

The Airbus Safety Magazine

July 2015

#20

Safety first



Safety first

The Airbus magazine contributing to the enhancement of the safety of aircraft operations by increasing knowledge and communication on safety related topics.

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editorial



YANNICK MALINGE

SVP & Chief
Product Safety Officer

In the current era of wealth of data where Big Data, smart data and other data related trends emerge, a key question arises: what can data tell us, and under what conditions?

Over the past decades, safety has evolved from primarily reactive approaches such as accident and incident investigation, to more proactive approaches to try to anticipate and thus prevent safety issues. In line with this evolution, there is a change of scale in the nature and the amount of data. If Big Data seems a promising complement to two other pillars of efficient safety enhancement - namely proper reporting and cascading of lessons learned - it requires some careful consideration as to how the data are collected and analysed.

From statistical patterns identified to relevant safety recommendations, the way is long and involves interpretation, sense-making... often requiring a qualitative analysis calling for a good knowledge and understanding of operations and safety context.

With this in mind, we must take great care with some Big Data approaches that use a variety of sources of data collected for a variety of purposes and through a generic and somehow magic algorithm come out with apparently very credible "safety results". Can we confuse "big" with "good" when it comes to data? Is it reasonable to make the assumption that big amounts of data could be self-sense-making?

Evolving towards more proactive approaches, better understanding of normal operations and detecting trends are keys to further enhancements in safety. However, whatever the amount of data, the experience of aviation professionals is essential to make sure they are processed and interpreted wisely.

A handwritten signature in black ink, appearing to read 'Y Malinge', with a horizontal line extending to the right.

 NEWS

A statistical Analysis on Commercial Aviation Accidents: check the 2015 edition!



The new edition of our yearly brochure on commercial aviation accidents statistics is now available. This statistical analysis examines the evolution of hull-loss and fatal accidents during revenue flights from 1958 to 2014. A particular focus is made on a breakdown of statistics by generations of aircraft and main accident categories, namely Controlled Flight Into terrain (CFIT), Loss Of Control In-flight (LOC-I) and Runway Excursion (RE).

Visit our airbus.com website (keyword “safety”) or find it on our tablet application.

SAVE THE DATE  NEWS

22nd FLIGHT SAFETY CONFERENCE – 2016

We are pleased to announce that the 22nd Flight Safety Conference will take place in Bangkok, Thailand, from the 21st to the 24th of March 2016. The formal invitations with information regarding registration and logistics, as well as the preliminary agenda will be sent to our customers in January 2016.

For any information regarding invitations, please contact Mrs. Nuria Soler, email nuria.soler@airbus.com.

The Flight Safety Conference provides an excellent forum for the exchange of information between Airbus and its customers. To ensure that we can

have an open dialogue to promote flight safety across the fleet, we are unable to accept outside parties.

As always, we welcome presentations from our operators. You can participate as a speaker and share your ideas and experience for improving aviation safety.

If you have something you believe will benefit other operators and/or Airbus and if you are interested in being a speaker, please provide us with a brief abstract and a bio or resume at nuria.soler@airbus.com.


22nd Flight Safety Conference

Bangkok, 21-24 March 2016







Safety first #20

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Control your speed... during climb

Second of a series of articles on the theme of speed control during a flight, which started in issue #18 of this magazine, we have just taken off and are now entering the climb phase. The main objective is to retract the slats / flaps at an adequate speed, while sustaining enough lift to accelerate and climb.



**LORRAINE
DE BAUDUS**

Flight Operations
Standards and Safety
management



**PHILIPPE
CASTAIGNS**

Experimental Test Pilot

After take-off, the aircraft continues in the climb phase and flies away from the busy airspace. The objective for the crew is to accelerate to the en-route climb speed and at the same time, manage various aircraft configuration changes, usually consisting of gears, slats and flaps retraction, and a change from take-off power to climb power.

This article aims at shedding some light on the way the different maneuvering and limit speeds that are of use during climb are defined and determined, and how they can be implemented in daily operations.

MANAGING YOUR CLIMB: UNDERSTANDING SPEEDS

A climb is generally flown at an airspeed that is often initially limited by Air Traffic Control (ATC) instructions. To safely manage the climb phase within these restrictions, some characteristic speeds are useful tools, and they require a close monitoring. What speeds exactly should be monitored? What do these speeds mean and what happens if they are exceeded?

For every flight, characteristic speeds are computed automatically by the aircraft Auto Flight Systems (Flight Management System (FMS), Flight Guidance (FG) and Flight Envelope (FE)) and effectively displayed on the PFD airspeed scale. They are extremely useful as maneuvering speeds and limit speeds to safely guide the pilots configuration change decisions through the climb phase.

Our objective is to highlight the design and operational considerations underlying all recommendations Airbus has issued to flight crews regarding the monitoring of these speeds during climb.

Amongst other parameters, the maneuvering speeds Flaps (F), Slats (S) and Green Dot (GD) are a function of the Zero Fuel Weight (ZFW) inserted by the crew at FMS initialization. Therefore, any erroneous entry will impair these speeds.

Maneuvering speeds

In nominal conditions (all engines operative), the climb phase poses some challenges to the crew: accelerate the aircraft, maintain a satisfactory climb gradient and manage several configuration changes at the same time. To

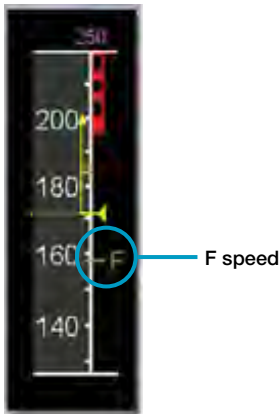
help pilots fly their aircraft safely through the different steps of this phase of flight, some characteristic speeds were defined as maneuvering speeds.

F, S and Green Dot speeds frame the aircraft climb performance limits.

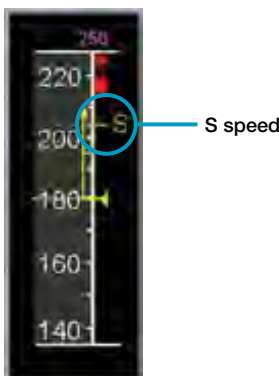
“ F, S and Green Dot speeds frame the aircraft climb performance limits. ”

PROCEDURES

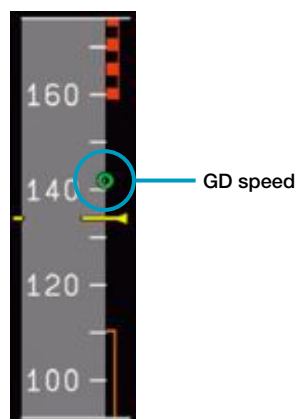
Control your speed... during climb



(fig.1)
F on the PFD speed scale



(fig.2)
S on the PFD speed scale



(fig.3)
GD on the PFD speed scale

F and S: Flaps and Slats minimum retraction speeds

» Definitions

F speed is the minimum speed at which flaps should be retracted from CONF 3 or 2 to CONF 1+F.

It is represented by a green “F” on the PFD speed scale and displayed only when the slats / flaps control lever is on position 3 or 2 (CONF 3 or 2) during the take-off phase, the initial climb and go-around **(fig.1)**. It is no longer displayed when in configuration 1 or 1+F.

S speed is the minimum slats retraction speed, i.e. the minimum speed at which a clean configuration should be selected.

It is represented by a green “S” on the PFD speed scale and displayed only when the slats / flaps control lever is on position 1 (CONF 1 and 1+F) **(fig.2)**.

» How are F and S determined during the take-off phase?

F speed varies according to the aircraft weight and altitude. It is tabulated in the Flight Envelope as a function of $V_{S1g CONF 1+F}$, which is the reference stall speed demonstrated by flight tests and agreed by the Airworthiness Authorities.

In this respect, F speed allows a margin above the stall speed in the configuration 1+F.

$$F \text{ speed} = k \times V_{S1g CONF 1+F}, \text{ with } k \text{ equal to about } 1.18 \text{ to } 1.26$$

$$V_{MCL} + 5 \text{ kts} \leq F \leq V_{FE CONF FULL} - 2 \text{ kts}$$

S speed varies according to the aircraft weight and altitude. It is tabulated in the Flight Envelope as a function of $V_{S1g CLEAN CONF}$.

In this respect, S speed allows a margin above the stall speed in the clean configuration.

$$S = k \times V_{S1g CLEAN CONF}, \text{ with } k \text{ equal to about } 1.21 \text{ to } 1.25$$

Green Dot (GD): best lift-to-drag ratio

» Definition

GD speed is the engine-out operating speed in clean configuration. In other words, it corresponds to the speed that allows the highest climb gradient with one engine inoperative in clean configuration.

In all cases (all engines operative), the GD speed gives an estimate of the speed for best lift-to-drag ratio. It is also the final take-off speed and it

represents the operational speed of the clean configuration and the recommended speed in holding in clean configuration.

It is represented by a green dot on the PFD speed scale and displayed only when the slats / flaps control lever is in the '0' (CLEAN) position and landing gears are not compressed **(fig.3)**.

» How is GD determined?

