CEE 5614: Analysis of Air Transportation Systems **Spring 2026**

Quiz 1 : Open Notes

Date Due: March 20, 2026 Instructor: Trani

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 40 Points)

Use the new generation twin-engine transport provided in class (Boeing 787-8 class) aircraft provided in class (http://128.173.204.63/cee5614/cee5614_pub/B787_class.m) to answer the following questions.

Simulate a flight using the aircraft departing San Diego Airport (SAN) to Tokyo Narita International Airport (NRT). The aircraft has the following parameters: For the flight, assume the aircraft has 240 seats (assume a 100% load factor) and carries 70,000 kilograms of fuel including fuel reserve.

a) Use the default climb speed profile provided in the aircraft data file to calculate the fuel burn in climb and the time to climb to an initial altitude that provides at least 500 ft/minute climb rate. Assume ISA atmospheric conditions in your calculations. Remember to round off to the nearest 1000 feet since cruise flight levels are assigned at 1,000 ft increments.

Aircraft Parameters

OEW = 117700; % Operating empty mass (kg)
Max_fuel = 101323; % Maximum fuel mass (kg)
Max_payload = 43300; % Maximum payload (kg)
MTOGW = 227930; % Maximum gross takeoff mass (kg)

Fuel carried = 70,000 kilograms
Payload = 24,000 kilograms
DTW = 117700 + 70000 + 24000 = 211,700 kilograms.

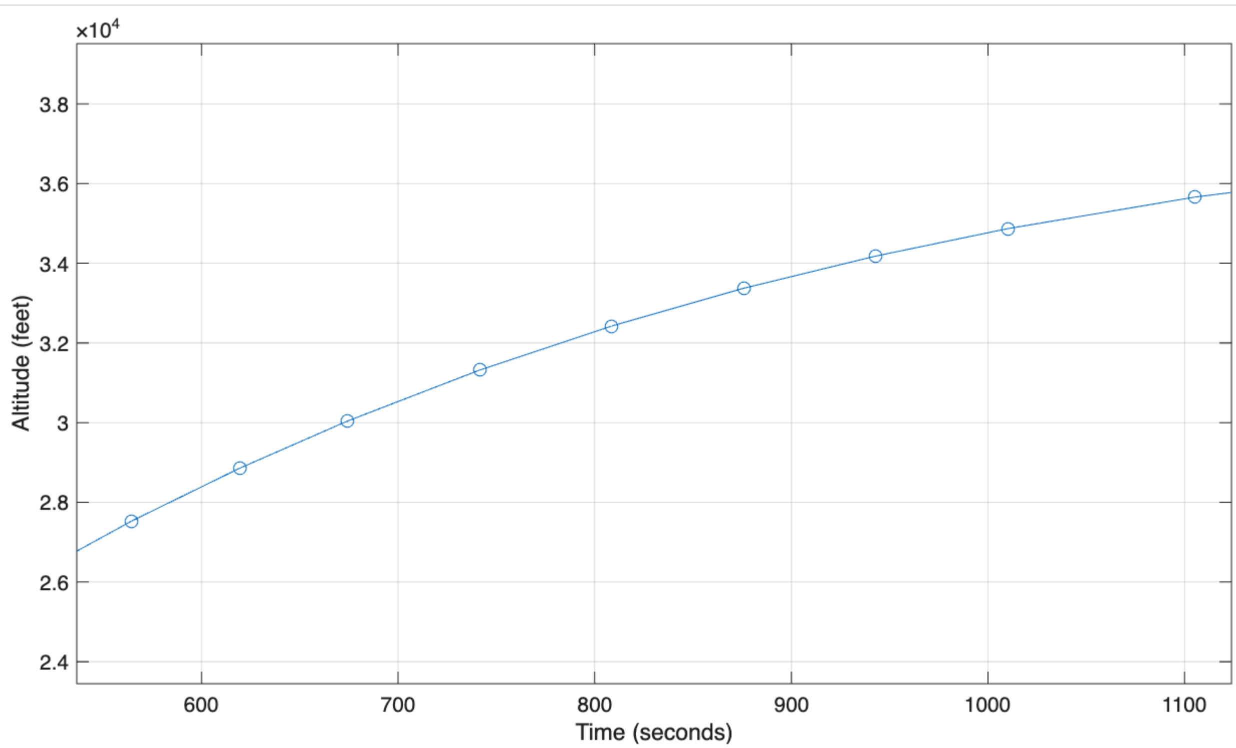

Figure 1. Climb Profile for Boeing 787-8 Class Aircraft. ISA Conditions.

