Final Exam for CEE 4674

Date Due: December 16, 2024 at midnight
Instructor: Trani

Sign VT Honor Code Pledge

This exam is the product of my own group's work. I pledge that I have not received help from anyone outside.

Problem 1 (25 Points)

Evaluate the runway length required for aircraft operations from a new airport located 1,850 feet above mean sea level conditions and with a design temperature of 86 degrees Fahrenheit. The critical aircraft is the Boeing 787-10 (see Figure 1). The aircraft information is described in Figure 1. **The airline would like to operate the aircraft at maximum takeoff weight**.

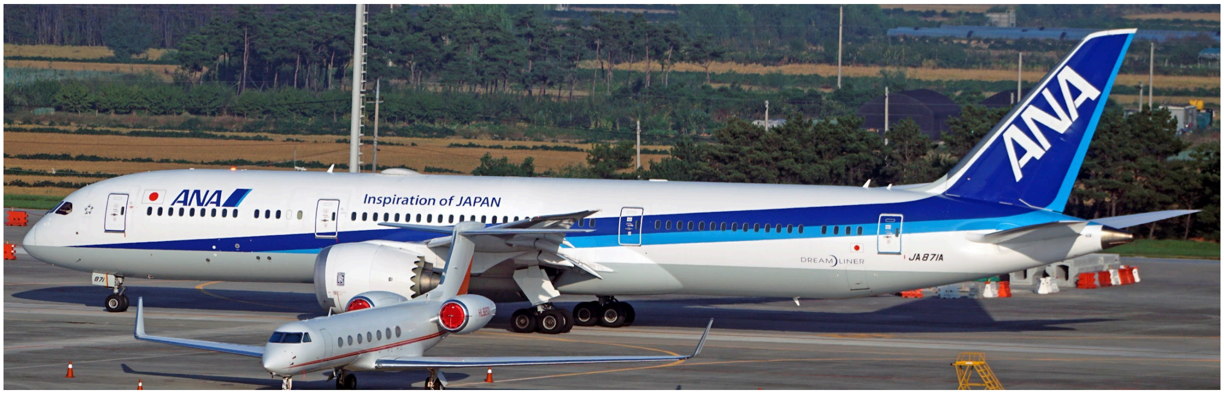


Figure 1. Boeing 787-10 with High-Thrust Rolls-Royce engines. Aircraft maximum design takeoff weight is 560,000 lb. 330 seats in a two-class layout. See other characteristics in the Boeing documents for airport planning and design.

a) Find the runway length needed for the aircraft to operate at **maximum takeoff weight** from the new airport. Please be clear in all your assumptions about solving the problem. Also, please show me the aircraft manufacturer figures used in your solution.

Airport altitude = 1,850 ft

Sea level temperature (ISA): 15 °C

ISA temperature lapse rate: −1.98 °C per 1000 ft up to 36,089 ft.

To find the ISA temperature at 1,850 ft above sea level:

$$\Delta T = 1.85 \times (-1.98) = -3.663\ ^\circ\text{C}$$
$$T_{1850\text{ ft}} = 15 - 3.663 = 11.337\ ^\circ\text{C}$$

The ISA temperature at 1,850 ft above sea level is approximately 11.3 °C.

Design temperature = 86 °F

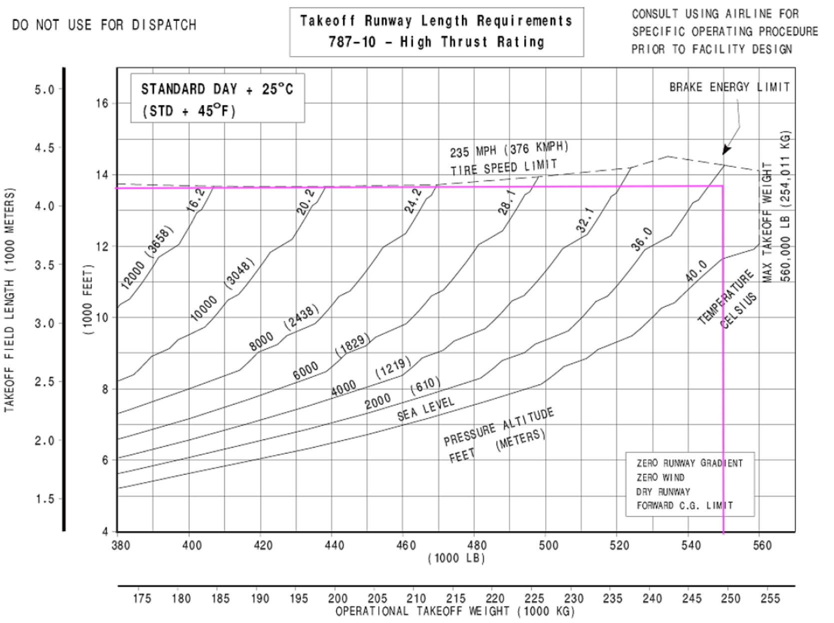
86 °F is 30 °C.

Therefore, the design temperature is equivalent to ISA (11.3 °C) + 18.7 °C = 30 °C

Use ISA + 25 deg. C. design charts (or ISA + 45 deg. F.)

Using the takeoff performance nomograph, the aircraft cannot takeoff at its MTOW (560,000 lb) while departing an airport located 1,850 feet above sea level at the desired design temperature. Therefore, the operators must reduce the takeoff weight to a 550,000 lb, as shown in the following figure.

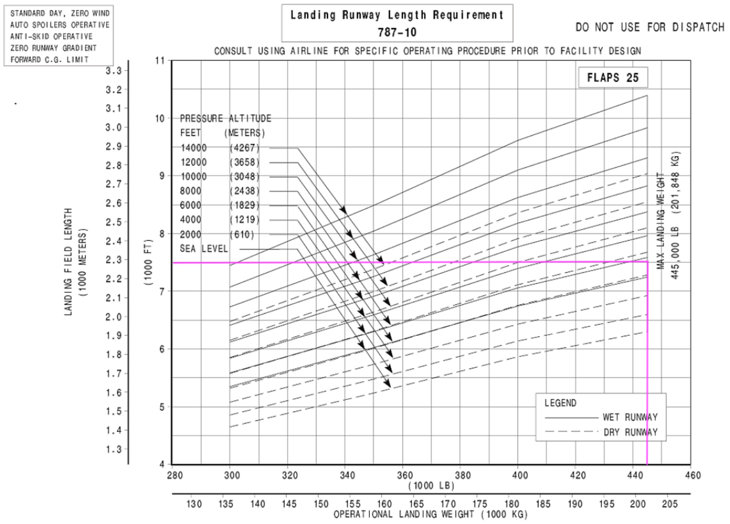
The runway length required for takeoff at the maximum allowable takeoff weight of 550,000 lb on a dry runway is 13,700 ft



