Quiz 1 (Open Book/Notes)

Solution

Instructor: Trani

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.

____

Signature Space

Show all your work. Create a PDF file and send to me by email.

Problem #1 (50 points)

Providence International Airport (PVD) is studying a runway extension program to attract a new cargo operator to the airport. Review Airnav and the satellite images at Google Earth to answer the following questions. The objective is to estimate the runway extension needed for the longest runway at PVD if the following aircraft are considered by the cargo operator (see Table 1).

More detailed information about the airport can be found at the Airnav database available on the web at: http://www.airnav.com/airports/. In your analysis use the latest version of the Boeing and Airbus documents for airport design (http://128.173.204.63/courses/cee5614/sites_ce_5614.html#Aircraft_Data).

Table 1. Proposed Services from PVD to Other Airports.

Origin-Destination Airport Pair	Aircraft Expected to Fly the Route
PVD-TLV	Boeing 747-8F with General Electric GEnx-2B67. Aircraft maximum design takeoff weight is 975,000 lb.
PVD-DOH	Boeing 747-8F with General Electric GEnx-2B67. Aircraft maximum design takeoff weight is 975,000 lb.

a) Find the runway length needed for each one of the routes. Determine which one of the trips constitutes the critical stage length and state the new runway length extension needed (if any).

PVD is located at 55 feet above sea level (practically at sea level conditions). Runway 5/23 is 7166 feet long. Runway 16/34 is 6081 feet long. Both runways are 150 feet wide. The mean high temperature of the hottest month of the year is 83 deg. F. (28.3 deg. C.). This is illustrated in Figure 1.

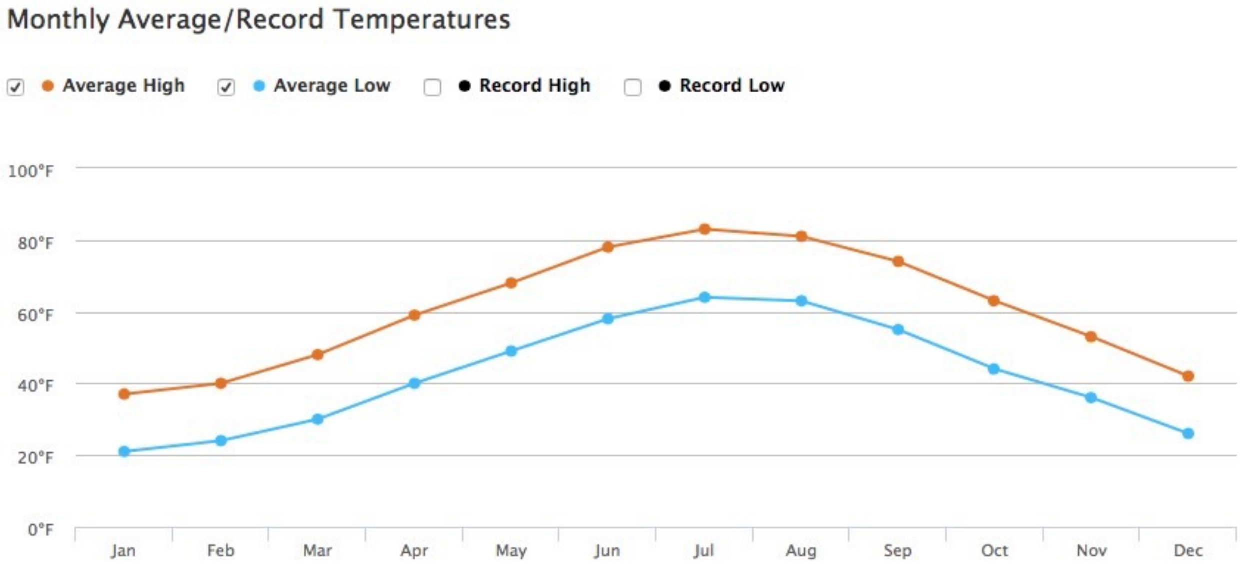


Figure 1. Temperature Profile for PVD Airport (source: weather.com).

