Lateral runway excursions upon landing

Lateral runway excursions upon landing have long been rather low on the safety issues list. With the remarkable improvements in other areas, they are getting higher up and deserve careful attention. The analysis of real cases allows for drawing interesting lessons on these events and reinforcing prevention.

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Safety statistics show that runway excursions have become one of the most common types of accident worldwide. If significant effort was put on the prevention of longitudinal runway excursions, it turns out that lateral runway excursion events are becoming a growing concern. Addressing them efficiently requires a good understanding of how they originate and what contributes to their occurrence.

This article will focus on the most safety critical veer off cases in terms of likelihood and severity consequences, namely: lateral runway excursions upon landing. It presents the outcome of a thorough analysis of a number of real cases and reviews the best operational practices to prevent lateral runway excursions upon landing.

LATERAL RUNWAY EXCURSIONS UPON LANDING: A GROWING SAFETY CONCERN?

What are we talking about?

In the frame of this article, a lateral runway excursion is: any aircraft getting off runway markings, whether it gets off the runway concrete or not. This implies that events at take-off and during taxi (e.g. during U-turns on the runway) are not considered here.

This definition is as valid as any other for describing facts. However, when it comes to enhancing safety and more specifically prevention, this definition is of little help. Indeed, the analysis of lateral runway excursion events corresponding to this definition combines situations that are so different in terms of their underlying phenomena that it is extremely challenging to derive efficient mitigation measures.

Of course there will be many cases where aircraft trajectories divert from the runway centerline and the desired landing path, but many of these never divert sufficiently to leave the runway surface and therefore never become classified as incidents or accidents. However, analysis of such "minor" events in the future may well be beneficial as we seek more data and information on this complex issue.

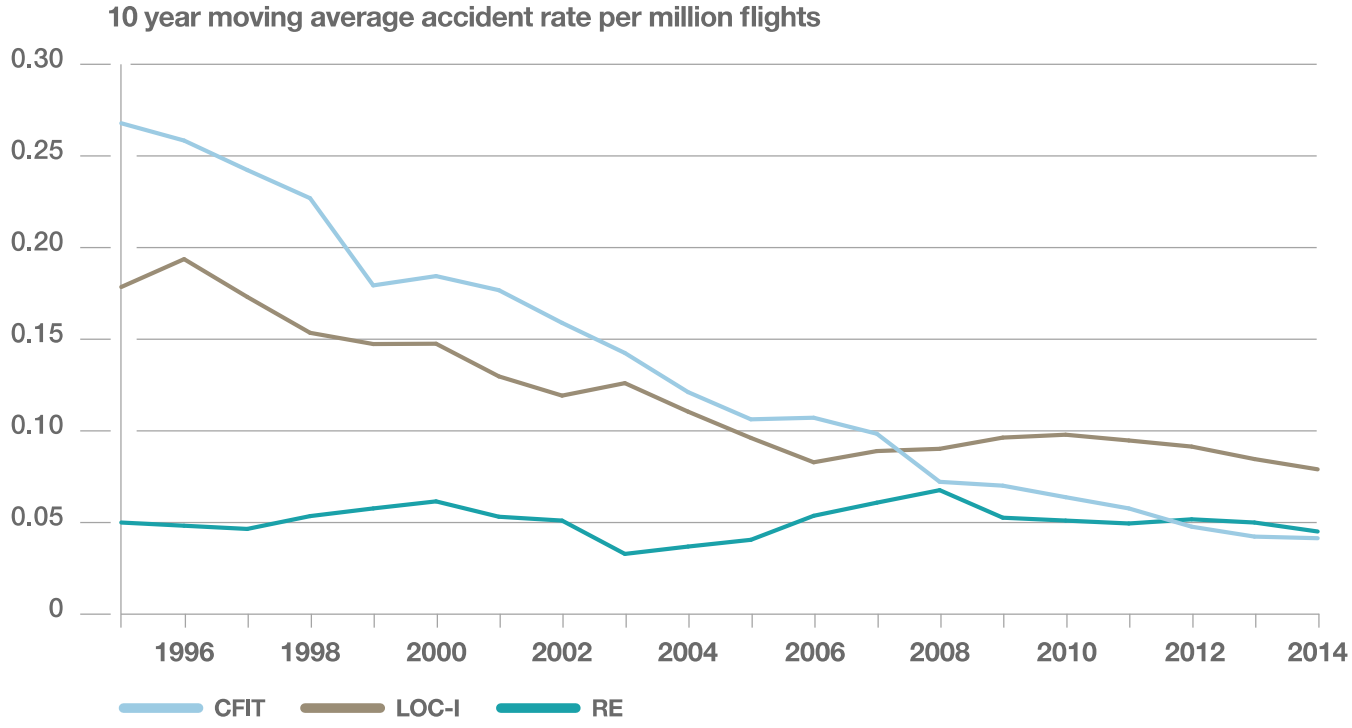
The events where aircraft get off runway markings need to be categorized according to what contributed to their occurrence, thus what can be done to prevent them.