3.3.23 FAA/EASA Takeoff Runway Length Requirements - Standard Day + 45°F (STD + 25°C), Dry Runway: Model 787-10 (Hi-Thrust Engines)

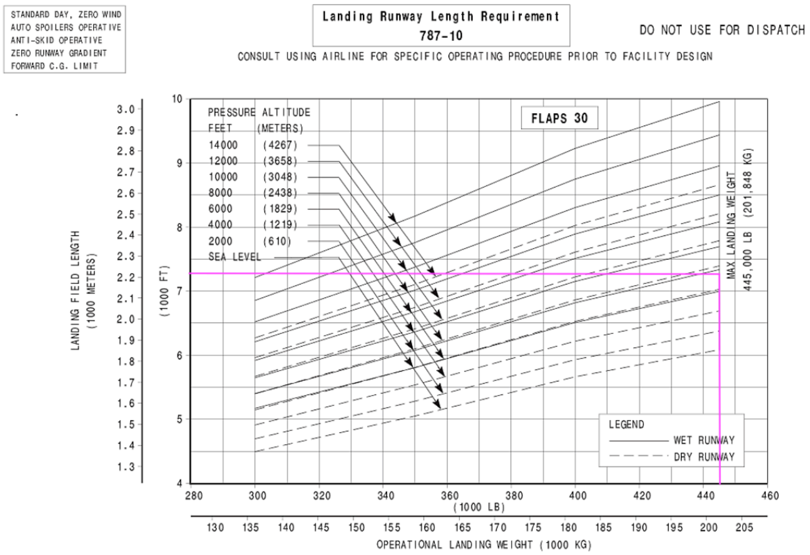
Runway length required for landing at MALW on a wet runway while the flaps are set to be 30 degrees = 7,250 ft

Runway length required for landing at MALW on a wet runway while the flaps are set to be 25 degrees = 7,500 ft



3.4.6 FAA/EASA Landing Runway Length Requirements – Flaps 25: Model 787-10 (All Engines)

3.4.5 FAA/EASA Landing Runway Length Requirements – Flaps 30: Model 787-10 (All Engines)



Therefore, the runway length must be at least 13,700 ft to accommodate Boeing 787-10 operations at this airport.

b) Find the amount of cargo (in addition to the full passenger load) the aircraft can carry departing the new airport.

OEW = 300,000 lb

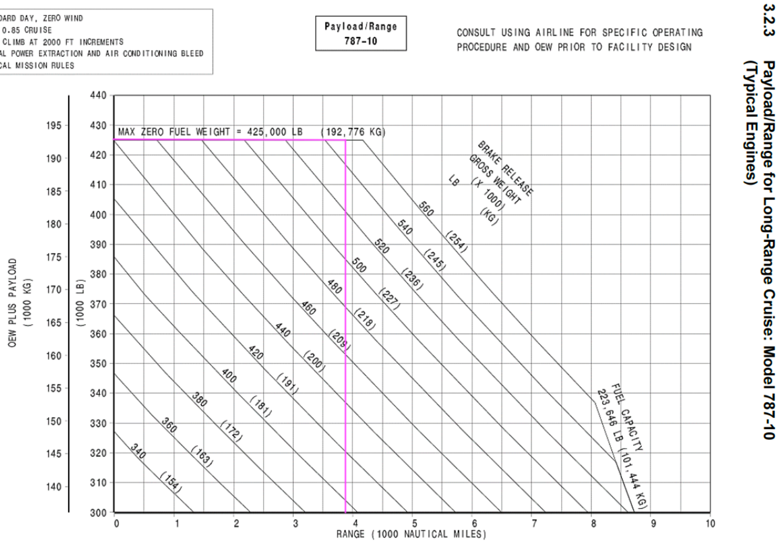
Total passenger weight (including their luggage) = 330 (number of passengers) * 100 (kg) = 33,000 kg = 72,753 lb

Maximum Zero Fuel Weight = 425,000 lb

Amount of cargo (in addition to the full passenger load) the aircraft can carry departing the new

airport = 425,000 lb - 300,000 lb (OEW) - 72,753 lb (passengers weight) = 52,247 lb

Note: as the following figure shows, the maximum range for this aircraft departing at DTOW of 550,000 lb with full passengers and carrying 52,247 lb of additional payload would be 3,850 nm.



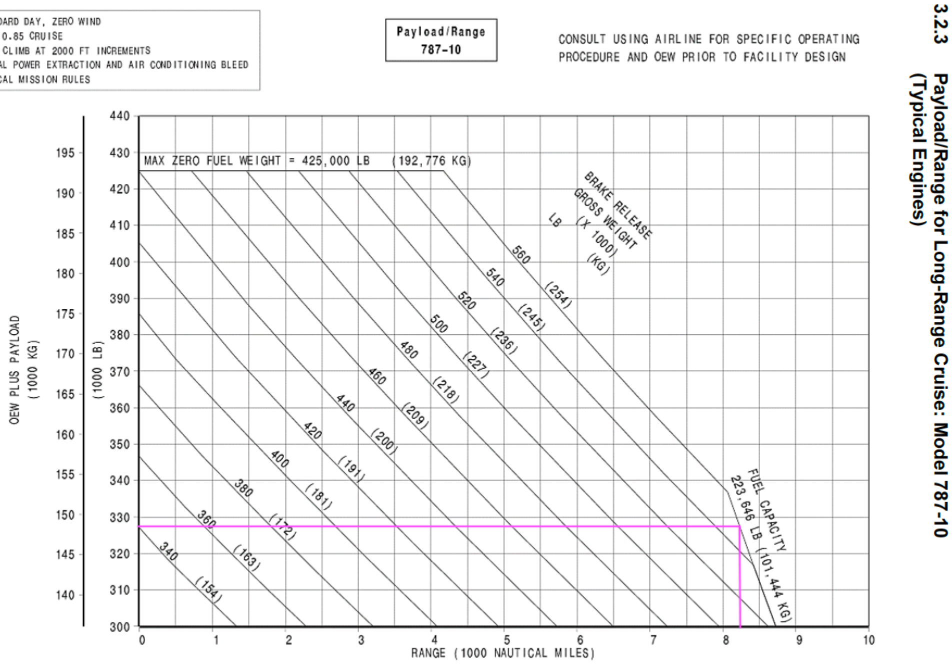
c) If the aircraft departs at the maximum allowable takeoff weight, find the maximum range possible.

