Assignment 6: ETOPS Operations and ATC

Solution Instructor: Trani

Problem 1

A new generation large twin engine aircraft with performance similar to the Boeing Dreamliner (http://128.173.204.63/courses/cee5614/cee5614_pub/boeing787_class.m) flies the route San Francisco (KSFO) to Auckland (NZAA) - see Figure 1. The route requires ETOPS certification because most of the flight crosses the Pacific Ocean. Assume the aircraft is flying at Mach 0.82 and 36,000 feet with a mass of 193,000 kg (with 53 metric tons of fuel remaining) when one of the engines is shut down in flight due to low pressure oil indication. At the time of the engine failure, the aircraft is located 1,200 nm from Honolulu, Hawaii and 1,090 nm from Cassidy International Airport (PLCH) in Kiribati (Christmas Island). Assume ISA conditions. The wind vector in the detour to Christmas Island is estimated to be -19 knots (headwind). The wind vector in the detour to Hawaii is estimated to be -36 knots (headwind).

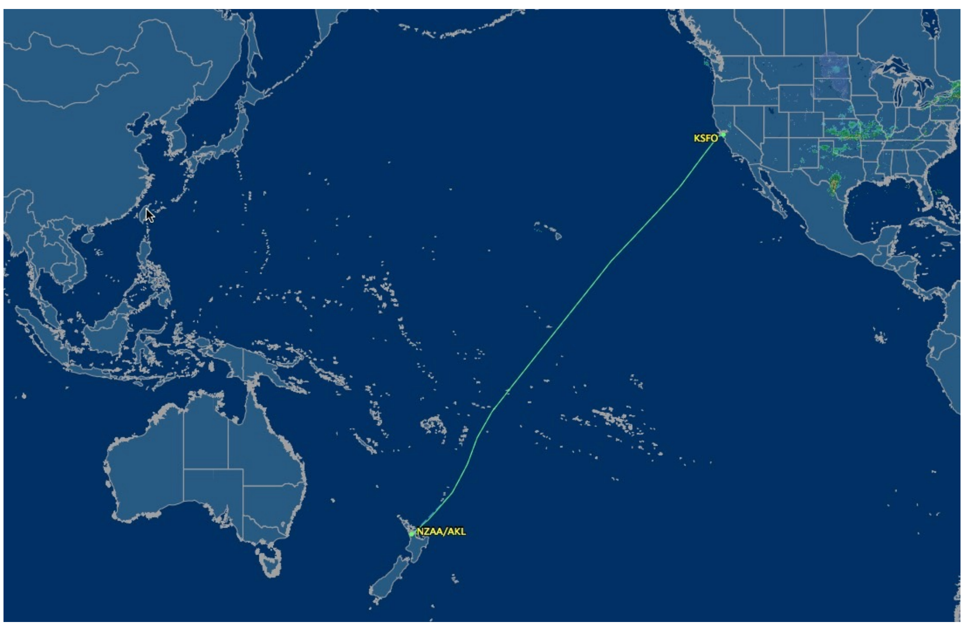

Figure 1. Route San Francisco (SFO) to Auckland (NZAA). Source Map: Flightaware.

a) Estimate the best Mach number and cruise altitude to continue to any one of the two alternate airports. Justify your selection.

Step # 1: By trial and error we study the drag and thrust characteristics of the aircraft flying with a single engine at various altitudes. Figures 2-5 show the results of the analysis using ISA conditions. Note that as the altitude is reduced, the flight envelope "opens" as expected because more thrust is available at lower altitudes.

Doing a quick check using Christmas Island as the destination, we estimate a true airspeed of 382 knots (196.5 m/s TAS) is needed to arrive within the 180 minutes ETOPS restriction. This calculation includes the 19 knot headwind to Christmas Island. At 24,000 feet (for example), the speed of sound is 311 m/s thus the required Mach number to be within the 180 minute ETOPS restriction is 0.63. Note that at 24,000 feet, the aircraft is able to maintain Mach 0.63 to the destination with one engine with some margin for maneuvering. Since the calculation ignored the decent profile from 24,000 feet in the estimation of the Mach number I will use Mach 0.65 in the rest of the analysis.

