CEE 5614: Analysis of Air Transportation Systems **Fall 2018**

Quiz 1 : 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

Use the new generation long-range transport aircraft provided in class (http://128.173.204.63/courses/cee5614/cee5614_pub/boeing787_class.m) to answer the following questions. The flight in question is a flight from Miami, (MIA) to Paris, France (CDG). The aircraft has OEW of 117,500 kg., carries 71,000 kg. of fuel and 36,000 kg of payload (passengers and belly cargo). Use the default climb speed profile provided in the aircraft data file. Use ISA atmospheric conditions in your calculations.

a) Based on the data provided, estimate the Top of Climb Point (TOC) if the pilot wants to cruise at an altitude that provides a minimum climb rate of 400 ft/minute. Airline dispatch suggest a cruise speed of Mach 0.82. For the selected altitude, estimate the mass of the aircraft at the Top of Climb (TOC) point. State the distance and travel time to reach the TOC point.

Use the unrestricted climb Matlab script to determine the TOC.

Takeoff mass = OEW + FW + PYL = 117500+36000+71000 = 224,500 kilograms

Make sure to change the takeoff mass in the Boeing_787Class file.

mass = 224500;   % mass at operating point (kg)

In main file (unrestrictedClimb.m) make sure to place correct initial conditions.

h_airport = 0;   % airport altitude (m) - departing field elevation

rhos = 1.225;   % sea level density (kg/m-m-m)

deltaTemp = 0;   % ISA + deltaTemp conditions for analysis (deg. Kelvin)

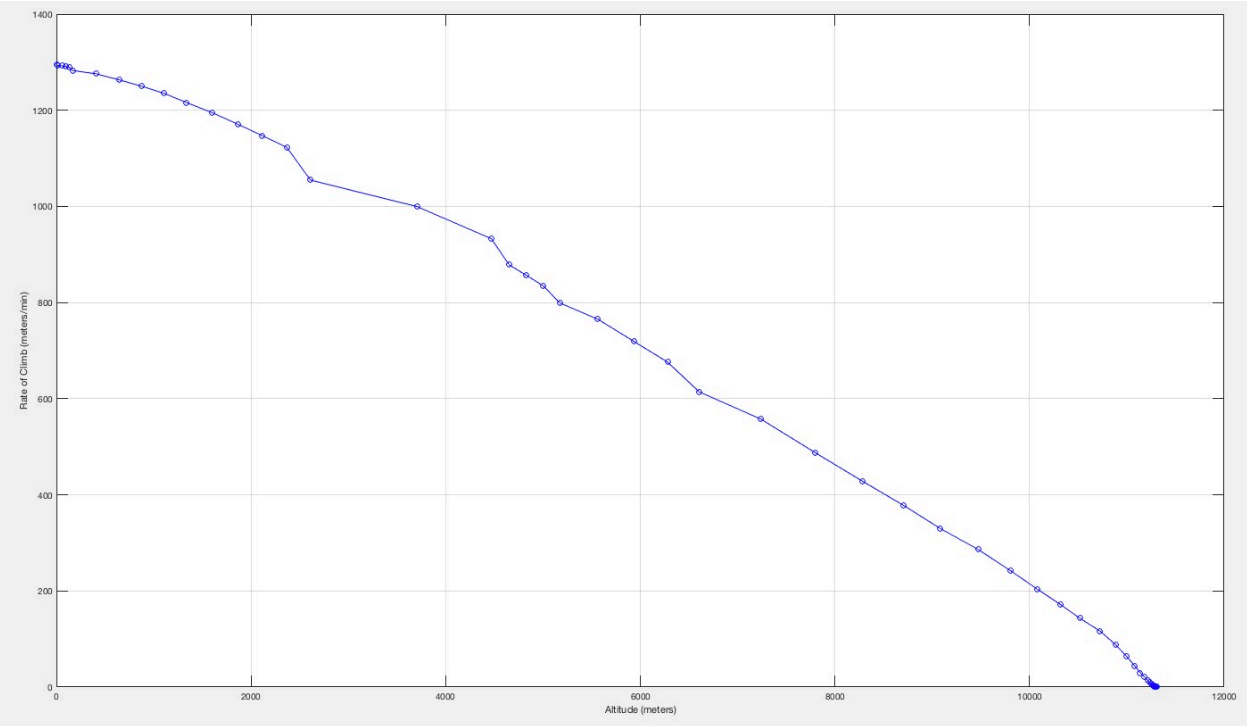


Figure 1. Rate of Climb vs Altitude Plot.