OEW = 300,000 lb

Maximum Fuel Weight = 223,646 lb

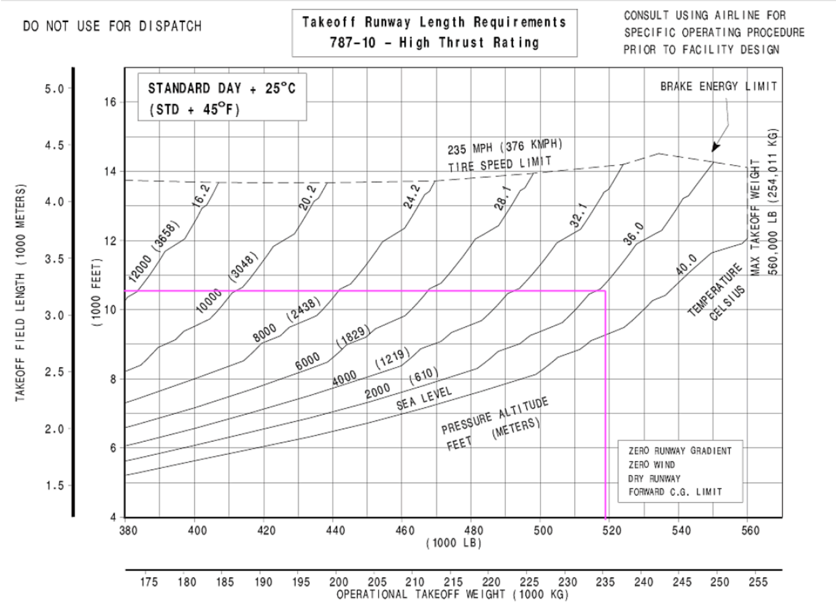
Payload = DTW - OEW - Maximum Fuel Weight = 550,000 lb - 300,000 lb - 223,646 lb = 26,354 lb. This is not a realistic payload since the number of passengers will be 120 people.

Maximum range = 8,200 nm



d) Find the maximum passenger and cargo capacity if the runway is limited to 10,500 feet.

With the runway length limited to 10,500 ft, the DTW would be approximately 519,000 lb, as shown in the following figure.

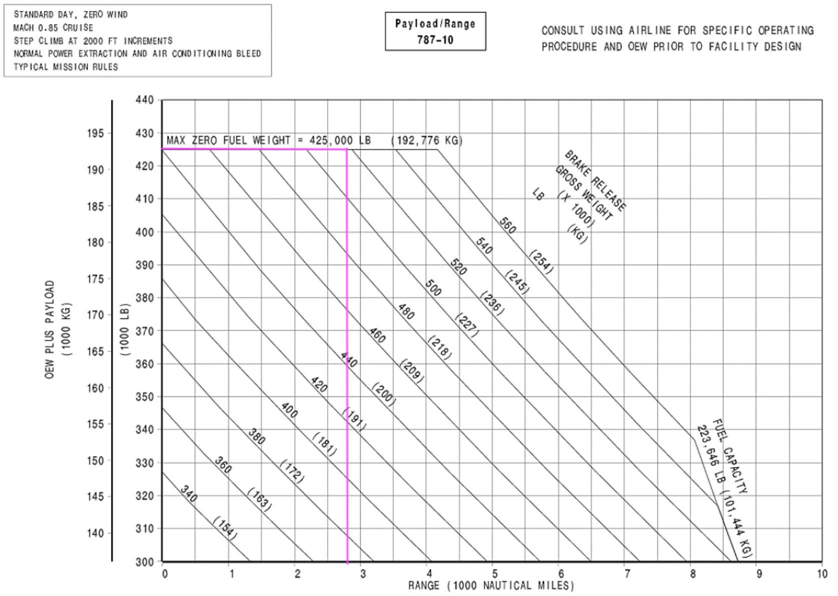


3.3.23 FAA/EASA Takeoff Runway Length Requirements - Standard Day + 45°F (STD + 25°C), Dry Runway: Model 787-10 (Hi-Thrust Engines)

As shown in the following payload-range diagram, the maximum zero fuel weight would be 425,000 lb. Therefore, the maximum passenger and cargo capacity is:

425,000 lb - 300,000 lb = 125,000 lb

If the aircraft departs at DTW = 519,000 lb and carries 125,000 lb payload, the maximum range could be 2,800 nm.



3.2.3 Payload/Range for Long-Range Cruise: Model 787-10 (Typical Engines)

Problem 2 (30 Points)

The problem is to estimate departure and arrival delays for the airport configuration provided in Figure 2. The airport aircraft mix, runway occupancy times, and approach speeds are shown in Table 2. The airport has an airport surveillance radar (ASR) and ADS-B surveillance to track aircraft up to 60 nautical miles from the airport site. The ADS-B system can update the position of aircraft every second. The airport conducts departures from runway 09 and arrivals from runway 5.

Table 1 shows the technical parameters at the airport under Instrument Meteorological Conditions (IMC). Three aircraft groups (of the nine groups included in the Consolidated Wake Categories defined by FAA) operate at the airport. The airport has the following additional technical parameters: a) in-trail delivery error of 18 seconds, b) probability of violation is 5%. Air traffic controllers direct traffic to intercept a final approach path at a fix-in space 12 miles from the runway threshold. Arrivals follow in trail after crossing the final approach fix. To solve the problem, use the Consolidated Wake Separations provided in class (see your class notes). Use the departure-departure separations supplied in class.