GD speed is computed by the Auto-flight systems and is based on the aircraft weight. The GD formula has been set up so that the resulting airspeed provides the best lift-to-drag ratio for a given altitude, air tempera-

ture and aircraft weight, in clean configuration with one engine out.

In some phases of flight, GD is computed to minimize drag and thus, the fuel consumption (for example during the HOLD phase).

Limit speed

We have seen that deviations from the maneuvering speeds F , S and GD during climb can have an impact on the aircraft's aerodynamic performance. We will now focus on the limit speed V_{FE} .

V_{FE} : Maximum speed with Flaps Extended

With the A/THR engaged and active (CLB / OP CLB / SPEED green on FMA), the aircraft remains below V_{FE} .

When the A/THR is not active, V_{FE} exceedance may occur (for example during a go-around).

» Definition

V_{FE} is the maximum speed with flaps extended. It has a specific value for each flap setting.

Generally speaking, the maximum speed defining the aircraft's flight envelope is called V_{MAX} . V_{MAX} is equal to V_{LE} (maximum speed with landing

gears extended) or V_{FE} according to the aircraft configuration. V_{MAX} is equal to V_{MO} (or speed corresponding to MMO) only in the clean configuration.

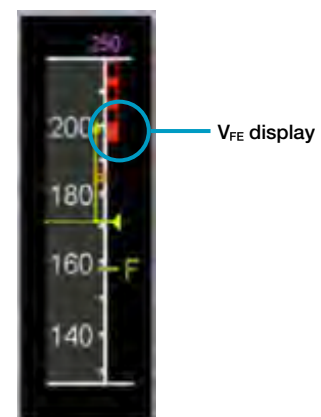
On the PFD speed scale, it corresponds to the lower end of the red and black strip (**fig.4**).

» How is V_{FE} determined?

V_{FE} is the maximum speed for high lift configurations, i.e. with slats / flaps extended: it is related to the structural limitation of the slats / flaps. A V_{FE} is computed for each slats / flaps configuration, based on either the slats / flaps control lever position or the actual aircraft configuration (slats / flaps con-

trol surfaces position), depending on the aircraft type.

In order to keep a sufficient margin between the $V_{FE CONF 3}$ and the speed at which the next configuration is selected, the following inequality is met: $V_{FE CONF 3} \geq F + 10$ kts.



(fig.4)

V_{FE} on the PFD speed scale



MANAGING YOUR CLIMB: OPERATIONAL RECOMMENDATIONS

Flying a safe and steady climb requires pilots' attention to carefully manage the different configuration changes, while accelerating to the en-route climb speed and eventually, cruise speed.

Indeed, not respecting the maneuvering and limit speeds leads to adverse consequences that we will review. Avoiding an overspeed situation during the slats / flaps retraction - with its potential structural damage conse-

quences - is important. It is therefore worth understanding the different V_{FE} display logics implemented in each aircraft family, and the resulting overspeed aural warning behaviour during the climb.

What are the operational implications of not respecting the maneuvering or limit speeds?

F and S: Flaps and Slats minimum retraction speeds

F speed (resp. S) is defined as the recommended minimum flaps (resp. slats) retraction speed. Retracting the flaps (resp. slats) at a speed significantly lower than F (resp. S) would reduce the margin against the high Angle-Of-Attack (AOA) protection. This could lead the aircraft to reach a speed below the lowest selectable speed VLS CONF 1 (or 0), and possibly low enough to break through the high AOA protection threshold.

Retracting the flaps (resp. slats) at a speed significantly higher than F speed (resp. S) would reduce the climb performance and thus, possibly compromise the aircraft ability to clear any obstacles (this is more likely if one engine is inoperative).

If flaps need to be maintained for a turn before acceleration altitude for instance, F speed (resp. S) can be used safely to perform a turn while climbing.

GD: Green Dot

At a given weight and engine rating, the potential climb gradient is maximum when (Thrust - Drag) is at a maximum - i.e. when the lift-to-drag ratio is maximum.

Deviating below GD involves an increase in the drag on the aircraft and would eventually undermine the aircraft's ability to continue a climb. Indeed, if the aircraft speed goes significantly below GD, with the maximum available thrust already in use (assuming that thrust levers have just

been set to CLIMB / MCT), then the only way for the crew to recover a satisfactory climb gradient is to decrease the rate of climb (even enter a descent if necessary) in order to accelerate to or above GD. This maneuver is obviously counteractive to the objectives of the climb phase.

Therefore in the clean configuration, the crew should not fly below GD in order to avoid degrading climb performance.

GD IN A NUTSHELL
Avoid flying below
GD during climb.

V_{FE}: Maximum speed with flaps extended

In case of take-off with A/THR not active, flying with slats / flaps extended, or extending slats / flaps well above V_{FE} directly poses a risk of structural damage through the slats / flaps track mechanisms. This may result in distortion of the flaps and slats or the extension mechanism or even the aircraft structure upstream. In case V_{FE} is exceeded, an overspeed aural warning is triggered in the cockpit in order to alert the crew.

The flight crew will have to reduce the speed or to retract the slats / flaps accordingly.

Exceeding V_{FE} may subsequently trigger inspections of the slats/flaps mechanism and/or the aircraft structure.

Specific trouble shooting procedures exist to inspect and repair an aircraft after flight above V_{FE}. These procedures are available in the Aircraft Maintenance Manual (AMM).

V_{FE} IN A NUTSHELL

Do not fly with slats / flaps extended above V_{FE}.

How to avoid an overspeed during slats / flaps retraction?

Avoiding an overspeed during slats / flaps retraction relies on a variety of complementary aspects. Procedures, pilots' attention and coordination, anticipation of configuration

changes, understanding of the limit speed and of the different V_{FE} display logics and overspeed aural warning behaviour implemented in each aircraft family.

The common approach

Slats and flaps retraction during climb can be managed safely by following SOP, and observing the visual F and S indications on the PFD. Incidentally, doing so allows the crew to respect the V_{FE} indication displayed on the PFD and thus, avoid triggering an aural overspeed warning (with potential structural damage).

The use of A/THR also enables the crew to avoid an overspeed condition during slats / flaps retraction.

While the PF is expected to manage these configuration changes, the PM plays a key role in facilitating his/her

task by anticipating them. During the initial climb phase, the PM needs to be vigilant to speed trends and alert the PF in case the margin that is left against the applicable limit speed V_{FE} becomes too tight.

This is valid at all time, for all aircraft families.

Differences arise when we look more closely at the V_{FE} display logics for each family. In particular, we want to emphasize the possibility of a temporary, yet inconsequential, overspeed aural warning on A300/A310, A320 and A330/A340 Families.

The case of untimely temporary overspeed aural warning during slats / flaps retraction

» A300/A310, A320 and A330/A340 Families

On A300/A310, A320 and A330/A340 Families,

- The V_{FE} value displayed on the PFD is based on the slats / flaps control lever position and it moves by one step as soon as this lever is moved.
- The overspeed aural warning triggering threshold varies according to the actual aircraft configuration, i.e. the slats / flaps surfaces real time position.

Therefore, during slats / flaps transition, the dynamic acceleration of the airplane may lead to a temporary OVERSPEED WARNING even if the current speed is out of the red and black strip displayed on the PFD. In this situation, there are neither operational consequences nor safety issues.

» A350 and A380 Families

On A350 and A380 Families, a different logic was developed. The V_{FE} display on the PFD is directly based on the actual aircraft configuration, as is the overspeed aural warning trigger-

This is due to the following logic:

- When the flap lever is moved from CONF 2 (or 3) to CONF 1+F, F speed could be very close to V_{FE} before flaps retraction. Once the flap retraction is initiated, $V_{FE CONF (2 \text{ or } 3)}$ moves in one step to $V_{FE CONF 1+F}$ before the flaps actually reach CONF 1+F. As a consequence, in acceleration towards S speed, the V_{FE} aural warning could activate although the actual surfaces speed is below the displayed V_{FE} .
- When the flap lever is moved from CONF 2 (or 3) to CONF 1+F, S speed could be greater than $V_{FE CONF 1+F}$ before the surfaces retract. When automatic flap retraction occurs, the barber's pole does not move before the flaps fully retract.

ing threshold. This means that the two signals are perfectly synchronized, thus the risk of an untimely temporary overspeed warning is eliminated.

The case of temporary overspeed aural warning during slats / flaps retraction after a heavy-weight take-off

In the particular case of a heavy-weight take-off, the risk of a temporary overspeed aural warning is increased. Indeed, in this configuration, S speed is quite close to $V_{FE CONF 1+F}$ because the aircraft weight is higher and the lift needed to climb is higher too. Therefore the slats need to remain extended for longer. As a result, the crew will order flaps retraction at a speed that might be higher than the Flaps Auto-retraction speed. In that case, should the acceleration of the airplane be rapid, a V_{FE} aural warning may momentarily trigger. This logic is as per design and structural limits are not encountered.

For example, an A320 at a Take-Off Weight (TOW) of 76T, S speed of 205 kts, the pilot will order flaps retraction most probably at or slightly above 210 kts, which is precisely the Flaps Auto-retraction speed. Once the slats / flaps control lever is in the retracted position, the V_{FE} red and black strip is no longer displayed on the PFD speed scale. If the airplane accelerates rapidly, then the airspeed may catch up the actual instantaneous V_{FE} momentarily, which will trigger the V_{FE} aural warning.

