Landing on Slippery Runways
Landing on a Slippery Runway

Agenda

- Review events of 2006
- Discuss issues involved with landing on a slippery runway
  - Requirements
  - Data available from Boeing
- Runway condition reporting
  - Real world examples of runway condition reporting
- Flying the airplane
Brief History

- In January 2006 the NTSB released a communication which recommended that the FAA:
  - Immediately prohibit …. operators from using the reverse thrust credit in landing performance calculations

- In August of 2006 the FAA released a Safety Alert for Operators (SAFO) addressing the NTSB concerns

- August, 2006 Workshop on Runway Condition Reporting – FAA Sponsored, Wash. DC
  - ATC, airport operators, operators (airline), National Business Jet Assoc., FAA, ALPA, SWAPA, manufacturers, others
Documents FAA finding that airlines:

- **Did not require landing distance assessments** at time of arrival
- **Did not train or provide guidance** on how to use operational landing distance information provided by manufacturer nor address safety margins
- **Did not include manufacturer data** in operations procedures
- **Had confusion on whether reverse thrust** has been included in the calculations
- **Have misused or misinterpreted** the information the manufacturer supplied
Recommended:

- Enroute evaluation of landing performance
- Margin of Safety of at least 15% in non-emergency situations
- “All flight crewmembers must have hands-on training and validate proficiency in these procedures ….” referring to how to use the airlines slippery runway data to evaluate landing performance
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  - Data available from Boeing
- Runway condition reporting
  - Real world examples of runway condition reporting
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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

No Reversers
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

Reversers Included

Stop

Reverse

d_{DEMO}

1000'
# Slippery Runway

**Landing Distance Advisory Data QRH Page**

**ADVISORY INFORMATION**

**Normal Configuration Landing Distance**

Flaps 30

Dry Runway

### Landing Distance and Adjustments (FT)

<table>
<thead>
<tr>
<th>BRICKING CONFIGURATION</th>
<th>REF DIST*</th>
<th>WT ADJ</th>
<th>ALT ADJ</th>
<th>WIND ADJ PER 10 KTS</th>
<th>SLOPE ADJ PER 1%</th>
<th>TEMP ADJ PER 10°C</th>
<th>VREF ADJ</th>
<th>REVERSE THRUST ADJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>450000 LB LANDING WT</td>
<td>450000 LB</td>
<td>+70/-40</td>
<td>60</td>
<td>-120</td>
<td>+40</td>
<td>-30</td>
<td>60</td>
<td>-60</td>
</tr>
<tr>
<td>PER 10000 LB ABOVE / BELOW 450000 LB</td>
<td>PER 1000 FT ABOVE S.L.</td>
<td>HEAD WIND</td>
<td>TAIL WIND</td>
<td>DN HILL</td>
<td>UP HILL</td>
<td>ABV</td>
<td>ISA</td>
<td>BLW</td>
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<tr>
<td>MAX MANUAL</td>
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<td>+70/-40</td>
<td>60</td>
<td>-120</td>
<td>+40</td>
<td>-30</td>
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<td>-60</td>
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<tr>
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<td>+70/-40</td>
<td>60</td>
<td>-120</td>
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<td>-30</td>
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<td>-120</td>
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<td>-120</td>
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<td>-120</td>
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<td>-120</td>
<td>+40</td>
<td>-30</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

**Good Reported Braking Action**

Based on these notes, JAR operators advisory data in QRH include 1.15 factor.

Reference distance is for sea level, standard day, VREF 30 approach speed and 2 engine reverse thrust.

Actual (unfactored) distances are shown.

Includes distance from 50 ft. above the threshold (1000 ft of air distance).

**Poor Reported Braking Action**

Based on these notes, JAR operators advisory data in QRH include 1.15 factor.

Reference distance is for sea level, standard day, no wind or slope, VREF 30 approach speed and 1 engine reverse thrust.

Max Manual braking data valid for auto speedbrakes. For manual speedbrakes, increase reference landing distance by 200 ft.

Auto brake data valid for both auto and manual speedbrakes.

Actual (unfactored) distances are shown.

