Takeoff/Landing on Wet, Contaminated and Slippery Runways

Paul Giesman
Performance Engineering Operations
Boeing Commercial Airplanes
January 2005
“I glanced at the air speed indicator and saw it registered 105 knots and was flickering. When it reached 117 knots I called out \`V1\' [Velocity One, the point on the runway after which it isn’t safe to abandon take-off]. Suddenly the needle dropped to about 112 and then 105. Ken shouted, \`Christ, we can’t make it\’ and I looked up from the instruments to see a lot of snow and a house and a tree right in the path of the aircraft”.

Inside the passengers’ compartment Bill Foulkes had sensed that something was wrong:

“There was a lot of slush flying past the windows and there was a terrible noise, like when a car leaves a smooth road and starts to run over rough ground”.

The Elizabethan left the runway, went through a fence and crossed a road before the port wingstruck a house. The wing and part of the tail were torn off and the house caught fire. The cockpit struck a tree and the starboard side of the fuselage hit a wooden hut containing a truck loaded with fuel and tyres. This exploded.
At 3:57 the crew set the airspeed bug settings to 138 knots for $V_1$, 140 knots for $V_R$ and 144 knots for $V_2$.

The FO asked the captain, “There’s slush on the runway—do you want me to do anything special for this or just go for it?”

The captain replied, “Unless you’ve got something special you’d like to do.”

The FO then said, “Unless just take off the nosewheel early like a soft-field takeoff or something. I’ll just take the nosewheel off and then we’ll let it fly off.”

Air Florida, Palm 90 cockpit voice recorder, Jan. 13, 1982
Contaminated and Slippery Runways

Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
  – Special performance considerations
    • $V_{1\text{MCG}}$ Considerations
      – Data / Applications
      – Snow Accountability
      – Crosswind

• Landing on slippery runway
Regulatory Requirements - Takeoff

• FAA Operators
  – Historically
    • No definitive regulatory requirements for contaminated or slippery runway performance adjustments in Part 25 or 121
• Current (737-6/7/8/900, 757-300, 767-400)
  – Wet runway is part of AFM certification basis
  – No definitive regulatory requirements for contaminated or slippery (non-wet)
Regulatory Requirements - Takeoff

• FAA Guidelines:
  – Provides guidelines for operation with standing water, slush, snow or ice on runway
  – Does not provide for wet runways
  – Proposed Advisory Circular 91-6B (draft)
Regulatory Requirements - Takeoff

• JAA Operators - New certifications
  – Specific requirements covered in the AFM
  – Includes performance based on various runway conditions (wet, compact snow, wet ice, slush, dry snow)

• JAROPS 1
  – Requires operational contaminated/slippery runway data based on possibility of an engine failure during the takeoff
  – Stop accountability
• Never approved but used in the ’80’s as guidance for Boeing contaminated runway data and methods

• Guidelines for takeoff and landing with water, slush, snow or ice on runway
  – Defines contaminated runway
  – Defines braking coefficient used for accelerate-stop distance calculation
  – Includes wet runway
  – Reverse thrust credit for accelerate-stop

Did not specifically address, but were adopted in the advisory data of the time

• 15-foot screen height for accelerate-go
• Guidelines for takeoff and landing with water, slush, snow or ice on runway
  – Defines contaminated runway
  – Defines braking coefficient and contaminant drag to be used in calculations
  – Includes wet runway
  – 15-foot screen height for accelerate-go
  – Reverse thrust credit for accelerate-stop
Dry, Damp, and Wet Runways are NOT Contaminated

- **Dry:** Neither wet or contaminated (JAR-OPS 1.480)
  - FAA - No definitive definition

- **Damp:** Surface is not dry, but moisture on the surface does not give a shiny appearance (JAR-OPS 1.480)

- **Wet:** FAA - neither dry nor contaminated (Draft AC 91-6B)
  - Shiny in appearance, depth less than 3 mm of water (JAR-OPS 1.480)

*Note: JAR-OPS 1 verified as of Dec. 2004*
Runways are Contaminated When*

*As defined by FAA Advisory Circular 91-6B and JAROPS 1.480

- More than 25% of the surface to be used is covered by:
  - Standing water or slush more than 1/8 inch (3 mm) deep
  - Snow
  - Ice covered
Additional considerations

• If the contaminants are lying on that portion of the runway where the high speed part of the takeoff roll will occur, it may be appropriate to consider the runway contaminated. (Draft AC 91-6B)

• Do NOT takeoff when the depth of standing water or slush is more than:
  – 1/2 inch (13 mm) deep
    • Some advisory material has 15 mm as threshold
    • Boeing BTM modules limited to 12.7 mm (1/2”)
Boeing Contaminated Runway Takeoff Performance

- Slush / Standing Water Data
  - Acceleration/deceleration capability

- Slippery runway
  - Deceleration capability
  - Ice covered, compacted snow, or wet

- Note: for airplanes where wet runway takeoff performance is not certified we consider wet runway a subset of slippery
- Slippery can also be used if it is desired to have additional wet runway conservatism
Regulatory Requirements – Landing

• Landing requirements will be discussed in more detail in the landing presentation
  – JAR/JAROPS 1 requires contaminated/slippery runway landing distance calculation for dispatch
  – FAA
    • FAR dispatch requirements on a slippery runway is 1.15*FAR dry runway requirement (same as FAR wet)
    • In 2006 FAA released a Safety Alert for Operators (SAFO) advising an enroute check of contaminated and slippery runway landing distances
Agenda

• Basic Regulations and Definitions
  • Takeoff
    – Wet Runway
    – Slush/Standing Water
    – Slippery Runway
    – Special performance considerations
      • $V_{1MCG}$ Considerations
    – Data / Applications
    – Snow Accountability
    – Crosswind
  • Landing on slippery runway
Takeoff – Wet Runway

- Physics
- Regulations (wet runway specific)
- Data basis and assumptions
- Special considerations
  - Clearway considerations
  - Skid-resistant
  - Reverser inoperative
  - Antiskid inoperative
Contaminated and Slippery Runways

Fundamental - Wheel/Tire Braking

Wheel braking coefficient

Dry

Wet

0 Free Rolling

Slip ratio

1.0 Locked Wheel
Aircraft Braking Considerations

Dry runway performance - Maximum manual wheel braking

Torque Limited Region

\[ F_B = \text{Constant} \]

Airplane Braking Coefficient

\[ \mu_B = \frac{F_B}{W - L} = \text{Constant} \]

Average weight
On wheels

Brake energy

\( F_B \), brake force

Anti-skid (\( \mu \)) limited region
Friction Limited Braking

Dry runway performance - Maximum manual wheel braking

Less available runway friction results in lower airplane braking coefficient and therefore stopping force due to the wheel brakes.
Runway Friction and Runway Texture
or How Slippery Is Wet

Macrotexture, Microtexture

- **Microtexture refers to the fine scale roughness** contributed by small individual aggregate particles on pavement surfaces which are not readily discernible to the eye but are apparent to the touch, i.e., the feel of fine sandpaper.

- **Macrotexture refers to visible roughness** of the pavement surface as a whole.

- **Microtexture** provides frictional properties for aircraft operating at **low** speeds.

- **Macrotexture** provides frictional properties for aircraft operating at **high** speeds.

Reference FAA AC 150 5320-12
Macrotexture, Microtexture

- Macrotexture provides paths for water to escape from beneath the aircraft tires.

- Microtexture provides a degree of "sharpness" necessary for the tire to break through the residual water film that remains after the bulk water has run off.

- Both properties (macro/microtexture) are essential in providing good wet runway stopping performance.

Reference FAA AC 150 5320-12
As macrotexture affects the high speed tire braking characteristics, it is of most interest when looking at runway friction capability when wet.

