Final Exam for CEE 4674

Solution
Instructor: Trani

Sign VT Honor Code Pledge

This exam is the product of my own group's work (two students per group). We have not received help from anyone outside our group.

Problem 1 (30 Points)

Evaluate the runway length required for aircraft operations from a new airport located at sea level and with a design temperature of 82 degrees Fahrenheit. The critical aircraft is the Boeing 787-8 (see Figure 1). **The airline would like to operate the aircraft at maximum takeoff weight**.

Boeing 787-8 with Rolls-Royce engines. Aircraft maximum takeoff weight is 502,500 lb. 242 seats in dual-class seating layout.

Figure 1. Japan Airlines Boeing 787-8 Dreamliner Landing at San Diego International Airport. Source: A. A. Trani.

a) Find the runway length needed for the aircraft to operate at **maximum takeoff weight** (unconstrained) from the new airport. Please be clear in all your assumptions to solve the problem.

Sea level conditions temperature = 59 deg. Fahrenheit

Design temperature = 82 deg. Fahrenheit

There is a 23 deg. Fahrenheit difference. Use ISA + 27 deg. Fahrenheit tables from Boeing. These are the closest chart above ISA + 23 deg. Fahrenheit.

Takeoff field length = 10,800 feet. (Dry pavement)

Landing field length (at maximum landing weight) = 6,200 feet (wet pavement)

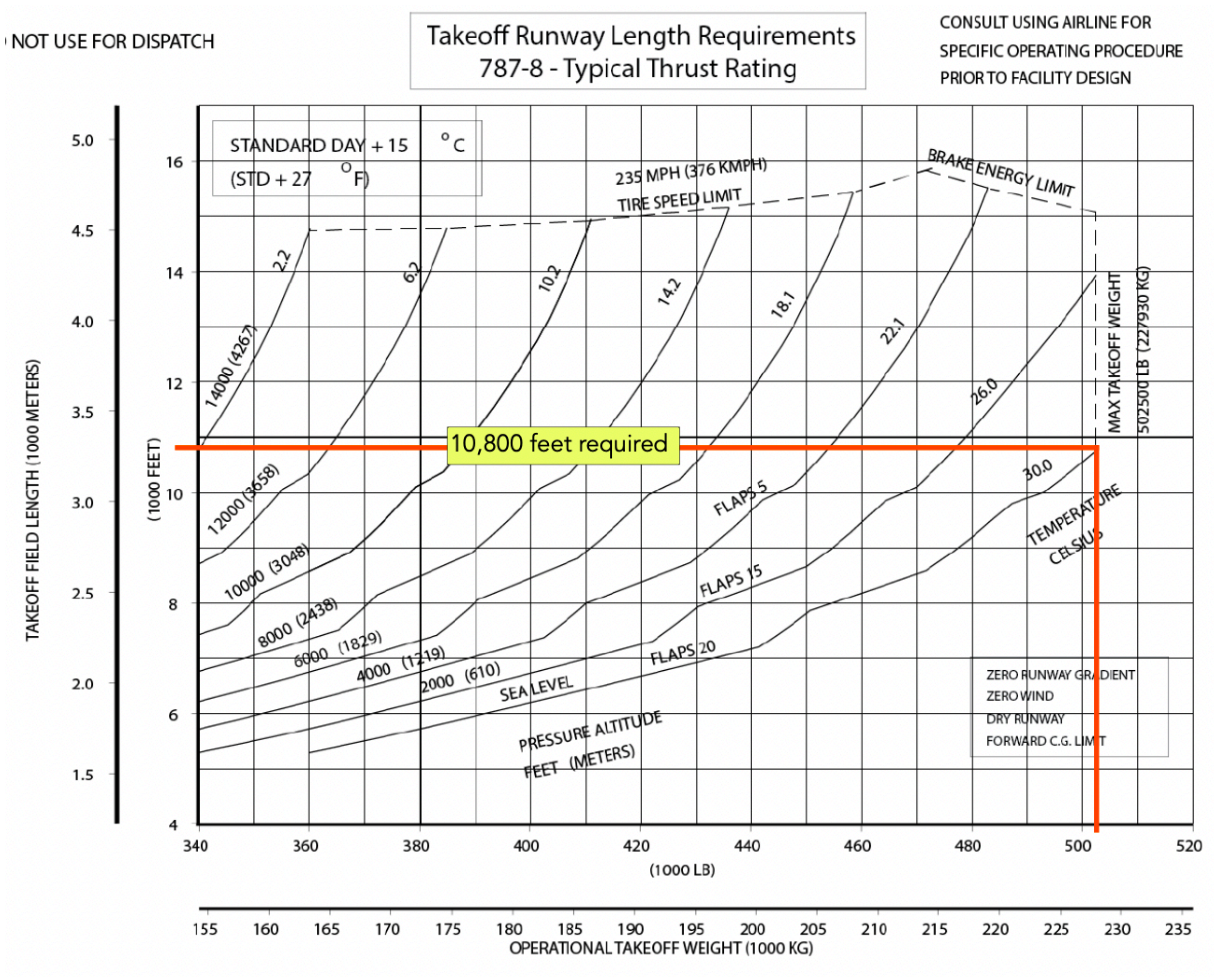

Figure 2. Boeing 787-8 Dreamliner Takeoff Field Length. ISA + 27 deg. Fahrenheit.

