CEE 5614: Analysis of Air Transportation Systems **Spring 2024**

Quiz 1 : Open Notes and Take Home

Date Due: March 13, 2023 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 (60 Points)

Use the new generation Transonic Truss-Braced Wing (TTBW) aircraft provided in class (http://128.173.204.63/courses/cee5614/cee5614_pub/SUGAR_class.m) to answer the following questions.

The goal is to model a transcontinental flight from DCA to LAX. The aircraft has the following parameters: OEW of 40,000 kg., carries 13,000 kg. of fuel, and 13,000 kg of payload (130 passengers and bags). The flight dispatch plans the following route to avoid some weather over Omaha, Nebraska.

DCA HORTO4 BUFFR Q178 LIVER WHETT ROKKK KD78A TRUMA NEOLA LAKRR Q73 HAKMN LAX

A) Use sky vector.com to study the flight plan and estimate the route distance for the flight.

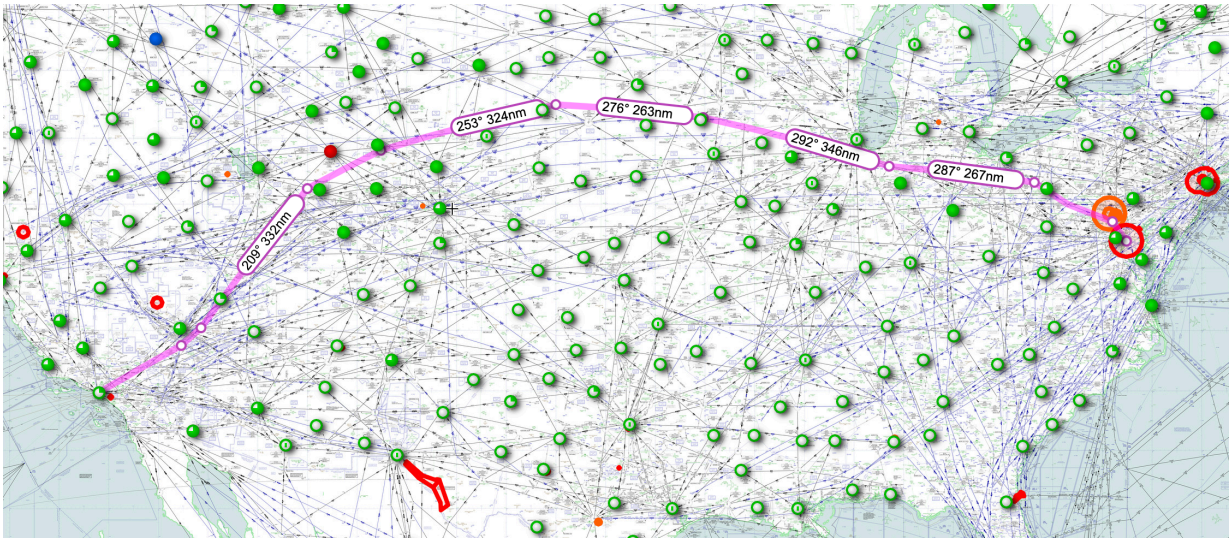

Figure 1. Sky Vector Route. The Route is 2134 Nautical Miles Long.

B) 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 150 m/minute climb rate. Use ISA atmospheric conditions in your calculations. In your recommended cruise flight levels consider that Air Traffic Control requires that Westbound flights use even flight levels (FL 320, 340, 360,380, etc.). State the initial cruise altitude that satisfies the climb and ATC constraints.

