Wind shear: an invisible enemy to pilots?

Weather plays a significant role in aviation safety and is regularly cited as a contributing factor in accidents or major incidents. Wind shear in the form of microbursts particularly, can be a severe hazard to aircraft during take-off, approach and landing.

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As commercial aviation began to develop in the middle of the last century, we knew very little about wind shear. The detection and reporting of wind shear related events was actually really poor. Yet, in its many forms, although actual encounters with severe wind shear are fairly remote in a pilot's career, this phenomenon can change a routine approach into an emergency recovery in a matter of seconds.

As research and technology progressed, we have learned to identify, prevent and if necessary, handle such events.

We will look at the effects of wind shear on an aircraft and at piloting techniques for coping with a shear situation, focusing more particularly on microbursts.

UNDERSTANDING WIND SHEAR

Definitions

>> Wind shear

Wind shear can be defined as a sudden change in wind velocity and/or direction over a short distance. It can occur in all directions, but for convenience, it is considered along vertical and horizontal axis, thus introducing the concepts of vertical and horizontal wind shear:

- Vertical wind shear consists of wind variations along the vertical axis of typically 20 to 30 knots per 1000 ft. The change in velocity or direction can drastically alter the aircraft lift, indicated airspeed, and thrust requirements when climbing or descending through the wind shear layers.
- Horizontal wind shear consists of variations in the wind component along the horizontal axis – e.g. decreasing headwind or increasing tailwind, or a shift from a headwind to a tailwind – of up to 100 knots per nautical mile. **(Fig.1)** shows how a penetration would appear as an aircraft crosses a cold front.

This weather phenomenon can occur at many different levels of the atmosphere; however it is most dangerous at the lower levels, as a sudden loss of airspeed and altitude can occur.

It is usually associated with the following weather conditions: jet streams, mountain waves or temperature inversion layers, frontal surfaces, thunderstorms and convective clouds or microbursts, occurring close to the ground.

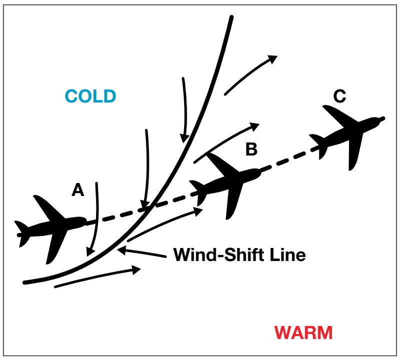
>> What is a microburst?

A microburst clearly creates the most dangerous forms of wind shear. It consists of a small column of exceptionally intense and localized sinking air, which descends to the ground (called "the downdraft") and upon contact with the earth's surface, diverges outwards in all directions, thus forming a ring vortex. It is capable of producing powerful winds near ground level.

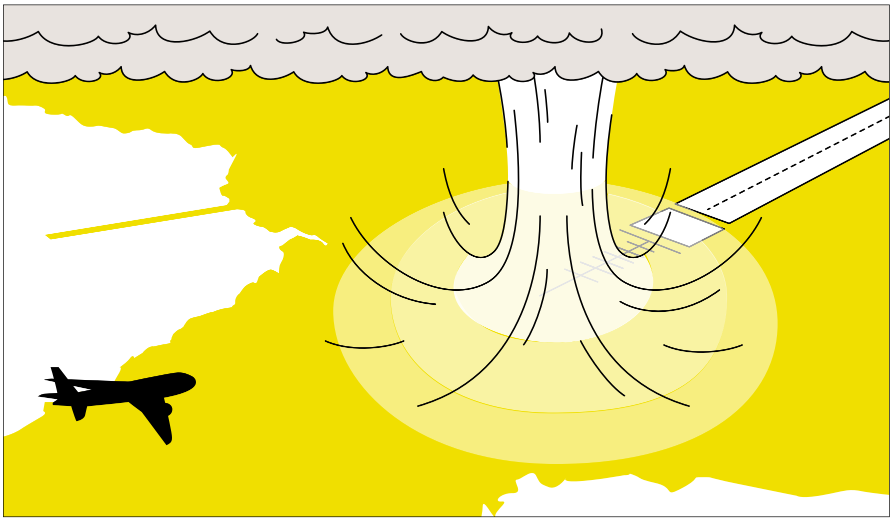
Microbursts are either dry (i.e. little or no rain reaches the ground) or wet (usually within a downpour). They typically form under or close to thunderstorms and cumulonimbus clouds in particular **(fig.2)**.

