Quiz 1 - Solution

Open Notes and Internet

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Problem 1 (40 points)

Perform an assessment of the runway length for John Wayne Airport (SNA). Airlines operating at SNA use the Boeing 737-8 (Boeing 737-8 Max) with characteristics shown in Table 1. For this analysis, use the latest version of the Boeing 737-8 Max documents for airport design (Revision G published on May 2022).

Table 1. Aircraft Considered in the Runway Length Analysis of SNA. Picture Source: A.A. Trani.

Aircraft	*Engine*	*Remarks*
Boeing 737-8 (Max) with CFM LEAP-1B28B1 engines. Aircraft maximum design takeoff weight is 179,800 lb. 160 seats in a two-class layout.		
		

a) Can the Boeing 737-8 Max operate from SNA in routes to Chicago (ORD) and Seattle-Tacoma (SEA) with 90% of the seats full at the airport design temperature? Show me all the steps in the analysis to estimate runway length for the critical route. Clearly state al your assumptions and show your intermediate calculations.

Route	Great Circle Distance (nm)	Route Distance Flown (nm)	Remarks
SNA-ORD	1,499	1,589	Critical
SNA-SEA	850	901	

August is the hottest month of the year in Santa Anna (where SNA is located). Using the Climate Explorer web site the mean maximum temperature of the hottest month is 82.4 deg. Fahrenheit. Note that the same temperature in nearby Los Angeles is 88 deg. Fahrenheit. Runway 2L/20R is the longest runway with 5,700 feet total runway length. The airport elevation is 55.9 feet (practically at sea level conditions).

Difference between ISA and design conditions is ~23.4 deg. Fahrenheit. **Use the ISA + 27 deg. F runway performance curves (closest to the design temperature condition).**

Table 2. Boeing 737-8 Max Weight Data.

CHARACTERISTICS	UNITS	MODEL 737-8		
MAX DESIGN TAXI WEIGHT	POUNDS	159,900	180,300	182,700
	KILOGRAMS	72,529	81,782	82,871
MAX DESIGN TAKEOFF WEIGHT	POUNDS	159,400	179,800	182,200
	KILOGRAMS	72,302	81,555	82,644
MAX DESIGN LANDING WEIGHT	POUNDS	150,300	150,300	152,800
	KILOGRAMS	68,174	68,174	69,308
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	142,900	142,900	145,400
	KILOGRAMS	64,818	64,818	65,952
SEATING CAPACITY	TWO-CLASS	178	178	178
	SINGLE-CLASS	189	189	189
MAX CARGO VOLUME LOWER DECK	CUBIC FEET	1,540	1,540	1,540
	CUBIC METERS	43.6	43.6	43.6
USABLE FUEL *[1]	US GALLONS	6,820	6,820	6,820
	LITERS	25,817	25,817	25,817
	POUNDS	45,694	45,694	45,694
	KILOGRAMS	20,730	20,730	20,730

NOTES:
*[1] FUEL DENSITY = 6.7 LBS/US GAL

The Operating Empty Weight is estimated to be 99,000 lbs. from the Range-Payload diagram for the Boeing 737-8 Max (see Figure 2).

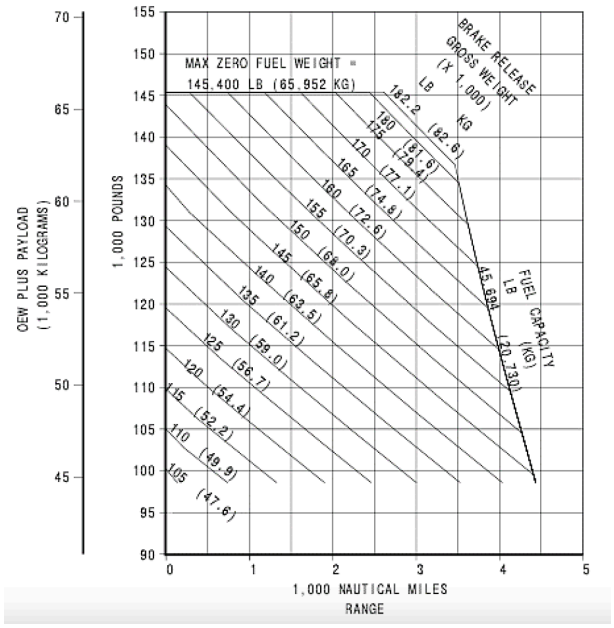


Figure 2. Payload Range Diagram for Boeing 737-8 Max. Figure 3.2.3 in Boeing 7378 Max Airplane Characteristics for Airport Planning.