Top of Climb (feet) = 33,000
Target Altitude (meters) = 10256.7
Mass at TOC (kilograms) = 208,449

b) Based on the data provided, estimate the fuel and time used to reach the Top of Climb Point (TOC).

Time to Climb (seconds) = 849.3
Mass at TOC (kilograms) = 208,449
Climb Fuel (kilograms)   3251.04
Distance to TOC (meters) = 163,286
Distance to TOC (nm) = 88.17

c) For the cruise segment, the airline dispatch suggests a cruise speed of Mach 0.82 at the altitude selected in port (a). For the selected altitude, estimate the mass of the aircraft at the Top of Climb (TOC) point and the fuel burn (lbs/hr) at the start of the cruise profile.

Cruise Mach Number (dim) = 0.82
Initial Mass (kg) 208,449
Fuel Burn (kg/min) 106.43

d) Estimate the fuel used in cruise assuming the standard 6% detour factor to account for ATC restrictions and weather deviations. For the cruise analysis, use the unrestricted descent profile to estimate the distance from TOD to the destination airport (NRT). Perform the analysis using the following cruise scenarios:

Run the unrestricted descent profile to estimate the fuel and distance to descent from TOD to sea level conditions.

SAN-NRT Great Circle Distance is 4,829 nm. Adding 6% to the GCD distance yields 5,118 nm.

OEW + Payload = 117700 + 24000 = 141,700 kilograms

Fuel left at TOC = 70,000 - 3,251 = 66,749 kilograms

Guess TOD mass = 148,000 kilograms

Climb distance = 88.17 nm

Descent distance = 160 nm

1. No climb between TOC and TOD (constant altitude).

Cruise distance = 4,870 nm

Mass at TOC = 208,449 kilograms

Mass at TOD = 148,000 kilograms

Computational Steps   1000

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 4870
Cruise Fuel (kg) 60,073
Cruise Time (minutes) 612.7
Cruise Time (hrs) 10.2
Initial Mass (kg) 208,449
Final Mass (kg) 148,376

Descent fuel using mass at TOD of 148,400 kilograms (from 33,000 feet) is 1,100 kilograms.

Landing weight = 148,400 -1,100 = 147,300 kilograms

Reserve fuel = ~ 147,300 - 141,700 = 5,600 kilograms

Total fuel used (constant altitude - 33,000 feet) = 3,251 + 60,073 + 1,100 = 64,424 kilograms

2. Schedule multiple climbs throughout the flight so that a climb is requested and granted when the aircraft mass allows the aircraft to climb at a minimum of 500 ft/min at the start of each climb point (see Figure 1). Since the flight is mostly over the Pacific Ocean, assume climbs can be granted at 1,000 foot intervals (with Reduced Vertical Separation Minima).

Create a table to estimate the aircraft mass versus climb rate to estimate the positions in the flight where the aircraft may be able to climb at 500 ft/min.

Table 1. Sample Estimates of Times Burn Fuel Allowing the Aircraft to Climb to the Next Flight Level.