From the rate of climb vs altitude plot, The TOC for 122 m/minute rate of climb is 34,000 feet (~10,600 meters). Note that we need to use an integer cruise altitude. If you use hemispherical rules, the TOC will be 33,000 feet. Both answers are acceptable.

Aircraft climbs to 34,000 feet and takes 112 nautical miles (207 kilometers). At TOC the weight of the aircraft is reported to be 2.169e6 Newtons (see Figure 6 of the plots generated by unrestricted Climb profile). The mass is 221,100 kilograms. The aircraft burns 3.4 metric tons of fuel in the climb profile to 34,000 feet. Travel time is estimated to be 1150 seconds (19.6 minutes).

b) Estimate the fuel used by the aircraft in cruise assuming the standard 6% detour factor to account for ATC restrictions and weather deviations. Perform the analysis using two scenarios: i) One 1000-foot step climb every 3 hours of flight time and ii) Optimize the 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 ocean, assume climbs can be granted at 1,000 foot intervals (Reduced Vertical Separation Minima).

The distance corrected for 6% detour is 4,226 nautical miles. At Mach 0.82 and 34,000 feet, the true airspeed is 474 knots (speed of sound is 297.88 m/s).

At 34,000 feet the aircraft cruises for 3 hours and burns 19,221.7 kilograms of fuel (see Figure 2). The distance traveled at Mach 0.82 is 1,422 nm (see Figure 2). I used a numerical integration of the cruise profile to obtain the answers.

First climb at Mach 0.82 takes 148.4 seconds to go from 34,000 feet to 35,000 feet. The aircraft travels 17.5 nautical miles and burns 268 kilogram of fuel. **Note that you need to adjust the velocity profile in climb (variable climb) in the aircraft profile to reflect the climb conditions of the problem.**

```
Vclimb = [230 250 270 290 325 320 313 307 320];                 % knots indicated

Vdescent = [210 250 250 310 320 320 320 320 320];               % knots indicated

altc = [ 0 4000 10000 15000 34000 35000 36000 37000 43000]/3.28;      % units of altitude are meters
```

After the first climb from 34,000 to 35,000 feet, the aircraft has traveled 1,551 nautical miles. The aircraft cruises for another 3 hours and burns 17,833 kilograms while cruising 1,415 nautical miles. At the end of the second cruise phase (at 35,000 feet) the aircraft has a mass of 183,788 kilograms. A new climb to 36,000 feet burns 198 kilograms. The aircraft travels 13.6 nm in the second climb event from 35,000 to 36,000 feet. At State 3 the aircraft has traveled 2,980 nautical miles and weights 183,590 kilograms. The aircraft has another 1,246 nm to go to CDG. Since each cruise segment flown at Mach 0.82 is equivalent to 1,415 nm of travel, it is important to estimate the third cruise segment (at 36,000 feet) to reach the Top of Descent Point (TOD) so that the aircraft travels a total distance of 4,226 nm.

Use the **unrestricted descent profile program** to estimate the time and fuel used to descent from cruise altitude to sea level conditions. Figure 2 shows the descent profile solution. The aircraft takes 1945 seconds to descent from 36,000 feet to sea level conditions. The descent profile takes 170 nautical miles and uses 1,047 kilograms (see Figure 3).

The distance traveled from takeoff to TOC and from TOD to landing is 282 nautical miles. Adding two cruise segments at 34,000 (1,422 nm) and 35,000 feet (1,415 nm) plus two additional climb segments (17.5 and 13.6 nm, respectively), the remaining cruise distance at 36,000 feet is 1,076 nautical miles (see Figure 4). The third cruise segment burns 12,695 kilograms with a travel time of 137.2 minutes.The rest of the calculations are shown in Figure 4.

