FSF ALAR BRIEFING NOTE 8.7

Crosswind Landings

Operations in crosswind conditions require adherence to applicable limitations or recommended maximum crosswinds and recommended operational and handling techniques, particularly when operating on wet runways or runways contaminated by standing water, snow, slush or ice.

Statistical Data

The Flight Safety Foundation (FSF) Approach-and-landing Accident Reduction (ALAR) Task Force found that adverse wind conditions (i.e., strong crosswinds, tail winds or wind shear) were involved in about 33 percent of 76 approach-and-landing accidents and serious incidents worldwide in 1984 through 1997.[1]

The task force also found that adverse wind conditions and wet runways were involved in the majority of the runway excursions that comprised 8 percent of the accidents and serious incidents.

The FSF Runway Safety Initiative (RSI) team found that crosswinds were involved in 12 percent of 435 runway-excursion landing accidents worldwide in 1995 through March 2008.[2]

Runway Condition and Maximum Recommended Crosswind

The maximum demonstrated crosswind and maximum computed crosswind are applicable only on a runway that is dry, damp or wet.

On a runway contaminated with standing water, slush, snow or ice, a recommended maximum crosswind (Table 1) usually is defined as a function of:

- Reported braking action (if available);
- Reported runway friction coefficient (if available); or,
- Equivalent runway condition (if braking action and runway friction coefficient are not reported).

Equivalent runway condition, as defined by the notes in Table 1, is used only for the determination of the maximum recommended crosswind.

Table 1 cannot be used for the computation of takeoff performance or landing performance, because it does not account for the effects of displacement drag (i.e., drag created as the tires make a path through slush) and impingement drag (i.e., drag caused by water or slush sprayed by tires onto the aircraft).

Recommended maximum crosswinds for contaminated runways usually are based on computations rather than flight tests, but the calculated values are adjusted in a conservative manner based on operational experience.

The recommended maximum crosswind should be reduced for a landing with one engine inoperative or with one thrust reverser inoperative (as required by the aircraft operating manual [AOM] and/or quick reference handbook [QRH]).

Some companies also reduce the recommended maximum crosswind when the first officer is the pilot flying (PF) during line training and initial line operation.

AOMs/QRHs prescribe a maximum crosswind for conducting an autoland operation.

The pilot-in-command should request assignment of a more favorable runway if the prevailing runway conditions and crosswind are unfavorable for a safe landing.

Approach Techniques

Figure 1 shows that, depending on the recommendations published in the AOM/QRH, a final approach in crosswind conditions may be conducted:

- With wings level (i.e., applying a drift correction to track the runway centerline); this type of approach usually is referred to as a *crabbed approach*; or,
- With a steady sideslip (i.e., with the fuselage aligned with the runway centerline, using a combination of into-wind aileron and opposite rudder [cross-controls] to correct the drift).

Reported Braking Action (Index)	Reported Runway Friction Coefficient	Equivalent Runway Condition	Recommended Maximum Crosswind
Good (5)	0.40 and above	(See note 1)	35 knots
Good/medium (4)	0.36 to 0.39	(See note 1)	30 knots
Medium (3)	0.30 to 0.35	(See notes 2 and 3)	25 knots
Medium/poor (2)	0.26 to 0.29	(See note 3)	20 knots
Poor (1)	0.25 and below	(See notes 3 and 4)	15 knots
Unreliable (9)	Unreliable	(See notes 4 and 5)	5 knots

Factors Included in Typical Recommended Maximum Crosswind

Notes:

1. Dry, damp or wet runway (less than three millimeters [0.1 inch] of water) without risk of hydroplaning.
2. Runway covered with dry snow.
3. Runway covered with slush.
4. Runway covered with standing water, with risk of hydroplaning, or with slush.
5. Runway with high risk of hydroplaning.

Source: FSF ALAR Task Force

Table 1

The following factors should be considered when deciding between a wings-level approach and a steady-sideslip approach:

- Aircraft geometry (pitch-attitude limits and bank-angle limits, for preventing a tail strike, engine contact or wing-tip contact);
- Aileron (roll) and rudder (yaw) authority; and,
- The magnitude of the crosswind component.