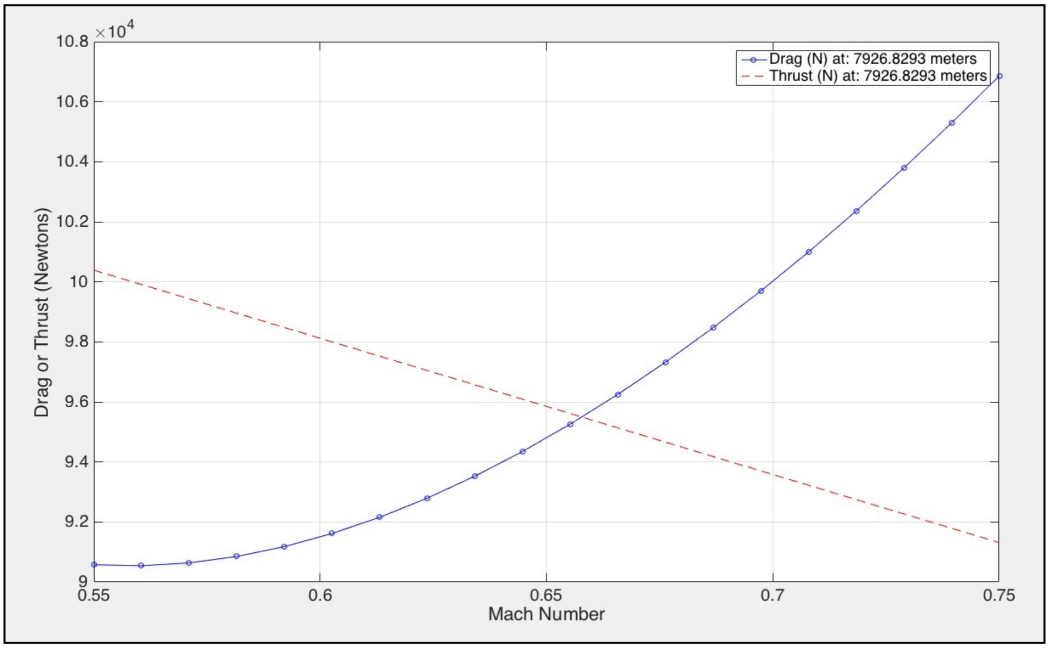

Figure 2. Thrust and Drag for Single Engine Aircraft at 26,000 feet. Mass = 193,000 kg.