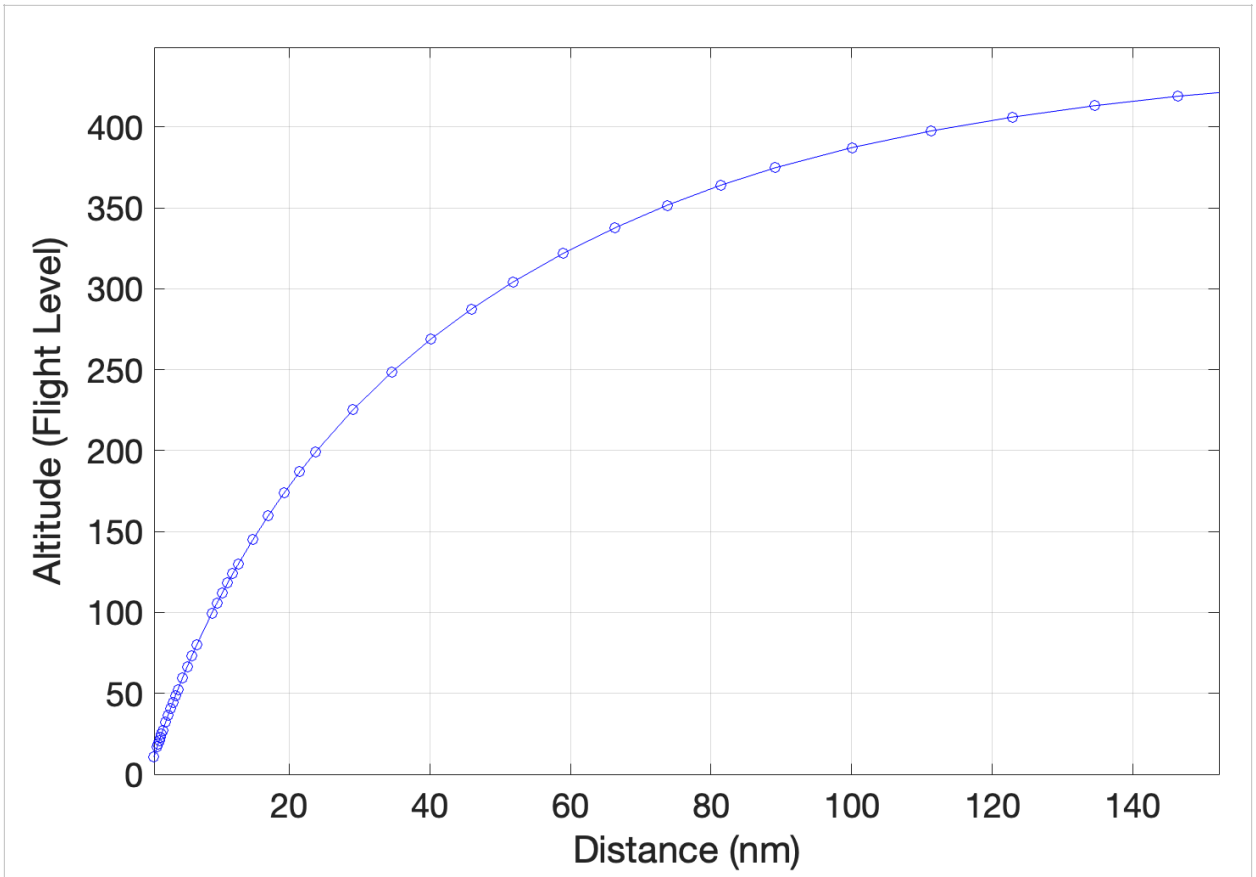

Figure 2. The TTBW Takes 21.7 minutes to Climb to FL400. At FL 400, the Rate of Climb is

TOC Flight Level (dim) 400
Fuel Used in Climb (kg) 1197.5
Climb Time (min) 21.7
Climb Distance (nm) 114.9

C) For your selected altitude in part (a), estimate the mass of the aircraft at the Top of Climb (TOC) point.

Flight level 400. The mass of the aircraft at TOC is 64,802 kilograms

D) Use the unrestricted descent profile program to estimate the distance required to descent from the proposed cruise altitude (part B) to the destination airport (LAX). Estimate the distance and fuel used. For the calculation, assume that 75% of the fuel is used in the climb and cruise profiles.

Assume a mass of 56,250 kilograms at TOD (75% of the fuel has been used).