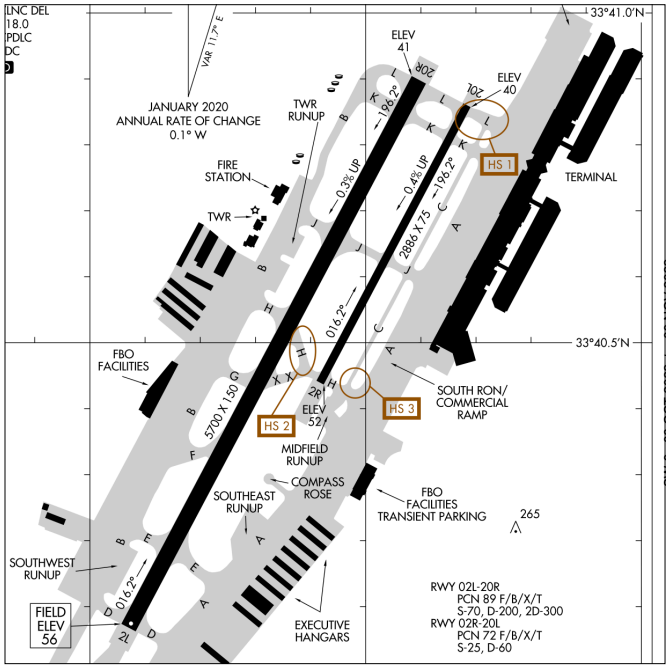


Figure 3. SNA Airport Diagram. The Diagram Shows a Difference in Runway Elevation for 2L/20R of 15 feet (Rounded to 0.3% in the Diagram)

Table 3. Calculations of Takeoff and Landing Distances at SNA. Boeing 737-8Max.

Parameter	SNA-ORD	SNA-SEA
Operating Empty Weight (lbs)	99,000	99,000
Payload (lbs)	31,680	31,680
OEW + Payload (lbs)	130,680	130,680
Route Distance (nm)	1,589	901
Desired Takeoff Weight (lbs)	154,000	146,000
FAR Takeoff Runway Length (ft) Zero runway grade	**5,100**	**4,600**
SNA Runway grade (%)	0.3	0.3
Difference in Runway Centerline Elevations (feet) using Airnav or FAA Airport Daigram	15	15
Adjustment of Runway Length due to Runway Grade (feet)	150	150
Adjusted Takeoff Field Length (feet)	**5,250**	**4,750**
Weight for Landing length Calculation (lbs)	150,300 (1)	146,000 (2)
FAR Landing Runway Length (ft) 40-deg. Flaps	**5,500** (3)	**5,300** (3)
Feasibility	yes	yes

Notes:

1) The landing field length calculation was done at the Maximum Allowable Landing Weight (MALW) for the SNA-ORD route

2) The landing field length calculation uses the Desired Takeoff Weight for the SNA-SEA route because the departure weight is below MALW.

3) The FAR landing distance exceed the FAR takeoff distances in both cases.

Table 3 shows that, with 90% of the seats full (160 seating configuration) the aircraft can safely takeoff and fly both routes. The SNA-ORD route requires 5,250 feet (adjusted) takeoff field length.

The wet pavement landing distance in the SNA-ORD route is 5,500 feet or 200 feet below the Landing Distance Available (LDA) - 5,700 feet. Remember to use wet pavement conditions in landing distance computations. Takeoff field length is estimated using dry pavement performance charts.

b) Use Google Maps or Google Earth to examine the runway ends for the longest runway at SNA. Tell me if the airport complies with the Runway Safety Areas required. The critical aircraft is the Boeing 757-200.

