Assignment 3: Aircraft Performance Calculations

Solution Instructor: Trani

Problem 1

A low-fidelity Simulink-based aircraft runway simulator has been developed and it was demonstrated in class. The simulator for this analysis has been modified to approximate the runway performance characteristics of a Boeing 737-8 Max (see Figure 1). You can pick up the Boeing 737-8Max runway simulator at the website. Before using the runway simulator download the Aerospace Blockset from the Mathworks website and install it.

a) Study the effect of temperature on the runway length required to reach the takeoff safe speed. Start with sea level conditions and estimate the runway length required. Create a table and repeat the runway length needed (to reach the takeoff safe speed) for temperatures ISA, ISA + 10 degrees, ISA + 20 degrees, and ISA + 30 degrees. For each simulation, you estimate the runway length required by inspecting the distance traveled versus speed plot. The runway length needed is the distance required to reach the takeoff safe speed labeled "Takeoff Speed at Altitude (knots)". For example, if the "Takeoff Speed at Altitude (knots)" is calculated to be 160 knots, the runway length is the distance traveled by the aircraft to reach the 160 knots. In the calculations use 81,000 kgs. as the aircraft takeoff mass.

Altitude (feet)	Temperature (deg. Above ISA)	Takeoff Speed (knots)	Distance to Takeoff Speed (m)
0	0	150.0	1550
0	10	152.3	1600
0	20	155.1	1640
0	30	157.6	1715

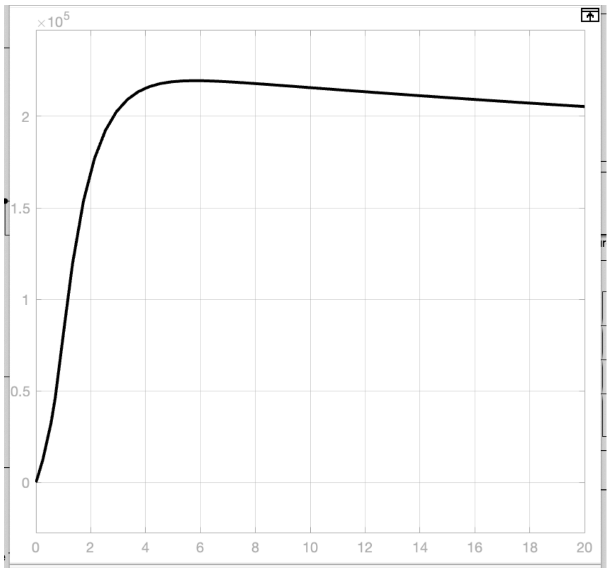
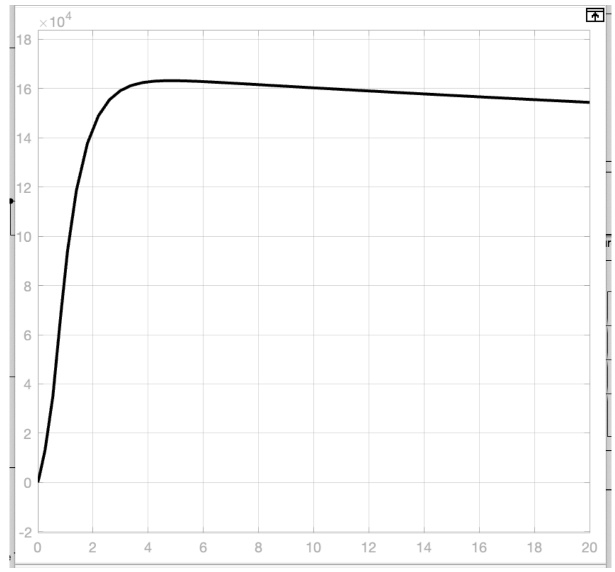
b) Plot the runway length versus temperature above ISA and comment on the effect of temperature above ISA on runway length.

c) Study the effect of airport elevation on the runway length required to reach the takeoff safe speed. Start with sea level conditions and estimate the runway length required for airport altitudes 750, 1500, 2250, and 2,500 meters. In the calculations use 81,000 kgs. as the aircraft takeoff mass.