Fuel Used in Descent (kg) 455.9

Descent Time (min) 50.8

Descent Distance (nm) 222.7

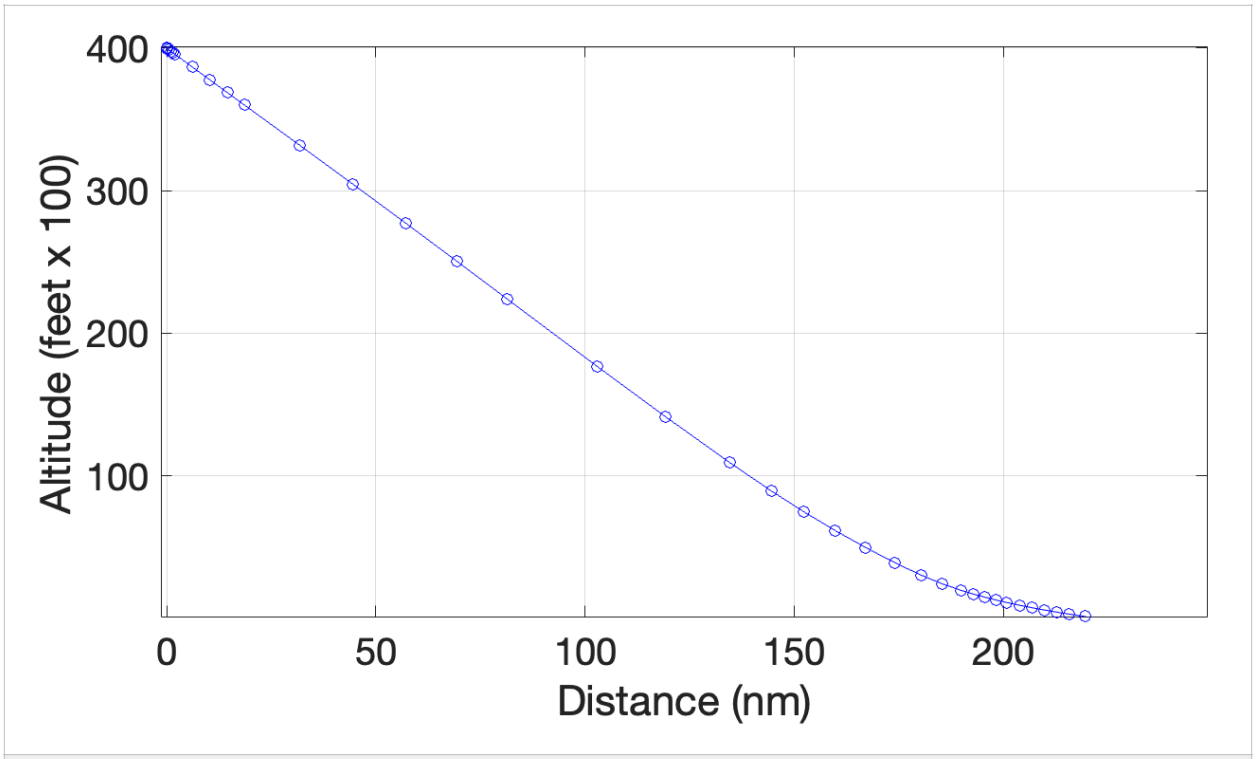

Figure 3. The TTBW Takes 50.8 Minutes in the Descent Profile and Uses 455.9 Kilograms.

E) Using the numerical technique explained in class, estimate the fuel used and the average fuel burn (kg/min) of the TTBW aircraft in cruise (TOC to TOD) knowing the estimated climb and descend distances calculated in parts (B-D). Assume the aircraft cruises a constant flight level. The airline dispatch office suggest a cruise speed of Mach 0.76 for this trip.

The mass of the aircraft at TOC is 64,802 kilograms.

Initial guess for mass at TOD is 56,250 kilograms.

The cruise distance is 1796.4 nm

The following results are obtained running a numerical simulation with 100 steps.

Cruise Distance (nm) 1796.4

Cruise Fuel (kg) 5872.9169

Cruise Time (minutes) 247.235

Initial Mass (kg) 64802

Final Mass (kg) 58929.0831

Average Fuel Burn (kg/min) 23.7544

Average SAR (nm/kg) 0.30588

Average Drag (N) 29875.7

Average Thrust (N) 32586.3

Refine the mass at TOD. Assume a mass of 58,929 kilograms. Then the following results are obtained for the descent profile.

Fuel Used in Descent (kg) 448.6

Descent Time (min) 50.6

Descent Distance (nm) 223.6

The total fuel used in the trip is:

$F_{trip} = 448.6 + 5873 + 1198 = 7{,}520$ kilograms

F) Will the TTBW aircraft be able to do a step climb in the transcontinental flight? Remember that a climb from the cruise altitude selected in part (a) requires a 2,000 ft climb because westbound flights require a separation of two flight levels. For example, a flight initially assigned FL340 will be required to climb to FL360 if the direction of flight is the same.