The Boeing 757-200 belongs to ADG group IV and AAC C. The RSA length after the runway end is 1,000 feet. The required length prior to the landing threshold is 600 feet. **The RSA areas are protected by more than 1,000 feet. The airport meets the RSA requirement.**

c) if the airport wants to expand services to Boston, estimate the new runway length needed using the Boeing 737-8 Max as the critical aircraft. In the analysis, assume the same 90% seats full.

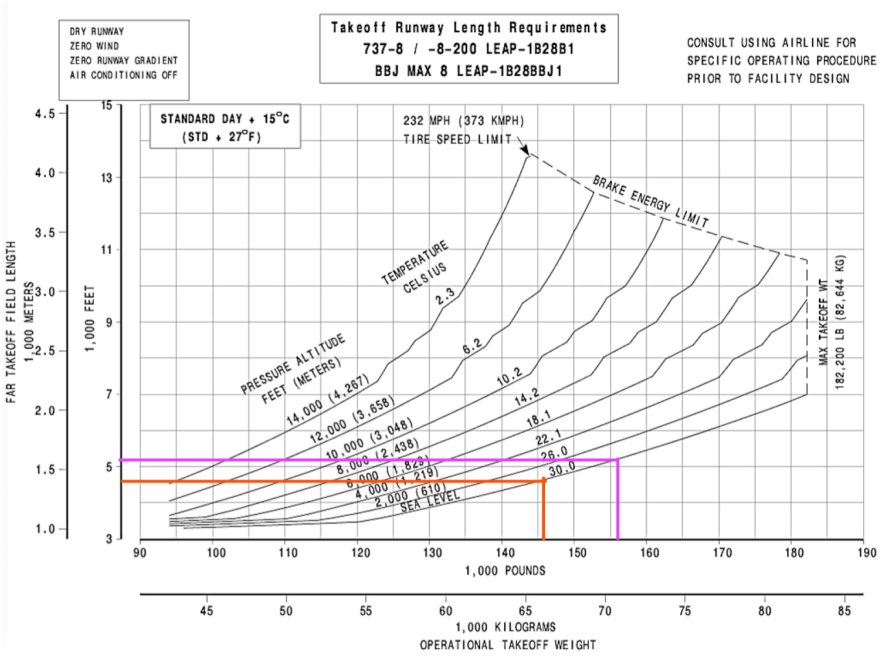


Figure 3.3.14 in Boeing 737-8Max Airport Planning Document

ISA + 27 deg. F.

Figure 4. FAR Takeoff Field Length for Boeing 737-8Max. Source: Boeing Aircraft Co. (Figure 3.3.14 in Boeing 737-8Max Airplane Characteristics for Airport Planning).

