CEE 5614: Analysis of Air Transportation Systems **Spring 2022**

Quiz 2 : Open Notes

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Instructions

Write your solutions in the spaces provided. Add any additional pages with calculations as needed. Make sure each additional page has your name.

Honor Code Pledge

The information provided in this exam is my own work. I have not received information from another person while doing this exam.

____ (your signature/name)

Problem 1 (50 Points)

The airport shown in Figure 1 is the subject of an investigation under IMC conditions. The airport has two runways as shown in Figure 1. Arrival traffic is controlled in time and space at two Navaids called Fix1 and Fix2. For metering purposes, aircraft are required to cross the arrival Fixes at FL 250 and about 400 knots (true airspeed). Sample velocity profiles measured at a similar airport in the NAS is shown in Figure 2. Figure 2 shows the nominal speed vs. distance for arrivals at a similar airport.

Figure 2 shows the runway located around 80 nm from the point where aircraft are initially tracked inside the terminal area. Figure 3 shows the altitude vs. distance traveled profiles for the same airport. In your analysis use the nominal descent profiles (red lines). The runway configuration is such that landing aircraft touchdown before the intersection at a point 1,500 feet from the landing threshold. You can (i.,e., neglect wake vortex effects of a landing aircraft on a departure on the intersecting runway departure. According to the Landing Events Database, the touchdown speed is close to 95% of the runway threshold speed. Assume the touchdown speed is maintained for another 1,000 feet on the landing runway before the pilot activates the thrust reverser and the brakes. Aircraft accelerate on the departure runway at 2.3 m/s-s.

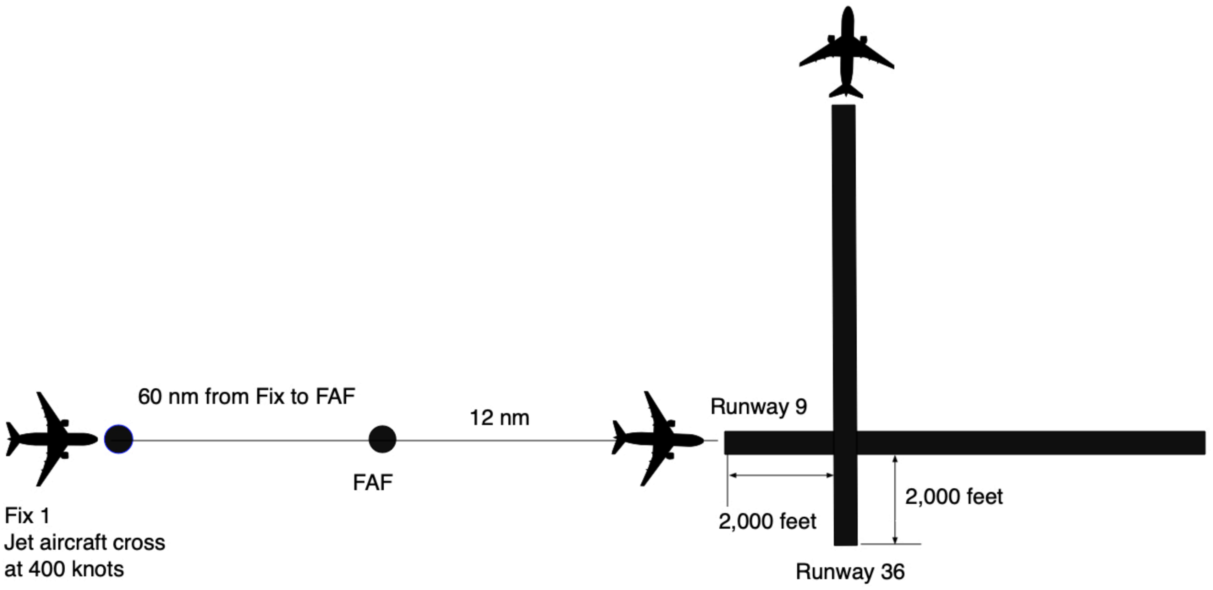


Figure 1. Runway configuration for Problem 1.

The airport has an advanced PRM airport surveillance radar which tracks aircraft up to 80 miles form the airport site. Assume the ATC probability of violation is 5% with standard deviation of the in-trail delivery error at 18 seconds due to the installation of a PRM radar (i.e., faster update rate). Use the on-approach separation matrix according to the consolidated wake separations applicable today. Other technical parameters and departure-departure are shown in Tables 1 and 2.