The recommended maximum crosswind and the recommended crosswind landing technique depend on the aircraft type and model; limitations and recommendations usually are published in the AOM/QRH.

Flare Techniques

When approaching the flare point with wings level and with a crab angle, as required for drift correction, one of three techniques can be used:

- Align the aircraft with the runway centerline, while preventing drift, by applying into-wind aileron and opposite rudder;
- Maintain the crab angle for drift correction until the main landing gear touch down; or,
- Perform a partial decrab, using the cross-controls technique to track the runway centerline.

Some AOMs and autopilot control requirements for autoland recommend beginning the alignment phase well before the flare point (typically between 200 feet and 150 feet), which results in a steady-sideslip approach down to the flare.

Landing Limitations

Knowledge of flight dynamics can provide increased understanding of the various crosswind techniques.

Landing Capabilities

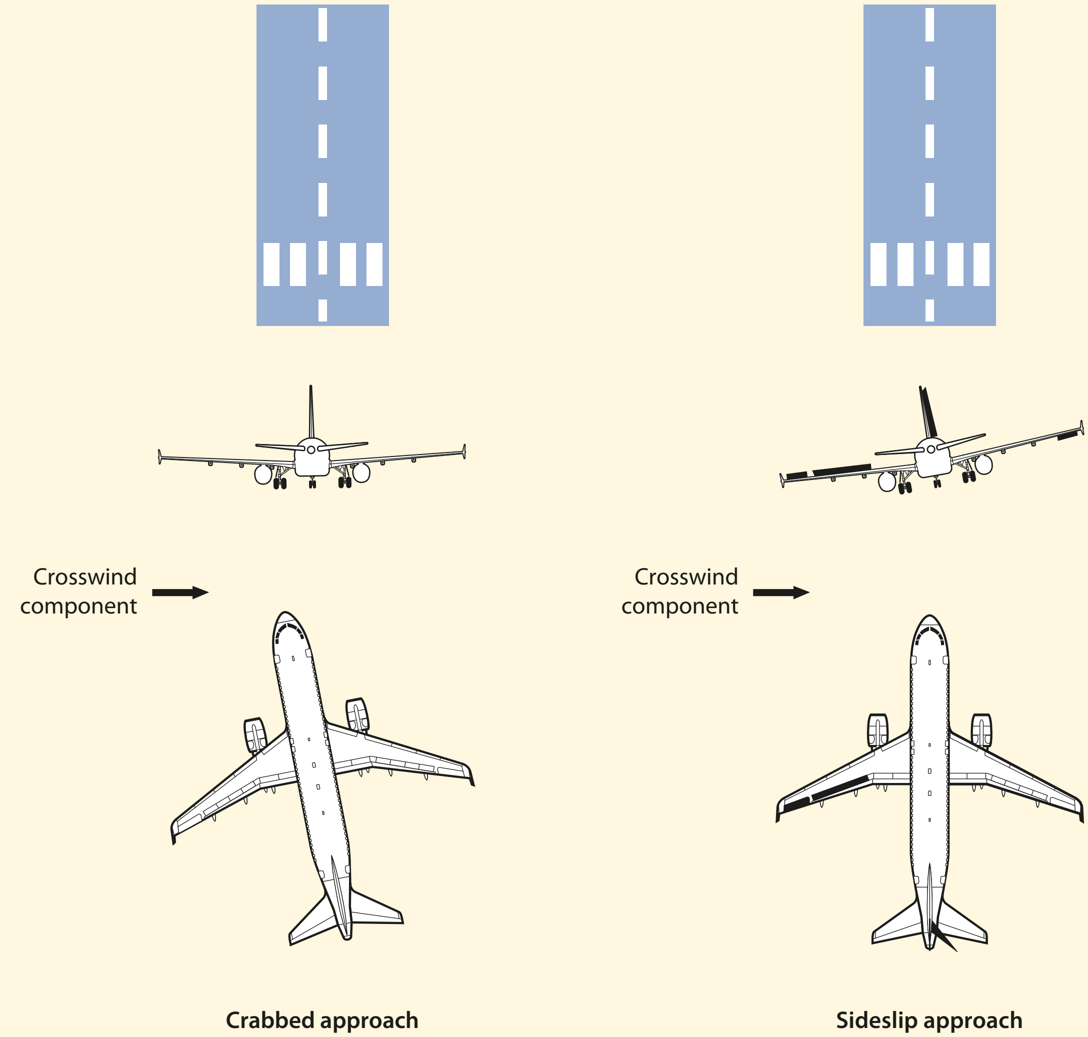
Figure 2 and Figure 3 show the limitations involved in crosswind landings (for a given steady crosswind component):