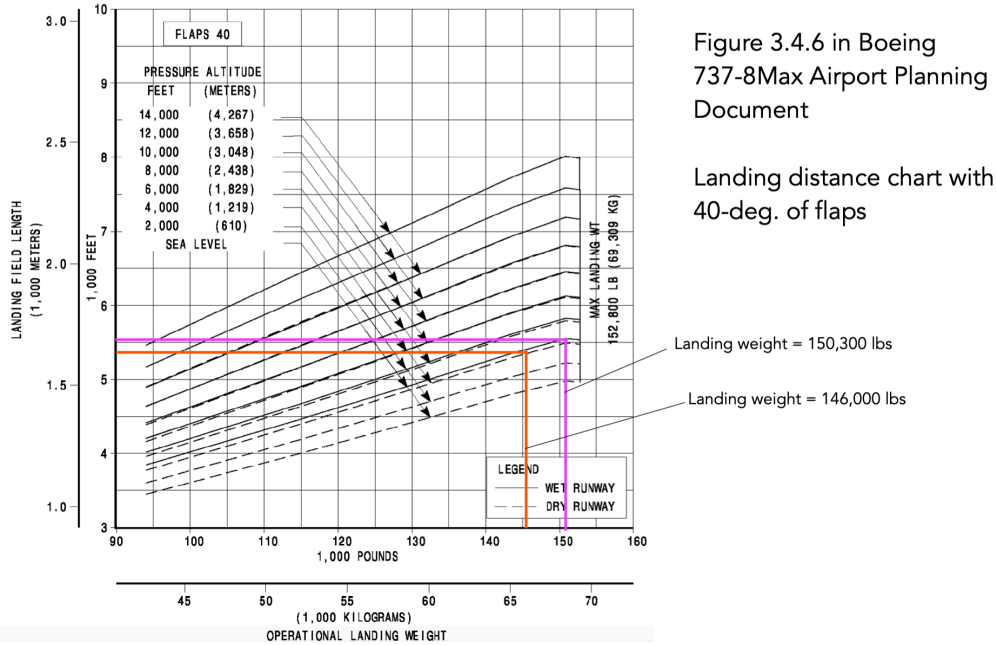


Figure 3.4.6 in Boeing 737-8Max Airport Planning Document

Landing distance chart with 40-deg. of flaps

Figure 5. Landing Distance for Boeing 737-8Max. Source: Boeing Aircraft Co. (Figure 3.4.6 in Boeing 737-8Max Airplane Characteristics for Airport Planning).

Table 4. Calculations of Takeoff and Landing Distances for the SNA-BOS Route.

Parameter	**SNA-BOS**
Operating Empty Weight (lbs)	99,000
Payload (lbs)	31,680
OEW + Payload (lbs)	130,680
Route Distance (nm)	2,387
Desired Takeoff Weight (lbs)	163,000
FAR Takeoff Runway Length (ft). Zero runway grade	**5,700**
SNA Runway grade (%)	0.3
Difference in Runway Centerline Elevations (feet) using Runway Grade	15
Adjustment of Runway Length due to Runway Grade (feet)	150
Adjusted Takeoff Field Length (feet)	**5,850**
Landing Weight for Calculation (lbs)	150,300
FAR Landing Runway Length (ft) 40-deg. Flaps	**5,700**
Feasibility	yes

Notes:

1) The landing field length calculation was done at the Maximum Allowable Landing Weight (MALW) for the SNA-BOS route.

2) The FAR takeoff distance is greater than the landing distance. **The runway needs an extension of 150 feet.** Normally, runway extension values are rounded to the nearest 100-foot value. So a 200-foot runway extension is appropriate.Figure 5. FAR Takeoff Field Length for Boeing 737-8Max. Source: Boeing Aircraft Co. (Figure 3.3.14 in Boeing 737-8Max Airplane Characteristics for Airport Planning).

