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Quiz AS103
Airport Engineering

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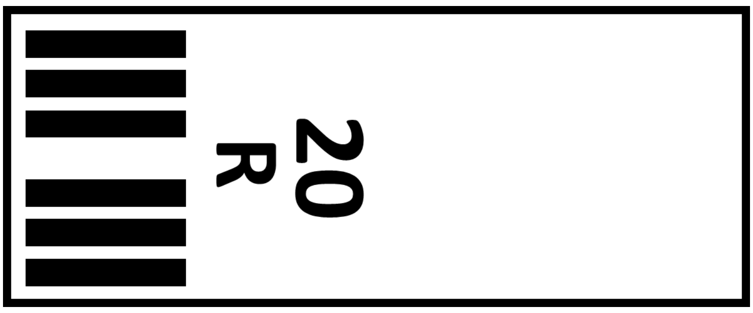
Problems

Problem 1

Regarding aspects of airport engineering, true or false?

1.( ) Runway threshold markings help identify the beginning of the runway that is available for landing. Runway threshold markings come in two configurations. They either consist of eight longitudinal stripes of uniform dimension disposed symmetrically about the runway centerline or the number of stripes is related to the width of the runway, as indicated in the next table. Accordingly, the runway illustrated below has a width of 30 meters.

Runway Width (ft)	Number of Stripes
60	4
75	6
100	8
150	12
200	16



2.( ) The number 20 in the runway illustrated above could indicate that the direction of the runway has a magnetic azimuth of 200 degrees. The letter R, in turn, could mean that the runway is to the right of a second runway in a parallel-runway configuration.

3.( ) A stopway is an area beyond the takeoff runway, centered on the extended runway centerline, designated by the airport owner for use in decelerating an airplane during an aborted takeoff. This segment of the accelerate-stop distance is crucial in aborted takeoff maneuvers and as such must be constructed with full-strength pavement, especially when accommodating turbojet-powered aircraft.

4.( ) When classifying runway lengths for small airplanes with maximum certificated takeoff weight of 12,500 lb or less and less than 10 passenger seats, the AC 150/5235-4B distinguishes between two family groupings according to "percent of fleet." The 95 percent of fleet designation applies to airports intended to serve communities on the fringe of a metropolitan area.

5.( ) Asphalt and concrete have been used in the construction of apron pavements. One of the advantages of asphalt pavements is their inherent resistance to spilled kerosene and gasoline when compared to concrete.

6.( ) The function of the subbase of a flexible pavement, when required, is similar to the base course, such as withstanding wheel loads and resisting volume changes caused by fluctuations in moisture content. The engineer can do away with the need for this pavement layer when the California Bearing Ratio (CBR) value is high enough.

7.( ) The ACN/PCN system was introduced by the ICAO as a method of reporting relative pavement strength so airport evaluators can evaluate the acceptable operations of airplanes. Furthermore, the ICAO has introduced the Pavement

Classification Number (PCN) with the intention of incorporating it in airfield pavement design procedures in projects conceived in member countries. The collective use of this parameter in design has led to a more homogeneous flow of information in airport projects across the world.

8.( ) The following table lists the allowable tire pressure categories identified by the ACN/PCN system. Aircraft tire pressures will have little effect on pavements with Portland cement concrete surfaces. Rigid pavements are inherently strong enough to resist tire pressures higher than currently used by commercial aircraft and can usually be rated as code W.

Category	Code	Tire pressure range
Unlimited	W	No pressure limit
High	X	Pressure limited to 254 psi (1.75 MPa)
Medium	Y	Pressure limited to 181 psi (1.25 MPa)
Low	Z	Pressure limited to 73 psi (0.50 MPa)

9.( ) Airport pavement design using the FAA's FAARFIELD software considers both arrivals and departures of the fleet mix so as to account for all loading configurations, both light and heavy, and thereby provide the safest design.

10.( ) Advisory circulars published by the FAA, e.g. AC 150/5380-9, *Guidelines and Procedures for Measuring Airfield Pavement Roughness*, address the issue of pavement roughness and its evaluation. Such documents reveal that airport pavement roughness is mainly defined by perceived ride quality and passenger discomfort.

11.( ) There are two commonly used definitions to describe airport capacity: throughput capacity and practical capacity. Practical capacity is the ultimate rate at which aircraft operations may be handled without regard to any small delays that might occur as a result of imperfections in operations or small random events that might occur.

12.( ) In the United States, the main cause of flight operation delays greater than 15 minutes is weather conditions.

13.( ) Many airports are equipped with automated weather reporting facilities to provide pilots with up-to-date meteorological information. Two of the most common systems are the Automated Weather Observation System (AWOS) and the Automated Surface Observation System (ASOS). The AWOS is a suite of sensors that provide a minute-to-minute update that is usually provided to pilots by a radio on a frequency between 118.0 and 136 MHz. There are six different AWOS types, which differ in terms of the information they are capable of detecting and conveying to pilots. The most robust and advanced system is labeled AWOS I.

