FLIGHT SAFETY FOUNDATION

ALAR

APPROACH-AND-LANDING ACCIDENT REDUCTION

TOOL KIT

FSF ALAR BRIEFING NOTE 8.5

Wet or Contaminated Runways

The conditions and factors associated with landing on a wet runway or a runway contaminated by standing water, snow, slush or ice should be assessed carefully before beginning the approach.

Statistical Data

The Flight Safety Foundation (FSF) Approach-and-landing Accident Reduction (ALAR) Task Force found that wet runways were involved in 11 approach-and-landing accidents and serious incidents involving runway overruns and runway excursions worldwide in 1984 through 1997.[1]

The FSF Runway Safety Initiative (RSI) team found that wet runways and runways contaminated by standing water, snow, slush or ice were involved in 96 percent of the runway-excursion accidents, in which runway condition was known, that occurred during landing worldwide in 1995 through March 2008.[2]

Defining Runway Condition

Dry Runway

The European Joint Aviation Authorities (JAA)[3] defines *dry runway* as "one which is neither wet nor contaminated, and includes those paved runways which have been specially prepared with grooves or porous pavement and maintained to retain 'effectively dry' braking action even when moisture is present."

Damp Runway

JAA says that a runway is considered damp "when the surface is not dry, but when the moisture on it does not give it a shiny appearance."

Wet Runway

JAA says that a runway is considered wet "when the runway surface is covered with water, or equivalent, less than specified [for a contaminated runway] or when there is sufficient moisture on the runway surface to cause it to appear reflective, but without significant areas of standing water."

Contaminated Runway

JAA says that a runway is contaminated "when more than 25 percent of the runway surface area (whether in isolated areas or not) within the required length and width being used is covered by the following:

- "Surface water more than 3.0 mm [millimeters] (0.125 in [inch]) deep, or by slush or loose snow, equivalent to more than 3.0 mm (0.125 in) of water;
- "Snow which has been compressed into a solid mass which resists further compression and will hold together or break into lumps if picked up (compacted snow); or,
- "Ice, including wet ice."

The U.S. Federal Aviation Administration[4] says that a runway is considered contaminated "whenever standing water, ice, snow, slush, frost in any form, heavy rubber, or other substances are present."

Factors and Effects

Braking Action

The presence on the runway of a fluid contaminant (water, slush or loose snow) or a solid contaminant (compacted snow or ice) adversely affects braking performance (stopping force) by:

- Reducing the friction force between the tires and the runway surface. The reduction of friction force depends on the following factors:
  - Tire-tread condition (wear) and inflation pressure;
  - Type of runway surface; and,

– Anti-skid system performance; and,

- Creating a layer of fluid between the tires and the runway, thus reducing the contact area and creating a risk of hydroplaning (partial or total loss of contact and friction between the tires and the runway surface).

Fluid contaminants also contribute to stopping force by:

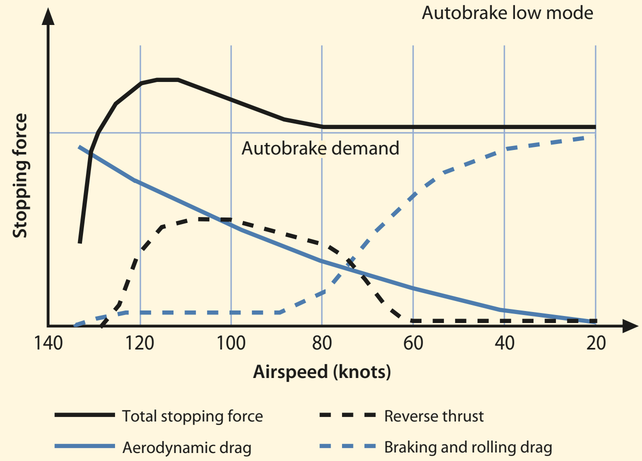
- Resisting forward movement of the wheels (i.e., causing *displacement drag*); and,
- Creating spray that strikes the landing gear and airframe (i.e., causing *impingement drag*). Certification regulations require spray to be diverted away from engine air inlets.