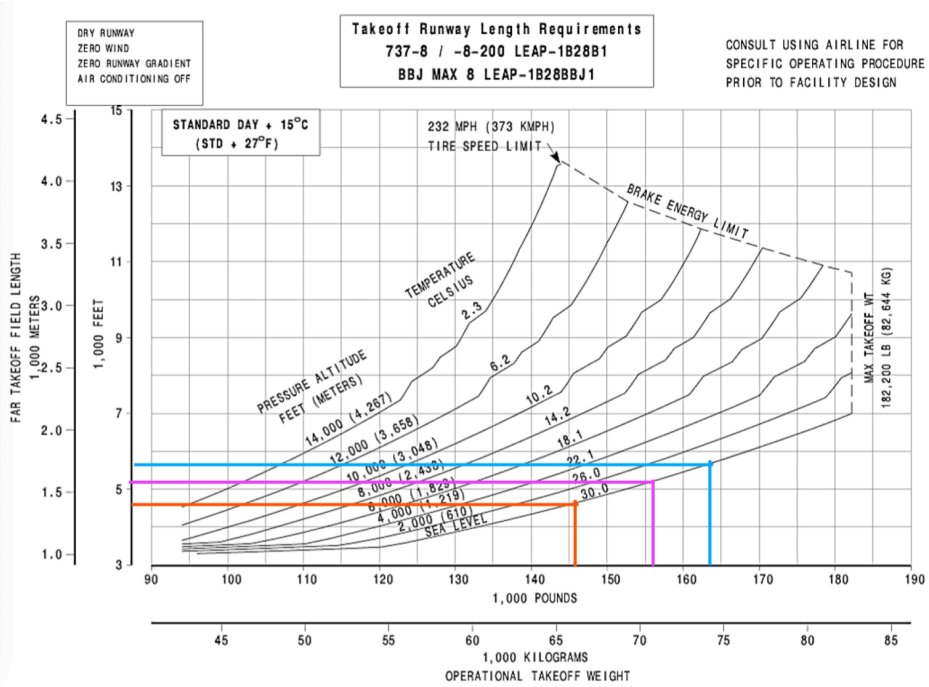


Figure 3.3.14 in Boeing 737-8Max Airport Planning Document

ISA + 27 deg. F.

SNA-BOS Analysis

Figure 6. Takeoff Field Length for Boeing 737-8Max. Source: Boeing Aircraft Co. (Figure 3.4.6 in Boeing 737-8Max Airplane Characteristics for Airport Planning).

Problem 2 (30 Points)

Use the Small Aircraft Runway Length Analysis Tool (SARLAT) to evaluate and improve an existing 4,900 foot long runway located at an airport 3,900 feet above mean sea level conditions. The average of the maximum daily temperatures of the hottest month of the year is 82 degrees F. The runway has a grade of 0.7%. The airport is expected to serve single, multi-engine piston, turboprop and jet powered aircraft (see Table 2).

Table 2. Aircraft Fleet Mix for Problem 2.

Aircraft Type	Aircraft	Percent of Fleet Mix (%)
Piston	Cessna 172	20
Piston	Cessna 402	10
Piston	Diamond Twin-Star	10
Turboprop	Beechcraft King Air C90	10
Turboprop	Socata TBM 850	10
Jet	Cessna 560 560 XL	10
Jet	Hond Jat 420	10
Jet	Cessna Citation I	10
Jet	Embraer Phenom 300	10
Total		100

a) Is the existing runway length available suitable for corporate jet operations if the runway pavement is wet? Explain some of the constraints with numbers obtained in your analysis.

A wet runway limits the operations of corporate aircraft to useful load values between 61-74%. The Honda Jet cannot operate in wet runway conditions. Piston and turboprop aircraft can operate from the existing runway with good useful load factors.

Aircraft Name	Aircraft Mix	Takeoff Weight (Useful Load)		Landing at Maximum Landing			
				No Correction		Part 135 Eligible	
		Dry	Wet	Dry	Wet	Dry	Wet
Jet							
Cessna 560 XL	10%	18741 lbs 80 %	17372 lbs 61 %	✓	✓	✓	✗
Cessna CitationJet 1	10%	9602 lbs 77 %	9125 lbs 63 %	✓	✓	✓	✓
Honda Jet 420 Elite	10%	9493 lbs 66 %	✗	✓	✓	✗	✗
Phenom 300	10%	17342 lbs 90 %	16327 lbs 74 %	✓	✓	✓	✓

b) Name the most critical aircraft operating at the airport.

The Honda Jet 420.

c) Find the runway extension needed in order to allow **takeoffs** with wet runway operations with at least 75% useful load for the most critical aircraft in the fleet.

A 5800-foot runway produces the desired results. The 900-foot extension allows the Honda Jet 420 to operate with a useful load of 77% (see Table below).

Aircraft Name	Aircraft Mix	Takeoff Weight (Useful Load)		Landing at Maximum Landing Weight					
				No Correction		Part 135 Eligible		Part 135	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	W
Piston									
Cessna 172 Skyhawk	20%	2300 lbs 100 %	2300 lbs 100 %	✓	✓				
Cessna 402B	10%	6300 lbs 100 %	6300 lbs 100 %	✓	✓				
Diamond 42 Twin Star	10%	3748 lbs 100 %	3748 lbs 100 %	✓	✓				
Turboprop									
Beechcraft King Air C90	10%	10485 lbs 100 %	10485 lbs 100 %	✓	✓			✓	✓
Socata TBM 850	10%	7394 lbs 100 %	7394 lbs 100 %	✓	✓			✓	✓
Jet									
Cessna 560 XL	10%	20200 lbs 100 %	19033 lbs 84 %	✓	✓	✓	✓	✗	✗
Cessna CitationJet 1	10%	10269 lbs 96 %	9708 lbs 80 %	✓	✓	✓	✓	✓	✗
Honda Jet 420 Elite	10%	10700 lbs 100 %	9875 lbs 77 %	✓	✓	✓	✓	✗	✗
Phenom 300	10%	17968 lbs 100 %	17547 lbs 93 %	✓	✓	✓	✓	✓	✗