Includes distance from 50 ft above threshold (1000 ft of air distance).
**Description and Airplane Performance**

**Runway Surface Description**
- Dry
- Wet grooved
- Wet ungrooved
- Compact Snow T<15C
- Dry Snow
- Sanded Ice
- Compact Snow T>15C
- Ice
- Slush
- Melting Ice

**Pilot Reports**
- Dry
- Good
- Medium (Fair)
- Poor
- Nil

**Boeing QRH data**

**ADVISORY INFORMATION**

**Normal Configuration Landing Distance**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dry</th>
<th>Wet</th>
<th>Wet Grooved</th>
<th>Wet Ungrooved</th>
<th>Dry Snow</th>
<th>Sanded Ice</th>
<th>Compact Snow T&lt;15C</th>
<th>Ice</th>
<th>Slush</th>
<th>Melting Ice</th>
<th>Dry</th>
<th>Wet</th>
<th>Wet Grooved</th>
<th>Wet Ungrooved</th>
<th>Dry Snow</th>
<th>Sanded Ice</th>
<th>Compact Snow T&gt;15C</th>
<th>Ice</th>
<th>Slush</th>
<th>Melting Ice</th>
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</thead>
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<tr>
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</tbody>
</table>

**Notes:**
- All distances measured in meters (feet) unless otherwise specified.
- Maximum braking distance is defined as the distance from the end of the runway to the point where the aircraft is brought to a complete stop.
- For maximum braking distance, assume 10% weight loss for both main and nose gear.
- Aircraft equipped withvenient or dry.
- Aircraft equipped with anti-braking system.
Reverse Thrust Application Sequence

As Applied in QRH Advisory Data

- Touchdown
  - 1 sec.
- Transition
  - Brake Application
    - 1 sec.
  - 1 – 3 sec.*
- Interlock cleared
  - 2 – 4 seconds*
- Reverser deployed
- Reverser spinup to selected level
- At 60 knots decrease to reverse idle
- Selected reverse thrust level – max or detent depending on model

* Actual time dependant on engine/airframe
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**

  - **Braking Applied**
    - Max Manual
      - Drag Brakes
      - Drag Brakes
      - Drag Brakes
      - Drag Brakes
      - Reverse Thrust
    - Autobrake Max
      - Drag Brakes
      - Drag Brakes
      - Drag Brakes
      - Drag Brakes
      - Reverse Thrust
    - Autobrake 2
      - Drag Brakes
      - Drag Brakes
      - Drag Brakes
      - Drag Brakes
      - Reverse Thrust

  - Deceleration level achieved
    - Distance based on autobrake decel rate
Maximum Deceleration Available from Brakes

- **Runway condition**: Better, Med, Poor
- **Braking action**: Dry, Antiskid limited
- **Deceleration Available from Brakes**: Less, More

- **Goals**:
  - e.g. stand on the brake pedals
  - Max Brakes

- **Notes**:
  - Dry: Good
  - Med: Antiskid limited
  - Poor: Antiskid limited
Maximum Deceleration
Poor Braking

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

<table>
<thead>
<tr>
<th>Manual Brakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Dry runway: Reversers DO increase deceleration</td>
</tr>
<tr>
<td>- Slippery runway: Reversers Do increase deceleration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Autobrakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Dry runway: Reversers typically do NOT increase deceleration</td>
</tr>
<tr>
<td>- Slippery runway: Reversers MAY decrease deceleration depending how slippery the runway is</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Landing Distance Advisory Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>includes reversers for Manual and Autobrakes</td>
</tr>
</tbody>
</table>
Variability in Touchdown Point

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

Examples: 2 bar VASI and 3 bar VASI
Autoland Touchdown Data

- Autoland air distance from 50 ft to touchdown is typically less than 2100 ft
  - Based on flight test
  - Assuming 3° glideslope

\[ X - \text{average touchdown point from autoland testing} \]

\[ 3\sigma - 99.7\% \text{ probability of touchdown prior to this distance} \]
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
    - SAFO – JAROPS1
  - Used for making operational decisions

- The data sets are different with a different purpose
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Runway condition is typically provided three ways

- PIREPs (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 a friction measurement
  - 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 and ICAO advisory material indicate friction surveys are not reliable when there is a depth of snow, slush or standing water on the runway

- 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 ….
       - depth of dry snow does not exceed 1 inch (2.5 cm)
       - 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)
BRAKING ACTION

Correlating Expected Runway Conditions
The correlation between various sources of weather conditions (e.g., PIREPs, runway surface conditions and METAR values) can be challenging. Under extreme cold temperatures or for runways that have been continuously treated, the braking capabilities may be better than the runway surface conditions estimated below. When multiple sources are provided (e.g., braking action medium, runway covered with ice and snow, and runway MU value of 0.2), conflicts are possible. If such conflicts occur, consider all factors including data currency and the type of runway that a PIREP was given from. A valid PIREP or runway surface condition report is more reliable indicator of what to expect than a reported runway MU values.