14.( ) The noise generated by aircraft creates problems in making decisions regarding airport layout and capacity. The correct assessment of future noise patterns, to minimize the effect on surrounding communities, is essential to the optimal layout of the runways. Regulations regarding aircraft noise emissions have grown more stringent with every passing decade since the FAA imposed the first noise regulations to turbojet aircraft in 1969. Indeed, as of the early 2000s the first-generation jet aircraft are now completely banned from flight in the United States and other developed countries.

Problem 2 **(Modified from Horonjeff et al., 2010, w/ permission)**

Determine the runway length requirements according to the specifications of FAR 25 and FAR 121 for a turbine-powered aircraft with the following performance characteristics. True or false?

Normal Takeoff
Liftoff Distance = 6700 ft
Distance to height of 35 ft = 7400 ft

Engine Failure
Liftoff Distance = 7700 ft
Distance to height of 35 ft = 8100 ft

Engine-Failure Aborted Takeoff
Accelerate-Stop Distance = 8600 ft

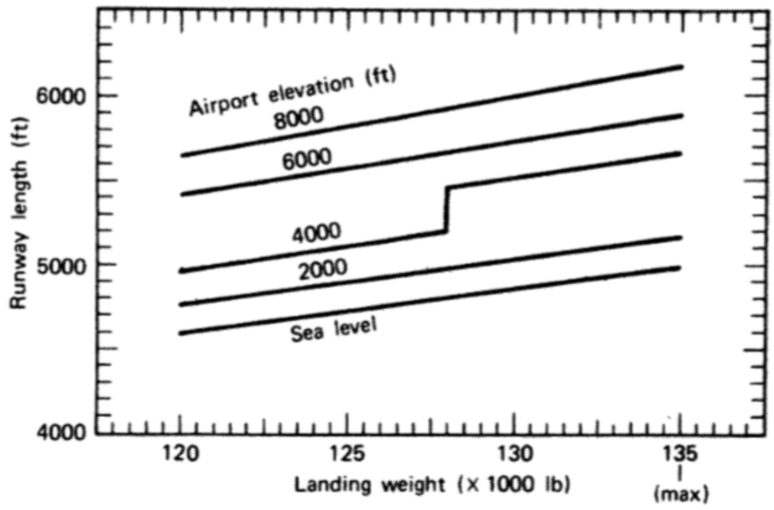
Normal Landing
Stop Distance = 5000 ft

1.( ) The required field length is greater than 8500 ft.
2.( ) The required full-strength pavement length is greater than 8300 ft.
3.( ) The required stopway distance is greater than 400 ft.
4.( ) The required clearway distance is greater than 200 ft.

Problem 3 (Modified from Ashford & Wright, 1992, w/ permission)

The landing aircraft performance curves for the Boeing 727-00 series are shown in continuation.

Boeing 727–00 series
Pratt & Whitney JT8D–1 engine



Consider a 727-00 with the following characteristics and environmental conditions:

→ Maximum landing weight: 130,000 lb
→ Normal maximum temperature: 80°F
→ Airport elevation: 2000 ft
→ Flight distance: 1000 mi
→ Effective runway gradient: 0.5%

The runway length required for landing is most nearly:

A) L = 4500 ft
B) L = 5000 ft
C) L = 5500 ft
D) L = 6000 ft

Problem 4

The following table provides taxiway dimensional standards posed by the ICAO. All measures are in meters. With reference to these data, suppose a runway with ICAO aerodrome code letter D will accommodate aircraft with wingspans up to 60 m. The minimum taxiway-to-taxiway separation is:

Aerodrome code letter	A	B	C	D	E
Edge safety margin	1.5	2.25	3	4.5	4.5
Minimum wingtip clearance	3	3	4.5	7.5	7.5

A) S_{TT} = 73.5 m
B) S_{TT} = 76.5 m
C) S_{TT} = 79.5 m
D) S_{TT} = 81.5 m

Problem 5 (Modified from Ashford & Wright, 1992, w/ permission)

A −0.6% runway longitudinal grade intersects a −1.2% grade, which in turn intersects a +0.4% grade. Based on the specification for ICAO code number 3, what minimum distance should be used between the points of intersection for these grades?

A) L = 650 ft

B) L = 810 ft

C) L = 1080 ft

D) L = 1250 ft,

Problem 6

The PCN system uses a coded format to maximize the amount of information contained in a minimum number of characters and to facilitate computerization. The PCN for a pavement is reported as a five-part code, with parts separated by forward slashes. Consider, for instance, a pavement with the following code. Which of the following is **false**?

80/R/C/W/T

A) The pavement is flexible.

B) The subgrade material is of low strength.