Aircraft Mass (kg)	Altitude (feet)	Mach Number	Rate of Climb (ft/min)	Fuel Flow (kg/min)	Time to Next Level (minutes)
208,449	33,000	0.82	528	106.1	81.4
200,000	34,000	0.82	541	101.5	80.5
192,000	35,000	0.82	539	97.2	62.8
186,000	36,000	0.82	550	93.9	65.0
180,000	37,000	0.82	519	90.8	90.3
172,000	38,000	0.82	523	86.5	95.3
164,000	39,000	0.82	520	81.3	113.0
155,000	40,000	0.82	521	78.0	105.2
147,000	41,000	0.82	547	74.1	
Averages					86.7

The table shows that the aircraft requires 87 minutes on average to burn enough fuel to climb to the next flight level. As the aircraft burns fuel towards the end of the flight, the travel time to climb to the next level increases to over 100 minutes. The times to the next flight level are estimated using the average fuel burn between two consecutive flight levels.

Using the table we can estimate the distance travel to climb to the next level and hence estimate the fuel used in multiple segments of the flight.

Example calculation:

Step 1 Aircraft cruises at FL330 for 82 minutes.

Initial Mass = 208,449 kgs

Mach 0.82 equates to 476 knots

Distance traveled is 650 nautical miles

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 650
Cruise Fuel (kg) 8599.4983
Cruise Time (minutes) 81.779
Cruise Time (hrs) 1.363
Initial Mass (kg) 208449
Final Mass (kg) 199849.5017
Fuel Burn (kg/min) 105.1553

Step 2 Aircraft Climbs from FL330 to FL 340

Rate of climb at mass of 199,840 kilograms is estimated to be 541 ft/minute (see Table 1). It takes 1.85 minutes to climb to FL 340.

Fuel burn in climb is 127.7 kg/minute (perform a point mass calculation to estimate the rate of climb). Climbing from FL330 to FL340 is 236 kilograms.

Step 3 Aircraft cruises FL 340 for 81 minutes (see Table 1)

Initial Mass = 199,604 kgs

Mach 0.82 equates to 474 knots

Distance traveled is 640 nautical miles

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 640
Cruise Fuel (kg) 8142.0737
Cruise Time (minutes) 80.9622
Cruise Time (hrs) 1.3494
Initial Mass (kg) 199604
Final Mass (kg) 191461.9263
Fuel Burn (kg/min) 100.5664

Step 4 Aircraft Climbs from FL340 to FL 350

Rate of climb at mass of 191,462 kilograms is estimated to be 634 ft/minute (see Table 1). It takes 1.58 minutes to climb to FL 350.

Fuel burn in climb is 122.9 kg/minute (perform a point mass calculation to estimate the rate of climb). Climbing from FL340 to FL350 is 194 kilograms.

Step 5 Aircraft cruises FL 350 for 63 minutes (see Table 1)

Initial Mass = 191,268 kgs

Mach 0.82 equates to 473 knots

Distance traveled is 495 nautical miles

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 495
Cruise Fuel (kg) 6071.0553
Cruise Time (minutes) 62.955
Cruise Time (hrs) 1.0493
Initial Mass (kg) 191,268
Final Mass (kg) 185,197
Fuel Burn (kg/min) 96.4348

Step 6 Aircraft Climbs from FL350 to FL 360

Rate of climb at mass of 185,197 kilograms is estimated to be 640 ft/minute (see Table 1). It takes 1.56 minutes to climb to FL 360.

Fuel burn in climb is 118.2 kg/minute (perform a point mass calculation to estimate the rate of climb). Climbing from FL350 to FL360 is 185 kilograms.

Step 7 Aircraft cruises FL 360 for 65 minutes (see Table 1)

Initial Mass = 185,012 kgs

Mach 0.82 equates to 470 knots

Distance traveled is 509 nautical miles

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 509
Cruise Fuel (kg) 6018.0148
Cruise Time (minutes) 64.9257
Cruise Time (hrs) 1.0821
Initial Mass (kg) 185012
Final Mass (kg) 178994
Fuel Burn (kg/min) 92.6908

Step 8 Aircraft Climbs from FL360 to FL 370

Rate of climb at mass of 178,994 kilograms is estimated to be 640 ft/minute. It takes 1.56 minutes to climb to FL 370.

Fuel burn in climb is 114 kg/minute (perform a point mass calculation to estimate the rate of climb). Climbing from FL360 to FL370 is 179 kilograms.