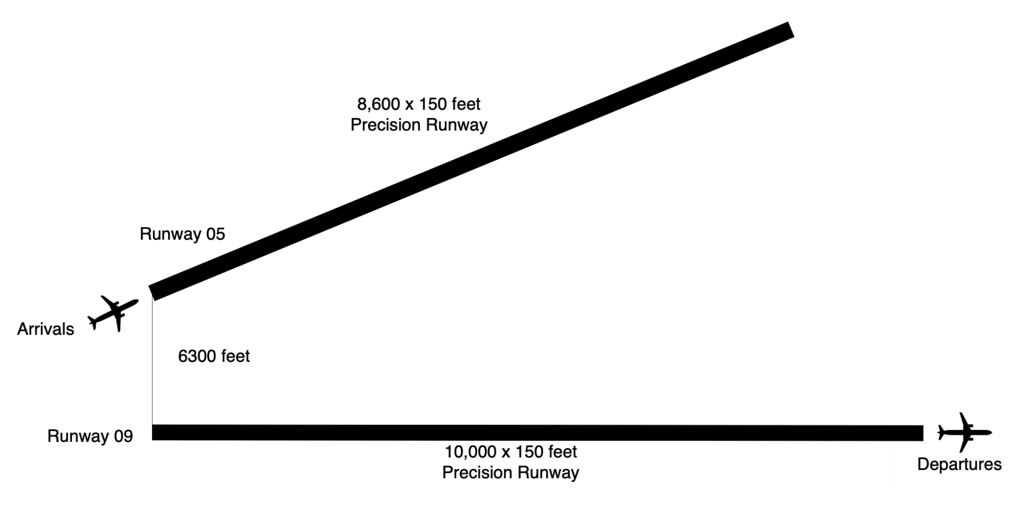
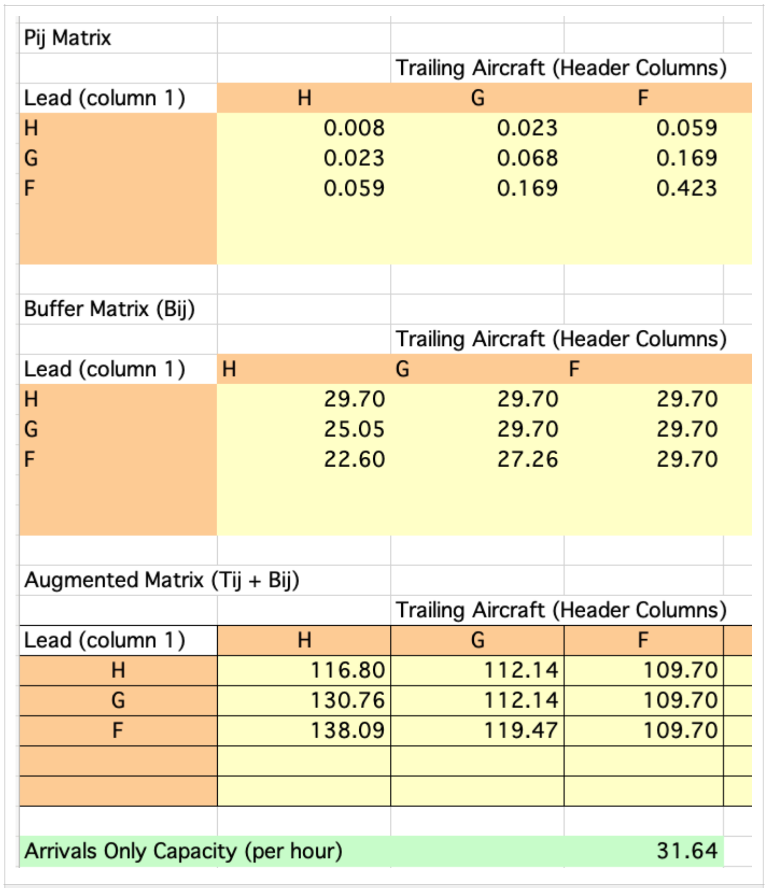


Figure 2. Airport Configuration for Problem 2.

You can modify the spreadsheet provided in class to solve the problem. Show me sample calculations for opening and closing cases so that I know you can do such calculations by hand.

a) Calculate the arrivals-only saturation capacity under IMC conditions.



Pij Matrix

		Trailing Aircraft (Header Columns)	
Lead (column 1)	H	G	F
H	0.008	0.023	0.059
G	0.023	0.068	0.169
F	0.059	0.169	0.423

Buffer Matrix (Bij)

		Trailing Aircraft (Header Columns)	
Lead (column 1)	H	G	F
H	29.70	29.70	29.70
G	25.05	29.70	29.70
F	22.60	27.26	29.70

Augmented Matrix (Tij + Bij)

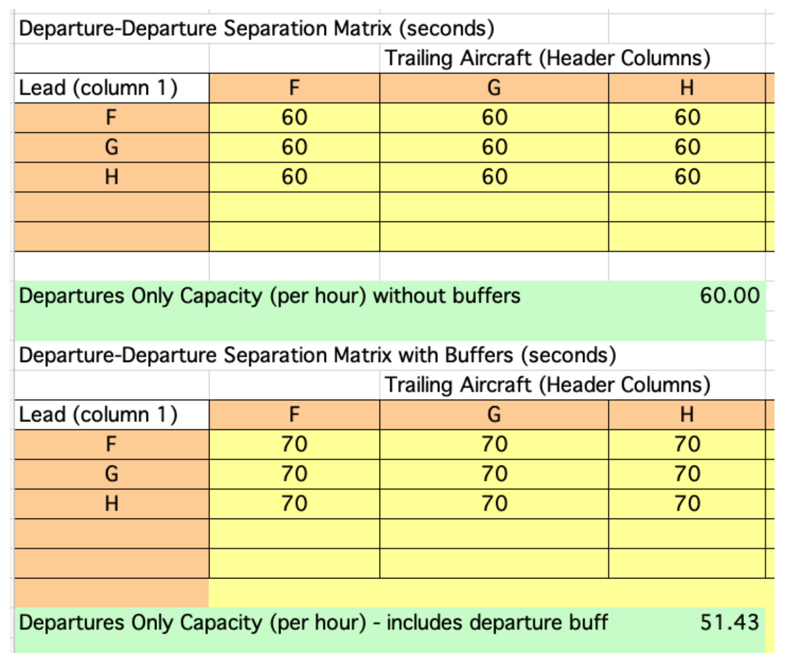
		Trailing Aircraft (Header Columns)	
Lead (column 1)	H	G	F
H	116.80	112.14	109.70
G	130.76	112.14	109.70
F	138.09	119.47	109.70

Arrivals Only Capacity (per hour) 31.64

Figure 2.1 Arrival Capacity Computations.

The Arrival Capacity is: 31.6 per hour

b) Calculate the departures-only saturation capacity under IMC conditions.



Departure-Departure Separation Matrix (seconds)

	Trailing Aircraft (Header Columns)		
Lead (column 1)	F	G	H
F	60	60	60
G	60	60	60
H	60	60	60

Departures Only Capacity (per hour) without buffers 60.00

Departure-Departure Separation Matrix with Buffers (seconds)

	Trailing Aircraft (Header Columns)		
Lead (column 1)	F	G	H
F	70	70	70
G	70	70	70
H	70	70	70

Departures Only Capacity (per hour) - includes departure buff 51.43

Figure 2.2 Arrival Capacity Computations.

The Departure Capacity is: 51.4 per hour

c) **Draw the arrival-departure capacity diagram** (Pareto diagram) under IMC conditions. No sketches are accepted.