C) There is no pressure limit in terms of tire pressure.

D) The PCN value was obtained by technical evaluation.

Problem 7

The following data apply to an Airbus A 320-200 Dual.

→ Maximum takeoff mass: 73,500 kg
→ Actual operating mass: 60,500 kg
→ Operating empty mass: 39,750 kg

The following data apply to a tire pressure of 1.45 MPa.

Conditions	ACN for rigid pavement subgrades (MN/m³)			
	High (150)	Medium (80)	Low (40)	Very Low (20)
Maximum takeoff mass	44	46	48	50
Operating empty mass	20	22	25	29

Conditions	ACN for flexible pavement subgrades (CBR value)			
	High (15)	Medium (10)	Low (6)	Very Low (3)
Maximum takeoff mass	38	40	44	50
Operating empty mass	19	19	20	24

Estimate the actual ACN of this craft on a flexible pavement with high strength subgrade (CBR ~ 15).

A) ACN = 20

B) ACN = 25

C) ACN = 31

D) ACN = 36

Problem 8

The mode of rigid pavement failure considered in the FAA's FAARFIELD pavement design software is:

A) Joint spalling due to freeze-thaw.

B) Bottom-up cracking of the concrete slab.

C) Pumping of subbase material due to high hydraulic gradients.

D) Gradual scaling of cement concrete due to repeated aircraft loads.

Problem 9.1 (Modified from Horonjeff et al., 2010, w/ permission)

Compute the average delay to arriving aircraft on a runway system which services only arrivals if the mean service time is 90 seconds per aircraft with a standard deviation in the mean service time of 15 s and the average rate of arrivals is 30 aircraft per hour.

A) W_a = 1.1 min

B) W_a = 2.3 min

C) W_a = 3.1 min

D) W_a = 4.0 min

Problem 9.2

With other parameters held constant, determine the runway service rate that corresponds to a delay of 3 minutes.

A) μ_a = 23 arrivals/hour

B) μ_a = 26 arrivals/hour

C) μ_a = 30 arrivals/hour

D) μ_a = 38 arrivals/hour

Problem 10 (Modified from Ashford and Wright, 1992, w/ permission)

Given a length of common approach path γ = 6 nautical miles and a minimum separation of 3 nautical miles, calculate the ultimate capacity for the following population of aircraft landing on a single runway, assuming error-free approaches.

Percentage of Aircraft	Approach Speed (kn)
20	90
30	100
50	120

A) c = 33 arrivals/hour

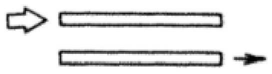
B) c = 43 arrivals/hour

C) c = 50 arrivals/hour

D) c = 60 arrivals/hour

Problem 11 (Modified from Ashford and Wright, 1992, w/ permission)

Determine the annual service volume of a dual parallel runway configuration under the following operation conditions.

Operating condition			Mix Index	Percentage of Year	Hourly Capacity
No.	Ceiling and Visibility	Runway Use			
1	VFR		140	60%	95
2	VFR		125	30%	71
3	IFR		160	10%	58

In addition, consider the following data.

Total Annual Operations	390,000
Average Daily Operations	1100
Average Peak Hour Operations, Peak Month	75

A) ASV = 248,000 operations per year

B) ASV = 305,000 operations per year

C) ASV = 362,000 operations per year

D) ASV = 410,000 operations per year

Problem **12.1** (Modified from Ashford and Wright, 1992, w/ permission)

Determine the capacity of 15 gates that serve three classes of aircraft, given the following aircraft mix and average gate occupancy times. Assume that each gate is available for all aircraft.

Aircraft Class	Mix (%)	Average Occupancy Time (min)
1	20	20
2	30	40
3	50	60

A) C = 17 aircraft/hour

B) C = 20 aircraft/hour

C) C = 26 aircraft/hour

D) C = 35 aircraft/hour

Problem **12.2**

Suppose the 15 gates in the preceding example are assigned for exclusive use of the three classes of aircraft as follows. Determine the gate capacity.

Aircraft Class	Gate Group	Number of Gates	Mix (%)	Mean Service Time (min)
1	A	3	20	20
2	B	4	30	40
3	C	8	50	60

A) C = 16 arrivals/hour

B) C = 19 arrivals/hour

C) C = 24 arrivals/hour

D) C = 31 arrivals/hour

Problem **13** (Modified from Horonjeff et al., 2010, w/ permission)

The sound exposure levels of five aircraft flyovers were measured over the course of a 24-h period, as listed below. Determine the Day-Night Average Sound Level (DNL).

