CEE 5614

Quiz 1 Solution

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Problem 1

Problem 1 Description

- The San Diego Airport Authority would like to request your services to study possible runway length improvements to runway 09-27
- Review Airnav and the satellite images at Google Earth to answer the following questions. The goal of this exercise is to improve runway 09-27 allowing airlines to support international services and also to serve and some long-distance domestic destinations
- Estimate the runway extension needed (if any) for runway 09-27 if the critical stage length services have been identified at this airport for various airlines (see Table 1)

Table 1. Typical Services from SAN to Critical Airports.

Origin-Destination Airport Pair	Aircraft Flying the Route
KSAN - SCEL San Diego - Santiago (Chile)	Boeing 767-400ER with *CF6-80C2B8* engines. Aircraft maximum design takeoff weight is 450,000 lb. Aircraft has a typical three-class configuration.
KSAN - HKG San Diego - Hong Kong	Boeing 787-8 powered by two *General Electric GEnx-1B* engines rated at 70,000 lb. of thrust. Aircraft maximum takeoff weight is 502,500 lb. Three-class layout.

Problem 1 Description (cont.)

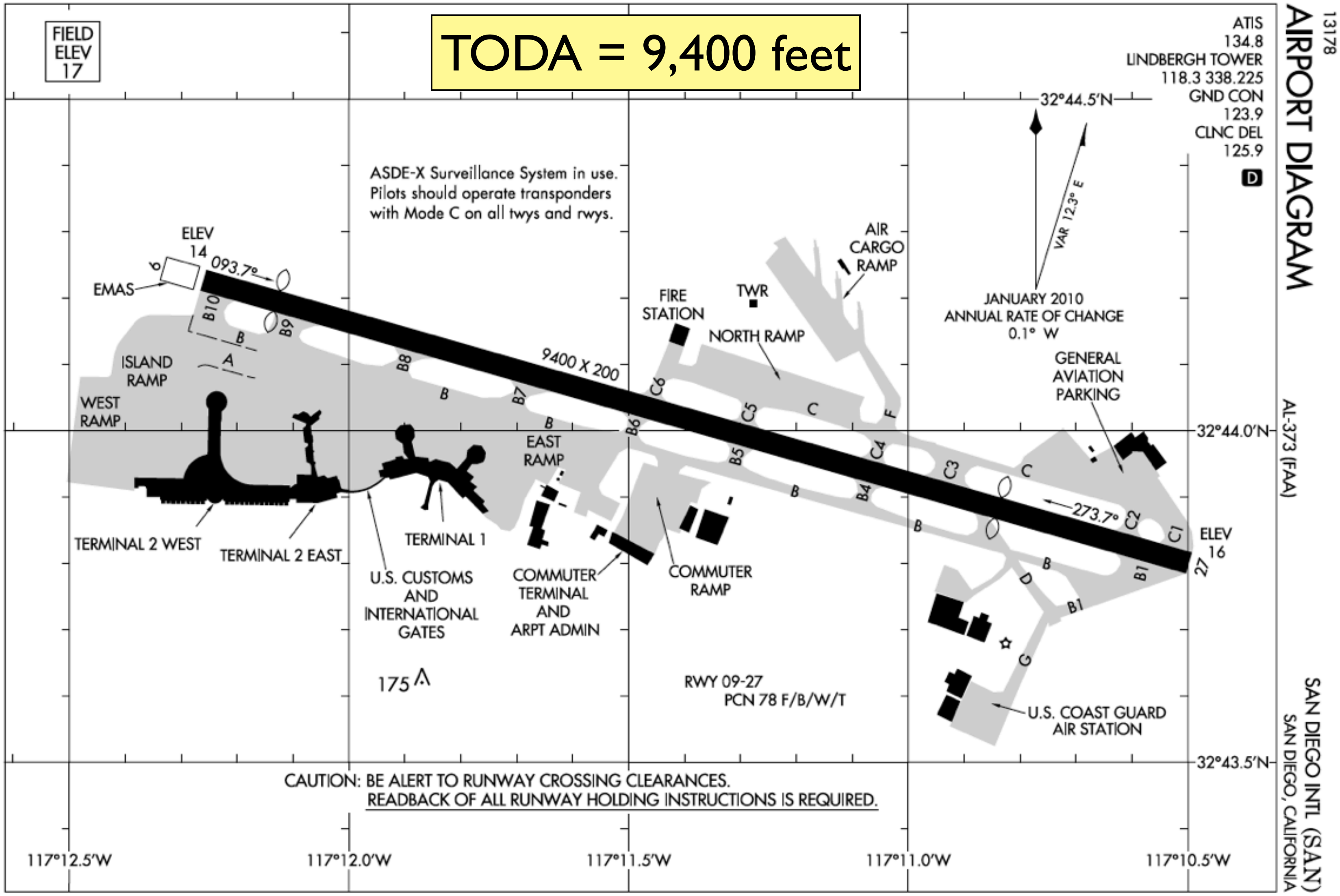
- Find the average stage length to be flown between each one of the critical OD airport pairs
  - In your analysis use the Great Circle Flight Path mapper link provided in our interesting web sites (see below). Add 6% to the distances calculated to account for real Air Traffic route conditions and to account for possible weather deviations from the optimal flight path.
- Find the runway length needed for each one of the routes. Determine which one of the trips constitutes the critical stage length and design the new runway length extension if needed. Comment on your solution.

Table 1. Typical Services from SAN to Critical Airports.

Origin-Destination Airport Pair	Aircraft Description	Route Length (nm) with 6% detour factor
KSAN - SCEL San Diego - Santiago (Chile)	Boeing 767-400ER with *CF6-80C2B8* engines	5,030
KSAN - HKG San Diego - Hong Kong	Boeing 787-8 powered by two *General Electric GEnx-1B* engines rated at 70,000 lb. of thrust. layout.	6,786