- Bank angle at a given crab angle or crab angle at a given bank angle:
  - The graphs show the bank-angle/crab-angle relationship required to correct drift and to track the runway centerline at the target final approach speed.

    Positive crab angles result from normal drift correction and sideslip conditions (i.e., with the aircraft pointing into the wind).

    Negative crab angles are shown but would require an excessive sideslip rudder input, resulting in a more-than-desired bank angle;
- Aircraft geometry limits:
  - Limits result from the maximum pitch attitude/bank angle that can be achieved without striking the runway with the tail or with the engine pod (for underwing-mounted engines), the flaps or the wing tip; and,
- Aileron/rudder authority:
  - This limitation results from the aircraft's maximum capability to maintain a steady sideslip under crosswind conditions.

Crabbed Approach and Sideslip Approach



Source: FSF ALAR Task Force

Figure 1

Figure 2 and Figure 3 assume that the approach is stabilized and that the flare is conducted at a normal height and rate.

The data in these figures may not apply to all aircraft types and models, but all aircraft are subject to the basic laws of flight dynamics that the data reflect.

Figure 2 shows that with a 10-knot steady crosswind component:

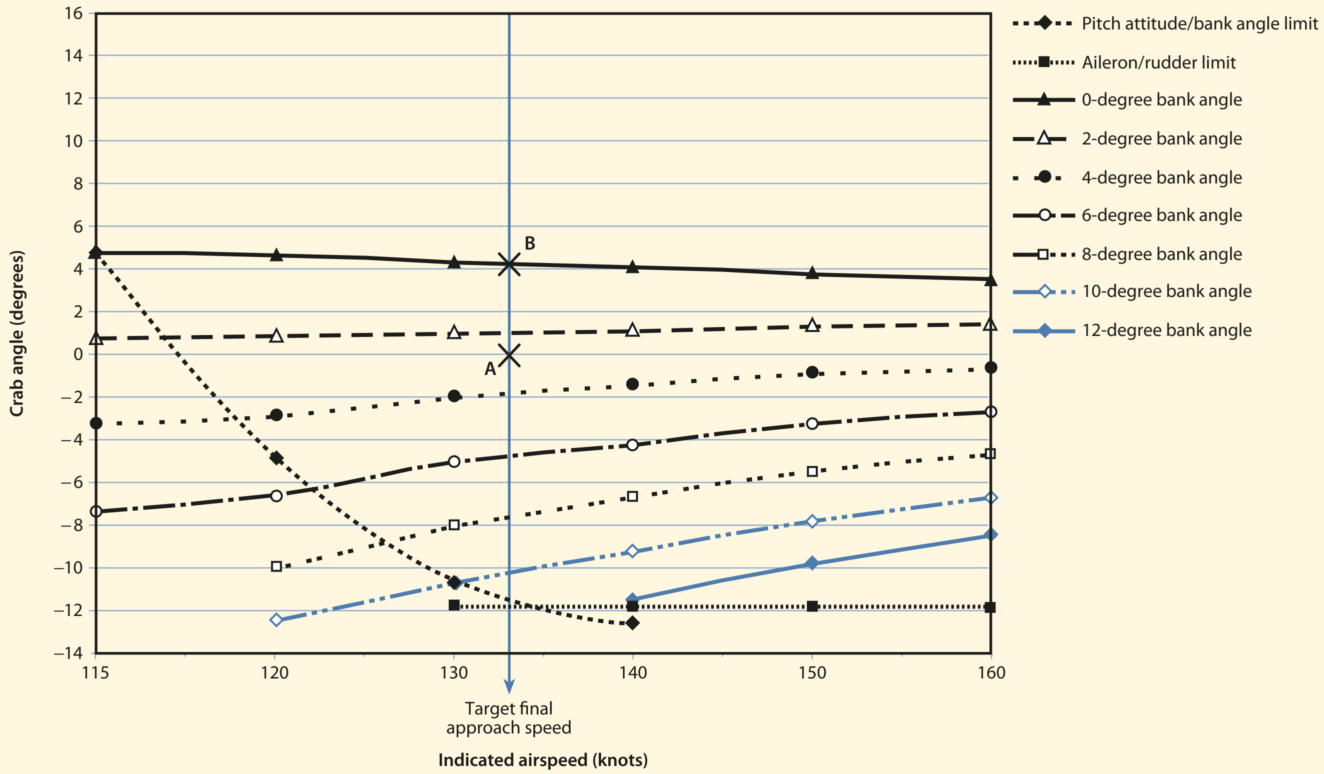
- Achieving a steady-sideslip landing (zero crab angle) requires only a three-degree into-wind bank angle (point A on the graph); or,
- Achieving a wings-level landing (no decrab) requires only a four-degree to five-degree crab angle at touchdown (point B).