Time	Intensity
6:15 AM	79.5 dB
11:10 AM	81.7 dB
3:25 PM	86.0 dB
7:15 PM	84.4 dB
11:10 PM	80.1 dB
2:30 AM	82.0 dB

A) DNL = 43.1 dB

B) DNL = 47.0 dB

C) DNL = 50.8 dB

D) DNL = 53.2 dB

ADDITIONAL INFORMATION

Table 1 Runway longitudinal grade design criteria for civilian airports

	Maximum Longitudinal Grade (%)	Maximum Grade, First and Last Quarter (%)	Maximum Effective Grade (%)	Maximum Change (%)	Distance Between Points of Inter-section (ft)[a]	Length of Vertical Curve[b] (ft/1% grade change)
FAA						
Transport airports	1.5	0.8	1.0	1.5	1000(A + B)	1000
Utility airports	2.0	—	—	2.0	250(A + B)	300
ICAO						
Code number 4	1.25	0.8	1.0	1.5	984(A + B)	984
Code number 3	1.5	0.8[c]	1.0	1.5	492(A + B)	492
Code number 2	2.0	—	1.0	2.0	164(A + B)	246
Code number 1	2.0	—	2.0	2.0	164(A + B)	246

Table 2 Weights to the capacity for each operating condition (Problem 11)

	Weight			
	Mix Index in VFR	Mix Index in IFR		
Percentage of Predominant Capacity	0–180	0–20	21–50	51–180
91 or more	1	1	1	1
80–90	5	1	3	5
66–80	15	2	8	15
51–65	20	3	12	20
0–50	25	4	16	25

Solutions

P.1 ■ Solution

1. False. The runway illustrated has six stripes, which corresponds to a runway width of 75 feet or 22.8 meters.

2. True. The aforementioned number, known as the runway designator, indeed depends on the magnetic azimuth of the runway. The marking is given to the nearest 10° with the last digit omitted. Accordingly, a "20" marker may refer to a runway with azimuth of 200 degrees. Lastly, the "R" marking could indicate the relative position of a runway in a parallel-runway configuration.

3. False. Recognizing the fact that aborted takeoff is a rare instance in the operation of turbine-powered aircraft, regulators have allowed the construction of the stopway with lesser strength pavement for that part of the accelerate-stop distance beyond the takeoff run.

4. False. In the FAA circular in question, the "95 percent of fleet" category applies to airports primarily intended to serve medium size population communities, whereas the "100 percent of fleet" designation is intended for airport projects in communities located on the fringe of a metropolitan area or a relatively large population remote from a metropolitan area.

5. False. It is asphalt pavements, not concrete pavements, that have a lower resistance against spilt fuel. In addition, they are especially vulnerable to damage from the hot exhaust gases emitted by military jet engines, and for that reason are commonly not utilized in military aerodromes.

6. True. It has been suggested that subbases are required when flexible pavement is to be supported by soils of CBR value less than 20. The material requirements for the subbase are not as strict as for the base course since the subbase is subjected to lower load intensities. AC 150/5320-6F observes that any material suitable for use in a base course can also be used as a subbase.

7. False. The ACN/PCN system was never intended for use in pavement design or evaluation and neither does it restrict the methodology used to design or evaluate a pavement structure. Pavement design and evaluation are complex engineering problems that require detailed analysis. They cannot be reduced to a single number.

8. True. Indeed, rigid concrete pavements have superior strength and can be associated with tire pressure code W, which pertains to the "no pressure limit" tire pressure range. For flexible pavements constructed with a high stability asphalt, tire pressures up to 254 psi (1.75 MPa) may be accommodated.

9. False. Airport pavement design using FAARFIELD only considers departures and ignores arrival traffic when determining the number of airplane passes. This is because in most cases airplanes arrive at an airport at a significantly lower weight than at takeoff due to fuel consumption.

10. False. Passenger discomfort, while important, does not constitute the basis upon which airfield pavement roughness is evaluated. Perceived discomfort is not a significant issue since the degree of annoyance is low and usually does not last more than a few seconds. Further, passenger discomfort often occurs during takeoff and landing operations, during which engine noise, aerodynamic noise, and horizontal acceleration or deceleration otherwise distract the passengers.

11. False. The definition offered in the statement is that of throughput capacity. Throughput capacity is an "absolute" measurement of capacity in that it ignores any delays and imperfections associated with airport operation such as the possibilities that a given aircraft might take more than necessary to takeoff or a runway might close for a short period of time because of the presence of small debris. Throughput capacity is an inherently theoretical measure of capacity and constitutes the basis by which initial airport design is conceived.

12. True. Indeed, the main cause of delays greater than 15 minutes is weather conditions. The following table indicates the relative occurrence of the main causes of delay in 1985 and 1990, as compiled by the FAA. It can be seen that, while weather continues to be the main cause of delay, terminal traffic operations also contribute substantially and have been on the rise.

