Assignment 3: Runway Length Calculations for Large Aircraft

Solution Instructor: Trani

Problem 1

a) Estimate the desired takeoff weight for an Embraer 145LR (see Figure 1) carrying 47 passengers and operating from an airport located at elevation of 2,500 feet. The airline operator would like to fly 1,200 nm which includes the route detour factor. The 145LR is powered by the Rolls-Royce/ Allison AE3007-A1 engine. Use the average passenger weight suggested in class in your calculations. In your analysis, use the Embraer E-145 document APM-145/1100 REVISION 16 - 29 NOVEMBER 2024.

Embraer 145 landing at CLT Runway 18R.



Figure 1. Embraer 145LR landing at CLT Runway 18R. Source: A. A. Trani.

Use the Embraer document to estimate the takeoff weight. Refer to the Payload-Range diagram for the E145LR (see below).

Payload is 47 passengers (4,700 kilograms at 100 kilograms per passenger). The operational weights of the E145LR can be found in Table 2.1.1.1 of the Embraer manual.

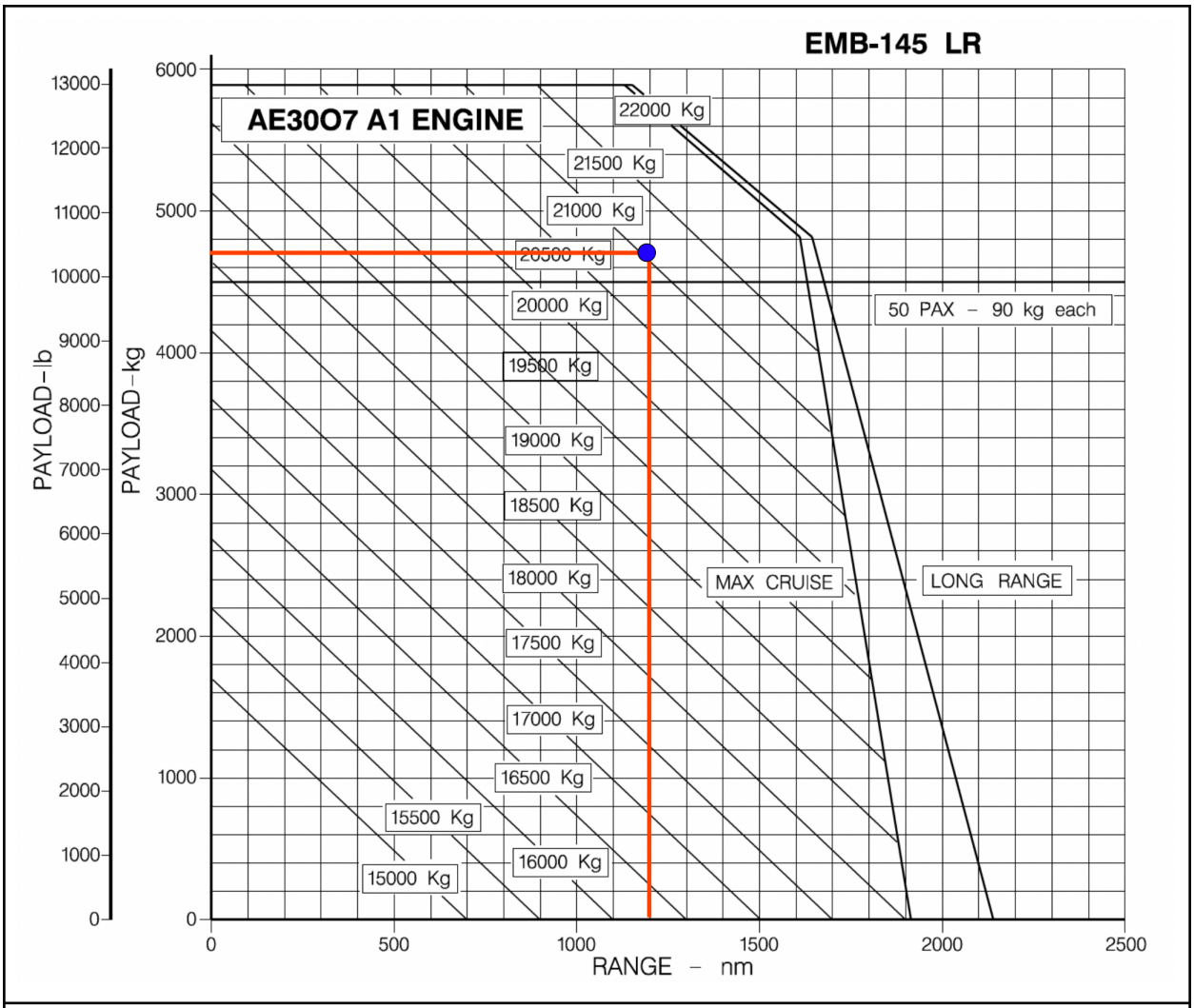
Max. takeoff weight = 22,000 kilograms

Max. allowable landing weight = 19,300 kilograms

Operating empty weight = 12,144 kilograms

Max. design zero fuel weight = 17,900 kilograms

The desired takeoff weight (DTW) is 21,500 kilograms. *This is around 500 kilograms below the maximum takeoff weight for the E145-LR.*