Step 9 Aircraft cruises FL 370 for 90 minutes (see Table 1)

Initial Mass = 178,994 kgs

Mach 0.82 equates to 470 knots

Distance traveled is 705 nautical miles

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 705
Cruise Fuel (kg) 7987.5028
Cruise Time (minutes) 89.9282
Cruise Time (hrs) 1.4988
Initial Mass (kg) 178994
Final Mass (kg) 171007
Fuel Burn (kg/min) 88.8209

Step 10 Aircraft Climbs from FL370 to FL 380

Rate of climb at mass of 171,007 kilograms is estimated to be 640 ft/minute. It takes 1.56 minutes to climb to FL 380.

Fuel burn in climb is 108.9 kg/minute (perform a point mass calculation to estimate the rate of climb). Climbing from FL370 to FL380 is 170 kilograms.

Step 11 Aircraft cruises FL 380 for 95 minutes (see Table 1)

Initial Mass = 170,837 kgs

Mach 0.82 equates to 470 knots

Distance traveled is 744 nautical miles

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 705
Cruise Fuel (kg) 7618.9469
Cruise Time (minutes) 89.9282
Cruise Time (hrs) 1.4988
Initial Mass (kg) 170837
Final Mass (kg) 163218.0531
Fuel Burn (kg/min) 84.7226

Step 12 Aircraft Climbs from FL380 to FL 390

Rate of climb at mass of 163,218 kilograms is estimated to be 640 ft/minute. It takes 1.56 minutes to climb to FL 390.

Fuel burn in climb is 164 kilograms.

Step 13 Aircraft cruises FL 390 for 1050 nm to TOD

Initial Mass = 170,837 kgs

Mach 0.82 equates to 470 knots

Distance traveled is 1050 nautical miles to TOD

Fuel burned (using numerical simulation) is:

Cruise Mach Number (dim) 0.82
Cruise Distance (nm) 1050
Cruise Fuel (kg) 10753.0291
Cruise Time (minutes) 133.9356
Cruise Time (hrs) 2.2323
Initial Mass (kg) 163054
Final Mass (kg) 152300.9709
Fuel Burn (kg/min) 80.2851

Aircraft Mass (kg)	Altitude (feet)	Segment	Distance (nm)	Fuel Used (kg)	Total Distance Flown from TOC (nm)	Total Fuel Used from TOC (kg)
208,449	33,000	Cruise	650	8599.5	650.0	8599.5
		Climb	14.7	236.0	664.7	8835.5
199,604	34,000	Cruise	640	8142.1	1304.7	16977.6

Aircraft Mass (kg)	Altitude (feet)	Segment	Distance (nm)	Fuel Used (kg)	Total Distance Flown from TOC (nm)	Total Fuel Used from TOC (kg)
		Climb	12.6	194.0	1317.3	17171.6
191,268	35,000	Cruise	495	6071.1	1812.3	23242.6
		Climb	12.5	185.0	1824.8	23427.6
185,012	36,000	Cruise	509	6018.0	2333.8	29445.6
		Climb	12.5	179.0	2346.3	29624.6
180,000	37,000	Cruise	705	7987.5	3051.3	37612.1
		Climb	12.5	170.0	3063.8	37782.1
170,837	38,000	Cruise	744	7618.9	3807.8	45401.1
		Climb	12.5	164.0	3820.3	45565.1
163,054	39,000	Cruise	1050	10753.0	4870.3	56318.1
	39000	Descent	160	1100.0	5030.3	57418.1
211,700	0-33000	Climb	88	3271.0	5118.3	60689.1

All segments flown at Mach 0.82.

e) What is the fuel savings using the multi-climb profile in the route to Japan?

Constant cruise altitude fuel used is 64,424 kilograms

Multi-climb cruise profile fuel used is 60,689 kilograms

Fuel savings is 3,735 kilograms. A substantial savings.

f) Calculate the additional cost to the airline per flight (between the two profiles estimated in part (b)) if the fuel price today in large volumes is $2.45 per gallon of Jet-A fuel (http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx). Comment if the cost differential is significant.