CHARACTERISTICS	**UNITS**	**747-8F**
MAX DESIGN	POUNDS	978,000
TAXI WEIGHT	KILOGRAMS	443,613
MAX DESIGN	POUNDS	975,000
TAKEOFF WEIGHT	KILOGRAMS	442,253
MAX DESIGN	POUNDS	761,000
LANDING WEIGHT	KILOGRAMS	345,184
MAX DESIGN	POUNDS	725,000
ZERO FUEL WEIGHT	KILOGRAMS	328,854
OPERATING	POUNDS	434,600
EMPTY WEIGHT (1)	KILOGRAMS	197,131
MAX STRUCTURAL	POUNDS	290,400
PAYLOAD (1)	KILOGRAMS	131,723
TYPICAL CARGO – MAIN DECK	CUBIC FEET	24,462
CONTAINERS	CUBIC METERS	693
MAX CARGO - LOWER DECK	CUBIC FEET	5,850
CONTAINERS (LD-1)	CUBIC METERS	166
MAX CARGO - LOWER DECK	CUBIC FEET	520
BULK CARGO	CUBIC METERS	14.7
USABLE FUEL CAPACITY	U.S. GALLONS	59,734 (2)
	LITERS	226,118
	POUNDS	400,218
	KILOGRAMS	181,536

Figure 2. Characteristics of Boeing 747-8F Aircraft (source: boeing.com).

Table 2 shows the critical route distances. Using values published in Figure 2. OEW = 197,131 kilograms. Maximum Structural Payload is 131,723 kilograms. For maximum flexibility assume the aircraft carries the maximum structural payload. Hence:

OEW + PAY = 197131 + 131723 = 328854 kilograms.

Note that this value is the Maximum Zero Fuel Weight of published by Boeing in Figure 2. For maximum flexibility, we would expect the operator to use Maximum Takeoff Weight as shown in Figure 3. The figure illustrates that under MTOW and to cover the Doha segment, the aircraft OEW + PAY has to be be 300 metric tons. This implies that 28.854 metric tons of cargo estimated above cannot be carried. The maximum payload for the Doha route is then estimated to be 98.8 metric tons.

DTW = MTOW = 442.2 metric tons. Fuel weight is estimated to be 146.2 metric tons. Check that maximum fuel is not above the maximum capacity for the aircraft (181.5 metric tons).

Table 2. Distances from PVD Airport to Critical Destinations.

Origin-Destination Airport Pair	Great Circle Distance (nm)	Route Distance (nm)
PVD-TLV	4809	5049
PVD-DOH	5703	5988

The critical stage length is Providence-Doha.