d) Find the runway extension needed in order to allow landing operations under Part 135 eligible with wet runway operations for all the aircraft in the fleet.

The proposed 5800 foot runway allows all aircraft to operate under FAR Part 135 Eligible.

e) Comparing solutions in parts © and (d), what is the recommended runway extension for the airport to satisfy both conditions?

Both conditions are achieved simultaneously. The runway extension of 900 feet is sufficient to satisfy both conditions.

Problem 3 (30 points)

True or false section.

Question	True / False
Runway 31L at JFK has a displaced threshold longer than 3,000 feet.	TRUE
The Bombardier CRJ200 is a popular 70-seat regional aircraft.	FALSE
The Douglas DC-8 was a popular turboprop-powered aircraft in the 1950s.	False (the DC-8 was a turbojet powered aircraft)
San Francisco runway 28L is a precision runway with medium intensity approach lights.	TRUE
Part 135 refers to non-scheduled operations conducted by air taxi operators in the US.	TRUE
A 70-knot exit speed EMAS designed for a Boeing 757-200 has a total length of 450 feet.	TRUE
The ADG group for the Boeing 747-8 is V.	FALSE
An aircraft with a 155 knot approach speed belongs to AAC group D.	TRUE
Approach speeds used to designate AAC groups are measured at the minimum landing weight.	FALSE
The taxiway design group for the Airbus A350-1000 is 5.	TRUE
The route distance typically flown from Los Angeles International to Sidney (Australia) is 6,500 nautical miles.	FALSE
In the year 2021, the number of **arriving** passengers to Bangor Maine exceeded 300,000.	False (286,000)
In 2021, Spirit Airlines carried the largest number of passengers from Fort Lauderdale International Airport	True (30% share)
Runway 1 threshold at DCA airport has a non-compliant RSA area (Boeing 757-200 is the critical aircraft).	True (700-foot RSA). 1000 feet needed.

Further Explanation of Operating Empty Weight Estimates

Boeing does not publish OEW values for the new generation aircraft. This is perhaps because every airline customer has unique requirements (seating, galleys, etc.) that change the value of OEW. Nevertheless, a typical OEW is important for some of the calculations we do.

An earlier Boeing 737-8 Max document (Revision A) contained information about OEW in the Airplane Characteristics for Airport Design document. OEW was cited to be 99,360 lbs. in 2017 when the aircraft entered service (se Table below).

737 MAX
Airplane Characteristics for Airport Planning

DOCUMENT NUMBER:	REVISION:	REVISION DATE:
D6-38A004	**A**	**August 2017**

CONTENT OWNER:

Boeing Commercial Airplanes

2.1.1 General Characteristics: Model 737-8 / -8-200 /

CHARACTERISTICS	UNITS	MODEL 737-8
MAX DESIGN TAXI WEIGHT	POUNDS	181,700
	KILOGRAMS	82,417
MAX DESIGN TAKEOFF WEIGHT	POUNDS	181,200
	KILOGRAMS	82,190
MAX DESIGN LANDING WEIGHT	POUNDS	152,800
	KILOGRAMS	69,308
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	145,400
	KILOGRAMS	65,952
OPERATING EMPTY WEIGHT *[1]	POUNDS	99,360
	KILOGRAMS	45,070
MAX STRUCTURAL PAYLOAD *[1]	POUNDS	46,040
	KILOGRAMS	20,882

The latest version of the Boeing 737-8Max Airplane Characteristics for Airport Design document skips that information and offers information on three variants of the Boeing 737-8 Max (see table below).