Runway Friction MU Report
MU values in the U.S. are typically shown as whole numbers (40) and are reported to the FAA standard decimal values (40.0). Each MU value below the lowest friction and 100 is the highest friction. When the MU value for any one-third zone of an active runway is 40 or less, a report should be given to ATC by airport management for dissemination to pilots. The report will identify the runway, the time of measurement, the type of friction measuring device used, MU values for each zone and the contaminant conditions (e.g., snow, dry snow, slush, snow drifts). The table below includes information published by FAA correlating runway friction measurements to estimated friction values. The FAA confirms that no reliable correlation exists. Runway MU values can vary significantly due to the same contaminant condition due to the friction measuring devices and the time passage since the measurement. Do not base landing distance assessments solely on runway MU friction reports. If MU is the only information provided, attempt to ascertain the depth and type of runway contaminant to make a better assessment of actual conditions.

<table>
<thead>
<tr>
<th>Braking Action</th>
<th>Estimated Correlations</th>
<th>FAA Code</th>
<th>MU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.</td>
<td>Water depth of 1/8&quot; or less</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry snow less than 1/4&quot; in depth</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compressed snow with OAT at or below 15°C</td>
<td></td>
</tr>
<tr>
<td>Good to Medium</td>
<td>Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be slightly reduced.</td>
<td>Dry snow 1/4&quot; or greater in depth</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sanded snow</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sanded ice</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compressed snow with OAT above 15°C</td>
<td></td>
</tr>
<tr>
<td>Medium (Fair)</td>
<td>Braking deceleration is significantly reduced for the wheel braking effort applied. Directional control may be significantly reduced.</td>
<td>Wet snow</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water depth more than 1/8&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ice (not melting)</td>
<td></td>
</tr>
<tr>
<td>Medium to Poor</td>
<td>Braking deceleration is minimal to nonexistent for the wheel braking effort applied. Directional control may be uncertain. Note: Run, takeoff, and braking operations are not recommended.</td>
<td>Ice (melting)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet Ice</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The FAA recommends that the MU code of 09 indicates contamination is outside the approved operational range for the friction measuring equipment issue and therefore MU values are not provided. This typically occurs in desert or very cold conditions (greater than 1/8" of wet snow, snow on standing water) where the potential for hydroplaning should be expected. Use PIREPS and the depth and type of runway contaminant to assess actual braking conditions.

*This page is advisory information developed by a team of US airline technical pilots and other interested parties. The creation of the table was initiated by a FAA workshop on runway condition reporting in held in August of 2006.
## Example 1

### Changing Conditions - Snowing

<table>
<thead>
<tr>
<th>Time, min</th>
<th>Event</th>
<th>Friction measured during operations</th>
<th>Reported braking action, flight crew</th>
<th>Airplane braking coefficient ($\mu_b$)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Runway cleaned</td>
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<tr>
<td>2</td>
<td>Friction measured</td>
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<tr>
<td>7</td>
<td>A320 landed/report</td>
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<tr>
<td>10</td>
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<td>737-700 landed</td>
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<td>18</td>
<td>737-700 landed</td>
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<td>20</td>
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<td>26</td>
<td>Citation landed</td>
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<tr>
<td>28</td>
<td>Gulfstream landed</td>
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<tr>
<td>30</td>
<td>737-700 landed</td>
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<tr>
<td>37</td>
<td>Friction measured</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
### Example 1

#### Changing Conditions - Snowing

<table>
<thead>
<tr>
<th>Time, min</th>
<th>Event</th>
<th>Friction measured during operations</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Runway cleaned</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2</td>
<td>Friction measured</td>
<td>72/59/68 not reported to crew above reporting threshold</td>
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</tr>
<tr>
<td>7</td>
<td>A320 landed/report</td>
<td></td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>737-700 landed</td>
<td></td>
<td>Fair/poor at the end</td>
<td>Medium (fair)+</td>
</tr>
<tr>
<td>16</td>
<td>737-700 landed</td>
<td></td>
<td></td>
<td>Medium (fair)+</td>
</tr>
<tr>
<td>18</td>
<td>737-700 landed</td>
<td></td>
<td>Good 1st and 2nd thirds, poor last third</td>
<td>Poor+</td>
</tr>
<tr>
<td>20</td>
<td>737-700 landed</td>
<td></td>
<td></td>
<td>Medium (fair)</td>
</tr>
<tr>
<td>26</td>
<td>Citation landed</td>
<td></td>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>28</td>
<td>Gulfstream landed</td>
<td></td>
<td></td>
<td>Fair to poor</td>
</tr>
<tr>
<td>30</td>
<td>737-700 landed</td>
<td></td>
<td></td>
<td>Poor+</td>
</tr>
<tr>
<td>37</td>
<td>Friction measured</td>
<td>41/40/38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on Boeing analysis of FDR and braking action relationships used in creation of QRH data
**Example 1** Shows the Complexity of the Issues Involved In Reporting Runway Condition