The radial pattern means winds of various directions within a small area, and hence considerable wind shear near the ground, for up to several minutes.

> "The change in velocity or direction can drastically alter the aircraft lift, indicated airspeed, and thrust requirements when climbing or descending through the wind shear layer."



(fig.1)
Horizontal wind shear



(fig.2)
Microburst caused by a cumulonimbus

Typical characteristics of microbursts

Size	Covers an area less than 2.5 nautical miles in diameter.
Intensity	Downdrafts are 40 knots (4000 ft/minute), horizontal winds between 45 and 100 knots.
Duration	Approximately 15 minutes.
Visual signs	Often associated with heavy thunderstorms, embedded in heavy rain.

Microbursts: a threat to aviation safety

From a safety perspective, microbursts bring a threat to aircraft due to the scale and suddenness of this phenomenon. To put it briefly, microbursts combine two distinct threats to aviation safety **(fig.3)**:

- The **downburst part,** resulting in strong downdrafts that rapidly push the aircraft downward. The power of the downburst can actually exceed aircraft climb capabilities.
- The **outburst part**, resulting in large horizontal wind shear and wind component shift from headwind to tailwind. This sudden change from headwind to tailwind reduces the lift of the aircraft, which may force the aircraft down, typically during take-off or landing.

An aircraft actually encountering a microburst in the vicinity of an airfield while it is about to land or take-off, may be flying through 3 different and difficult phases of wind conditions at a critical phase of flight, at low altitude. For example, an aircraft flying through a microburst at landing should expect to encounter the following phases:

>> Phase 1: Headwind

- When first entering a microburst, the pilot notices a performance enhancing headwind gust, which instantaneously increases the aircraft airspeed, thus causing lift and the aircraft to rise above its intended path and/or accelerate (see **(fig.3)**, items 1 and 2).
- To descend the aircraft back on its descent path and decrease speed, the pilot will naturally retard the engines and push the side stick, thereby forcing the aircraft to descend.

>> Phase 2: Downdraft

- As the aircraft continues into the microburst, it meets a sudden surge of downdraft affecting both the aircraft flight path and then the Angle-Of-Attack (AOA): the aircraft will sink and the AOA will increase (see **(fig.3)**, item 3).
- The pilot, now traveling at a lower speed and pushed downwards, will attempt to regain the original trajectory by initiating a climb.

>> Phase 3: Tailwind

- As the pilot attempts to climb to recover his/her altitude, the aircraft now experiences a change in wind direction and encounters a tailwind.
- The tailwind gust instantaneously decreases the aircraft lift and airspeed and thus, it tends to make the aircraft fly below its intended path and/or decelerate(see **(fig.3)**, item 4).

A microburst is a serious threat to flight because of its direct and aggressive impact on the aircraft airspeed, altitude, Angle-Of-Attack, and thus, lift capability.