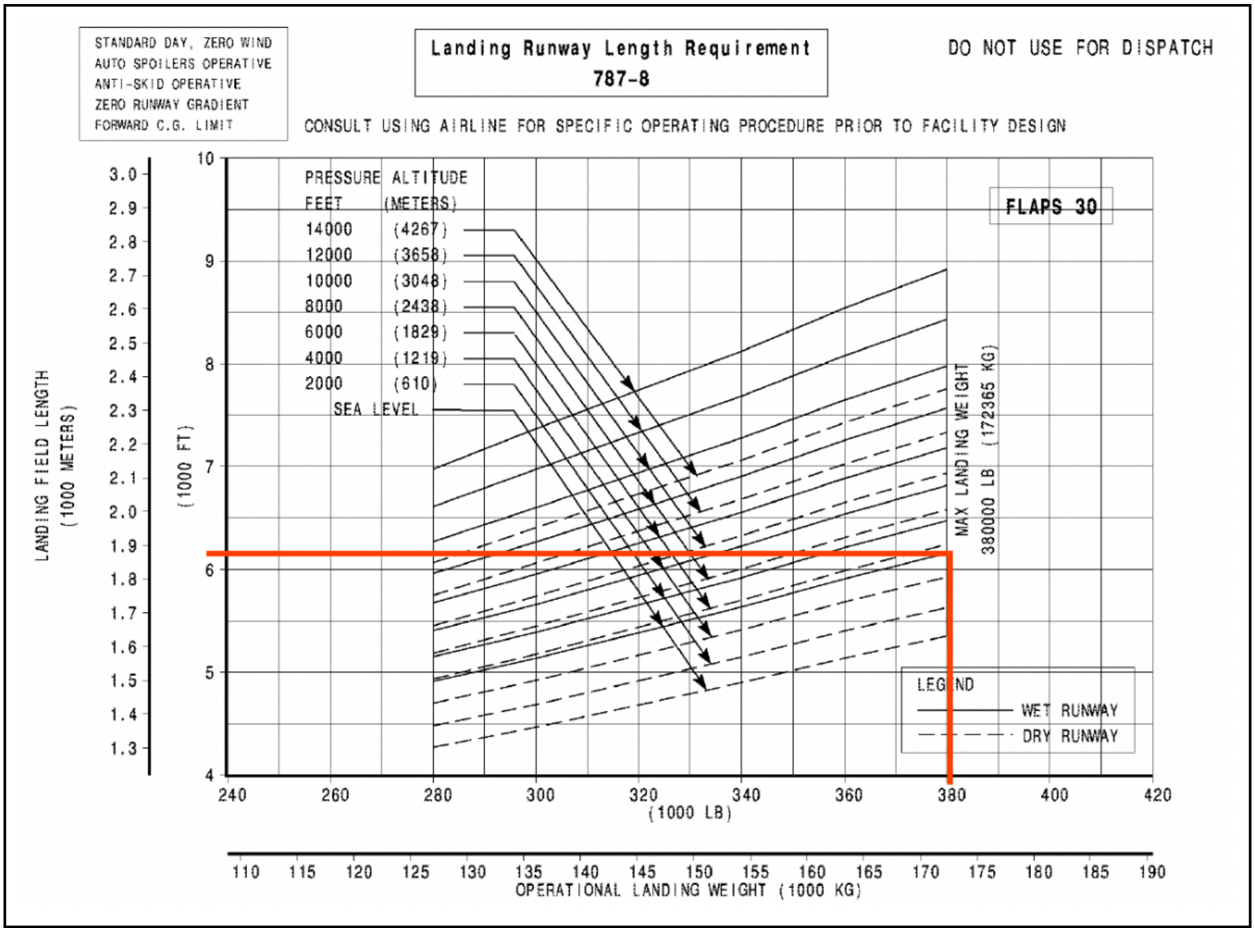

Figure 3. Boeing 787-8 Dreamliner Landing Field Length.

b) Find the number of cargo containers the aircraft can carry departing at the maximum takeoff weight.

242 seats translates to 53,240 lbs. OEW is 260,000 lbs (from the payload-range diagram). For full seat operations, OEW + passenger payload is 313,240 lbs. Each LD-3 container has a maximum weight of 3,500 lbs.

The maximum range is estimated to be 7,600 nautical miles (see Figure 4). With full seats, flying 7,600 nm no containers can be carried. A better proposition is to carry 10 LD-3 containers (35,000 lbs) plus 242 seats full and fly 5,700 nautical miles.

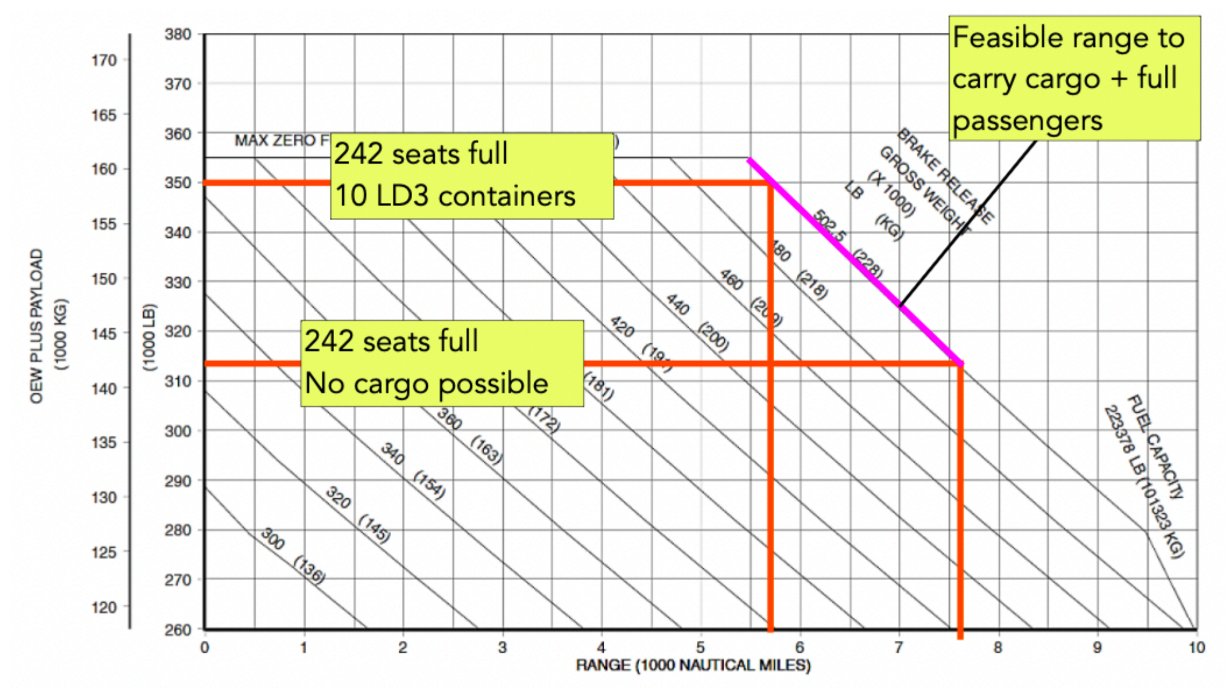

Figure 4. Boeing 787-8 Dreamliner Payload-Range Diagram. With 242 seats full, the maximum range is 7,600 nautical miles but no cargo. With full seats, the aircraft can fly 5,700 nm and carry 10 LD3 containers (36,760 lbs of cargo).

c) If the aircraft departs at maximum takeoff weight, find the maximum distance the aircraft can fly (i.e., range). Show me the steps in your analysis.