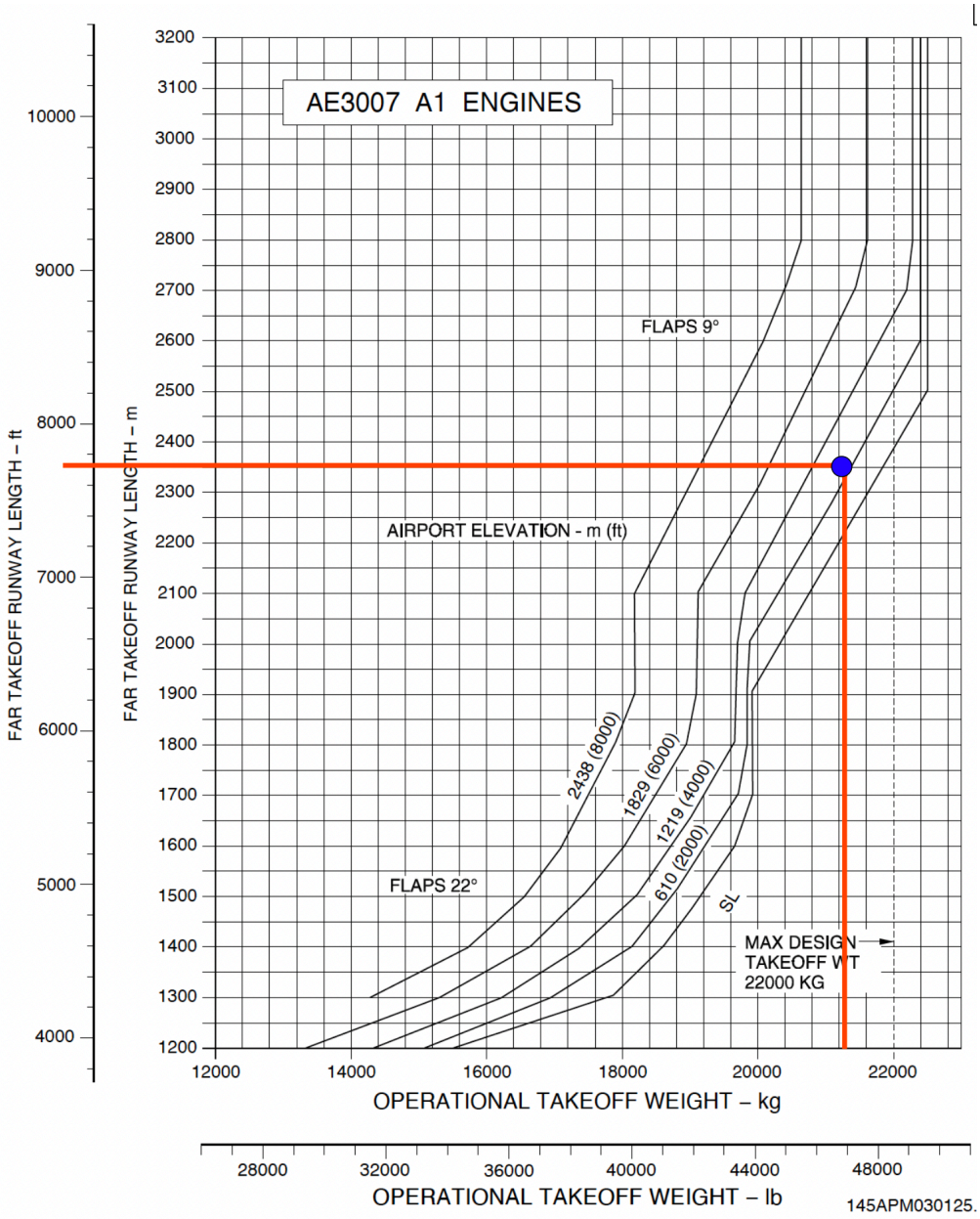


Embraer 145LR Payload Range Diagram. Source: Embraer.

b) Find the Takeoff Field Length for the Embraer 145LR described in (a) if the aircraft departs the airport with a design temperature is 25 deg. Centigrade. State the figure(s) used in your calculations.

ISA conditions at 2,500 feet produce a temperature of 10.05 deg. C. The design temperature is 25 degrees C. Hence we need to estimate the runway length using ISA + 15 deg.C. performance charts.

The FAR takeoff runway length is 2,350 meters (7,710 feet).



Embraer 145LR Takeoff Runway Performance for ISA + 15 deg. C. The Engine is Rolls-Royce/ Allison AE3007-A1. Source: Embraer.

c) For the takeoff conditions above, state the takeoff flap setting used.

*The graphic above shows **flaps 9 deg. for takeoff** and 21,500 kilograms weight.*

d) For the same Embraer 145LR, find the landing field length landing at the maximum landing weight. State the landing flap setting used. State the figure(s) used in your calculations.

The E145LR has a maximum landing weight of 19,300 kilograms (see Table 2.1.1.1 in the Embraer Airport Planning Document). The landing distance is estimated to be 1,500 meters on a dry runway. Since no wet runway performance is given, adjust the landing distance by adding 15%.

Landing distance (wet pavement) is 1,725 meters.

