Paine Field Master Plan 2040

Appendix D | Runway Length Analysis

D

May 2024

PREPARED FOR
Snohomish County

PREPARED BY
Landrum & Brown, Incorporated

D. Runway Length Analysis

Runway Length Analysis Methodology

The aircraft manufacturers' airport planning manuals from Boeing and Embraer were utilized in conjunction with the future forecast fleet mix developed for the Master Plan Update to calculate the future runway length requirements specific to unique conditions at PAE. Aircraft runway length requirements are determined using many factors including:

- Aircraft Fleet
- Density Altitude (temperature and elevation)
- Runway Characteristics

Aircraft Fleet

The aircraft fleet currently operating are projected to operate at an airport are critical components to determining runway length requirements for that airport. There are two separate fleets at PAE that were used to calculate runway length requirements.

Commercial Passenger and Cargo Aircraft

The commercial and cargo aircraft projected to serve PAE in the future was used to calculate the payload-range analysis. This consisted of the most critical passenger and cargo aircraft traveling their furthest destinations that made up at least 500 operations annually in the future fleet mix per FAA AC 150/5000-17, *Critical Aircraft and Regular Use Determination*. The analysis was paired down to three aircraft that could potentially end up as the critical aircraft for runway length at PAE. These three aircraft include the B737-900ER, EMB175, and B757F.

Other Commercial Aircraft

Additionally, a separate runway length analysis was conducted for aircraft in the Other Commercial aircraft category, which consists of Boeing test aircraft and Maintenance, Repair and Overhaul (MRO) traffic. Aircraft in this category are likely to take off and land with substantially less weight since they are not carrying passengers or cargo to and from other airports. Two aircraft in the Other Commercial aircraft category depicted over 500 annual operations in the future fleet mix for 2040. These two aircraft were used to calculate runway length requirements using a different methodology than the commercial and cargo aircraft. The two other commercial aircraft analyzed at PAE were the B737-800, which is projected to make up nearly 900 operations by 2040 and the B777X, which is projected to make up nearly 1,378 operations by 2040. The B777X is expected to replace the B787 operations at PAE once Boeing testing progresses and production begins on the aircraft. Since the planning manual is not complete from Boeing at this time, the B777-300ER was used as a substitute in the runway length analysis conducted in this Master Plan. The B777-300ER is not a direct reflection of the B777X required runway length but a temporary substitute for this analysis. It is recommended a complete

runway length analysis be conducted once Boeing releases the B777X airport planning manual graphs for runway length.

The forecasted aircraft fleet and the distance to each of their furthest destinations used in the runway length analysis are further depicted in **Table D-1, *Aircraft / Destination used for Runway Length Analysis***.

Table D-1 Aircraft / Destination used for Runway Length Analysis

Aircraft	Type	2040 Annual Forecast Operations	Furthest Destination[1]	Distance from RDU (NM)
B737-900ER	Commercial Passenger	20,753	ORD	1,494
EMB175	Commercial Passenger	20,753	PHX	984
B757F	Cargo	1,248	MEM	1,634
B777X/B777-300ER[2]	Other Commercial	1,378	N/A[3]	N/A[3]
B737-800	Other Commercial	877	N/A[3]	N/A[3]

[1] MEM - Memphis International Airport, ORD - Chicago O'Hare International Airport, PHX - Phoenix Sky Harbor International Airport

[2] B787's from the historical forecast were converted to B777X aircraft due to the shift in the B787's to the east coast and the potential development of the B777X in PAE. B777-300ER will be used as a comparable substitute aircraft in the runway length analysis since the B777X airport planning manual does not depict enough information yet to conduct a complete runway length analysis. The B777-300ER is also a representative aircraft in the fleet making up over 500 annual operations.

[3] Destinations were not identified for the other commercial aircraft.

Note: NM stands for nautical mile.

Source: Landrum & Brown

Density Altitude

Density altitude is a natural phenomenon that results in decreased aircraft and engine performance as density altitude increases. It is a function of the combination of an airport's elevation and temperature. The higher the elevation and/or temperature, the higher the density altitude and its effects will be. Because higher density altitude decreases an aircraft's operational performance, longer runway distances are required for takeoffs and landings at airports with a higher elevation or in hotter climates.