The feasible range is 7,600 nm with full passengers.

Problem 2 (40 Points)

The problem is to estimate delays for departures and arrivals 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 form the airport site. The ADS-B system can update the position of aircraft every one second. The airport conducts departures from runway 5L and arrivals from runway 5R.

Tables 1 through 3 show the technical parameters and the Air Traffic Control separations at the airport under Instrument Meteorological Conditions (IMC). Two aircraft groups (of the nine groups included in the Consolidated Wake Categories defined by FAA) operate at the airport. The airport has the following technical parameters: a) in-trail delivery error of 17 seconds, b) probability of violation is 5%. Air traffic controllers direct traffic to intercept a final approach path at a fix in space located 13 miles from the runway threshold. Arrivals follow in-trail after crossing the final approach fix.

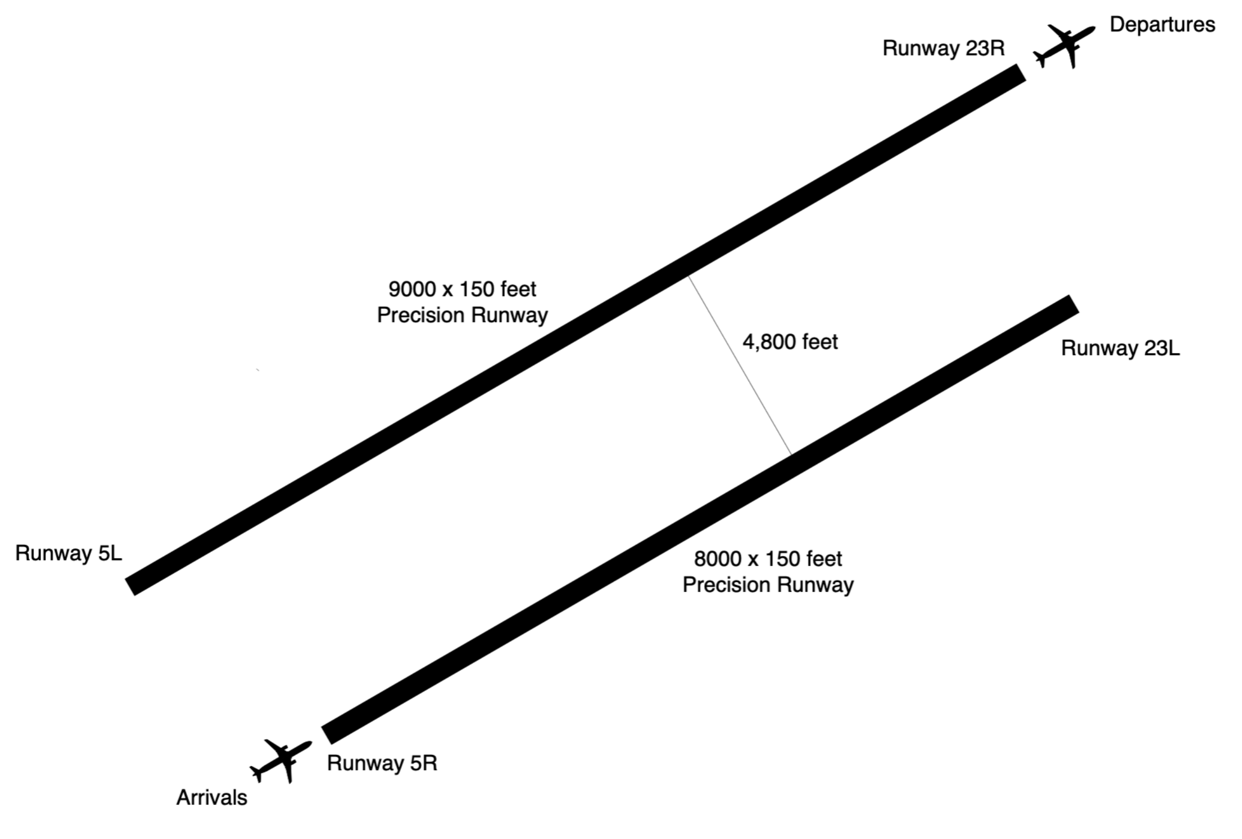

Figure 5. Airport Configuration for Problem 2.

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

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

Arrivals-only capacity is 31.6 operations/hour.

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

Departures-only capacity is 45.6operations/hour.