Rough macrotexture will be capable of a greater tire to ground friction than a smoother macrotexture surface when wet.
Effect of Runway Surface On Airplane Wheel Braking Performance

NASA testing published in Technical Paper 2917, “Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions”

- Dry
- Wet, smooth
- “Damp”
- Wet, skid-resistant
Effect of Runway Surface On Airplane Wheel Braking Performance

NASA testing published in Technical Paper 2917, “Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions”

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Test Surface</th>
<th>Macrotexture Depth, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA Wallops Flight Facility</td>
<td>Slurry Sealed Asphalt (SSA)</td>
<td>0.019</td>
</tr>
<tr>
<td>NASA Wallops Flight Facility</td>
<td>Canvas Belt Finished Concrete</td>
<td>0.006</td>
</tr>
<tr>
<td>NASA Wallops Flight Facility</td>
<td>Large Aggregate Asphalt</td>
<td>0.015</td>
</tr>
<tr>
<td>Langley AFB</td>
<td>Portland Cement Concrete</td>
<td>0.027</td>
</tr>
<tr>
<td>Brunswick Naval Air Station –  BNAS</td>
<td>Small Aggregate Asphalt</td>
<td>0.017</td>
</tr>
<tr>
<td>FAA Technical Center</td>
<td>Dryer Drum Mix Asphalt Overlay</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Contaminated and Slippery Runways

Effect of Wet Runway Surface on Airplane Wheel Braking

Data based on NASA report TP2 917

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Texture (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slurry Sealed Asphalt - 727</td>
<td>0.019&quot;</td>
</tr>
<tr>
<td>Slurry Sealed Asphalt - 737</td>
<td>0.019&quot;</td>
</tr>
<tr>
<td>Large aggregate asphalt texture - 737</td>
<td>0.017&quot;</td>
</tr>
<tr>
<td>Dryer Drum Mix Asphalt Overlay aggregate size &lt; 1&quot; - 737</td>
<td>0.017&quot;</td>
</tr>
<tr>
<td>BNAS Small Aggregate Asphalt - 727</td>
<td>0.008&quot;</td>
</tr>
<tr>
<td>Portland Cement Concrete texture - 737</td>
<td>0.027&quot;</td>
</tr>
<tr>
<td>Canvas Belt Concrete texture - 727</td>
<td>0.006&quot;</td>
</tr>
<tr>
<td>Canvas Belt Concrete texture - 737</td>
<td>0.006&quot;</td>
</tr>
</tbody>
</table>
Effect of Damp Runway Surface on Airplane Wheel Braking

Data based on NASA report TP2 917

Contaminated and Slippery Runways
Effect of Wet Grooved Runway Surface on Airplane Wheel Braking

Data based on NASA report TP2 917

Contaminated and Slippery Runways
Contaminated and Slippery Runways

Effect of Wet Grooved Runway Surface on Airplane Wheel Braking

Data based on NASA report TP2 917

Canvas Belt Concrete, burlap drag 1” groove 737

Canvas Belt Concrete, burlap drag 1” groove 727

Canvas Belt Concrete - 737

Canvas Belt Concrete - 727

Surface texture ~ inches

0.072”

0.008”

% of dry runway effective friction

Ground speed - knots

Data based on NASA report TP2 917
FAA AC 150/5320-12C, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces," specifies that the FAA standard groove configuration is:

- 1/4 in (6 mm) in depth,
- 1/4 in (6 mm) in width
- 1 1/2 in (38 mm) in spacing
Effect of Wet PFC Runway Surface on Airplane Wheel Braking

Data based on NASA report TP2 917

Airport comparison
BNAS/Portland Intl/Peace AFB

% of dry runway effective friction

Ground speed - knots

Peace AFB - PFC 727
Portland Intl - 11 year old PFC 727

Data based on NASA report TP2 917
Summary of TP 2917 Information

• Wet runway
  – Smooth (lower) macrotexture surface creates less friction than a rough surface
  – Pavement material makes a significant difference in the available friction on a wet surface

• Wet Grooved or PFC treatment of runways
  – Improved the wet runway friction capability
  – Not the same capability as a dry runway
  – Improvement is dependant on runway material (PFC) and groove spacing

• “Damp” runway
  – Friction was reduced compared to dry
  – Friction may be better than wet
  – Subjective term
Contaminated and Slippery Runways

Boeing Historical Wet Runway Testing

Support of UK CAA Certifications

<table>
<thead>
<tr>
<th>Airplane</th>
<th>Antiskid (μ) limited airplane braking coefficient, % (approximate)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>707-300C landing data</td>
<td>50</td>
</tr>
<tr>
<td>727-200 landing:</td>
<td></td>
</tr>
<tr>
<td>• Main and nose brakes</td>
<td>50</td>
</tr>
<tr>
<td>• Main brakes only</td>
<td>50</td>
</tr>
<tr>
<td>737-200 ADV</td>
<td></td>
</tr>
<tr>
<td>• Mark III A/S</td>
<td>60</td>
</tr>
<tr>
<td>• Goodyear A/S</td>
<td>45</td>
</tr>
<tr>
<td>747-100</td>
<td>55</td>
</tr>
</tbody>
</table>

*Dry runway compared with a wet, smooth runway. Based on flight tests for UK CAA.

- Later UK CAA certifications used ½ the dry
- Recommendation to use performance labeled Good (0.2 airplane braking coefficient) for wet runway for operational data
Airplanes **Not** FAA Certified for Wet Runway Takeoff Accountability

- 707, 727, 737-100/-200/Adv/-300/-400/-500, 747-100/-200/-300/-400 757-200, 767-200/-300/-200ER/-300ER, 777-2/300, DC-9/-10, MD-80/-90/-11

- Wet runway performance is in UK CAA and JAA AFMs were appropriate

- Operational data is provided in QRH and FPPM and operational computer programs, weight reductions and $V_1$ adjustments (not applicable for Douglas aircraft)

- JAR-OPS 1
  - Essentially the same as operational data
  - Douglas aircraft data created as required, different methods of accounting for wet runway braking
Wet Runway Performance Considerations – Airplanes Not Certified to FAA Criteria

Performance assumptions are changed for wet runway takeoff calculations

• Reduced runway friction capability taken into account
  • UK CAA certification
    – Test data or \( \frac{1}{2} \) dry airplane antiskid (\( \mu \)) limited airplane braking coefficient
  • QRH, FPPM data labeled reported braking action of “Good” recommended for wet runway accountability
    – Airplane braking coefficient (\( \mu_B \)) = 0.20
• 15 foot screen height
  • Engine inoperative accelerate-go calculation
  • Results in \( V_1 \) reduction when re-balancing
• Reverse thrust credit accelerate-stop calculation
  • Controllability and re-ingestion issues considered
Airplanes With Wet Runway Performance In the FAA AFM — Amendment 25-92

• 737-600/-700/-800/900, 757-300, 767-400, 777-200LR/-300ER, 717

• Covers skid-resistant performance
  – Runway must be built and maintained to requirements of AC 150/5320-12C

• Same data in JAA AFM
• Amendment 25-92 of the FARs required inclusion of wet runway takeoff performance in the AFM

• Provided a method to account for wet runway wheel braking capability that was based on ESDU 71026
  – Both smooth and skid-resistant surfaces are addressed

• Method documented in the FAR’s and AC 25-7
### Runway Construction

<table>
<thead>
<tr>
<th>Runway surface type</th>
<th>Runway surface treatment</th>
<th>Approximate number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt, approximately 3,640 runways</td>
<td>Grooved</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>PFC</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>Other friction treatment</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>No data available or no special treatment listed</td>
<td>2,980</td>
</tr>
<tr>
<td>Concrete, approximately 1,040 runways</td>
<td>Grooved</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>No data available or no special treatment listed</td>
<td>870</td>
</tr>
</tbody>
</table>

- Information from databases may tell surface type and treatment
- Typically there isn’t information provided on standards to which the runway was constructed and is maintained

Data from Boeing Airport Information Retrieval System
Special Wet Runway Performance Questions

• Is clearway allowed on a wet runway?
• Can a reverser be inoperative on a wet runway?
• Can an antiskid be inoperative on a wet runway?
Contaminated and Slippery Runways

Maximum Clearway Available for Wet Runway Regulatory Accountability

Dry runway AFM clearway credit available

Accelerate $V_1$ dry bal

Runway available

Clearway available

35 ft

UK CAA wet runway and 747-400 JAA AFM clearway credit available

Accelerate $V_1$ wet

Full credit for distance from LO to 15 feet

15 ft

777-200 JAA wet runway AFM clearway credit available

Accelerate $V_1$ wet

Half credit for distance from LO to 15 feet

15 ft

Current FAA (Amend. 25-92)/JAA wet runway AFM clearway credit available

Accelerate $V_1$ wet

No clearway credit allowed

15 ft

Contaminated and Slippery Runways
Clearway and Wet Runway
Boeing Operational Software

• Boeing Operational Software – BTOPS/BTM databases follow regulatory guidelines where they are addressed
  – Amend. 25-92, UK CAA, 747-400 and 777-200 JAR certification

• BTOPS databases provide data for slippery runway
  – Clearway is not allowed in the calculation
  – Data based on OM/FPPM/PEM weight reductions and $V_1$ adjustments
  – Data created based on equal distance concept and balanced field length considerations

• MTOPS
  – Clearway is not allowed in the calculation
Reverser Inoperative and Wet Runway

• Amendment 25-92 inclusion of wet runway takeoff performance caused creation of a new proviso in MMEL
  – AFM performance credit for reverse thrust for wet runway takeoff
  – New proviso only applicable for Amend 25-92 certified performance

• Most non-Amend 25-92 airplanes have performance available in operational computer programs, FCOM and FPPM
### SYSTEM & SEQUENCE NUMBER

<table>
<thead>
<tr>
<th>Item</th>
<th>NUMBER REQUIRED FOR DISPATCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2</td>
</tr>
<tr>
<td>2.</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>1</td>
</tr>
</tbody>
</table>

#### REMARKS OR EXCEPTIONS

- Thrust reverser guide carriage is verified to be in the over-center (forward thrust) position, and
- The Override System is armed only after landing.

**NOTE:** Relief also applies to airplanes modified by STC SA5730NM or ST00131SE.

- Thrust reverser is locked in the forward thrust position.
- Appropriate performance adjustments are applied.
• Prior to Amend. 25-92 wet runway takeoff and antiskid inoperative performance had not been addressed in the FAA AFM or MMEL.

