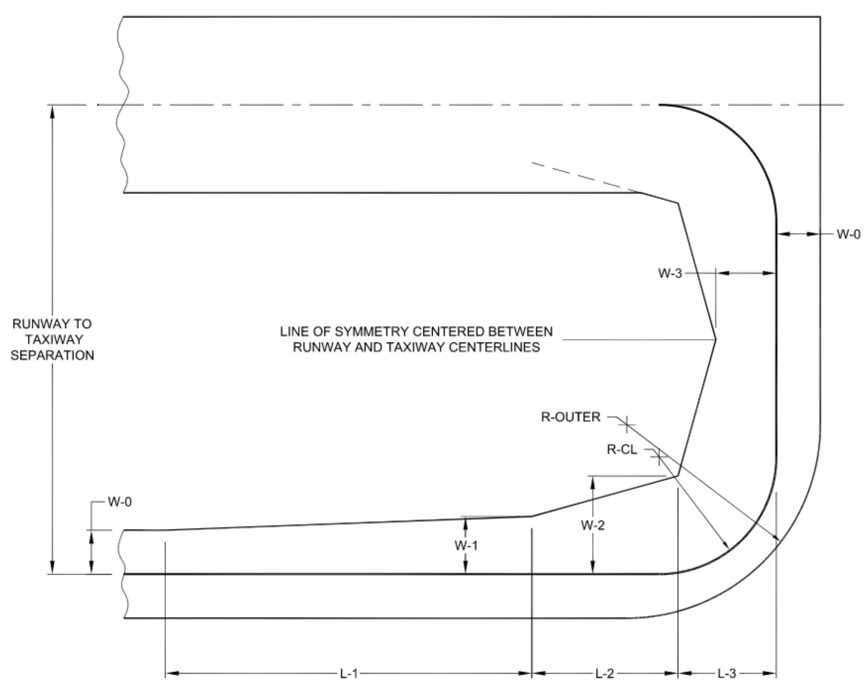


RUNWAY / TAXIWAY INTERSECTIONS

Except for high-speed exit taxiways and taxiways that are parallel to crossing runways, intersections should be designed with right angles, regardless of whether the airport has a control tower or not. A taxiing pilot has the best visibility to see both directions at a right-angle intersection and holding position signs can be placed in ideal visual locations. FAA research indicates non-orthogonal intersections significantly raise the risk of aircraft accidents. No taxiway should ever cross the intersection of two runways. Taxiway intersections should also avoid large expanses of pavement and too many markings, which lead to disorientation of the pilots. AC 150/5300-13A provides guidance and data on exit taxiway locations based on percentages of cumulative utilization percentages. Bypass, crossover, and end-around taxiways are not addressed in this course.

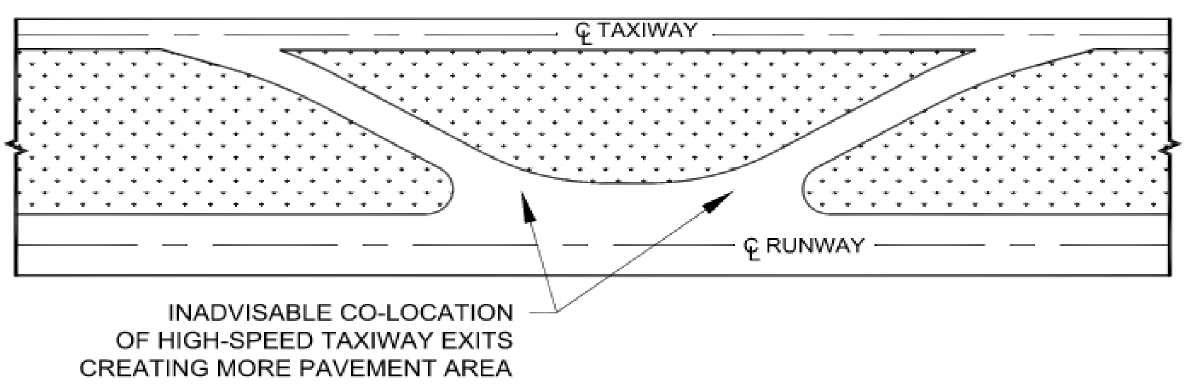
There is no specific line-of-sight constraints for intersecting taxiways as long as the sight distance along a runway from an intersecting taxiway is sufficient for safe visibility of taxiing aircraft entering or crossing the runway.

