Kuliah Pertemuan 13: Basic Runway Length

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Basic Runway Length

- Basic runway length is the length of runway required based on the imposed performance requirements of the critical aircraft under standard conditions.
- Basic runway length has to be determined for the following three general cases:
  - Normal landing case
  - Normal Takeoff case
  - Engine failure case
    - Continued takeoff
    - Aborted takeoff (Engine failure accelerated stop)
Runway Component

- The three basic components of runway are: – Full strength pavement (FS) – Clearway (CL) – Stopway (SW)
  - **Full strength pavement** should support the full weight of the aircraft
  - **Clearway** is a prepared area beyond FS, clear of obstacles (max slope is 1.25%), allowing the aircraft to climb safely to clear an imaginary 11 m (35’) obstacle.
  - **Stop way** is a paved surface that allows an aircraft overrun to take place without harming the vehicle structurally (cannot be used for takeoff).
Runway Component

- Each runway end has to be considered individually for runway length analysis
Clearway

Direction of operation

Departure end of runway
Maximum Upward Slope (1.25%)

Clearway

Clearway Length

150 m

Stopway

Performance Speed – Take off Case
Performance Speeds

- Once the maximum permissible take off weight has been determined and it is confirmed that the actual weight is within the limits, it is necessary to find the take off speeds corresponding to the actual weight.

- The flight crew must be thoroughly familiar with each of the speeds that affect the aircraft’s takeoff performance and how they are used in takeoff planning.

- Performance speeds change relative to aerodrome conditions, aircraft weight and configuration.
Performance Speeds

$V_1$ – decision speed
$V_R$ – rotation speed
$V_{LOF}$—lift-off speed.
$V_2$—the takeoff safety speed.
Performance Speeds

- \( V_1 \) – decision speed, the speed which dictates whether a malfunction during the takeoff roll results in rejecting the takeoff, or continuing. (go or no go speed)
- \( V_R \) – rotation speed, at which aircraft nose is lifted from the ground (rotated) for take off;
- \( V_{LOF} \) – lift-off speed. The speed at which the aircraft first becomes airborne.
- \( V_2 \) – the takeoff safety speed which must be attained at the 35ft height at the end of the required runway distance.
Relationships Between V-speeds

- VR must always be ≥ V1
- VLO must always be ≥ VR
- V2 must always be > VR
- These relationships will always hold true, but the speeds themselves will change according to aircraft weight, atmospheric conditions, aircraft configuration, and runway conditions.
- V1, VR, and V2 will float between their minimum and maximum limits dependant on conditions and requirements.
Runway Dimensions

• For any particular take off it must be shown that the distance required for take-off at any conditions does not exceed the **Take-off Distance Available (TODA)** at the runway.

• Take-off Distance Available = TODA.
Declared distances

- For any given runway, four declared distances defined by ICAO are

- Take Off Run Available \( \text{TORA} \)
- Take-off Distance Available \( \text{TODA} \)
- Accelerate-stop Distance Available \( \text{ASDA} \)
- Landing Distance Available \( \text{LDA} \)
Nomenclatures

- FL = field length (total amount of runway needed)
- FS = full strength pavement distance
- CL = clearway distance
- SW = stopway distance
- LOD = lift off distance
- TOR = takeoff run
- TOD = takeoff distance
- LD = landing distance
- SD = stopping distance
- D35 = distance to clear an 11 m (35 ft.) obstacle
Declared distances
Declared distances

- **Runways:** A defined area for aircraft take-off & landing.
- **Stopways:** Area beyond the end of runway.
- **Clearways:** Include the stopway and any additional surface cleared of obstacle.
Stopways & Clearway

Stopways

- An area of ground where the aircraft can be safely brought to a stop in an emergency.
- The stopway should be clear of obstructions that could damage the aircraft.

Clearway

- An area under the control of the appropriate authority, selected or prepared as a suitable area over which an aircraft may make a portion of its initial climb to a specified height.
Declared distances

- **TODA** is equal to the length of the take-off run available plus the length of the clearway.
  \[ \text{TODA} = \text{TORA} + \text{CWY} \]

- **TORA** is defined as the length of runway available for the ground run of an aeroplane taking off.
  \[ \text{TORA} = \text{Full Length of RW} \]

- **ASDA** is defined as the length of the take-off run available plus the length of any SWY.
  \[ \text{ASDA} = \text{TORA} + \text{SWY} \]

- **LDA** is defined as the length of runway available for the ground run of a landing aeroplane.
Normal Landing Case