Again, this logic is as per design and structural limits are not encountered. ■



BEST PRACTICE

After a heavy-weight take-off, do not delay slats / flaps 0 selection above S speed in order to prevent possible temporary V_{FE} overspeed aural warning.



During climb, in manual flight, the main risk is to experience an aural overspeed warning (with potential structural damage) as a result of a late slats / flaps retraction. Understanding the implications of climb speeds is paramount to enable pilots to sense instantly the available margin they have left to avoid exceeding the limit slats / flaps retraction speed.

In practice, once the aircraft is airborne, pilots must be fully cognisant of the airspeed as well as the speed trends at all time in flight.



DID YOU KNOW _____

To know more about speeds, read our brochure “Getting to grips with aircraft performance”, available on AirbusWorld.

A presentation was also made at the 11th Perf and Flight Ops Conference in Dubai in 2011.



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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Test Pilot

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

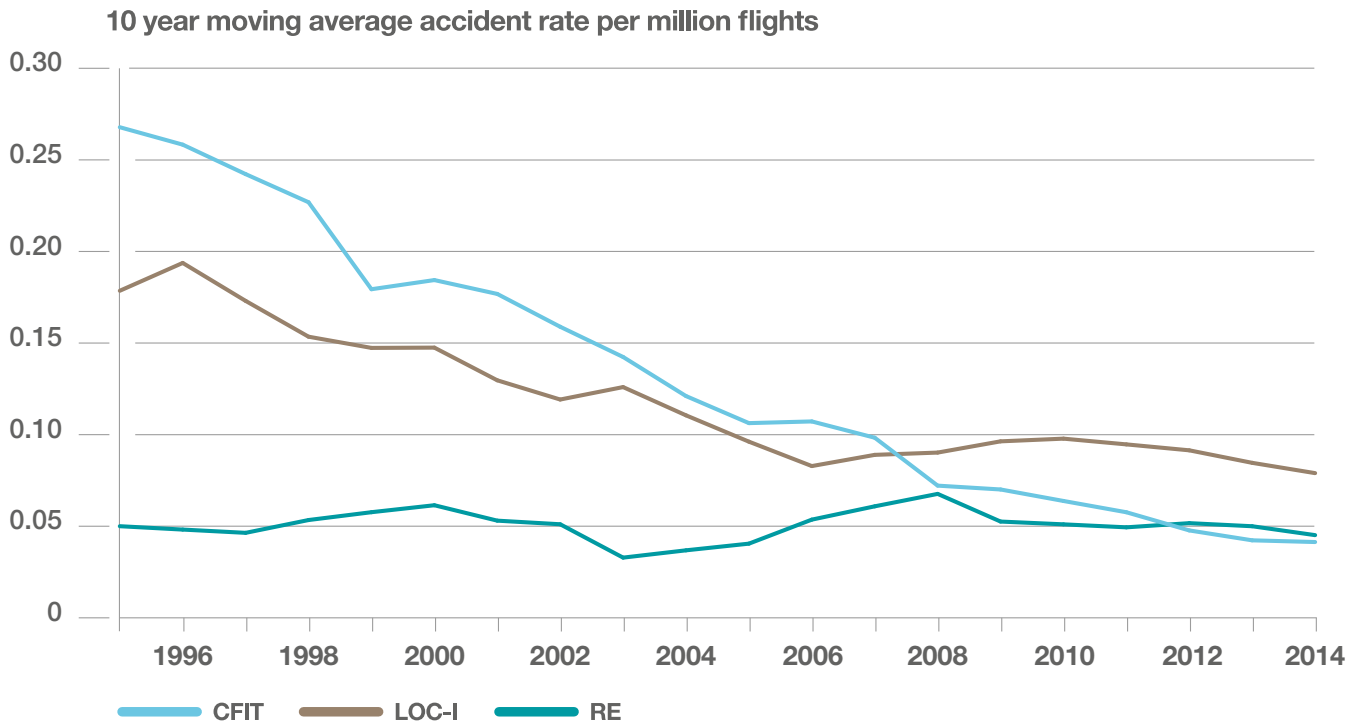
For decades, accident statistics have kept highlighting the three same accident types at the top of the list of contributors, namely: Loss Of Control In-flight (LOC-I), Controlled Flight Into Terrain (CFIT) and Runway Excursion (RE). If virtually all CFIT and LOC-I accidents lead to both fatalities and 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.



PROCEDURES

Lateral runway excursions upon landing



(fig.2)

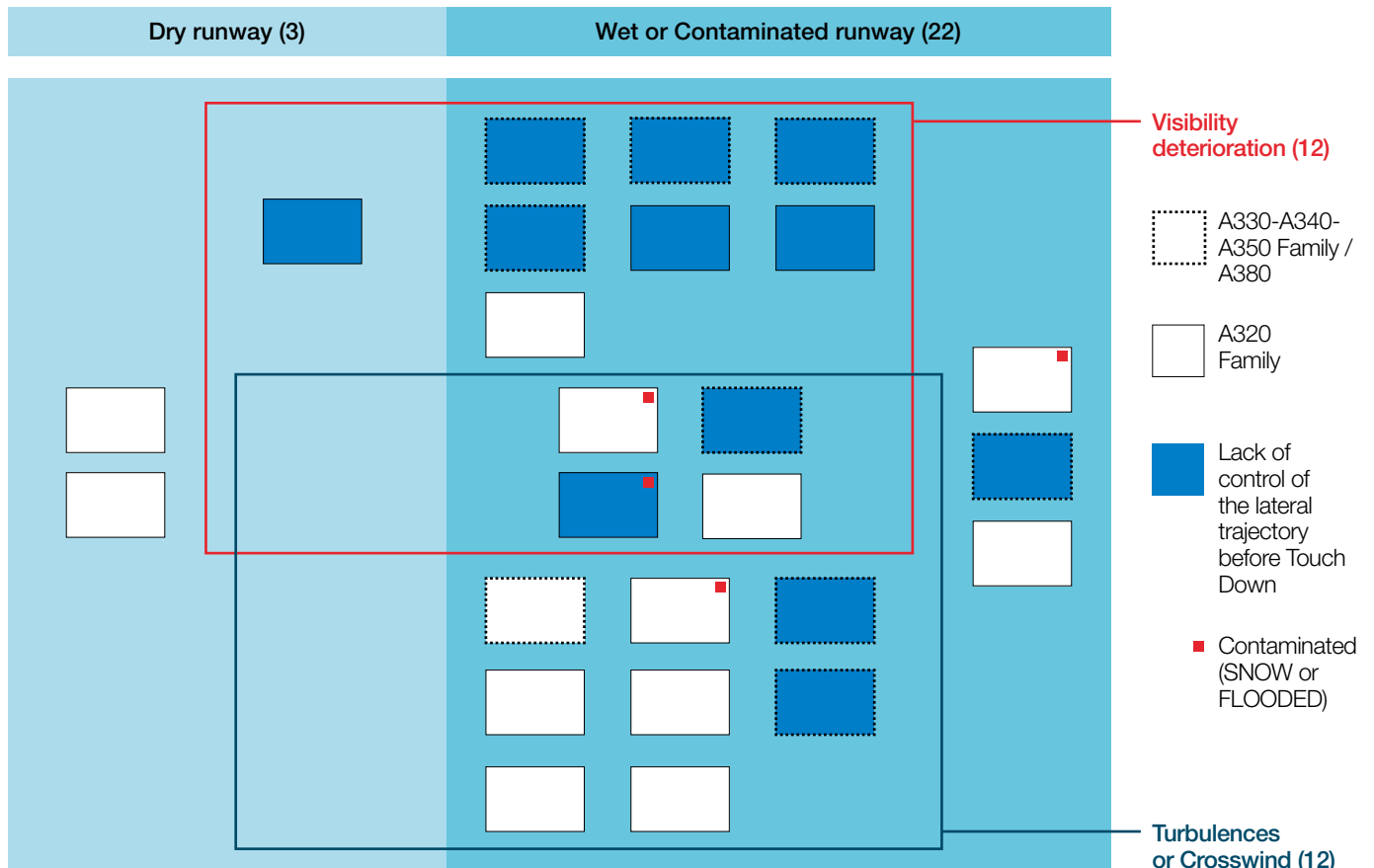
Categorization of RE events according to contributing weather conditions factors