The total fuel used in all phase os flight is 54,652 kilograms.

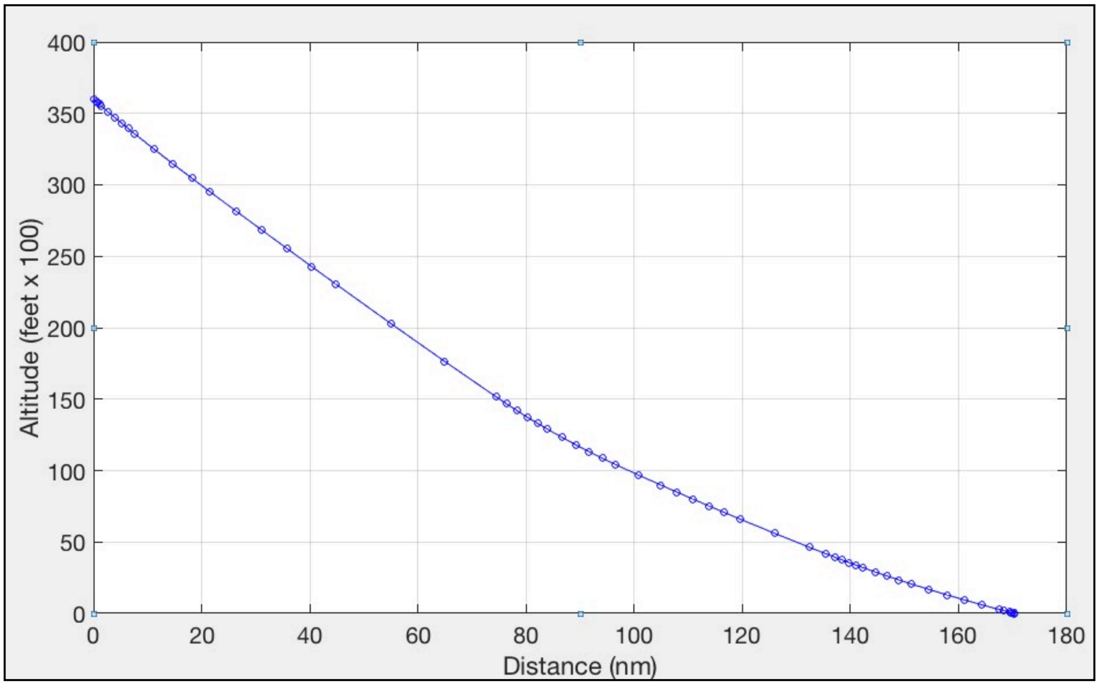


Figure 2. Descent Profile vs Time Plot. Initial Altitude is Assumed to be 36,000 feet. This is a General Descent Profile Solution. Mass at TOD is Assumed to be 166,000 kilograms.

