FLIGHT SAFETY FOUNDATION

ALAR

APPROACH-AND-LANDING ACCIDENT REDUCTION

TOOL KIT

FSF ALAR BRIEFING NOTE 8.4

Braking Devices

The following braking devices are used to decelerate the aircraft until it stops:

- Ground spoilers/speed brakes;
- Wheel brakes (including anti-skid systems and autobrake systems); and,
- Thrust-reverser systems.

Statistical Data

The Flight Safety Foundation (FSF) Approach-and-landing Accident Reduction (ALAR) Task Force found that runway excursions were involved in 20 percent of 76 approach-and-landing accidents and serious incidents worldwide in 1984 through 1997.[1]

The task force also found that delayed braking action during the landing roll-out was involved in some of the accidents and serious incidents in which slow/delayed crew action was a causal factor.[2] Slow/delayed crew action was a causal factor in 45 percent of the 76 accidents and serious incidents.

The FSF Runway Safety Initiative (RSI) team found that improper use and malfunction of speed brakes, wheel brakes and reverse thrust were significant factors in 435 runway-excursion landing accidents worldwide in 1995 through March 2008.[3]

Braking Devices

Ground Spoilers/Speed Brakes

Ground spoilers/speed brakes usually deploy automatically (if armed) upon main-landing-gear touchdown or upon activation of thrust reversers.

Ground spoilers/speed brakes provide two aerodynamic effects:

- Increased aerodynamic drag, which contributes to aircraft deceleration; and,
- Lift-dumping, which increases the load on the wheels and, thus, increases wheel-brake efficiency (Figure 1).

Wheel Brakes

Braking action results from the friction force between the tires and the runway surface.

The friction force is affected by:

- Aircraft speed;
- Wheel speed (i.e., free-rolling, skidding or locked);
- Tire condition and pressure (i.e., friction surface);
- Runway condition (i.e., runway friction coefficient);
- The load applied on the wheel; and,
- The number of operative brakes (as shown by the minimum equipment list [MEL]/dispatch deviation guide [DDG]).

Braking force is equal to the load applied on the wheel multiplied by the runway friction coefficient.

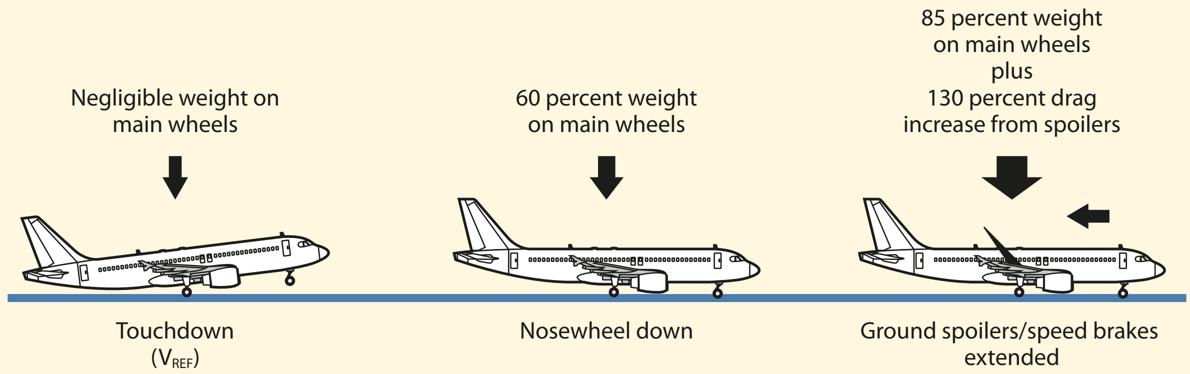
Anti-skid systems are designed to maintain the wheel-skidding factor (also called the slip ratio) near the point providing the maximum friction force, which is approximately 10 percent on a scale from zero percent (free-rolling) to 100 percent (locked wheel), as shown by Figure 2.

With anti-skid operative, maximum pedal braking results typically in a deceleration rate of eight knots to 10 knots per second.

Autobrake systems are designed to provide a selectable deceleration rate, typically between three knots per second and six knots per second.

When a low autobrake deceleration rate (referred to hereafter as a "LOW" mode) is selected, brake pressure is applied usually after a specific time delay to give priority to the thrust-reverser deceleration force at high airspeed.

Effects of Nosewheel Contact and Ground Spoilers on Weight-on-Wheels and Aerodynamic Drag