The resulting braking action is the net effect of the above stopping forces (Figure 1 and Figure 2).

Hydroplaning (Aquaplaning)

Hydroplaning occurs when the tire cannot squeeze any more of the fluid-contaminant layer between its tread and lifts off the runway surface.

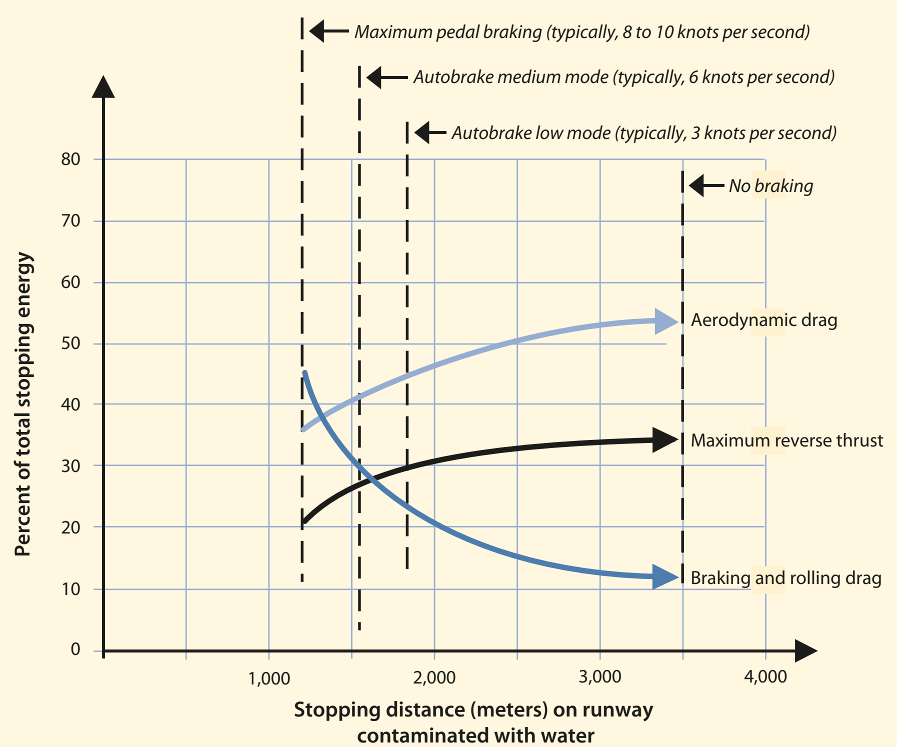
Typical Decelerating Forces During Landing Roll



Source: FSF ALAR Task Force

Figure 1

Effect of Braking Devices on Stopping Energy and Stopping Distance



Note: Examples assume that airplane touches down at maximum landing weight and at landing reference speed (V_{REF}) on a dry runway at sea level and standard pressure and temperature.

Source: FSF ALAR Task Force

Figure 2

Hydroplaning results in a partial or total loss of contact and friction between the tire and the runway, and in a corresponding reduction of friction coefficient.

Main wheels and nosewheels can be affected by hydroplaning. Thus, hydroplaning affects nosewheel steering, as well as braking performance.

Hydroplaning always occurs to some degree when operating on a fluid-contaminated runway.

The degree of hydroplaning depends on the following factors:

- Absence of runway surface roughness and inadequate drainage (e.g., absence of transverse saw-cut grooves);
- Depth and type of contaminant;
- Tire inflation pressure;
- Groundspeed; and,
- Anti-skid operation (e.g., locked wheels).

A minimum hydroplaning speed is defined usually for each aircraft type and runway contaminant.

Hydroplaning may occur at touchdown, preventing the wheels from spinning and from sending the wheel-rotation signal to various aircraft systems.