1,227 gallons is 3,735 kilograms. The cost difference is $3,006 per flight.

Problem 2 (30 Points)

A cargo airline would like to operate a Boeing 747-8F from Querétaro Intercontinental Airport (QRO) during the hottest month of the year.

a) Find the longest route that can be flown by the aircraft operating at maximum payload conditions for the existing runway length conditions. Clearly indicate the design conditions used (i.e., temperature, elevation and the runway length at the airport).

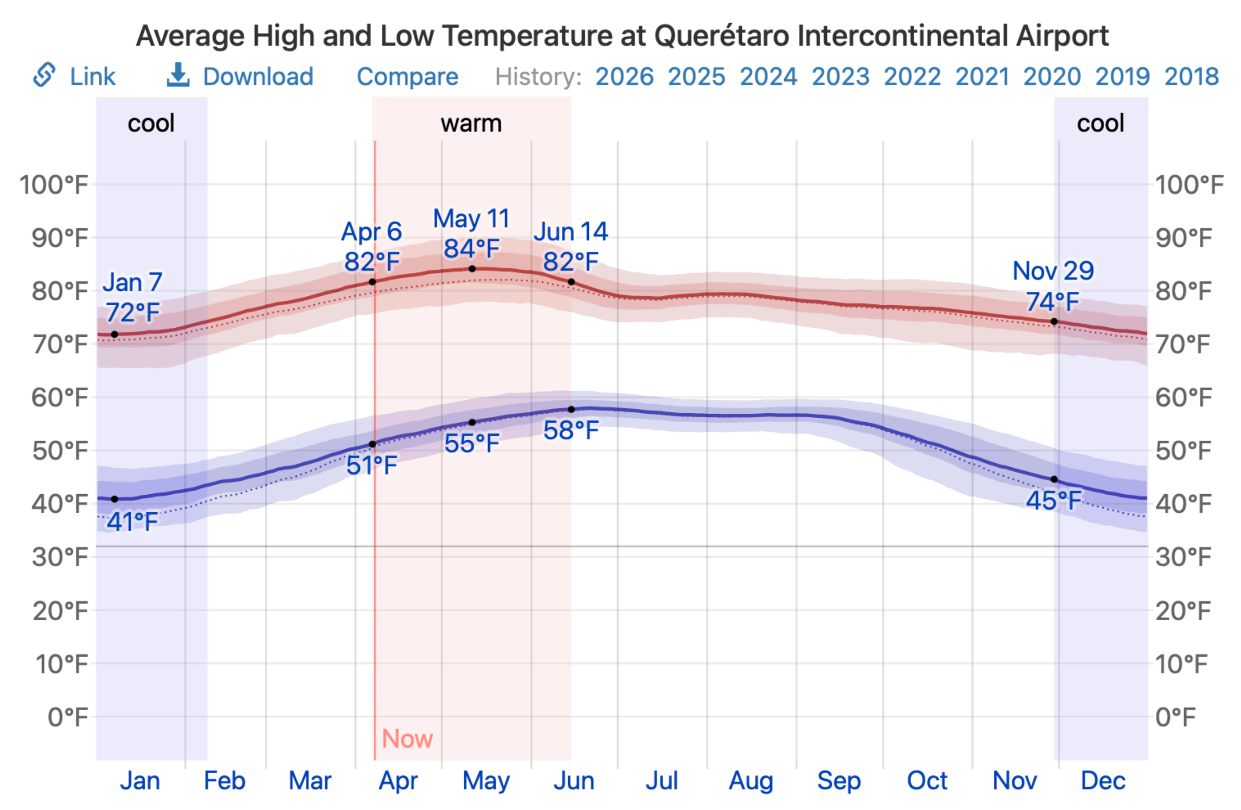

Figure. Weather Spark Data for Queretaro.

The design temperature is 84 deg. Fahrenheit.