Cause of Delay	1985	1990
Weather	68%	53%
Terminal air traffic conditions	12%	36%
Air traffic center operations	11%	2%
Airfield-runway closures	6%	4%
NAS CNS/ATM	2%	2%
Other	1%	3%
Total delayed operations	334,000	404,000

13. False. AWOS I is in fact the least sophisticated subtype of AWOS. The most robust subtype is AWOS III, which encompasses all the capabilities of AWOS I and II with the addition of sky conditions, cloud heights and type, and its variant AWOS-III-P-T, which also includes present weather and lighting detection. The data types gathered by each system are outlined below.

System	Capabilities
AWOS I	Wind speed, wind gust, wind direction, variable wind direction, temperature, air pressure, and density altitude
AWOS II	AWOS I capabilities, visibility, and variable visibility
AWOS III	AWOS II capabilities, present thunder and precipitation identification
AWOS III-P	AWOS II capabilities, thunderstorm and lighting detection
AWOS III-T	AWOS II capabilities, present weather and lighting detection
AWOS III-P-T	AWOS III capabilities, present weather and lighting detection

14. True. Indeed, the so-called stage 1 aircraft, which encompasses old first generation turbojets with bypass ratios greater than 2 such as the B707s and DC8s, have been retired in the developed world. In more recent times, most stage 2-compliant aircraft, including the B727 and B737-200s, have either been upgraded to meet stage 3 requirements or were retired as well.

P.2 ■ Solution

Consider first the runway length requirements for a normal takeoff with all engines fully operating. In this case, the takeoff distance (TOD) is defined as 115 percent of the actual distance the aircraft uses to reach a height of 35 ft. In the present case, D_{35} = 7400 ft and

$$TOD_1 = 1.15 D_{35} = 1.15 \times 7400 = 8510 \text{ ft}$$

Given this value of TOD_1 and the liftoff distance LOD_1 = 6700 ft, the corresponding clearway is calculated as

$$CL_{1,\max} = 0.50\left(TOD_1 - 1.15 LOD_1\right) = 0.50 \times \left(8510 - 1.15 \times 6700\right) = 403 \text{ ft}$$

The corresponding takeoff run (TOR_1) follows as

$$TOR_1 = TOD_1 - CL_{1,\max} = 8510 - 403 = 8110 \text{ ft}$$

Consider now the engine-failure takeoff scenario. In this case, the TOD equals the distance required to achieve a height of 35 ft, that is,

$$TOD_2 = D_{35,2} = 8100 \text{ ft}$$

while the clearway follows as

$$CL_{2,\max} = 0.50\left(TOD_2 - LOD_2\right) = 0.50\left(8100 - 7700\right) = 200 \text{ ft}$$

The corresponding takeoff run is then

$$TOR_2 = TOD_2 - CL_{2,\max} = 8100 - 200 = 7900 \text{ ft}$$

The third scenario is an engine-failure aborted takeoff. In this case, we simply have the accelerate-stop distance DAS = 8600 ft. The fourth and final scenario refers to the landing situation. The regulations require that the landing distance (LD) required for an aircraft landing on a given runway must be sufficient to permit the aircraft to come to a full stop within 60 percent of this distance. Accordingly, the distance in question, termed the stop distance (SD), is given by

$$LD = \frac{SD}{0.60} = \frac{5000}{0.60} = 8000 \text{ ft}$$

The field length shall be the largest of the following four results,

$$FL = \max\left[TOD_1, TOD_2, DAS, LD\right]$$

In the present case,

$$FL = \max\left[8510, 8100, 8600, 8330\right] \rightarrow \boxed{FL = 8600 \text{ ft}}$$

That is, the engine-failure aborted takeoff scenario requires the highest field length and hence governs the choice of FL.

The full-strength pavement length, FS, is given by

$$FS = \max\left[TOR_1, TOR_2, LD\right]$$

In the case at hand,

$$FS = \max\left[8110, 7900, 8000\right] \rightarrow \boxed{FS = 8110 \text{ ft}}$$