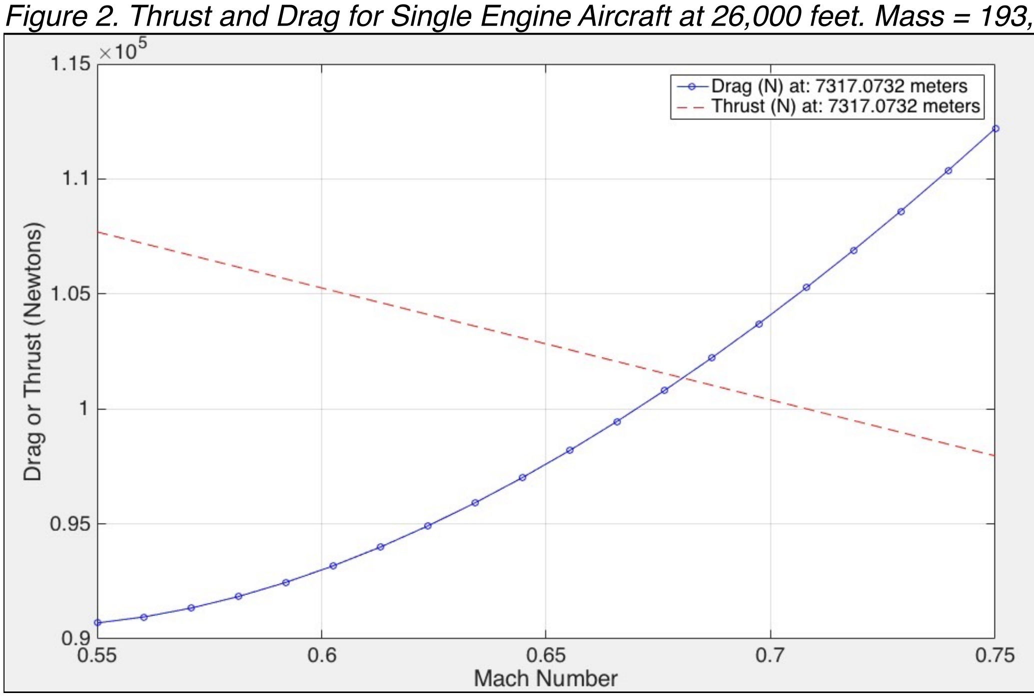

Figure 3. Thrust and Drag for Single Engine Aircraft at 24,000 feet. Mass = 193,000 kg.

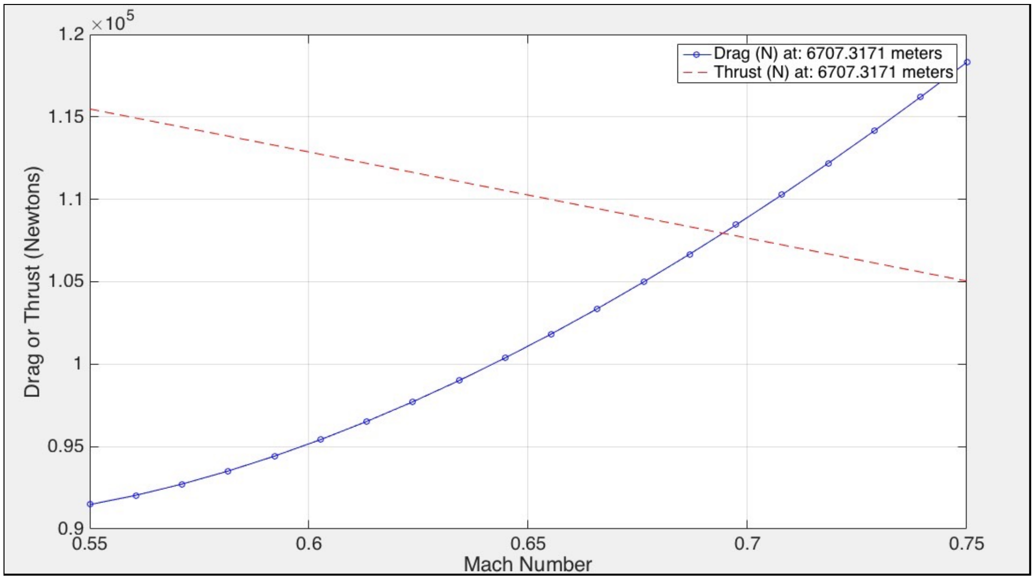

Figure 4. Thrust and Drag for Single Engine Aircraft at 22,000 feet. Mass = 193,000 kg.