Altitude (feet)	Temperature (deg. Above ISA)	Takeoff Speed (knots)	Distance to Takeoff Speed (m)
0	0	150.0	1550
750	0	155.5	1850
1500	0	161.4	2260
2250	0	167.6	2840
2500	0	169.7	3065

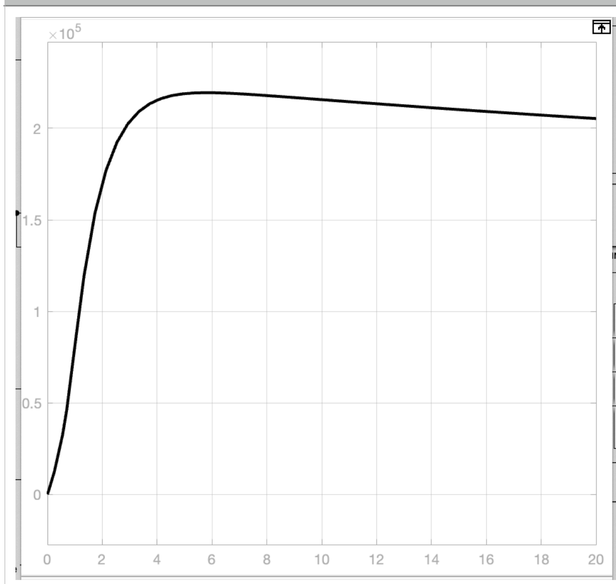
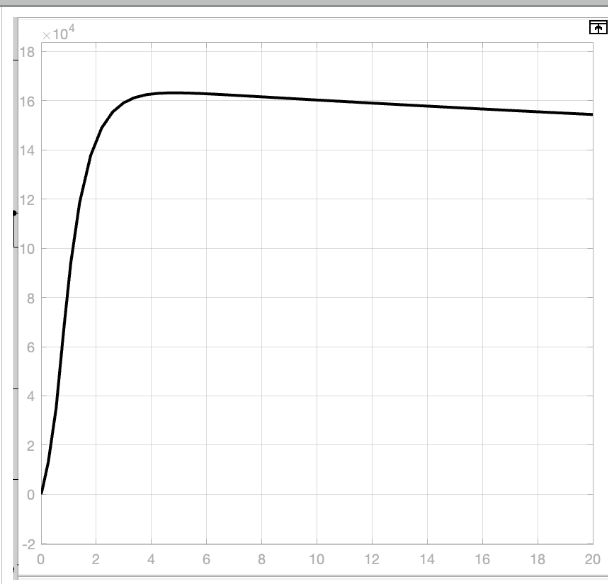
Note a very significant non-linear effect in the takeoff distance. Takeoff distance doubles from sea level to the 2,500 meter elevation airfield.

d) For part (c) comment on the reduction of the maximum (peak) takeoff thrust versus airport elevation. Estimate the percent of thrust loss from sea level to 2,500 meters.

<table>
<tr><th>Sea Level Airfield</th><th>2500 Meter Airfield Elevation</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Peak thrust is 2.2e5 Newtons</td><td>Peak thrust is 1.6e5 Newtons</td></tr>
</table>

The peak thrust reduction is 27%. The density of air decreases 22% from sea level to 2,500 meters in airfield elevation.

e) For part (c) comment on the reduction of the maximum acceleration versus airport elevation. Estimate the percent of the maximum acceleration loss from sea level to 2,500 meters.

<table>
<tr><th>Sea Level Airfield</th><th>2500 Meter Airfield Elevation</th></tr>
<tr><td>
</td><td>
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</table>

f) Study the effect of aircraft mass on the runway length required to reach the takeoff safe speed. Start with a low takeoff mass of 65,000 kgs. Repeat the estimate of runway length using takeoff mass of 70,000 kgs., 75,000 kgs., and 80,000 kgs. Comment on the trends observed.

Mass (kg)	Temperature (deg. Above ISA)	Takeoff Speed (knots)	Distance to Takeoff Speed (m)
65,000	0	150	1200
70,000	0	150	1300
75,000	0	150	1400
80,000	0	150	1500

The simulator fails to adjust the takeoff speed as aircraft mass increases. This is a weakness of the simulator. It will be improved in the next iteration.

Problem 2

An airline is evaluating two aircraft to operate flights from Austin–Bergstrom International Airport (AUS) Airport. The following table shows the aircraft proposed by Boeing. Two origin-destination pairs the airline would like to fly with the selected aircraft are: a) AUS-LHR and b) AUS-ICN. In your analysis use the latest version of the Boeing documents.

The design airport temperature used should be the average of the daily high temperatures of the hottest month of the year. Use the Climate Explorer website (https://crt-climate-explorer.nemac.org/climate_graphs) to find the mean maximum temperature of the hottest month of the year. More detailed information about the airport can be found at the AIRNAV database available on the web at: http://www.airnav.com/airports/ or visit the airport site.

Design temperature is 96.3 deg. F (historical since 1950).

ISA temperature in Austin (541 feet above mean sea level) is 57.7 deg. F.

Difference in temperature is 39.2 deg. F.

Use Boeing ISA + 45 deg. Charts in the calculation of runway performance.

a) Find the average stage length to be flown between each one of the critical OD airport pairs. In your analysis use the Great Circle Flight Path mapper link provided in our interesting web sites.