Generally speaking, the most safety critical (as a result of likelihood and severity of consequences) veer off events are the lateral runway excursions upon landing where the aircraft goes off runway markings at touch-down, or during the roll-out phase. This article will focus more particularly on them.

Statistics say a word

For decades, accident statistics have kept highlighting the three same accident types at the top of the list of contributors, namely: Loss Of Control In-flight (LOC-I), Controlled Flight Into Terrain (CFIT) and Runway Excursion (RE). If virtually all CFIT and LOC-I accidents lead to both fatalities and hull loss, other accident categories generate mainly only material damage. As an example, 15% of RE accidents cause fatalities, and are the third source of fatal accidents. Yet, RE have become the main source of hull losses.
A closer look at the evolution of the figures and tendencies over the past 20 years shows that CFIT and LOC-I have significantly decreased whereas Runway Excursion remains relatively stable **(fig.1)**.

(fig.1)
Evolution of the three main accident categories from 1995



Over the last decade, a huge effort was put on runway overrun to prevent them. As a matter of fact, among the runway excursions, not only did they use to be the most frequent ones, but also their consequences are statistically more severe than that of lateral excursions. The main issue addressed was then related to the management of aircraft's energy given the aircraft performance, deceleration, runway state…

In recent years, lateral runway excursions have emerged as a growing safety concern. Is it because of or thanks to the progress made on the runway overrun front? Because they are more reported than before? For other reasons or any combination of reasons? Difficult to say, but through the events reported to Airbus by airlines, the trend is clear: the number of lateral runway excursions is increasing.

Therefore it is worth to try and reinforce prevention, and to start with, understand what lies behind real events.

WHEN REALITY HELPS SHAPE THE SCOPE TO CONSIDER: AFTER TOUCH-DOWN, YES, BUT NOT ONLY...

Thanks to airlines support, 31 in-service lateral runway excursion events were reported to Airbus over a 2012-July 2014 period. A first analysis with a prevention objective in mind led to distinguish between several lateral runway excursions categories due to there being a variety of issues identified and therefore, a variety of potential corrective actions.

Within the defined scope of lateral runway excursion upon landing, 25 events from the initial 31 were considered as relevant and usable.

Of course, the events studied were only those reported to Airbus and therefore, they represented a limited sample. However, they were corroborated by a study of the lateral runway excursion events reported to Airbus from 2007, making the sample much bigger and the results more robust.

They were studied with a main question in mind: is there a global or common signature for these events that could allow us to learn some generic prevention lessons? Interesting insights could be drawn from this work as we shall see later.

When searching for common contributing factors, two main families came out:
- weather environmental conditions
- flying technique