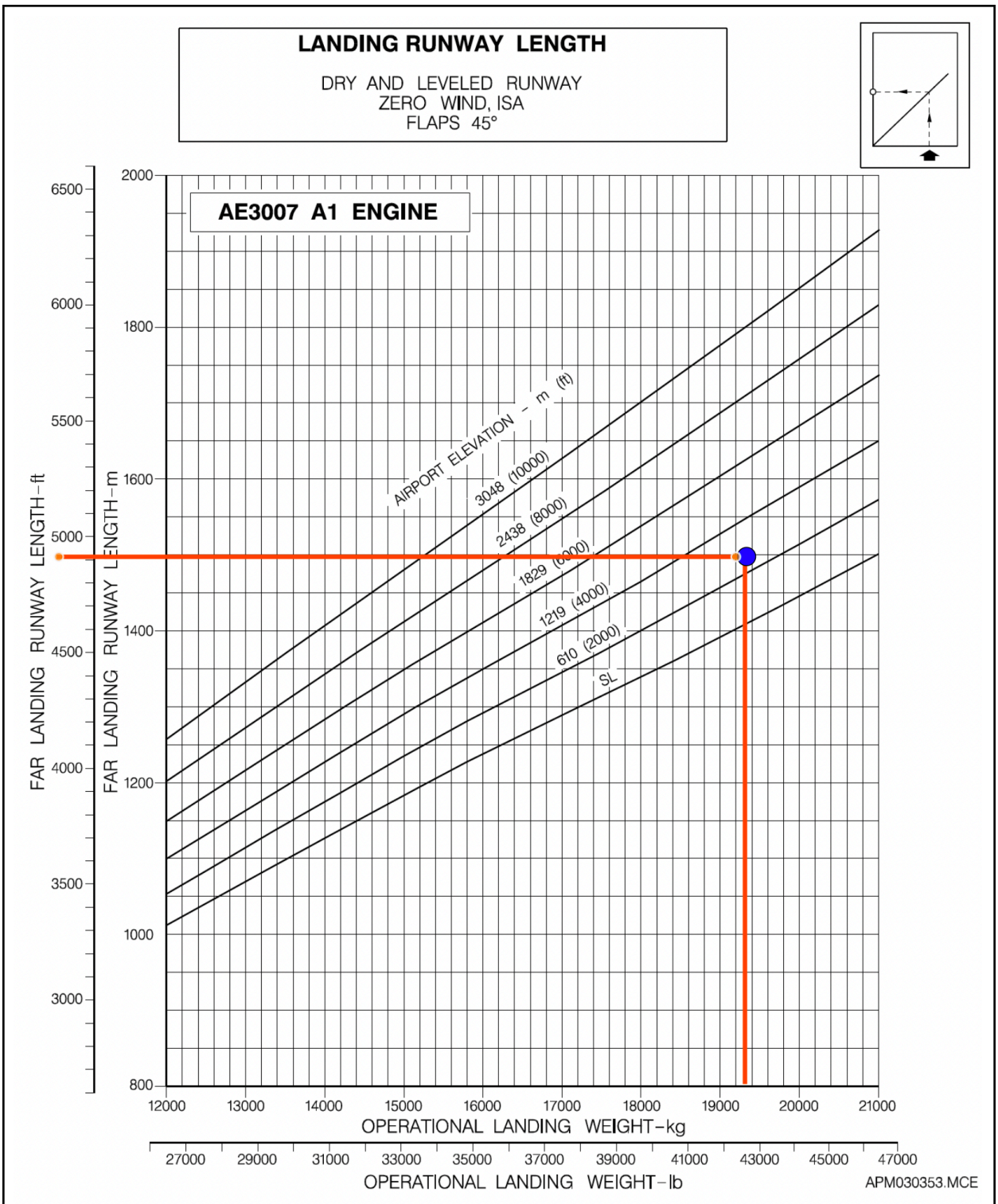


Figure 3.4.1 - FAR Landing Runway Length Requirements - Flaps 45º

Embraer 145LR Dry Runway Landing Performance. The Engine is Rolls-Royce/Allison AE3007-A1. Source: Embraer.

e) For the 1,200 nm trip described above, estimate the fuel carried in the flight.

Operating empty weight (OEW) = 12,144 kilograms

Payload (PYL) = 4,700 kilograms

The desired takeoff weight (DTW) is 21,500 kilograms.

Fuel weight = DTW - (OEW+PYL) = 4,656 kilograms.

Problem 2

Estimate the runway length required to operate an Airbus A330-900 (see Figure 2) from a new international airport. The client requires the Airbus A330-900 to operate at **maximum takeoff weight of 251,000 kgs (model WV900 in Airbus document)**. The **design temperature at the airport is ISA +15 degrees Celsius**. The **airport elevation is 1,000 feet above mean sea level**. The characteristics of the Airbus 330-900 can be found in the Airbus Documents for Airport Design (https://aircraft.airbus.com/en/customer-care/fleet-wide-care/airport-operations-and-aircraft-characteristics/aircraft-characteristics). The latest document for the Airbus A330-900 is Revision No. 34 - Dec 01/25.