Unadjusted distances (GCD)

AUS-LHR = 4,274 nm

AUS-ICN = 6,057 nm

Adjusted distances (1.06 * GCD)

AUS-LHR = 4,530 nm

AUS-ICN = 6,420 nm

b) Find the runway length needed for each one of the aircraft operating the critical route. Determine if AUS has enough runway length to support flights with all seats full.

Unadjusted takeoff distances.

Boeing 787-9 requires 10,500 feet (DTW is estimated to be 520,000 lbs.)

Boeing 787-10 requires 13,000 feet (DTW is estimated to be 560,000 lbs.)

At Austin, runway 18R/36L is 12,250 feet long. Runway 18R/36L has a maximum difference in runway elevations between runway end points of 54.10 feet (this is substantial). Such difference requires an additional correction (10 foot for each one-foot in delta elevation). Add 541 feet to the calculations without consideration of runway grade.

Adjusted takeoff distances.

Boeing 787-9 requires 11,041 feet

Boeing 787-10 requires 13,541 feet

Operating the Boeing 787-10 requires a runway extension.

c) Repeat part (b) assuming a load factor of 0.84 (84% of the seats used).

Both aircraft can operate from AUS with takeoff distances less than 12,250 feet. The Boeing 787-10 requires close to 12,050 feet (corrected for grade).

d) If the aircraft carries 84% of the seats full, can the flight carry additional belly cargo as payload?

e) Using the Payload-Range diagram of each aircraft, and using the longest route, find the Specific Air Range (SAR) parameter for each aircraft. Comment on the SAR values calculated.

SAR calculations.

Boeing 787-9 with 100% passengers is 0.037 nm/lbs

Boeing 787-10 with 100% passengers is 0.034 nm/lbs

f) Considering various factors such as payload, fuel economy, and potential of additional belly cargo, which aircraft is the best for this airline? Explain.

The Boeing 787-9 seems a better fit for this operation. The aircraft is able to operate from the existing runway infrastructure without a runway extension.

Problem 3

A new low-cost airline is evaluating The Airbus A220-300 to operate flights from a variety of airports including Washington, Reagan Airport (DCA) and Eagle County Airport (EGE). The airline would like your help to evaluate the A220-300 with the Pratt and Whitney PW1524G or with the lower thrust PW1521G.

The design airport temperature used should be the average of the maximum daily temperatures of the hottest month of the year. Use the Climate Explorer website (https://crt-climate-explorer.nemac.org/climate_graphs) to find the mean maximum temperature of the hottest month of the year. More detailed information about the airport can be found at the AIRNAV database available on the web at: http://www.airnav.com/airports/ or visit the airport site.

In your analysis use the latest version of the Airbus A220-300 documents for airport design (http://128.173.204.63/courses/cee5614/sites_ce_5614.html#Aircraft_Data).

a) Find the maximum range that the airline can fly from both airports at maximum takeoff weight. Evaluate the departure conditions for both engines and the usual airport design temperature conditions.

Airbus provides charts up to ISA+15 C. deg. Design temperature for DCA is ISA + 16.3 deg.C. Use the ISA + 15 deg. C chart. The design temperature conditions for Eagle County require ISA + 27 deg. C charts. The chart is not available so we use the ISA+27 deg. C to complete the problem. All our calculations for EGE will be optimistic.

A220-300 with PW1521G requires around 11,000 feet from EGE (at the ISA + 15 deg. C) conditions. The high thrust version (PW1524G) requires 8,000 feet from EGE.

b) Estimate the average fuel per passenger on a 2,000 nm (includes detour factor)for the aircraft.

Fuel/passenger ~ 159 lbs/passenger

c) Find the SAR for the same 2,000 nm trip.

SAR is 0.091 nm/lb for the A220-300.

d) Considering various airport operating conditions which aircraft engine would you recommend?

The A220-300 with the high thrust engine (24,000 lbs.) is the way to go. The aircraft offer better performance that the standard engine (21,000 lbs).

Problem 4

Use the data for the transport aircraft similar to the Boeing 737-800 (http://128.173.204.63/courses/cee5614/cee5614_pub/Boeing737800Jet_class.m) to answer the following questions.

a) Calculate total drag produced by the aircraft during a climb profile with an Indicated Airspeed of 240 knots at 1,200 meters above mean sea level conditions. Assume atmospheric conditions to be ISA. The aircraft weight is 72,000 kgs.

Drag = 39,850 Newtons

b) Repeat the process when the aircraft is climbing at 10,300 meters and an indicated Mach number of 0.76.

Drag = 48,500 Newtons

c) Estimate the instantaneous fuel consumption for each flight condition given in parts (a) and (b).

Fuel burn = 3.4 kg/s at 1,200 meters (240 knots IAS)

Fuel burn = 0.9 kg/s at 10,300 meters (at Mach 0.76)

d) Comment on the observed trends.