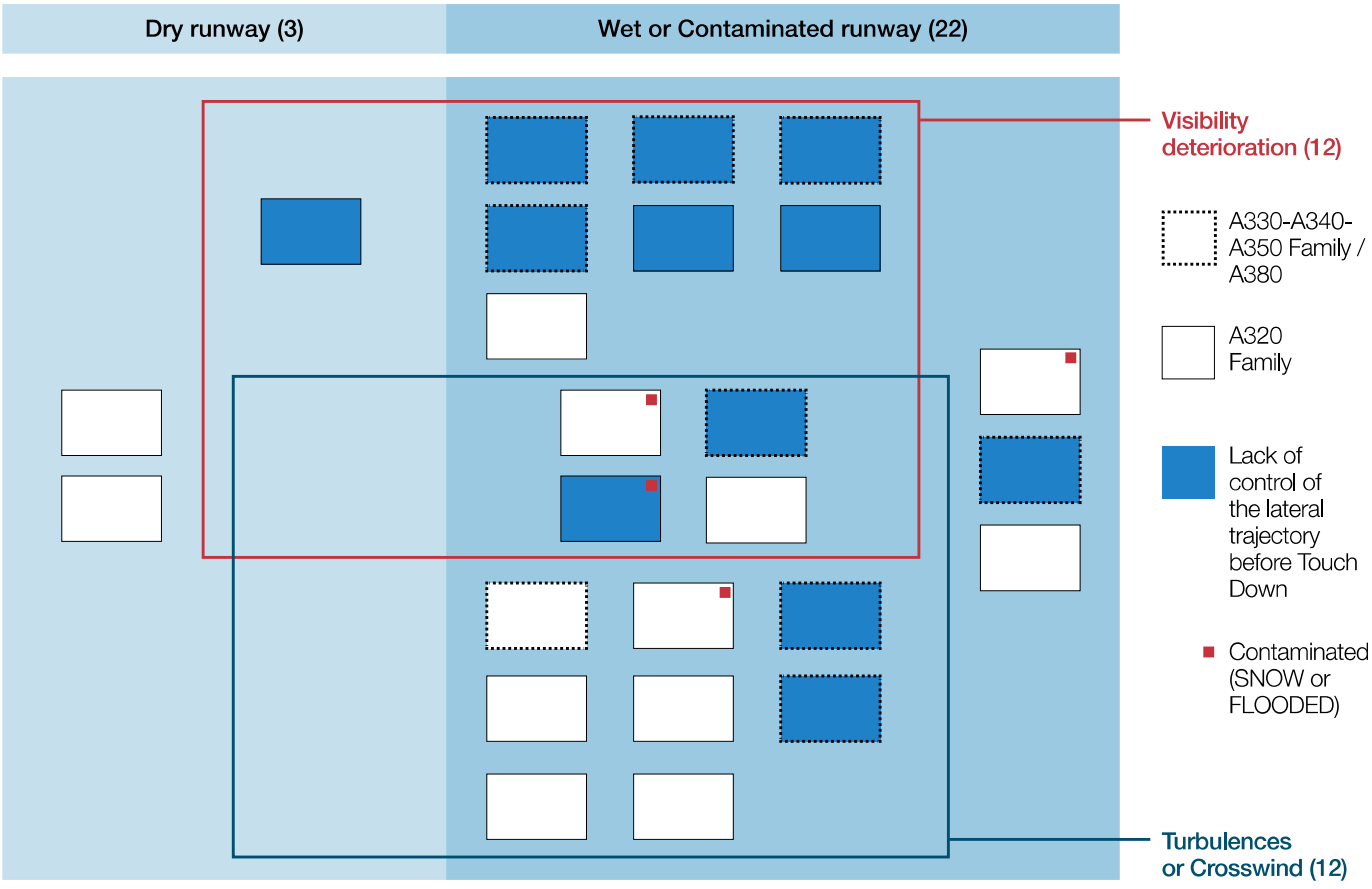
These two aspects were found in a number of events, most of the time in combination with one another, but with variations as to their detailed nature. A closer look at these two fields allowed for refining the understanding of the underlying phenomena.