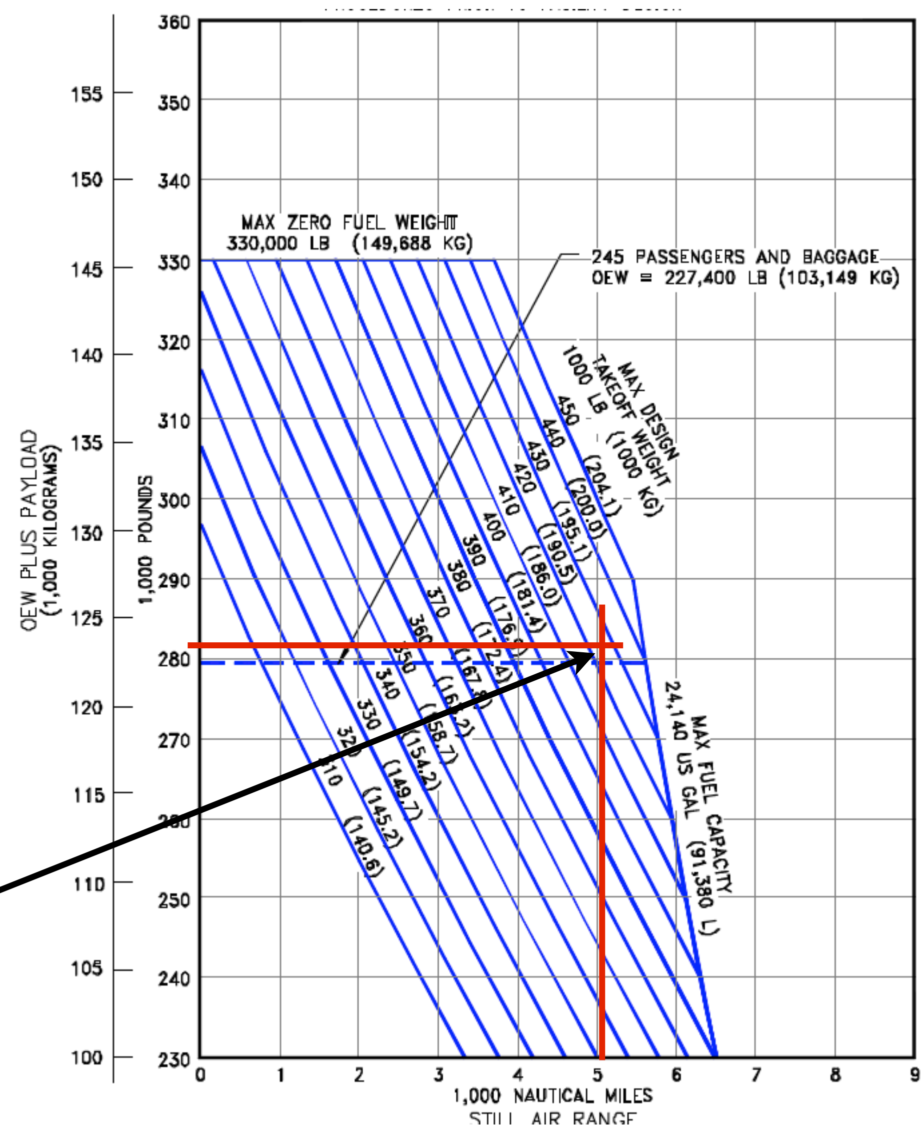
Current Airport (SAN)

- sources of data: FAA and Airnav.com



Boeing 767-400ER

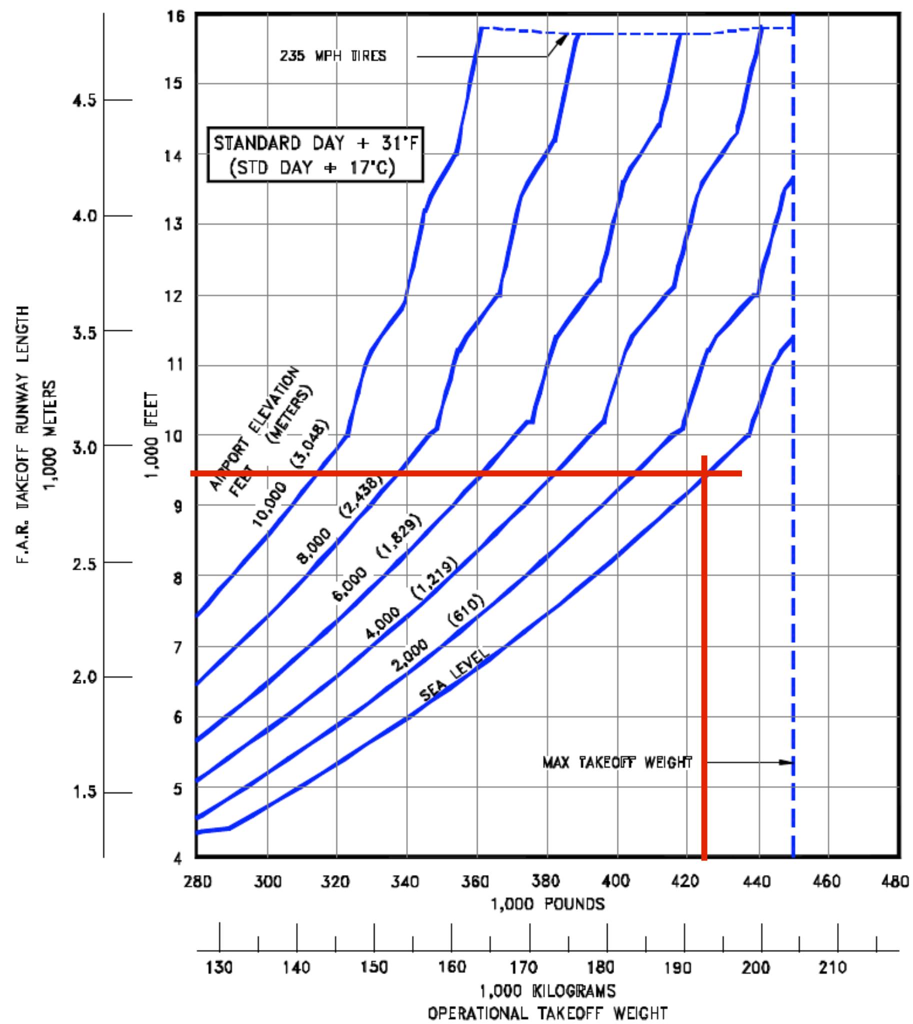
CHARACTERISTICS	UNITS	767-400ER (1)	
		GE ENGINES	PW ENGINES
MAX DESIGN TAXI WEIGHT	POUNDS	451,000	451,000
	KILOGRAMS	204,570	204,570
MAX DESIGN TAKEOFF WEIGHT	POUNDS	450,000	450,000
	KILOGRAMS	204,116	204,116
MAX DESIGN LANDING WEIGHT	POUNDS	350,000	350,000
	KILOGRAMS	158,757	158,757
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	330,000	330,000
	KILOGRAMS	149,685	149,685
SPEC OPERATING EMPTY WEIGHT (1)	POUNDS	227,400	229,000
	KILOGRAMS	103,147	103,872
MAX STRUCTURAL PAYLOAD	POUNDS	102,600	101,000
	KILOGRAMS	46,538	45,813
SEATING CAPACITY (1)	ONE-CLASS	409 ALL ECONOMY	
	TWO-CLASS	296 - 24 FIRST + 272 ECONOMY	
	THREE-CLASS	243 - 16 FIRST + 36 BUSINESS + 189 ECONOMY	



- With 9400 feet the aircraft is restricted to 425,000 lb takeoff

Boeing 767-400ER

- With 9400 feet the aircraft is restricted to 425,000 lb takeoff weight
- DTW = 425,000 lb
- Good to carry 245 passengers based on Boeing payload-diagram
- Aircraft can operate the SAN-SCEL route albeit with some restrictions



3.3.28 F.A.R. TAKEOFF RUNWAY LENGTH REQUIREMENTS

STANDARD DAY + 27°F (STD + 15°C), WET SMOOTH RUNWAY SURFACE

MODEL 767-400ER (CF6-80C2B8F ENGINES)