Table 1. Runway Operational Parameters and Fleet Mix for Airport in Problem 1.

Aircraft RECAT Group	Percent Mix (%)	Runway Occupancy Time (s)	Typical Approach Speed (knots) at Threshold VREF	Typical Approach Speed (knots) at FAF (10 nm out)
F	60	59	142	VREF + 35 knots
G	40	55	136	VREF + 35 knots
Totals	100			

Table 2. Departure-Departure Separations with Buffers Included. Columns 2-7 are the Following Aircraft. First Column Presents the Lead Aircraft. Values in are seconds (values include departure buffers).

	Trailing Aircraft	
Lead Aircraft (below)	**F**	**G**
F	70	85
G	70	65

a) Find the saturation arrival capacity of the airport under IMC conditions. In your solution consider the speed difference between the FAF and the runway threshold. Comment on how this changes the solution.

No consideration of changing speed.

Arrivals only capacity = 32.7 per hour

Using the average speed between the FAF and the runway such that (Vref + Vref + 35)/2

Arrivals only capacity = 35.7 per hour

Just like in traffic engineering, aircraft traveling at faster speeds result in higher runway capacity. Unfortunately, aircraft need to fly at Vref near the runway and hence pilots need time (and considerable distance) to configure the aircraft with flaps and landing gear in order lo land. Aircraft need to land in a very narrow window of speed. In normal airline operations, if a pilot deviates +/- 10-15 knots from the Vref speeds, the landing typically results in a go-around mandated by airline SOP (standard operating procedure).

b) Find the saturation departure capacity of the airport under IMC conditions.

Departures only capacity = 50.14 per hour on runway 36 with no arrivals on runway 9.

c) Find two additional points (your choice) along the Pareto frontier to estimate the complete arrival-departure saturation capacity diagram.

The solution presented applies when using the average speed in the last 12 nm of the flight track.

Distance to Interection (departures)		2000	G	F	E	C	B
Time to cross intersection			8.13	7.82	7.92	7.63	
Distance to intersection (arrivals)		2000	G	F	E	C	B
Time to cross intersection			23.03	23.03	23.03	23.03	
TD speed Multiplier	0.95						
Acceleration (m/s-s)	2.3						
feet2nm	6076						
feet2meters	0.304878049						
			Time for departure to cross runway				
Engine time lag	6		51.03				
Pilot-ATC time lag	4						
ATC lag to clear departure	10						

Augmented Matrix (Tij + Bij)-Time to Cross

		Trailing Aircraft (Header Columns)			
Lead (column 1)	G	F	E	C	B
G	49.03	46.38	47.24	44.72	42.76
F	56.97	46.38	47.24	44.72	42.76
E	54.39	43.80	47.24	44.72	42.76
C	105.97	62.36	65.80	44.72	42.76
B	131.91	99.96	103.40	71.97	42.76

Distance Left for next arrival to runway threshold

		Trailing Aircraft (Header Columns)			
Lead (column 1)	G	F	E	C	B
G	2.09	2.05	2.07	2.03	2.00
F	2.43	2.05	2.07	2.03	2.00
E	2.32	1.94	2.07	2.03	2.00
C	4.52	2.76	2.88	2.03	2.00
B	5.62	4.43	4.52	3.27	2.00

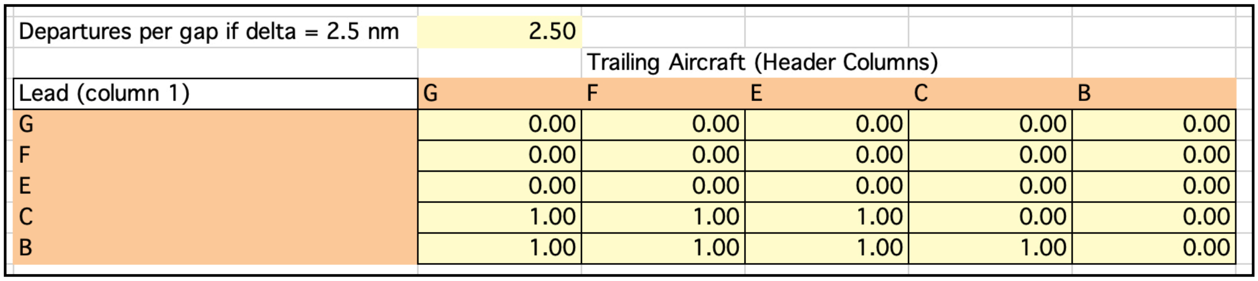
Departures per gap if delta = 2 nm 2.00

		Trailing Aircraft (Header Columns)			
Lead (column 1)	G	F	E	C	B
G	1.00	1.00	1.00	1.00	1.00
F	1.00	1.00	1.00	1.00	1.00
E	1.00	0.00	1.00	1.00	1.00
C	1.00	1.00	1.00	1.00	1.00
B	1.00	1.00	1.00	1.00	1.00