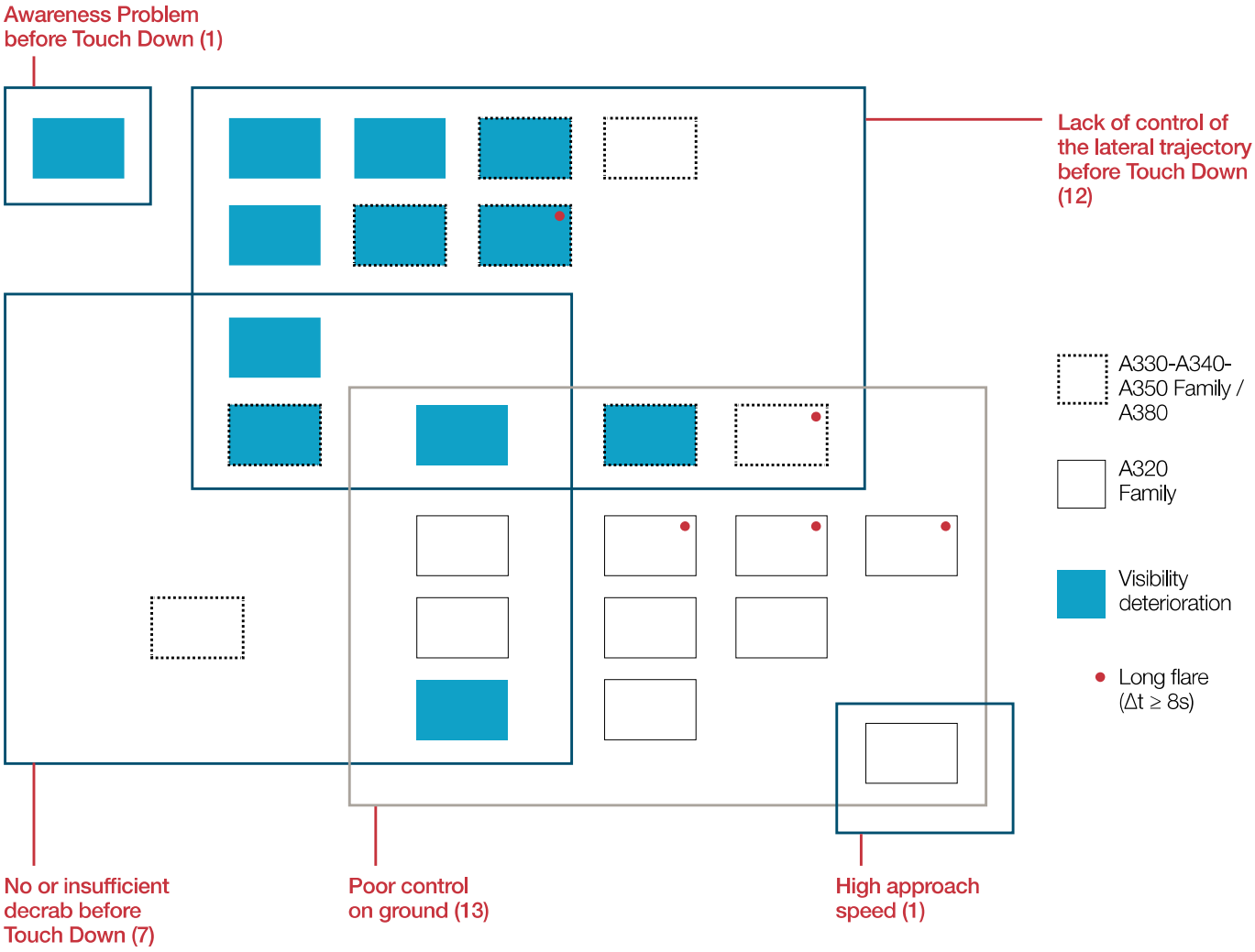
Weather environmental conditions

Three main environmental factors came out of the analysis:
- Runway state, wet or contaminated
- Turbulences or cross-wind
- Visibility deterioration

22 events out of 25 analyzed involved a wet or contaminated runway. In 19 out of the 25, there were at least two of the aforementioned environmental factors in the situation **(fig.2)**.

(fig.2)
Categorization of RE events according to contributing weather conditions factors





Flying technique

Regarding the flying technique in the environmental conditions mentioned earlier, three areas were identified as contributing factors to the events occurrence:

- Control of the lateral trajectory before touch-down
- Flare and decrab before touch-down
- Ground control

In some situations, as illustrated in **(fig.3)**, there was a combination of them.

A major outcome of the analysis is the significant contribution of the air-phase, before touch-down, to lateral runway excursions.

The next question, and more precisely, THE question is: With these insights from real events, how to enhance prevention of lateral runway excursions? If there is nothing we can do to change environmental conditions, it seems worth going back to some operational best practices.

(fig.3)
Categorization of RE events according to contributing flying technique factors

PREVENTING LATERAL RUNWAY EXCURSIONS UPON LANDING: BEST OPERATIONAL PRACTICES

As stated earlier, handling issues turn out to be a significant contributor to lateral runway excursion events upon landing, especially under some difficult environmental conditions such as wet or contaminated runway or cross wind or turbulence.

What is the appropriate landing technique and why? Let's prepare for landing and review the technique, including some explanations behind the scene, with a special focus on the conditions that were highlighted by the lateral runway excursion events analysis.

Landing technique: general principles

The appropriate landing technique, whatever the weather conditions, is a "whole" that combines a variety of dimensions: information and awareness (e.g. environmental conditions), state of mind & preparedness and handling skills.

> "Be stabilized until the flare. If not, go-around."

> "As long as reversers are not selected, a go-around is always possible."

1/ Before flare

» Be aware of the landing conditions

If landing with crosswind or on a contaminated runway rely on specific techniques, the first thing to make sure of is that:
- the crosswind, if any, is and remains within the limits of the aircraft
- the runway state allows for a safe landing and the runway braking coefficient is known.

» Be correctly seated

During cruise, sometimes a long one, pilots may move their seat a bit. Yet, upon landing, the full deflection of all flight control and braking may be needed to control the situation. Therefore, make sure the pilot seat is in a position (both horizontally and vertically) to allow for those full deflections should they be necessary. This is a key preliminary condition to a safe landing.

» Be stabilized

In a number of events, there was a localizer deviation away from the centerline. Beyond the lateral control before touch-down, it is essential that the aircraft be on the correct lateral and vertical flight path at the correct configuration and speed up to the initiation of the flare.

» Be Go-Around minded, as long as needed

Experience shows that some pilots are increasingly reluctant to initiate a go-around as the aircraft gets closer to the ground, even if the aircraft is not well aligned with the runway. Nevertheless, from a safety viewpoint, initiating a go-around close to the ground or even after a bounced landing is always better than performing an unsafe landing.