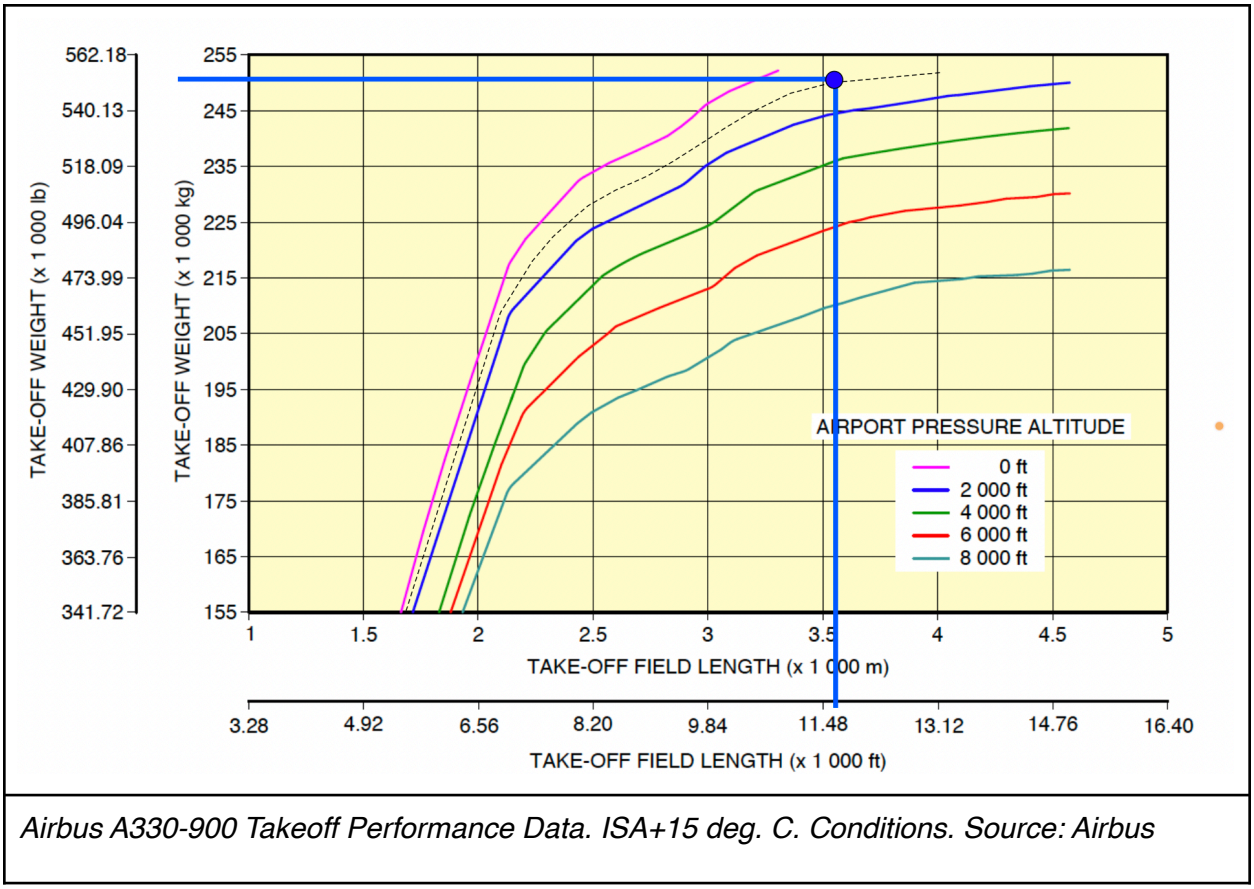
Airbus A330-900 with Trent 7000 engines. The aircraft maximum takeoff weight is 251,000 kgs. The seating configuration is **280 seats**.



Figure 2. Airbus 330-900 at Atlanta Hartsfield-Jackson Airport. Source: A. A. Trani.

b) Find the runway length needed to operate the Airbus A330-900 at maximum takeoff weight from the new airport under I**SA +15 degrees Celsius conditions**.

Refer to Figure 3-3-2 in the Airbus document. The estimated takeoff field length is 3,600 meters (see graphic below).



Airbus A330-900 Takeoff Performance Data. ISA+15 deg. C. Conditions. Source: Airbus

c) State the design temperature for part (a) in degrees Celsius.

The design temperature is 28.0 deg. C. The ISA temperature at 1,000 feet is 13.0 deg. C.

d) Find the runway length needed to operate the Airbus A330-900 at maximum takeoff weight from the new airport under I**SA temperature conditions**.

If the temperature is ISA conditions, the estimated field length is 3,400 meters.

e) Compare the two solutions above. Briefly explain the changes in runway length as the design temperature changes.

The takeoff performance is affected by temperature. Higher temperature reduce air density and hence reduce mas flow rate going through the engine which reduces the engine thrust. A lower density increases takeoff speeds requiring more runway length. A reduction in temperature of 15 deg.C. reduces the takeoff field length by 5.6% (200 meters).