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

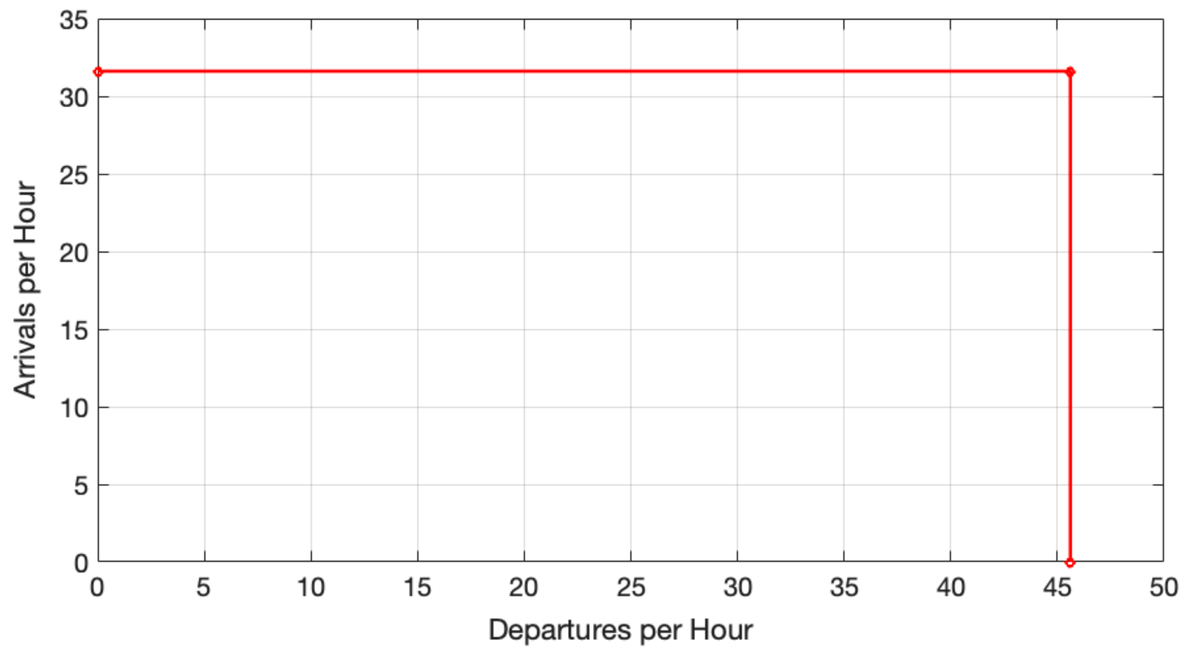

Figure 6. Departure-Arrival Diagram (Pareto Frontier). Two Runways Operated Independently.

Table 1. Runway Occupancy Times and Fleet Mix for Problem 3.

Consolidated Weight Turbulence Group	Percent Mix (%)	Runway Occupancy Time (s)	Typical Approach Speed (knots) from FAF
F	86	56	138
B	14	67	152
Totals	100		

Table 2. Minimum arrival-arrival separations under IMC conditions. Values in are nautical miles. ***Values Shown Do Not Include Buffers.*** *Full Table Available on Page 54 of Aircraft Classifications Handout.*

	Trailing Aircraft (Columns 2-3)	
Lead (Column 1)	**F**	**B**
F	3	3
B	5	3

Table 3. Minimum departure-departure separations under IMC conditions. Values in are seconds. ***ATC Buffers are Included.***

	Trailing Aircraft (Columns 2-3)	
Lead (Column 1)	**F**	**B**
F	70	75
B	130	125

Figures 3 and 4 show the arrival and departure schedules for the future year of analysis.

d) Use the Deterministic Queueing theory method explained in class to estimate the total delay (in units aircraft-hours) for arrivals to runway 5L. You can use the MATLAB code provided in class. Show me the input parameters that you changed to solve the problem.

```
time = 0.5:1:23.5;                    % values of time (time vector in vector form)
demand = [4 5 4 10 12 19 32 39 32 28 20 17 28 32 29 24 23 28 33 32 22 15 11 4];
capacity = ones(1,24)*[31.6];
```

Figure 7. Matlab Deterministic Queueing Model Inputs Changed.

Specifically estimate the following:

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

Total delay = 19.45 aircraft-hours

To find the average delay, find the number of aircraft that were affected by the queue.

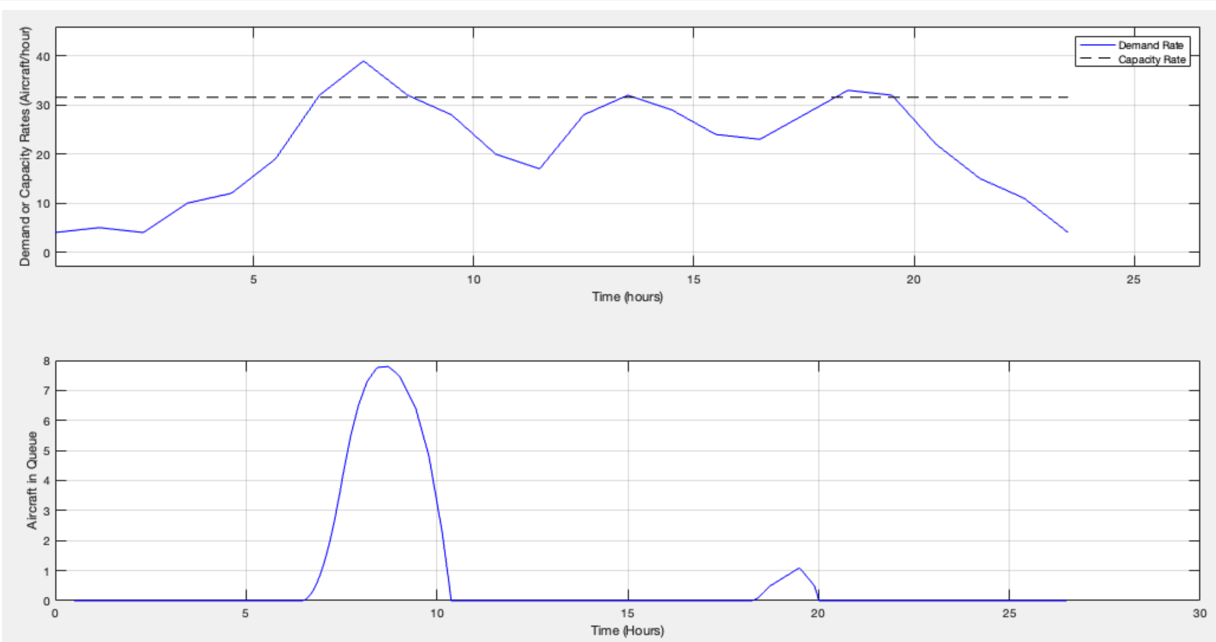

Figure 8. Queue Length Calculated for Arrivals. Two Queueing Periods Observed.

The queueing periods for arrivals are as follows:

Period 1: starts at 6.47 hours in the morning and ends at 10.37 hours. A total of 127 (190-63) aircraft are affected by the first period of delay.

Period 2: starts at 18.22 hours and ends at 20.01 hours. A total of 57 (450-393) aircraft are affected in the second queueing period.

The total delay for both periods is reported to be 19.45 aircraft-hours. As calculated by the Matlab script.

The number of aircraft affected in both periods is 184. The average arrival delay is then 0.106 hours per aircraft (6.34 minutes per aircraft.

