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

## Assignment 4: Air Transportation Systems Analysis

**Solution**                                                          **Instructor: Trani**

# Problem 1

Use the new generation,long-range, twin-engine aircraft (similar to the Boeing 787-8 Dreamliner) file to answer this question (http://128.173.204.63/cee5614/cee5614_pub/B787_class.m).

a) Estimate the **aircraft rate of climb** after departing Phoenix International Airport (PHX) as the aircraft flies at an altitude of 5,000 feet mean sea level with an indicated airspeed of 250 knots. Assume the aircraft mass at 5,000 feet is 195,000 kilograms. Assume ISA conditions.

**At 5,000 feet**

Indicated airspeed =  250  knots

Altitude =  1524.3902  meters

Mass of aircraft =  195000  kilograms

Drag =  93434.0996  Newtons

Thrust =  426463.0052  Newtons

Fuel Burn =  65.2488  N/s

Mach Number =  0.40615  dimensionless

True Airspeed =  135.797  m/s

Rate of Climb =  23.6411  m/s

Rate of Climb =  4652.5761  ft/min

b) Repeat the rate of climb calculation at 15,000 feet (280 knots indicated airspeed), and 30,000 feet while climbing at Mach 0.75. Assume the aircraft mass at 15,000 feet is 193,000 kilograms and at 30,000 feet is 190,000 kilograms. Assume ISA conditions in both scenarios.

**At 15,000 feet**

Indicated airspeed =  280  knots

Altitude =  4573.1707  meters

Mass of aircraft =  193000  kilograms

Drag =  96166.9107  Newtons

Thrust =  295158.6767  Newtons

Fuel Burn =  45.1593  N/s

Mach Number =  0.52749  dimensionless

True Airspeed =  169.9  m/s

Rate of Climb =  17.87  m/s

Rate of Climb =  3516  ft/min

**At 30,000 feet (Mach 0.75)**

Indicated airspeed =  316  knots

Altitude =  9146.3415  meters

Mass of aircraft =  190000  kilograms

Drag =  97490.3645  Newtons

Thrust =  157898.7267  Newtons

Fuel Burn =  24.1585  N/s

Mach Number =  0.7504  dimensionless

True Airspeed =  227.4989  m/s

Rate of Climb =  7.3732  m/s

Rate of Climb =  1451.0384  ft/min

c) Repeat part(a) if the aircraft suffers an engine failure while climbing at 5,000 feet and 250 knots indicated airspeed.

Make the number of engines to be one in the aircraft performance file.

Indicated airspeed =  250  knots

Altitude =  1524.3902  meters

Mass of aircraft =  195000  kilograms

Drag =  93434.0996  Newtons

Thrust =  213231.5026  Newtons

Fuel Burn =  32.6244  N/s

Mach Number =  0.40615  dimensionless

True Airspeed =  135.797  m/s

Rate of Climb =  8.5042  m/s

Rate of Climb =  1673.63  ft/min

d) Compare the rates of climb obtained in parts (a-c). Comment on the implications of an engine out condition at 5,000 feet in altitude for the aircraft.

The rate of climb with one engine out is ~1/3 of the rate of climb with two engines.

