Landing on Slippery Runways

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Landing on a Slippery Runway

**Agenda**

- Review available landing data
  - Certified data
  - QRH advisory data
    - Unfactored status
    - Autobrake performance
- Operational implementation of QRH advisory data
  - Runway condition reporting
  - Margins
- Flying the airplane
Landing Distance Data

Boeing provides two distinct and different data sets:

**Certified Data**
- **Purpose**: Provide landing distance as required by regulations
- **Requirements**: FAR Parts 25 and 121, JAR Part 25 and JAROPS 1
- **Use**: Determine landing distance requirements prior to dispatch

**Advisory Data**
- **Purpose**: Provide landing distance capability for different runway conditions and braking configurations
- **Requirements**: FAR 121 and JAROPS 1
- **Use**: Determine landing distance for making operational decisions
Landing Distance Data
CERTIFIED Data Method

• Dry runway
• Max manual braking
• No reverse thrust

50 ft — x

Reference Runway

DEMONSTRATED CAPABILITY

CERTIFIED FAR Dry

CERTIFIED FAR Wet/slippery
Landing Distance Data

ADVISORY Data Method

- Dry runway
- Max manual braking
- With reverse thrust

Reference Runway – FAR wet/slippery

**ADVISORY**

- **Dry runway**

**Good** braking
*30-40% margin*

**Medium** braking
*0-5% margin*

**Poor** braking
*-20-25%

* Values dependant on airplane model

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• 1000' Reverse

- Values dependant on airplane model
Reference distance is for sea level, standard day, VREF 40 approach speed and 2 engine detent reverse thrust
Actual (unfactored) distances are shown
Includes distance from 50 ft. above the threshold (1000 ft of air distance)

JAR operators advisory data in QRH include 1.15 factor

Based on these notes
Reverse Thrust Application Sequence

As Applied in QRH Advisory Data

1. Touchdown
   - At 60 knots decrease to reverse idle
   - Selected reverse thrust level – max or detent depending on model

2. Transition
   - 2 – 4 seconds*
   - Interlock cleared reverse deployed

3. Brake Application
   - 1 sec.
   - Select reverse to interlock

4. Reverser spinup to selected level
   - 1 – 3 sec.*
   - Reverser deployed

5. At 60 knots decrease to reverse idle
   - Selected reverse thrust level – max or detent depending on model

* Actual time dependant on engine/airframe
### Landing Distance Data

**ADVISORY Data—QRH Page**

- Provides adjustments for several variables

### Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Land Distance and Adjustments (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B- Configuration</td>
<td>105000 LB Landing Weight</td>
</tr>
<tr>
<td>MAX MANUAL</td>
<td>2510</td>
</tr>
<tr>
<td>MAX AUTO</td>
<td>2610</td>
</tr>
<tr>
<td>AUTOBRAKES 3</td>
<td>3140</td>
</tr>
<tr>
<td>AUTOBRAKES 2</td>
<td>4460</td>
</tr>
<tr>
<td>AUTOBRAKES 1</td>
<td>5100</td>
</tr>
</tbody>
</table>
Landing With Autobrakes Selected

• Autobrake system
  – Targets a deceleration level
  – Brakes applied as required to reach target deceleration level

• Deceleration is affected by three factors:
  – Aerodynamic drag
  – Wheel brakes – dependant on runway friction available
  – Reverse thrust
Maximum Deceleration Manual Versus Autobrakes

Dry runway

<table>
<thead>
<tr>
<th>Braking Applied</th>
<th>Max Manual</th>
<th>Autobrake Max</th>
<th>Autobrake 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
</tr>
<tr>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
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<tr>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
<td>Drag Brakes</td>
</tr>
<tr>
<td>Reverse Thrust</td>
<td>Reverse Thrust</td>
<td>Reverse Thrust</td>
<td>Reverse Thrust</td>
</tr>
</tbody>
</table>

Deceleration level achieved
Distance based on autobrake decel rate

Deceleration

Less

More
Maximum Deceleration Available from Brakes

- **Runway condition**
  - **Braking action**: e.g. stand on the brake pedals

- **Max Brakes**

- **Deceleration Available from Brakes**
  - **Better**
    - **Dry**
    - **Good**
    - **Med**
    - **Antiskid limited**
    - **Antiskid limited**
    - **Antiskid limited**
  - **Worse**
    - **Poor**
    - **Antiskid limited**
    - **Antiskid limited**