Conducting a firm touchdown can reduce hydroplaning at touchdown.

Directional Control

On a contaminated runway, directional control should be maintained using the rudder pedals; do not use the nosewheel-steering tiller until the aircraft has slowed to taxi speed.

On a wet runway or a contaminated runway, use of nosewheel steering above taxi speed may cause the nosewheels to hydroplane and result in the loss of nosewheel cornering force with consequent loss of directional control.

If differential braking is necessary, pedal braking should be applied on the required side and should be released on the opposite side to regain directional control. (If braking is not completely released on the opposite side, brake demand may continue to exceed the anti-skid regulated braking; thus, no differential braking may be produced.)

Landing Distances

Landing distances usually are published in aircraft operating manuals (AOMs)/quick reference handbooks (QRHs) for dry runways and for runway conditions and contaminants such as the following:

- Wet;
- 6.3 millimeters (0.25 inch) of standing water;
- 12.7 millimeters (0.5 inch) of standing water;
- 6.3 millimeters (0.25 inch) of slush;
- 12.7 millimeters (0.5 inch) of slush;
- Compacted snow; and,
- Ice.

Landing distances are published for all runway conditions, and assume:

- An even distribution of the contaminant;
- Maximum pedal braking, beginning at touchdown; and,
- An operative anti-skid system.

Landing distances for automatic landing (autoland) using the autobrake system are published for all runway conditions.

In addition, correction factors (expressed in percentages) are published to compensate for the following:

- Airport elevation:
  - Typically, +5 percent per 1,000 feet;
- Wind component:
  - Typically, +10 percent per five-knot tail wind component; and,
  - Typically, −2.5 percent per five-knot head wind component; and,
- Thrust reversers:
  - The thrust-reverser effect depends on runway condition and type of braking.

Stopping Forces

Figure 1 shows the distribution of the respective *stopping forces* as a function of decreasing airspeed during a typical landing roll using autobrakes in "LOW" mode (for a low deceleration rate) and maximum reverse thrust.

Total stopping force is the combined result of:

- Aerodynamic drag (the term refers to drag on the airplane during the roll-out [including impingement drag on a fluid-contaminated runway]);
- Reverse thrust; and,
- Rolling drag.

Distribution of Stopping Energy on a Contaminated Runway

Figure 2 shows the contribution to the total *stopping energy* of various braking devices as a function of the desired or achieved landing distance on a runway contaminated with water.

Figure 2 can be used to determine:

- For a given braking procedure (pedal braking or an autobrake mode), the resulting landing distance; or,
- For a desired or required landing distance, the necessary braking procedure (pedal braking or an autobrake mode).

Figure 2 shows that on a runway contaminated with standing water (compared to a dry runway):

- The effect of aerodynamic drag increases because of impingement drag;
- The effect of braking and rolling drag (balance of braking force and displacement drag) decreases; and,
- *Thrust-reverser stopping force is independent of runway condition*, and its effect is greater when the deceleration rate is lower (i.e., autobrakes with time delay vs. pedal braking [see Figure 1]).

Factors Affecting Landing Distance

Runway Condition and Type of Braking

Figure 3 shows the effect of runway condition on landing distance for various runway conditions and for three braking procedures (pedal braking, use of "LOW" autobrake mode and use of "MEDIUM" autobrake mode).

Figure 3 is based on a 1,000-meter (3,281-foot) landing distance (typical manual landing on a dry runway with maximum pedal braking and no reverse thrust).

For each runway condition, the landing distances for a manual landing with maximum pedal braking and an automatic landing with autobrakes can be compared.

Similarly, for a manual landing or an autoland (with autobrakes), the effect of the runway condition can be seen.

When autobrakes are used, braking efficiency is a function of the selected autobrake mode and of the anti-skid activation point, whichever is achieved first, as shown by Figure 3 and Figure 4.