737 MAX
Airplane Characteristics for Airport Planning

DOCUMENT NUMBER:	REVISION:	REVISION DATE:
D6-38A004	**REV G**	**May 2022**

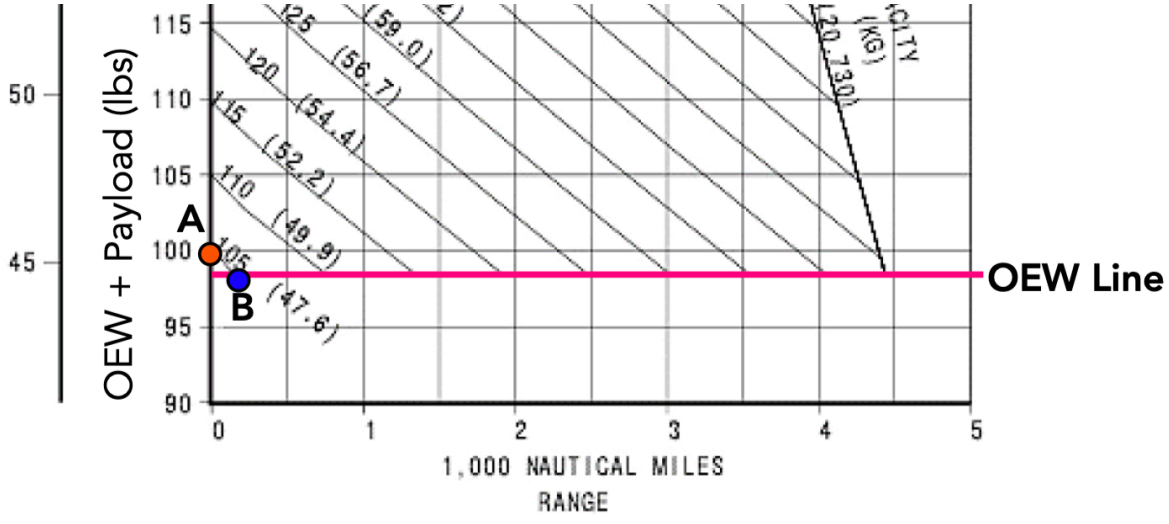
CONTENT OWNER:

Boeing Commercial Airplanes

2.1.2 General Characteristics: Model 737-8

CHARACTERISTICS	UNITS	MODEL 737-8		
MAX DESIGN TAXI WEIGHT	POUNDS	159,900	180,300	182,700
	KILOGRAMS	72,529	81,782	82,871
MAX DESIGN TAKEOFF WEIGHT	POUNDS	159,400	179,800	182,200
	KILOGRAMS	72,302	81,555	82,644
MAX DESIGN LANDING WEIGHT	POUNDS	150,300	150,300	152,800
	KILOGRAMS	68,174	68,174	69,308
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	142,900	142,900	145,400
	KILOGRAMS	64,818	64,818	65,952

The payload-range diagram seems to be an alternative to estimate OEW (see picture below).



Consider the definition of Operating Empty Weight offered by Boeing:

"Operating Empty Weight (OEW). Weight of structure, power plant, furnishing systems, ***unusable fuel and other unusable propulsion agents,*** *and other items of equipment that are considered an integral part of a particular airplane configuration. Also included are certain standard items, personnel, equipment, and supplies necessary for full operations, excluding usable fuel and payload."*

Note that OEW includes fuel and oils trapped on the fuel lines and tanks - fuel that is kind of unusable once the aircraft is in service. It seems reasonable to assume that the horizontal line shown in the figure above, represents a good estimate of OEW. Note that the 2017 Boeing 737-8 Max document validates the point. OEW in early models was 99,360 lbs. The pink OEW line shown in the closeup payload range diagram validates the early number.

After certification, aircraft manufacturers perform more testing on the aircraft that could result in small changes to the OEW value of the aircraft. However, those changes are small because any reduction in the OEW will require expensive flight and static testing to ensure the aircraft meets the safety margins required in certification.