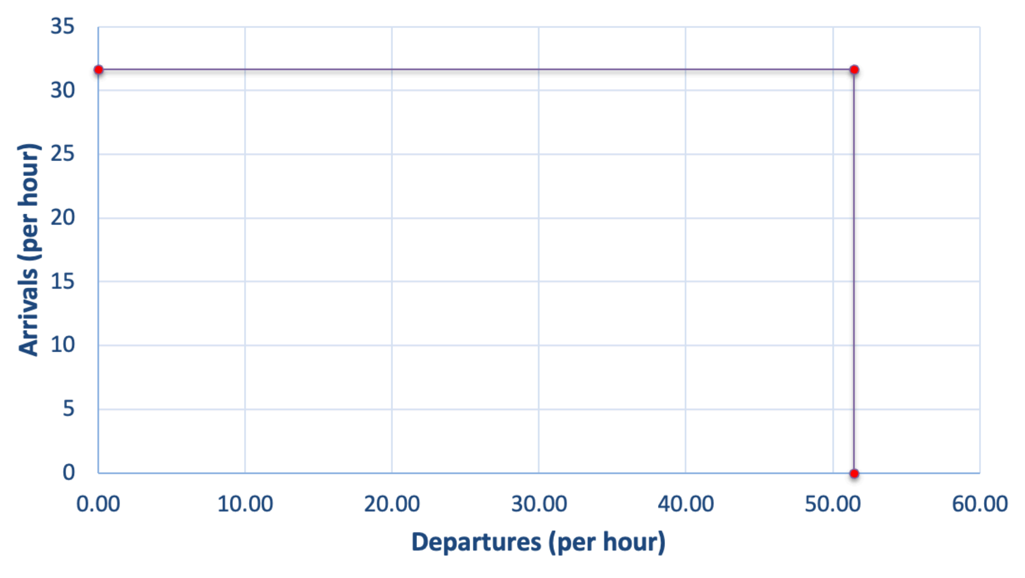


Figure 2.3 Pareto Diagram.

Table 1. Runway Occupancy Times and Fleet Mix for Problem 2.

Consolidated Weight Turbulence Group	Percent Mix (%)	Runway Occupancy Time (s)	Typical Approach Speed (knots) from FAF
F	65	56	135
G	26	53	131
H	9	51	124

d) Use the Deterministic Queueing theory method explained in class to estimate the total delay (in units of aircraft hours) for arrivals to runway 5. You can use the MATLAB code provided in class. Please show me the input parameters that you changed to solve the problem. Specifically, estimate the following:

e) Estimate the average delay (in minutes per arrival) for arrivals to runway 5. Show how many arrivals are subject to delays.

f) Estimate the average departure delay (in minutes per departure operation). Show how many departures are subject to delays.

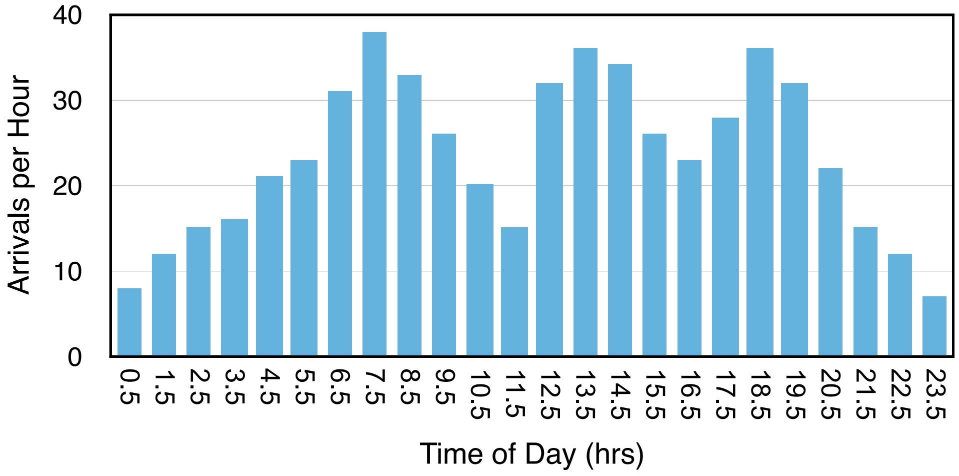


Figure 3. Airport Arrival Demand over Time.

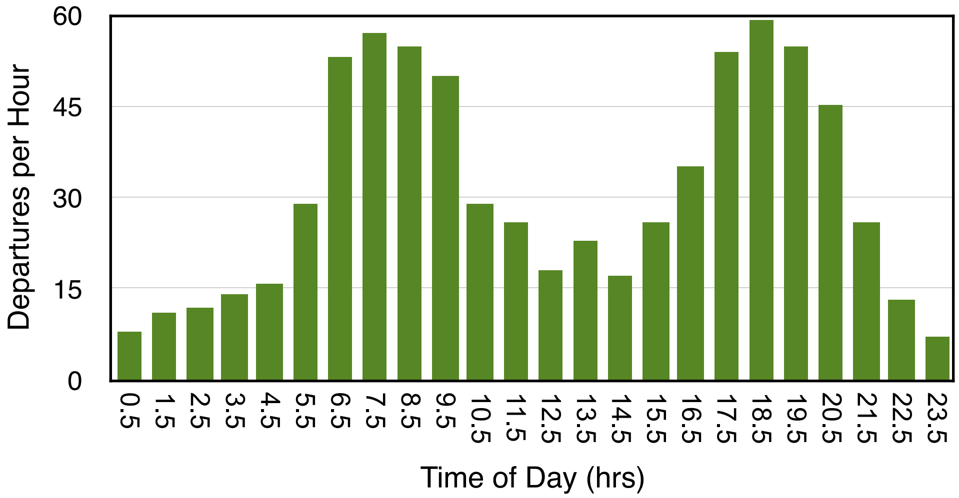


Figure 4. Airport Departure Demand over Time.

Arrival Delay Analysis

Inputs to Deterministic Queueing Model script.

```
   time = 0.5:1:23.5;   % values of time (time vector in vector form)

  % Arrival demand
   demand = [8 12 15 16 21 23 31 38 33 26 20 15 32 36 34 26 23 28 36 32 22 15 12 7];
% Arrival capacity for runway 05
   capacity = ones(1,24)*31.64;
```

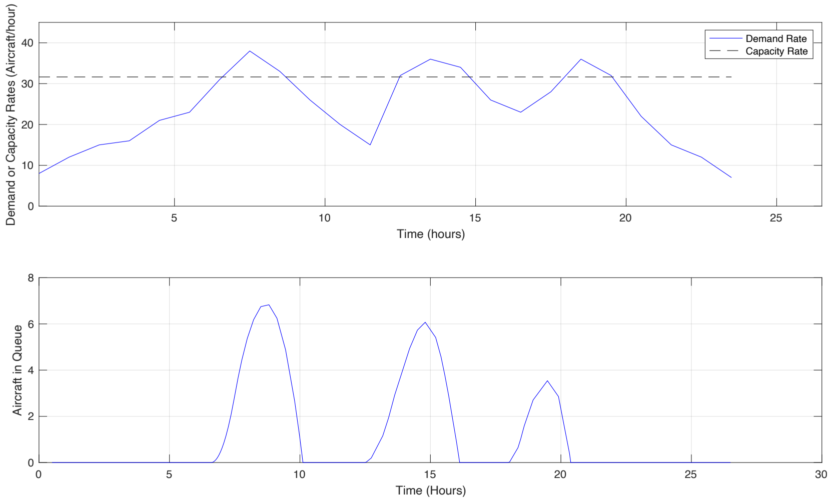


Figure 4.1 Arrival Delay Analysis.