Find the Rate of Climb for various weights.

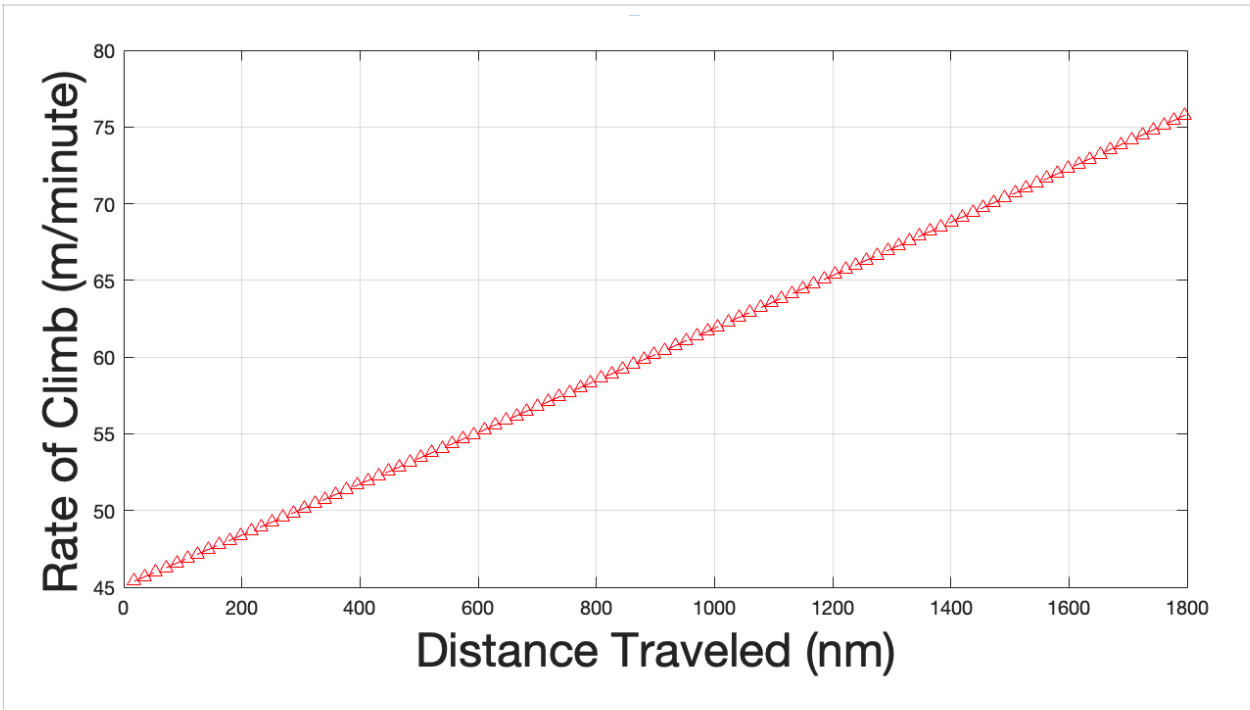

Figure 4. Rate of Climb Capability of the TTBW Aircraft Flying at Mach 0.76 and Cruising at FL400. The Aircraft Cannot Climb to FL 420 in the Flight.

G) Calculate the fuel cost of the flight using the weekly IATA fuel monitor (http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx). Use the North America jet-a fuel price. And assume the Jet-A fuel density of 0.8 kg/liter.

The fuel cost is $2.65 per gallon of fuel. One kilogram of Jet-A fuel is 0.3284 gallons. 7520 kilograms is equivalent to 2,470 gallons or $6,544.

H) Compare the fuel cost of the TTBW in cruise with a Boeing 737-8Max that burns an average of 35 kg/min in cruise at FL360.

TTWB burns 23.75 kilograms/minute. The Boeing 737-800 burns 35 kilograms/min. The reduction is substantial (32%).

l) If the average wind in cruise is 50 knots headwind, explain who would you change the cruise analysis to estimate the fuel used to fly from DCA to LAX. Neglect the wind effects in climb and descent.