A sideslip landing can be conducted while retaining significant safety margins relative to geometry limits or to aileron/rudder authority limits.

Figure 3 shows that with a 30-knot steady crosswind component:

- Achieving a steady-sideslip landing (zero crab angle) requires nearly a nine-degree into-wind bank angle, placing the aircraft closer to its geometry limits and aileron/rudder authority limits (point A on the graph); or,
- Achieving a wings-level landing (no decrab) would result in a 13-degree crab angle at touchdown, potentially resulting in landing gear damage (point B).

Crab Angle/Bank Angle Requirements in 10-knot Crosswind



Examples: A sideslip landing (zero crab angle) requires about a three-degree bank angle at touchdown (point A). A wings-level landing (no decrab) requires a crab angle between four degrees and five degrees at touchdown (point B).

Source: FSF ALAR Task Force

Figure 2

With a 30-knot crosswind component, adopting a combination of sideslip and crab angle with five degrees of crab angle and five degrees of bank angle restores significant safety margins relative to geometry limits and aileron/rudder authority limits while eliminating the risk of landing-gear damage (i.e., moving from point A to point C).

On aircraft models limited by their geometry, increasing the final approach speed (e.g., by applying a wind correction to the final approach speed, even under full crosswind) would increase the safety margin with respect to this limitation (i.e., moving from point A to point D).

Operational Recommendations and Handling Techniques

Figure 2 and Figure 3 show that:

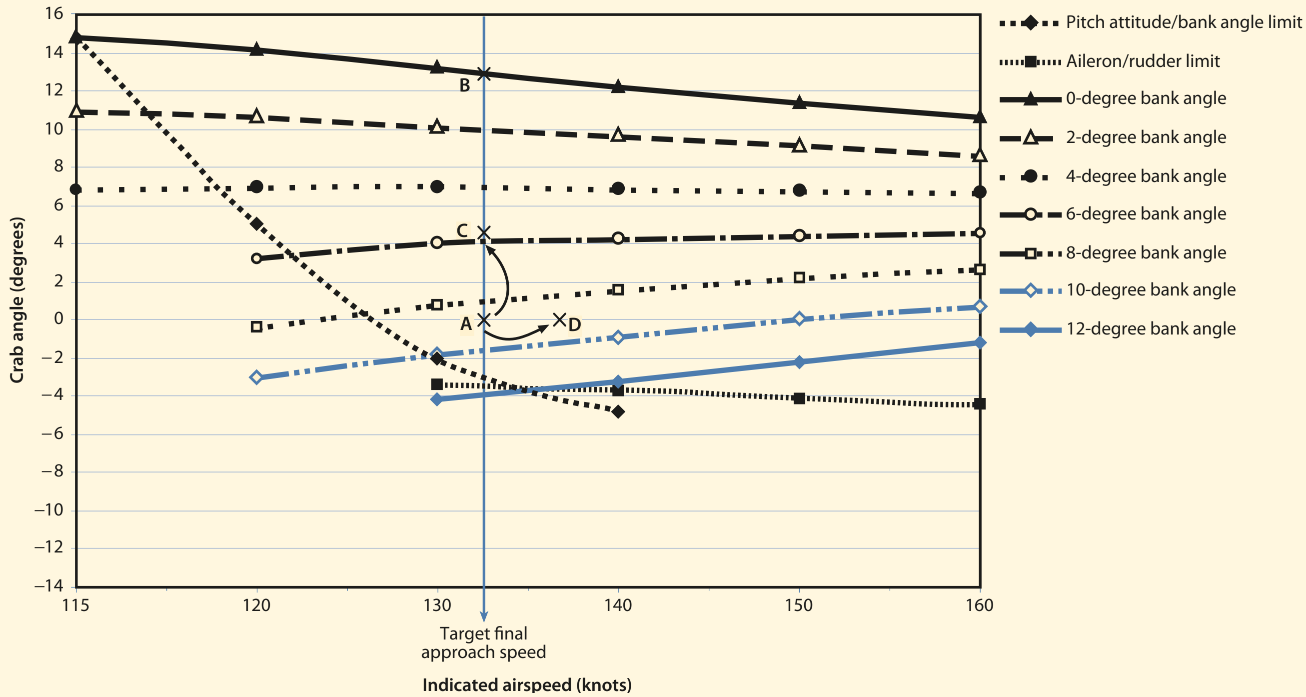
- With a relatively light crosswind (typically up to a 15-knot to 20-knot crosswind component), a safe crosswind landing can be conducted with either:
  - A steady sideslip (no crab); or,
  - Wings level, with no decrab prior to touchdown; and,
- With a strong crosswind (typically above a 15-knot to 20-knot crosswind component), a safe crosswind landing requires a crabbed approach and a partial decrab prior to touchdown.

For most transport category airplanes, touching down with a five-degree crab angle (with an associated five-degree bank angle) is a typical technique in strong crosswinds.

The choice of handling technique should be based on the prevailing crosswind component and on the following factors:

- Wind gusts;
- Runway length;
- Runway surface condition;
- Type of aircraft; and,
- Pilot experience in type.

Crab Angle/Bank Angle Requirements in 30-knot Crosswind



Examples: A sideslip landing (zero crab angle) requires about a nine-degree bank angle at touchdown (point A). A wings-level landing (no decrab) requires about a 13-degree crab angle at touchdown (point B). Point C represents a touchdown using a combination of sideslip and crab angle (about five degrees of bank angle and about five degrees of crab angle). Point D represents a steady-sideslip landing conducted about four knots above V_{REF}.

Source: FSF ALAR Task Force

Figure 3

Touchdown — Friction Forces

Upon touchdown following a crabbed approach down to flare with a partial decrab during flare, the flight deck should be on the upwind side of the runway centerline to ensure that the main landing gear is close to the runway centerline.

After the main landing gear touches down, the aircraft is influenced by the laws of ground dynamics.

The following are among the events that occur upon touchdown:

- Wheel rotation, unless hydroplaning is experienced. Wheel rotation is the trigger for:
  - Automatic ground-spoiler/speed-brakes extension (as applicable);
  - Autobrake system operation; and,
  - Anti-skid system operation.

To minimize the risk of hydroplaning and to ensure rotation of the wheels, a firm touchdown should be made when landing on a contaminated runway.

- Buildup of friction forces begins between the tires and the runway surface because of the combined effect of:
  - Wheel-braking forces; and,
  - Tire-cornering forces (Figure 4).

Wheel-braking forces and tire-cornering forces are based on tire conditions and runway conditions, and also on each other — the higher the braking force, the lower the cornering force, as shown by Figure 5.