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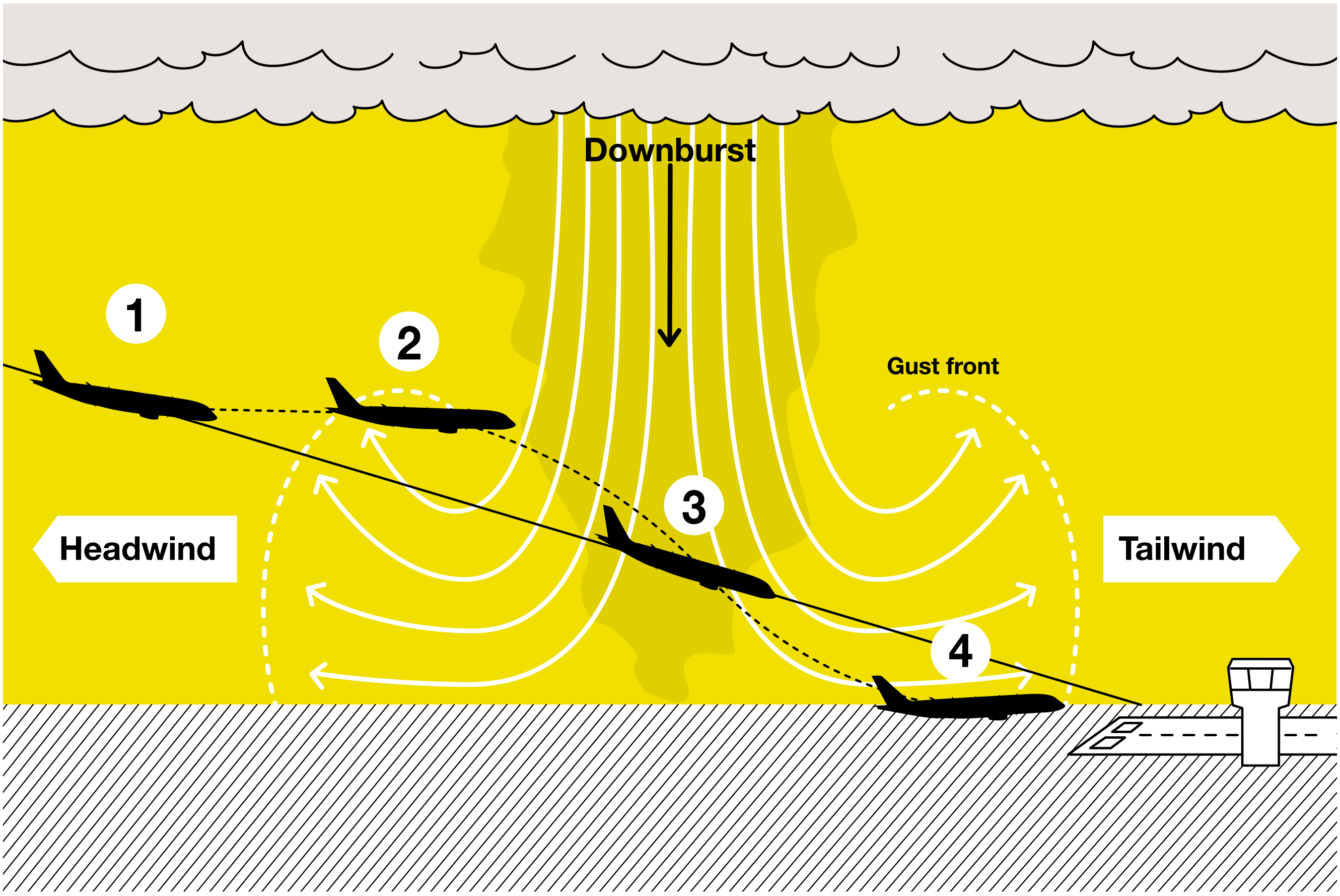
(fig.3)
Effects of a microburst on aircraft performance



PREVENTION: HOW TO DETECT AND AVOID WIND SHEAR

Wind shear has a negative effect on aircraft performance and is therefore a real threat to the safe conduct of flight. The best line of defence against such hazards is: detection and avoidance.

Since the discovery of the effects of wind shear on aircraft performance in the early 1980's, different tools have been developed to help pilots recognize these events, and take appropriate actions. In practice, flight crew awareness and alertness are key factors in the successful application of wind shear avoidance techniques.

Wind shear awareness and detection means

The best ways a pilot can prevent an encounter with wind shear is to know wind shear is there and to avoid it where possible. However, should an encounter be unavoidable, it is important to know the likely magnitude of the change, and be prepared to react immediately. Although there is no absolutely reliable way to predict the occurrence, different tools and information can be used to detect areas of potential or observed wind shear, and thus be able to develop efficient avoidance strategies.

>> Weather reports and forecast

Many airports – particularly those that are prone to microburst and wind shear – are now equipped with a Low Level Wind shear Alerting System (LLWAS) and/or a Terminal Doppler Weather Radar (TDWR). These devices are able to detect microbursts and warn aircraft of their occurrences by sending an alert to ATC. In this respect, a good communication between flight crews and ATC is essential.

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INFORMATION

The LLWAS is comprised of a central anemometer (sensing wind velocity and direction) and peripheral anemometers located approximately two nautical miles 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.

There are two LLWAS alerting modes: wind shear alert and microburst alert. A wind shear alert is generated whenever the wind speed loses 15 to 29 knots, or gains more than 15 knots. Microburst alert condition is when the wind speed loses more than 30 knots. LLWAS may not detect downbursts with a diameter of 2 nm or less. This system enables Air Traffic Controllers to warn pilots of existing or impending wind shear conditions.