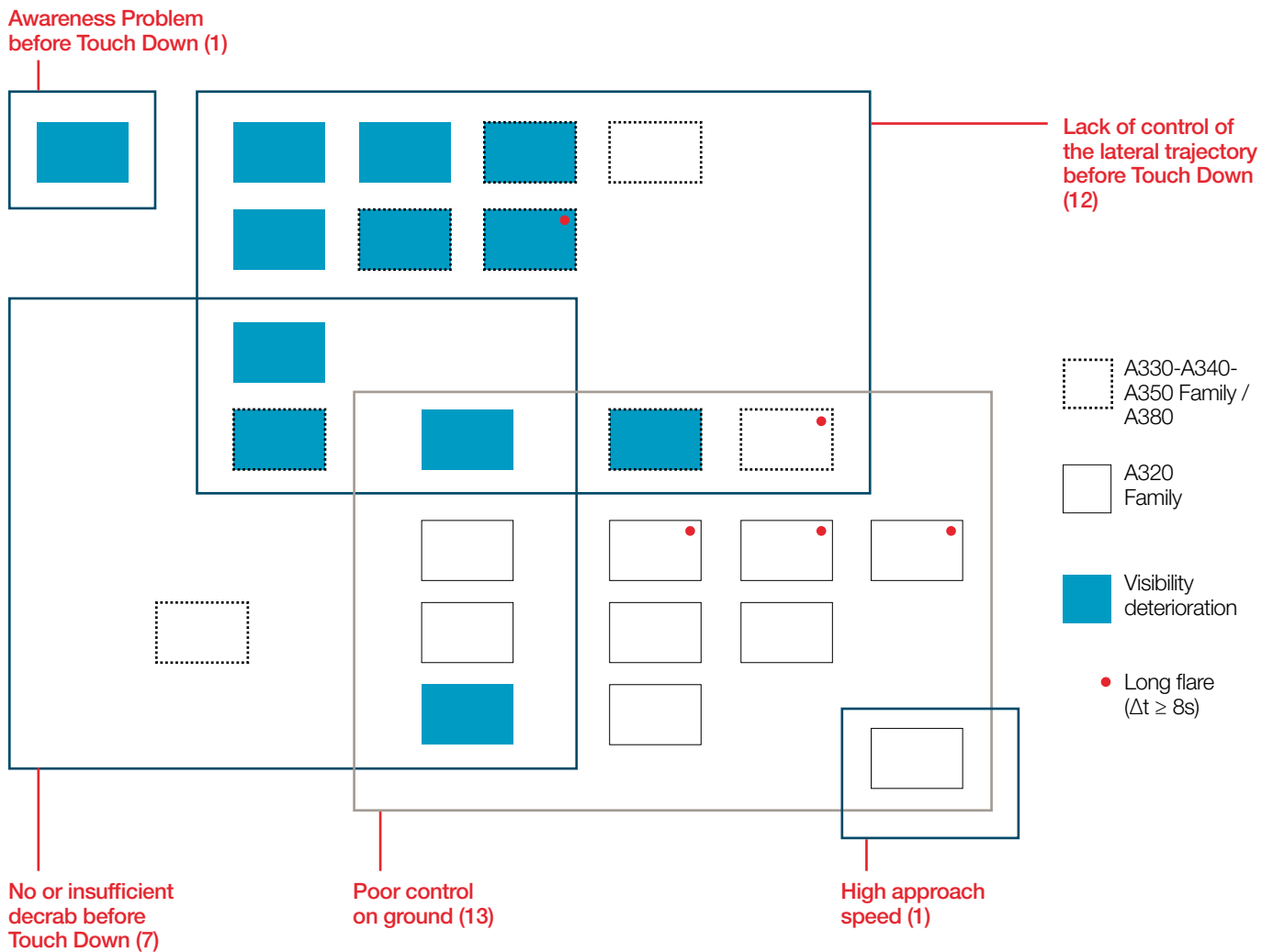
Weather environmental conditions

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)**.





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.

1/ Before flare

» Be aware of the landing conditions

» Be stabilized

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.

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 correctly seated

» Be Go-Around minded, as long as needed

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.

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.

“ Be stabilized until the flare. If not, go-around. ”

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

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

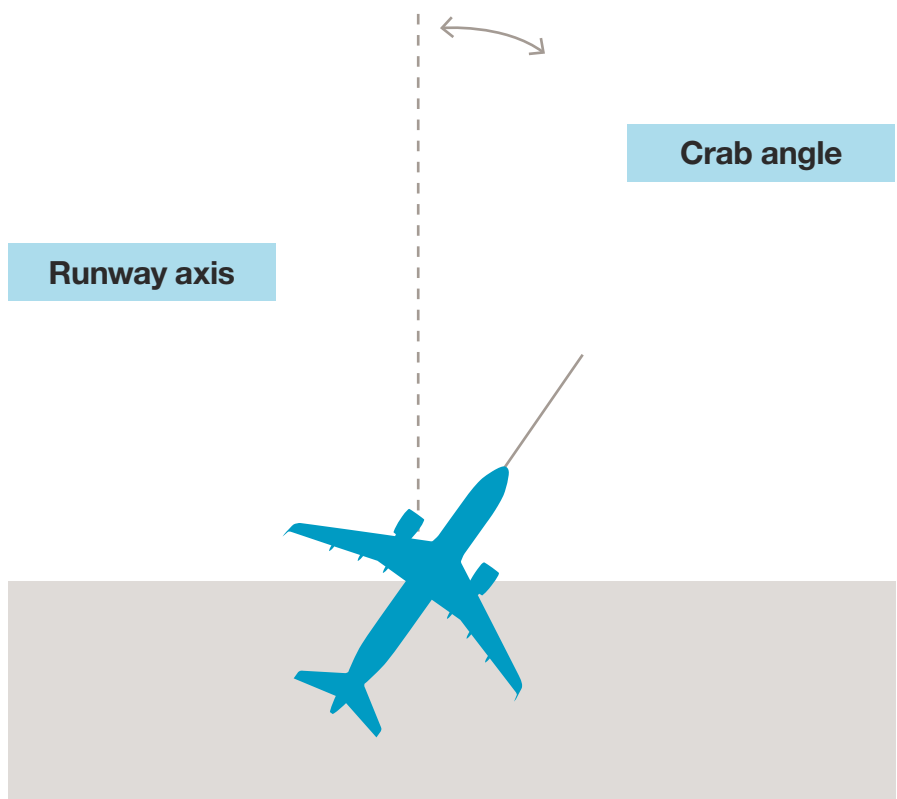
Let’s examine how these three principles translate into practice in case of crosswind ... and why.

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

PROCEDURES

Lateral runway excursions upon landing

(fig.5)

Location of the localizer antenna



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 local-

izer 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.

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 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

» 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

- 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.

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.

ral 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 crosswind. 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**

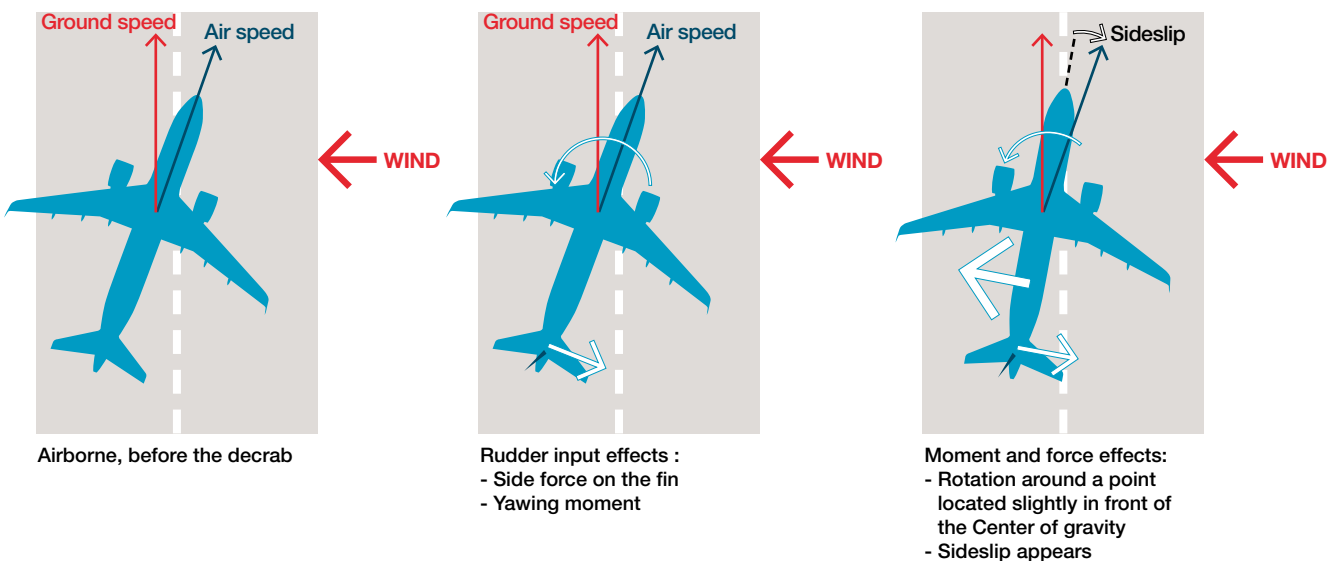
As mentioned earlier, keeping a crabbed approach is the only way to keep the aircraft on the correct lateral flight path. However, before touch-down, the aircraft needs to be decrabbed to align with the runway axis. The aircraft is to be decrabbed at the time of the flare, using the rudder.

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)**.

However, it is worth going into further

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



PROCEDURES

Lateral runway excursions upon landing

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.