Boeing 767-400ER

- With 9400 feet the aircraft is restricted to 425,000 lb takeoff weight
- DTW = 425,000 lb
- Good to carry 245 passengers based on Boeing payload-diagram
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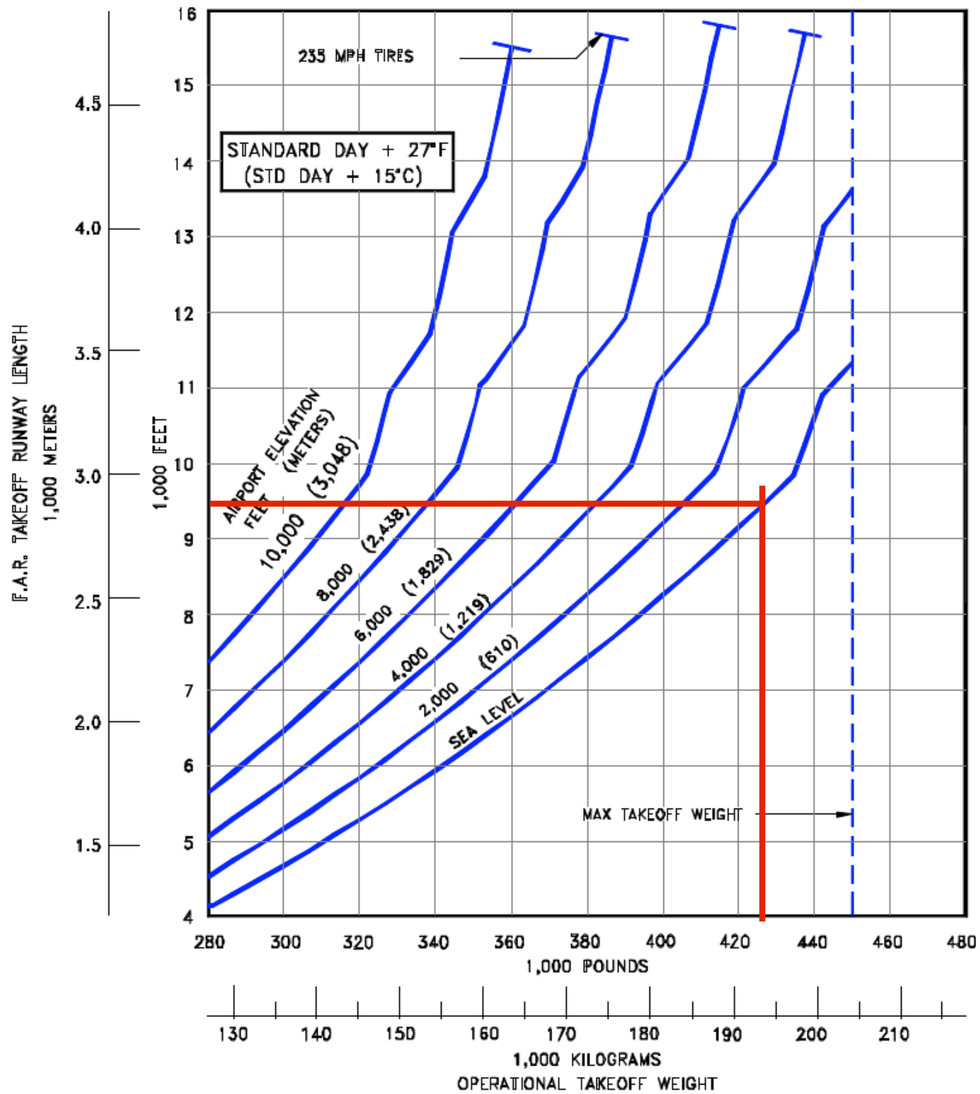


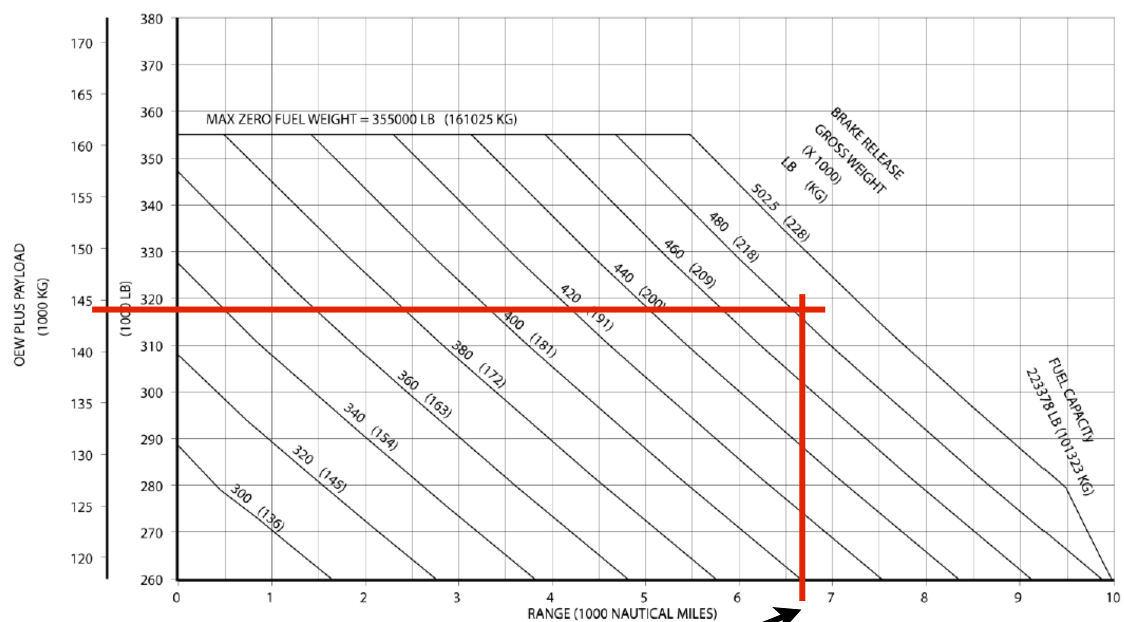
3.3.32 F.A.R. TAKEOFF RUNWAY LENGTH REQUIREMENTS

STANDARD DAY + 27°F (STD + 15°C), WET SMOOTH RUNWAY SURFACE

MODEL 767-400ER (CF6-80C2B7F1 ENGINES)

Boeing 787-8 with Genx-1B Engines

CHARACTERISTICS	UNITS	ENGINE MANUFACTURER	
		GENERAL ELECTRIC	ROLLS-ROYCE
MAX DESIGN TAXI WEIGHT	POUNDS	503,500	503,500
	KILOGRAMS	228,384	228,384
MAX DESIGN TAKEOFF WEIGHT	POUNDS	502,500	502,500
	KILOGRAMS	227,930	227,930
MAX DESIGN LANDING WEIGHT	POUNDS	380,000	380,000
	KILOGRAMS	172,365	172,365
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	355,000	355,000
	KILOGRAMS	161,025	161,025
OPERATING EMPTY WEIGHT (1)	POUNDS	259,500	259,700
	KILOGRAMS	117,707	117,798
MAX STRUCTURAL PAYLOAD (1)	POUNDS	95,500	95,300
	KILOGRAMS	43,318	43,227
SEATING CAPACITY	ONE-CLASS	375 ALL-ECONOMY SEATS; FAA EXIT LIMIT = 381 SEATS	
	MIXED CLASS	242 THREE-CLASS; 16 FIRST CLASS, 44 BUSINESS CLASS, 182 ECONOMY CLASS (SEE SEC 2.4)	