The TDWR enables to detect approaching wind shear areas and thus, to provide pilots with more advance warning of wind shear hazard.

>> Crew observations

Blowing dust, rings of dust, dust devils (i.e. whirlwinds containing dust and sand), intense rainfall or any other evidence of strong local air outflow near the surface often are good indications of potential or existing downburst. A large difference between actual wind (on ND) and wind reported by tower can also be a good indication. Therefore it is better to avoid these areas.

>> Pilots' reports (PIREPS)

PIREPS of wind shear in excess of 20 knots or downdraft / updraft of 500 ft per minute below 1000 ft above ground level are all good indications of severe conditions and should be avoided at any time.
Considering that these conditions develop, change or dissipate rapidly, those reports should however be interpreted with great care and judgement. A pilot must consider the amount of time since the report was made. Indeed, knowing that microbursts intensify for several minutes after they first impact the ground, the severity may be higher than that initially reported. Conversely, the microburst reported may well have dissipated by the time the aircraft plans to cross the incriminated area.
Therefore it is very important to remember that the aircraft ahead may experience vastly different conditions than the following one will encounter in the same airspace.

>> On-board weather radar

Generally microbursts are accompanied by heavy rainfalls, which can be detected and identified using the on-board weather radar. Those areas should be avoided.

“Remember that the aircraft ahead may experience vastly different conditions than the following one will encounter in the same airspace.”

(fig.4)
"W/S AHEAD" predictive caution display on PFD

>> On-board predictive wind shear system

Today, most aircraft models have predictive wind shear equipment to warn pilots of possible threats via aural and visual means.

To provide an early warning of potential wind shear activity, some on-board weather radars feature the capability to detect wind shear areas ahead of the aircraft, based on a measure of wind velocities ahead of the aircraft both vertically and horizontally.

This equipment is referred to as a Predictive Wind shear System (PWS). This system is active and provides reliable indications between 50 and approximately 1000 feet above the ground surface.

The PWS provides typically a one-minute advance warning by showing first an amber "W/S AHEAD" message on the PFD **(fig.4)**.

If conditions worsen and the wind shear location gets closer to the aircraft, the "W/S AHEAD" amber caution turns into a red warning and is associated with an aural synthetic voice "WIND SHEAR AHEAD, WIND SHEAR AHEAD" during take-off, or "GO AROUND, WIND SHEAR AHEAD" at landing. This is a possible indication that the aircraft is approaching a microburst.

>> Summary

Flight crew should consider all available wind shear awareness means and assess the conditions for a safe take-off or safe descent, approach and landing based on:

- Most recent weather reports and forecast. Pay a careful attention to ATC indications in particular.
- Visual observations.
- Crew experience with the airport environment and the prevailing weather conditions.
- Weather radar implemented at airports. These systems serve to detect microbursts in close proximity to the airport and send out alerts to both pilots and ATC alike.
- On-board weather radar to ensure that the flight path is clear of hazard areas.
- On-board Predictive Wind shear System (PWS).

Operational best practices: how to avoid wind shear and get prepared altogether

The wealth of tools and indications listed previously should allow crews to gather sufficient knowledge about the weather conditions ahead, and thus plan accordingly. But how can these pieces of information be best used to be prepared to react and effectively avoid an actual encounter with wind shear? Here are a few tips.

>> Take-off

- Consider delaying the take-off until conditions improve. Remember a downburst is not a long-lasting phenomenon and can clear within minutes.
- Select the most favourable runway and initial climb out path, considering the location of the likely wind shear / downburst. This may involve asking ATC for “an immediate left or right turn after take-off to avoid”.
- Use the weather radar (and the predictive wind shear system, as available) before commencing the take-off roll to ensure that the flight path is clear of hazard areas.
- Select the maximum take-off thrust.
- Closely monitor the airspeed and speed trend during the take-off roll to detect any evidence of wind shear.

BEST PRACTICE

If wind shear is suspected, or is detected by the Predictive Wind shear System (PWS), delay the take-off.