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

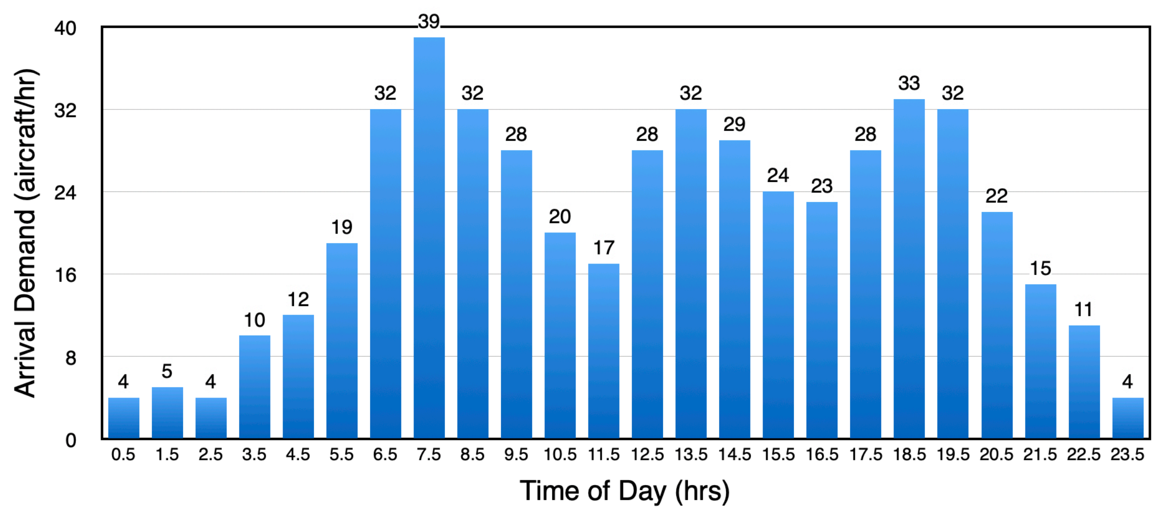

Figure 9. Airport Arrivals Schedule for Problem 2.

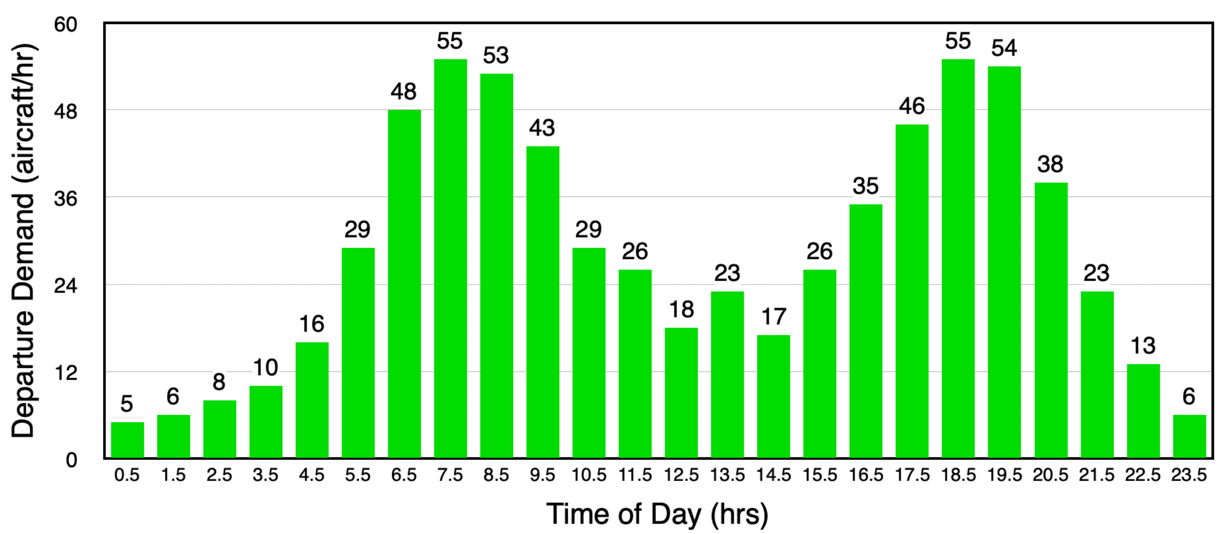

Figure 10. Airport Departures Schedule for Problem 2.

```
% Departure demand
demand = [5 6 8 10 16 29 48 55 53 43 29 26 18 23 17 26 35 46 55 54 38 23 13 6];
capacity = ones(1,24)*31.6;
```

Figure 11. Matlab Deterministic Queueing Model Inputs to Calculate Departure Delays.

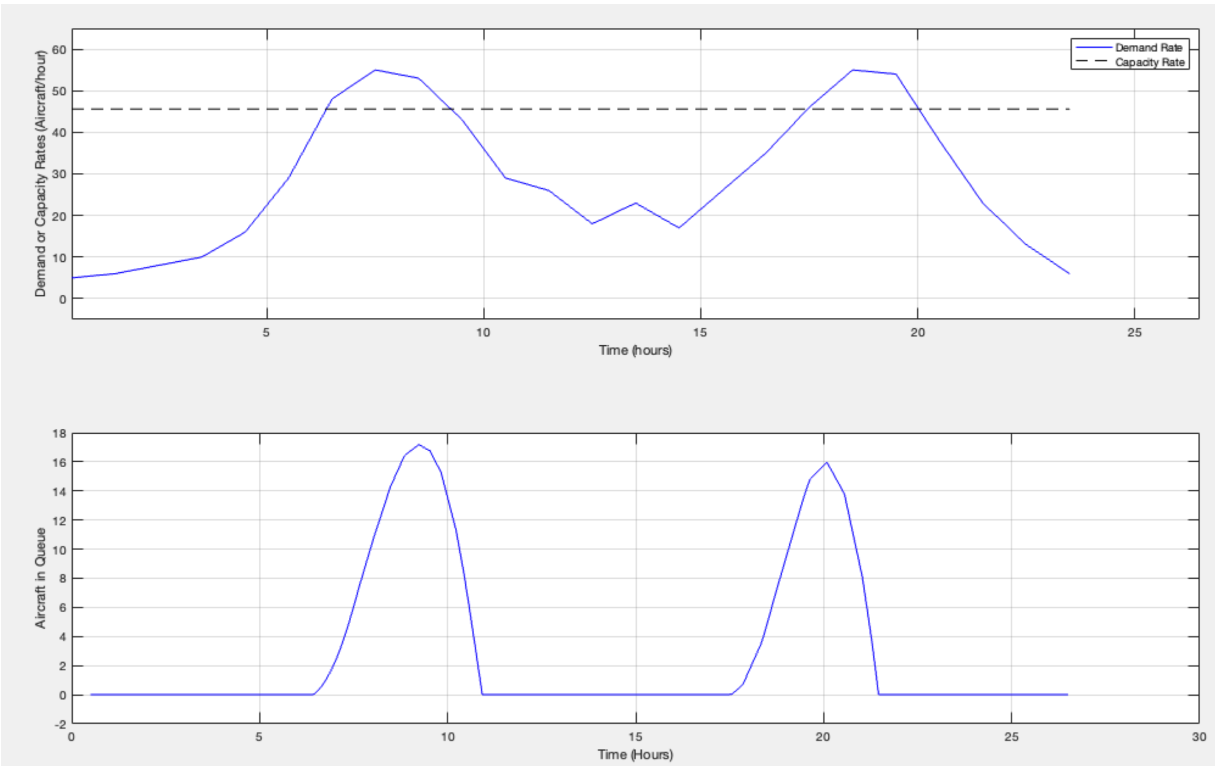

Figure 12. Queue Length Calculated for Arrivals. Two Queueing Periods Observed.