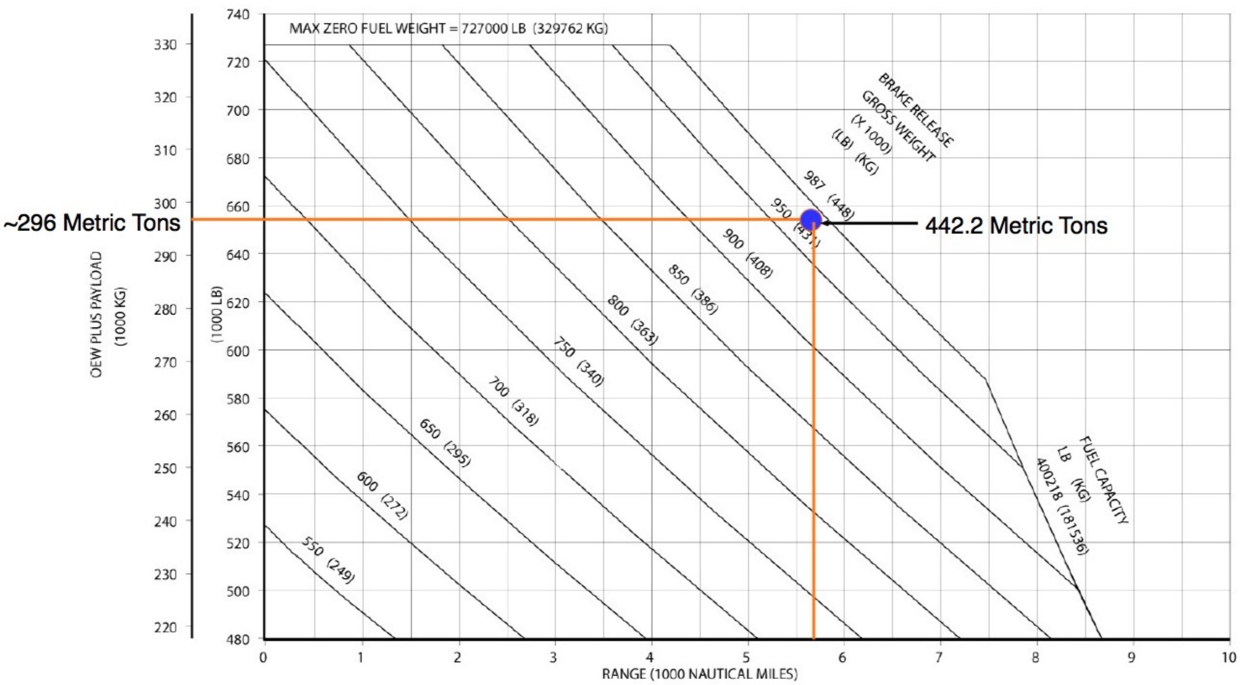


Figure 3. Payload-Range Diagram of 747-8F Aircraft (source: boeing.com).

The runway length requirement operating from PVD at ISA + 15 deg. C is shown in Figure 4. Note that 30 deg. Celsius is close to the design temperature of 28.3 deg. C. At sea level conditions the aircraft requires 10,600 feet with zero gradient. Runway 5/23 has a0.1% gradient. Correcting for gradient this yields:

Rc = 10600 * (7.17 * 10) = 10,672 ~ **10,700 feet for design**

The correction is adding 10 feet for each 1 foot in maximum elevation difference in centerline elevations. A 0.1% gradient difference for a 7166 for runway is 7.17 feet.

The runway extension required at PVD is estimated to be 3,534 feet.

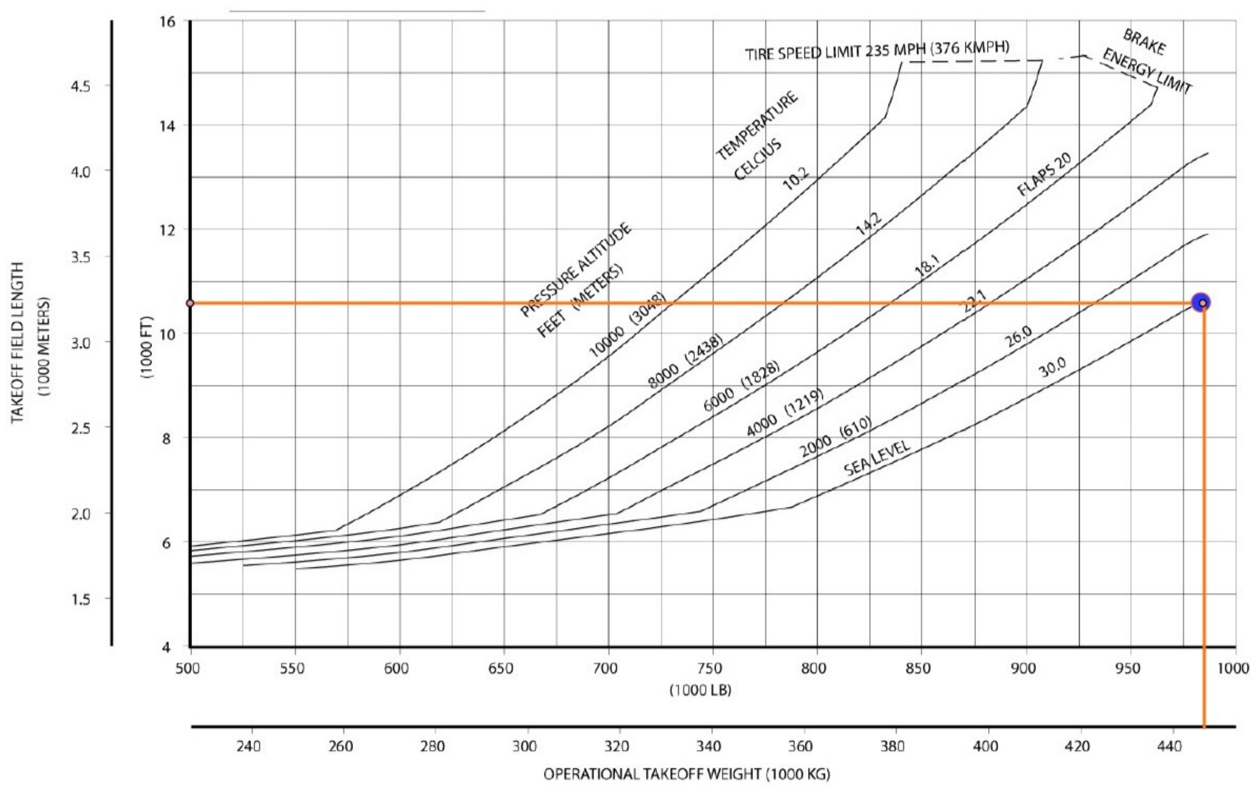


Figure 4. Runway Length Requirements for 747-8F Aircraft (source: boeing.com). Performance at ISA + 15 deg. C.

b) Find the maximum payload to be carried in each route with the extension you suggested in part (a).Comment on your solution.