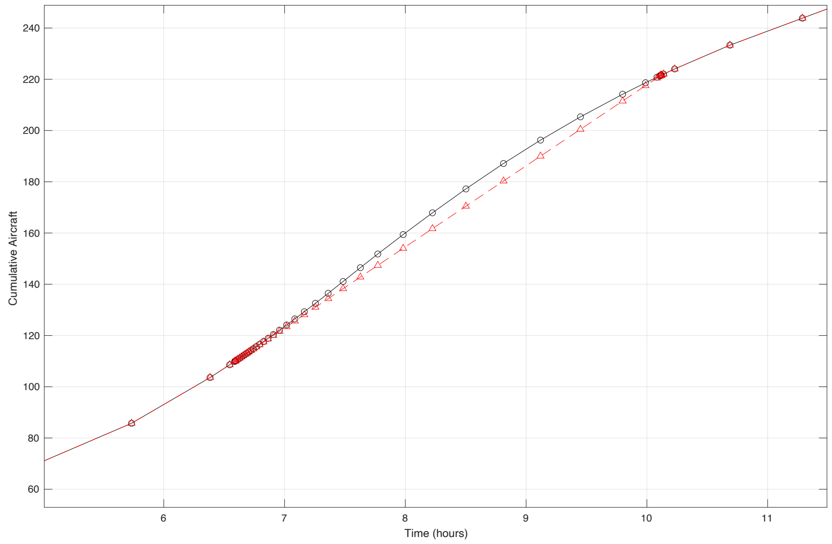


Figure 4.2 Arrival Delay Analysis. First Arrival Queue.

Total delay (aircraft-hour) = 30.90
Max queue length (aircraft) = 6.828

Name	**Time (hrs)**	**Number of Aircraft**	**Remarks**
Start first queue	6.5	114	First queue
End of first queue	10.2	220	End of first queue
Start second queue	12.5	270	Second queue
End of second queue	16.2	385	End of second queue
Start third queue	17.9	435	Third queue
End of third queue	20.4	510	End of third queue
Total Aircraft Affected		296	

Average arrival delay = $W_d = (30.9/296)$ = 0.104 hours = 6.26 minutes.

Departure Runway Delay Analysis

Inputs to Deterministic Queueing Model script.

```
time = 0.5:1:23.5;   % values of time (time vector in vector form)

   % Departure demand
demand = [8 11 12 14 16 29 53 57 55 50 29 26 18 23 17 26 35 54 59 55 45 26 13 7];
capacity = ones(1,24)*51.3;
```

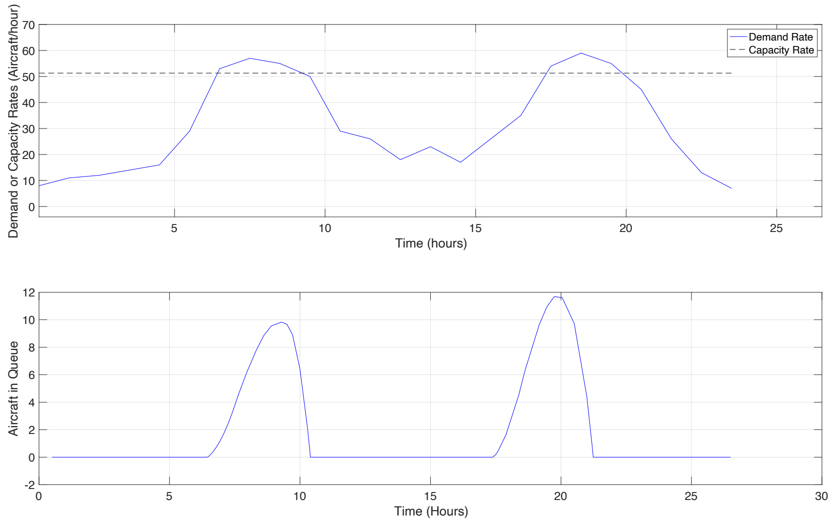


Figure 4.3 Departure Delay Analysis.

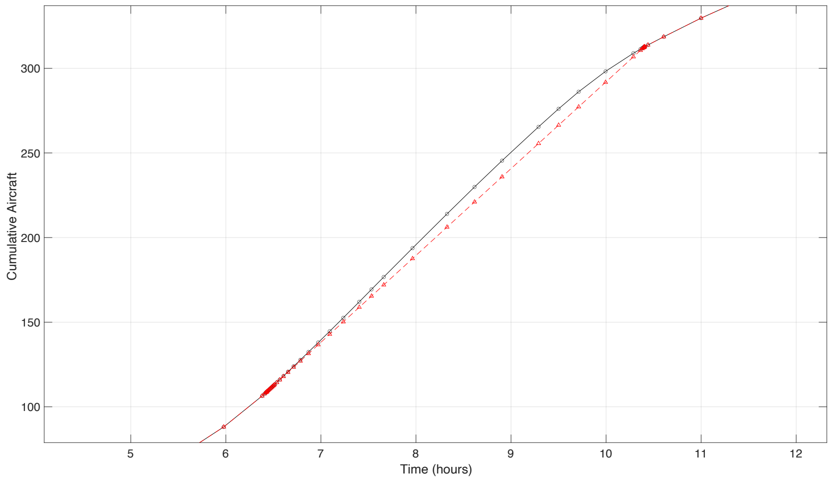


Figure 4.4 Departure Delay Analysis. First Departure Queue.

Total delay (aircraft-hour) = 49.42
Max queue length (aircraft) = 11.69

Name	Time (hrs)	Number of Aircraft	Remarks
Start first queue	6.4	106	First queue
End of first queue	10.4	311	End first queue
Start second queue	17.35	494	Second queue
End of second queue	21.3	694	End of second queue
Total Aircraft Affected		405	

Average arrival delay = $W_d = (49.4/405)$ = 0.122 hours = 7.3 minutes.