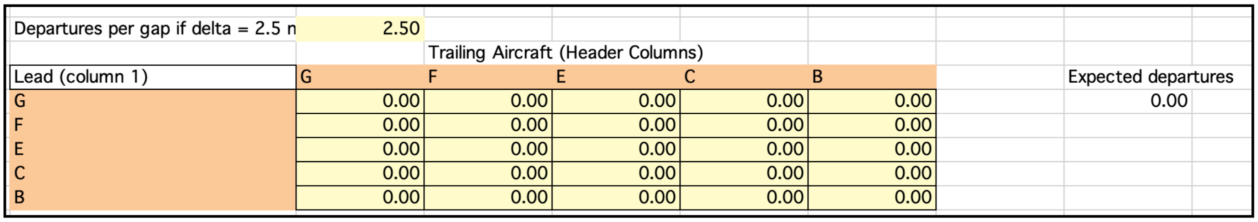
Departures per gap if delta = 2 nm	2.00						
		Trailing Aircraft (Header Columns)					
Lead (column 1)	G	F	E	C	B		Expected departures
G	12.48	8.32	0.00	0.00	0.00		34.68
F	8.32	5.55	0.00	0.00	0.00		
E	0.00	0.00	0.00	0.00	0.00		
C	0.00	0.00	0.00	0.00	0.00		
B	0.00	0.00	0.00	0.00	0.00		

If the minimum arrival-departure separation as the departing aircraft crosses the intersection is 2 nm, the analysis shows that with 100% arrival priority (i.e., natural gaps between successive arrivals), the ATC should be able to accommodate 34.7 departures per hour. This implies that one departure per arrival gap is possible.

If the ATC releases the departure on runway 36 estimating that the departure crosses the intersection and the next arrival is **2.5 nm, the analysis shows that not a single gap will allow a departure**.



Departures per gap if delta = 2.5 nm	2.50				
		Trailing Aircraft (Header Columns)			
Lead (column 1)	G	F	E	C	B
G	0.00	0.00	0.00	0.00	0.00
F	0.00	0.00	0.00	0.00	0.00
E	0.00	0.00	0.00	0.00	0.00
C	1.00	1.00	1.00	0.00	0.00
B	1.00	1.00	1.00	1.00	0.00



Departures per gap if delta = 2.5 n	2.50						
		Trailing Aircraft (Header Columns)					
Lead (column 1)	G	F	E	C	B		Expected departures
G	0.00	0.00	0.00	0.00	0.00		0.00
F	0.00	0.00	0.00	0.00	0.00		
E	0.00	0.00	0.00	0.00	0.00		
C	0.00	0.00	0.00	0.00	0.00		
B	0.00	0.00	0.00	0.00	0.00		

d) Draw the Pareto diagram for the airport under IMC conditions.

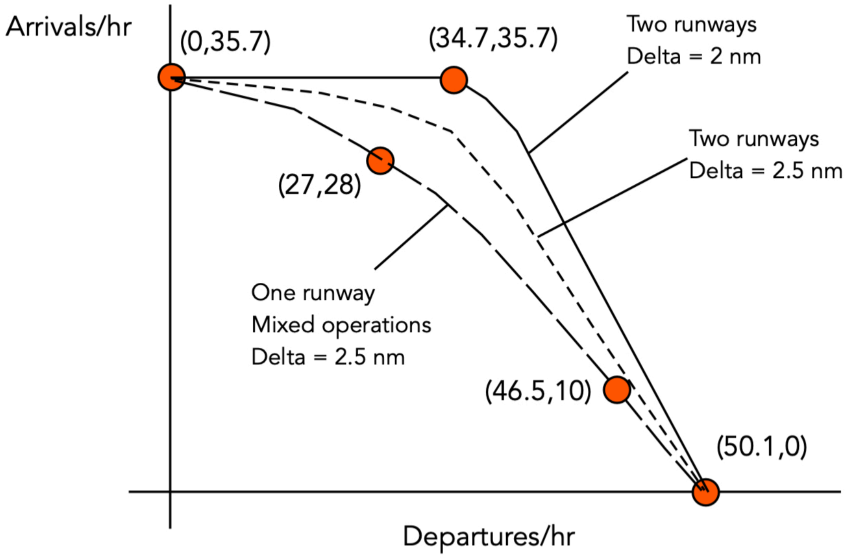


Figure 2. Arrival-Departure Diagram for Arrivals on Runway 9 and departures on Runway 36. Three Distinct Runway Operational Configurations Shown.