• The new certification standard raised the visibility of the combination of wet runway and antiskid inoperative

• Initial 737NG AFM was released with this operation prohibited.

• In 2002, the FAA published a policy letter (PL) which specifically addressed takeoffs on wet runways with antiskid inoperative.

  – FAA PL-113 dated 20 December, 2002
**FOEBs may continue to grant relief….**

- The runway is grooved or has a PFC surface
- All reversers are operative
- Approved performance data is available
- Operator training programs include antiskid inoperative braking procedures

*FOEB is Flight Operations Engineering Board. They control the contents of the MMEL.*
• 737NG – Boeing performed flight test
  – AFM-DPI alternate performance (equivalent of an AFM appendix)
  – Must be specifically called out in the AFM

• Pre Amend. 25-92 airplanes
  – Not addressed by FAA AFM or MMEL
  – No performance data specifically supplied
  – Recent studies indicate the use of the braking action “poor” data would be conservative

  • Apply “poor” weight and \( V_1 \) adjustments to the dry runway antiskid operative field/obstacle limited weight to obtain wet runway anti-skid inoperative takeoff performance
Contaminated and Slippery Runways

Wet Runway Takeoff With Antiskid Inoperative
Flight Crew Issues

• Additional pilot education and training
  – Stopping sequence change with antiskid inoperative
    • With antiskid inoperative the last step in the RTO procedure in brake application
  – Light brake application through out the maneuver
Summary

• Runway surface can have a significant effect on an airplane’s stopping performance on a wet runway
  – Macrotexture, treatment (grooved, PFC)

• Certification standards for wet runway takeoff have changed over the years
  – Current certification standard, includes wet runway takeoff performance in AFM
  – 15 foot screen height, reverse thrust credit
  – Clearway accountability

• Other items
  – Wet Skid-resistant
  – Reverser inoperative
  – Antiskid inoperative
Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
  – Special performance considerations
  • $V_{1\text{MCG}}$ Considerations
    – Data / Applications
    – Snow Accountability
    – Crosswind

• Landing on slippery runway
Dry Runway Acceleration

\[ a = \frac{g}{W} \quad [ \text{Thrust} - \text{Drag} - \text{Friction} ] \]
Acceleration with Slush/Standing Water

\[ a = \frac{g}{W} \quad [\text{Thrust} - \text{Drag} - \text{Friction} - \text{Slush Drag}] \]
Contaminated and Slippery Runways

\[ F_{\text{Slush}} = \frac{1}{2} \rho V_g^2 C_{D \text{ Slush}} A_{\text{Tire}} \]

Data Sources: FAA/NACA Convair 880 Tests 1962

- \( \rho = \) Slush Density, 1.65 slugs/ft\(^3\) Equal to Specific Gravity of 0.85

- \( V_g = \) Ground Speed - Feet per Second

- \( C_{D \text{ Slush}} = \) Slush Drag Coefficient for airplane's specific gear arrangement

- \( A_{\text{Tire}} = \) Reference Area for Slush Force Calculation
**C_D Slush Accounts for Displacement and Impingement**

**Displacement Drag**

**Impingement Drag**
Contaminated and Slippery Runways

Slush Force

- Slush force vs. Ground speed
- Hydroplaning

Contaminated and Slippery Runways

53
Dynamic Hydroplaning

Tire Pressure in PSI evaluated for Main Gear

\[ V_{HP} = 8.63 \sqrt{\frac{\text{Tire Pressure}}{\text{Specific Gravity}}} \]

80’s, 90’s method

\[ = 8.63 \sqrt{\text{Tire Pressure}} \]

Current method
Contaminated and Slippery Runways

**Slush Force From Rotation to Liftoff**

\[ F_s = \left( \frac{1}{2} \rho \ C_{D_{\text{Slush}}} \ V_g^2 \ A_{\text{Tire}} \right) \times f_{\text{HP}} \times f_R \times f_{\text{LOF}} \]

- \( F_s \): Slush force
- \( \rho \): Density
- \( C_{D_{\text{Slush}}} \): Slush drag coefficient
- \( V_g \): Ground speed
- \( A_{\text{Tire}} \): Tire area
- \( f_{\text{HP}} \), \( f_R \), \( f_{\text{LOF}} \): Factors

**Graph:**
- Slush force vs. ground speed
- Key points: \( V_{\text{HP}} \), \( V_R \), \( V_{\text{LOF}} \)
Contaminated and Slippery Runways

Force Variation With Speed

Total Acceleration Force = Thrust - (Slush force + Aero drag + Friction)
Contaminated and Slippery Runways

All Engine Acceleration Capability

130 Knots

6 mm of slush - 10-20 % reduction in all engine acceleration

13 mm of slush - 20-40 % reduction in all engine acceleration

All engine acceleration Kt/sec

Dry 6 mm 13 mm

Dry 6 mm 13 mm

Dry 6 mm 13 mm

Dry 6 mm 13 mm
Engine Out Acceleration Capability

130 Knots

6 mm of slush - 15-50 % reduction in all engine-out acceleration

13 mm of slush - 30-110 % reduction in all engine-out acceleration

Contaminated and Slippery Runways
Force Variation With Speed – possible “negative acceleration”

Airplane acceleration forces

Engine out thrust

All engine thrust

Rolling Friction

Aero Drag

Slush Drag

Ground speed

\[ V_{HP}, V_{R}, V_{LOF} \]

Total Acceleration Force = Thrust - (Slush force + Aero drag + Rolling Friction)
Effect of Slush On Airplane Stopping

- Tire to ground friction reduced due to slush
- Retarding slush drag acts to slow the airplane

\[
\text{Total Slush stopping force} = \text{Slush Drag} + \text{Wheel braking}
\]

Dry runway

Average brake force

Retarding force

Retarding force

Ground speed, knots

\[0.9V_{hp}\]

\[V_{hp}\]
One Engine Inoperative Deceleration Capability

130 Knots

- Dry - AFM performance - includes maximum braking, spoilers, idle thrust

- Slush - includes wheel braking, spoilers, reverse thrust, and slush drag

![Bar Chart]

<table>
<thead>
<tr>
<th></th>
<th>Deceleration Kt/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry 6 mm</td>
<td>8.0</td>
</tr>
<tr>
<td>Dry 13 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>Dry 6 mm</td>
<td>8.0</td>
</tr>
<tr>
<td>747</td>
<td></td>
</tr>
<tr>
<td>Dry 6 mm</td>
<td>6.0</td>
</tr>
<tr>
<td>767</td>
<td></td>
</tr>
<tr>
<td>Dry 13 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>757</td>
<td></td>
</tr>
<tr>
<td>Dry 6 mm</td>
<td>4.0</td>
</tr>
<tr>
<td>737</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13 mm</td>
</tr>
</tbody>
</table>
Effect of using dry runway performance on a slush covered runway - all engine

767-300 - 182,800 kg, $V_1 = 163$ IAS

Baseline - AFM balance field length – 9,520 Feet

$V_1 = 163$ IAS

Accelerate

35 Feet

Go

$V = 0$

Stop

Runway available

Effect of using dry runway performance on slush covered runway

All engine performance - 6 mm slush

Margin 15%

All engine performance - 13 mm slush

Margin 5%
Effect of using dry runway performance on a slush covered runway – engine inoperative

767-300 - 182,800 kg, V1 = 163 IAS

- Effect of using dry runway performance on slush covered runway
- Engine out performance - 6 mm slush

Runway available – 9,520 feet

- Engine out performance - 13 mm slush
Agenda

Operational Methods to Account for Slush / Standing Water.
Boeing Contaminated Runway Data Adjustments Choices

Data presented in airplane Operations Manual, FPPM, and PEM

• Engine failure is considered - JAROPS 1, default in FPPM and OM
  – Weight reduction and $V_1$ adjustment provided
  – Credit for reverse thrust
  – 15 foot screen height

• All engines operating – in PEM, may be requested for operational documents
  – Weight reduction
  – No $V_1$ adjustment provided
  – Preserves 15% margin
Contaminated and Slippery Runways

FAR Dry Field Length
Typical Twin Engine Airplane

- Accelerate - Go
- Accelerate - Stop

Minimum runway required - FAR dry
1.15 All Eng Distance

Distance

Weight
altitude
temperature
flap

V₁
V₁ balanced

V₁ balanced
Contaminated Runway Case
All Engine Data

Distance

Increase distance

Accelerate - Go

1.15 all eng distance
(slush)

All engine slush runway required

Minimum runway required - FAR dry

1.15 all eng distance

V_1

V_1 balanced

Weight
altitude
temperature
flap
Contaminated and Slippery Runways

Constant Field Length Weight Reduction
All Engine Data

Note: Stop has not been considered nor has continued takeoff following engine failure

Altitude temperature flap

Field length

Brake release gross weight

Slush all engine field length

FAR dry field length
Constant Field Length Weight Reduction
All Engine Data

Note: Stop has not been considered nor has continued takeoff following engine failure