- **Braking Conditions**
  - **Less**
  - **More**

- **Max Brakes**
  - **e.g.** stand on the brake pedals
Good Braking

Max Braking Available

- Dry
  - Good
  - Med
  - Poor

Deceleration
- Decel Target

Braking Applied

Max Manual
- Drag
  - Brakes
- Reverse Thrust

Autobrake Max
- Drag
  - Brakes
  - Reverse Thrust

Autobrake 2
- Drag
  - Brakes
  - Reverse Thrust

Distance based on runway friction

Deceleration level NOT achieved

Deceleration level achieved
Distance based on autobrake decel rate
Maximum Deceleration

Poor Braking

Deceleration level NOT achieved
Distance based on runway friction
Autobrakes Versus Manual Brakes

- **Manual Brakes**
  - Dry runway: Reversers are additive
  - Slippery runway: Reversers are additive

- **Autobrakes**
  - Dry runway: Reversers NOT additive
  - Slippery runway: Reversers may be additive

- **Landing Distance Advisory Data includes reversers for Manual and Autobrakes**
Landing Distance Data
Summary

• **Certified Data** Set
  – NO reversers
  – Factored data
  – Required for dispatch

• **Advisory Data** Set
  – Reversers included
  – Unfactored data
  – Operators add margin appropriate to their operation
  – Used for making operational decisions

• The data sets are different with a different purpose
Landing on a Slippery Runway

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- **Operational implementation of QRH advisory data**
  - Runway condition reporting
  - Margins
- **Flying the airplane**
Runway Condition Reporting

Runway condition is typically provided three ways:

- **PIREP’s (pilot reports)** – braking action – good, fair, medium, poor, nil
- **Description of runway condition**
  - Snow, wet, slush, standing water, sand treated compact snow etc.
- **Reported friction based on Ground Friction Vehicle Report**
  - 30 or 0.30 etc.
Evaluate the Information

- Flight crew needs to evaluate all the information available to them
  - Time of report
  - Changing conditions
  - Wind conditions

- Information may be conflicting
  - For example:
    - Braking action is good, runway description is slush covered
    - Measured friction is 40, braking action poor
FAA AC 150.5200-30A addresses the conditions that the friction surveys should be conducted.

- "13b. Conditions Not Acceptable for Conduct of Friction Surveys on Frozen Contaminated Surfaces. The data obtained from friction surveys are not considered reliable if conducted under the following conditions:
  - (1) when there is more than .04 inch (1 mm) of water on the surface, or
  - (2) when the depths of dry snow and/or wet snow/slush exceed the limits in the note above." (presented below)

- “13a.......It is generally accepted that friction surveys will be reliable as long as the depth of dry snow does not exceed 1 inch (2.5 cm), and/or the depth of wet snow/slush does not exceed 1/8 inch (3 mm).”
"… A decelerometer should not be used in loose snow or slush, as it can give misleading friction values. Other friction measuring devices can also give misleading friction values under certain combinations of contaminants and air/pavement temperature." (ICAO Annex 14, Att. A-6, 6.8)
Landing Performance Data Available to Crews (Boeing OM—Section PI)

Boeing performance data is provided for pilot decision making

- Information published as a function of Reported Braking Action
  - Good – Wet runway, JAR defined compact snow
  - Medium – Ice, not melting
  - Poor – Wet melting ice
  - For landing, Boeing recommends the use of the data labeled poor for slush/standing water due to the possibility of hydroplaning
Airplane Performance Terminology

- **Pavement**
  - Better Braking:
    - Dry
    - Wet grooved
  - Wet ungrooved
  - Dry Compacted Snow
  - Cold Ice
  - Wet Ice

- **Airplane Braking Coefficient** used in calculation of advisory data
  - Boeing Tests
  - QRH Data

- **Advisory Data**
  - * All airplanes for FAA cert
  - ** 707/727/737-200/ADV/747-100 for CAA cert
Runway Terminology