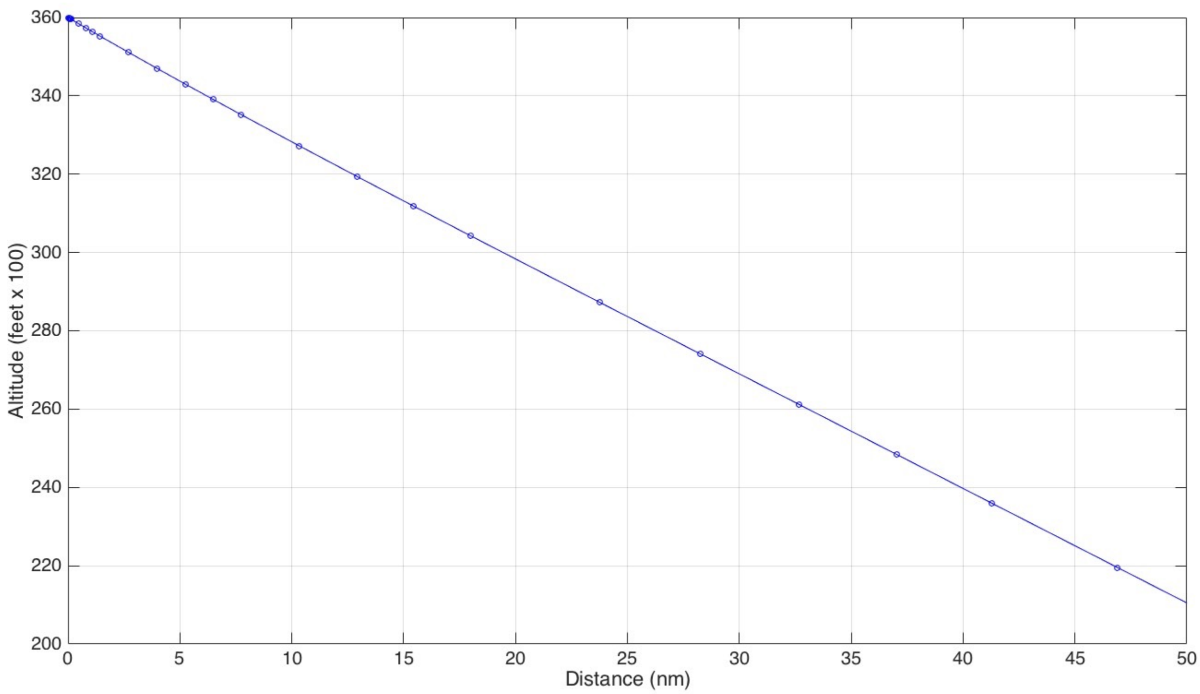

Figure 5. Altitude vs. Distance Traveled in Descent from 36000 to 24000 feet.

Step # 2: Estimate the fuel used in the descent profile from the original altitude of 36,000 feet to the one-engine out altitude selected in Step # 1.

The aircraft takes 326 seconds (using the nominal descent profile) to descend 12,000 feet. The aircraft travels 40 nm to descend 12,000 feet. It takes 326 seconds to reach the new altitude. The numerical simulation using unrestrictedDescent profile provides information about fuel burned in the descent maneuver. With one engine out the aircraft uses 41 kilograms in the descend profile to 24,000 feet. The new mass at 24000 feet is estimated to be 1.9296e+05 kilograms.

Step # 3: Estimate the fuel used at one engine speed to cover the distance to Christmas Island. Note that we start making a simple approximation that would be refined later. Using 50 distance steps in numerical integration procedure to estimate the cruise parameters we find:

Cruise Fuel (kg) 14313.2708

Cruise Time (minutes) 160.3386

Cruise Distance (nm) 1050

The aircraft will have a mass at the TOD point of around 1.7865e+05 kilograms. Using this information we estimate the descent profile from TOD to the destination airport in Step #4.

Step # 4: Use the descent analysis code to estimate the fuel, travel time and distance from the selected altitude in Step # 1 and using the mass at TOD estimated in Step # 3.