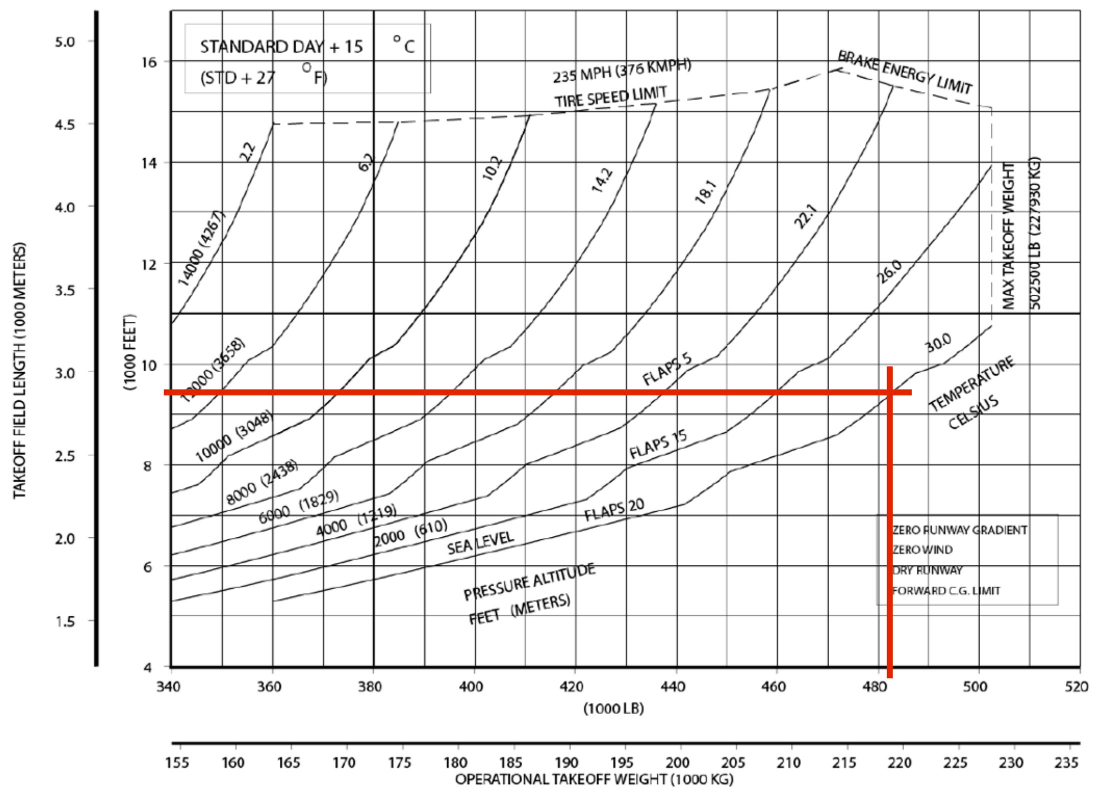


- With 9400 feet the aircraft is restricted to 483,000 lb takeoff

DTW = 483,000 lb
is good for 242 passengers
and no extra cargo

Boeing 787-8 (with High Thrust Engines)

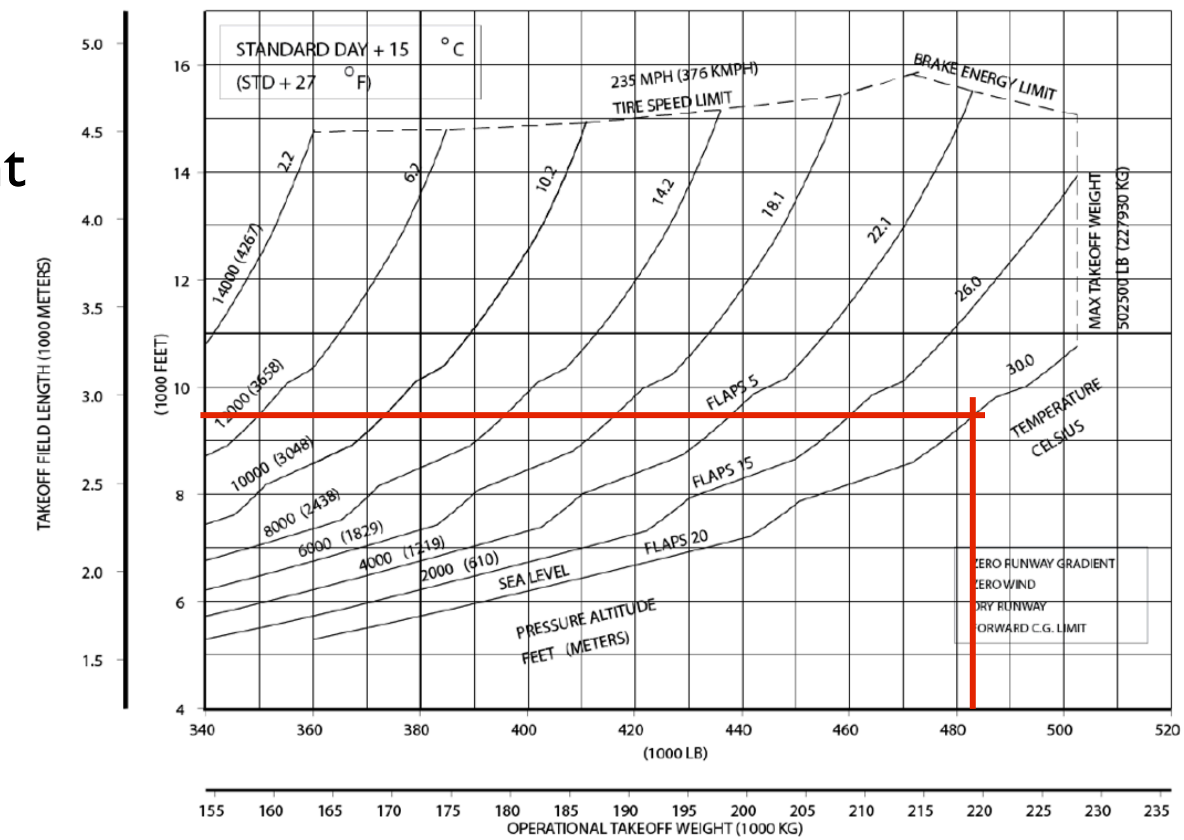
- With 9400 feet the aircraft is restricted to 483,000 lb takeoff weight
- DTW = 483,000 lb
- Good to carry 242 passengers based on Boeing payload-diagram
- Aircraft can operate the SAN-HKG route albeit with some restrictions



Used ISA + 15 deg. C curves (typical engine)
Figure 3.3.6 in Boeing Document

Boeing 787-8 (with Typical Engines)

- With 9400 feet the aircraft is restricted to 483,000 lb takeoff weight
- DTW = 483,000 lb
- Good to carry 242 passengers based on Boeing payload-diagram
- Aircraft can operate the SAN-HKG route albeit with some restrictions



Used ISA + 15 deg. C curves (typical engine)
Figure 3.3.2 in Boeing Document

Final Observations

- Both services are possible with a full complement of passengers
- Both services are restricted by runway length if the airline want to adds cargo beyond passengers
- Two generations of commercial airliners show the improvements in performance. The Boeing 787-8 has significant more range than the Boeing 767-400 ER

Problem 2

Problem 2 Description

- 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 answer the following questions. This file represents a typical 50-seat regional jet powered by two turbofan engines developing 41,800 Newtons at sea level static conditions.

- The airline would like to fly this aircraft from Roanoke, Virginia to Atlanta, Georgia using the climb and descent profile speeds stated below.

- Vclimb = [160 190 240 270 270]; % Indicated airspeed in knots

- Vdescent = [200 220 240 240 210]; % Indicated airspeed in knots

- altc = [0 1000 3000 6000 14000]; % altitude vector in meters

- The pilot files for a cruise altitude of 31,000 and Mach 0.71. The takeoff mass is comprised of the following:

- Operating empty mass = 13,700 kg; Fuel weight onboard= 4,000 kg; Payload = 5,500 kg (50 passengers plus small amount of cargo).