Total delay = 78.58 aircraft-hours

To find the average delay, find the number of aircraft departures that were affected by the queue.

The queueing periods for arrivals are as follows:

Period 1: starts at 6.3 hours in the morning and ends at 10.92 hours. A total of 210 (296-86) aircraft are affected by the first period of delay.

Period 2: starts at 17.45 hours and ends at 21.45 hours. A total of 183 (648-465) aircraft are affected in the second queueing period.

The total delay for both periods is reported to be 78.58 aircraft-hours. As calculated by the Matlab script.

The number of aircraft affected in both periods is 393. The average arrival delay is then 0.20 hours per aircraft (12 minutes per aircraft.

Problem 3 (30 Points)

Table 4 shows data collected at a proposed airport site. The data is supplied as a companion spreadsheet to the problem. The critical aircraft for this airport is expected to be the Cessna Citation Excel (560 XLS) (see Figure 5). The airport site is located at 850 feet above sea level with a design temperature of 80 deg. Fahrenheit.

Table 4. Data for Wind Rose Analysis.

		Wind Speed in Knots					
Azimuth (degrees)	Calm Winds	3.0 - 4.9	5.0 - 9.9	10.0 - 15.9	16.0 - 20.9	21.0 - 26.9	> 27.0
355-004		0.375	1.085	0.578	0.116	0.034	0.012
005-014		0.306	0.959	0.702	0.212	0.095	0.015
015-024		0.235	0.924	0.831	0.368	0.149	0.020
025-034		0.200	0.827	0.851	0.317	0.093	0.025
035-044		0.218	0.759	0.713	0.278	0.088	0.023
045-054		0.186	0.727	0.714	0.223	0.064	0.016
055-064		0.203	0.796	0.707	0.224	0.066	0.012
065-074		0.218	0.793	0.765	0.199	0.040	0.005
075-084		0.210	0.717	0.508	0.121	0.029	0.008
085-094		0.194	0.561	0.367	0.075	0.023	0.005

Figure 13. Cessna Citation Excel (model 560 XLS) used as Critical Aircraft for Problem 3.

a) State the crosswind component used in the wind rose analysis.

B-II requires 13 knots of crosswind component.

b) Find the optimal runway orientation for the new runway using the wind rose analysis.

The data provided is from Martha's Vineyard (2010-2023).

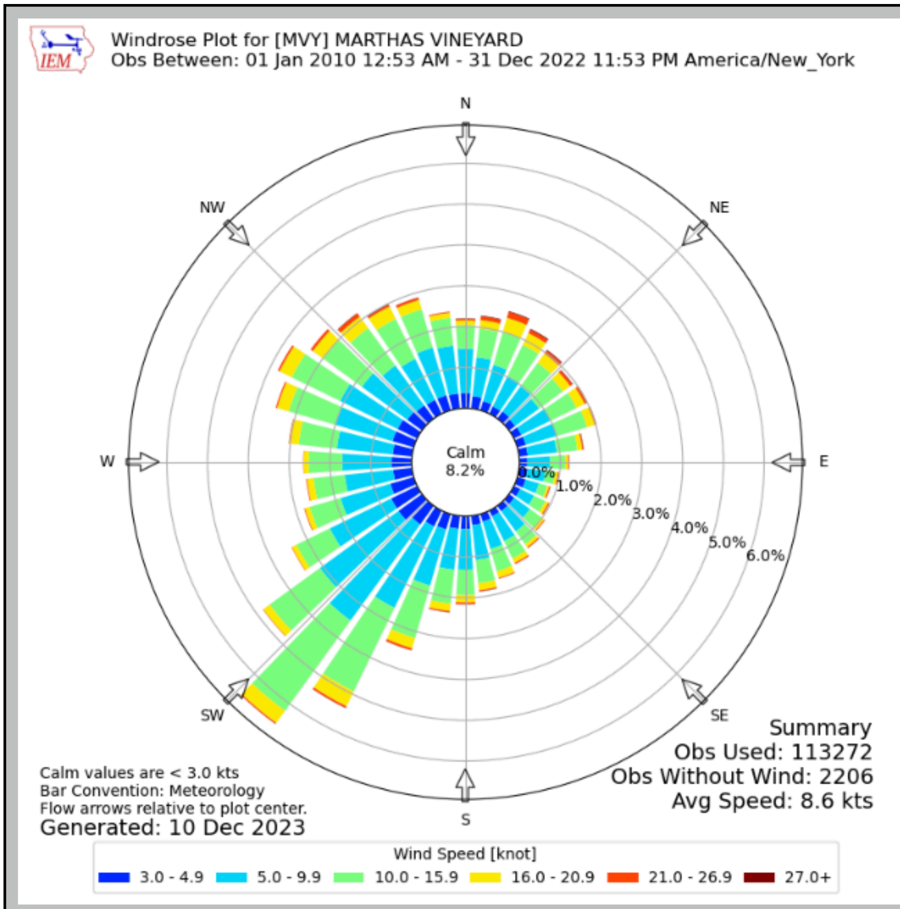

Figure 14. Wind Rose Data Plot.

Optimal orientation is between 210-190 degrees. Coverage is 93.3% for orientations 205-190 degrees.

c) Is one runway good enough to satisfy the FAA 95% coverage criteria? Comment.

No. One runway does not satisfy the 95% coverage.

d) Show the wind rose used in your analysis.