Runway Friction

ICAO Annex 14

Better Braking

Dry
Wet grooved
Wet ungrooved
Dry Compacted
Snow
Cold Ice
Wet Ice

Worse Braking

FAA terminology - Not related directly to Runway friction by any FAA publication

Good
Med
Poor

FAA terminology - Not related directly to Runway friction by any FAA publication
• Advisory data for FAA operators is unfactored.
• Operators add margin specific to their operations.
  – Advisory data supplied to JAROPS 1 customer includes 1.15 factor.
• Boeing does not provide specific margins.
• Margins vary by operator.
Landing

BOEING

737 NG Flight Crew Training Manual

Slippery Runway Landing Performance

When landing on slippery runways contaminated with ice, snow, slush or standing water, the reported braking action must be considered. Advisory information for reported braking actions of good, medium and poor is contained in the PI section of the QRH. The performance level associated with good is representative of a wet runway. The performance level associated with poor is representative of a wet ice covered runway. Also provided in the QRH are stopping distances for the various autobrake settings and for non-normal configurations. Pilots should use extreme caution to ensure adequate runway length is available when poor braking action is reported.

Pilots should keep in mind slippery/contaminated runway advisory information is based on an assumption of uniform conditions over the entire runway. This means a uniform depth for slush/standing water for a contaminated runway or a fixed braking coefficient for a slippery runway. The data cannot cover all possible slippery/contaminated runway combinations and does not consider factors such as rubber deposits or heavily painted surfaces near the end of most runways. With these caveats in mind, it is up to the airline to determine operating policies based on the training and operating experience of their flight crews.
## Landing Distance Data

### Examples of Margin Versus Braking Conditions

Conditions: 737-800 145,000 lb (65800 kg), $V_{REF} + 5$
Flaps 40, sea level, std.day, no wind, max man. brakes

### Margin to baseline (feet)

<table>
<thead>
<tr>
<th></th>
<th>Dry</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFM FAR Wet - baseline</td>
<td>6130</td>
<td>6130</td>
<td>6130</td>
<td>6130</td>
</tr>
<tr>
<td>QRH Advisory - unfactored</td>
<td>2990</td>
<td>1780</td>
<td>200</td>
<td>X</td>
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<tr>
<td>QRH Advisory - + 500 feet</td>
<td>2490</td>
<td>1280</td>
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<tr>
<td>QRH Advisory * 1.15</td>
<td>2510</td>
<td>1130</td>
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<td>X</td>
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<tr>
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<td>470</td>
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<td>1450</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Landing Distance Data
Examples of Margin Versus Braking Conditions

Conditions: 737-800 145,000 lb (65800 kg), $V_{\text{REF}} + 5$

Flaps 30, sea level, std.day, no wind, max man. brakes

<table>
<thead>
<tr>
<th>Margin to baseline (feet)</th>
<th>Dry</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>9000 ft (2745m) of runway</td>
<td>8000</td>
<td>8000</td>
<td>8000</td>
<td>8000</td>
</tr>
<tr>
<td>QRH Advisory - unfactored</td>
<td>4700</td>
<td>3460</td>
<td>1780</td>
<td>X*</td>
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<tr>
<td>QRH Advisory - + 500 feet</td>
<td>4200</td>
<td>2960</td>
<td>1280</td>
<td>X</td>
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<tr>
<td>QRH Advisory * 1.15</td>
<td>4210</td>
<td>2770</td>
<td>840</td>
<td>X</td>
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<tr>
<td>QRH Advisory * 1.15 + 200m</td>
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<td>2120</td>
<td>190</td>
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<td>3120</td>
<td>570</td>
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</tbody>
</table>

Note Flaps 40 would increase margin by approximately:

- ~ 170
- ~ 210
- ~ 330
- ~ 430

*Flaps 40 410 ft margin*
Landing Distance Data
Examples of Margin Versus Braking Conditions

Conditions: 737-800 145,000 lb (65800 kg), \( V_{\text{REF}} + 5 \)
\[ \text{Flaps 30, sea level, std.day, no wind, max man. brakes} \]