The stopway distance, SW, is given by

$$SW = \left[DAS - \max\left(TOR_1, TOR_2, LD\right)\right]$$

Thus,

$$SW = 8600 - \max\left(8110, 7900, 8000\right) = \boxed{490 \text{ ft}}$$

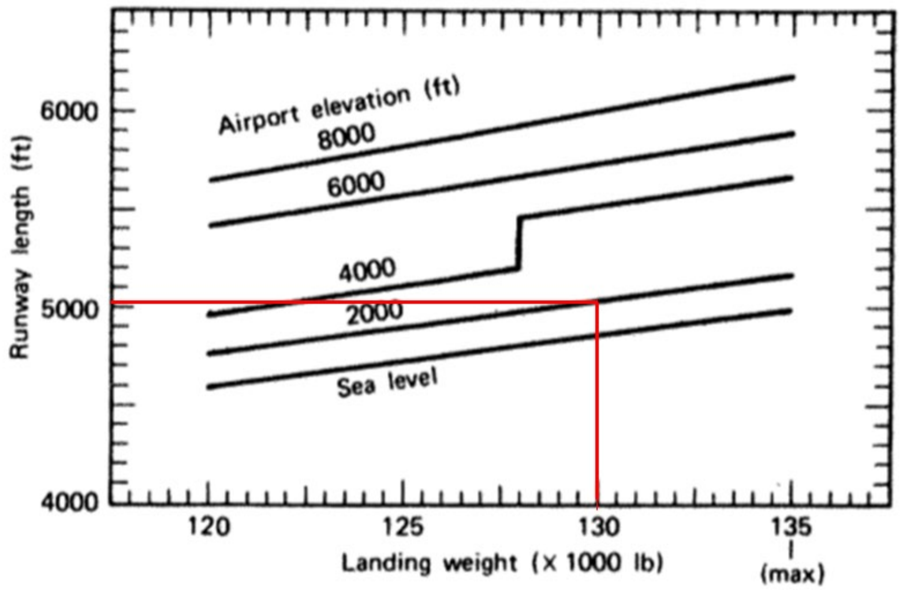
Lastly, the clearway is given by

$$CL = \min\left[\left(FL - DAS\right), CL_{1,\max}, CL_{2,\max}\right] = \min\left[8600 - 8600, 403, 200\right] = \boxed{0}$$

★ Statements **1** and **3** are true, while statements **2** and **4** are false.

P.3 ■ Solution

The graphical determination of landing runway length is quite simple. First, enter a landing weight of 130,000 in the horizontal axis of the chart. Then, extend this point vertically until it crosses the 2000-ft airport elevation curve. Finally, project the point of intersection to the vertical axis and read the runway length. In the case at hand, the runway length is found to be about 5050 ft; see below.



★ The correct answer is **B**.

P.4 ■ Solution

The taxiway-to-taxiway separation can be estimated as

$$S_{TT} = WS + 2U_1 + C_1$$

where WS is the wingspan of the most demanding aircraft, U_1 is the taxiway edge safety margin, and C_1 is the minimum wingtip clearance. With reference to the table, we read U_1 = 4.5 m and C_1 = 7.5 m. Accordingly,

$$S_{TT} = 60 + 2 \times 4.5 + 7.5 = \boxed{76.5 \text{ m}}$$

The taxiway-to-taxiway separation should be no less than 76-and-a-half meters.

★ The correct answer is **B**.

P.5 ■ Solution

The absolute value of the grade change for the first point of intersection is given by

$$|A| = |-0.6-(-1.2)| = 0.6\%$$

Similarly, the absolute value of the grade change for the second point of intersection is given by

$$|B| = |-1.2-(+0.4)| = 1.6\%$$

Referring to Table 1, the equation to use for ICAO code number 3 is L = 482(A + B). Accordingly,

$$L = 492(0.6+1.6) = \boxed{1080\text{ ft}}$$

★ The correct answer is **C**.

P.6 ■ Solution

The PCN code has the form *PCN Value/pavement type/subgrade category/allowable tire pressure/method used to determine the PCN*. Accordingly, number 80 indicates the numerical PCN value; letter C indicates a subgrade material of low strength; letter W indicates that there is no pressure limit in terms of allowable tire pressure; letter T indicates that the PCN value was obtained by technical evaluation. Lastly, code R indicates that the pavement is rigid; a flexible pavement would've been associated with code F.

★ The false statement is **A**.

P.7 ■ Solution

The ACN can be estimated with the formula

$$ACN = ACN_{\max} - \frac{MTOM - AOM}{MTOM - OEM}\left(ACN_{\max} - ACN_{\text{empty}}\right)$$

For a flexible pavement with high strength subgrade, we can read $ACN_{\max}$ = 38 and ACN_{empty} = 19 from the second table. Substituting these and other data in the formula above, we obtain

$$ACN = 38 - \frac{73{,}500-60{,}500}{73{,}500-39{,}750}\times(38-19) = \boxed{31}$$

★ The correct answer is **C**.

P.8 ■ Solution

The only rigid pavement failure mechanism considered by FAARFIELD is bottom-up cracking of the concrete slab. Cracking is controlled by limiting the horizontal stress at the bottom of the PCC slab and does not consider failure of subbase and subgrade layers. In contrast, the design process for flexible pavement considers two failure modes: vertical strain in the subgrade and horizontal strain in the asphalt layer.

★ The correct answer is **B**.