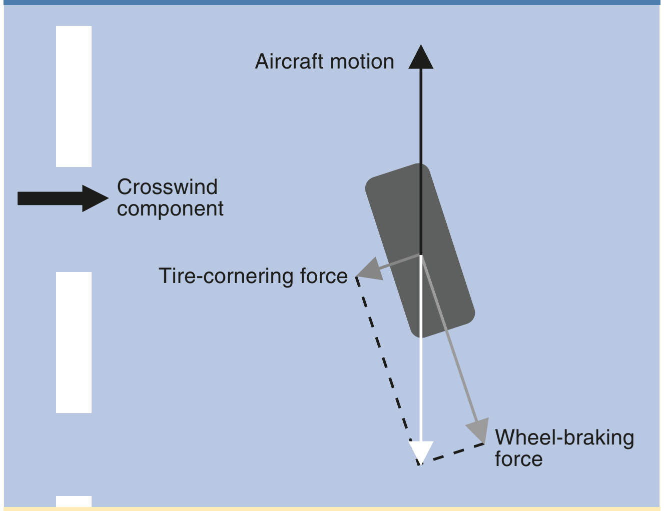
Transient effects, such as distortion of tire tread (caused by a yawing movement of the wheel) or the activation of the anti-skid system, affect the tire-cornering forces and wheel-braking forces (in both magnitude and direction), and therefore affect the overall balance of friction forces.

Thus, the ideal balance of forces shown in Figure 3 is maintained rarely during the initial landing roll.

Effect of Touchdown on Alignment

When touching down with some crab angle on a dry runway, the aircraft tends to realign itself with the direction of travel down the runway.

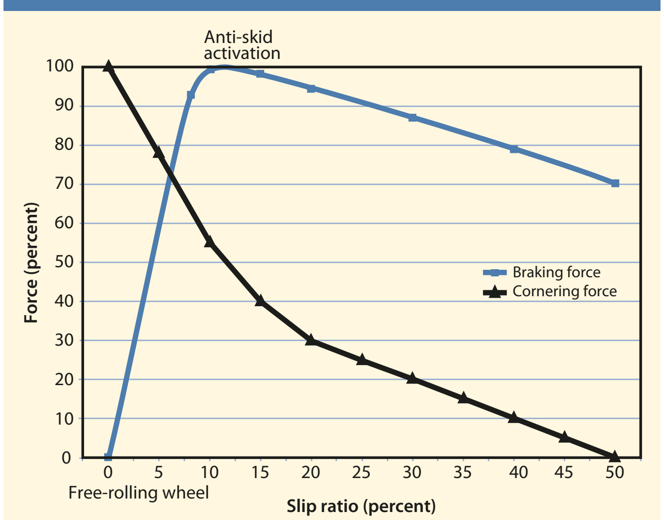
Tire-Cornering and Wheel-Braking Forces



Source: FSF ALAR Task Force

Figure 4

Interaction of Tire-Cornering and Wheel-Braking Forces



Source: FSF ALAR Task Force

Figure 5

When touching down with some crab angle on a contaminated runway, the aircraft tends to continue traveling with a crab angle along the runway centerline.

Effect of Wind on the Fuselage and Control Surfaces

As the aircraft touches down, the side force created by the crosswind striking the fuselage and control surfaces tends to make the aircraft skid sideways off the centerline (Figure 6).

Thrust Reverser Effect

When selecting reverse thrust with some crab angle, the reverse thrust results in two force components:

- A stopping force aligned with the aircraft's direction of travel (runway centerline); and,
- A side force, perpendicular to the runway centerline, which further increases the aircraft's tendency to skid sideways.

The thrust-reverser effect decreases with decreasing airspeed.

Rudder authority also decreases with decreasing airspeed and is reduced further by airflow disturbances created by the thrust reversers. Reduced rudder authority can cause directional-control problems.