e) Use the Unrestricted climb rate Matlab script to estimate the time to climb to 30,000 feet after departing an airport at sea level conditions with a takeoff weight of 210,000 kilograms. Use the climb profile provided in the Matlab file (http://128.173.204.63/cee5614/cee5614_pub/B787_class.m).
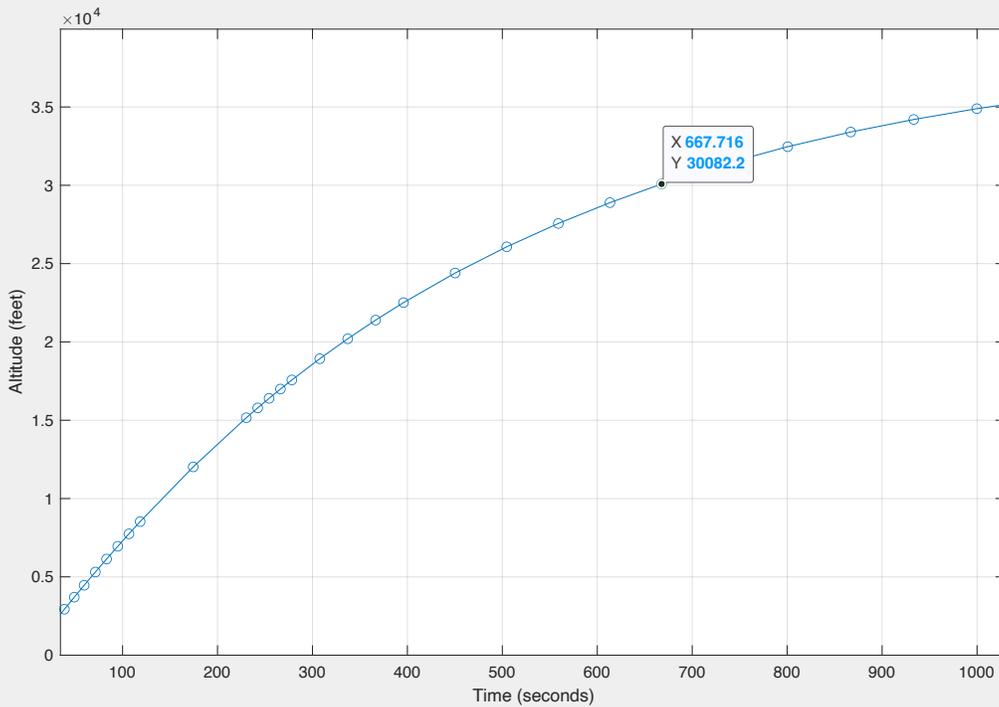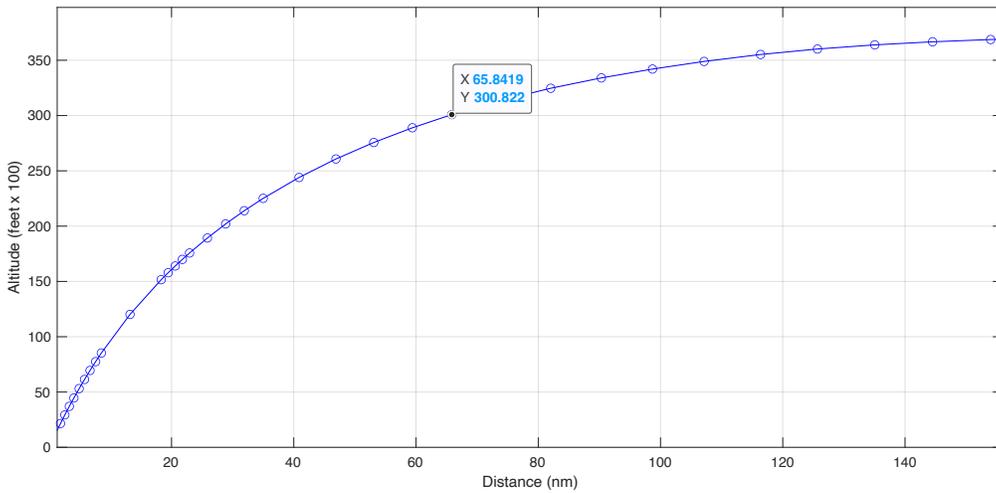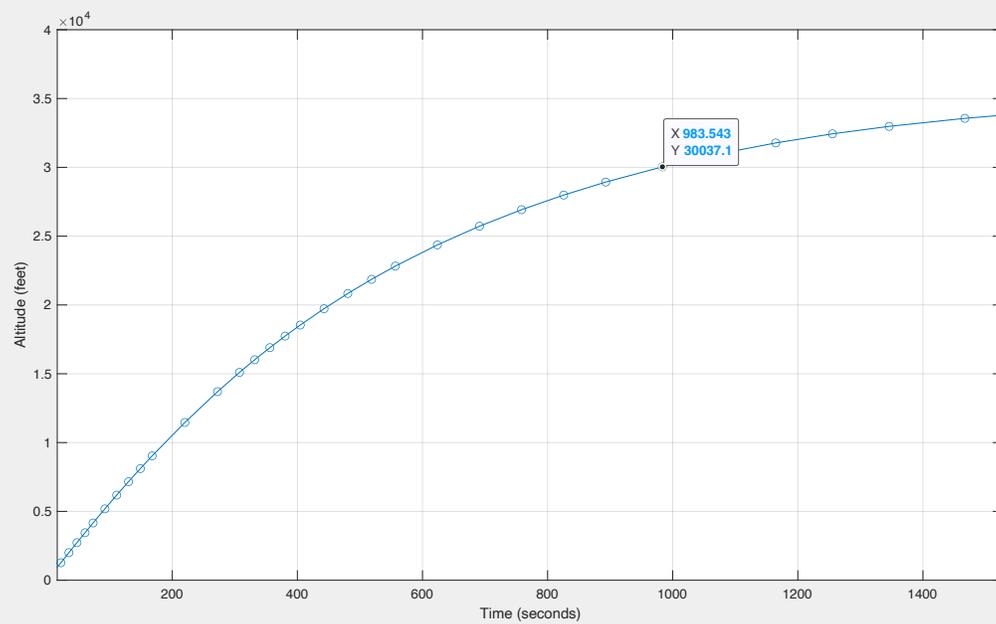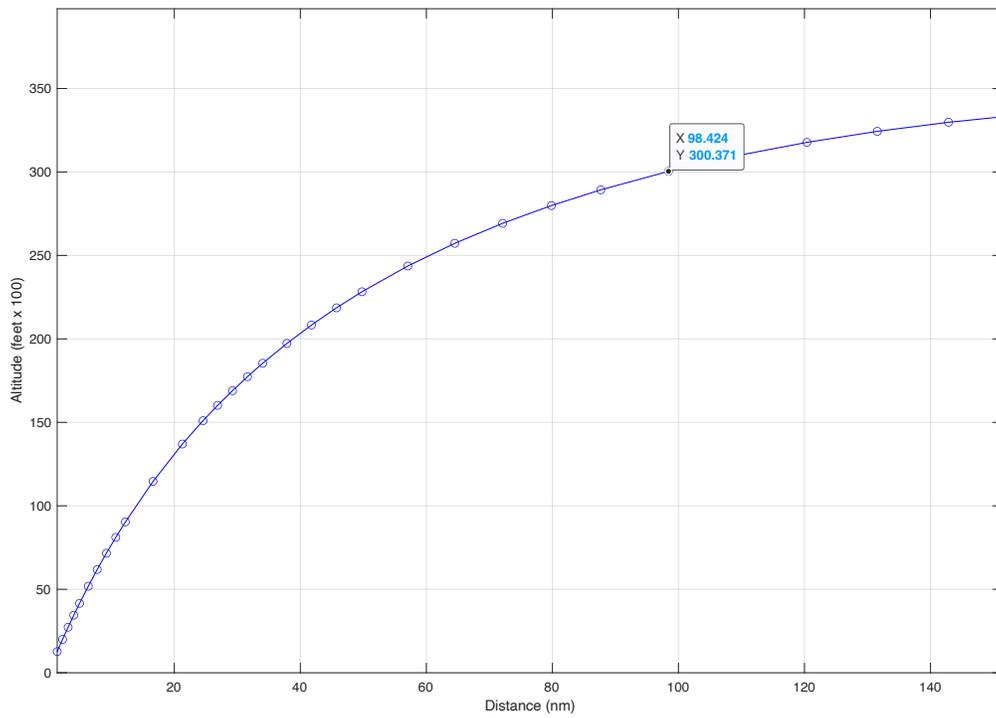
Climb Profile for Boeing 787 -Class Aircraft. Mass 210,000 kilograms.