Airport elevation is 6,460 ft. (1,969 m).

ISA conditions at 6,460 feet is 36 deg. Fahrenheit.

The design conditions are ISA + 48 deg. F.

Boeing provides a performance chart for ISA + 45 deg. F. The chart is within 3 deg. F. Hence is usable for the analysis.

Runway length at Queretaro is 11,483 feet.

OEW = 434,600 lbs.

Max. Payload = 290,400 lbs.

Max. Zero fuel weight = 434,600 + 290,400 = 725,000 lbs.

DTW = 800,000 lbs.

Fuel weight = DTW - OEW - Max. Payload = 800,000 - 434,500 - 290,400 lbs.

Fuel weight = 75,100 lbs.

The longest route that can be flown with the max. **Payload is a mere 900 nautical miles.**

CHARACTERISTICS	UNITS	747-8F	747-8F
MAX DESIGN TAXI WEIGHT	POUNDS	978,000	990,000
	KILOGRAMS	443,613	449,056
MAX DESIGN TAKEOFF WEIGHT	POUNDS	975,000	987,000
	KILOGRAMS	442,252	447,695
MAX DESIGN LANDING WEIGHT	POUNDS	761,000	763,000
	KILOGRAMS	345,183	346,091
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	725,000	727,000
	KILOGRAMS	328,854	329,761
OPERATING EMPTY WEIGHT (1)	POUNDS	434,600	434,600
	KILOGRAMS	197,131	197,131
MAX STRUCTURAL PAYLOAD (1)	POUNDS	290,400	292,400
	KILOGRAMS	131,723	132,630
TYPICAL CARGO – MAIN DECK CONTAINERS	CUBIC FEET	24,462	24,462
	CUBIC METERS	693	693
MAX CARGO - LOWER DECK CONTAINERS (LD-1)	CUBIC FEET	5,850	5,850
	CUBIC METERS	166	166
MAX CARGO - LOWER DECK BULK CARGO	CUBIC FEET	520	520
	CUBIC METERS	14.7	14.7
USABLE FUEL CAPACITY	U.S. GALLONS	59,734 (2)	59,734 (2)
	LITERS	226,117	226,117
	POUNDS	400,217	400,217
	KILOGRAMS	181,572	181,572

Figure. Characteristics of the Boeing 747-8F.