2/ From flare to touch-down

» Use proper flare and decrab (if needed) flying techniques

Landing in the correct zone, with the right alignment and at the right energy level is a good summary of what a pilot should aim at. Easier said than done?

In the case of crosswind, this requires specific techniques that will be detailed in the next section in this article.

3/ After touch-down

» "Fly" until you vacate the runway

Do not relax immediately after touch-down. There is still work to do.

A number of lateral runway excursions resulted from poor ground control in the rollout phase. This is obviously more often the case when a crosswind makes the day more difficult. Indeed, a number of physical phenomena come into play requiring specific actions to be managed. More details about these phenomena and how to maintain ground control with crosswind is provided in next section in this article.

Landing with crosswind

As general principles, the landing technique mentioned earlier remains valid. However, it is worth getting a bit further into details and background explanations when crosswind is involved in the landing conditions such as those underlined hereafter:

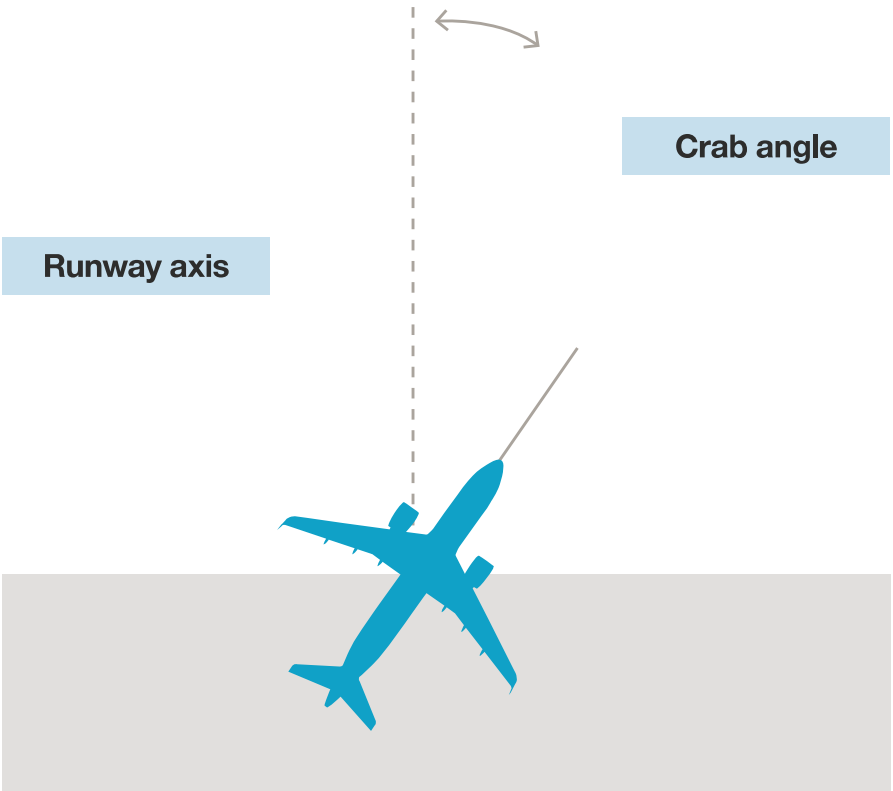
- Be aware of the landing conditions
- Be correctly seated
- Be stabilized
- Be go-around minded as long as needed
- Use proper flare and decrab flying techniques
- "Fly" until you vacate the runway

Let's examine how these three principles translate into practice in case of crosswind … and why.

Be stabilized

In crosswind situations, the major difference in technique lies in how to keep the aircraft on the correct lateral flight path. In order to do so, it is necessary to fly a wings level and crabbed approach to correct for the crosswind component on the final trajectory to the runway. Adopting a crab angle allows the pilot to keep the aircraft trajectory along the runway axis **(fig.4)**.

A CRABBED APPROACH



(fig.4)
Aircraft attitude during a crabbed approach

But what does correct lateral flight path mean precisely? What part of the aircraft needs to be aligned with the runway axis? The answer is the same whether the approach is flown manually or not, in visual conditions or not. The reference is the cockpit. Considering the location of the localizer antenna, under the radome, at the center of the nose of the aircraft below the cockpit **(fig.5)**, "correct lateral flight path" means localizer centered or nose of the aircraft trajectory aligned with the runway axis, thus ensuring the pilot's eye is aligned with the runway axis.

(fig.5)
Location of the localizer antenna

Some common tendencies to be avoided.

Experience shows that in some situations, some pilots have tendencies to destabilize the aircraft approach trajectory, especially along the lateral axis. It happens mainly in these 3 cases:

- When disconnecting the Auto Pilot (AP) for a manual landing.
- When initially becoming visual below a low cloud ceiling
- When performing the decrab in the flare.

