Flight Safety Foundation

ALAR

Approach-and-landing Accident Reduction

Tool Kit

FSF ALAR Briefing Note 5.4 — Wind Shear

Flight crew awareness and alertness are key factors in the successful application of wind shear avoidance techniques and recovery techniques.

Statistical Data

The Flight Safety Foundation 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]

Definition

Wind shear is a sudden change of wind velocity/direction.

The following types of wind shear exist:

- Vertical wind shear (vertical variations of the horizontal wind component, resulting in turbulence and affecting aircraft airspeed when climbing or descending through the shear layer); and,
- Horizontal wind shear (horizontal variations of the wind component (e.g., decreasing head wind or increasing tail wind, or a shift from a head wind to a tail wind), affecting the aircraft in level flight, climb or descent).

Wind shear is associated usually with the following weather conditions:

- Jet streams;
- Mountain waves;
- Frontal surfaces;
- Thunderstorms and convective clouds; and,
- Microbursts.

Microbursts present two distinct threats to aviation safety:

- A downburst that results in strong downdrafts (reaching 40 knots vertical velocity); and,
- An outburst that results in strong horizontal wind shear and wind-component reversal (with horizontal winds reaching 100 knots).

Avoidance

TThe following information can be used to avoid areas of potential wind shear or observed wind shear:

- Weather reports and forecasts:
  - The low-level wind shear alert system (LLWAS) is used by controllers to warn pilots of existing or impending wind shear conditions:
    - LLWAS consists of a central wind sensor (sensing wind velocity and direction) and peripheral wind sensors located approximately two nautical miles (nm) from the center. Central wind sensor data are averaged over a rolling two-minute period and compared every 10 seconds with the data from the peripheral wind sensors.
    - An alert is generated whenever a difference in excess of 15 knots is detected. The LLWAS may not detect downbursts with a diameter of two nm or less:

– Terminal doppler weather radar (TDWR) detects approaching wind shear areas and, thus, provides pilots with an advance warning of wind shear hazard;

- Pilot reports:

  – Pilot reports (PIREPS) of wind shear causing airspeed fluctuations in excess of 20 knots or vertical-speed changes in excess of 500 feet per minute (fpm) below 1,000 feet above airport elevation should be cause for caution;

- Visual observation:

  – Blowing dust, rings of dust, dust devils (i.e., whirlwinds containing dust or sand) and any other evidence of strong local air outflow near the surface often are indications of wind shear;

- Onboard wind-component and groundspeed monitoring:

  – On approach, a comparison of the head-wind component or tail-wind component aloft (as available) and the surface head-wind component or tail-wind component indicates the likely degree of vertical wind shear;

- Onboard weather radar; and,

- Onboard predictive wind shear system.

Recognition

Timely recognition of wind shear is vital for successful implementation of a wind shear recovery procedure.

Some flight guidance systems can detect a wind shear condition during approach, and during go-around, based on analysis of aircraft flight parameters.

The following are indications of a suspected wind shear condition:

- Indicated airspeed variations in excess of 15 knots;
- Groundspeed variations (decreasing head wind or increasing tail wind, or a shift from head wind to tail wind);
- Vertical-speed excursions of 500 fpm or more;
- Pitch attitude excursions of five degrees or more;
- Glideslope deviation of one dot or more;
- Heading variations of 10 degrees or more; and,
- Unusual autothrottle activity or throttle lever position.

Reactive/Predictive Warnings

In addition to flight director (FD) wind shear recovery guidance, some aircraft provide a "wind shear" warning.

The wind shear warning and FD recovery guidance are referred to as a *reactive wind shear system*, which does not incorporate any forward-looking (anticipation) capability.

To complement the reactive wind shear system and provide an early warning of wind shear activity, some weather radars detect wind shear areas ahead of the aircraft (typically providing a one-minute advance warning) and generate a wind shear warning (red "WIND SHEAR AHEAD"), caution (amber "WIND SHEAR AHEAD") or advisory alert messages.

This equipment is referred to as a *predictive wind shear system.*

Operating Procedures

The following opportunities are available to enhance wind shear awareness and operating procedures.

Standard Operating Procedures

Standard operating procedures (SOPs) should emphasize the following wind shear awareness items:

- Wind shear awareness and avoidance:

  – Approach briefing; and,

  – Approach hazards awareness;

- Wind shear recognition:

  – Task-sharing for effective cross-check and backup, particularly for excessive parameter deviations;

  – Energy management during approach; and,

  – Elements of a stabilized approach (Table 1) and approach gate[2]; and,

- Wind shear recovery procedure:

  – Readiness and commitment to respond to a wind shear warning.