Altitude temperature flap

FAR dry field length

Slush all engine field length

\[ \Delta \text{Wt (slush)} \]

Contaminated and Slippery Runways
### All Engine Data - 737-500 / 20K Rating

#### Weight Reductions – 1,000 Kg

<table>
<thead>
<tr>
<th>Dry field /obstacle limit weight 1,000 kg</th>
<th>0.25 in (6 mm) slush/standing water depth</th>
<th>0.50 in (13 mm) slush/standing water depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport pressure altitude</td>
<td>S. L.  4000 ft  8000 ft</td>
<td>S. L.  4000 ft  8000 ft</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>35</td>
<td>0.0 0.0 0.0 0.0 0.3 0.0 0.5 1.0 0.0 0.0 0.3 0.5 1.0</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.0 0.0 0.0 0.1 0.8 0.0 1.2 2.1 0.0 0.0 0.5 0.0 1.2 2.1</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>0.1 0.2 0.6 1.4 1.9 3.1 1.7 2.1 0.6 1.4 1.9 3.1 1.7 2.1 3.1</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.3 0.5 1.1 2.0 2.7 4.2 1.1 2.1 0.6 1.1 2.1 3.1 1.1 2.1 3.1</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>0.5 0.8 1.7 2.5 3.4 5.1 1.7 2.1 0.6 1.7 2.1 3.1 1.7 2.1 3.1</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.6 1.1 2.1 3.2 4.3 6.2 2.1 3.1 1.7 2.1 3.1 4.1 2.1 3.1 4.1</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>0.7 1.3 2.3 4.1 5.2 7.2 2.3 3.1 1.7 2.3 3.1 4.1 2.3 3.1 4.1</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>0.8 1.4 2.2 4.9 6.1 8.3 2.2 3.1 1.7 2.2 3.1 4.1 2.2 3.1 4.1</td>
<td></td>
</tr>
</tbody>
</table>
Contaminated and Slippery Runways

All Engine Slush Takeoff Distance

767-300 - 182,800 kg, V1 = 163 IAS

Baseline - AFM balance field length – 9,520 feet

V1=163 IAS  35 Feet  Go

Accelerate

V=0  Stop

Runway available

All engine performance - 1/2 inch slush

Slush limit weight = AFM weight - \( \Delta \) weight slush

= 182,800 - 3,800 = 179,000 kg

35 feet

Margin 15%
V₁ Speed Recommendation when Performance based on All Engine Calculation

• What is the recommended V₁ speed when the slush/standing water takeoff weight is based on all engines operating during the entire takeoff?
Engine Inoperative Contaminated Runway Case

Engine Failure Considered

- Weight altitude
- Temperature flap

- Accelerate – Go with 15 foot screen height credit (slush)
- Accelerate – Stop with reverse thrust credit (slush)

Distance

Increase distance

- 1.15 all eng distance (slush)
- Slush runway required
- Minimum runway required - FAR dry

- V_1 adjustment
- V_1 balanced

Contaminated and Slippery Runways
Contaminated and Slippery Runways

Constant Field Length Weight Reduction and $V_1$ Adjustment

Engine Failure Considered

Field length

Slush Field Length

Altitude temperature flap

FAR dry field length

$V_1$

FAR $V_1$

Slush $V_1$

Brake release gross weight

Contaminated and Slippery Runways
Contaminated and Slippery Runways

Constant Field Length Weight Reduction and \( V_1 \) Adjustment

Engine Failure Considered

- Field length
- Slush Field Length
- Constant Field Length \( \Delta Wt \) (slush)
- Altitude temperature flap
- FAR dry field length
- FAR \( V_1 \)
- \( \Delta V_1 \) (slush)
- Slush \( V_1 \)

Brake release gross weight
Engine Failure Considered - 737-500 / 20K Rating

Dry runway field length/obstacle limit weight = **62,000 kg**, Sea level

### Weight adjustment (1,000 kg)

<table>
<thead>
<tr>
<th>Field/obstacle limit weight (1,000 kg)</th>
<th>6 mm (0.25 inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.L.</td>
</tr>
<tr>
<td>68</td>
<td>-9.4</td>
</tr>
<tr>
<td>64</td>
<td>-8.8</td>
</tr>
<tr>
<td>60</td>
<td>-7.9</td>
</tr>
</tbody>
</table>

**Dry field/obs limit**  = **62,000 kg**  
**Weight adjustment**  =  **- 8350 kg**

**6 mm slush field/obstacle limit weight**  =  **53,650 kg**

### V₁ adjustment (1,000 kg)

<table>
<thead>
<tr>
<th>Weight (1000 kg)</th>
<th>6 mm (0.25 inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.L.</td>
</tr>
<tr>
<td>68</td>
<td>-3</td>
</tr>
<tr>
<td>64</td>
<td>-5</td>
</tr>
<tr>
<td>60</td>
<td>-7</td>
</tr>
<tr>
<td>56</td>
<td>-10</td>
</tr>
<tr>
<td>52</td>
<td>-13</td>
</tr>
</tbody>
</table>

53,650 kg V₁ Bal  =  **137**

V₁ adjustment  =  **-12**

6 mm slush V₁  =  **125**
Contaminated and Slippery Runways

Engine Out Slush Takeoff Distance

767-300 - 182,800 kg, V1 = 163 IAS

Baseline - AFM balance field length – 9,520 Feet

V1=163 IAS
35 Feet
Go

Accelerate
V=0
Stop
Runway available

Engine out performance – 6 mm (1/2 inch slush )

Slush limit weight = AFM weight - Δ weight slush
= 182,800 - 28,900 = 153,900 kg

V1 = QRH V1 at actual weight - ΔV1 slush

V1 = 147 - 10 = 137 IAS

15 feet
Go

Accelerate
V=0
Stop
Contaminated and Slippery Runways

Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
    – Special performance considerations
  
    • $V_{1\text{MCG}}$ Considerations
    – Data / Applications
    – Snow Accountability
    – Crosswind

• Landing on slippery runway
Slippery Runway

(Non-dry, non-slush/standing water covered)

• No effect on acceleration

• All engine - No effect on calculation of all engine takeoff distance

• Accelerate - stop
  – Reduce tire to ground friction
  – Credit for reverse thrust

• Engine out accelerate - go
  – Go to 15-ft screen height
Airplane Braking Coefficient - $\mu_B$

- $\mu_B =$ Average airplane braking coefficient during the stop
  (Note: this is not tire to ground friction)

Stopping force due to wheel brakes

$$= \mu_B ( W - L )$$
Airplane Braking Coefficient - $\mu_B$
not tire to ground friction

- Typical dry values from Boeing certification testing
  - $\mu_B = 0.35$ to $0.41$
  - Maximum manual braking, anti-skid limited region
- Boeing slippery runway data (PEM/JAROPS 1)
  - RTO - $\mu_B = 0.05, 0.1, 0.15, 0.2$
  - Landing - $\mu_B = 0.05, 0.1, 0.15, 0.2$
- AC 91-6B and AMJ25X1591
  - Wet can be approximated $\mu_B = 0.2$ – Good
  - JAR certifications, Compact snow - $\mu_B = 0.20$
- Wet ice - $\mu_B = 0.05$ - nil
Contaminated and Slippery Runways

1.15 All engine distance

Accelerate - Stop

Minimum runway required - FAR Dry

Slippery Runway Case

Increase distance

Accelerate - Go
Slippery - 15 foot screen height

Accelerate - Stop (slippery)

Weight altitude
Temperature flap

Slippery runway required

Minimum runway required - FAR Dry

1.15 All engine distance

\( V_1 \) adjustment

\( V_1 \) balanced

Engine Failure Considered
Contaminated and Slippery Runways

Constant Field Length Weight Reduction and $V_1$ Adj.

Engine Failure Considered

- Field length
- Slippery Field Length
- Constant Field Length
- Altitude temperature flap
- FAR dry field length
- $\Delta Wt$ (slippery)
- FAR $V_1$
- $\Delta V_1$ (slippery)
- Slippery $V_1$
- Brake release gross weight

Contaminated and Slippery Runways
### Slippery Runway

- Boeing does not correlate “friction vehicle reported runway friction” to airplane braking coefficient.