P.9 ■ Solution

Part 1: The mean delay of arriving aircraft can be estimated as

$$W_a = \frac{\lambda_a\left(\sigma_a^2 + 1/\mu_a^2\right)}{2\left(1-\lambda_a/\mu_a\right)}$$

where λ_a is the mean arrival rate of aircraft, σ_a is the standard deviation of the mean service time of the arriving aircraft, and μ_a is the mean service rate for arrivals or the reciprocal of the mean service time. In the present case, this latter term is μ_a = 60/90 = 0.67 aircraft per minute or 40 aircraft per hour. Substituting this quantity, along with λ_a = 30 aircraft/hour and σ_a = 15 s, yields

$$W_a = \frac{\lambda_a\left(\sigma_a^2 + 1/\mu_a^2\right)}{2\left(1-\lambda_a/\mu_a\right)} = \frac{30\times\left[\left(15/3600\right)^2 + 1/40^2\right]}{2\times\left(1-30/40\right)} = 0.0385 \text{ h} = \boxed{2.3 \text{ min}}$$

★ The correct answer is **B**.

Part 2: All we have to do is substitute W_a = 3 min = 0.05 hours in the foregoing expression and solve the ensuing equation for μ_a,

$$W_a = 0.05 = \frac{30\times\left[\left(15/3600\right)^2 + 1/\mu_a^2\right]}{2\times\left(1-30/\mu_a\right)}$$

The solution is μ_a = 37.9 ≈ 38 arrivals per hour. If the delay criterion was that arrival delays could not exceed 3 min then the runway capacity would be 38 arrivals per hour. It should be observed that an increase in capacity from 38 to 40 arrivals per hour, a 5 percent increase, results in a delay reduction of 0.7 minutes, or 23 percent. This is typical at airports nearing saturation. Small increases in capacity can result in significant decreases in delay.

★ The correct answer is **D**.

P.10 ■ Solution

The minimum time separation over the threshold for various combinations of speeds follows from the formula

$$m\left(v_2, v_1\right) = \frac{\delta}{v_2} \text{ for } v_2 \geq v_1$$

$$m\left(v_2, v_1\right) = \frac{\delta}{v_2} + \gamma\left(\frac{1}{v_2} - \frac{1}{v_1}\right) \text{ for } v_2 < v_1$$

where $m(v_2, v_1)$ is the error-free minimum time separation over threshold for aircraft 2 following aircraft 1, v_i is the speed of aircraft i, and γ is the length of common approach path. For the situation v_1 = 90 kn, v_2 = 100 kn, for instance, we have $v_2 > v_1$ and hence

$$m\left(100, 90\right) = \frac{\delta}{v_2} = \frac{3}{100} = 0.03 \text{ h} = 108 \text{ sec}$$

In a similar manner, when v_1 = 120 kn, v_2 = 100 kn, the equation to use is

$$m\left(100, 120\right) = \frac{3}{100} + 6\times\left(\frac{1}{100} - \frac{1}{120}\right) = 0.04 \text{ h} = 144 \text{ s}$$

Proceeding in similar fashion, the following matrix is obtained.

Speed of Trailing Aircraft, v_j \ Speed of Leading Aircraft, v_i	90	100	120	Probability, P_j
90	120	144	144	0.2
100	108	108	144	0.3
120	90	90	90	0.5

The expected minimum landing interval can be approximated by the weighted sum

$$\bar{m} = \Sigma_{ij} P_i m_{ij} P_j$$

In the present case,

$$\bar{m} = \left(120\times0.2 + 108\times0.3 + 90\times0.5\right)\times0.2 + \left(144\times0.2 + 108\times0.3 + 90\times0.5\right)\times0.3$$
$$+ \left(144\times0.2 + 144\times0.3 + 90\times0.5\right)\times0.5 = 110.6$$

Finally, the ultimate capacity is calculated as

$$c = \frac{1}{\bar{m}} = \frac{1}{110.6}\times3600 \approx \boxed{33 \text{ arrivals/hour}}$$

★ The correct answer is **A**.

P.11 ■ Solution

The predominant capacity occurs in operating condition No. 1 and is 95 operations per hour. From Table 2, the following weights for each operating condition are established.

Operating Condition Number	Hourly Capacity, Operations per Hour	Percent of Predominant Capacity	Weight (Table 2)
1	95	95/95 = 100%	1.0
2	71	71/95 = 75%	15
3	58	58/95 = 61%	20

The weighted hourly capacity C_w of the runway component is given by the formula

$$C_W = \frac{\sum_{i=1}^{n} C_i W_i P_i}{\sum_{i=1}^{n} W_i P_i}$$

where P_i is the proportion of the year with capacity C_i and W_i is the weight associated with capacity as calculated above. Thus,

$$C_W = \frac{(0.60\times 95\times 1)+(0.30\times 71\times 15)+(0.10\times 58\times 20)}{(0.60\times 1)+(0.30\times 15)+(0.1\times 20)} = 69.4 \text{ operations per hour}$$

For the assumed conditions,

$$\text{Daily ratio } = D = \frac{390{,}000}{1100} = 355$$

$$\text{Hourly ratio} = H = \frac{1100}{75} = 14.7$$

The annual service volume is determined to be

$$ASV = C_W \times D \times H = 69.4\times 355\times 14.7 = \boxed{362{,}000 \text{ operations per year}}$$

★ The correct answer is **C**.