<table>
<thead>
<tr>
<th>Time – runway condition may be changing with time</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Friction is taken at a specific time</td>
</tr>
<tr>
<td>• Cannot be redone without interrupting operations</td>
</tr>
<tr>
<td>• In this example the friction deteriorated as snow fall continued</td>
</tr>
</tbody>
</table>

**Effect of snow and slush on accuracy of friction measurement**

| • FAA and ICAO guidance warn against the use of friction measurements when the runway is covered with snow or slush |
| • Demonstrated by the second friction test |
| • Braking action reports and the FDR data analysis does not agree with the friction measured |

**Reported braking action**

| • Braking action reports do support that the runway was becoming more slippery |
| • Braking action reports aren’t always consistent |
| – Equipment |
| – Flight crew experience |
| • Braking action reports aren’t always made or made in a timely manner |
Example 1 (continued)

Braking Action Reports

Consider braking action report - ‘good 1st and 2nd thirds, poor last third’

- **Analysis of FDR data showed**
  - Flight crew used light braking during the first 2/3rds of the stop
  - In the last third the stop the flight crew used heavy braking
  - FDR data did not show an appreciable change in the capability of the wheel brakes to stop the airplane during the stop

- **Conjecture**
  - Since the flight crew used moderate braking during the first part of the stop and the reversers were deployed, and aerodynamic drag was high
    - The deceleration rate was as expected for the amount of wheel braking used by flight crew hence the report of good
  - However later in the stop maximum wheel braking was applied but now the speed was lower
    - Less drag, less reverse thrust (speed effect)
    - The deceleration rate was less than expected for the amount of wheel braking used by flight crew hence the report of poor
  - The perception was the runway had gotten slipperier part way down the runway
  - No evidence in FDR data that runway slipperiness changed
### Example 2  Operation At 0°C With Mixed Reports of Slush, Ice, and Wet Runway

**Runway condition was:**

- Center of the runway for 100% of the length was 50% bare and wet and 50% trace slush
- Center of the runway for 100% of the length has been chemically deiced and treated with heated sand
- Outside the center of the runway the conditions were ice
- Canadian Runway Friction Index (CRFI) 0.43
  - Canadian AIP indicates a CRFI of 0.43 would occur on a runway that was:
    - Concrete or asphalt with rain between 0.01” and 0.03” depth
    - Compacted snow below -15°C
    - Packed and sanded snow
    - Sanded ice
    - CRFI of 0.43 CRFI should result in an a “good” braking action
Example 2 (continued) Operation At 0°C With Mixed Reports of Slush, Ice, and Wet Runway

Further crew information
- Temperature was 0°C
- Flight crew reported freezing rain during the approach

FDR analysis
- Airplane braking action was:
  - Was consistent with “poor” above 70 knots
  - At 70 knots it was “poor” and improved to “medium” or “between medium and good” as the airplane slowed down and progressed along the runway
  - These values are much lower than the values that would have been expected for a CRFI of 0.43
  - Trend of increasing wheel brake effectiveness with decreasing speed is consistent with slush/standing water
- Flight crew reported the braking action as poor
Landing on a Slippery Runway

Current Activities - 2008

FAA is forming “Takeoff/Landing Performance Assessment Aviation Rulemaking Committee (ARC)"

- Discuss landing performance assessment methods
- Takeoff performance on a contaminated runway
Landing on a Slippery Runway

Agenda

- Review events of 2006
- Discuss issues involved with landing on a slippery runway
  - Requirements
  - Data available from Boeing
- Runway condition reporting
  - Real world examples of runway condition reporting
- **Flying the airplane**
Flying the Airplane

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

- **Flight Operations Technical Bulletin**
  - August 2007

- **In depth white paper – Boeing Flight Operations and Performance Engineers Conference**
  - September 2007
  - More in depth discussion on performance issues
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)
7-series airplanes autoland touchdown point has been demonstrated to be less than 2100 ft +/- 200 with a high degree of probability (greater than 99%)
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

Reverse Thrust
- Immediate initiation of at main gear touchdown
  - Reduces brake pressure to minimum level
  - Reduces stopping distance on slippery runways
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
Reverse thrust

- After touchdown rapidly raise the reverse thrust levers to the interlock position
- Apply reverse thrust as required (up to maximum)
- 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)
Landing on Slippery Runways