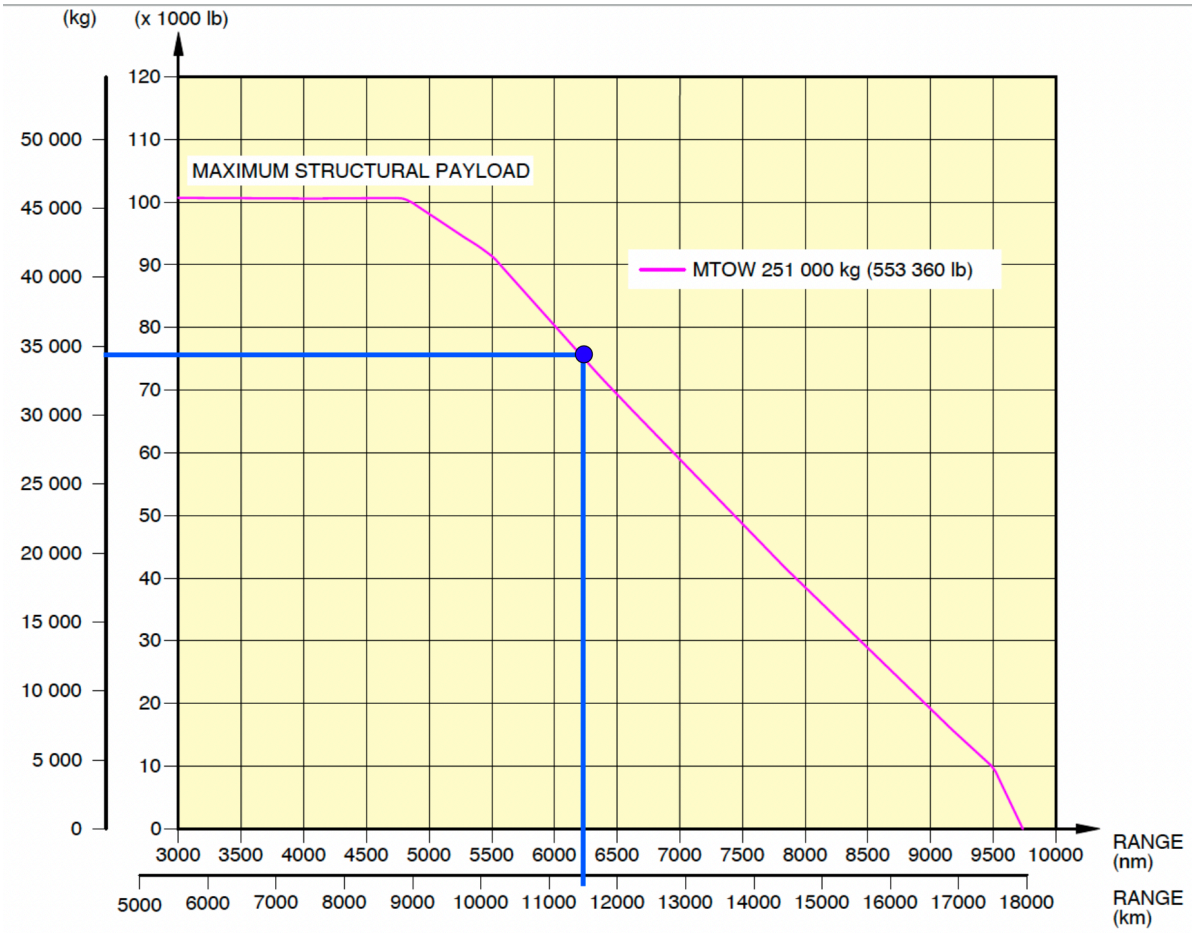
f) If an airline operates the Airbus A330-900 at maximum takeoff weight in ISA temperature conditions, find the longest route that can be flown with all seats full and additional 15,000 lbs. of belly cargo.

Passenger load = 280 seats x 100 kg/seat = 28,000 kilograms

Extra cargo = 15,000 lbs = 6,818 kilograms

Payload = 28,000 + 6,818 kilograms = 34,818 kilograms

The range is estimated at 6,250 nautical miles (see the graphic below).



Airbus A330-900 Payload-Range Diagram. ISA Conditions. Source: Airbus

Problem 3

The airport authority of Denver International Airport (DEN) wants to build a third parallel runway to the north of runway 26. The objective of this analysis is to determine the length of the new runway allowing Boeing 787-10 (see picture below) operations from Denver using the design temperature. Use the latest Boeing 787-10 data provided by Boeing (see document in Figure 3).

The design temperature at the site can be found using the Climate Explorer web site. For this analysis use the historical temperature. If you need to find the International Standard Atmospheric (ISA) values, you can use the table in the notes (you need to interpolate) or use a web site like Digital Dutch to facilitate the analysis (https://www.digitaldutch.com/atmoscalc/).

Boeing 787-10 with **Rolls-Royce Typical Engines** engines. The aircraft maximum design takeoff weight is 574,000 lbs. The airline uses an aircraft with 330 seats in a two-class layout. Assume the Operating Empty Weight is 300,000 lbs. (the lowest value in the y-axis of the the payload range diagram).