Let's revisit the first two cases, see what happens behind the scene and then deal with the third case in more depth.

» When disconnecting the AP

A tendency sometimes observed is that of making large inputs on the sidestick when disconnecting the AP. Yet, the aircraft attitude has no reason to change at this very moment compared to what it was under AP. Therefore, it is key to analyze the stable trajectory before any stick input. This should avoid large inputs on the sidestick.

» When becoming visual

When first seeing the runway, some pilots have a tendency to start an immediate decrab and align the aircraft with the runway axis. By doing so, the aircraft drifts due to the crosswind and moves away from the correct lateral flight path. Again, becoming visual makes no difference as to the correct aircraft trajectory. It is normal to keep a crabbed approach and see the runway from a certain angle.

Use proper flare and decrab flying techniques

» Flare

If the flare technique is not modified by the presence of crosswind, some aspects need to be particularly kept in mind in such situations, especially:

- A high or extended flare significantly increases the landing distance, whereas, due to possible adverse reversers effects explained later in this article, it is even more important than usual to keep as much runway length as possible to decelerate after touch-down.
- In case of an extended flare, the decrease in the aircraft energy will make it even more sensitive to cross-wind. Counteracting crosswind becomes more and more difficult as speed decays in the flare. Eventually, the crosswind may move the aircraft away from the centerline.

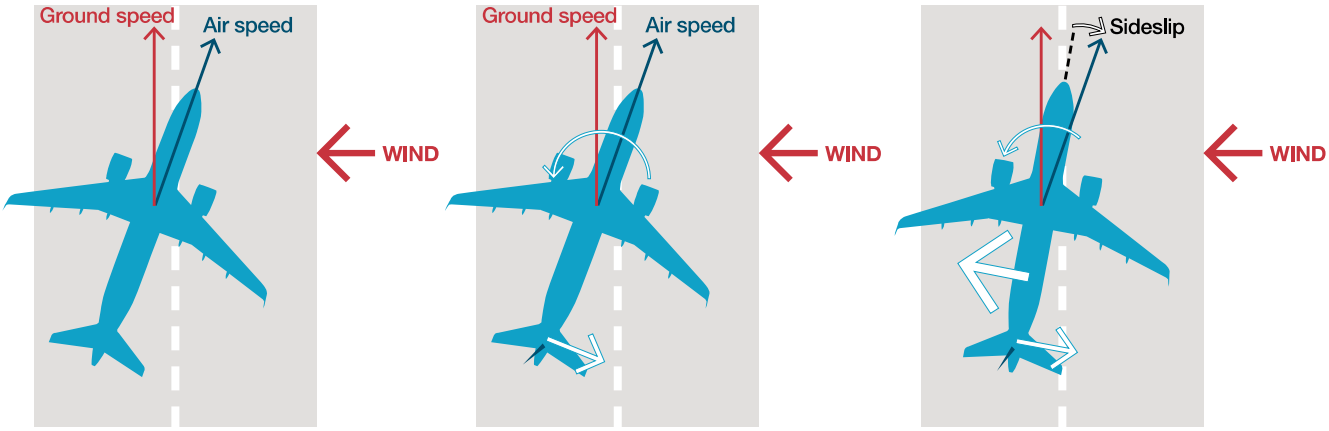
In summary, flare at normal height and do not look for a kiss landing.

» Decrab

As mentioned earlier, keeping a crabbed approach is the only way to keep the aircraft on the correct lateral flight path. However, before touch-down, the aircraft needs to be decrabbed to align with the runway axis. The aircraft is to be decrabbed at the time of the flare, using the rudder.

However, it is worth going into further detail to better understand what results from this action on the rudder. Indeed, when doing so, the aircraft will move a bit towards the wind. Why is it so?
In fact, when pushing on the rudder, the aircraft will yaw around a vertical axis that is located a bit forward from the CG, the yaw axis. The moment induced will make the aircraft move slightly towards the wind as illustrated in **(fig.6)**.

(fig.6)
Forces and moments effects on aircraft during decrab



Airborne, before the decrab

Rudder input effects :
- Side force on the fin
- Yawing moment

Moment and force effects:
- Rotation around a point located slightly in front of the Center of gravity
- Sideslip appears

FLARE AND DECRAB IN THE SPECIAL CASE OF HIGH CROSSWIND, ESPECIALLY ON CONTAMINATED RUNWAYS

In such situations, allowing a slight bank angle to maintain the runway axis, less than 5°, and a small crab angle, less than 5°, from the approach through to touchdown is the only way to keep the cockpit aligned with the runway axis.