Training

A wind shear awareness program should be developed and implemented, based on the industry-developed *Windshear Training Aid* or the Flight Safety Foundation-developed *Windshear Training Aid Package*.[3]

Training on the wind shear recovery procedure should be conducted in a full-flight simulator, using wind shear profiles recorded during actual wind shear encounters.

Departure Briefing

The takeoff-and-departure briefing should include the following wind shear awareness items:

- Assessment of the conditions for a safe takeoff based on:

Table 1
Recommended Elements Of a Stabilized Approach

All flights must be stabilized by 1,000 feet above airport elevation in instrument meteorological conditions (IMC) and by 500 feet above airport elevation in visual meteorological conditions (VMC). *An approach is stabilized when all of the following criteria are met:*

1. The aircraft is on the correct flight path;
2. Only small changes in heading/pitch are required to maintain the correct flight path;
3. The aircraft speed is not more than V_{REF} + 20 knots indicated airspeed and not less than V_{REF};
4. The aircraft is in the correct landing configuration;
5. Sink rate is no greater than 1,000 feet per minute; if an approach requires a sink rate greater than 1,000 feet per minute, a special briefing should be conducted;
6. Power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual;
7. All briefings and checklists have been conducted;
8. Specific types of approaches are stabilized if they also fulfill the following: instrument landing system (ILS) approaches must be flown within one dot of the glideslope and localizer; a Category II or Category III ILS approach must be flown within the expanded localizer band; during a circling approach, wings should be level on final when the aircraft reaches 300 feet above airport elevation; and,
9. Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.

An approach that becomes unstabilized below 1,000 feet above airport elevation in IMC or below 500 feet above airport elevation in VMC requires an immediate go-around.

Source: Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force (V1.1 November 2000)

  - Most recent weather reports and forecasts;
  - Visual observations; and,
  - Crew experience with the airport environment and the prevailing weather conditions; and,
- Consideration to delaying the takeoff until conditions improve.

Takeoff and Initial Climb

If wind shear conditions are expected, the crew should:

- Select the most favorable runway, considering the location of the likely wind shear/downburst condition;
- Select the minimum flaps configuration compatible with takeoff requirements, to maximize climb-gradient capability;
- Use the weather radar (or the predictive wind shear system, if available) before beginning the takeoff to ensure that the flight path is clear of hazards;
- Select maximum takeoff thrust;
- After selecting the takeoff/go-around (TOGA) mode, select the flight-path-vector display for the pilot not flying (PNF), as available, to obtain a visual reference of the climb flight path angle; and,
- Closely monitor the airspeed and airspeed trend during the takeoff roll to detect any evidence of impending wind shear.

Wind Shear Recovery

If wind shear is encountered during the takeoff roll or during initial climb, the following actions should be taken without delay:

- Before V_1:
  - The takeoff should be rejected if unacceptable airspeed variations occur (not exceeding the target V_1) and if there is sufficient runway remaining to stop the airplane;
- After V_1:
  - Disconnect the autothrottles (A/THR), if available, and maintain or set the throttle levers to maximum takeoff thrust;
  - Rotate normally at V_R; and,
  - Follow the FD pitch command if the FD provides wind shear recovery guidance, or set the required pitch attitude (as recommended in the aircraft operating manual [AOM]/quick reference handbook [QRH]);
- During initial climb:
  - Disconnect the A/THR, if available, and maintain or set the throttle levers to maximum takeoff thrust;
  - If the autopilot (AP) is engaged and if the FD provides wind shear recovery guidance, keep the AP engaged; or,

    Follow the FD pitch command, if the FD provides wind shear recovery guidance; or,

    Set the required pitch attitude (as recommended in the AOM/QRH);
  - Level the wings to maximize the climb gradient, unless a turn is required for obstacle clearance;
  - Closely monitor the airspeed, airspeed trend and flight-path angle (as available);

- Allow airspeed to decrease to stick shaker onset (intermittent stick shaker activation) while monitoring the airspeed trend;
- Do not change the flaps or landing-gear configurations until out of the wind shear condition; and,
- When out of the wind shear condition, increase airspeed when a positive climb is confirmed, retract the landing gear, flaps and slats, then establish a normal climb profile.

Approach Briefing

The approach briefing should include the following:

- Based on the automatic terminal information service (ATIS) broadcast, review and discuss the following items:
  - Runway in use (type of approach);
  - Expected arrival route (standard terminal arrival [STAR] or radar vectors);
  - Prevailing weather; and,
  - Reports of potential low-level wind shear (LLWAS warnings, TDWR data); and,
- Discuss the intended use of automation for vertical navigation and lateral navigation as a function of the suspected or forecasted wind shear conditions.