Problem 2 Description (cont.)

- Estimate the climb, cruise and descent distances for this flight. Account for a 6% detour factor due to weather and ATC deviations
- Estimate the fuel consumed and the travel time in the the route ROA-ATL
- Estimate the L/D ratio of the aircraft at both TOC and TOD points
- If the airline wants to fly a long distance with the aircraft, what speed (i.e., Mach number) would you recommend? Comment

ROA-ATL Analysis

- Given takeoff parameters estimate the DTW as:

$$DTW = OEW + PYL + FW$$

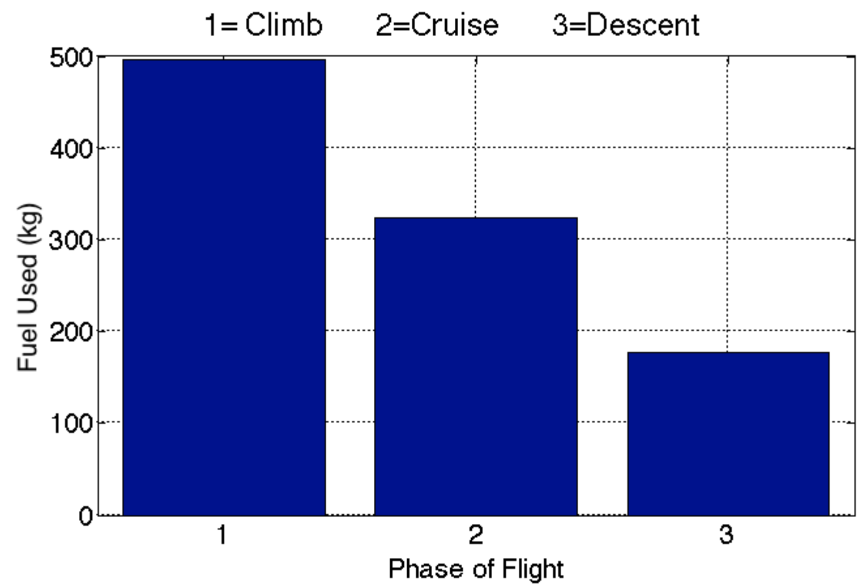
$$DTW = 13700 + 4000 + 5500$$

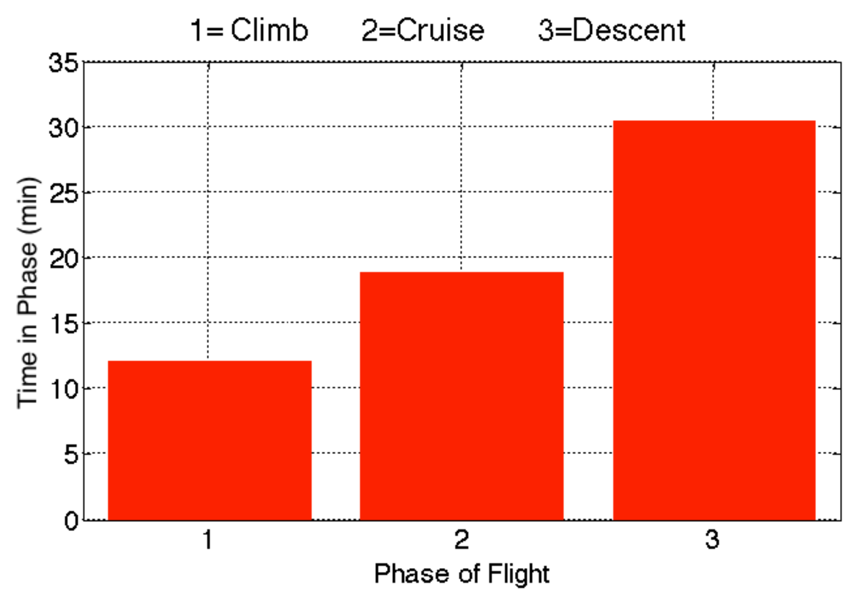
$$DTW = 23,200 \text{ kg}$$

- Use unrestricted climb, unrestricted descent and a cruise segment code calculation to obtain the fuel used in the flight
- Cruise altitude = 31,000 feet
- Mach No. = 0.71
- 329 nm (adjusted by 6% detour factor)

ROA-ATL Analysis

- Mission Fuel (kg) 997.0697
- Travel Time (minutes) 61.5255
- Total Distance (nm) 329
- Average Speed (knots) 320.8426
- Climb Fuel (kg) 495.8704
- Climb Time (minutes) 12.1457
- Climb Distance (nm) 65.1111
- Cruise Fuel (kg) 324.1679
- Cruise Time (minutes) 18.8723
- Cruise Distance (nm) 131.0448
- Descent Fuel (kg) 177.0314
- Descent Time (minutes) 30.5075
- Descent Distance (nm) 132.8441





L/D Ratio Analysis at TOC

- At the TOC the aircraft has a mass of:

$$m_{TOC} = DTW - FW_{climb} = 23200 - 496$$

$$m_{TOC} = 22,704 \text{ kg}$$

- The atmospheric characteristics at 31,000 feet are:

$$\rho = 0.4415 \text{ kg/m}^3$$

$$a = 301.87 \text{m/s}$$

L/D Ratio Analysis

- The aerodynamic characteristics at Mach 0.71 and 22,704 kg (TOC point) are:

$$C_l = 0.3761 \text{ dim}$$

$$C_d = 0.0244 \text{ dim}$$

$$D = 14,452 \text{ N}$$

$$\boxed{L / D_{TOC} = 15.4 \text{ dim}}$$

L/D Ratio Analysis at TOD

- At the TOD the aircraft has a mass of:

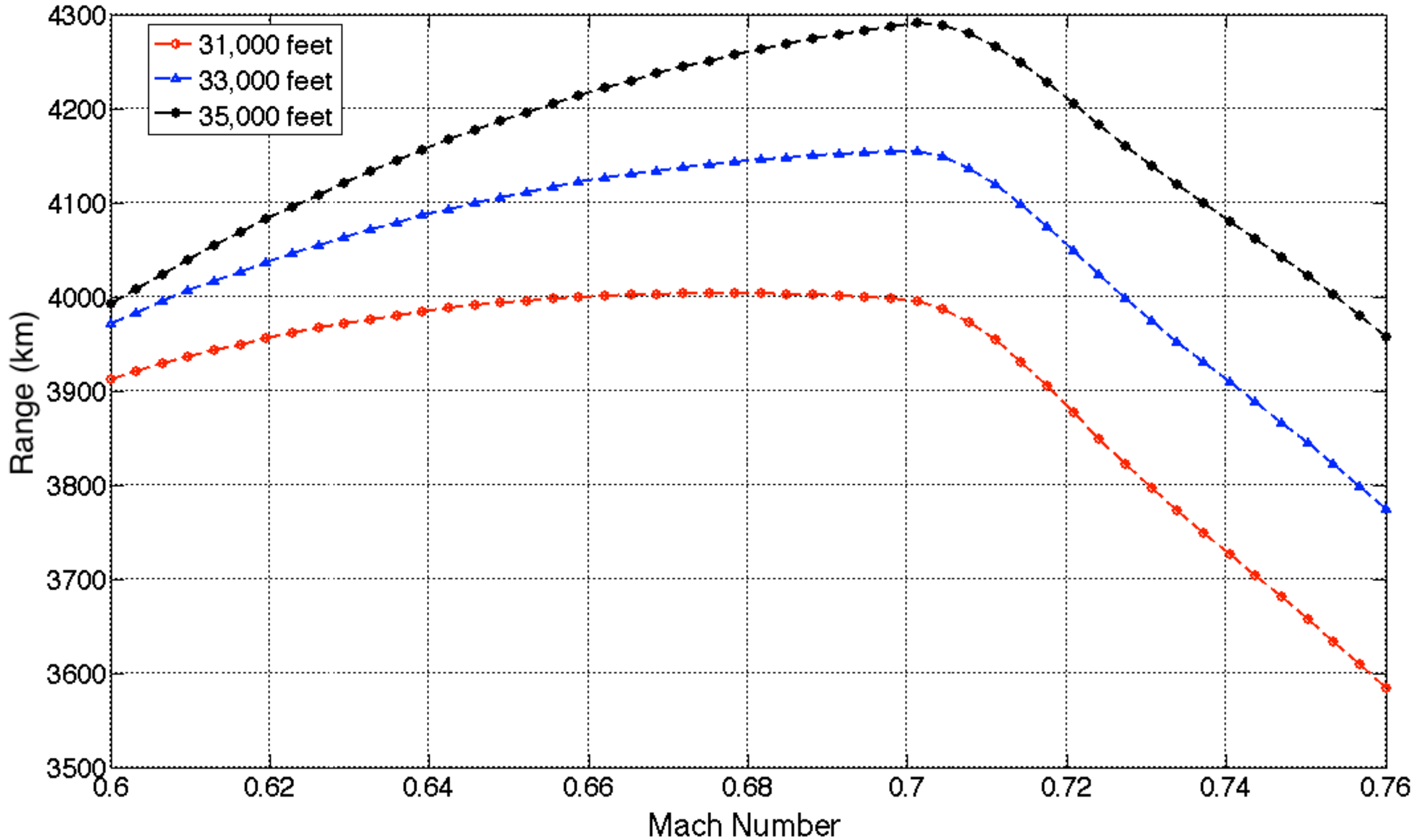
$$m_{TOD} = DTW - FW_{climb} - FW_{cruise} = 23200 - 496 - 324$$
$$m_{TOD} = 22{,}380 \text{ kg}$$

- The aerodynamic characteristics at Mach 0.71 and 22,380 kg (TOD point) are:

$$C_l = 0.3708 \text{ dim}$$
$$C_d = 0.0242 \text{ dim}$$
$$D = 14{,}347 \text{ N}$$
$$\boxed{L / D_{TOD} = 15.3 \text{ dim}}$$

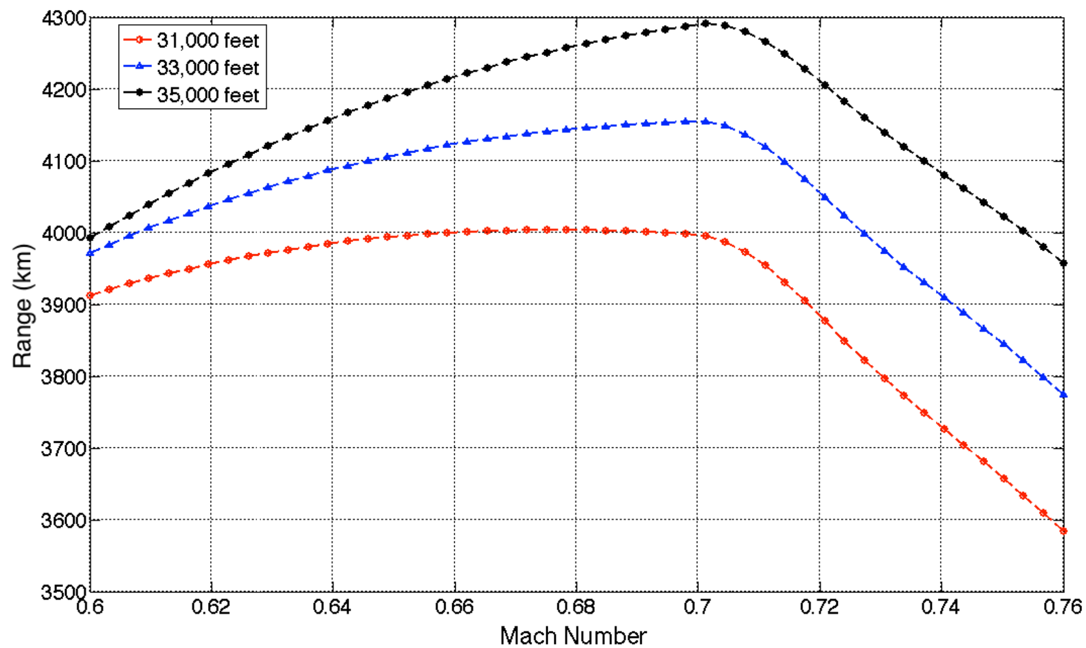
Long-Distance Flight

- Sensitivity analysis of Range parameter vs Mach number and cruise altitude



Long-Distance Range Flight Analysis

- At 31,000 feet the maximum range is obtained flying at Mach 0.675
- At 33,000 feet the maximum range is obtained flying at Mach 0.701
- At 35,000 feet the maximum range is obtained flying at Mach 0.703



Note: Flying faster and higher increases the range by 300 km

Problem 3

Problem 3 Description

- Use the twin-engine jet aircraft performance file provided in the Matlab files for CEE 5614 (http://128.173.204.63/courses/cee5614/cee5614_pub/Boeing737800Jet_class.m) to answer this question
- The file represents a typical 150 seat narrow body jet powered by two turbofan engines (CFM56 engines) similar in size to those of the Boeing 737-800
- Boeing is expecting to introduce the Boeing 737-8 Max in the year 2017
- The aircraft has slight aerodynamic refinements (say a reduction in Cdo of 1%) with the use of better winglets and fuselage streamlining to reduce drag
- Boeing estimates that the new CFM LEAP-1B engines will reduce the TSFC by 10% compared to the engines used today (i.e., ones in the aircraft performance file provided)
- This is a significant improvement (in paper) over the existing third generation of Boeing 737 aircraft like the 737-800.

Problem 3 Description (cont.)

- Estimate the fuel savings of a combined 1% reduction in Cdo and 10% reduction in TSFC for the airline
    - Assume a typical airline uses Boeing 737-800 3,500 hours per year. In your analysis calculate the typical stage length flown by B738 aircraft using the NAS_operations file provided in HW 4 and use that stage length to estimate the typical fuel consumption of a Boeing 738-800 vs. the new Boeing 737-8 Max
- Estimate the fuel savings per aircraft if the typical airline pays $2.90 per gallon according to BTS (http://www.transtats.bts.gov/fuel.asp).