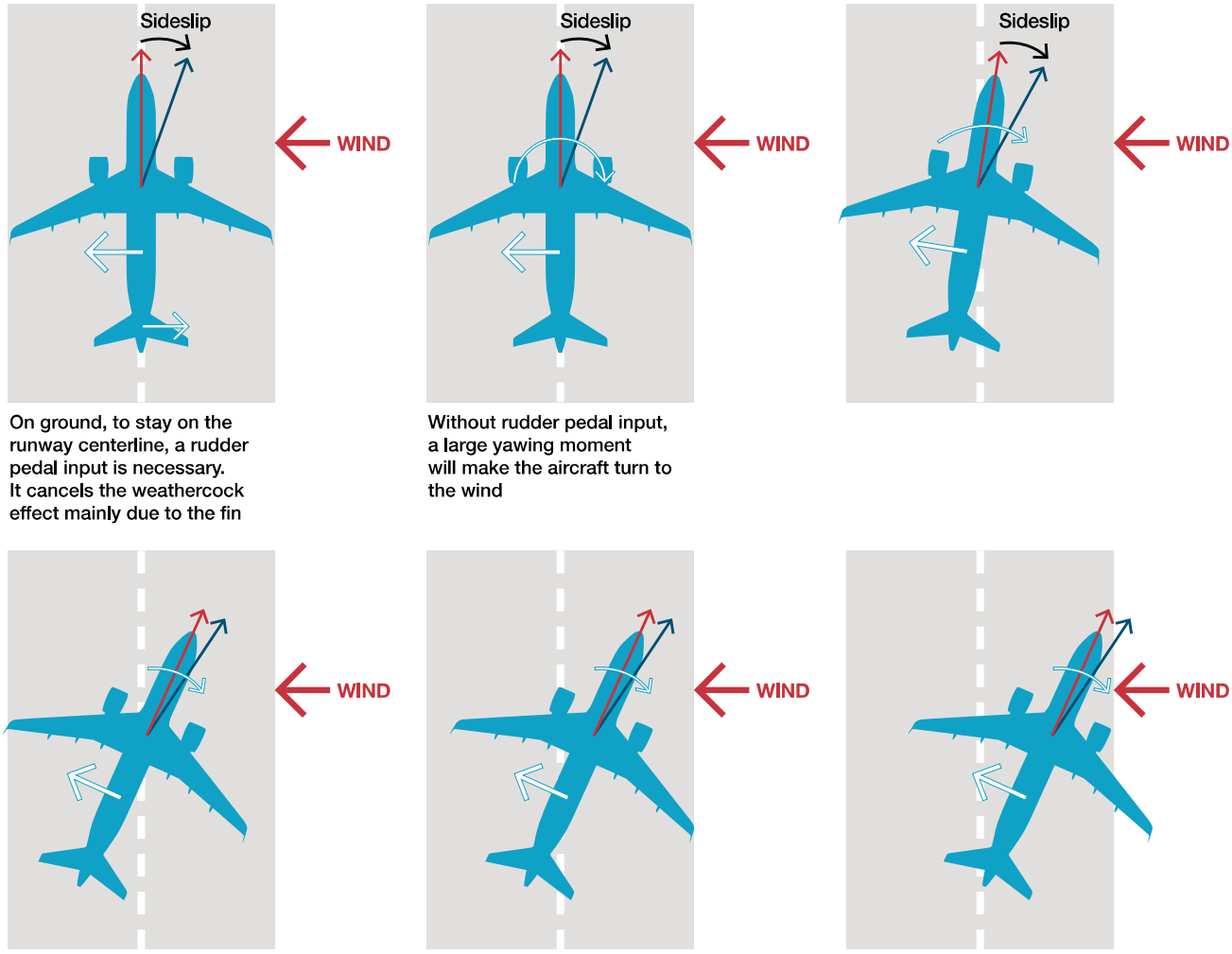
Why 5° maximum for the bank angle? It is the appropriate balance between the bank angle needed to keep the aircraft trajectory aligned with the runway centerline and the risk of hitting the runway with the wing tip or engine nacelle.

Why 5° maximum for the crab angle? Here again, it is an appropriate trade-off between maintaining the aircraft trajectory and experiencing an acceptable load at the landing gear on touch-down.

A common tendency to be avoided

Some pilots appear to be reluctant to keep a bank angle, even a small one, prior to touch-down. They then try and compensate the crosswind impact using the rudder only. However, an action on the rudder does not change immediately the CG speed vector. Therefore, if the aircraft lateral flight path starts drifting away from the runway centerline, using the rudder alone may not allow for an easy realignment of the aircraft.

Should such drift occur too close to the ground, the safe practice is to go-around. And as mentioned earlier, as long as reversers are not selected, a go-around is always possible!