- Pilot reported runway braking condition advisory information only

<table>
<thead>
<tr>
<th>Assumed Airplane Braking Coefficient</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.20</td>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>

- **Good**
  - 0.2 Wet, JAR certified compact snow for many models
- **Medium**
  - 0.1 Comparable to 727 cold ice (-10 to -15 C) test data
- **Poor**
  - 0.05 Wet ice – nil braking
### Sample Ops Manual Slippery Runway Data

Engine Failure Considered - 737-500 / 20K Rating  
Dry runway field length/obstacle limit weight = **62,000 kg**, Sea level

#### Weight adjustment (1,000 kg)

<table>
<thead>
<tr>
<th>Field/obstacle limit weight (1,000 kg)</th>
<th>Medium</th>
<th>4,000 ft</th>
<th>8,000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>-4.1</td>
<td>-4.1</td>
<td>-4.1</td>
</tr>
<tr>
<td>64</td>
<td>-4.2</td>
<td>-4.2</td>
<td>-4.2</td>
</tr>
<tr>
<td>60</td>
<td>-4.2</td>
<td>-4.2</td>
<td>-4.2</td>
</tr>
</tbody>
</table>

**Dry field/obs limit weight** = **62,000 kg**  
**Weight adjustment** = **-4200 kg**  

#### Medium field/obstacle limit weight

**= 57,800 kg**

**53,650 kg V_1 Bal** = **141**  
**V_1 adjustment** = **-16**  
**Medium V_1** = **125**
Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
    – Special performance considerations
      • $V_{1\text{MCG}}$ Considerations
        – Data / Applications
        – Snow Accountability
        – Crosswind

• Landing on slippery runway
V$_1$MCG Considerations

- $V_1$ reductions associated with slippery and contaminated runways increases the possibility of being limited by $V_1$MCG considerations
  - $V_1$ reductions can be as high as 40 kts for data labeled as slippery – “poor”
Contaminated and Slippery Runways

$V_{1mcg}$ Case

- Accelerate - Go
- Slippery - 15 foot screen height
- Runway Required $V_{1mcg}$ limited
- Slippy Runway Required Balanced
- 1.15 All Eng Distance

- Altitude temperature flap
- Accelerate - Stop

Distance

$V_1$ slippery

$V_{1mcg}$ balanced
### Contaminated and Slippery Runways

**Sample OM Slush/Standing Minimum Field Length Page**

**737-500 / 20K Rating**

\[ V_1 = V_{1mcg} \quad \text{limit weight} \quad 1,000 \text{ kg} \]

<table>
<thead>
<tr>
<th>Available field length ft</th>
<th>6 mm (0.25 inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pressure altitude</td>
</tr>
<tr>
<td></td>
<td>S.L.</td>
</tr>
<tr>
<td>4,200</td>
<td>30.7</td>
</tr>
<tr>
<td>4,600</td>
<td>37.6</td>
</tr>
<tr>
<td>5,000</td>
<td>30.7</td>
</tr>
<tr>
<td>5,400</td>
<td>44.5</td>
</tr>
<tr>
<td>5,800</td>
<td>51.8</td>
</tr>
<tr>
<td>6,200</td>
<td>59.1</td>
</tr>
<tr>
<td>6,600</td>
<td>66.5</td>
</tr>
<tr>
<td>7,000</td>
<td>73.8</td>
</tr>
<tr>
<td>7,400</td>
<td></td>
</tr>
</tbody>
</table>

Contaminated and Slippery Runways
**$V_{1mCG}$ Limitation Based on Accelerate – Stop Distance**

- Distance Required to accelerate to a given velocity and stop is lower for deeper slush.

  737-500/20k rating, $V_{1mcg} = 109$ kias, GW = 52,000 kg

<table>
<thead>
<tr>
<th>Slush Depth</th>
<th>Accel-stop distance to $V_{1mcg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>6,050 feet</td>
</tr>
<tr>
<td>6 mm</td>
<td>5,800 feet</td>
</tr>
<tr>
<td>13 mm</td>
<td>5,600 feet</td>
</tr>
</tbody>
</table>

- This is because the slush drag penalty on the all engine acceleration segment is less than the benefit that the slush drag provides on the stop.

<table>
<thead>
<tr>
<th>Slush Depth</th>
<th>$V_{1mcg}$</th>
<th>Weight @ 6200 feet field length</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>$V_{1mcg}$</td>
<td>56,300 kg</td>
</tr>
<tr>
<td>6 mm</td>
<td>$V_{1mcg}$</td>
<td>59,100 kg</td>
</tr>
<tr>
<td>13 mm</td>
<td>$V_{1mcg}$</td>
<td>61,700 kg</td>
</tr>
</tbody>
</table>
$V_{1MCG}$ Speed and Slush

Field length required

$V_1 = V_{1MCG}$

$W_{13 \text{ mm}} > W_{3 \text{ mm}}$

Brake release gross weight
### $V_{1\text{MCG}}$ Speed, Slush, and Derate

<table>
<thead>
<tr>
<th>Thrust</th>
<th>TO</th>
<th>TO-1</th>
<th>TO-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{1\text{mcg}}$</td>
<td>126</td>
<td>123</td>
<td>117</td>
</tr>
</tbody>
</table>
Reduced thrust for acceleration is offset by lower $V_{1mcg}$ at derate
Lower speed to accelerate to, lower speed to stop from

$W_{TO-2} > W_{TO}$
**$V_{1\text{MCG}}$ Limited Weight**

- Example of 777-200ER/-94B engine

$$V_{1\text{mcg}} \text{ Weight @ 2400 m field length – kg}$$

<table>
<thead>
<tr>
<th>Slush Depth</th>
<th>TO</th>
<th>TO-1</th>
<th>TO-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>187,400</td>
<td>218,100</td>
<td>278,600</td>
</tr>
<tr>
<td>6 mm</td>
<td>201,600</td>
<td>232,500</td>
<td>293,400</td>
</tr>
<tr>
<td>13 mm</td>
<td>225,400</td>
<td>256,300</td>
<td>316,800</td>
</tr>
</tbody>
</table>
Contaminated and Slippery Runways

Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
  – Special performance considerations

• \( V_{1\text{IMC}} \) Considerations
  – Data / Applications
  – Snow Accountability
  – Crosswind

• Landing on slippery runway
Operational Data Calculation Steps

• Condition: 737-500
  CFM56-3 series @ 20K engines
  Runway length available = 6,000 ft
  Field/obstacle limit weight = 60,000 kgs
  Sea level, 0 C, flaps 5
  6 mm (0.25”) of slush

• Step 1 - Determine gross weight reduction

• Step 2 - Determine $V_{1mcg}$ limit weight

• Step 3 - Lowest of step 1 and 2 is limiting weight

• Step 4 - Determine $V_1$ at actual takeoff weight
### 0.25 in (6mm) Slush/Standing Water Depth

#### Weight adjustment (1,000 kg)

<table>
<thead>
<tr>
<th>Field/obstacle limit weight (1000 kg)</th>
<th>6 mm (0.25 inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.L.</td>
</tr>
<tr>
<td>68</td>
<td>-9.4</td>
</tr>
<tr>
<td>64</td>
<td>-8.8</td>
</tr>
<tr>
<td>60</td>
<td>-7.9</td>
</tr>
<tr>
<td>56</td>
<td>-7.1</td>
</tr>
<tr>
<td>52</td>
<td>-6.2</td>
</tr>
<tr>
<td>48</td>
<td>-5.5</td>
</tr>
<tr>
<td>44</td>
<td>-4.8</td>
</tr>
<tr>
<td>40</td>
<td>-4.5</td>
</tr>
<tr>
<td>36</td>
<td>-4.3</td>
</tr>
</tbody>
</table>
Operational Data

- Condition: 737-500
  CFM56-3 series @ 20K engines
  Runway length available = 6,000 ft
  Field/obstacle limit weight = 60,000 kgs
  Sea level, 0°C, flaps 5
  6 mm (0.25”) of slush

- Step 1 - Determine gross weight reduction
  \[60,000 - 7900 = 52,100 \text{kgs}\]

- Step 2 - Determine \(V_{1mcg}\) limit weight

- Step 3 - Lowest of step 1 and 2 is limiting weight

- Step 4 - Determine \(V_1\) at actual takeoff weight
0.25 in (6mm) Slush/Standing Water Depth

\[ V_1 = V_{1mcg} \text{ limit weight } 1,000 \text{ kg} \]

<table>
<thead>
<tr>
<th>Available field length ft</th>
<th>6 mm (0.25 inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pressure altitude</td>
</tr>
<tr>
<td></td>
<td>S.L.</td>
</tr>
<tr>
<td>4,200</td>
<td>30.7</td>
</tr>
<tr>
<td>4,600</td>
<td>37.6</td>
</tr>
<tr>
<td>5,000</td>
<td>44.5</td>
</tr>
<tr>
<td>5,400</td>
<td>51.8</td>
</tr>
<tr>
<td>5,800</td>
<td>59.1</td>
</tr>
<tr>
<td>6,200</td>
<td>66.5</td>
</tr>
<tr>
<td>6,600</td>
<td>73.8</td>
</tr>
<tr>
<td>7,000</td>
<td>63.2</td>
</tr>
<tr>
<td>7,400</td>
<td>53.5</td>
</tr>
</tbody>
</table>
Contaminated and Slippery Runways

Operational Data

• Condition: 737-500
  CFM56-3 series @ 20K engines
  Runway length available = 6,000 ft
  Field/obstacle limit weight = 60,000 kgs
  Sea level, 0 C, flaps 5
  6 mm (0.25”) of slush

• Step 1 - Determine gross weight reduction
  \[60,000 - 7900 = 52,100 \text{ kgs}\]

• Step 2 - Determine \(V_{1mcg}\) limit weight
  55,450 kgs

• Step 3 - Lowest of step 1 and 2 is limiting weight
  52,100 kgs, lowest of step 1 and 2