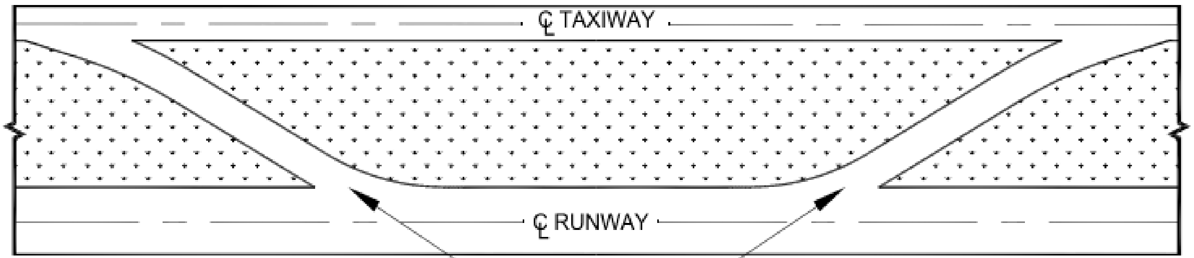
A runway should have a right-angle entrance/exit taxiway at each end. The exception to this is a taxiway turnaround at low traffic airports where a parallel taxiway is not established. If there is enough space, two 90° turns is sufficient providing the steering angle is less than 50°. If space is insufficient between runway and taxiway, the turn radius and corresponding fillet must be increased. Standard layout and dimensions for a right-angle entrance are as follows:



Dimension (see Figure 4-17)	TDG													
	2				4			5	6				7	
Runway Centerline to Taxiway Centerline Distance	240	250	300	350	300	350	400	400	400	450	500	550	500	550
W-0 (ft)	17.5	17.5	17.5	17.5	25	25	25	37.5	37.5	37.5	37.5	37.5	41	41
W-1 (ft)	27	27	26	26	34	38	37	49	53	53	54	54	55	55
W-2 (ft)	50	50	49	49	62	77	75	84	102	105	101	99	100	99
W-3 (ft)	28	27	25	24	49	43	38	52	63	58	53	50	54	52
L-1 (ft)	190	186	185	185	288	322	316	312	414	429	432	433	394	398
L-2 (ft)	75	75	75	75	125	128	130	125	175	164	155	150	154	150
L-3 (ft)	50	50	49	49	119	77	75	84	102	92	93	93	94	93
R-Fillet	0	0	0	0	90	0	0	0	0	0	0	0	0	0
R-CL (ft)	65	65	65	65	110	105	100	100	135	130	125	120	125	120
R-Outer	82	82	82	82	138	130	129	165	200	192	190	186	200	198

High-speed runway exits increase airport capacity, as they allow aircraft to exit the runway faster. The extra pavement construction cost is typically justified on a runway intended for AAC "C" aircraft. High speed exits must be acute angles and should be separated from each other in this way:





Taxiway Gradients

The maximum longitudinal grade is 2.0% for AAC A & B and 1.5% for AAC C, D, and E. The maximum longitudinal grade change is 3.0%. However, changes in longitudinal grades should be avoided unless no other options are available. If absolutely necessary, longitudinal grade changes should follow parabolic vertical curves (minimum length 100 ft. for each 1.0% of change) except when the change is less than 0.40% or where a taxiway crosses a runway or taxiway crown. The minimum distance between points of intersection of vertical curves equals 100 ft. multiplied by the sum of grade changes in percent. Future connecting taxiways should be considered. The crown of a taxiway should not be higher than the crown of the runway. Transverse grades should be kept to a minimum.

These figures show the standards transverse gradients:

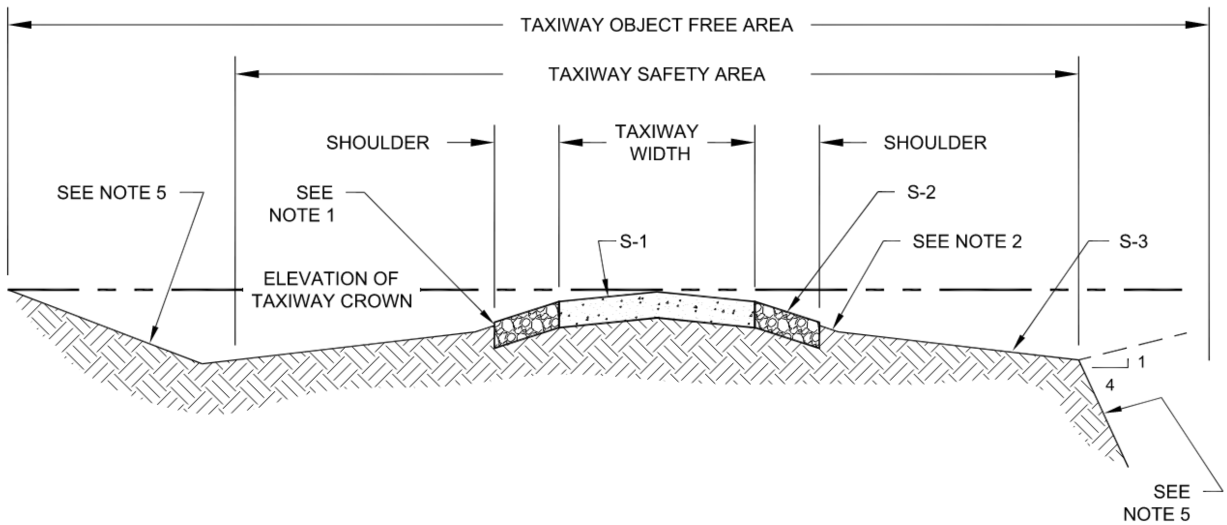


Table 3-3. Transverse grades

Dimension	Approach Category	
	A & B	C, D, & E
S-1	1.0% - 2.0%	1.0% - 1.5%
S-2 (≥ S-1)	1.5% - 5.0%	1.5% - 5.0%
S-3	1.5% - 5.0%	1.5% - 3.0%

TAXIWAY MARKINGS & LIGHTING

Taxiway markings and lighting are not addressed in this course. A following course in this series will detail these subjects.

Circular Runways: The Unsold Concept

This course would not be complete without a brief historical review of a curious, albeit unconventional, idea that was revealed in the early 1960's. US Navy Lieutenant J.R. Conrey revealed a concept for a bowl-shaped 360-degree runway, offering unlimited heading options for upwind takeoffs and also unlimited length. Conrey determined the proper bank angle for a 300 ft. wide runway around a 32,000 ft. circumference circle (nearly 2 mile diameter). This geometry would accommodate speeds from 40 mph at the inner edge and 170 mph at the outer edge. For two years, Conrey propagated this idea, secured sponsors, and eventually patented his concept. Unfortunately, he was killed in 1963 when his A-5 struck the ramp of the USS Independence while attempting to land. Another Navy man, Commander Lloyd Smith took up the project and conducted flight tests at General Motors Automotive Proving Ground in a T-28 with remarkable results; even better than expected. Centrifugal g-force was minimal and takeoffs were surprisingly routine. Other aircraft were tested: and A-1, C-54 transport, and an A-4 bomber; all with great success. Steering was accomplished merely by throttle alone. The final official report assigned the circular runway "a vital place in the future of aviation". The FAA, however, was less enthusiastic and quite indifferent to the idea. Also, the cost of constructing the precise bank, lengthy pavement, and tunnels underneath to a central terminal may have checked the feasibility of making it a reality, and no circular runways were ever certified.

Aviation has greatly advanced since the 1960's and it causes one to speculate on the resurfaced feasibility of such an idea in our modern age. Could these challenges be met and overcome in today's world to provide a safer, more efficient airport? Engineers are at the helm of such advancements; who is to say it can't happen?

Reference Material

1. AC 150/5300-13A *Airport Design*; 9-28-2012 including 5-17-2018 Errata
2. AC 150/5320-6F *Airport Pavement Design & Evaluation*; 11-10-2016
3. AC 150/5325-4B *Runway Length Requirements for Airport Design*; 7-1-2005
4. AC 150/5340-1L *Standards for Airport Markings;* 9-27-2013
5. 14 CFR Part 77 *Safe, Efficient Use, and Preservation of the Navigable Airspace*
6. Air & Space, *Landing in a Bowl*, Stephen Joiner, April/May 2004.
7. Airport Engineering, Ashford et al., *Wiley & Sons, 4th ed.*
8. Planning and Design of Airports, *Horonjeff et al., McGraw-Hill, 5th ed.*

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