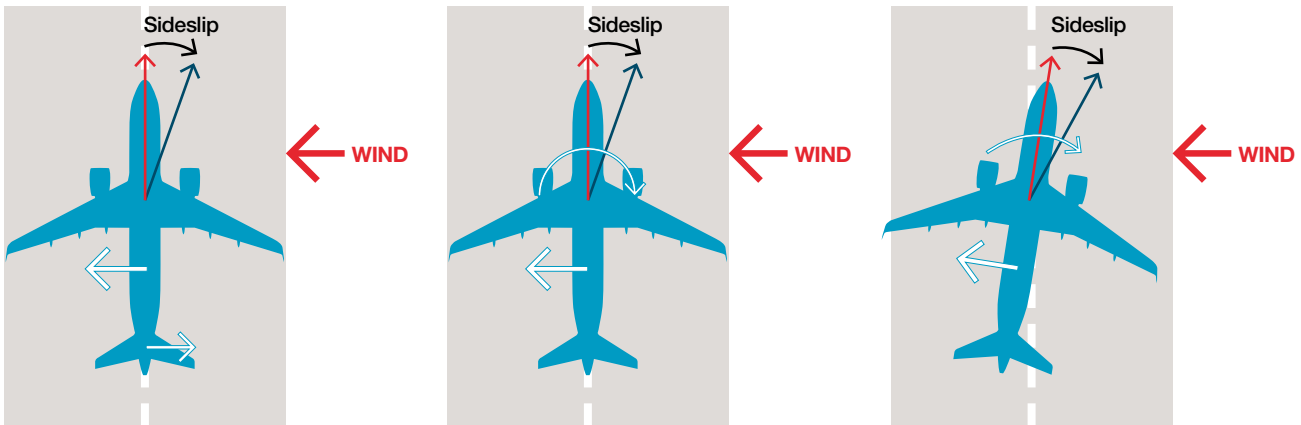
A common tendency to be avoided

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.

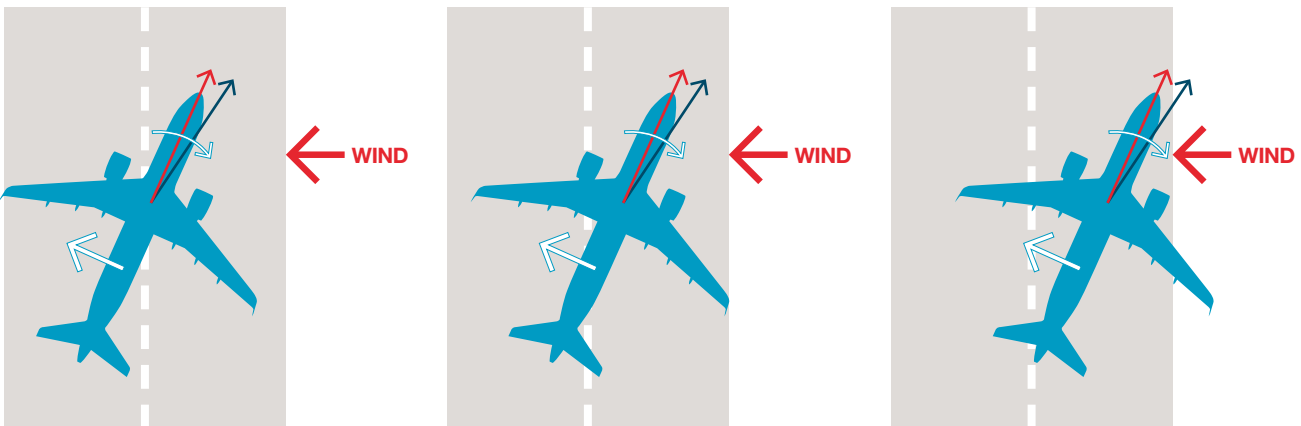
Should such drift occur too close to the ground, the safe practice is to go-around. And as mentioned earlier, as long as reversers are not selected, a go-around is always possible!





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



« 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.

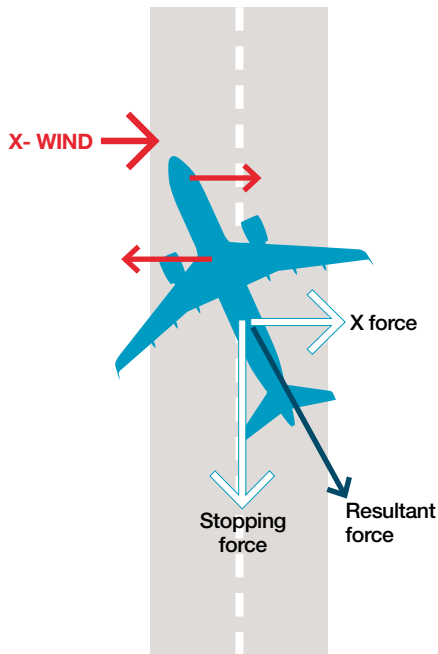
(fig.7)
Counteracting the weathercock effect

PROCEDURES

Lateral runway excursions upon landing

(fig.8)

Forces exerted on the aircraft when reversers are used



» 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, 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:

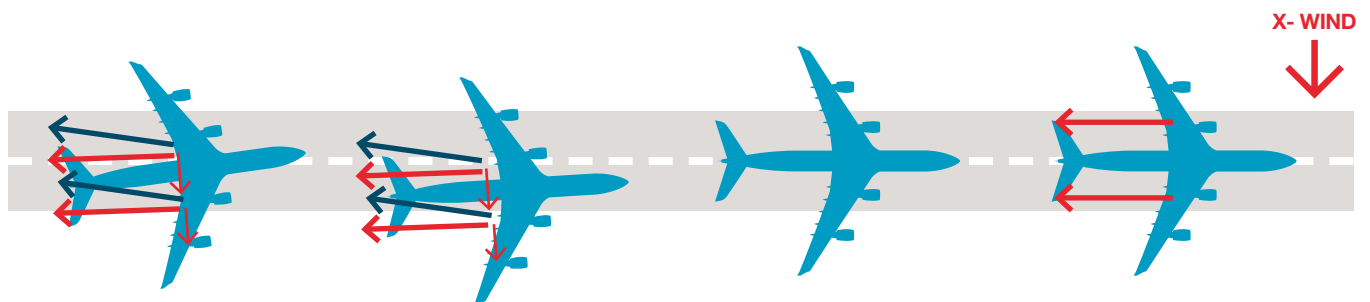
- Consider reducing reverse thrust.
- If braking manually, consider reducing braking temporarily or use differential braking.

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). ■

(fig.9)

Recovering from the destabilization effect of thrust reversers







Fuel monitoring on A320 Family aircraft

Since the first A320 entry into service, very few events have involved undetected fuel quantity issues. Yet, coming across a situation where engines shut down by lack of fuel is a situation no one wants to experience.



GÉRALDINE VALLÉE
Product Safety
Enhancement manager



REGIS PERNET
Flight Operations
engineer



ALBERT URDIROZ
Director Flight Safety

If fuel systems have proven their reliability, in case of failure, the ultimate safety barrier to avoid finding oneself in a fuel critical situation is fuel monitoring by the crew. Let's go back to some fundamental questions around fuel monitoring on A320 Family aircraft. How to determine the fuel quantity available in the tanks? What are the various sources of information and how redundant are they? Why is it key to perform regular fuel checks?

RARE BUT STRIKING EVENTS

In more than 25 years of Airbus A320 Family aircraft operation, there have been not more than a handful of events involving undetected fuel quantity issues.

Event 1

During cruise of an A320 Family aircraft, the crew observed 3 occurrences of the ECAM warning L TK PUMP 1 + 2 LO PR. In line with this warning, they noticed a more rapid fuel level decrease in the left fuel tank compared to the right one. Following the applicable FCOM procedure, they opened the fuel cross feed valve, only to close it soon after as fuel quantity was abnormally decreasing. Minutes later, engine 1 shut down by itself and the ECAM warning ENG 1 FAIL triggered.

The crew managed to land the aircraft uneventfully with engine 2 still running,

The reasons for these fuel quantity issues vary from one event to another. Early detection and management of the issue remains key to successfully deal with such events.

and passengers disembarked safely. The remaining fuel quantity upon landing turned out to be 840 kg in the right fuel tank, and no fuel in the left tank. Investigation into this event highlighted that maintenance was done on the fuel tanks prior to the event flight, and both engines 1 and 2 fuel pump filters had been replaced. After the event flight, engine 1 HP fuel pump filter cover was found not properly fitted, with 4 threaded inserts out of 6 being reported unserviceable, thus allowing the cover to partially open. It was estimated that approximately 4 to 5 tons of fuel had leaked.

Event 2

In another event, the Fuel Quantity Indication (FQI) system had been showing discrepancies for a period of time. Given the intermittent nature of the fault, entries in the aircraft logbook were investigated but without findings by maintenance despite carrying out precautionary maintenance. On two occasions, different crews failed to identify or properly record the FOB discrepancy during pre-departure or post-flight fuel checks.

For the event flight, the aircraft departed with an indicated FOB of approximately 5000kg (fuel at arrival from previous leg was approx. 3800kg and fuel uplift was 1200kg). The flight crew performed the initial fuel checks with reference to the fuel logs of the preceding flight. The calculated values remained consistent.