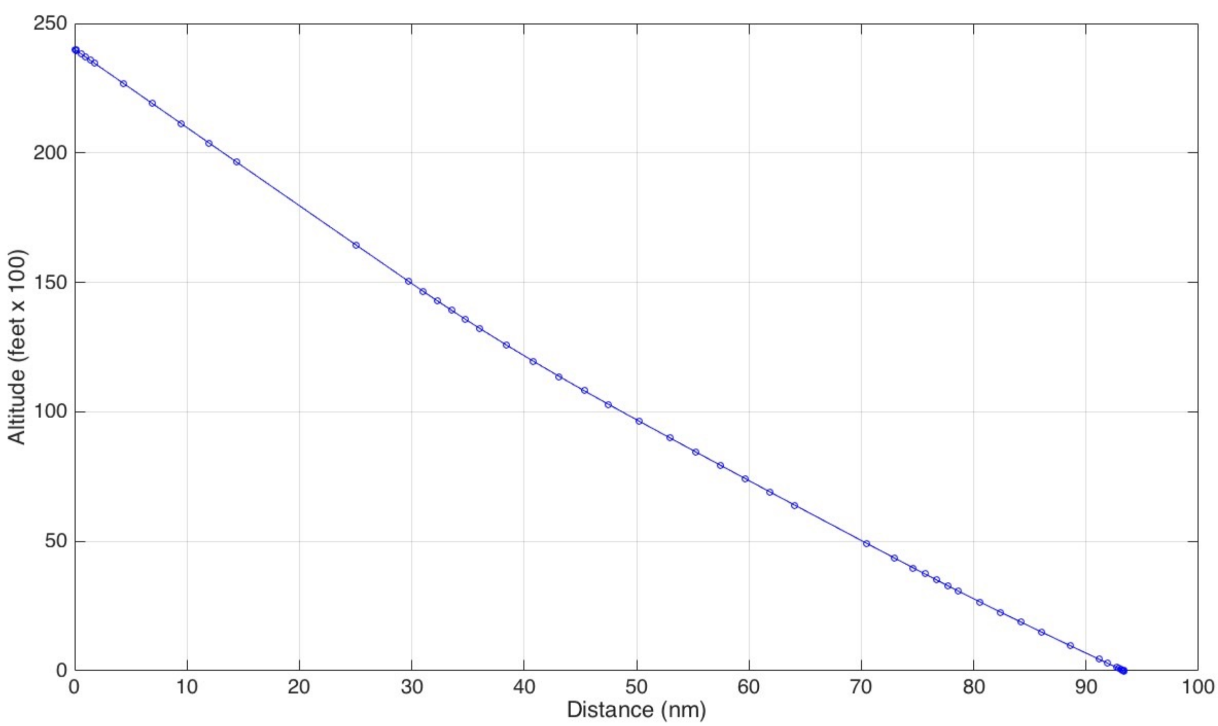

Figure 6. Descent Profile for Boeing 787 Class Aircraft from 24,000 feet with One Engine Out.

The aircraft travels 93.4 nm in the descent profile. The travel time to the destination airport is 1125 seconds (18.7 minutes) and the fuel used is estimated to be 322 kilograms. The final mass at the destination airport is 1.7833e+05 kilograms.

Step # 5

Note: With results obtained in Steps #3 through 5 we can now revise the estimates of Step # 3 since we have a good estimate of the distance from the TOD point to the airport. The revised cruise distance (flown at one engine speed of Mach 0.65) is then (1090-40-93.4) 956.6 nm. This distance is used in the revised analysis to produce:

Cruise Fuel (kg) 13065.679

Cruise Time (minutes) 146.0761

Cruise Distance (nm) 956.6

The new mass at TOD is estimated to be 1.7989e+05 kilograms. Recalculating the fuel in the descent phase we have:

Fuel in descent phase = 323 kilograms

Final mass at destination airport = 1.7957e+05 kilograms

Distance traveled in descent = 18.6 minutes

The total travel time from engine failure to landing at Christmas Island is: 326/60 + 146.1 + 1127/60 or 170.1 minutes. This satisfies the 180 ETOPS diversion. The total fuel used in the diversion is (41 + 13066 + 323) 13430 kilograms. This amount of fuel is very little for this aircraft.

The diversion to Hawaii would not be recommended unless the cruise speed is increased.

b) Find the best alternate for this flight. Is the flight legal within the 180 minute ETOP rule? In your analysis justify your selection based on the single engine capability of the aircraft, the flight to the closest alternate and the runway length available at the alternate airports.