On a runway contaminated with standing water or slush, the landing distances with a "MEDIUM" or a "LOW" autobrake mode are similar because the deceleration rate is affected primarily by aerodynamic drag, rolling drag and reverse thrust, and because the selected autobrake deceleration rate (e.g., "MEDIUM" mode) cannot be achieved.

Thrust Reversers

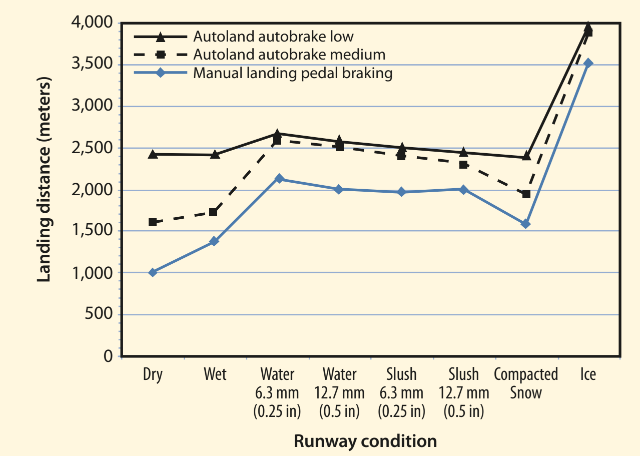
Figure 4 shows the effect of reverse thrust with both thrust reversers operative.

When autobrakes are used, the thrust reverser effect (i.e., contribution to landing-distance reduction) is a function of:

- The selected deceleration rate and the time delay on autobrake activation, as applicable; and,
- Runway condition (contribution of contaminant to the deceleration rate).

On a dry runway or on a wet runway, the effect of the thrust reversers on landing distance depends on the selected autobrake mode and on the associated time delay (e.g., "MEDIUM" mode

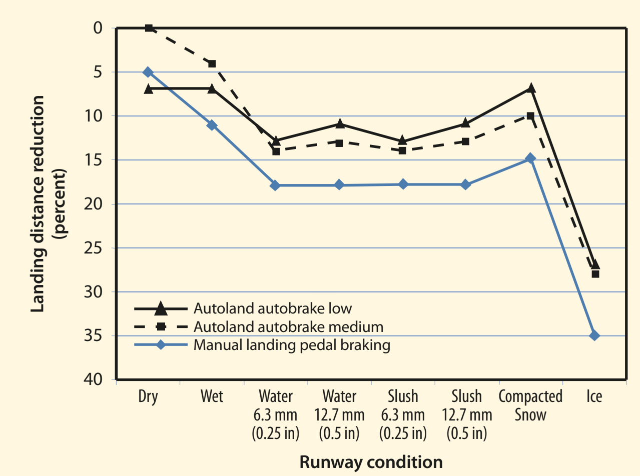
Effect of Anti-Skid on Friction Force and Slip Ratio



Source: FSF ALAR Task Force

Figure 3

Effect of Anti-Skid on Friction Force and Slip Ratio



Source: FSF ALAR Task Force

Figure 4

without time delay vs. "LOW" mode with time delay), as shown by Figure 1 and Figure 4.

Operational Guidelines

When the destination-airport runways are wet or contaminated, the crew should:

- Consider diverting to an airport with better runway conditions or a lower crosswind component when actual conditions significantly differ from forecast conditions or when a system malfunction occurs;