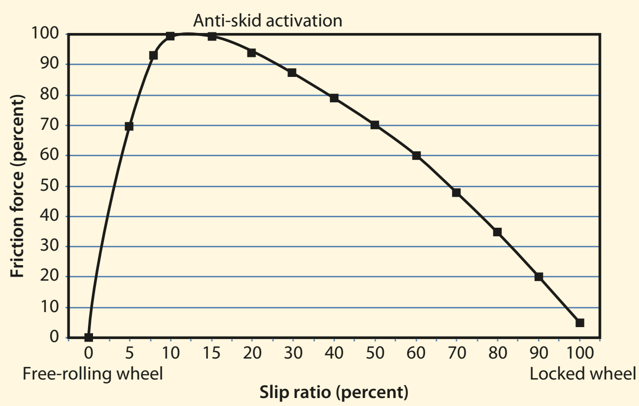


V_{REF} = reference landing speed

Source: FSF ALAR Task Force

Figure 1

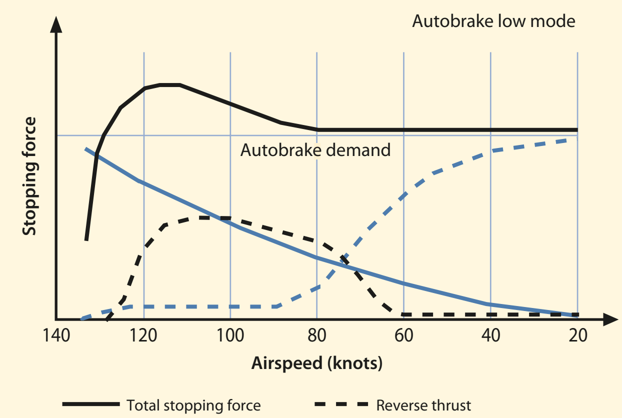
Effect of Anti-Skid on Friction Force and Slip Ratio



Source: FSF ALAR Task Force

Figure 2

Typical Decelerating Forces During Landing Roll



Source: FSF ALAR Task Force

Figure 3

Thrust Reversers

Thrust reversers provide a deceleration force that is independent of runway condition.

Thrust-reverser efficiency is higher at high airspeed (Figure 3); therefore, thrust reversers must be selected as early as possible after touchdown (in accordance with standard operating procedures [SOPs]).

Thrust reversers should be returned to reverse idle at low airspeed (to prevent engine stall or foreign object damage) and stowed at taxi speed.

Nevertheless, maximum reverse thrust can be maintained to a complete stop in an emergency.

Runway Conditions

Runway contamination increases impingement drag (i.e., drag caused by water or slush sprayed by the tires onto the aircraft) and displacement drag (i.e., drag created as the tires move through a fluid contaminant [water, slush, loose snow] on the runway), and affects braking efficiency.

The following landing distance factors are typical:

- Wet runway, 1.3 to 1.4;
- Water-contaminated or slush-contaminated runway, 2.0 to 2.3;
- Compacted-snow-covered runway, 1.6 to 1.7; and,
- Icy runway, 3.5 to 4.5.

Typical Landing Roll

Figure 3 shows a typical landing roll and the relation of the *different deceleration forces* to the total stopping force as a function of *decelerating airspeed* (from touchdown speed to taxi speed).

The ground spoilers are armed and the autobrakes are selected to the "LOW" mode (for time-delayed brake application).

The autobrake demand in "LOW" mode (typically, three knots per second constant deceleration rate) is equivalent, at a given gross weight, to a constant deceleration force.

At touchdown, the ground spoilers automatically extend and maximum reverse thrust is applied.

The resulting total stopping force is the combined result of:

- Aerodynamic drag (the normal drag of the airplane during the roll-out, not the drag produced by the incorrect technique of keeping the nose high during an extended landing flare);
- Reverse thrust; and,
- Rolling drag.

Autobrake activation is inhibited because the total stopping force exceeds the selected rate of the autobrakes or because of the autobrake time delay.

As airspeed decreases, total stopping force decreases because of a corresponding decrease in:

- Aerodynamic drag; and,
- Reverse thrust efficiency.

When the total stopping force becomes lower than the autobrake setting or when the autobrake time delay has elapsed, the wheel brakes begin contributing to the total deceleration and stopping force.

Typically, at 60 knots indicated airspeed (KIAS) to 80 KIAS, the thrust-reverser levers are returned to the reverse-idle position (then to the stow position at taxi speed).

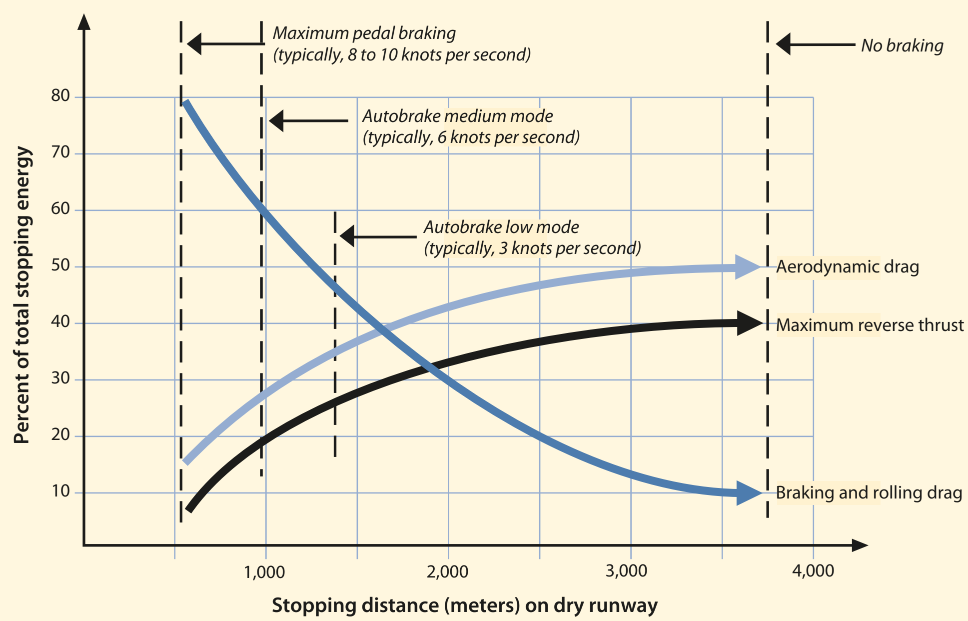
As a result, the wheel brakes' contribution to stopping force increases to maintain the desired deceleration rate (autobrake demand) to a complete stop or until the pilot takes over with pedal braking.