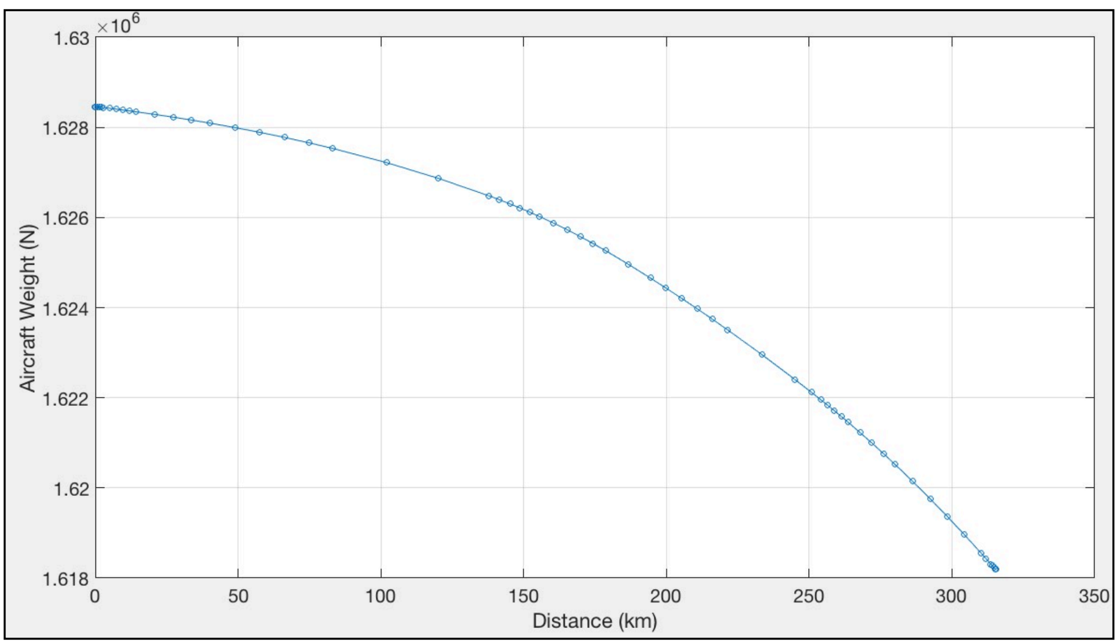


Figure 3. Descent Profile vs Aircraft Weight Plot. Initial Altitude is Assumed to be 38,000 feet. This is a General Descent Profile Solution. Mass at TOD is Assumed to be 166,000 kilograms. Aircraft Burns 1,047 kilograms of Fuel.

c) What is the fuel savings using the optimized profile?

Doing the problem over, using optimized climbs saves around 200-250 kilograms per flight. Faster climbs make the aircraft reach higher altitudes where is more economical to cruise.

d) Calculate the additional cost to the airline per flight (between the two profiles estimated in part (b)) if the fuel price today is $2.28 per gallon of Jet-A fuel (http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx). Comment if the cost differential would be significant if this aircraft makes 350 oceanic crossings per year in that route.