Temperature

The aircraft manufacturers' manuals contain charts to calculate takeoff runway length requirements based on temperature. Takeoff length requirements may be calculated based on "standard day" (defined as 59 degrees Fahrenheit) or a "hot day." The hot day charts in the aircraft manufacturers' manuals vary the conditions of the hot day depending on the aircraft type. Most airport planning manuals offer one "hot day" chart, which utilizes 86 degrees Fahrenheit.

The determination of which temperature chart to use depends upon the average or typical weather conditions for a particular airport. FAA guidance prescribes the use of an airport's mean-max temperature for runway length calculations, which would indicate the use of the "hot day" charts, where possible. The mean-max temperature is defined as the average daily maximum temperature of the hottest month. The mean daily maximum temperature at PAE is 73 degrees Fahrenheit.[1]

Advisory Circular 150/5325-4B, *Runway Length Requirements for Airport Design* states "takeoff length calculations for a "hot day" analysis must be within 3 degrees Fahrenheit of the "hot day" charts available in the Airport Planning Manuals". All airport planning manuals in this analysis offered an 86-degree Fahrenheit "hot day" chart so that was not used as the preferred method of temperature adjustment in this analysis. With a mean daily maximum temperature of 73 degrees, this does not fall within the 3-degree window of acceptability according to the FAA's AC. Therefore, a temperature adjustment was used for these three aircraft. International Civil Aviation Organization (ICAO) Document 9157, Aerodrome Design Manual, Part 1- Runways, Fourth Edition 2020 was used to assist in the calculation of the hot day runway length requirements. This was used because the airport planning manuals do not offer takeoff length charts for 73 degrees Fahrenheit adjustments. ICAO states the runway length determined on a standard day chart may be increased at the rate of one percent for every one degree Celsius above the standard atmospheric condition (15 degrees Celsius or 59 degrees Fahrenheit). This resulted in approximately an eight-percentage increase in runway length from the standard day requirement for each aircraft.

Airfield Elevation

Airfield elevation is the second component to density altitude. It is used as an input factor on the takeoff charts from the aircraft manufacturers' airport planning manuals to determine accurate takeoff and landing requirements. The higher the elevation of PAE, the less efficient an aircraft wing is at producing lift, thus requiring higher airspeeds to produce a comparable amount of lift. Longer runways are required to accommodate aircraft traveling at higher airspeeds. The Airport elevation at PAE is 606.9 feet above Mean Sea Level (AMSL).[2]

Runway Characteristics

Runway characteristics such as runway slope and surface contamination (wet conditions) are also an important part of the inputs used to determine runway length requirements for an airport.

Runway Slope

The runway length charts in the aircraft manufacturers manuals are based on a runway slope of zero. An aircraft taking off on an uphill gradient requires more runway length than it does on a flat or downhill slope. FAA AC 5325-4b recommends an adjustment for non-zero effective runway gradients.[3] At PAE, there is a positive slope on existing Runway 16R takeoffs, an elevation change of 15.1 feet. For this

1 Airport mean-max temperature defined by the National Oceanic & Atmospheric Administration (NOAA), Summary of Daily Normals 1991-2020, July.
2 FAA Airport Master Records and Reports, Form 5010 for Paine Field, effective October 07, 2021.
3 AC 150/5325-4B states that runway lengths are increased at the rate of 10 feet (3 meters) for each foot (0.3 meters) of elevation difference between the high and low points of the runway centerline.

reason and per the AC, 151 feet was added to the required takeoff length analysis for each aircraft analyzed.

Surface Contamination (Wet Conditions)

Runways that are subject to frequent surface contaminants such as rain and snow often require longer landing lengths than dry surfaces. Some aircraft manufacturers have designated landing length charts for contaminated surfaces, while others do not. Boeing landing charts offer contaminated landing length charts, while Airbus did not. In this analysis, 15 percent was added to each dry landing length calculation where a contaminated chart did not exist per FAA AC 5325-4b, *Runway Length Requirements for Airport Design*, 2005.

Takeoff Length Requirements

Commercial Passenger and Cargo Aircraft

For commercial and cargo aircraft in the future fleet, runway takeoff length requirements were calculated using a payload/range analysis with 100 percent payload, where possible, to the furthest destination for each aircraft in the fleet mix.