- Pilot approaches with proper speed and crosses the threshold of the runway at a height of 15m
- The demonstrated distance to stop an aircraft should be within 60% of landing distance

\[ LD = 1.667 \times SD \]

\[ FS_{\text{land}} = LD \]
Normal Takeoff Case

- The length of runway depends on
  - Lift off distance (LOD)
  - Distance to reach a height of 35 feet (~11 m) (D35)
- Take of Distance (TOD) is taken as 1.15 times the D35
  - The entire length of TOD need not be of full strength pavement.
  - The regulations permit the use of Clearway at the end of full strength pavement
- Clearway Length (CL) = 0.5(TOD-1.15LOD)
- The full strength runway, which is TOD-CL, is also termed as Take off Run (TOR)
Normal Takeoff Case

\[\text{TOD}_n = 1.15 \times \text{D35}_n\]

\[\text{CL}_n\]

\[\text{Clearway}\]

\[11\text{ m (35 ft)}\]

\[\text{TOD}_n - 1.15 \text{ LOD}_n\]

\[1.15 \text{ LOD}_n\]

\[\text{D35}_n\]

\[\text{LOD}_n\]

**RELATIONSHIPS:**

\[\text{CL}_n = \frac{1}{2} (\text{TOD} - 1.15 \text{ LOD})\]

\[\text{TOR}_n = \text{TOD}_n - \text{CL}_n\]

\[\text{FS}_n = \text{TOR}_n\]

\[\text{FL}_n = \text{FS}_n + \text{CL}_n\]
Engine Failure Continued
Takeoff Case

- Engine failure continued takeoff
  - TOD and LOD will be longer than those in normal takeoff case
  - TOD is taken as D35 with no percentage applied
  - Regulations permit the use of clearway at the end
  - Length of Clearway (CL) is half the difference between TOD and LOD
  - FS = TOR = TOD-CL
  - FL = FS + CL
Engine Failure Aborted Takeoff Case

- The length of runway should be sufficient to bring the plane to a stop.
- The distance required by an aero plane for accelerating, decelerating and coming to a stop, in such a situation, is termed as Distance to Accelerated Stop (DAS).
- For piston engine aircrafts, full strength pavement is used for the entire DAS.
- For turbine engine aircrafts, regulations permit the use of Stopway for portion of DAS beyond TOR.
Engine Failure Case

Aborted Takeoff

\[ F_{S_{eo-a}} = DAS - SW \]

\[ F_{L_{eo-a}} = F_{S_{eo-a}} + SW \]

Continued Takeoff

\[ TOD_{eo} = D35_{eo} \]

\[ CL_{eo} = \frac{1}{2} (D35_{eo} - LOD_{eo}) \]

\[ TOR_{eo} = D35_{eo} - CL_{eo} \]

\[ F_{S_{eo-c}} = TOR_{eo} \]

\[ F_{L_{eo-c}} = F_{S_{eo-c}} + CL_{eo} \]
Example Problems

- Determine the runway length requirements according to the specifications for a turbine powered aircraft with the following performance characteristics:
  - Normal Landing:
    - SD = 2540 m
  - Normal Takeoff:
    - LOD = 2134 m
    - D35 = 2438 m
  - Engine Failure Continued Takeoff:
    - LOD = 2500 m
    - D35 = 2774 m
  - Engine Failure Aborted Takeoff:
    - DAS = 2896 m
Solution

- Normal landing:
  \[ LD = 1.667 \times SD = 1.667 \times 1524 = 2540 \text{ m} \]

- Normal takeoff:
  \[ TOD = 1.15 \times (D35) = 1.15 \times 2438 = 2804 \text{ m} \]
  \[ CL = 0.5 \times (TOD - 1.15 \times LOD) = 0.5 \times (2804 - 1.15 \times 2134) = 175 \text{ m} \]
  \[ TOR = TOD - CL = 2804 - 175 = 2629 \text{ m} \]

- Engine failure take off:
  \[ TOD = D35 = 2774 \text{ m} \]
  \[ CL = 0.5 \times (TOD - LOD) = 0.5 \times (2774 - 2500) = 137 \text{ m} \]
  \[ TOR = TOD - CL = 2774 - 137 = 2637 \text{ m} \]

- Engine failure aborted take off:
  \[ DAS = 2896 \text{ m} \]

- Summary:
  \[ FL = \max (LD, TOD, DAS) = 2896 \text{ m} \]
  \[ FS = \max (TOR, LD) = 2637 \text{ m} \]
  \[ SW = (DAS - FS) = 259 \text{ m} \]
  \[ CL = FL - (FS + SW) = 2896 - 2896 = 0 \]
Environs at the Airport

- Basic runway length is valid under the following assumed conditions at the airport
  - Altitude is at sea level
  - Temperature at the airport is standard
  - Runway is level in the longitudinal direction
  - No wind is blowing on runway
  - Aircraft is loaded to its full loading capacity
  - No wind is blowing en route to the destination
  - En route temperature is standard
Corrections to Basic Runway Length