Maximum payload was estimated to be 98.8 metric tons.

c) What is the ferry range for the Boeing 787-8F?

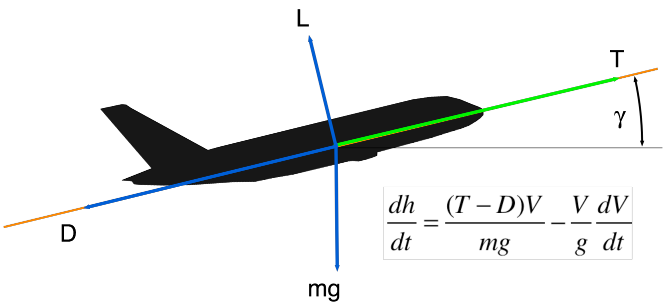
The ferry range is 8,600 nm directly from the payload-range diagram.

Problem # 2 (50 points)

The differential equation of motion that explains the behavior of a climbing aircraft is given as:

$$V\sin\gamma = \frac{dh}{dt} = \frac{V[T-D]}{mg} - \frac{V}{g}\frac{dV}{dt}$$

The terminology has been explained in the class notes.



$$\frac{dh}{dt} = \frac{(T-D)V}{mg} - \frac{V}{g}\frac{dV}{dt}$$

In class so far we ignored the second term (the so-called acceleration term) in the equation.

a) Develop a procedure using a flowchart or steps (as needed) to account for the second term in the analysis. In other words, how would you solve the problem if the second term is no longer ignored.

The suggested method includes a variation of the calculations done in class.

Step 1: Estimate true airspeed using atmospheric model

Step 2: Estimate the lift coefficient needed to sustain flight using the basic lift equation

Step 3: Estimate drag coefficient

Step 4: Estimate total drag (D)

Step 5: Estimate the thrust produced by the engines at altitude (T)

Step 6: Find the rate of climb (dh/dt) without the acceleration term

Step 7: Estimate the rate of change of speed as a function of time using the solution obtained in Step 6. Save the values of dV/dt obtained in this step for calculations in Step 7.

Step 8: Solve the rate of climb (dh/dt) problem using the new values of dV/dt obtained in Step 7.

Step 9: Compare two solutions

b) Use the regional jet aircraft performance file provided in the Matlab files for CEE 5614 (http://128.173.204.63/courses/cee5614/cee5614_pub/regionalJet_class.m) to demonstrate (**with actual calculations**) the procedure developed in part (a). Assume:

i) The regional jet climbs at 220 knots (indicated) at 4,000 feet above sea level (state 1).

ii) Suppose the aircraft accelerates to a new state (called state 2), and reaches 240 knots (indicated) at 8,000 feet.

c) Compare the answer obtained in part (b) with the baseline conditions where the acceleration term is ignored. Comment on the two answers obtained.

A numerical simulation of the two profiles is shown in Figure 5. The blue profile is the uncorrected climb profile without the dV/dt term added. The red profile is the corrected climb profile with the terms dV/dt added. Note that for the aircraft climbing from 4000 feet to 8000 feet takes an extra 10 seconds to reach the new altitude after the rate of climb equation has been corrected.