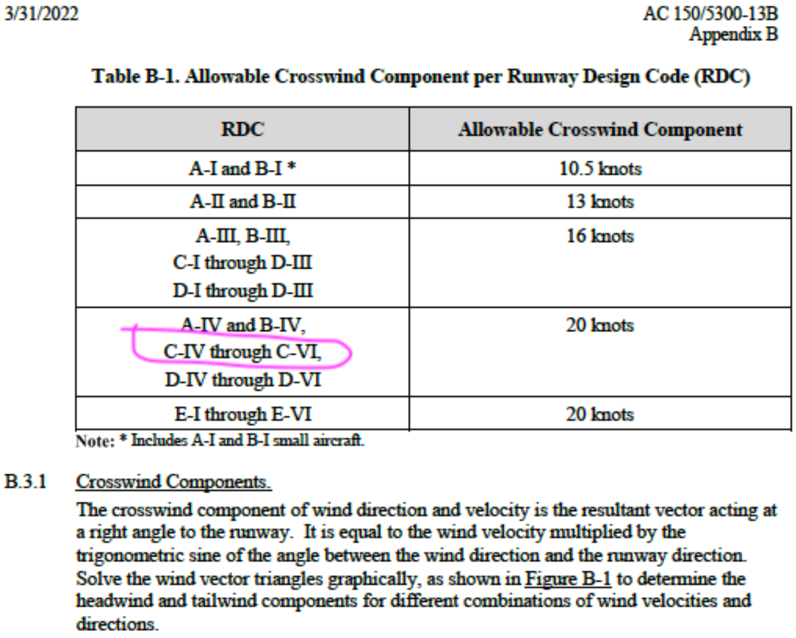
Problem 3 (25 Points)

Provide quick answers to each question.

a) State the critical crosswind design value if the Airbus A330-900 is the largest aircraft operating at the airport.

RDC: AAC-ADG
Airbus A330-900: C-V

The critical crosswind design value is 20 knots.



3/31/2022

AC 150/5300-13B
Appendix B

Table B-1. Allowable Crosswind Component per Runway Design Code (RDC)

RDC	Allowable Crosswind Component
A-I and B-I *	10.5 knots
A-II and B-II	13 knots
A-III, B-III, C-I through D-III D-I through D-III	16 knots
A-IV and B-IV, C-IV through C-VI, D-IV through D-VI	20 knots
E-I through E-VI	20 knots

Note: * Includes A-I and B-I small aircraft.

B.3.1 Crosswind Components.

The crosswind component of wind direction and velocity is the resultant vector acting at a right angle to the runway. It is equal to the wind velocity multiplied by the trigonometric sine of the angle between the wind direction and the runway direction. Solve the wind vector triangles graphically, as shown in Figure B-1 to determine the headwind and tailwind components for different combinations of wind velocities and directions.

b) Use the SARLAT tool to estimate the dry runway length required for a Honda Jet 420 operating at a 90% load factor from an airport at 2,600 feet above sea level and 89 degrees Fahrenheit.

Assumptions:

Zero wind

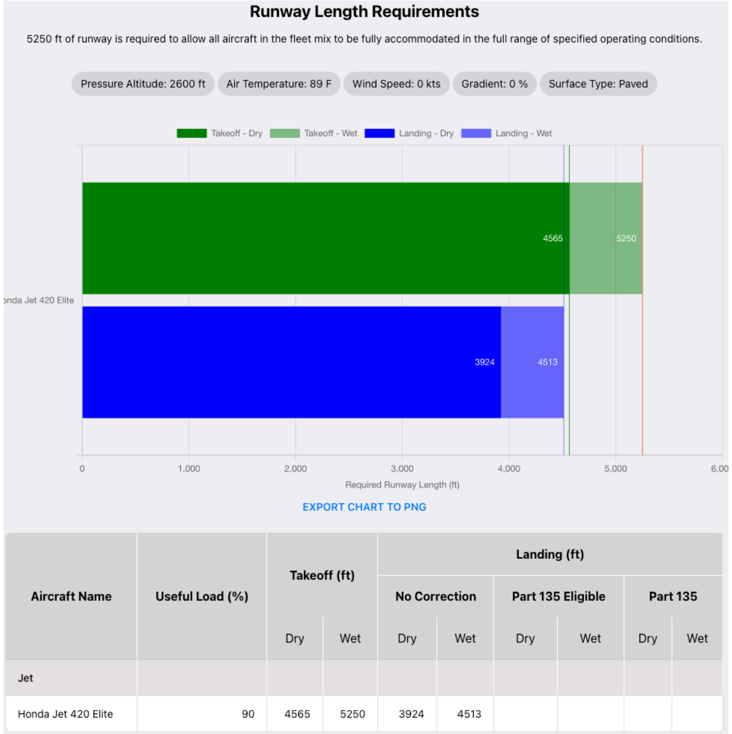
Zero runway gradient

Required runway length for takeoff on a dry runway = 4,565 ft

Required runway length for landing on a wet runway = 4,513 ft

Therefore, the required runway length is rounded up to 4,600 ft.

Note: the FAA requires designers to determine the length of runway needed based on takeoff operations on a dry runway and landing operations on a wet runway.



Runway Length Requirements

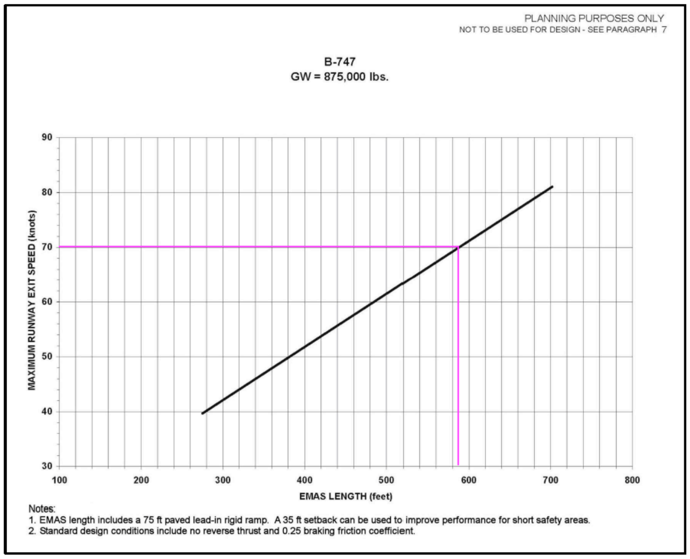
5250 ft of runway is required to allow all aircraft in the fleet mix to be fully accommodated in the full range of specified operating conditions.

Pressure Altitude: 2600 ft
Air Temperature: 89 F
Wind Speed: 0 kts
Gradient: 0 %
Surface Type: Paved

Aircraft Name	Useful Load (%)	Takeoff (ft)		Landing (ft)					
				No Correction		Part 135 Eligible		Part 135	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Jet									
Honda Jet 420 Elite	90	4565	5250	3924	4513				

c) Find the EMAS length required to stop a Boeing 747-400 at the FAA-recommended design speed. Compare that against the FAA RSA length needed.