787 Airplane Characteristics for Airport Planning

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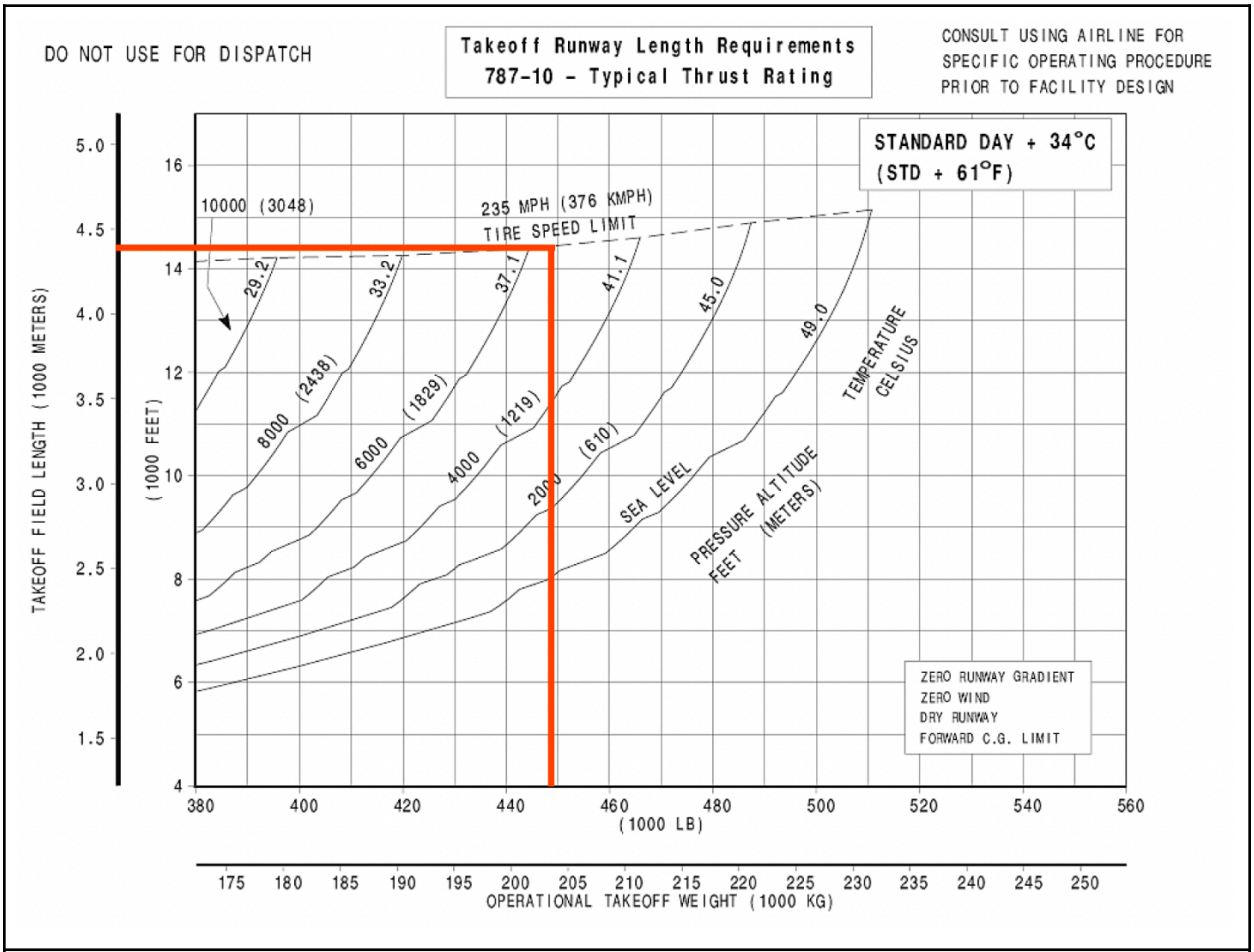
Figure 3. Boeing 787-10 in tow at ORD Airport. Source: A. A. Trani.

a) Find the maximum takeoff weight for the Boeing 787-10 at Denver airport using the design temperature. Clearly indicate the figure used in the Boeing document. Also indicate the practical constraint that limits the Boeing 787-10 takeoff weight while operating at Denver.

The historical mean maximum daily temperature of the hottest month (July) is 88.1 degrees Fahrenheit.

Denver is located at 5433.8 feet above mean sea level conditions (see Arnav web site). The ISA temperature in Denver is 39.6 deg. Fahrenheit. The difference in temperature is 48.5 degrees Fahrenheit. Use ISA + 61 deg. F.

*The estimated **maximum takeoff weight from Denver is 448,000 lbs.** (see graphic below). The constraint that limits Boeing 787-10 operations at Denver is the tire speed limit.*



Boeing 787-10 Performance Chart. ISA + 61 deg. F. (Figure 3.3.20 in Boeing Document). Source: Boeing.

b) Using the design constrain in part (a), find the recommended runway length needed to operate the Boeing 787-10.

Recommended takeoff field length (runway length) is ~14,300 feet.