- Anticipate asymmetric effects at landing that would prevent efficient braking or directional control (e.g., crosswind);
- Avoid landing on a contaminated runway without anti-skid or with only one thrust reverser operational;
- For inoperative items affecting braking or lift-dumping capability, refer to the applicable:
  - AOM/QRH for in-flight malfunctions; or,
  - Minimum equipment list (MEL) or dispatch deviation guide (DDG) for known dispatch conditions;
- Select autobrake mode per standard operating procedures (some AOMs/QRHs recommend not using autobrakes if the contaminant is not evenly distributed);
- Approach on glide path and at the target final approach speed;
- Aim for the touchdown zone;
- Conduct a firm touchdown;
- Use maximum reverse thrust as soon as possible after touchdown (because thrust reverser efficiency is higher at high airspeed);
- Confirm the extension of ground spoilers/speed brakes;
- Do not delay lowering the nosewheel onto the runway. This increases weight-on-wheels and activates aircraft systems associated with the nosegear squat switches;
- Monitor the autobrakes (on a contaminated runway, the selected deceleration rate may not be achieved);
- As required or when taking over from autobrakes, apply the pedal brakes normally with a steady pressure;
- For directional control, use rudder pedals (and differential braking, as required); do not use the nosewheel-steering tiller;
- If differential braking is necessary, apply braking on the required side and release the braking on the opposite side; and,
- After reaching taxi speed, use nosewheel steering with care.

Summary

Conditions associated with landing on a wet runway or a runway contaminated by standing water, snow, slush or ice require a thorough review before beginning the approach.

The presence on the runway of water, snow, slush or ice adversely affects the aircraft's braking performance by:

- Reducing the friction force between the tires and the runway surface; and,
- Creating a layer of fluid between the tires and the runway, which reduces the contact area and leads to a risk of hydroplaning.

Directional control should be maintained on a contaminated runway by using the rudder pedals and differential braking, as required; nosewheel steering should not be used at speeds higher than taxi speed because the nosewheels can hydroplane.

The following FSF ALAR Briefing Notes provide information to supplement this discussion:

- 7.1 — Stabilized Approach;
- 8.3 — Landing Distances;
- 8.4 — Braking Devices; and,
- 8.7 — Crosswind Landings.

The following FSF RSI Briefing Notes also provide information to supplement this discussion:

- Pilot Braking Action Reports; and,
- Runway Condition Reporting.

Notes

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2. Flight Safety Foundation. "Reducing the Risk of Runway Excursions." Report of the FSF Runway Safety Initiative, May 2009.
3. Joint Aviation Authorities. *Joint Aviation Requirements — Operations*. 1.480 "Terminology."
4. U.S. Federal Aviation Administration. *Flight Services, 7110.10N*. Appendix A "Pilot/Controller Glossary."

Related Reading From FSF Publications

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FSF Editorial Staff. "Runway Overrun Occurs After Captain Cancels Go-around." *Accident Prevention* Volume 58 (June 2001).

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Yager, Thomas J. "The Joint FAA/NASA Aircraft/Ground Vehicle Runway Friction Program." *Flight Safety Digest* Volume 8 (March 1989).

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Notice

The Flight Safety Foundation (FSF) Approach-and-Landing Accident Reduction (ALAR) Task Force produced this briefing note to help prevent approach-and-landing accidents, including those involving controlled flight into terrain. The briefing note is based on the task force's data-driven conclusions and recommendations, as well as data from the U.S. Commercial Aviation Safety Team's Joint Safety Analysis Team and the European Joint Aviation Authorities Safety Strategy Initiative.

This briefing note is one of 33 briefing notes that comprise a fundamental part of the FSF *ALAR Tool Kit,* which includes a variety of other safety products that also have been developed to help prevent approach-and-landing accidents.

The briefing notes have been prepared primarily for operators and pilots of turbine-powered airplanes with underwing-mounted engines, but they can be adapted for those who operate airplanes with fuselage-mounted turbine engines, turboprop power plants or piston engines. The briefing notes also address operations with the following: electronic flight instrument systems; integrated autopilots, flight directors and autothrottle systems; flight management systems; automatic ground spoilers; autobrakes; thrust reversers; manufacturers'/operators' standard operating procedures; and, two-person flight crews.

This information is not intended to supersede operators' or manufacturers' policies, practices or requirements, and is not intended to supersede government regulations.

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