EMAS length required to stop a Boeing 747-400 at the design speed of 70 knots is 585 ft.



Notes:
1. EMAS length includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Standard design conditions include no reverse thrust and 0.25 braking friction coefficient.

Figure A2-5.

9/27/2012

AC 150/5220-22B
Appendix 2

d) Find the runway width, the runway shoulder width, and the blast pad length for a Boeing 747-8. Assume low visibility operations below 1/2 mile.

Boeing 747-8: AAC-ADG
Boeing 747-8: D-VI
Boeing 747-8 TDG is 6.
Boeing 747-8 number of engines is 4.

Runway width = 150 ft
Runway shoulder width = 50 ft
Runway blast pad width = 250 ft

Footnote 14 in AC-150-5300-13B change 1: standard paved runway shoulders for aircraft with four or more engines in ADG VI and TDG 6 are 50 feet (15.2 m), and the paved blast pad width is 400 x 250 feet (76 m).

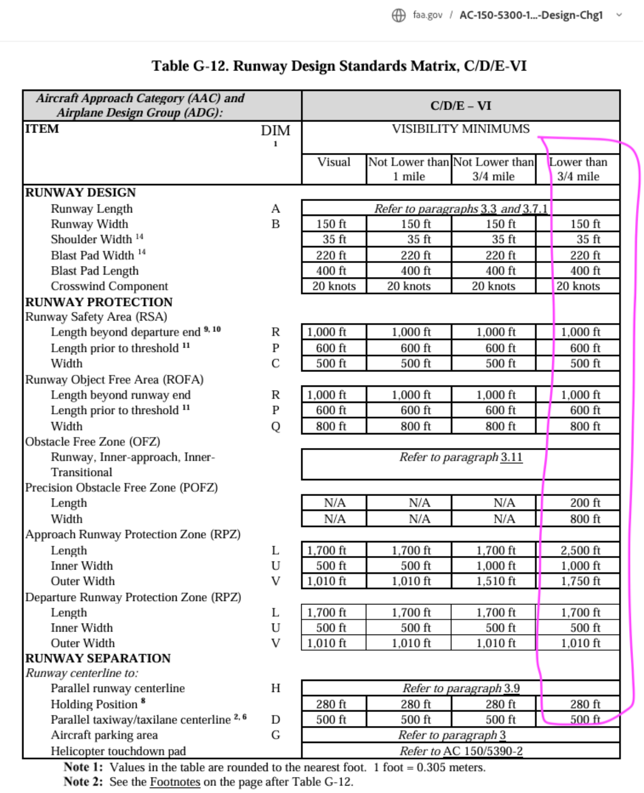


Table G-12. Runway Design Standards Matrix, C/D/E-VI

Aircraft Approach Category (AAC) and Airplane Design Group (ADG):		C/D/E – VI			
ITEM	DIM [1]	VISIBILITY MINIMUMS			
		Visual	Not Lower than 1 mile	Not Lower than 3/4 mile	Lower than 3/4 mile
RUNWAY DESIGN					
Runway Length	A	*Refer to paragraphs* 3.3 *and* 3.7.1			
Runway Width	B	150 ft	150 ft	150 ft	150 ft
Shoulder Width [14]		35 ft	35 ft	35 ft	35 ft
Blast Pad Width [14]		220 ft	220 ft	220 ft	220 ft
Blast Pad Length		400 ft	400 ft	400 ft	400 ft
Crosswind Component		20 knots	20 knots	20 knots	20 knots
RUNWAY PROTECTION					
Runway Safety Area (RSA)					
Length beyond departure end [9, 10]	R	1,000 ft	1,000 ft	1,000 ft	1,000 ft
Length prior to threshold [11]	P	600 ft	600 ft	600 ft	600 ft
Width	C	500 ft	500 ft	500 ft	500 ft
Runway Object Free Area (ROFA)					
Length beyond runway end	R	1,000 ft	1,000 ft	1,000 ft	1,000 ft
Length prior to threshold [11]	P	600 ft	600 ft	600 ft	600 ft
Width	Q	800 ft	800 ft	800 ft	800 ft
Obstacle Free Zone (OFZ)					
Runway, Inner-approach, Inner-Transitional		*Refer to paragraph* 3.11			
Precision Obstacle Free Zone (POFZ)					
Length		N/A	N/A	N/A	200 ft
Width		N/A	N/A	N/A	800 ft
Approach Runway Protection Zone (RPZ)					
Length	L	1,700 ft	1,700 ft	1,700 ft	2,500 ft
Inner Width	U	500 ft	500 ft	1,000 ft	1,000 ft
Outer Width	V	1,010 ft	1,010 ft	1,510 ft	1,750 ft
Departure Runway Protection Zone (RPZ)					
Length	L	1,700 ft	1,700 ft	1,700 ft	1,700 ft
Inner Width	U	500 ft	500 ft	500 ft	500 ft
Outer Width	V	1,010 ft	1,010 ft	1,010 ft	1,010 ft
RUNWAY SEPARATION					
Runway centerline to:					
Parallel runway centerline	H	*Refer to paragraph* 3.9			
Holding Position [8]		280 ft	280 ft	280 ft	280 ft
Parallel taxiway/taxilane centerline [2, 6]	D	500 ft	500 ft	500 ft	500 ft
Aircraft parking area	G	*Refer to paragraph* 3			
Helicopter touchdown pad		*Refer to* AC 150/5390-2			

Note 1: Values in the table are rounded to the nearest foot. 1 foot = 0.305 meters.
Note 2: See the Footnotes on the page after Table G-12.

e) Why do low visibility operations require more protection around a runway? Briefly explain.

Low-visibility runway operations require more runway protection. Reduced visibility limits pilots' and controllers' situational awareness, increasing the risk of runway incursions/excursions. Wider and longer safety buffers reduce hazards and unexpected aircraft deviations.

f) Find the taxiway design group for the Boeing 777-300ER.

TDG for 777-300ER is 6.

Problem 4 (20 Points)

Use Google Earth to comment on the airport terminal design configuration for one of the following airports (pick one and comment).

a) Los Angeles International Airport
b) Atlanta International Airport
c) Singapore International Airport
d) Beijing Daxing International Airport

1) Tell me the airport terminal configuration (vertical and horizontal distribution elements)
2) Explain some of the positive aspects of the selected airport terminal configuration.
3) Explain some of the negative aspects of the selected airport terminal configuration.
4) Explain how the airport terminal fits between the runways, taxiways, and other airside design elements. Explain the runway separations observed and the possible use of the runways for simultaneous operations.
5) Find the number of gates at the airport terminal(s)
6) Comment on the possible need for people movers to transport passengers from the land to the air. Consider the distance from the area where passengers are dropped off to the gates.