On ground, to stay on the runway centerline, a rudder pedal input is necessary. It cancels the weathercock effect mainly due to the fin

Without rudder pedal input, a large yawing moment will make the aircraft turn to the wind

(fig.7)
Counteracting the weathercock effect

« Fly » until you vacate the runway

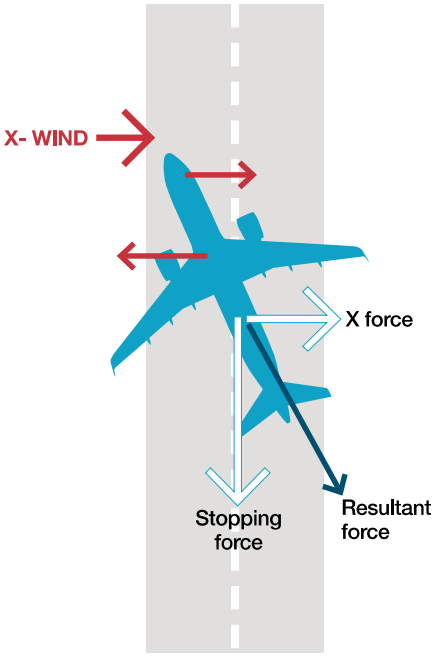
» After decrab

When the main landing gear touches the ground with residual crab, a pivoting moment is created around a vertical axis located at the level of the main landing gear by the combined effect of the lateral friction of the tires on the surface and by the inertia force applied at the center of gravity. This moment tends to turn the aircraft so as to align the aircraft longitudinal axis with the ground speed vector. In short, wheels tend to be more willing to go in the same direction as the aircraft trajectory, more than to skid. The intensity of the pivoting moment depends a lot on runway friction.

However, the sideslip coming from the crosswind when the aircraft is decrabbed creates an opposite moment tending to yaw the aircraft towards the wind direction by weathercock effect. Indeed, the effect of the wind on the aircraft fin aligned with the runway axis induces a rotation of the aircraft around a vertical axis located at the CG that yaws the aircraft nose back towards the wind. This opposite moment thus tends to move the aircraft upwind, away from the centerline. It needs to be counteracted by the rudder.

Nevertheless, as the aircraft speed decreases, the rudder efficiency drops. Therefore, the action on the rudder to counteract the weathercock effect needs to be amplified **(fig.7)**. As speed further decreases, the rudder effect could become insufficient, therefore the pilot must be prepared to apply differential braking.

(fig.8)
Forces exerted on the aircraft when reversers are used



(fig.9)
Recovering from the destabilization effect of thrust reversers

» Roll-out

During the roll-out, the primary means to maintain the aircraft on the runway is the cornering force exerted on the wheels through the tires. However, in order to keep the aircraft on the runway, it is important to understand some wind and aircraft related aspects.

Auto Pilot disconnection effect

As long as the Auto Pilot (AP) is connected, the aircraft automatically compensates the effects of crosswind with the rudder. As for the pedals, they remain in the neutral position. Yet, at AP disconnection after touch-down, since the pedals are at neutral position, the aircraft fin will naturally go back to a centered position, exposing the aircraft to weathercock effect, thus aircraft nose movement towards the wind, away from the centerline, unless immediately countered by the pilot. Countering the weathercock effect requires immediate inputs on rudder pedals, possibly large inputs. It may even be that differential braking is needed in addition to inputs on rudder pedals in case of high crosswind.

Therefore, at AP disconnection after touch-down it is key to:
- Have your FEET UP on the pedals
- Be ready for immediate and possibly large inputs on rudder pedals
- Be ready to use differential braking in addition if needed and keep in mind that the rudder effectiveness reduces when speed decreases. Considering the difficulty in performing a balanced braking on the pedals when they are not aligned, the use of Auto Brake is highly recommended.

Destabilizing reversers' effect

On slippery runways, the aircraft may start leaving the runway axis and going downwards the wind when reversers are used. Indeed, in slippery condition, the moment created by the tires friction that tend to align the aircraft fuselage on the runway axis, is not effective enough. And if the aircraft remains crabbed, the reverser thrust resultant force can be resolved in 2 components **(fig.8)**:
- One parallel to the runway and actually stopping the aircraft.
- One perpendicular to the runway, in the same direction as the wind, i.e. adding to that induced by crosswind.

This second force may make it more difficult to control the aircraft on the ground. Therefore, if a directional problem occurs:
- Consider reducing reverse thrust.
- If braking manually, consider reducing braking temporarily or use differential braking.

Once directional control is recovered and the aircraft is on the runway centerline again **(fig.9)**:
- Manual braking can be re-applied
- Reverse thrust can be re-applied (only the component parallel to the runway remains with no adverse effect on the lateral control of the aircraft). ■