Travel time increases with a 50-knot headwind. Fuel burn increases. For example, the estimates fuel burn for the cruise segment with no wind is 23.75 kg/minute. The cruise segment without wind is 247.2 minutes flying at 435 knots (Mach 0.76 at FL400). A 50-knot wind produces a ground speed of 385 knots hence increasing the cruise time from 4.12 to 4.67 hours. The aircraft will cruise for an additional 32 minutes with **the 50-knot headwind burning an additional 764 kilograms.**

Problem 2 (40 Points)

A South American airline (GOL Airlines) would like to operate Boeing 737-8Max between Brasilia (BSB) and Miami International Airport (MIA). The Boeing 737-8Max (see Figure 1) operated by the airline has 186 seats in a three-class seating configuration. The airline uses the CFM Leap 1B28B1 engine and the Maximum Takeoff Weight is rated at 182,200 lbs.

a) Find the runway length needed at both airports to satisfy FAA/EASA runway length requirements. Use the airport design temperatures at both locations. You can find worldwide weather and temperature data at: https://weatherspark.com/.

Brasilia has an average high temperature of the hottest month of the year at 84 degrees Fahrenheit.

BSB airport elevation is 3,498 feet

Longest runway is 10,827 feet

ISA temperature at BSB = 46.52 degrees F.

Design condition using historical data is ISA + 37.5 deg. F. Use ISA + 45 deg. F. *available.

The typical distance flown is 3,315 nm (adding 6%).

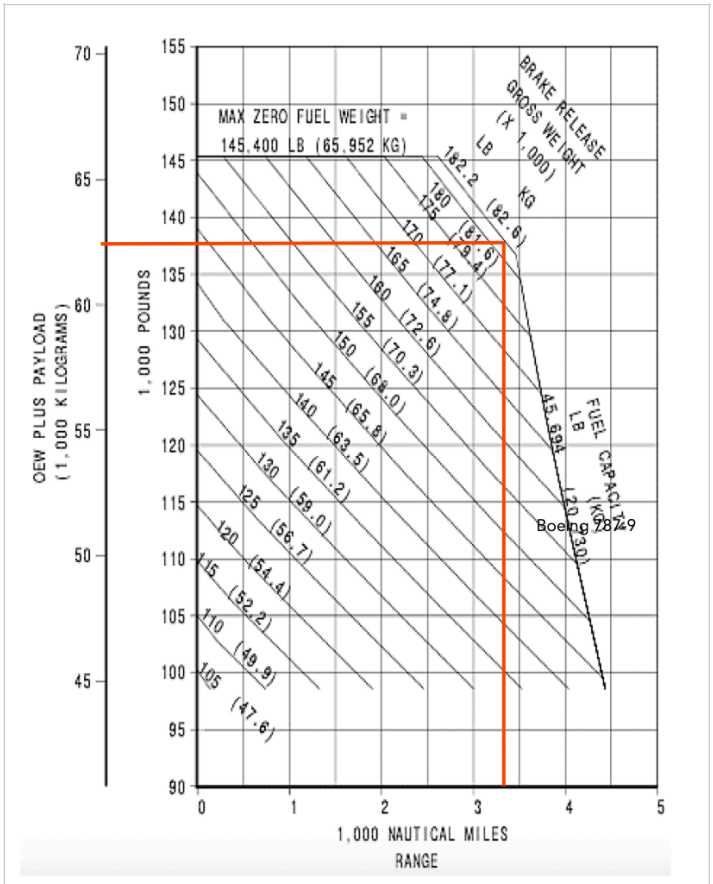

Figure. Boeing 737-8Max Payload-Range Diagram. The Aircraft Can Operate at 138,000 lbs. (OEW+PYL).