e) Estimate the in-trail separations required at Fix1 to match the saturation capacity of the runway under IMC conditions. State the desired separations at Fix1 in nautical miles and also estimate the headways in seconds.

The expected time between successive arrivals at the runway threshold or at the FAF (for the opening case) is ~72 seconds. Converting 72 seconds to distance while flying at 400 knots ground speed is equivalent to 8 nautical miles at Fix 1. Therefore, when ATC separates two successive aircraft over Fix 1, the distance separations are two and a half times those applied at the threshold. This effect is a distance compression that is considered by ATC in applying separations at arrival fixes.

Problem 2 (50 Points)

Use the aerodynamic performance of the regional jet file (http://128.173.204.63/courses/cee5614/cee5614_pub/regionalJet_class.m) to solve the problem.

b) The aircraft reaches the TOC point (35,000 feet) with a mass of 22,000 kilograms. Find the most economical cruise Mach number for the aircraft that minimizes the fuel burn at 35,000 feet. Your solution should only consider practical Mach numbers and avoid the back side of the drag curve.

The most economical cruise Mach is the one that minimizes the Thrust required to overcome Drag. In cruise thrust and drag are the same. Figure 3 shows the drag and thrust available by both engines. The Mach number that minimizes the drag is 0.59. Such Mach number is never used in real commercial operations because the aircraft will be traveling too slow. The regional jets like the one modeled are normally operated at Mach 0.70-0.75.

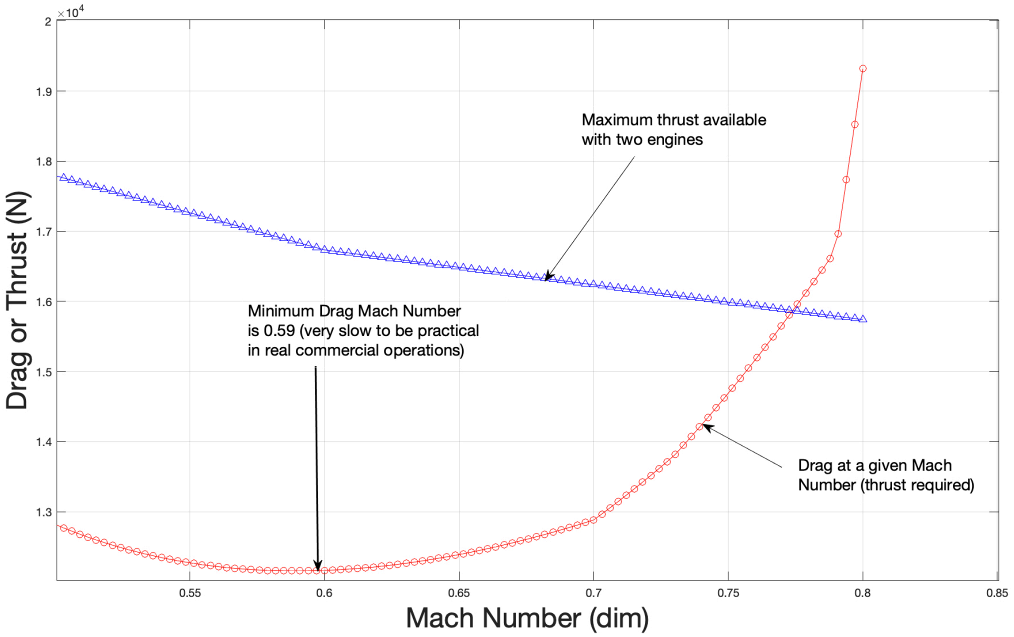


Figure 3. Drag and Maximum Thrust Available versus Mach Number.

c) Find the maximum speed that the aircraft can reach at 35000 feet limited by engine thrust.

The intersection of maximum thrust and drag is Mach 0.77. That is the maximum speed in cruise at 35,000 feet.