Diverting to Christmas Island seems the best alternative.

c) Find the fuel used to the best alternate and the travel time considering wind conditions.

The total fuel used is 13430 kilograms (calculated above).

Problem 2

For the selected alternate selected in Problem1, now assume the failure is a combination of pressurization and one engine failure. Estimate the travel time and fuel used to the best alternate. State all your assumptions.

Step # 1

The descent phase from 36,000 to 10,000 feet takes 90 nm and 829 seconds (13.8 minutes). This is shown in Figure 7. The fuel consumption is estimated to be 150.7 kilograms. The final mass at 10,000 is 1.9285e+05 kilograms.

Step # 2

At 10,000 feet we need to reach the destination (1,000 nm away) in 3 hours at one engine speed. The speed of sound at 10,000 feet is 328.4 m/s. Figure 8 shows the thrust and drag characteristics of the aircraft flying at 10,000 feet. The aircraft requires 381 knots (196 m/s) average to reach the destination in the remaining 2.77 hours. The minimum speed required is Mach 0.60. I selected Mach 0.62 for the remaining of the analysis.

Step # 3

Calculation of cruise fuel yields the following.

Cruise Fuel (kg) 17805.6128

Cruise Time (minutes) 151.5927

Cruise Distance (nm) 1000

Mass at TOD = 1.7504e+05 kilograms

Step # 4

Calculation of descent profile from 10,000 feet to sea level conditions. The aircraft travels 44.7 nm in the descent profile. The travel time to the destination airport is 635 seconds (10.6 minutes) and the fuel used is estimated to be 220 kilograms. The final mass at the destination airport is 1.7482e+05 kilograms.

The total travel time from engine failure to landing at Christmas Island is: 13.8 + 151.6 + 635/60 or 176 minutes. This satisfies the 180 ETOPS diversion. The total fuel used in the diversion is 18076 kilograms. This amount of fuel is within the limits for this aircraft.

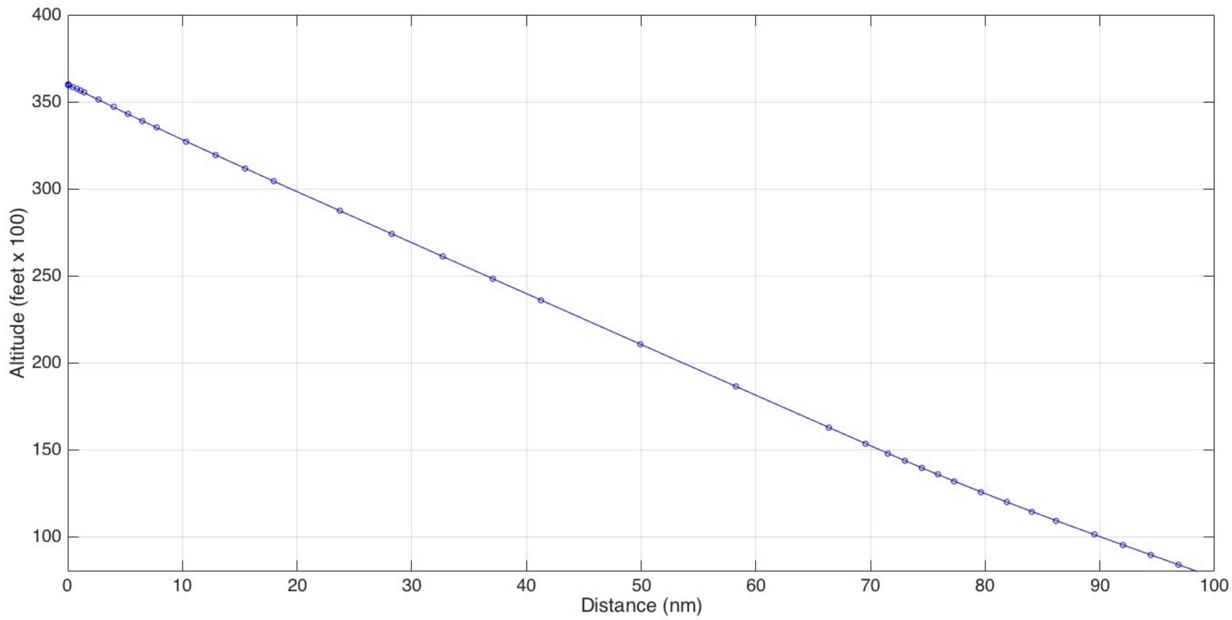

Figure 7. Descent from 36000 to 10000 feet.