<table>
<thead>
<tr>
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<th>Good</th>
<th>Medium</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000 ft (3050m) of runway</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>QRH Advisory - unfactored</td>
<td>6700</td>
<td>5460</td>
<td>3780</td>
<td>1020</td>
</tr>
<tr>
<td>QRH Advisory - + 500 feet</td>
<td>6200</td>
<td>4960</td>
<td>3280</td>
<td>520</td>
</tr>
<tr>
<td>QRH Advisory * 1.15</td>
<td>6210</td>
<td>4770</td>
<td>2840</td>
<td>700</td>
</tr>
<tr>
<td>QRH Advisory * 1.15 + 200m</td>
<td>6050</td>
<td>4120</td>
<td>2190</td>
<td>50</td>
</tr>
<tr>
<td>NTSB rec. – no rev. in calc.</td>
<td>6690</td>
<td>5120</td>
<td>2570</td>
<td>X*</td>
</tr>
</tbody>
</table>

Note Flaps 40 would increase margin by approximately: ~ 170 ~ 210 ~ 330 ~ 430

*NTSB rec. would require 11,000+ runway at this condition
Variability in Touchdown Point

- QRH data based on 1000 ft. touchdown point (747 1200 ft.)
- Approach type is a consideration when considering touchdown point at a specific airport

Examples: 2 bar VASI and 3 bar VASI

1000 ft. VASI glidepath
1800 ft. Main gear path – no flare
Autoland Touchdown Data

- Autoland air distance from 50 ft to touchdown is less than 2500 feet
  - Based on flight test
  - Assuming 3° glideslope

\[ X - \text{average touchdown point from autoland testing.} \]
\[ 3\sigma - 99.7\% \text{ probability of touchdown prior to this distance} \]
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• Flying the airplane
Flying the Airplane

- Reference – Boeing Flight Crew Training Manual
  - Chapter 6 – Landing
    - Landing techniques
    - Factors affecting landing distance
    - Slippery runway landing
Flying the Airplane

Factors Affecting Landing Distance

• Approach, Flare and Touchdown
  – Fly the airplane onto the runway
    – On Glideslope, On Speed
  – Do not allow the airplane to float
  – Do not extend flare by increasing pitch attitude
  – Do not attempt to hold the nose wheel off the runway
    – Deceleration on the runway is approximately 3 times greater than in the air (dry runway)
Autoland Touchdown Data

7 series airplanes autoland touchdown point has been demonstrated to be less than approximately 2100 feet +/- 200 with a high degree of probability (greater than 99%)

Note: based on 3° glideslope and 1000 foot from the threshold glideslope intersection.
Flying the Airplane

• Transition
  – After main gear touchdown - initiate landing roll procedure
  – Speedbrakes
    – Manually raise speedbrake if they do not extend automatically
    – Increase load on the gear for brake effectiveness
  – Drag
    – Fly the nose wheel on to the runway smoothly
  – Use appropriate autobrake or manually apply wheel brakes smoothly
• Automatic wheel brakes
  – 3 or 4 should be used for wet or slippery runways
  – Immediate initiation of reverse thrust at main gear touchdown
    – Reduces brake pressure to minimum level
    – Reduces stopping distance on slippery runways
Flying the Airplane

- Manual wheel brakes
  - Immediately after touchdown apply a constant brake pedal pressure
  - Short or slippery runways – use full brake pedal pressure
    - Do not attempt to modulate, pump, or improve braking by any other special technique
    - Do not release brake pressure until the airplane has been reduced to safe taxi speed
  - The antiskid system stops the airplane for all runway conditions in a shorter distance than is possible with either antiskid off or brake modulation
Flying the Airplane

• Reverse thrust
  – After main gear touchdown rapidly raise the reverse thrust levers to the interlock position

Detent No. 2
Maximum Reverse Thrust

Detent No. 1
Interlock

Stowed

Reverse Thrust (Stowed)

Reverse Thrust (Deployed)
Forward Thrust Lever
Flying the Airplane

• Reverse thrust
  – After touchdown rapidly raise the reverse thrust levers to the interlock position
  – Apply reverse thrust as required (up to maximum)
  – Reverse thrust always reduces the “brake only” stopping distance
  – Reverse thrust is most effective at high speed

“The importance of establishing the desired reverse thrust in a timely manner on slippery runways can not be overemphasized.”

(Reference: Boeing Flight Crew Training Manual, section on use of automatic wheel brakes for all conditions)