Effect of Braking

In a strong crosswind, cross-control usually is maintained after touchdown to prevent the into-wind wing from lifting and to counteract the weather-vane effect (i.e., the aircraft's tendency to turn into the wind). (Some flight crew training manuals say that the pilot should continue to "fly the aircraft" during the landing roll.)

However, into-wind aileron decreases the lift on the into-wind wing, thus resulting in an increased load on the into-wind landing gear.

Because braking force increases as higher loads are applied on the wheels and tires, the braking force increases on the into-wind landing gear, creating an additional tendency to turn into the wind (Figure 7).

When runway contamination is not evenly distributed, the anti-skid system may release the brakes on only one side.

Maintaining Directional Control

The higher the wheel-braking force, the lower the tire-cornering force. Therefore, if the aircraft tends to skid sideways, releasing the brakes (i.e., by taking over from the autobrakes) will increase the tire-cornering force and help maintain directional control.

Selecting reverse idle thrust will cancel the side-force component caused by the reverse thrust, will increase rudder authority and will further assist in returning to the runway centerline.

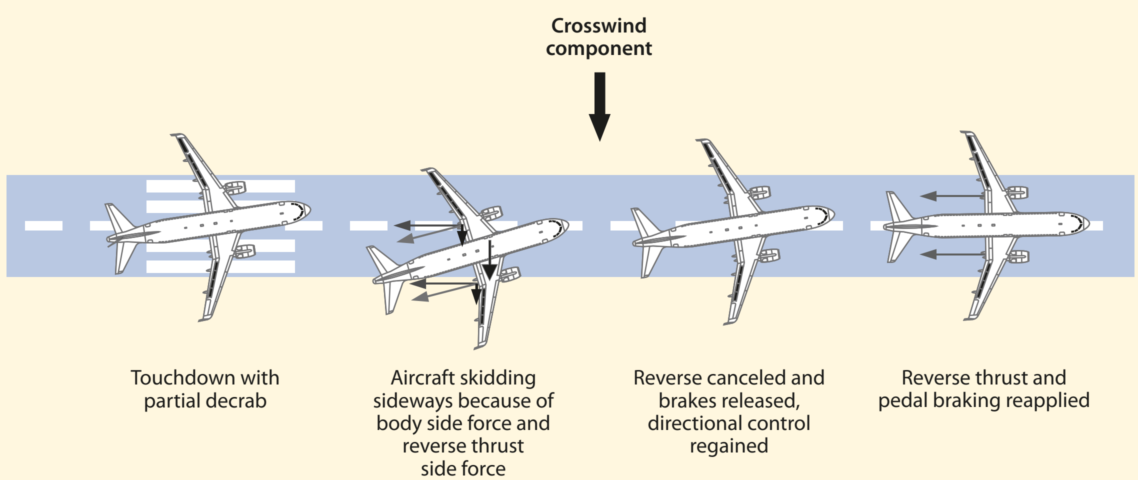
After the runway centerline and directional control have been regained:

- Pedal braking can be applied (autobrakes were previously disarmed) in a symmetrical or asymmetrical manner, as required; and,
- Reverse thrust can be reselected.

Factors Involved in Crosswind Incidents and Accidents

The following factors often are involved in crosswind-landing incidents and accidents:

Recovery From a Skid Caused by Crosswind and Reverse Thrust Side Forces

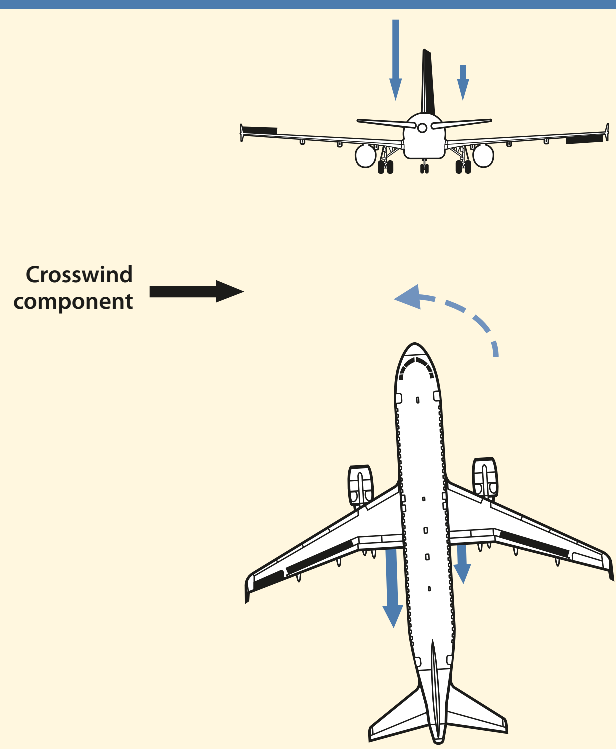


Examples: A sideslip landing (zero crab angle) requires about a nine-degree bank angle at touchdown (point A). A wings-level landing (no decrab) requires about a 13-degree crab angle at touchdown (point B). Point C represents a touchdown using a combination of sideslip and crab angle (about five degrees of bank angle and about five degrees of crab angle). Point D represents a steady-sideslip landing conducted about four knots above V_{REF}.

Source: FSF ALAR Task Force

Figure 6

Effect of Uneven Braking Forces on Main Landing Gear



Source: FSF ALAR Task Force

Figure 7

- Reluctance to recognize changes in landing data over time (e.g., wind shift, wind velocity/gust increase);
- Failure to seek additional evidence to confirm initial information and initial options (i.e., reluctance to change plans);
- Reluctance to divert to an airport with more favorable wind conditions;
- Insufficient time to observe, evaluate and control aircraft attitude and flight path in a highly dynamic situation; and/or,
- Pitch effect on aircraft with underwing-mounted engines caused by the power changes required in gusty conditions.

Summary

To increase safety during a crosswind landing, flight crews should:

- Understand all applicable operating factors, recommended maximum values and limitations;
- Use flying techniques and skills designed for crosswind landings;
  - A wings-level touchdown (i.e., without any decrab) usually is safer than a steady-sideslip touchdown with an excessive bank angle;
- Request assignment of a more favorable runway if the prevailing runway conditions and crosswind are unfavorable for a safe landing;

- Adjust the autopilot-disconnect altitude for prevailing conditions to provide time to establish manual control and trimming of the aircraft before the align/decrab and flare;
- Detect changes in automatic terminal information service (ATIS) broadcasts and tower messages (e.g., wind shift, wind velocity/gust increase); and,
- Understand small-scale local effects associated with strong winds:
  - Updrafts and downdrafts; and,
  - Vortices created by buildings, trees or terrain.

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

- 8.1 — Runway Excursions;
- 8.2 — The Final Approach Speed;
- 8.3 — Landing Distances;
- 8.4 — Braking Devices;
- 8.5 — Wet or Contaminated Runways; and,
- 8.6 — Wind Information.

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. Flight Safety Foundation. "Reducing the Risk of Runway Excursions." Report of the FSF Runway Safety Initiative, May 2009.

Related Reading From FSF Publications

Darby, Rick. "Keeping It on the Runway." *AeroSafety World* Volume 4 (August 2009).

Lacagnina, Mark. "Short Flight, Long Odds." *AeroSafety World* Volume 4 (May 2009).

Berman, Benjamin A.; Dismukes, R. Key. "Pressing the Approach." *AviationSafety World* Volume 1 (December 2006).

Flight Safety Foundation (FSF) Editorial Staff. "Hard Landing Results in Destruction of Freighter." *Accident Prevention* Volume 62 (September 2005).

FSF Editorial Staff. "DC-10 Overruns Runway in Tahiti While Being Landed in a Storm." *Accident Prevention* Volume 62 (August 2005).

FSF Editorial Staff. "Crew Fails to Compute Crosswind Component, Boeing 757 Nosewheel Collapses on Landing." *Accident Prevention* Volume 57 (March 2000).

FSF Editorial Staff. "Unaware of Strong Crosswind, Fokker Crew Loses Control of Aircraft on Landing." *Accident Prevention* Volume 56 (November 1999).

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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