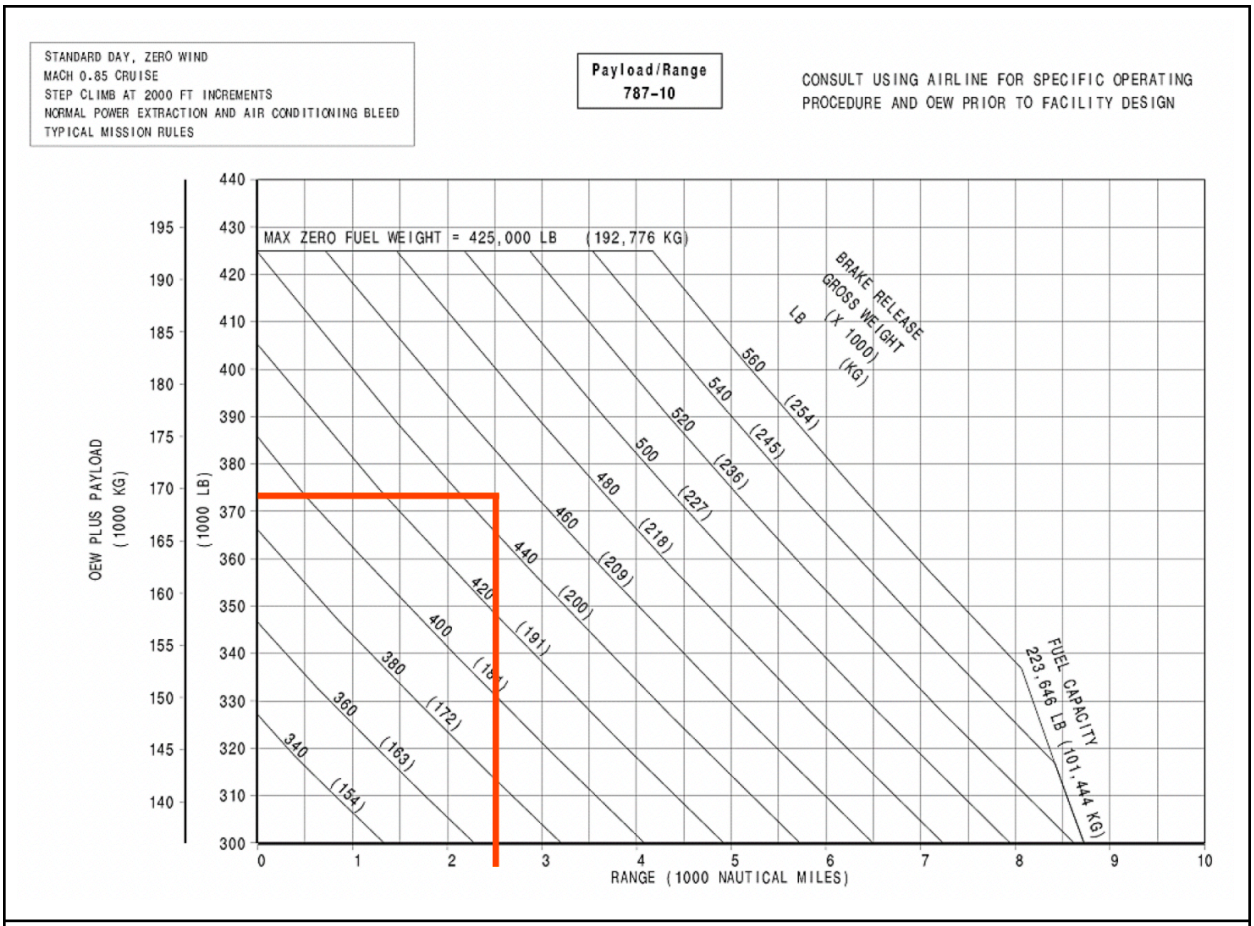
c) Using the maximum takeoff weight found in part (a), find the longest route distance (in nautical miles) that can be flown with all seats full.

Seats = 330 equivalent to 33,000 kilograms of passenger load.

OEW = 136,363 kilograms or 300,000 lbs. (using the lowest value in the Payload-Range diagram).

PYL + OEW = 169,363 kilograms (372,600 lbs).

***Departing Denver with a desired takeoff weight of 448,000 lbs, the Boeing 787-10 can fly 2,500 nautical miles (see graphic below).** The range is impacted by the high airfield elevation at Denver.*



Boeing 787-10 Payload-Range Diagram. Source: Boeing.

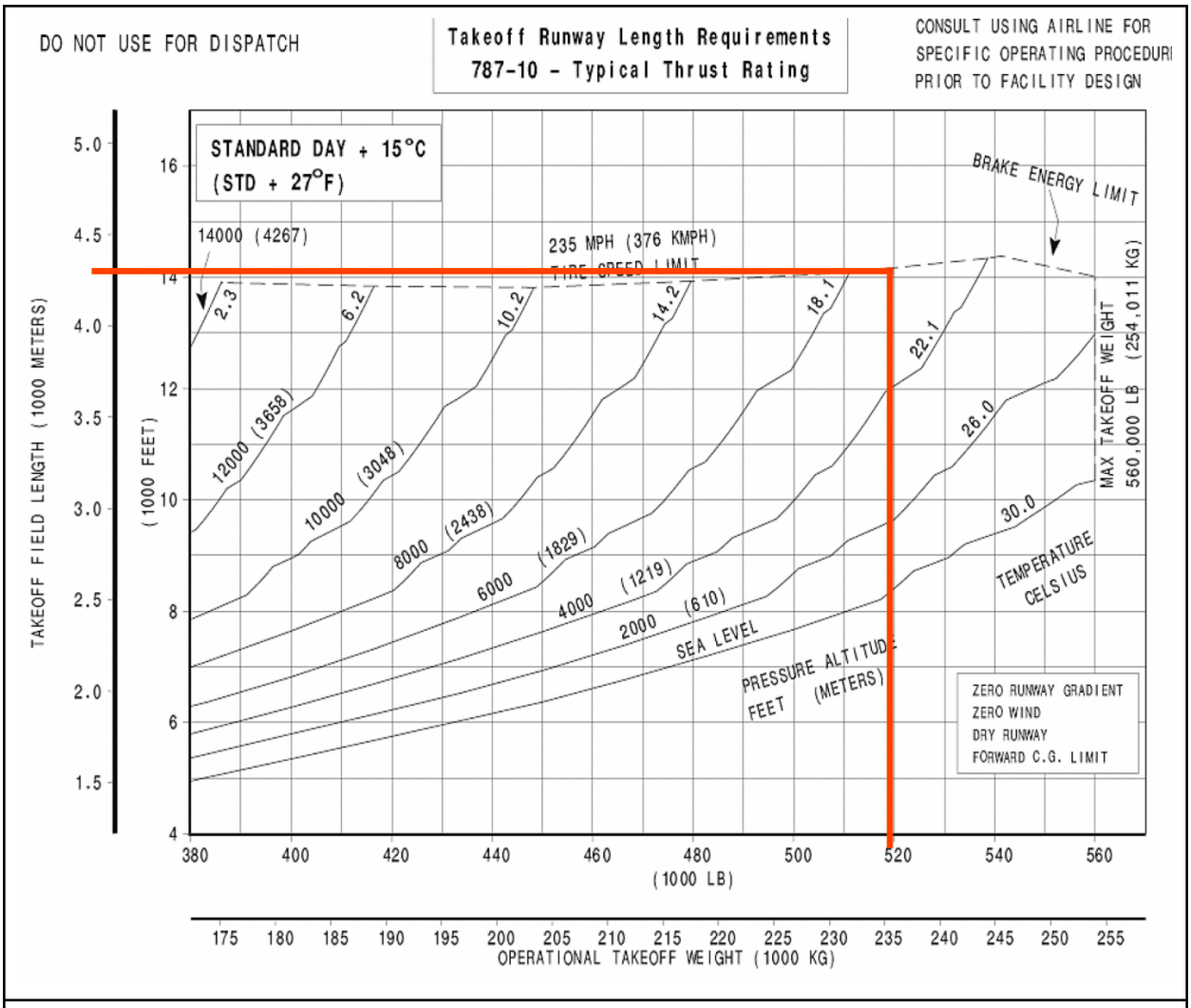
d) If the same aircraft operates from Denver at the average annual maximum temperature (year 2025), find the longest route that can be flown with all seats full. Comment on the differences observed between parts (c) and (d).