• The basic runway length is corrected for the actual conditions at the airport

• The following corrections are applied:
  – Correction for elevation
  – Correction for temperature
  – Correction for gradient
Correction for Elevation

- High altitudes reflect low air densities, resulting in lower output of thrust.
- Therefore, higher the altitude the longer the runway required.
- The increase in runway length with altitude is not linear and it varies with weight and temperature.
- The rate of increase at higher altitudes is higher than at lower altitudes.
- ICAO, however, recommends that the basic runway length should be increased at the rate of 7% per 300 m rise in elevation above mean sea level.
- There is exception for high temperature and high altitude areas, where the increase could be up to 10%.
Correction for Temperature

- Higher temperatures reflect lower air densities resulting in lower output of thrust.
- Therefore, higher the temperature the longer the runway required.
- The increase in runway length with temperature is not linear.
- The rate of increase at high temperatures is greater than at lower temperatures.
- ICAO, however, recommends that the base runway length after having been corrected for elevation, should be further increased at the rate of 1% for every 1°C rise of airport reference temperature above the standard atmospheric temperature at that elevation.
Airport Reference Temperature

If,

\[ T_1 = \text{Mean of the mean daily temperatures for the hottest month} \]

\[ T_2 = \text{Mean of the maximum daily temperatures for the hottest month} \]

Then, airport reference temperature \((T)\) is found out as

\[ T = T_1 + \frac{(T_2 - T_1)}{3} \]
Standard Atmospheric Temperature

- The standard temperature at mean sea level is 15°C.
- The temperature gradient of the standard temperature from the mean sea level to the altitude at which the temperature becomes -15.5°C is 0.0065°C per metre.
- The temperature gradient becomes zero at the elevation above the altitude at which the temperature is -15.5°C.
Check for Correction

- The total correction in basic runway length for elevation and temperature should not exceed 35%.
- If this correction exceeds 35% further checks are needed using model studies.
Correction for Gradient

- If the runway is on gradient, the aircraft has to overcome the grade resistance.
- More runway length is required to achieve the required speed for liftoff.
- Studies indicate that the runway length varies linearly with the gradient.
- Airport design criteria limits the runway gradient to a maximum of 1.5%
Effective Gradient

- For applying correction to runway length for gradient, FAA uses effective gradient.
- Effective gradient is defined as the maximum difference in elevation between the highest and the lowest points of runway divided by the total length of runway.

\[ \text{Effective gradient} = \frac{(h_4 - h_3)}{L} \]
Correction for Gradient

• FAA recommends that the runway length after having been corrected for elevation and temperature should be further increased at the rate of 20% for every 1% effective gradient.
Example Problem

- Determine the actual length of runway to be provided for the following data
- Basic runway length: 1500 m
- Elevation of the runway: 110 m +MSL
- Mean of average daily temperatures for the hottest month: 18°C
- Mean of maximum daily temperatures: 30°C
- The construction plan includes the following data:

<table>
<thead>
<tr>
<th>Station to Station</th>
<th>Gradient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 300</td>
<td>0.5</td>
</tr>
<tr>
<td>300 – 900</td>
<td>-0.3</td>
</tr>
<tr>
<td>900 – 1500</td>
<td>1.0</td>
</tr>
<tr>
<td>1500 – 1800</td>
<td>-0.5</td>
</tr>
<tr>
<td>1800 - 2100</td>
<td>-0.3</td>
</tr>
</tbody>
</table>
Solution

- Correction for elevation = $(7/100) \times (110/300) \times (1500) = 38.50 \text{ m}$
- Corrected length = $1500 + 38.50 = 1538.50 \text{ m}$
- Correction for temperature:
  - Standard temperature = $15 - 0.0065 \times 110 = 14.285^\circ \text{C}$
  - Airport reference temperature = $18 + (30-18)/3 = 22^\circ \text{C}$
  - Correction = $1538.5 \times (22-14.285) \times (1/100) = 118.7 \text{ m}$
  - Corrected length = $1538.5 + 118.7 = 1657.2 \text{ m}$
- Check for elevation and temperature correction
  - Increase in runway length = $(1657.2-1500)/(1500/100) = 10.48\% < 35\%$
  - Okay
Solution Contd.

- Correction for gradient
  - Station 0 300 900 1500 1800 2100
  - Elevation 100 101.5 99.7 105.7 104.2 103.3

- Effective gradient = \([(105.7 - 99.7)/1657.2] \times 100 = 0.362\%
- Correction = 1657.2 \times (0.362 \times 20)/100 = 120 m
- Corrected length = 1657.2 + 120 = 1777.2 m

- Actual runway length at the airport = 1780 m.