In flight, transient fuel quantity fluctuations were experienced and eventually the ECAM alert FUEL L (R) WING TK LO LVL triggered. It was pro-

OPERATIONS

Fuel monitoring on A320 Family aircraft

cessed as per SOP by the crew who checked the SD page as being nominal. The alert was thus considered spurious. The flight continued with repeated fuel checks at short intervals; however during the approach, engine 1 flamed out. Landing was performed on engine 2 safely. After the flight, the left wing tank was

confirmed empty with the FQI over reading by 1 ton.

The analysis of the event indicated that preceding fuel log entries did not allow the crew to identify a significant discrepancy of about 800 kg prior to departure.

Event 3

On the third flight of the day on an A320 Family aircraft, while the aircraft was approaching its destination, a LO LVL alert triggered on one side. The crew considered it spurious, as likely resulting from fuel movement in the tank. Shortly after this first alert, a new LO LVL alert triggered on the other side. The crew continued the flight and eventually landed uneventfully. The remaining fuel quantity upon landing turned out to be approximately 900 kg.

During the first flight of the day, the flight crew calculated a ~500 kg discrepancy at arrival. Nothing was mentioned in relation to fuel in the log book.

During the second flight of the day, the discrepancy calculated by the crew at arrival was almost 3000 kg. The First Officer noticed that it was not what he had expected but considered that they had benefited from a number of favorable factors such as a direct ATC routing, and they eventually had arrived 20 to 25 minutes earlier than scheduled. In addition, they sometimes ferry fuel according to the company policy. As a consequence, nothing unusual was mentioned in the log book.

Before the third flight - which was the event flight - the refueler only added little fuel since there was still a fuel over read. Yet, the flight crew



departed with a significantly over-estimated fuel quantity that ultimately led to the unanticipated LO LVL alerts on both sides. According to the investigation, the issue/over-

read was due to an intermittent FQI Computer (FQIC) failure. The maintenance record of this FQIC highlighted numerous returns to the shop in the months preceding the event.

HOW MUCH FUEL IS AVAILABLE ONBOARD?

Considering the consequences of running out of fuel in flight, knowing how much fuel is available on board during the flight is clearly essential to safety. What information can be used to determine the amount of fuel on board? How is this information established? Do the various pieces of

information relate to one another? Are they independent? Let's explore the various types of onboard fuel information that are available to the flight crew. Where does this information originate and how are fuel levels established on Airbus A320 Family aircraft?

FQI or Fuel Quantity Indication: a source based on measures performed inside fuel tanks

The FQI system calculates the fuel quantity based on values taken from probes in the tanks. The probes measure the level of the fuel in the tank, as a consequence of changing capacitance due to the amount the probe is immersed. This allows the determination of the fuel volume in the tank.

Yet the information that is needed by pilots is the quantity of fuel on board expressed as a weight. The translation of fuel volume into fuel weight is performed by the FQIC using the fuel density measured by specific devices in each wing tank **(fig. 1)**.

INFORMATION

The low level sensing does not appear on the System Description page. Therefore, for fuel indication, do not rely on SD page only.

Fuel Flow Meters: a source based on engines consumption

Each engine is equipped with Fuel Flow Meters that measure the quantity of fuel consumed by the engine. This information

is integrated by the FADEC and provides pilots with information on the fuel used.

Low level sensors: an additional independent source based on dedicated sensors in the wing tank

In addition to the sensors and probes feeding the FQI system, each wing tank is equipped with

three independent dedicated low level sensors. These sensors are located in such a way that they

(fig.1)
FUEL System page on Lower ECAM Display Unit



OPERATIONS

Fuel monitoring on A320 Family aircraft



(fig.2)
Low level alert display on ECAM

become dry when the remaining fuel in the tank is approximately 750 kg. If two sensors in the same tank remain dry for more than 30 seconds, a low level alert triggers in the cockpit **(fig.2)**.

The low level sensors are fully independent from the Fuel Quantity Indication, and are different in that they:

- Do not provide pilots with a continuous indication of the fuel quantity in the wing tanks, but only the signal that the fuel level has reached below 750 kg (threshold crossed).
- The information provided to pilots in the form of the low level alert results from a physical measure (sensors dry or wet) rather than from a calculation.

? DID YOU KNOW

The A320 Family aircraft low level indication is based on remaining fuel quantity in the tank being sufficient to meet the requirement of 30 minutes at 1500 ft (corresponding to approximately 1 200 kg). Should the low level alert trigger on both fuel tanks, the total remaining fuel is: 750kg + 750kg = 1 500 kg.

i INFORMATION

“ The low level sensors are fully independent from the Fuel Quantity Indication. ”

The presence of water in the fuel tanks can lead to erroneous (over reading) fuel indications. The parameters used by the fuel system (density and capacitance) are highly affected by the presence of water. Flight deck effects of a buildup of water in the fuel tanks include fuel gauging fluctuations and over reads.

Consequently, among the maintenance tasks that are to be performed if pilots detect an abnormal fuel indication during a fuel check is fuel tank draining **(fig.3)**. This can also help to prevent microbiological contamination, which is often another cause of fuel gauging fluctuations.

#	TASK NUMBER	ZONE	DESCRIPTION	STATUS	SOURCE	REFERENCE	Man. M.M.	APPLICABILITY
5	281100-01-2	120 130 140	TANKS DRAIN WATER CONTENT NOTE: DEPENDING ON OPERATING ENVIRONMENT AND OPERATOR'S EXPERIENCE, A LESS FREQUENT DRAIN FREQUENCY INTERVAL MAY BE USED. ACCESS: 12000 13000	AT SVCS 26 HR NOTE	MSG 5	AMT.FUELQD.201.001	1.0.10 1.0.10 1.0.10	ALL

(fig.3)
Maintenance Planning Document – ATA 28 Fuel – Task 281100-01-2 – Drain water content in tanks

FUEL CHECKS

An unnecessary burden or essential safety net?

Ensuring an accurate awareness of the quantity of fuel on board requires use of several sources of data. Certainly the FQI is the primary source of fuel indication, but the other key sources such as the Fuel Used, the fuel uplifted at the latest refuel, the crosscheck between what is expected to be uplifted and what is uplifted, information from the refue-

ler and fuel consumption figures during flight, are all important. But to ensure the information remains accurate, the safety barrier common to all cases is fuel monitoring by the crew.

Although fuel checks with the manual calculations they involve can sometimes be perceived as a tedious task,

they form in reality an integral part of the measures taken to ensure safe operations. They were designed and meant for detecting as early as possible any fuel quantity issue, ensuring timely and accurate maintenance intervention, and allowing appropri-

ate measures to secure the safety of the flight. They are applicable to all Airbus Families aircraft from the first A300B to the latest A350, and remain an essential part of airmanship when piloting the A320 Family aircraft.

What is to be checked and when?

The maximum efficiency of fuel checks relies on the flight crew performing a number of checks regu-

larly and at different times to either confirm anticipations, or detect any discrepancy.

Before start

The first fuel check to be performed is before start to consolidate the information about the total amount of fuel

available for the flight. This check consists in making sure that:

“ The fuel available onboard can be determined based on two independent sources of information... even three in case of low level. ”

$$\text{Initial Fuel On Board (FOB) + Fuel Uplifted} \\ = \text{Fuel On Board (FOB)} \pm \Delta$$

Where

FOB is the fuel quantity derived from the FQI system

Fuel Uplifted is the amount of fuel indicated by the refueler as having been added during refueling. This may require converting volume into weight,

based on the uplifted fuel density.

Δ is an acceptable tolerance (see *Why do we need to consider a certain tolerance on fuel onboard values?* insert).

During the flight

During the flight, fuel checks mainly aim at detecting any abnormal consumption, be it due to a leak or unanticipated drag (e.g. spoiler or landing gear, slats or flaps not fully retracted) or any other reason.

Indeed, such situation would make

the FMS fuel predictions too optimistic and potentially lead to fuel exhaustion in flight.

To ensure that there is no undetected fuel leak, the following calculation should be performed at each way point or every 30 minutes:

$$\text{Fuel On Board (FOB) + Fuel Used} \\ = \text{Initial Fuel On Board (FOB)} \pm \Delta$$

Where

Fuel Used is derived from the fuel flow meters

In addition, the remaining FOB and Fuel Used values must also be consistent with the values given by the computed flight plan at each waypoint.

“ All fuel checks are equally important in the detection and safe management of any fuel quantity issue. ”

Post flight

At the end of the flight, when the aircraft has reached its parking stand, a final fuel check is to be performed to check the consistency between the information provided by the var-

ious sources and thus detect any abnormal discrepancy that would call for maintenance actions. The post flight fuel check consists of making sure that:

$$\text{Fuel On Board (FOB) + Fuel Used} \\ = \text{Initial Fuel On Board (FOB)} \pm \Delta$$



NOTE

WHAT IF A FUEL CHECK IS MISSED?

Depending on the underlying reason for a fuel quantity issue, missing a fuel check may make it very difficult to detect. In the second event described, the failure of the Fuel Quantity Indication Computer did not lead to a systematic wrong indication but rather to quantity fluctuations. The fuel quantity indicated by the FQI system before the first flight of the day was correct. In such cases, skipping a fuel check may be a missed opportunity to detect a failure that may not be detectable later on, at the time of the following check. More generally, whatever the origin of a fuel quantity issue, detecting it as early as possible allows for managing it and making sure appropriate decisions can be made in time to best manage the rest of the flight as safely and efficiently as possible.