>> Descent and approach

- When downburst / wind shear conditions are anticipated based on pilots’ reports from preceding aircraft, or based on an alert issued by the airport LLWAS, the approach and landing should be delayed until conditions improve, or the aircraft should divert to a more suitable airport.
- Select the most favourable holding point, approach path and runway, considering the location of the likely wind shear / downburst condition, and the available runway approach aids.
- Select less than full flaps for landing (to maximize the climb gradient capability) and adjust the final approach speed (i.e. V_{APP}) accordingly.
- If an ILS is available, engage the autopilot for a more accurate approach tracking.
- If a gusty wind is expected, consider an increase in V_{APP} displayed on the FMS CDU (a maximum of minimum approach speed (i.e. V_{LS}) + 15 knots is allowed).
- Closely monitor the airspeed, speed trend and ground speed during the approach to detect any evidence of imminent wind shear. If the presence of wind shear is confirmed, be prepared for a possible missed approach and escape maneuver. A minimum ground speed should be maintained to ensure a minimum level of energy to the aircraft, and to ensure proper thrust management during the approach in case of sudden headwind to tailwind change. This is automatically performed on Airbus fly-by-wire aircraft by the Ground Speed mini function, when the speed target is managed.
- In anticipation of a possible wind shear event, be alert to respond immediately to any predictive wind shear advisory, “W/S AHEAD” caution or warning. And be prepared to perform a missed approach or go-around if necessary.

BEST PRACTICE

If wind shear is suspected, or is detected by the Predictive Wind shear System (PWS), delay the approach until conditions improve, or divert to a more suitable airport.

RECOVERY: HOW TO RECOGNIZE AND HANDLE ACTUAL WIND SHEAR CONDITIONS

Despite the available prevention means, an actual encounter with wind shear can happen. A timely recognition of this weather phenomenon is crucial to allow enough time for the crew to decide on the next course of action.

As far as wind shear is concerned, the best course of action is almost always avoidance. But in case of an actual encounter, piloting techniques exist for coping with a shear situation.

Recognition

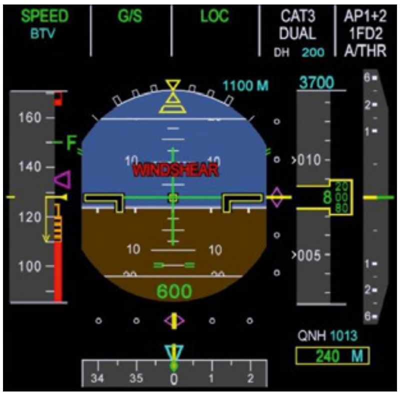
As rare as an actual encounter with severe wind shear may be, timely recognition of this condition is key for the successful implementation of wind shear recovery / escape procedures.

>> How to strengthen the wind shear situational awareness

The following deviations should be considered as indications of a possible wind shear condition:

- Indicated airspeed variations in excess of 15 knots
- Ground speed variations
- Analog wind indication variations: direction and velocity
- Vertical speed excursions of 500 ft/minute
- Pitch attitude excursions of 5 degrees
- Glide slope deviation of 1 dot
- Heading variations of 10 degrees
- Unusual autothrust or auto throttle activity.

>> On-board reactive wind shear system



(fig.5)
"WINDSHEAR" reactive warning display on PFD

A reactive wind shear warning system is available on most aircraft models.

This system is capable to detect a wind shear encounter based on a measure of wind velocities, both vertically and horizontally. When it activates, the audio "WIND SHEAR" is repeated 3 times, and a red "WINDSHEAR" warning appears on the PFD **(fig.5)**.

The wind shear warning system associated to the Speed reference System (SRS) mode of the flight guidance constitute the Reactive Wind shear System (RWS), since both components react instantaneously to the current variations of aircraft parameters.

Recovery technique for wind shear encounter

The aircraft can only survive severe wind shear encounters if it has enough energy to carry it through the loss-of-performance period. It can sustain this energy level in the following three ways:

- Carry extra speed. The aircraft does this automatically when in approach in managed speed (Ground speed mini).
- Add maximum thrust. The aircraft does this automatically with alpha floor protection, even if TOGA was already selected (do not forget to disconnect the Autothrust in this case, when out of alpha floor).
- If possible, trade height energy for speed. Any aircraft can do this.

Proper pilot technique helps in this process, providing the following few recommendations are duly followed, in a timely manner.

>> During take-off

If a wind shear is detected by the RWS or by pilot observation during the take-off roll, V1 may be reached later (or sooner) than expected. In this case, the pilot may have to rely on his/her own judgement to assess if there is sufficient runway remaining to stop the aircraft, if necessary.