Descent and Approach

Before conducting an approach that may be affected by wind shear conditions, the crew should:

- Assess the conditions for a safe approach and landing based on:
  - Most recent weather reports and forecasts;
  - Visual observations; and,
  - Crew experience with the airport environment and the prevailing weather conditions;
- Consider delaying the approach and landing until conditions improve, or consider diverting to a suitable airport;
- Whenever downburst/wind shear conditions are anticipated, based on pilot reports from preceding aircraft or based on an alert by the airport LLWAS, *the landing should be delayed or the aircraft should be flown to the destination alternate airport;*
- Select the most favorable runway, considering:
  - The location of the likely wind shear/downburst condition; and,
  - The available runway approach aids;
- Use the weather radar (or the predictive wind shear system, if available) during the approach to ensure that the flight path is clear of potential hazards;
- Select the flight-path vector display for the PNF, as available, to obtain a visual reference of the flight-path angle;
- Select less than full flaps for landing (to maximize climb-gradient capability), if authorized by the aircraft operating manual (AOM/QRH), and adjust the final approach speed accordingly;
- If an instrument landing system (ILS) approach is available, engage the AP for more accurate approach tracking and for warnings of excessive glideslope deviations;
- Select a final approach speed based on the reported surface wind — an airspeed correction (usually a maximum of 15 knots to 20 knots, based on the expected wind shear value) is recommended;
- Compare the head-wind component aloft or the tail-wind component aloft with the surface head-wind component or surface tail-wind component to assess the likely degree of vertical wind shear;
- Closely monitor the airspeed, airspeed trend and groundspeed during the approach to detect any evidence of impending wind shear;
  - Be alert for microbursts, which are characterized by a significant increase of the head-wind component followed by a sudden change to a tail wind; and,
- Be alert to respond without delay to a predictive wind shear warning or to a reactive wind shear warning, as applicable. The response should adhere to procedures in the AOM/QRH.

Recovery During Approach and Landing

If wind shear is encountered during the approach or landing, the following recovery actions should be taken without delay:

- Select the takeoff/go-around (TOGA) mode and set and maintain maximum go-around thrust;
- Follow the FD pitch command (if the FD provides wind shear recovery guidance) or set the pitch-attitude target recommended in the AOM/QRH;
- If the AP is engaged and if the FD provides wind shear recovery guidance, keep the AP engaged; otherwise, disconnect the AP and set and maintain the recommended pitch attitude;
- Do not change the flap configuration or landing-gear configuration until out of the wind shear;
- Level the wings to maximize climb gradient, unless a turn is required for obstacle clearance;
- Allow airspeed to decrease to stick-shaker onset (intermittent stick-shaker activation) while monitoring airspeed trend;

- Closely monitor airspeed, airspeed trend and flight path angle (if flight-path vector is available and displayed for the PNF); and,
- When out of the wind shear, retract the landing gear, flaps and slats, then increase the airspeed when a positive climb is confirmed and establish a normal climb profile.

Awareness

Company accident-prevention strategies and personal lines of defense should be developed to address the following factors:

- Aircraft equipment:
  - Absence of reactive/predictive wind shear system(s); and,
  - Absence of glideslope excessive-deviation warning;
- Airport equipment:
  - Absence of an LLWAS; and,
  - Absence of TDWR;
- Training:
  - Absence of a wind shear awareness program; and/or,
  - Absence of wind shear recovery (escape) simulator training;
- SOPs:
  - Inadequate briefings;
  - Inadequate monitoring of flight progress; and/or,
  - Incorrect use of automation; and,
- Human factors and crew resource management (CRM):
  - Absence of cross-checking (for excessive parameter deviations);
  - Absence of backup (standard calls); and/or,
  - Fatigue.

Summary

Avoidance

- Assess the conditions for a safe approach and landing, based on all available meteorological data, visual observations and on-board equipment;
- As warranted, consider delaying the approach, or consider diverting to a more suitable airport; and,
- Be prepared and committed to respond immediately to a wind shear warning.

Recognition

- Be alert for wind shear conditions, based on all available weather data, onboard equipment and aircraft flight parameters and flight path; and,
- Monitor the instruments for evidence of impending wind shear.

Recovery

- Avoid large thrust variations or trim changes in response to sudden airspeed variations;
- If a wind shear warning occurs, follow the FD wind shear recovery pitch guidance or apply the recommended escape procedure; and,
- Make maximum use of aircraft equipment, such as the flight-path vector (as available).