The aircraft takes 667 seconds to climb to 30,000 feet when the mass is 210,000 kilograms.

The aircraft flies 66 nautical miles to climb to 30,000 feet when the mass is 210,000 kilograms.

f) Repeat part (e) if the departure weight is 260,000 kilograms. Estimate the differences in climb distance and time to reach 30,000 feet.

Climb Profile for Boeing 787 -Class Aircraft. Mass 260,000 kilograms.

The aircraft takes 983 seconds to climb to 30,000 feet when the mass is 260,000 kilograms.

The aircraft flies 98.2 nautical miles to climb to 30,000 feet when the mass is 260,000 kilograms.

# Problem 2

Use the Boeing 787-class file (http://128.173.204.63/cee5614/cee5614_pub/B787_class.m) to answer the following questions

a) Estimate the value of Specific Air Range (SAR) for the aircraft while in cruise at Mach 0.80 and 37,000 feet. The aircraft mass is 205,000 kilograms.

I did the calculation of SAR estimating the time to cover one nautical mile (seconds), the fuel burn to cover one nautical mile (Newtons), and then taking the inverse of the fuel burn quantity to estimate SAR in nm/N and nm/kg.

At 205,000 kilograms mass

Indicated airspeed =  298  knots

Altitude =  11280.4878  meters

Mass of aircraft =  205000  kilograms

Drag =  101168.1766  Newtons

Thrust =  117423.8801  Newtons

Fuel Burn in Cruise =  15.4787  N/s

Mach Number =  0.80031  dimensionless

True Airspeed =  236.1704  m/s

Time to Travel One nm in Cruise =  7.8418  seconds

Fuel Burned in one nm in Cruise =  121.3811  Newtons

SAR =  0.0082385  nm/N

SAR =  0.08082  nm/kg

b) Repeat the process in part(a) after a long flight if the mass is now 165,000 kgs. Comment on the effect of aircraft mass on the value of SAR.
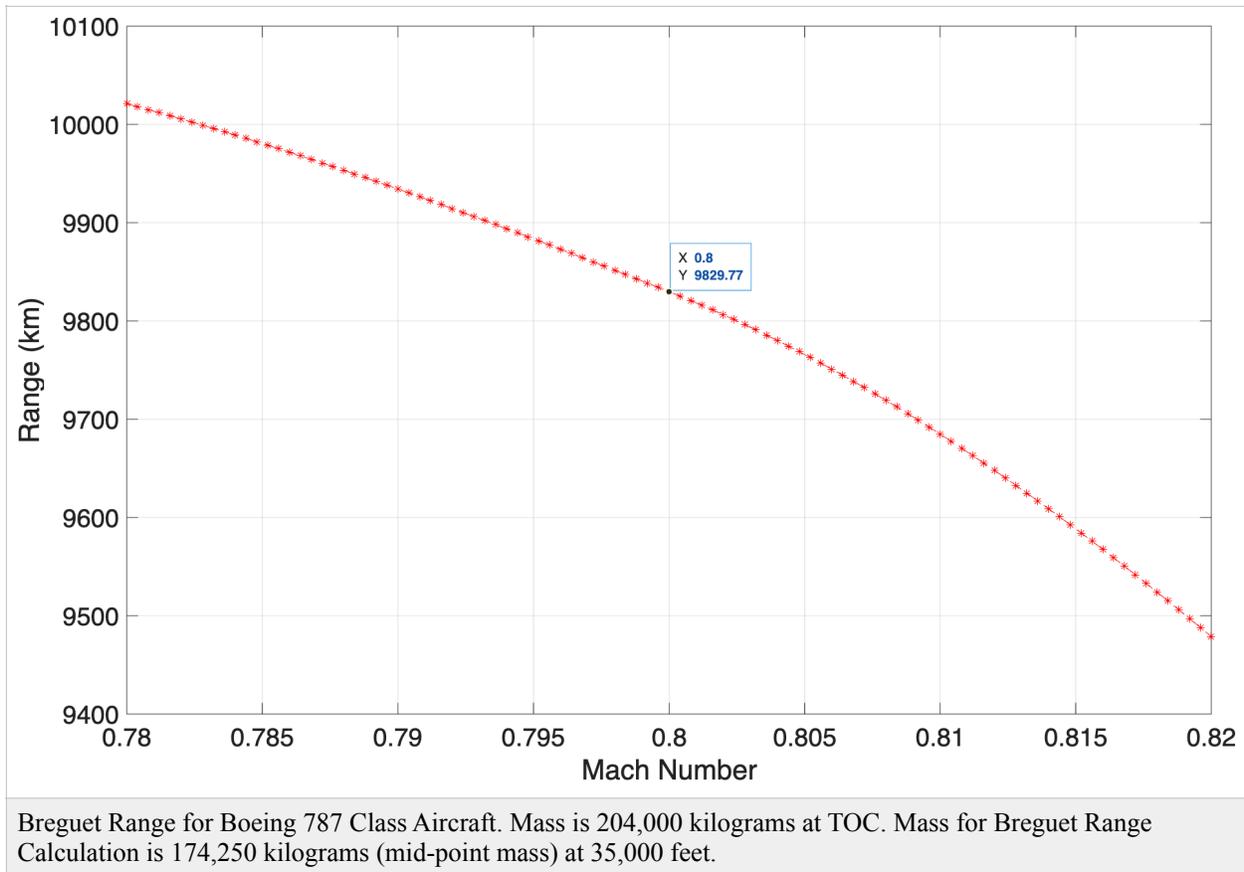
At 165,000 kilograms mass