• Step 4 - Determine \(V_1\) at actual takeoff weight
0.25 in (6mm) Slush/Standing Water Depth

QRH/FMC dry runway takeoff speeds at 52,100 kgs

<table>
<thead>
<tr>
<th>Weight (1000 kg)</th>
<th>6 mm (0.25 inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.L.</td>
</tr>
<tr>
<td>68</td>
<td>-3</td>
</tr>
<tr>
<td>64</td>
<td>-5</td>
</tr>
<tr>
<td>60</td>
<td>-7</td>
</tr>
<tr>
<td>56</td>
<td>-10</td>
</tr>
<tr>
<td>52</td>
<td>-13</td>
</tr>
<tr>
<td>48</td>
<td>-16</td>
</tr>
<tr>
<td>44</td>
<td>-18</td>
</tr>
<tr>
<td>40</td>
<td>-19</td>
</tr>
<tr>
<td>36</td>
<td>-19</td>
</tr>
</tbody>
</table>

V₁ adjustment (1,000 kg)

V₁mcg for this condition is 109 kias. Not limiting.
Exercises

• Calculate the allowable takeoff weight for the exercise handed out in class.
OM/FPPM Data vs. Computer Calcs

From the exercise

OM/FPPM data from exercises
60,500 kg 111/127/135

BTM computed data
65,300 kg 119/134/140

In this example approximately 5000 kg is gained using BTM

Note: BTOPS would show similar benefit for these examples
What is the conservatism in the OM/FPPM data which causes this reduced weight?

Consider the OM/FPPM method is based on equivalent distance principle. The original dry runway weight and the reduced slippery/slush/standing water weight require the same distance.
Consider the following data based on exercise 1

Balanced distance required for dry runway field/obs weight limit of 68,400 kg, V1 of 135 kias = 1977 meters

Balanced distance required for 6 mm SW field/obs limit weight using the OM/FPPM weight limit of 60,500 kg, V1 of 111 kias = 1977 meters

But, the dry runway baseline is an obstacle limited case not field limited. Actual runway available is 2600 m.

and, lighter 6 mm weight has extra climb capability and therefore extra margin for obstacle clearance.
Balanced distance required for 6 mm SW field/obs limit weight using the OM/FPPM weight limit of 60,500 kg, V1 of 111 kias = 1977 meters

Balanced distance required for 6 mm SW field/obs limit weight using BTM weight limit of 65,300 kg, V1 of 119 kias = 2492 meters

Computer programs (BTM/BTOPS) will optimize for obstacle clearance considerations. OM/FPPM method does not do this.
Contaminated and Slippery Runways

Net Flight Path Comparision

- Dry TO Weight 68400
- Runway Surface
- OM 6 mm SW 60500
- BTM 6 mm SW 65300
- Obstacle

Distance from Brake Release - m
Net Height - ft

Dry TO Weight 68400
Runway Surface
OM 6 mm SW 60500
BTM 6 mm SW 65300
Obstacle

35 feet
15 feet
Contaminated and Slippery Runways

Gross Flight Path Comparison

- Dry TO Weight 68400
- Runway Surface
- OM 6 mm SW 60500
- BTM 6 mm SW 65300
- Obstacle

Distance from Brake Release - m

Gross Height - ft

35 feet
15 feet
Contaminated and Slippery Runways

Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
  – Special performance considerations

• $V_{1\text{MCG}}$ Considerations
  – Data / Applications

  – Snow Accountability
  – Crosswind

• Landing on slippery runway
Snow Accountability

• JAR AFM contain performance for snow
  – Depth 1.27 mm to 101 mm
  – Resistant force based on slush modeling using snow specific gravity of 0.2
  – In operational software for 777,737-6/7/8/900, 757-300, 767-400
  – In 747-400

• NPA no. 14 for 25.1591
  – Updated calculation method that better reflects the physics of snow
    • Compression based not displacement based modeling
Snow

As Taken From Draft AC 91-6B

Note: This is not to be construed as an FAA or Boeing recommendation but it does reflect one method for accounting for the effect of snow which has been used.
Crosswind Guidelines

• Boeing publishes takeoff and landing crosswind guidelines in the Flight Crew Training Manuals
  – Derived from analysis and piloted simulations
  – Based on steady winds
  – Function of runway condition - dry, wet, standing water/slush, snow - no melting, ice - no melting
  – Accounts for asymmetric reverse thrust
  – Provides guidance on technique (side slip, crab)
Example of FCTM information
May be different for TO and Land

Runway Condition

<table>
<thead>
<tr>
<th>Runway Condition</th>
<th>Crosswind – Knots*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>40</td>
</tr>
<tr>
<td>Wet</td>
<td>25</td>
</tr>
<tr>
<td>Standing Water/Slush</td>
<td>15</td>
</tr>
<tr>
<td>Snow – No Melting**</td>
<td>20</td>
</tr>
<tr>
<td>Ice – No Melting**</td>
<td>15</td>
</tr>
</tbody>
</table>
Crosswind Guidelines

- Recently Boeing extended additional guidance upon request

<table>
<thead>
<tr>
<th>FCTM Rwy Condition (TO and Land Guidelines)</th>
<th>Pilot Reported Braking Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>Dry</td>
</tr>
<tr>
<td>Wet</td>
<td>Good</td>
</tr>
<tr>
<td>Snow – No Melting</td>
<td>Medium to Good</td>
</tr>
<tr>
<td>Slush/St. Water or Ice – No Melting</td>
<td>Medium to Poor</td>
</tr>
</tbody>
</table>
Contaminated and Slippery Runways

Agenda

• Basic Regulations and Definitions

• Takeoff
  – Wet Runway
  – Slush/Standing Water
  – Slippery Runway
  – Special performance considerations

• $V_{1\text{MCG}}$ Considerations
  – Data / Applications
  – Snow Accountability
  – Crosswind

• Landing on slippery runway
Landing on Wet/Slippery Runways

Landing

• Information - Condition Reporting
• Approach, Flare, and Touchdown
• Stopping
• Recommended Landing Procedure
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
Contaminated and Slippery Runways

Landing Distance Data
CERTIFIED Data Method

- Dry runway
- Automatic Spoilers
- Max manual braking
- No reverse thrust

Reference Runway

DEMONSTRATED CAPABILITY

CERTIFIED FAR Dry

CERTIFIED FAR Wet/slippery
Landing Distance Data
ADVISORY Data Method

- Dry runway
- Automatic Spoilers
- Maximum manual braking
- With reverse thrust

50 ft

Reference Runway – FAR wet/slippery

ADVISORY
Dry runway

Good braking

Medium braking

Poor braking

Contaminated and Slippery Runways
**PI Slippery Runway Landing Data**

Adjustments for:
- Weight
- Altitude
- Wind
- Approach speed
- Slope
- Reverse thrust

### Advisory Information

**Normal Configuration Landing Distance**
Flaps 40
Dry Runway

<table>
<thead>
<tr>
<th>BRKNG CONFIG</th>
<th>REF DIST</th>
<th>WT ADJ</th>
<th>ALT ADJ</th>
<th>WIND ADJ</th>
<th>SLOPE ADJ</th>
<th>TEMP ADJ</th>
<th>VREF ADJ</th>
<th>REVERSE THRUST ADJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX MANUAL</td>
<td>2510</td>
<td>270/-140</td>
<td>50</td>
<td>-90</td>
<td>320</td>
<td>30</td>
<td>-30</td>
<td>200</td>
</tr>
<tr>
<td>MAX AUTO</td>
<td>2610</td>
<td>250/-160</td>
<td>60</td>
<td>-90</td>
<td>350</td>
<td>20</td>
<td>-10</td>
<td>40</td>
</tr>
<tr>
<td>AUTOBRAKES 3</td>
<td>3140</td>
<td>370/-230</td>
<td>50</td>
<td>-140</td>
<td>540</td>
<td>30</td>
<td>-30</td>
<td>50</td>
</tr>
<tr>
<td>AUTOBRAKES 2</td>
<td>4460</td>
<td>560/-450</td>
<td>130</td>
<td>-230</td>
<td>820</td>
<td>40</td>
<td>-40</td>
<td>80</td>
</tr>
<tr>
<td>AUTOBRAKES 1</td>
<td>5100</td>
<td>560/-450</td>
<td>170</td>
<td>-280</td>
<td>1000</td>
<td>150</td>
<td>-140</td>
<td>90</td>
</tr>
</tbody>
</table>

### Good Reported Braking Action

<table>
<thead>
<tr>
<th>BRKNG CONFIG</th>
<th>REF DIST</th>
<th>WT ADJ</th>
<th>ALT ADJ</th>
<th>WIND ADJ</th>
<th>SLOPE ADJ</th>
<th>TEMP ADJ</th>
<th>VREF ADJ</th>
<th>REVERSE THRUST ADJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX MANUAL</td>
<td>3420</td>
<td>270/-230</td>
<td>80</td>
<td>-150</td>
<td>250</td>
<td>80</td>
<td>-60</td>
<td>50</td>
</tr>
<tr>
<td>MAX AUTO</td>
<td>3420</td>
<td>270/-230</td>
<td>80</td>
<td>-150</td>
<td>360</td>
<td>80</td>
<td>-60</td>
<td>50</td>
</tr>
<tr>
<td>AUTOBRAKES 3</td>
<td>3810</td>
<td>320/-280</td>
<td>100</td>
<td>-170</td>
<td>330</td>
<td>50</td>
<td>-30</td>
<td>50</td>
</tr>
<tr>
<td>AUTOBRAKES 2</td>
<td>4920</td>
<td>460/-410</td>
<td>140</td>
<td>-240</td>
<td>870</td>
<td>50</td>
<td>-70</td>
<td>50</td>
</tr>
<tr>
<td>AUTOBRAKES 1</td>
<td>5410</td>
<td>540/-470</td>
<td>170</td>
<td>-290</td>
<td>1030</td>
<td>150</td>
<td>-150</td>
<td>150</td>
</tr>
</tbody>
</table>

### Medium Reported Braking Action

### Reported Braking Action

Dry | Good | Medium | Poor

Sample data is from the 737 OM

Contaminated and Slippery Runways
Autobrakes are recommended on a slippery runway.