Use the annual average maximum daily temperature (64.5 degrees F.) found in the Climate Explorer.

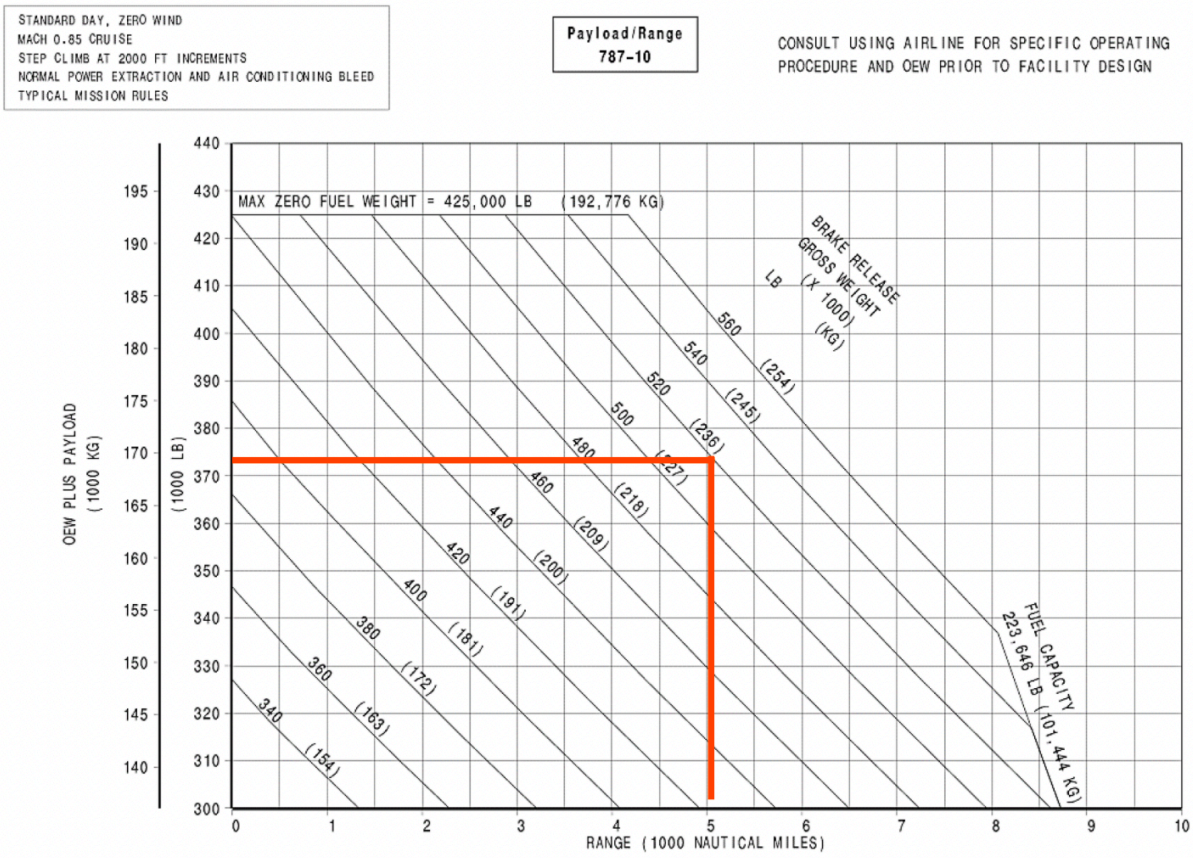
The ISA temperature in Denver is 39.6 deg. Fahrenheit. The difference in temperature is 24.9 degrees Fahrenheit. Use ISA + 27 deg. F. performance charts (closest to the the design temperature).

*The estimated **maximum takeoff weight from Denver is 520,000 lbs.** (see graphic below). The new takeoff weight is substantially higher than the design temperature case. The runway required to operate under the new conditions is 14,100 feet limited by tire-speed limit.*

***The maximum range doubles to 5,000 nautical miles (see graphic below).** The analysis shows the sensitivity of range with respect to operating temperature.*



Boeing 787-10 Performance Chart. ISA + 27 Deg.F. (Figure 3.3.20 in Boeing Document). Source: Boeing.



Boeing 787-10 Payload-Range Diagram Departing at 520,000 lbs. Source: Boeing.