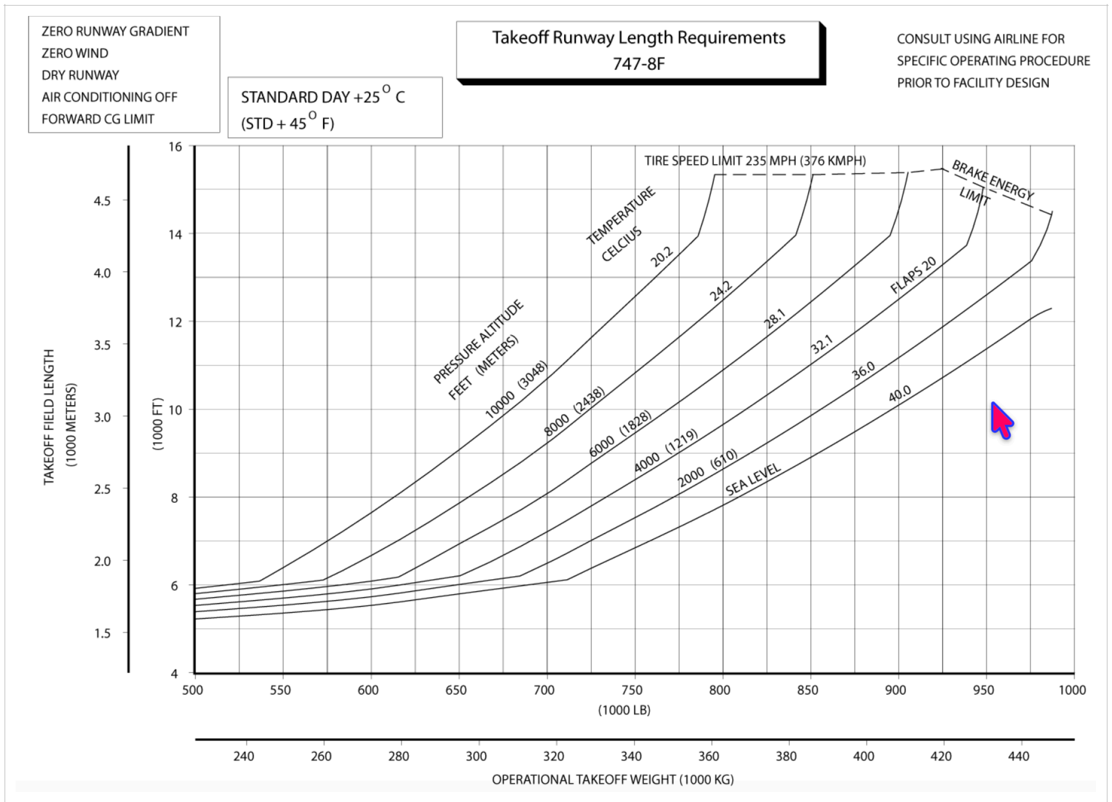

Figure. Characteristics of the Boeing 747-8F.

b) Find the fuel used and the specific air range for the route found in part (a).

Fuel weight = 75,100 lbs.

$$SAR = \frac{distance}{fuel} = \frac{900}{75100} = 0.01198 \text{ nm/lbs}$$

c) Would you recommend a runway extension for the existing runway? Comment.

Yes. The aircraft is very limited in range at maximum payload.

Problem 3 (30 Points)

Use the new generation twin-engine transport provided in class (Boeing 787-8 class) aircraft provided in class (http://128.173.204.63/cee5614/cee5614_pub/B787_class.m) to answer the following questions.

a) Find the thrust required to fly wings level at FL300 (no banking). The aircraft mass is 185,000 kilograms and ATC requests Mach 0.80 (fuel remaining is 35,000 kgs).

For the condition:

$$T = Drag$$

Indicated airspeed = 339 knots
Altitude = 9146.3415 meters
Mass of aircraft = 185,000 kilograms
Thrust = Drag = 107,427 Newtons

b) Repeat the analysis in part (a) if the aircraft performs a coordinated turn (I.e., no altitude loss) at the standard turn rate. Compare the answers of part (a) and (b).

For the standard turn rate - three degrees per second - the bank angle is:

$$tan(\phi) = \frac{V\Gamma}{g}$$

$$\phi = atan(\frac{V\Gamma}{g})$$

The speed of sound at 30,000 feet is 303 m/s.

$V = 303.2 * 0.8 = 242.5$ m/s (470 knots)

$g = 9.81$ m/s²

$\Gamma = 3 * (\frac{\pi}{180})$ = 0.0524 rad/second

$\phi = atan(\frac{242.5 * 0.0524}{9.81})$=0.91 radians

$> 30deg$

At high speed such as Mach 0.8, the bank angle for a standard turn is excessive. Try 1.5 deg/second instead.

$\Gamma = 1.5 * (\frac{\pi}{180})$ = 0.0262 rad/second

$\phi = atan(\frac{242.5 * 0.0262}{9.81})$=0.65 radians

The bank angle for 1.5 deg/second is still above 30 degrees which is the maximum permissible. Banking 33 degrees requires ~10% more thrust that in wings level condition.

Indicated airspeed = 339 knots
Altitude = 9146.3415 meters
Mass of aircraft = 185000 kilograms
Thrust = Drag = 117,618 Newtons

c) Find the radius of the turn for condition in part (b).

$R = \frac{V^2}{gtan\phi}$ = $\frac{242.5^2}{9.81tan(33)}$ = 9,270 meters

d) If the aircraft experiences a depressurization while at in condition (a), find the drift down maneuver to maximize the range.

The aircraft has to descend to 10,000 feet after a failure of the pressurization system.