WHY DO WE NEED TO CONSIDER A CERTAIN TOLERANCE ON FUEL ON BOARD VALUES?

Due to the nature of the fuel system, it is essential that the system tolerance be taken into consideration when performing fuel quantity calculations. The overall FQI system accuracy is designed to take into consideration several factors such as: attitude effects, wing deformation, systems tolerances, manufacturing tolerances, component tolerances, environmental effects, fuel characteristics.

These individual tolerances lead to an overall tolerance on the global system resulting from the worst case (maximum tolerance) on each individual element.

The maximum tolerance is defined for the aircraft to guarantee an acceptable level of integrity of the measure and the associated fuel quantity information. When a fuel check is performed, any fuel discrepancy calculated by the crew and exceeding this value may then be considered abnormal.

For an A320 Family aircraft, the instrumental tolerance on the ground is calculated as follows:

$$\pm (1\% \text{ of current FOB} + 1\% \text{ max possible FOB for this aircraft})$$

As an illustration, for an A320 aircraft, if there are 5 tons left in the aircraft, the maximum normal tolerance value is:

$$\pm (5000\text{kg (current FOB)} * 1\% + 20000\text{kg (max FOB)} * 1\%) = \pm 250\text{kg}$$

Note: The FQI system is designed in such a way that the lower the fuel quantity in the tank, the more accurate the fuel indication.

The FQI system is calibrated on ground during manufacturing and its accuracy (as per the formula above) will remain the same throughout the operational life of the aircraft.

TO FURTHER ENHANCE SAFETY...

Following the investigation of real events involving fuel monitoring issues, Airbus identified and implemented enhancements in several areas:

- Further refinement of the description of the Fuel Quantity Indicating and level sensing systems in the FCOM documentation. During the interactions with the airlines involved, it turned out that the independence of the two fuel measures coming from respectively the FQI system and the low level alert was not clear to all crews.
- Definition of empirical criteria on A320 Family aircraft to consider a fuel discrepancy “abnormal” or “unusual” when performing the before start fuel check. These thresholds will be expressed in
- kg or lbs and will vary depending on the fuel on board and fuel uplifted. They will lead to a generic maintenance task in the TSM (Trouble Shooting Manual).
- Service Bulletin A320-28-1214 for A318/A319/A320 and Service Bulletin A320-28-1202 for A321 aircraft introduce a new fuel leak detection function, which eases and improves the detection of a fuel leak. This new function is meant to prevent situations where a loss of fuel would remain undetected by the crew.
- A new FCOM evolution will be available soon, that will describe the triggering conditions of the low level alert in the procedure, and to show that the alert is independent of the displayed fuel. ■



DID YOU KNOW

A “GOLDEN RULE” IN THE TROUBLE SHOOTING MANUAL (TSM)

Until recently, there was no generic entry into the TSM in case of abnormal fuel quantity. It is therefore worth reminding everyone of a key sentence in the introduction of the TSM that encourages airlines to manage cases where there may be a doubt as to the aircraft airworthiness:

“If you cannot find a fault symptom and/or a fault isolation procedure necessary to ensure the continued airworthiness of the aircraft, or if you think that the information given is not complete, contact Airbus”.

An engine failing in flight, because of fuel starvation, is a situation all pilots would like to avoid. In order to do so, and to ensure the continuing accuracy of the FQI, performing thorough fuel checks before start, throughout the flight and after arrival at the parking stand is essential.

Should any discrepancy appear, effectively tackling the underlying issue, be it intermittent or permanent, is the only way to prevent further fuel quantity indication and possible resulting safety issues. This relies on good cooperation between flight crews, maintenance and the manufacturer.

Should the LO LVL alert trigger, it is to be trusted! It is the independent voice from the tanks themselves warning you ...



“Had I not known this, understood that or paid attention to that, I wouldn’t be here with you today” was a sentence Jacques often repeated when he referred to some of the thousands of flights he performed either as a fighter pilot or as an experimental test pilot. Sadly, Jacques is no longer with us today. He was a genius pilot, a humble man, a great man. Aviation was his passion, safety his quest. He was always ready to share his knowledge, experience and wisdom to improve safety, as he did with the following article.

HE WILL BE MISSED...



High-altitude manual flying

Flying an aircraft manually at high altitudes, and therefore necessarily at high Mach number, is a completely different discipline to what it may be like at low altitudes. As it turns out, opportunities to experience manual flying at high altitudes are rare in a pilot's career. Yet, regulations do require it in certain circumstances, such as when the Auto Pilot is unavailable.



JACQUES ROSAY

Experimental Test Pilot
Former Airbus Chief
Test Pilot

Most of the time, commercial aircraft fly at high altitudes, above FL 290. In other words, they fly within the RVSM (Reduced Vertical Separation Minima) space that extends from FL 290 to 410 included, and which now covers a very large part of the world's airspace. As it turns out, use of the Auto Pilot (AP) within this airspace is mandatory, meaning that the regulations actually prevent the pilots from acquiring practical manual flying experience of their aircraft within the part of the envelope where they most often fly.

Pushing this paradox further, in certain cases, especially if the AP is unavailable, these same regulations require that the pilots manually fly the aircraft to rapidly leave this airspace in coordination with air traffic control. In other words, pilots are requested to do maneuvers for which practicing in flight is prohibited.

However, the behaviour of an aircraft at high altitude is significantly different from that of an aircraft at low and medium altitudes.

The aim of this article is to recall some qualitative aerodynamic, flight mechanics and handling qualities notions specific to the high Mach numbers and to high altitudes, to share practical experiences lived by Airbus test pilots in these domains and to make suggestions for training. Lastly, note that, apart from passages specifically dedicated to the normal and alternate electrical flight control laws, the whole of this article applies to all types of commercial aircraft whether equipped with electrical flight controls or not.

AERODYNAMIC ESSENTIALS

The effects of Mach number

The air flow around the wings accelerates on the upper surface creating a negative pressure and it is this negative pressure which mainly keeps the aircraft up (**fig.1**).

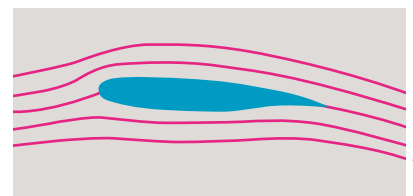
When the altitude increases and the air density falls, more aerodynamic speed is required to create the lift required for a given lift configuration. This reduction in the density and this increase in the aerodynamic speed is accompanied by an increase in the Mach number required for flight. We have seen that by passing over the wings, the

air flow accelerates on the upper surface. Therefore, the local Mach number around the wings is much higher than the aircraft flight Mach number and in certain locations reaches transonic values. In high-altitude stabilised flight, shock waves can be seen at certain locations by looking at the upper surface through the cabin windows.

This sonic phenomenon around the wings leads to a degradation of their aerodynamic properties. This, in turn, leads mainly to a reduction in the maximum lift angle of attack as the

(fig.1)

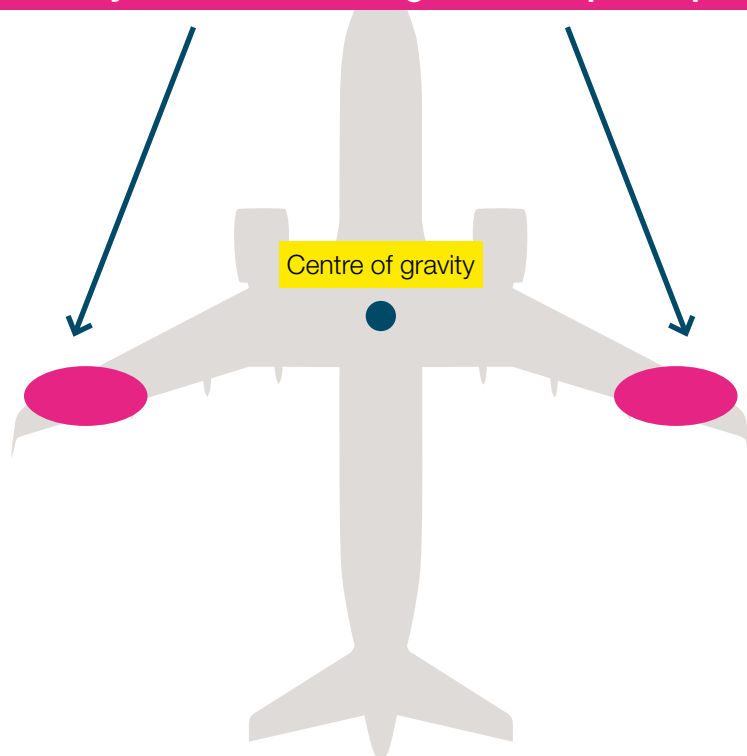
Air flow around an airfoil



Mach number increases, which significantly reduces the stall margin. Thus, at a high-altitude normal cruise Mach number value, when the angle of attack is increased to produce the load factor required to make a turn or a pull-out, the angle-of-attack limit is more easily approached than when the same maneuver is done at low altitude and at a low Mach number. Also, on most aircraft with sweepback

wings, another well-known phenomenon is added to the previous one. As the local Mach numbers along the span are not identical, the distribution of the lift does not vary uniformly with the angle of attack. This creates nonlinearities in the longitudinal balance of the aircraft most classically leading to spontaneous pitch-up tendencies or to self-tightening of the turn when the angle of attack increases **(fig.2)**.