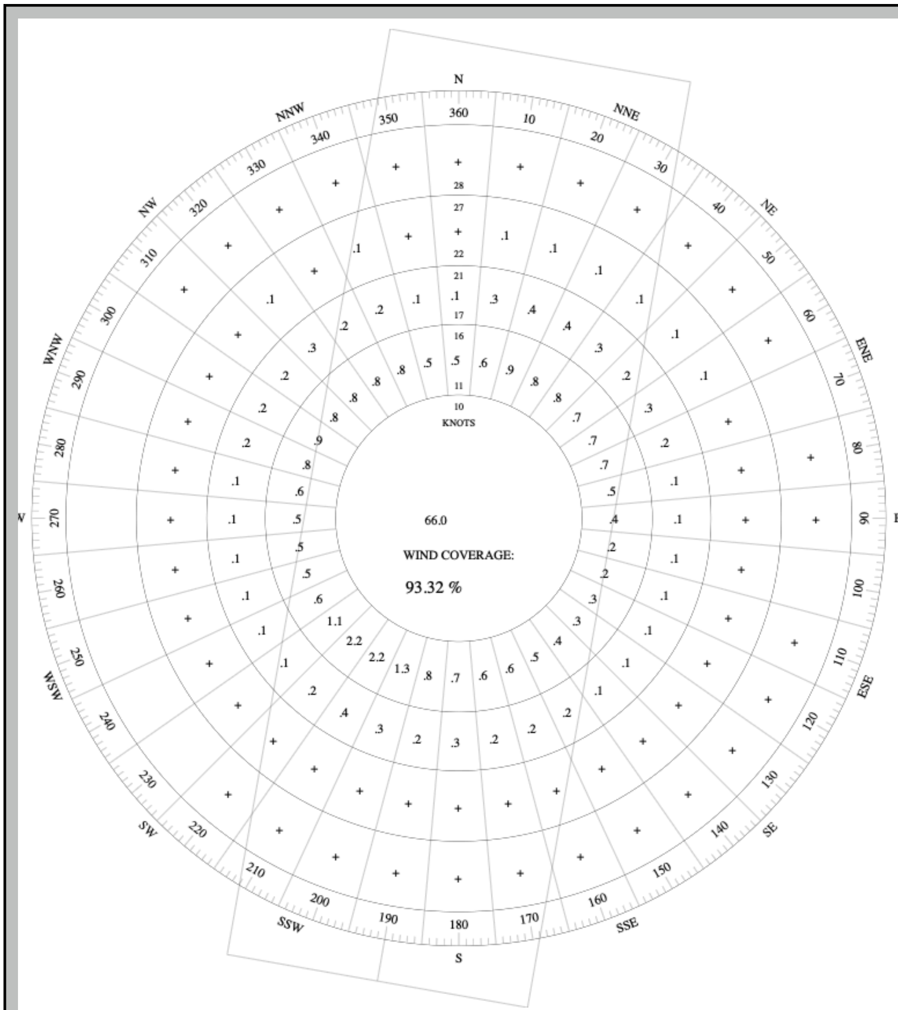

Figure 15. Wind Rose for 190 Degrees Orientation. Coverage is 93.32%.

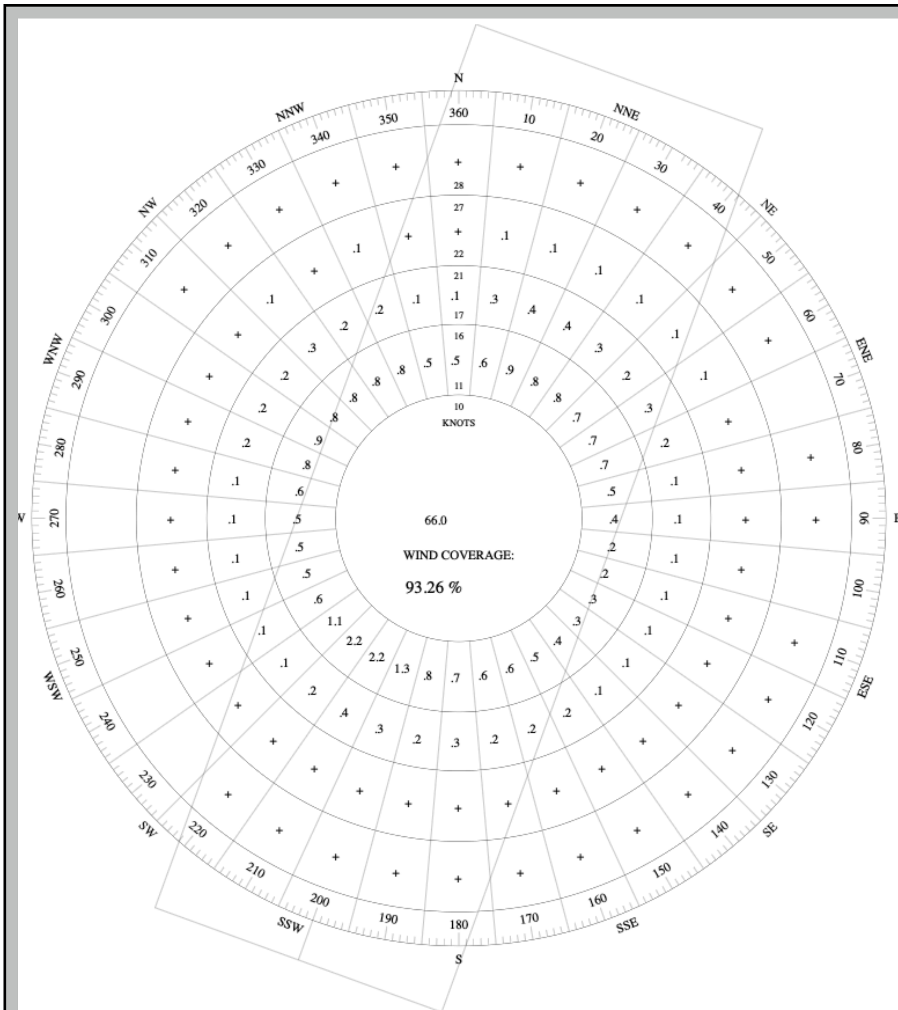

Figure 16. Wind Rose for 200 Degrees Orientation. Coverage is 93.26%.