- Medium, 3 or 4 are recommended depending on airplane

### Braking Configuration

| MAX MANUAL | 2510 | 270/-140 | 50 |
| MAX AUTO  | 2610 | 250/-160 | 60 |
| AUTOBRAKES 3 | 2140 | 370/-230 | 90 |
| AUTOBRAKES 2 | 4460 | 560/-450 | 130 |
| AUTOBRAKES 1 | 5100 | 560/-450 | 170 |

### Medium Reported Braking Action

| MAX MANUAL | 3420 | 270/-230 | 80 | -150 | 560 | 80 | -60 | 50 | -40 | 280 | 160 | 370 |
| MAX AUTO  | 3420 | 270/-230 | 80 | -150 | 560 | 80 | -60 | 50 | -40 | 280 | 160 | 370 |
| AUTOBRAKES 3 | 3810 | 320/-280 | 100 | -170 | 630 | 50 | -30 | 60 | -50 | 400 | 40 | 230 |
| AUTOBRAKES 2 | 4920 | 460/-410 | 140 | -240 | 870 | 70 | -70 | 80 | -80 | 470 | 70 | 70 |
| AUTOBRAKES 1 | 5410 | 540/-470 | 170 | -290 | 1030 | 160 | -150 | 90 | -90 | 440 | 490 | 640 |

Sample data is from the 737 OM
Sample OM

PI Slippery Runway Landing Data

**Poor Reported Braking Action**

<table>
<thead>
<tr>
<th>MAX MANUAL</th>
<th>6360</th>
<th>590/-550</th>
<th>200</th>
<th>-370</th>
<th>1450</th>
<th>450</th>
<th>-300</th>
<th>100</th>
<th>-90</th>
<th>420</th>
<th>1090</th>
<th>6370</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX AUTO</td>
<td>6360</td>
<td>590/-550</td>
<td>200</td>
<td>-370</td>
<td>1450</td>
<td>450</td>
<td>-300</td>
<td>100</td>
<td>-90</td>
<td>420</td>
<td>1090</td>
<td>6370</td>
</tr>
<tr>
<td>AUTO BRAKES 3</td>
<td>6380</td>
<td>590/-550</td>
<td>200</td>
<td>-370</td>
<td>1450</td>
<td>440</td>
<td>-280</td>
<td>100</td>
<td>-90</td>
<td>460</td>
<td>1080</td>
<td>6360</td>
</tr>
<tr>
<td>AUTO BRAKES 2</td>
<td>6820</td>
<td>630/-610</td>
<td>210</td>
<td>-390</td>
<td>1510</td>
<td>410</td>
<td>-290</td>
<td>100</td>
<td>-100</td>
<td>480</td>
<td>840</td>
<td>5910</td>
</tr>
<tr>
<td>AUTO BRAKES 1</td>
<td>7040</td>
<td>690/-650</td>
<td>230</td>
<td>-400</td>
<td>1550</td>
<td>460</td>
<td>-330</td>
<td>110</td>
<td>-110</td>
<td>480</td>
<td>1100</td>
<td>5830</td>
</tr>
</tbody>
</table>

Reference distance is for sea level, standard day, no wind or slope, VREF15 approach speed and 2 engine detent reverse thrust.
Actual (unfactored) distances are shown.
Includes distance from 50 ft above threshold (1000 feet of air distance).

*Note: JAROPS data includes a factor of 1.15

Sample data is from the 737 OM

Contaminated and Slippery Runways
Reverse Thrust Application Sequence

As Applied in QRH Advisory Data

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

* Actual time dependant on engine/airframe
Information

Weather - winds, gust - approach speed

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.
Evaluation of Information

• Flight crew needs to evaluate the information available to them
  – Time of report, possible changing conditions

• Information may be conflicting
  – For example:
    • Braking action is good, runway description is slush covered
    • Measured friction is 0.35, runway description is slush covered
  – If runway is reported to have slush/standing water covering, the flight crew should be suspicious of braking action reports and measured friction
Hydroplaning (aquaplaning) is possible

Ground friction measuring vehicles are unreliable when the runway is covered with a depth of contaminant that exceeds:
- Water - 1 mm
- Slush/wet snow - 3 mm
- Snow - 2.5 cm

Ground friction measuring vehicles measure friction at a point in time.
- Available runway friction may change with
  - Temperature change
  - Precipitation change
  - Traffic

*Reference - FAA AC 150.5200-30A
Industry Initiative

• In 2006, FAA held a workshop in Wash. D. C. to address methods of runway condition reporting.
  – Smaller workgroups were formed
  – Product of one work group was a voluntary table of braking action terminology and information
    • Team comprised of: US operators, FAA, ATC and Airport representatives
      – Expected to be baseline for future regulatory information on the subject (AC and/or regulatory activity)
  – Table
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
Crosswind Guidelines

<table>
<thead>
<tr>
<th>Runway Surface Condition</th>
<th>Crosswind Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry ***</td>
<td>36</td>
</tr>
<tr>
<td>Wet</td>
<td>32</td>
</tr>
<tr>
<td>Standing Water/Slush</td>
<td>20</td>
</tr>
<tr>
<td>Snow - No Melting</td>
<td>25</td>
</tr>
<tr>
<td>Ice - No Melting **</td>
<td>15</td>
</tr>
</tbody>
</table>

* Winds measured at 10 meter tower height.
** Landing on untreated ice should only be attempted when no melting is present.
*** Sideslip only (zero crab) landings are not recommended in crosswinds in excess of 16 knots at 1.1 Operating Empty Weight or 20 knots at Max Landing Weight. This recommendation ensures adequate ground clearance and is based on using a maximum 2/3 lateral control input for maneuver capability.

The crosswind guidelines shown in Table 4-4 were derived through analysis and piloted simulation evaluations. These crosswind guidelines are based on steady wind (no gust) conditions. Due to the difficulty in modeling gust magnitude, duration, frequency and direction, gust additive to these guidelines is not provided.

Discretion in evaluating and determining acceptable gust values is left to individual operators.

Reference: Boeing Flight Crew Training Manual - 747-400

Contaminated and Slippery Runways
Landing on Wet/Slippery Runways

Landing

• Information

• Approach, flare, and touchdown

• Stopping

• Recommended landing procedure
Approach, Flare, and Touchdown

- Objective
  - Position the airplane on the runway at the target point at the minimum speed for the existing conditions.
    - Minimize the air distance
    - Maximize the stopping distance available
  - Factors that influence air distance
    - Flare technique
    - Approach speed
    - Approach path
  - Type of approach flown
    - 2 bar / 3 bar VASI - FCTM
    - Autoland – 1500 to 2500 feet flare distance
    - Hud guidance – similar to autoland
Land in touchdown zone

• Do not allow the airplane to float. Fly the airplane onto the runway and accomplish the stopping procedure.

• Do not attempt achieve a perfectly smooth touchdown. Do not hold the nose wheel off the runway after touchdown.

• After main gear touchdown, begin to smoothly fly the nose wheel onto the runway by relaxing aft control column pressure.
Deceleration Rate Comparison

Air Versus Ground

Based on 747 at operational landing weight
Wheel brakes, spoilers, and reverse thrust as noted

Note: On airplanes with more effective reversers the ratio of ground attitude deceleration can be 9-10 times more than floating deceleration.
Excess speed:

- Bleeding off excess speed during flare will increase air distance by:
  - 150 to 200 feet / knot of speed reduction
  - 225 to 275 feet / second of additional air time

Based on 747 at operational landing weight - 4 thrust reverser
Excess Speed at Touchdown Effects Stopping Distance

Greater touchdown velocity causes longer ground distance

Same weight, same runway conditions

VTD

Stop

VTD + 10

Stop
Landing Distance Increase Due to Excess Touchdown Speed

Based on 747 at operational landing weight - 4-engine reverse thrust
Excess Threshold Height

Based on a 3-degree glideslope

Excess height at threshold, ft

Normal 50 ft

Increased in distance to touchdown, ft

Excess Height to Touchdown

Contaminated and Slippery Runways
Landing - Stopping / Roll out

Objective

• Stop the airplane within the remaining runway available.