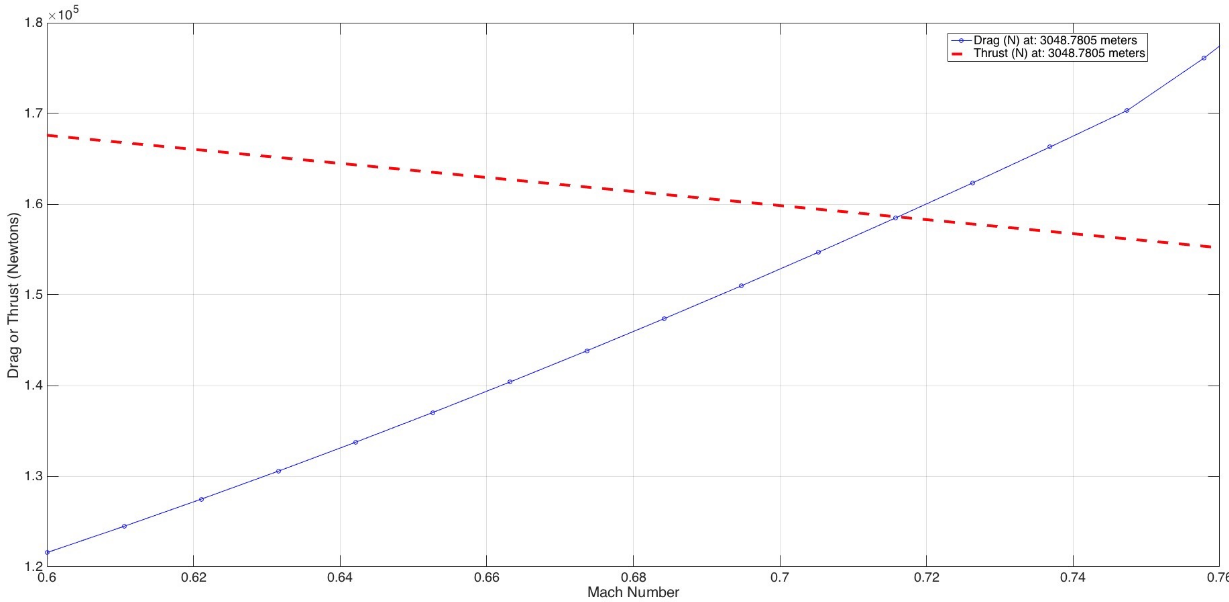

Figure 8. Thrust and Drag at 10,000 feet.

Problem 3

Short answers.

a) Can Atlanta conduct triple independent approaches in VMC conditions? Explain.

ATL can do triple approaches in VMC conditions.

b) Can Raleigh (North Carolina) conduct independent approaches in IMC conditions? Explain.

Yes with the use of PRM (Precision Runway Monitor). RDU has runways just above 3,000 feet in separation and also has a PRM installed.

c) Read the summary NextGen Implementation Plan 2015 and, in two paragraphs, discuss some of the terminal automation tools the FAA will introduce as part of NextGen.

d) Briefly describe (in 2-3 paragraphs) some of the improvements to multiple runway operational procedures expected under NextGen.

Wake Turbulence Mitigation procedures for departures (WTMD), Wake Turbulence Mitigation procedures for arrivals (WTMA), RECAT Phase 2 (re-categorization of aircraft categories phase 2).