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

- *1.1 — Operating Philosophy*;
- *1.2 — Automation*;
- *1.3 — Golden Rules*;
- *1.4 — Standard Calls*;
- *1.6 — Approach Briefing*;
- *5.1 — Approach Hazards Overview*; and,
- *6.1 — Being Prepared to Go Around*.♦

References

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 *approach gate* as "a point in space (1,000 feet above airport elevation in instrument meteorological conditions or 500 feet above airport elevation in visual meteorological conditions) at which a go-around is required if the aircraft does not meet defined stabilized approach criteria."

3. The two-volume *Windshear Training Aid*, developed primarily for operators of air carrier aircraft, is available for purchase from the U.S. National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161 U.S.A. Telephone: (800) 553-6847 (U.S.) or +1 (703) 605-6000. Fax: +1 (703) 605-6900. Internet site: www.ntis.gov. Each volume costs US$123 plus shipping-and-handling charges.

The multimedia *Windshear Training Aid Package*, developed by Flight Safety Foundation for operators of regional, on-demand, business and other general aviation aircraft, is available for purchase from NTIS for $330, plus shipping-and-handling charges.

Related Reading from FSF Publications

FSF Editorial Staff. "During Nonprecision Approach at Night, MD-83 Descends Below Minimum Descent Altitude and Contacts Trees, Resulting in Engine Flame-out and Touchdown Short of Runway." *Accident Prevention* Volume 54 (April 1997).

FSF Editorial Staff. "Flight Crew of DC-10 Encounters Microburst During Unstabilized Approach, Ending in Runway Accident." *Accident Prevention* Volume 53 (August 1996).

FSF Editorial Staff. "Unaware That They Have Encountered a Microburst, DC-9 Flight Crew Executes Standard Go-around; Aircraft Flies Into Terrain." *Accident Prevention* Volume 53 (February 1996).

FSF Editorial Staff. "Wind Shear Sends Commuter Aircraft Plunging Out of Control." *Accident Prevention* Volume 49 (September 1992).

U.S National Center for Atmospheric Research. "Improved Microburst Warnings Aim for Safer Terminal Operations." *Accident Prevention* Volume 47 (July 1990).

FSF. "Summer Hazards." *Accident Prevention* Volume 44 (July 1988).

Regulatory Resources

International Civil Aviation Organization (ICAO). *Preparation of an Operations Manual*. Second edition – 1997.

ICAO. Circular 186, "Wind Shear." 1987.

ICAO. *International Standards and Recommended Practices, Annex 6 to the Convention of International Civil Aviation, Operation of Aircraft.* Part I, *International Commercial Air Transport – Aeroplanes*. Chapter 6, "Aeroplane Instruments, Equipment and Flight Documents," 6.21 Seventh edition – July 1998, incorporating Amendments 1-25.

U.S. Federal Aviation Administration. *Federal Aviation Regulations*. 121.135 "Contents," 121.315 "Cockpit check procedure," 121.357 "Airborne weather radar equipment requirements," 121.358 "Low-altitude windshear system equipment requirements," 121.424 "Pilots: Initial, transition, and up-grade flight training," 121.542 "Flight crewmember duties," 121.599 "Familiarity with weather conditions." January 1, 2000.

FAA. *FARs*. 121.360 "Ground proximity warning-glide slope deviation alerting system." March 29, 2000.

FAA. Advisory Circular 00-54, *Pilot Windshear Guide*. November 25, 1988.

Notice

The Flight Safety Foundation (FSF) Approach-and-landing Accident Reduction (ALAR) Task Force has produced this briefing note to help prevent ALAs, 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 (CAST) Joint Safety Analysis Team (JSAT) and the European Joint Aviation Authorities Safety Strategy Initiative (JSSI).

The briefing note has been prepared primarily for operators and pilots of turbine-powered airplanes with underwing-mounted engines (but can be adapted for fuselage-mounted turbine engines, turboprop-powered aircraft and piston-powered aircraft) and with the following:

- Glass flight deck (i.e., an electronic flight instrument system with a primary flight display and a navigation display);
- Integrated autopilot, flight director and autothrottle systems;
- Flight management system;
- Automatic ground spoilers;
- Autobrakes;
- Thrust reversers;
- Manufacturers'/operators' standard operating procedures; and,
- Two-person flight crew.

This briefing note is one of 34 briefing notes that comprise a fundamental part of the FSF *ALAR Tool Kit,* which includes a variety of other safety products that have been developed to help prevent ALAs.

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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