Factors affecting stopping distance

• Reduced runway friction capability
  • Wet
  • Standing Water / Slush
  • Ice / compact snow
  • Effectiveness of stopping devices
    • Thrust reversers, ground spoilers, wheel brakes
Runway Friction Capability

Hydroplaning

- **Viscous** - normal wet runway friction
- **Dynamic** - “planing” of the tire on standing water and slush
- **Reverted rubber** - locked wheel hydroplaning
  - *Reverted rubber hydroplaning is not an issue on post-1980 airplane designs due the improvement in anti-skid system hydroplane protection.*
Viscous Hydroplaning

Normal Wet Runway Friction

Thin film of water acts like a lubricant. The microtexture (sandpaper type roughness) of the runway surface breaks up the water film and greatly improves traction.

<table>
<thead>
<tr>
<th>Ground speed, kt</th>
<th>Dry runway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smoother microtexture</td>
</tr>
<tr>
<td></td>
<td>Rougher microtexture</td>
</tr>
</tbody>
</table>

Airplane braking coefficient
Dynamic Hydroplaning

Commonly Called “Hydroplaning”, “Aquaplaning”

At high speeds the tire “planes” on deep slush/standing water. Tire grooves and macrotexture (stony or grooved surface) help drain water from the footprint and improve traction.

\[
V_{\text{HP}} = 8.63 \sqrt{\text{Tire pressure, psi}}
\]

Nil braking above 90% of dynamic hydroplaning speed.
Effect of Runway Condition on Stopping Distance

Based on 747 at operational landing weight - Wheel brakes, spoilers, 4-engine reverse thrust
Effectiveness of Stopping Devices

- Dry runway - Wheel brakes are the most effective stopping devices

- Lift reduction due to spoiler deployment contributes greatly to the generation of effective stopping force due to wheel brakes

Effect of ground spoilers

<table>
<thead>
<tr>
<th>Ground spoilers</th>
<th>Reverse thrust</th>
<th>Aero drag</th>
<th>Wheel brakes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>49,000</td>
<td>54,000</td>
<td>168,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No ground spoilers</th>
<th>Reverse thrust</th>
<th>Aero drag</th>
<th>Wheel brakes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>49,000</td>
<td>35,000</td>
<td>106,000</td>
</tr>
</tbody>
</table>

Based on 747 at operational landing weight - Wheel brakes, spoilers, 4-engine reverse thrust, 120 knots
Effect of Spoilers

Total stopping force, lb = Reverse thrust + aero drag + wheel brake

<table>
<thead>
<tr>
<th></th>
<th>Spoilers deployed</th>
<th>Spoilers stowed</th>
<th>Spoiler effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>270,100</td>
<td>190,400</td>
<td>29 %</td>
</tr>
<tr>
<td>Good</td>
<td>194,400</td>
<td>142,300</td>
<td>27 %</td>
</tr>
<tr>
<td>Medium</td>
<td>148,500</td>
<td>113,200</td>
<td>24 %</td>
</tr>
<tr>
<td>Poor</td>
<td>125,600</td>
<td>98,600</td>
<td>21 %</td>
</tr>
</tbody>
</table>

Based on 747 at operational landing weight - Wheel brakes, spoilers, 4-engine reverse thrust - 120 knots
Effectiveness of Stopping Devices

Slippery runway - thrust reverser and aerodynamic drag become dominate stopping force as runway slipperiness increases.

Based on 747 at operational landing weight - Wheel brakes, spoilers, 4-engine reverse thrust - 120 knots
Boeing recommends autobrake when landing on a slippery runway

- Setting 3 or 4 for wet or slippery runway
  - Actual setting dependent on model
- Autobrake assures prompt application of the brakes after touchdown
- Autobrake performance capability is limited by the runway friction capability
Maximum Deceleration
Manual Braking Versus Autobrakes

Dry runway

<table>
<thead>
<tr>
<th>Braking Applied</th>
<th>Deceleration Level</th>
<th>Distance based on autobrake decel rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Manual</td>
<td>Drag Brakes</td>
<td>Decel Target</td>
</tr>
<tr>
<td>Autobrake Max</td>
<td>Drag Brakes</td>
<td>Decel Target</td>
</tr>
<tr>
<td>Autobrake 2</td>
<td>Drag Brakes</td>
<td>Decel Target</td>
</tr>
<tr>
<td></td>
<td>Drag Reverse Thrust</td>
<td>Decel Target</td>
</tr>
</tbody>
</table>

Contaminated and Slippery Runways
Maximum Deceleration Available from Brakes

Runway condition
Braking action

Max Brakes

\{ e.g. stand on the brake pedals \}

Better

\begin{itemize}
\item Dry
\item Antiskid limited
\item Antiskid limited
\item Antiskid limited
\end{itemize}

Worse

\begin{itemize}
\item Poor
\end{itemize}

Deceleration Available from Brakes

\begin{itemize}
\item Less
\item More
\end{itemize}
Contaminated and Slippery Runways

Maximum Deceleration
Good Braking

Max Braking Available

- Dry
- Good
- Med
- Poor

Braking
Applied

Max Manual

- Drag Brakes
- Reverse Thrust

Autobrake Max

- Drag Brakes
- Reverse Thrust

Autobrake 2

- Drag Brakes
- Reverse Thrust

Deceleration level
NOT achieved
Distance based on
runway friction

Deceleration level
achieved
Distance based on
autobrake decel rate
Safety Alert for Operators published on 31 Aug, SAFO 06012

- FAA recommendation for enroute check of landing performance when conditions are worse than assumed at dispatch
- Safety Alert for Operators published on 31 Aug, SAFO 06012
  - Voluntary not mandatory
  - Prelude to rulemaking
  - Recommends the airlines a check of landing performance using the conditions expected at time of arrival
  - Recommends a 15% safety margin
SAFO 06012
“Survey Findings”

Documents FAA finding that some airlines:

- have **misused or misinterpreted the information** the manufacturer supplied.
- have **not revised their documents and methods** when manufacturer has made revisions.
- **did not train or provide guidance** on how to use actual operational landing distance information provided by manufacturer nor address safety margins.
- **did not include manufacturer data** in operations procedures.
- **did not require landing distance assessments** at time of arrival.
- had **confusion on whether reverse thrust has been included in the calculations**
SAFO 06012 Ops Spec Order Recommendations

- Recommends enroute evaluation of landing performance if actual conditions are worse than dispatch calculations.

- Recommends margin of Safety of at least 15% in non-emergency situations.

- Provides definitions of Braking Action terminology
  - Industry working group has created a voluntary set of definitions and explanations to be used in operation and as a starting point for future rulemaking.

- States 1000 feet air distance is not consistently achievable.

- Provides a method of compliance based on normal AFM dry runway data

- States “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
### 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

<table>
<thead>
<tr>
<th></th>
<th>Dry</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AFM FAR Wet - baseline</strong></td>
<td>6500</td>
<td>6500</td>
<td>6500</td>
<td>6500</td>
</tr>
<tr>
<td><strong>QRH Advisory * 1.15</strong></td>
<td>2850</td>
<td>1600</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>AFM FAR Wet - baseline</strong></td>
<td>9000</td>
<td>9000</td>
<td>9000</td>
<td>9000</td>
</tr>
<tr>
<td><strong>QRH Advisory * 1.15</strong></td>
<td>5380</td>
<td>4100</td>
<td>2170</td>
<td>130</td>
</tr>
</tbody>
</table>
Summary

Recommended Procedures

Information

• Evaluate all the information before the approach
  • Wind, weather, runway condition, etc.
  • If runway conditions warrant, review the performance data to ensure the runway length exceeds the expected stopping distance by an adequate margin
Summary

Recommended Procedures (continued)

• Prepare to land the aircraft
  – In the touchdown zone
    • 1,000-ft target
  – On centerline
  – With minimal lateral drift
  – Without excess speed
    • Normal speed additives
  – Be aware of longer touchdown distance associated with different approach types

• Arm auto spoilers and auto brakes as appropriate
  – Assures prompt stopping effort after touchdown
Summary

Recommended Procedures (continued)

• Flare and Touchdown
  – Flare should lead to a firm touchdown
  – Extended flare will extend touchdown and delay braking

• Lower the nose as soon as main gear touches down
  – Increases load on the gear
Summary

Recommended Procedures (continued)

• Raise spoilers as soon as possible after touchdown (confirm auto spoiler deployment)
  – Increase load on the gear

• Initiate braking once spoilers have been raised and nose wheels have contacted the runway
  – Apply brakes smooth and symmetrically
Contaminated and Slippery Runways

Summary

Recommended Procedures (continued)

• Initiate reverse thrust as soon as possible after touchdown

• Target the rollout to stop well short of the end of the runway
  – Leave margin for unexpectedly low friction due to wet rubber deposits or hydroplaning