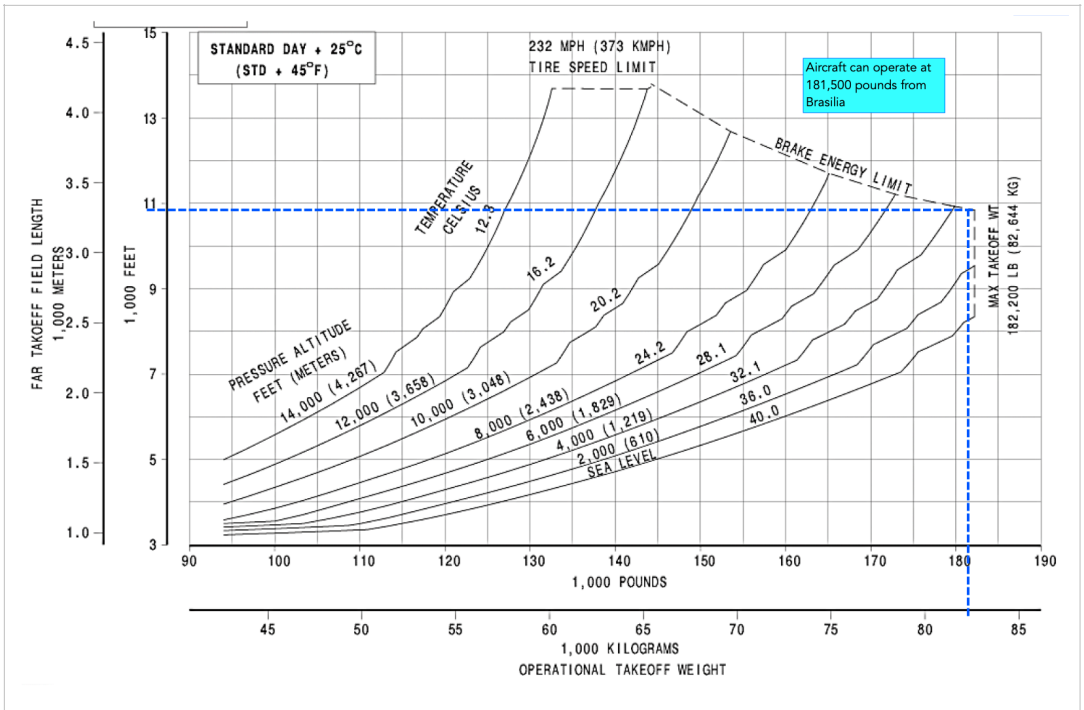

Figure. Boeing 737-8Max Takeoff Performance (ISA + 45 deg.F.) with Leap Engine (28,000 lbs). The Aircraft is Limited to 181,000 lbs. Using Brasilia's Runway Length and Design Temperature Condition.

b) Estimate the amount of fuel used for the flight between BSB and MIA.

Table 1. Boeing 737-8Max Analysis with 175 Passengers. Aircraft is Limited to 175 Passengers due to Runway Length and Mission Distance Constraints.		
Parameter	Kilograms	Pounds
OEW	45,000	99,000
PYL	17,500	38,500
OEW + PYL	62,500	137,500
DTW	82,273	181,000
FW	19,773	43,500
Passengers	175	

Table 1. Boeing 737-8Max Analysis with 175 Passengers. Aircraft is Limited to 175 Passengers due to Runway Length and Mission Distance Constraints.		
Parameter	Kilograms	Pounds
Fuel/passenger	113	249
Runway Length (takeoff)	**Can operate at 181000 pounds from BSB.**	**Can operate at 181000 pounds from BSB.**
Runway Length (Landing)	<10,830 feet available	<10,830 feet available
Route Distance	3315	
Average SAR (nm/kg)	0.1677	

c) Do you consider the Boeing 737-8Max a good fit to fly the route? Comment on any payload or runway length limitations using the aircraft in such long route.

The aircraft operates at the limits of its performance. Carrying 175 passengers out of 186 seats is an acceptable tradeoff.

d) The same airline would like to operate from Santos Dumont Airport (SDU) in Rio de Janeiro in Brazil (https://en.wikipedia.org/wiki/Santos_Dumont_Airport) to nearby Sao Paulo (Brazil). Estimate the operational payload limitations flying out of SDU with the Boeing 737-8Max. Can the airline carry a good passenger load in the busy route to Sao Paulo? Show me your analysis.

Rio de Janeiro (SDU) has an average high temperature of the hottest month of the year at 88 degrees Fahrenheit.

SDU airport elevation is located at 10 feet in elevation.

Longest runway is 4,341 feet (very short for most commercial flights)

ISA temperature at SDU = 59 degrees F.

Design condition using historical data is ISA + 29 deg. F. Use ISA + 27 deg. F..

The typical distance flown is 210 nm (adding 6%).