In any case, the following recovery techniques must be applied without delay:

- **Before V1:**
  Reject the take-off if unacceptable airspeed variations occur (not exceeding the target V1) and the pilot assesses there is sufficient runway remaining to stop the aircraft.
- **After V1:**
  - Maintain or set the thrust levers to the maximum take-off thrust (TOGA);
  - Rotate normally at VR;
  - Follow the Flight Director (FD) pitch orders if the FD provides wind shear recovery guidance, or set the required pitch attitude as recommended in the FCOM.

BEST PRACTICE

If wind shear is detected by the Reactive Wind shear System during take-off or approach, recover with maximum thrust and follow the Speed Reference System (SRS) guidance.

>> During initial climb, approach and landing

If a wind shear is detected by the pilot, or by the RWS, during initial climb or approach and landing, the following recovery technique must be applied without delay:

- Set the thrust levers to the maximum take-off thrust (TOGA);
- If the Auto Pilot (AP) is engaged and provides wind shear recovery guidance, keep the AP engaged; or, if the AP is not engaged, do not engage it. Follow the FD pitch command if the FD provides wind shear recovery guidance, or set the required pitch attitude, as recommended in the FCOM;
- Level the wings to maximize the climb gradient, unless a turn is required for obstacle clearance;
- Applying full back stick on Airbus fly-by-wire aircraft, or flying close to the stick shaker / stall warning Angle-Of-Attack (AOA) on aircraft models that do not have full flight envelope protection, may be necessary to prevent the aircraft from sinking down;
- Do not change the flaps and landing gear configuration until out of the wind shear condition;
- Closely monitor airspeed, airspeed trend and flight path angle (if flight path vector is available and displayed to the PM);
- When out of the wind shear, let the aircraft accelerate in climb, resume normal climb and clean aircraft configuration.

NOTE

To recover from an actual wind shear encounter, recovery measures are indicated in the FCOM ABNORMAL AND EMERGENCY PROCEDURES. Refer to PRO-ABN-80, or FCOM Inclement Weather Operations on A300/A310/A300-600.

RWS and PWS compared characteristics

	RWS	PWS
PURPOSE	- Detect **in** the wind shear - Guidance to **escape**	- Detect **ahead** of the aircraft - Guidance to **avoid** the event
WARNING	- Aural - Visual	- Aural - Visual
PRINCIPLE	- Comparison between inertial and aerodynamic data	- Doppler weather radar

SUMMARY: OPERATING IN WIND SHEAR CONDITIONS

Considering the threat that a severe wind shear represents to safety, the best option is always to avoid it whenever possible. Nevertheless, in the case of an actual encounter with wind shear, it is essential to recognize it and then, recover from it.

The following key points and recommendations on avoidance, recognition and recovery can be considered for the development of company strategies and initiatives aiming to enhance wind shear awareness.

Avoidance

- Assess the conditions for a safe take-off or approach-and-landing based on all the available meteorological data, visual observations and on-board equipment.
- As far as possible, delay the take-off or the approach, or divert to a more suitable airport.
- Be "go-around minded" when flying an approach under reported wind shear conditions.
- Be prepared and committed to respond immediately to a predictive wind shear caution or warning.

Recognition

- Be alert to recognize a potential or existing wind shear condition based on all available weather data, on-board equipment indications and on the monitoring of the aircraft flight parameters and flight path.
- Scan instruments for evidence of impending wind shear.

Recovery

- If a wind shear warning occurs, apply the recommended FCOM recovery / escape procedure i.e. set maximum thrust and follow the FD wind shear recovery / escape pitch guidance.
- Make maximum use of aircraft equipment, such as the flight-path vector (as available).

NOTE

To safely operate an aircraft in wind shear or downburst conditions, best recommendations are indicated in the FCOM SUPPLEMENTARY PROCEDURES.

Wind shear can be a serious threat to aviation safety. Thanks to extensive research into the understanding of the phenomenon, efficient equipment is now available to assist pilots in identifying, avoiding and if necessary, handling wind shear conditions. With the technology, flight crew awareness and alertness are key factors in the successful application of avoidance techniques and recovery / escape procedures.

But above all, remember that avoidance is undoubtedly the best defence against the hazards of wind shear.

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