P.12 ■ Solution

Part 1: The gate capacity of a single gate is given by

$$c = \frac{1}{\text{Weighted service time}} = \frac{1}{0.20\times 20 + 0.30\times 40 + 0.50\times 60} = 0.0217 \text{ aircraft/min/gate}$$

If G = 15 is the total number of gates, the capacity for all gates follows as

$$C = c\times G = 0.0217\times 15 = 0.326 \text{ aircraft/min}$$

$$\therefore \boxed{C \approx 20 \text{ aircraft/hour}}$$

★ The correct answer is **B**.

Part 2: If the effect of mix is ignored, the capacity of group A would be the inverse of service time, that is, $C_A = 1/T_A$ = 3 aircraft/hr. Likewise, $C_B = 1/T_B$ = 1.5 aircraft/hr and $C_C = 1/T_C$ = 1 aircraft/hr. One might (incorrectly) assume that the total capacity of these gates is the sum of capacities of the three groups or 3 × 3 + 4 × 1.5 + 8 × 1 = 23 aircraft/hr. When mix is taken into consideration, an overall demand of 23 aircraft/hr would result in excessive demand for gate groups B and C, as tabulated below.

Gate Group	Demand (aircraft/hr)	Capacity (aircraft/hr)
A	0.2 × 23 = 4.6	3 × 3 = 9.0
B	0.3 × 23 = 6.9	1.5 × 4 = 6.0
C	0.5 × 23 = 11.5	1 × 8 = 8.0

The capacity of the gate system is

$$C = \min\left[\frac{G_i}{T_i M_i}\right]$$

where G_i is the number of gates that can accommodate aircraft of class i, T_i is the mean gate occupancy time of aircraft of class i, and M_i is the fraction of aircraft of class i demanding service. For the problem at hand, we have, for aircraft class 1,

$$C_1 = \frac{3}{20 \times 0.2} = 0.75 \text{ aircraft/min} = 45 \text{ aircraft/hour}$$

For aircraft classes 2 and 3, in turn, we have

$$C_2 = \frac{4}{40 \times 0.3} = 0.333 \text{ aircraft/min} = 20 \text{ aircraft/hour}$$

$$C_3 = \frac{8}{60 \times 0.5} = 0.267 \text{ aircraft/min} = 16 \text{ aircraft/hour}$$

The lowest result controls, and hence we take 16 aircraft/hour as the capacity of the gate system.

★ The correct answer is **A**.

P.13 ■ Solution

The aircraft component of DNL can be estimated with the relation

$$DNL = 10\log\left[\frac{1}{86,400}\sum_{j=1}^{N} 10^{\left(L_{AE,i}+W_i\right)/10}\right]$$

where $L_{AE,i}$ is the sound exposure level produced by the i-th aircraft pass-by; W_i is the time-of-day weighting for the j-th aircraft pass-by (namely, zero if the pass-by occurred between 7 AM and 10 PM, or +10 dB if it occurred between 10 PM and 7 AM); and N is the number of aircraft noise events during the 24-h period. In the case at hand, we write

$$DNL = 10\log\left\{\frac{1}{86,400}\left[\begin{array}{c} 10^{(79.5+10)/10} + 10^{81.7/10} + 10^{86.0/10} + (\ldots) \\ (\ldots) + 10^{84.4/10} + 10^{(80.1+10)/10} + 10^{(82.0+10)/10} \end{array}\right]\right\}$$

$$\therefore DNL = 10\log(50,010) = \boxed{47.0 \text{ dB}}$$

To identify the aircraft which has the greatest contribution to the DNL, we evaluate the $(L_{AE,i} + W_i)/10$ value for each aircraft, as shown below. Clearly, we see that the aircraft flyover at 2:30 AM is the greatest contributor and the aircraft flyover at 11:10 AM is the least contributor to the day-night average sound exposure level.

Time	$(L_{AE,i} + W_i)/10$
6:15 AM	(79.5 + 10)/10 = 8.95
11:10 AM	(81.7 + 0)/10 = 8.17
3:25 PM	(86.0 + 0)/10 = 8.60
7:15 PM	(84.4 + 0)/10 = 8.44
11:10 PM	(80.1 + 10)/10 = 9.01
2:30 AM	(82.0 + 10)/10 = 9.20

★ The correct answer is **B**.

Answer Summary

Problem 1		T/F
Problem 2		T/F
Problem 3		B
Problem 4		B
Problem 5		C
Problem 6		A
Problem 7		C
Problem 8		B
Problem 9	9.1	B
	9.2	D
Problem 10		A
Problem 11		C
Problem 12	12.1	B
	12.2	A
Problem 13		B

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