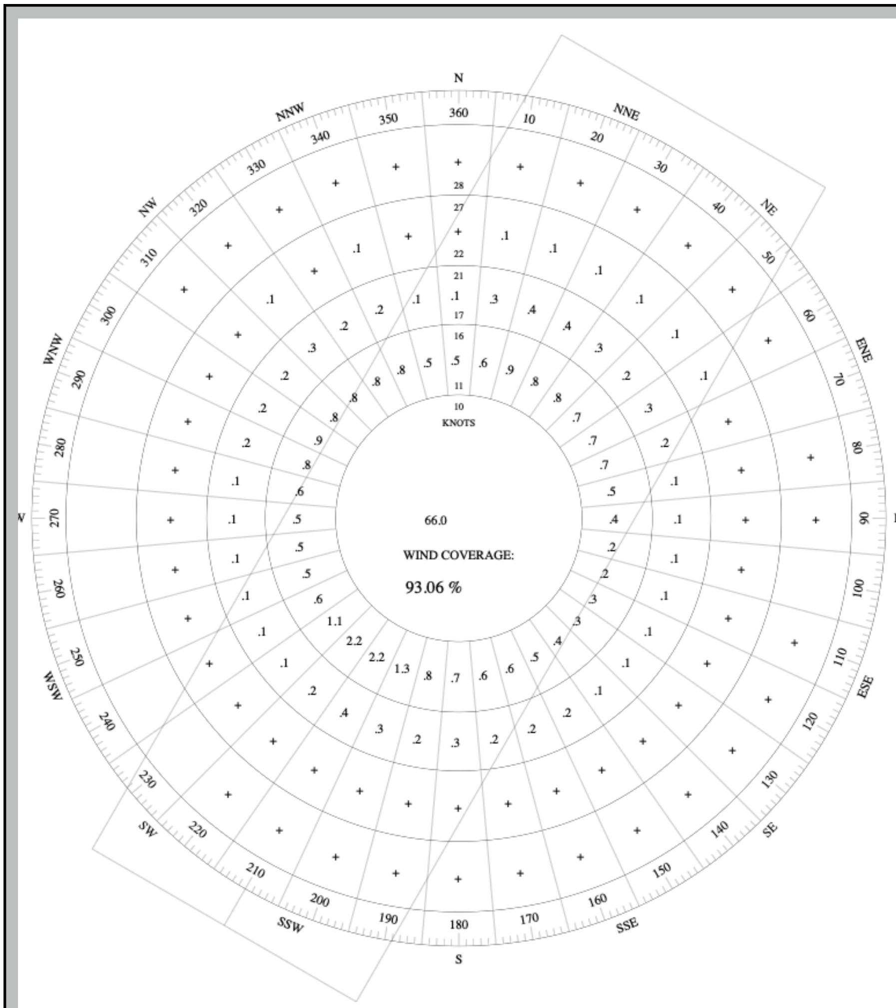

Figure 17. Wind Rose for 210 Degrees Orientation. Coverage is 93.06%.

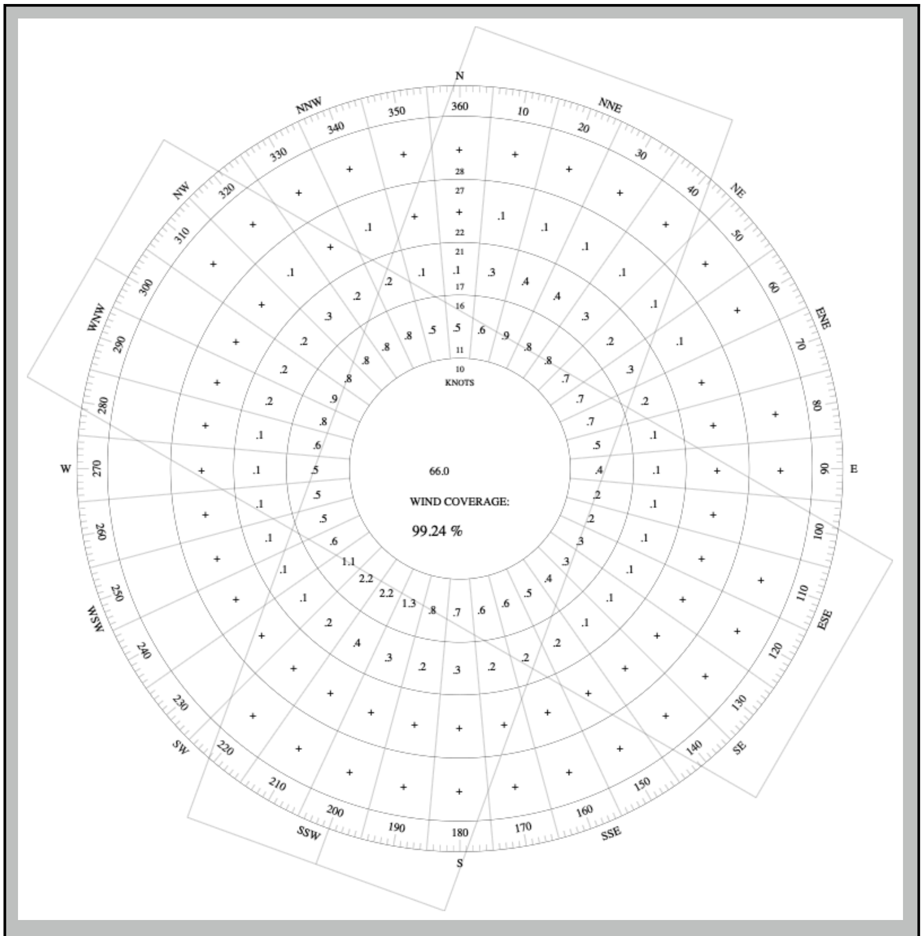

Figure 18. Wind Rose for Two Runway Oriented 210 and 300 Degrees. Coverage is 99.3%.

e) Use the SARLAT tool to design the runway length for the critical aircraft using a 90% useful load.

Aircraft Name	Useful Load (%)	Takeoff (ft)		Landing (ft)					
				No Correction		Part 135 Eligible		Part 135	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Jet									
Cessna 560 XL	90	3786	4354	3359	3863			5610	6451

The takeoff distance (dry) is 3,786 feet. Landing distance (wet) is 3,863 feet. Technically the FAA may pay for a wet landing and dry takeoff. A 4,000-foot runway is a reasonable choice of runway length.