Changes to Boeing 737-800 Class File

- According to our estimates, the Boeing 737-8 Max will have:
  - 10% reduction in TSFC
  - 1% reduction in aerodynamics

Small increase in aspect ratio due to new winglets

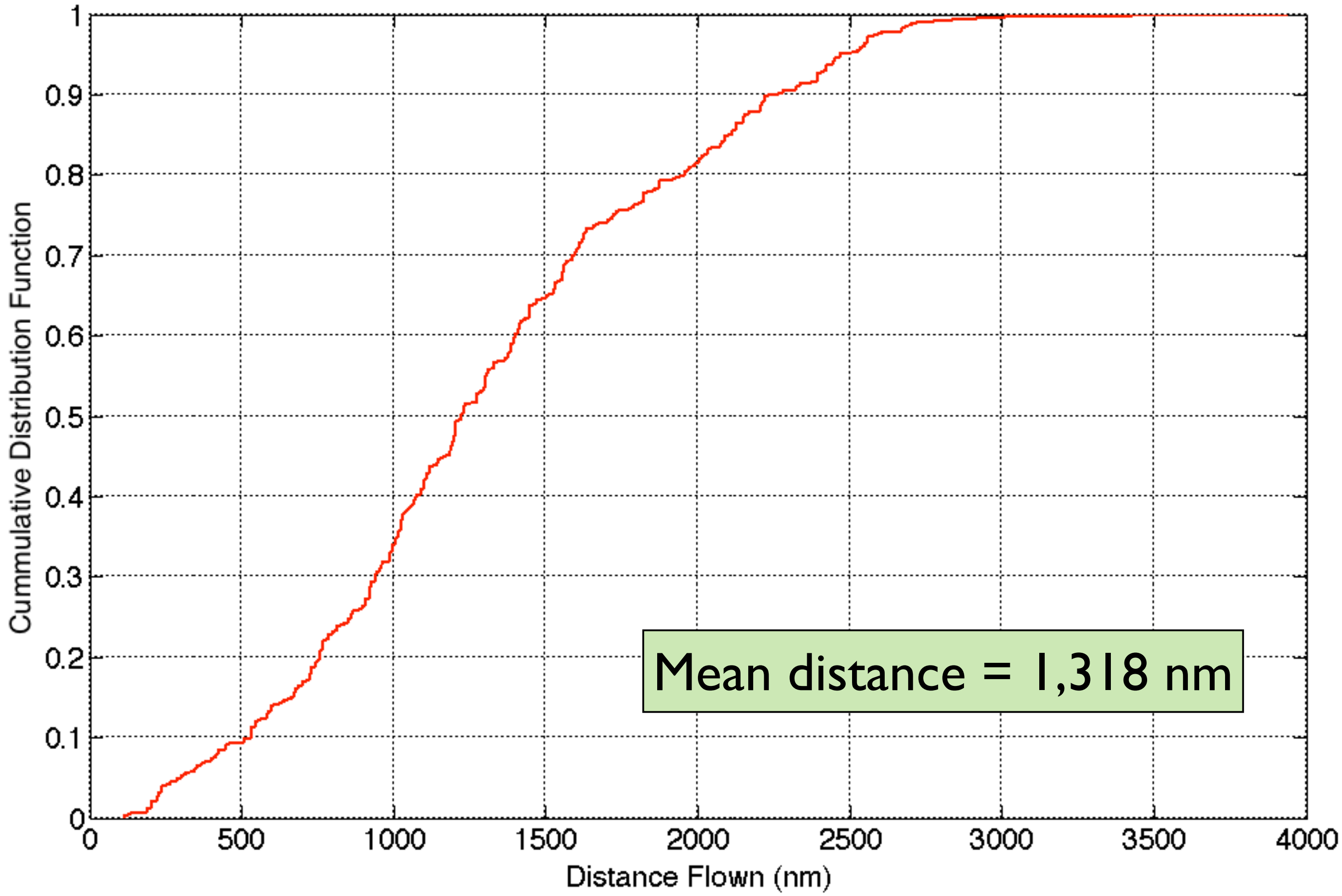
```
A = 8.9;                        % aspect ratio
e = 0.84;                       % Oswald's efficiency factor
S = 125;                        % wing area in m^2
tcRatio = 0.10;                 % thickness to chord ratio (dimansionless)
sweepAngle = 28;                % sweep angle of the wing (degrees)
g = 9.81;                       % gravity constant
neng = 2;                       % number of engines
tsfc = 1.7100e-04;              % TSFC in N/s / Newton - represents a 10% reduction in TSFC
                                %   compared to the older Boeing 737-800 aircaft

% Drag characterictics - CDO function (zero lift
% drag function)

Cdoct   = [0.0175  0.0175  0.018  0.022  0.038]*.99;     % represents a 1% reduction in CDo
macht   = [0.0  0.70 0.78 0.82 0.85];
```

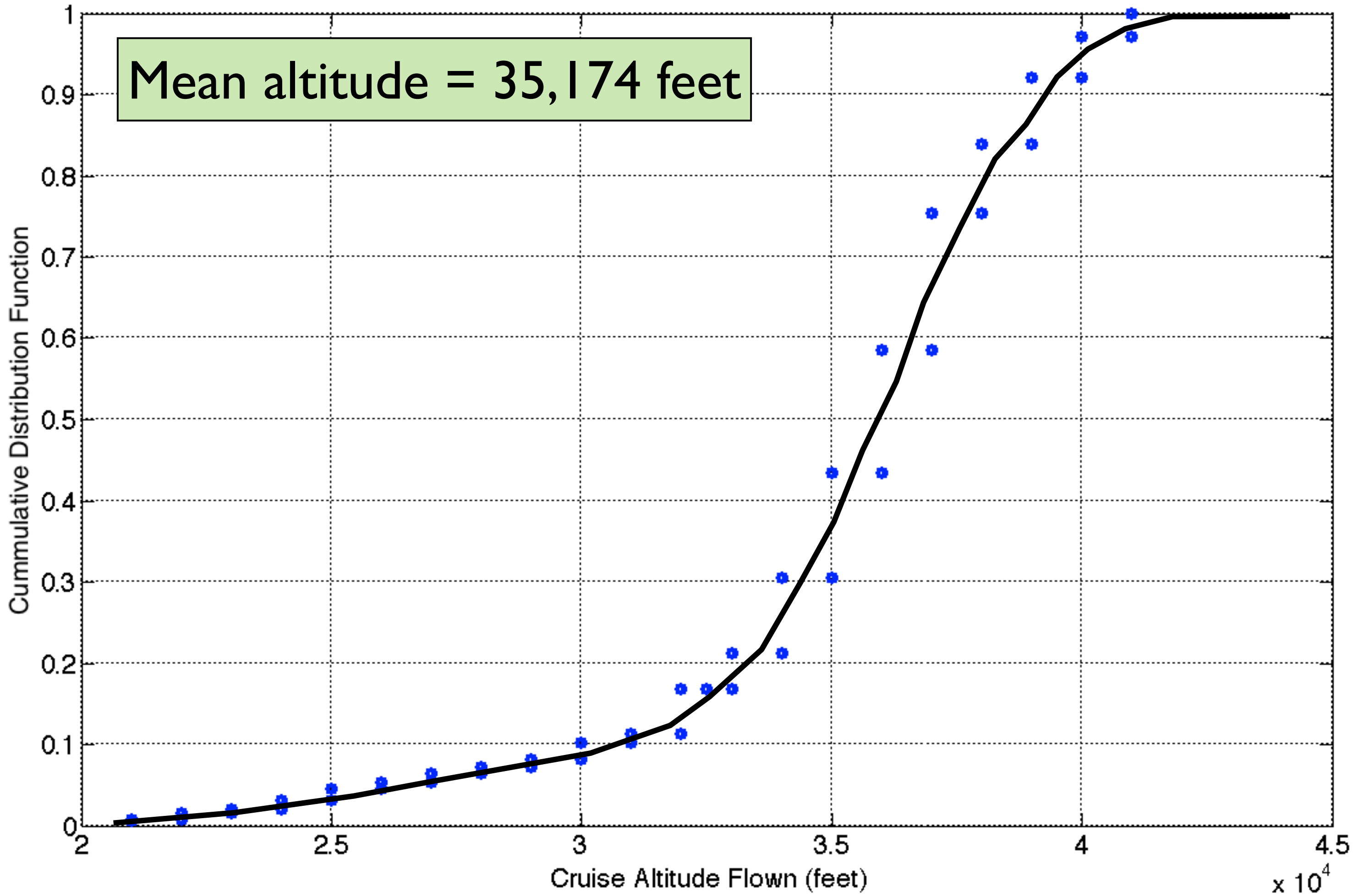
Boeing 737-800 Flights in the NAS

- Used the ETMS data to estimate the distribution of stage lengths flown by the Boeing 737-800 today