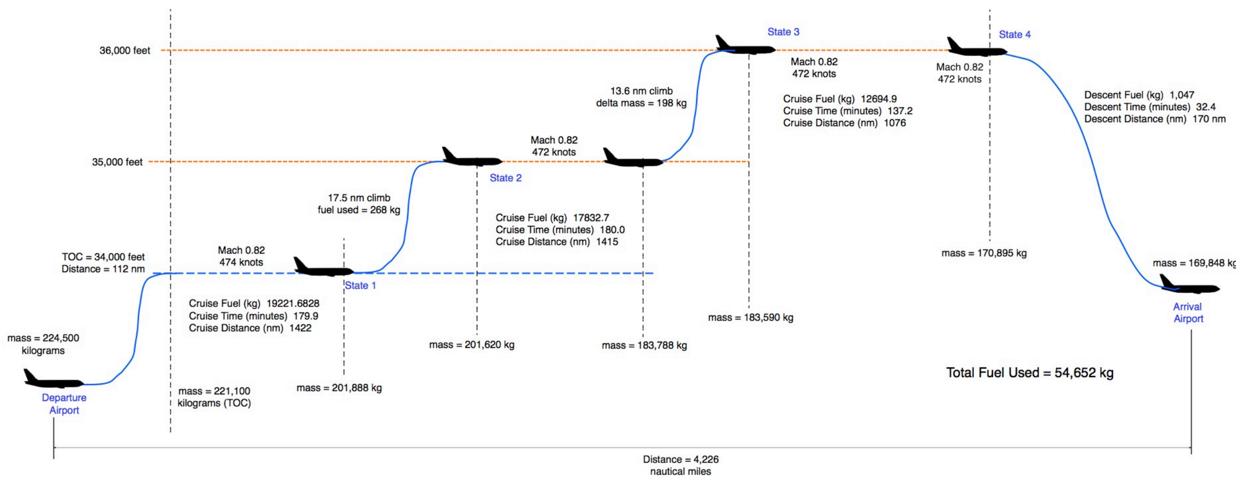
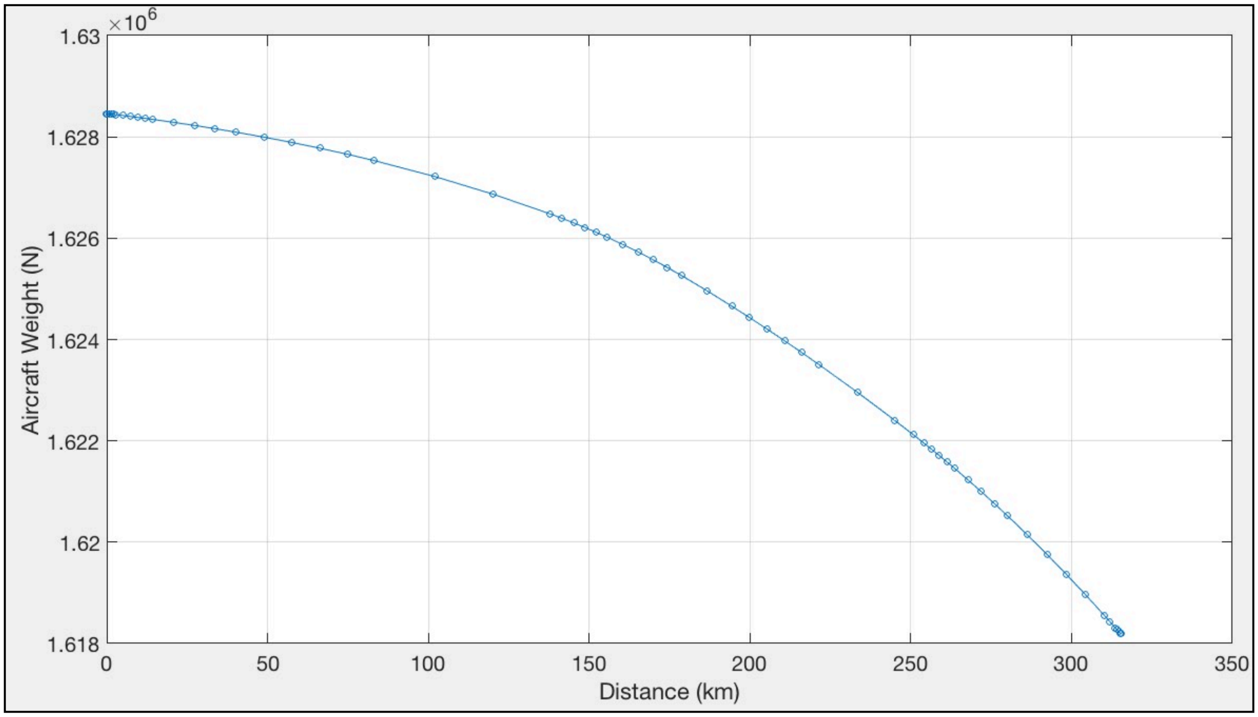


Figure 4. Complete Flight Profile for Boeing 787 Class Aircraft Flying from MIA to CDG. Three-Hours Cruise Segments.



Problem 2

Air Canada is expected to start operations of Boeing 737-8 Max between Montreal and Dublin. The aircraft has a two-class configuration with a maximum takeoff weight of 181,200 lb. The engine used is the CFM LEAP-1B27 engine.

a) Evaluate the suitability of the aircraft for the route in question.

The aircraft can operate in the route. The route is 2,740 nm. The payload range diagram for the aircraft shows the aircraft can operate at 80 metric tons under such conditions. This is 2,000 kilograms below MTOW.

b) Find the runway length needed at Montreal that satisfies FAA/EASA requirements.

The aircraft requires 8,000 feet of runway (ISA + 15 deg. C). YUL has enough runway for such operation.

c) If the total operating cost of the aircraft is 3.2 times the cost of the fuel used in the route, estimate the average fare required to breakeven with a load factor of 80%. The average flight time is 6.05 hours in that route. The cost of fuel is $2.28 per gallon at today's prices.

The fuel mass for a 2,740 nm trip is around 15 metric tons of fuel (4,925 gallons). The fuel cost is $11,230 or $1,720 per hour. The operating cost of the plane is then $5,528 per hour. The ticket cost (one-way) is $277 per person assuming an 80% load factor.