Analysis:

The Boeing 737-8Max can takeoff from SDU with only 141 passengers (of 186 seats) limited by runway length constraints. The aircraft DTW is 140,000 lbs. The value of OEW + PYL is 131,000 lbs. Fuel weight is 9,000 lbs.

The Boeing 737-8Max can land at SDU at a landing weight of 107,000 lbs. This is below the 131,000 lbs the aircraft weight if all the fuel is used in the Sao Paulo to Rio flight.

Conclusion:

The aircraft is not a good fit for the route.

Note: Most of the short flights operated from SDU to GRU (Sao Paulo), employ the Airbus A319 aircraft. The A319 has better short field performance compared to the Boeing 737-8Max and even the regular Boeing 737-800.

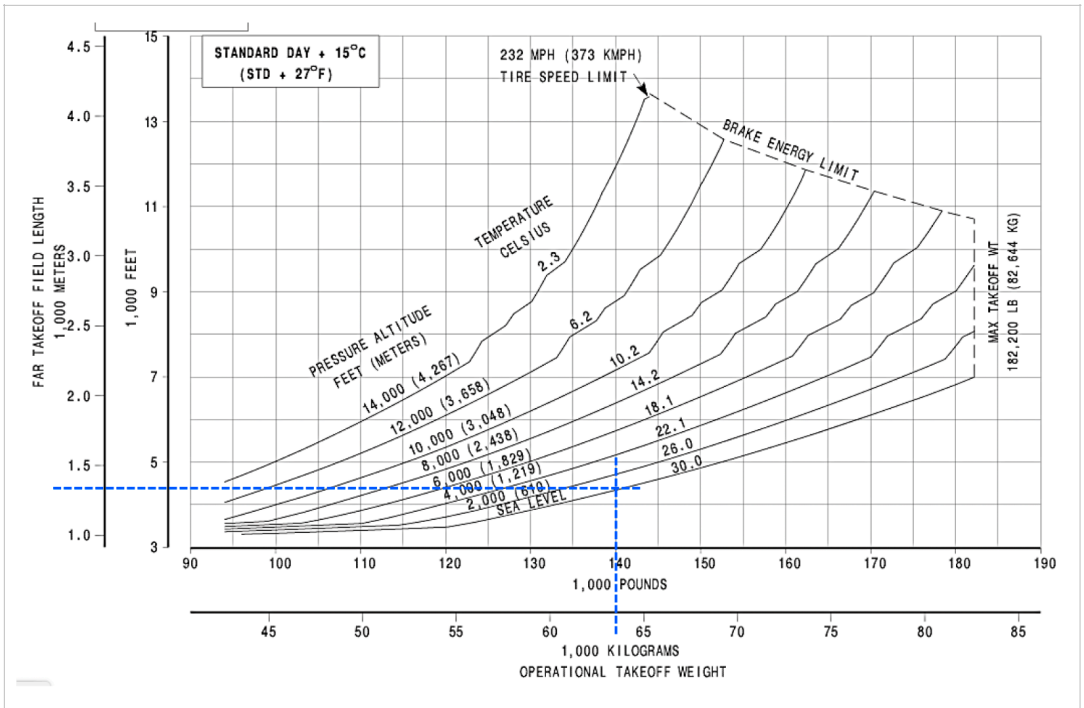

Figure. Boeing 737-8Max Takeoff Performance (ISA + 27 deg. F.) with Leap Engine (28,000 lbs). The Aircraft is Limited to 140,000 lbs. Using SDU's Runway Length and Design Temperature Condition.

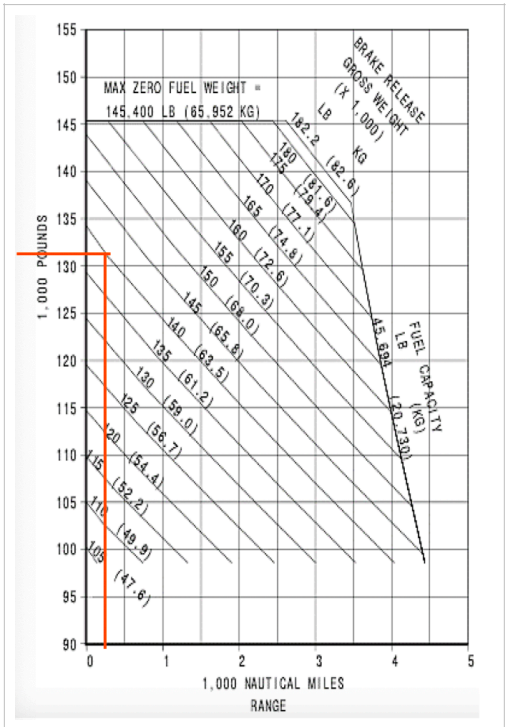

Figure. Boeing 737-8Max Payload-Range Diagram. Route SDU-GRU.