Ground Spoilers/Speed Brakes, Thrust Reversers and Brakes Stop the Aircraft

Figure 4 shows the respective contributions of the different braking devices to total *stopping energy*, as a function of the achieved or desired *stopping distance*.

Figure 4 shows the following:

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 4

- For a given braking procedure (maximum pedal braking or autobrake mode), the stopping distance; and,
- For a desired or required stopping distance, the necessary braking procedure (maximum pedal braking or autobrake mode).

Factors Affecting Braking

The following factors have affected braking in runway veer-offs or runway overruns:

- Failure to arm ground spoilers/speed brakes, with thrust reversers deactivated (e.g., reliance on a thrust-reverser signal for ground-spoilers extension, as applicable);
- Failure to use any braking devices (i.e., reliance on the incorrect technique of maintaining a nose-high attitude after touchdown to achieve aerodynamic braking);

(The nosewheel should be lowered onto the runway as soon as possible to increase weight-on-wheels and activate aircraft systems associated with the nose-landing-gear squat switches.)

- Asymmetric thrust (i.e., one engine above idle in forward thrust or one engine failing to go into reverse thrust);
- Brake unit inoperative (e.g., reported as a "cold brake" [i.e., a brake whose temperature is lower, by a specified amount, than the other brakes on the same landing gear]);
- Spongy pedals (air in the hydraulic wheel-braking system);
- Anti-skid tachometer malfunction;
- Failure to adequately recover from loss of the normal braking system;
- Late selection of thrust reversers;
- No takeover or late takeover from autobrakes, when required;
- No switching or late switching from normal braking to alternate braking or to emergency braking in response to abnormal braking; or,
- Crosswind landing and incorrect braking technique.

Summary

The following can ensure optimum braking during the landing roll:

- Arm ground spoilers/speed brakes;
- Arm autobrakes with the most appropriate mode for prevailing conditions (short runway, low visibility, contaminated runway);
- Select thrust reversers as soon as appropriate with maximum reverse thrust (this increases safety on dry runways and wet runways, and is mandatory on runways contaminated by standing water, snow, slush or ice);
- Monitor and call "spoilers" or "speed brakes" extension;
- Be ready to take over from the autobrakes, if required;
- Monitor engine operation in reverse thrust (exhaust gas temperature [EGT], evidence of surge);
- Monitor airspeed indication (or fluctuations) and return engines to reverse idle at the published indicated airspeed;
- If required, use maximum pedal braking; and,
- As a general rule, do not stop braking until assured that the aircraft will stop within the remaining runway length.

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

- 8.3 — Landing Distances;
- 8.5 — Wet or Contaminated Runways; and,
- 8.7 — Crosswind Landings.

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

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

Notes

1. Flight Safety Foundation. "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999): 1–121. The facts presented by the FSF ALAR Task Force were based on analyses of 287 fatal approach-and-landing accidents (ALAs) that occurred in 1980 through 1996 involving turbine aircraft weighing more than 12,500 pounds/5,700 kilograms, detailed studies of 76 ALAs and serious incidents in 1984 through 1997 and audits of about 3,300 flights.
2. The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force defines *causal factor* as "an event or item judged to be directly instrumental in the causal chain of events leading to the accident [or incident]." Each accident and incident in the study sample involved several causal factors.
3. Flight Safety Foundation. "Reducing the Risk of Runway Excursions." Report of the FSF Runway Safety Initiative, May 2009.

Related Reading From FSF Publications

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Mook, Reinhard. "Treacherous Thawing." *AeroSafety World* Volume 3 (October 2008).

Werfelman, Linda. "Safety on the Straight and Narrow." *AeroSafety World* Volume 3 (August 2008).

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

FSF Editorial Staff. "Managing Aircraft-tire Wear and Damage Requires Adherence to Removal Limits." *Aviation Mechanics Bulletin* Volume 47 (May–June 1999).

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FSF Editorial Staff. "Attempted Go-around with Deployed Thrust Reversers Leads to Learjet Accident." *Accident Prevention* Volume 56 (January 1999).

King, Jack L. "During Adverse Conditions, Decelerating to Stop Demands More from Crew and Aircraft." *Flight Safety Digest* Volume 12 (March 1993).

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

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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