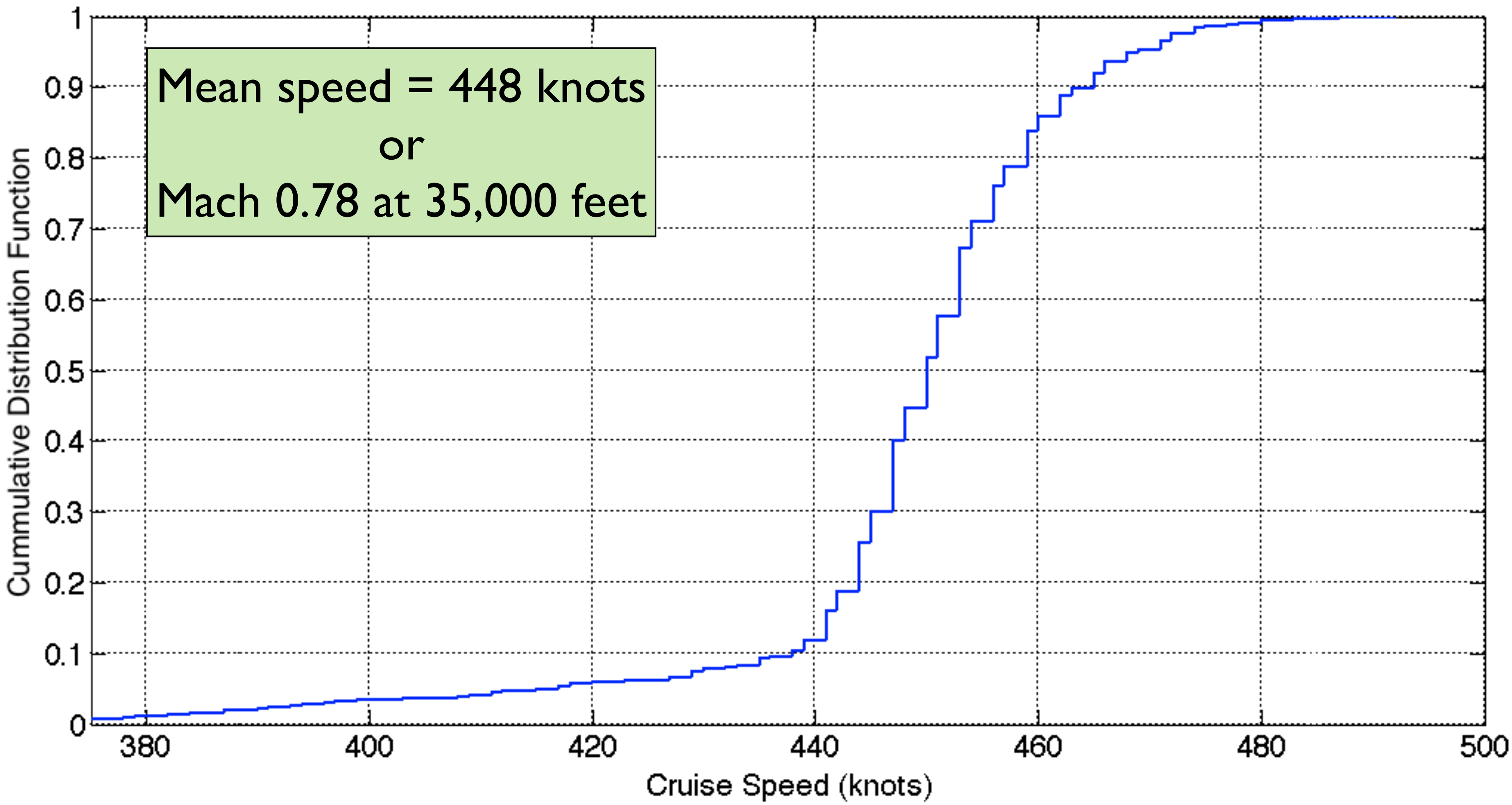
Boeing 737-800 Flights in the NAS

- Used the ETMS data to estimate the distribution of cruise altitudes flown by the Boeing 737-800 today



Boeing 737-800 Flights in the NAS

- Used the ETMS data to estimate distribution of cruise speeds flown by the Boeing 737-800 today



Analysis of Fuel Consumption

- For a given stage length, cruise speed and cruise altitude consistent with the parameters estimated, calculate:
  - Climb, cruise and descent fuel for Boeing 737-800 class aircraft (standard)
  - Climb, cruise and descent fuel for Boeing 737-8 Max class aircraft (standard)
  - Compare fuel statistics

Analysis of Initial Takeoff Mass (B738)

- Perform an iterative analysis to estimate a credible takeoff mass
- Consider the average stage length of 1,318 nm flown at 35,000 feet and Mach 0.78
    - OEW of Boeing 737-800 = 41,400 kg
    - Payload at 150 seats @ 82% load factor = 12,300 kg
    - Fuel to fly 1,318 nm with reserves = 11,000 kg
    - Typical DTW = 41,400 + 12,300 + 11,000 = 64,700 kg

Analysis for Both Variants

Parameter	Boeing 737-800	Boeing 737-8 Max	Delta
Mission Fuel (kg)	7761.30	6835.09	926.20
Travel Time (minutes)	190.50	191.20	-0.70
Total Distance (nm)	1318.00	1318.00	0.00
Average Airspeed (knots)	415.12	413.60	1.52
Climb Fuel (kg)	1502.39	1308.99	193.40
Climb Time (minutes)	16.43	15.92	0.51
Climb Distance (nm)	107.70	104.42	3.27
Cruise Fuel (kg)	5684.86	4976.64	708.22
Cruise Time (minutes)	139.21	138.64	0.57
Cruise Distance (nm)	1041.20	1036.94	4.27
Descent Fuel (kg)	574.06	549.47	24.59
Descent Time (minutes)	34.86	36.64	-1.78
Descent Distance (nm)	169.10	176.64	-7.54

Cost Savings Analysis

- DTW for Boeing 737-8 max was assumed to be 930 kg lighter for the 1,318 nm stage length because the mission fuel is reduced by 927 kg.
- A **11.9% reduction** in fuel burn has been estimated for the average stage length flown today with similar aircraft
- The aircraft could do 1,098 flights per year at 3,500 hrs of utilization (191.2 minute flights)
- 304 gallons of fuel saved per flight
- $881.9 per flight at $2.90 per gallon of Jet-A fuel
- **$968,596 per aircraft per year**
- Note: Boeing expects to sell the B738-Max at $103.7 million vs 90.5 million for the standard Boeing 737-800 (both in $2013 prices)