Indicated airspeed =  298  knots

Altitude =  11280.4878  meters

Mass of aircraft =  165000  kilograms

Drag =  86689.9713  Newtons

Thrust =  117423.8801  Newtons

Fuel Burn in Cruise =  13.2636  N/s

Mach Number =  0.80031  dimensionless

True Airspeed =  236.1704  m/s

Time to Travel One nm in Cruise =  7.8418  seconds

Fuel Burned in one nm in Cruise =  104.0102  Newtons

c) Use the Breguet Range equation, to estimate the maximum range for the aircraft if the aircraft reaches the TOC point (35,000 feet) at 204,000 kilograms. The aircraft cruises at Mach 0.80. The pilot estimates the aircraft carries 65,000 kilograms of fuel remaining at the TOC point. In the range calculation, assume the range is calculated using the aircraft mass at the mid-point between TOC and TOD. Also, assume that 5,500 kilograms of fuel are needed in the descent plus a possible diversion to an alternate airport.



Breguet Range for Boeing 787 Class Aircraft. Mass is 204,000 kilograms at TOC. Mass for Breguet Range Calculation is 174,250 kilograms (mid-point mass) at 35,000 feet.

The plot above shows the aircraft range using the Breguet range equation for various Mach numbers while cruising at 35,000 feet. At Mach 0.8, the range is estimated to be 9,830 kilometers with 65,000 kilograms of fuel remaining at the TOC and 5,500 kilograms needed from TOD to the destination airport plus fuel reserve (59,500 kilograms of effective fuel in cruise from TOC to TOD). The mass used in the Breguet Range equation is 174,250 kilograms (mid-point mass).

d) Solve the problem in part (c) using a piecewise numerical analysis method (as explained class). Use the range value obtained in part (b) and refine the answer obtained by dividing the range into five segments in the numerical solution. Comment on the differences obtained in parts (c) and (d).

| Number of Intervals | Cruise Fuel (lbs) |
|---|---|
| 5 | 61,185 |
| 10 | 60,611 |

| Number of Intervals | Cruise Fuel (lbs) |
|---|---|
| 100 | 60,111 |
| 500 | 60,068 |
| 5000 | 60,058 |

The table above illustrates the fuel used in cruise to fly 9,930 kilometers (5,308 nautical miles). The calculations breakdown the distance into equal segments and the aerodynamic calculations are performed for each segment individually.

The Breguet range equation solution assumed 59,500 kilograms of fuel used to fly the 5,308 nm distance. The best solution in the table above (5,000 segments) shows a total fuel use of 60,058 kilograms. The conclusion is that the Breguet range equation is relatively accurate considering its simplicity.

# Problem 3

Commercial Aviation is an industry that, for many years, has attempted to reduce its CO2 emissions in order to reduce the impact in Climate Change. One idea to decarbonize aviation is to use electric vehicles. Read the paper entitled: "Operation and Performance Optimization of an All-Electric, Narrow-Body Airliner" by Sampson and Drake (https://doi-org.ezproxy.lib.vt.edu/10.2514/6.2024-4185).

A) Explain if the findings of the study support the idea of introducing an all-electric aircraft similar to the Airbus A220-100 in the 2035-2040 timeframe.

B) Explain what are the main drawbacks of an all-electric airliner.

Range is the main drawback of all electric aircraft. The battery energy density still lags behind to produce practical operational ranges needed.

C) Comparing the payload-diagrams of the proposed all-electric aircraft and the Airbus A220-100 shown in the paper, what conclusions do you make about the utility of the all-electric aircraft operating in an airline network. Consider that the highest battery energy density today is around 600 Wh/kg.

Limited range even with the best battery energy density available today.

D) Comment on the mission profiles of the Airbus A220-100 and the all-electric commercial aircraft. Explain the tradeoffs of operating an all-electric aircraft in the mission profiles shown in the paper.

E) Hart Aerospace is attempting to bring a hybrid electric aircraft to regional airliners. Examine their web site (https://heartaerospace.com/es-30/) and contrast their approach compared idea of an all-electric vehicle you read in part (a). Comment on the possible benefits of a hybrid-electric aircraft.

Hybrid electric removes some of the range constraints of all-electric aircraft. Nevertheless, the hybrid engine technology adds weight to the aircraft with the corresponding impacts on drag and eventually range.