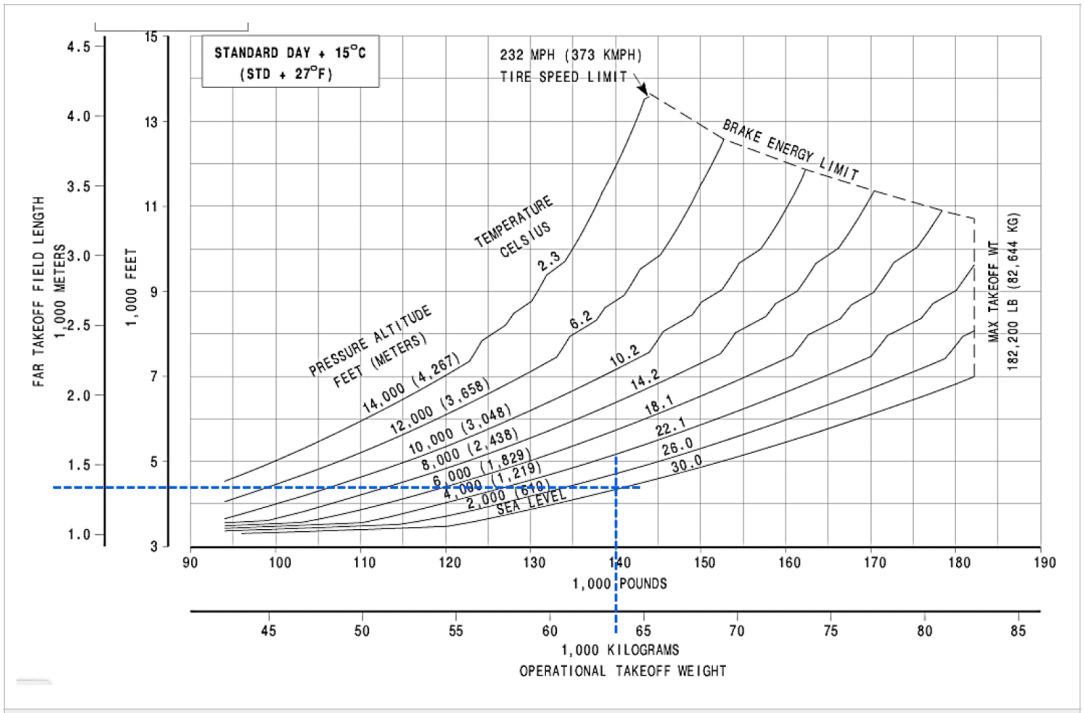

Figure. Boeing 737-8Max Landing Performance with Leap Engine (28,000 lbs). The Aircraft is Limited to 107,000 lbs. Using SDU's Runway Length and Design Temperature Condition.

Table 2. Boeing 737-8Max Analysis Operating from Santos Dumont Airport.		
Parameter	Kilograms	Pounds
OEW	45,000	99,000
PYL	14,100	31,020
OEW + PYL	59,100	130,020
DTW	63,636	140,000
FW	4,536	9,980
Passengers	141	
Fuel/passenger	32	71
Runway Length (takeoff)	**Can operate at 140,000 pounds from SDU.**	**Can operate at 140,000 pounds from SDU.**

Table 2. Boeing 737-8Max Analysis Operating from Santos Dumont Airport.		
Parameter	Kilograms	Pounds
Runway Length (Landing)	4340 feet at 107,000 lbs. landing weight	4340 feet at 107,000 lbs. landing weight.
Route Distance	210	
Average SAR (nm/kg)	0.0463	

Figure. Boeing 737-8Max (not a GOL Airlines Aircraft).