For commercial and cargo aircraft in the forecasted fleet mix, the EMB175 and B757F are both able to take 100 percent payload when taking off on the existing Runway 16R-34L. However, the B737-900ER requires 9,400 feet of runway length to take 100 percent payload to Chicago O'Hare International Airport (ORD). On 9,000 feet runway (Runway 16R-34L), the B737-900ER would need to take a reduced payload in order to get to ORD. This results in an eight percent reduction in total payload, meaning the B737-900ER could only take 92 percent of the maximum allowable payload to ORD when taking off on Runway 16R-34L from PAE.

Other Commercial Aircraft

Other commercial aircraft were analyzed differently since there are no scheduled destinations and no passengers are on-board the other commercial aircraft during these flights. These flights could be taking off from PAE post-MRO visits or as part of Boeing's production and testing at PAE. For these two aircraft, a reduced takeoff weight analysis was completed instead of a payload-range analysis. The B777X and B737-800 takeoff length analysis used the following assumptions on their reduced takeoff weights. Takeoff Weight (TOW) is representative of the operating empty weight (OEW) of the aircraft plus the fuel and payload needed for the flight:

- Fuel: 25% (10%-taxi, takeoff, and climb, 5%-descent, 10%-Cruise)
- Operating Empty Weight (OEW): 100%
- Payload: up to 50%

These weight reductions are identified in **Table D-2, *Other Commercial Aircraft- Reductions in Takeoff Weights***.

Table D-2 Other Commercial Aircraft- Reductions in Takeoff Weights

Takeoff Weight Component (lbs.)	Takeoff Weight Reduction (%)	B777X Weight (lbs.)	B737-800 Weight (lbs.)
Fuel	25%	80,215	11,515
OEW	100%	370,000	91,300
Payload	50%	77,000	23,500
Reduced Takeoff Weight Total		**527,215**	**126,315**

Source: Landrum & Brown

The takeoff length requirements for both categories of aircraft are presented in **Table D-3, *Takeoff Length Requirements***.

Table D-3 Takeoff Length Requirements

Aircraft	Furthest Destination[1]	Hot Day Takeoff Length Requirement (with slope adjustment in feet)[2,3,4]	% Payload to Destination
B737-900ER	ORD	9,400	100%
EMB175	PHX	8,600	100%
B757F	MEM	7,600	100%
B777X (B777-300ER)[5]	N/A	5,600	50%
B737-800	N/A	4,400	50%

1 MEM- Memphis International Airport; ORD- Chicago O'Hare International Airport; PHX- Phoenix Sky Harbor International Airport

2 AC 150/5325-4B, *Runway Length Requirements for Airport Design*, 2005 states that "Runway lengths are increased at the rate of 10 feet (3 meters) for each foot (0.3 meters) of elevation difference between the high and low points of the runway centerline".

3 ICAO Document 9157, *Aerodrome Design Manual, Part 1- Runways*, Fourth Edition 2020 was used to calculate hot day runway length requirements. This was used because the Boeing and Embraer Airport Planning Manuals do not offer takeoff length charts for 73 degrees Fahrenheit adjustments.

4 FAA AC 150/5325-4B, *Runway Length Requirements for Airport Design* states that analyses may round lengths of 30 feet and over to the next 100-foot interval.

5 B777-300ER will be used as a comparable substitute aircraft in the runway length analysis since the B777X airport planning manual does not depict enough information yet to conduct a complete runway length analysis.

Source: Landrum & Brown

Landing Length Requirements

Landing length requirements were calculated using maximum landing weights for dry conditions and with contaminated surface conditions (wet conditions). Contaminated or wet Landing length requirements ranged from 5,400 feet (EMB175) to 7,300 feet (B777X: B777-300ER used). The landing

length requirements are presented in **Table D-4, *Landing Length Requirements*.** As depicted, the runway length requirements for aircraft takeoffs exceed the requirements for aircraft landings.

Table D-4 Landing Length Requirements

Aircraft	MLW (lbs.)	Landing Length (feet) Dry Conditions	Landing Length (feet) Wet Conditions
B737-900ER	157,300	5,700	6,500
EMB175[1]	74,957	4,650	5,400
B757F	210,000	5,200	6,000
B777X (B777-300ER)[2]	554,000	6,300	7,300
B737-800	146,300	5,800	6,800

[1] Landing length requirements were calculated using contaminated runway input (wet charts where available and additional 15 percent where only dry charts were available).

[2] B777-300ER will be used as a comparable substitute aircraft in the runway length analysis since the B777X airport planning manual does not depict enough information yet to conduct a complete runway length analysis.

Note: lbs. stands for pounds.

Source: Landrum & Brown