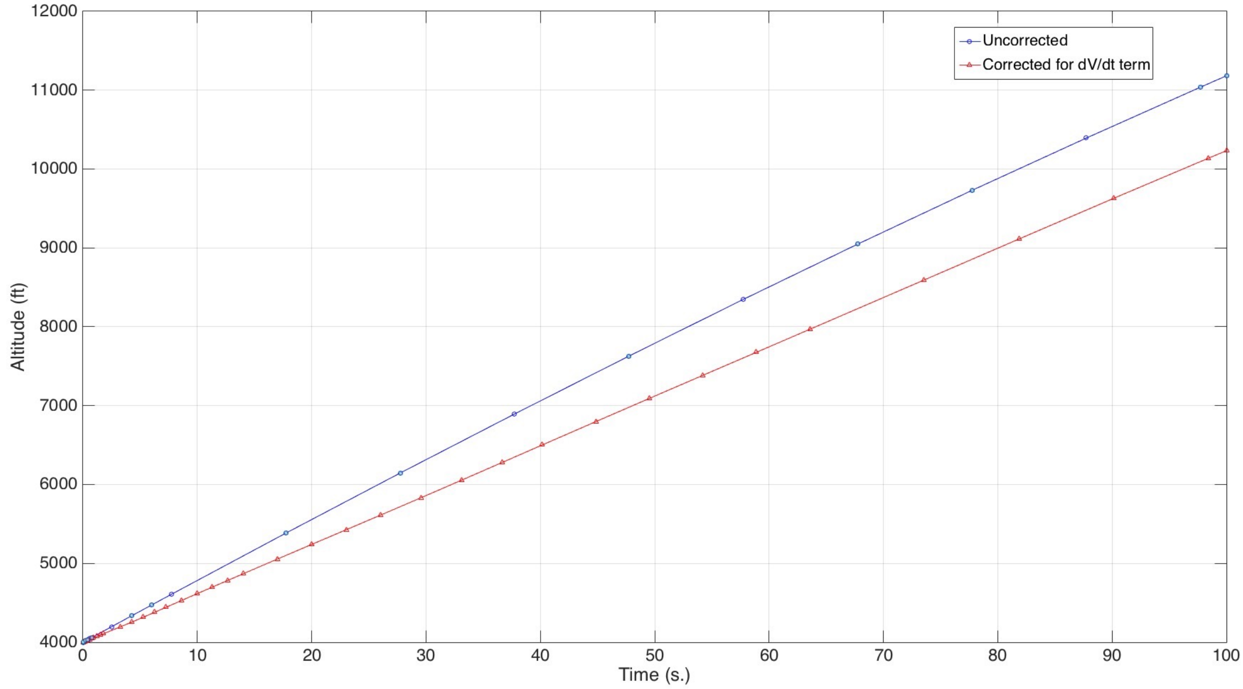


Figure 5. Numerical Solution for Regional Jet Climb Performance. ISA Conditions.

Table 3. Parameters for Climb Profile at 4,000 feet. Regional Jet with Mass of 24,000 kg.

Parameter	Uncorrected Profile	Corrected Profile
Altitude	4000.0000	4000.0000
IAS (knots)	220.0000	220.0000
True Mach	0.3524	0.3524
Speed of Sound (m/s)	335.5400	335.5400
TAS (m/s)	118.2443	118.2443
Mass (kg)	24000.0000	24000.0000
Cl (dim)	0.5298	0.5300
Cd (dim)	0.0304	0.0304
Drag (N)	13495.0000	13495.0000
Thrust (N)	61536.0000	61536.0000
dV/dt (m/s-s)	0.0000	0.1089
Rate of Climb (m/s)	24.1300	22.8100

Table 4. Parameters for Climb Profile at 8,000 feet. Regional Jet with Mass of 24,000 kg.

Parameter	Uncorrected Profile	Corrected Profile
Altitude	8000.0000	8000.0000
IAS (knots)	240.0000	240.0000
True Mach	0.3739	0.3739
Speed of Sound (m/s)	330.7900	330.7900
TAS (m/s)	123.7000	123.6824
Mass (kg)	24000.0000	24000.0000
Cl (dim)	0.5472	0.5472
Cd (dim)	0.0312	0.0312
Drag (N)	13421.0000	13421.0000
Thrust (N)	53160.0000	53160.0000
dV/dt (m/s-s)	0.0000	0.1089
Rate of Climb (m/s)	20.8800	19.5000

At a rate of climb of 24.13 m/s estimated in Table 3, it takes the aircraft 50.5 seconds to reach the new altitude. If the new speed is 240 knots IAS (123.7 m/s) then an initial estimate of dV/dt is:

$dV/dt = (123.7 - 118.2) / 50.5 = 0.1089\ m/s^2$.

The estimated ROC with the acceleration term added is 19.5 m/s versus 20.88 m/s. The difference is 1.37 m/s or 6.6%. If the same value of dV/dt is used in Table 3, the difference in ROC is 5.5%.