Early stalled areas at high mach -> pitch up



Clearly the aircraft has flight characteristics quite different at high altitude compared with its characteristics at low altitude. This means that if a Pilot has to fly manually at high altitude, he/she will not find the characteristics he/she is familiar with at low altitude. In addition, the aerodynamic speed, i.e. the speed in relation to the air molecules, therefore in relation to the earth coordinate system (excluding the wind), is much higher at high altitude. Consequently, the purely kinematic characteristics of the vehicle are radically different.

To get an idea of this, when flying in the initial approach zone at 3000 ft and 250 kt, which is often the case

in manual flying, the aerodynamic speed is 260 kt. When flying at FL350 at M 0.85, at standard temperature, the aerodynamic speed is 490 kt. If the temperature is ISA + 12°, the aerodynamic speed is then 500 kt. That is practically twice as fast as the highest speeds usually seen at low altitude.

This difference is not without consequences on flying. For example, for a maneuver at identical load factor, the radius of curvature of an altitude capture is multiplied by four and therefore, starting from a given slope, anticipation for this maneuver must be multiplied by four in order not to exceed the target altitude.

(fig.2)

Early stalled areas along the wings

“ If a Pilot has to fly manually at high altitude, he/she will not find the characteristics he/she is familiar with at low altitude. ”

Compressibility stall

We have seen that when the Mach number increases, the maximum lift angle-of-attack is reduced (**fig.3**).

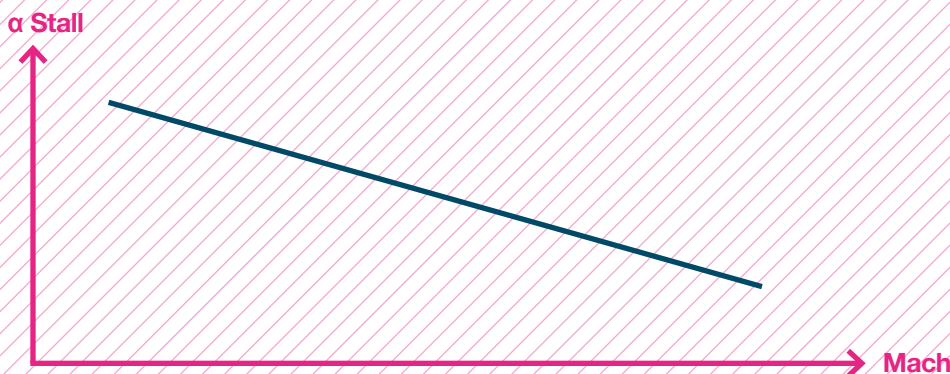
We can imagine that at a certain point in the increase of the Mach, the angle-of-attack can theoretically be so limited that the maximum lift the wings are capable of producing becomes insufficient to sustain the weight of the aircraft. In certain aerodynamic manuals, this theoretical point is called the “compressibility stall”.

It depends on the evolution of the curve lift versus Mach. This change depends on many aerodynamic characteristics of the aircraft, such as the wing profile, the chord, the sweep, the span, etc. Remember that this phenomenon does not exist on an aircraft where the wings are designed

for flight at supersonic speeds. Pilots who have flown on the T33 or the Alpha Jet may perhaps remember having reached subsonic Mach numbers beyond which the wings were incapable of providing a load factor of 1 g. Level flight could not be maintained: compressibility stall was reached. The Mach number had to be reduced to regain the load factor authority required for straight level flight. On the Alpha Jet in particular, with a little patience and a very small amount of fuel on-board, it is even possible to climb to an altitude where it was neither possible to decelerate due to low Mach number stall nor to accelerate due to compressibility stall. There was only one single practicable flight point: the aerodynamic ceiling was reached.

(fig.3)

General tendency in the evolution of the maximum angle-of-attack (α) versus the Mach number



Aerodynamic ceiling and buffeting margin

In practice, even if the compressibility stall and the aerodynamic ceiling can theoretically exist in aerodynamics in certain cases, they cannot be reached by a certified commercial aircraft and this for several reasons. Let us see why.

1) The certification regulations require that throughout the flight envelope, up to MMO, irrespective of the weight, the aircraft must have a buffeting margin of 0.3 g.

This means that a load factor of 1.3 g must be attainable before “buffet onset” is encountered. “Buffet onset”

is defined such that when an accelerometer located under the pilot’s seat measures peak-to-peak accelerations higher than 0.1 g. Therefore, the aircraft MMO value and the lift ceiling (which depends on the weight) are by definition such that there is always a buffeting margin of at least 0.3 g and therefore, a margin well above the compressibility stall is ensured.

2) The certification regulations also require that the flight tests check that the aircraft can fly above MMO up to MD.

MD is the highest Mach number at

which the aircraft must be able to fly without structural anomalies (this is the flutter margin) and without substantial degradation in the handling qualities allowing the aircraft to be always easily controlled. It is determined by calibrated maneuvers (FAA dive, JAA dive) defined by the certification regulations. In practice, typically $MD = MMO + 0.06$.

DETERMINING MD IN FLIGHT TESTS

During the flight test, MD must be reached fairly quickly by an accentuated dive before encountering another limit: the absolute speed limit VD (typically $VD = VMO + 35$ kt), which is approached as the altitude drops. For this, Airbus test pilots start from the aircraft ceiling, in direct law, at a Mach as close to MMO as possible. Then they accelerate by a dive with an attitude of around -15° at the start of the maneuver with engines at full throttle. When MD is reached, this Mach is maintained by adjusting the

pitch attitude and then, the structure is excited by programmed impulses into the flight controls. The purpose of this is to check that there are no divergent structure oscillations (flutter). Then, test pilots do a positive pull-out, engines idling, to return to the normal flight envelope. This pull-out requires an important increase in the load factor and demonstrates that compressibility stall is still far from being reached. However, the buffeting margin of 0.3 g is no longer observed beyond MMO and approach of MD at $n = 1$ is in reality

done with moderate buffeting, but the aircraft can still be controlled and maneuvered. Beyond MD, the structural integrity of the aircraft is no longer ensured! Based on the experience accumulated at Airbus and seeing how many aircraft still respond very well at MD load factor, very serious structural problems will be encountered before finding a possible compressibility stall which, if it exists, can be found only at Mach numbers well above MD, probably above Mach 1.

To conclude, the regulatory criteria related to the buffeting margin at MMO and to the flight characteristics up to MD imply that the “compressibility stall” and “aerodynamic ceiling” phe-

nomena cannot be physically encountered due to the design of the aircraft. “Compressibility stall” does not exist on current commercial aircraft.

FLYING MANUALLY

Definition

It would be interesting to survey pilots as to what they understand by the terms “flying manually”. Personally, I have often heard during test, demonstration, acceptance or airline flights, colleagues, young or older, airline pilots or test pilots, proudly say that they would do such or such a part of the flight - in general a complete approach followed by a landing - “in manual control mode”. I would then observe how they performed and saw that all they did was actually disconnect the AP and servilely follow the Flight Director, leaving the Auto Thrust engaged. And this until start of the flare. This

obviously allows an accurate trajectory to be followed, with correct captures, and good control of the speed. These functions are provided for this purpose.

However, within the scope of this article, which concerns manual flying, flying in this manner can in no way be considered as “flying manually”. Indeed, the orders given to the flight controls by the pilot consist in setting the Flight Director (FD) bars to zero, which corresponds to the orders generated by the guidance function. These stick inputs are actions done mechanically by the pilot but are in no way elaborated by him/her. These

“ The pilot must anticipate to a greater extent the changes in the trajectories both vertically and horizontally. ”

flight control orders are the same as those which the AP would give if it was engaged. Thus, the added value provided by the pilot is rather negative, as the cognitive resources that he/she uses to follow the FD bars are no longer available for the most elaborate flight monitoring and control functions. In other words, this exercise provides strictly nothing towards the manual flying training for the cases where the pilot would truly have to fly the aircraft manually.

The terms “flying manually” in this article imply that the guidance functions have become unavailable, possibly with the flight control laws in a degraded mode.

In this configuration, pilots must be

able to correctly perform, at any altitude, all the maneuvers required to manually control the aircraft and land it under satisfactory safety conditions. These safety conditions would not be met if a pilot is not at ease when performing, under all flight control conditions which may be encountered following failures, manual flying without the FD, without the ATHR and without speed vector, from the cruise ceiling of the aircraft to instrument landing under CAT1 weather conditions.

The type certifications of all the commercial aircraft in the world are established by the Authorities on the fundamental hypothesis that any qualified pilot is capable of meeting this requirement.

Specificities of flight control laws

We have seen that the rules applicable for RVSM mean that the situations where the aircraft must be flown manually at high altitude are limited to degraded cases, especially cases where the AP is lost and, possibly, where the normal law is also lost. As the aim of this article is to get a better knowledge of these situations, let us look at the specificities of the high-altitude flight control laws.

As said earlier, compared to low altitude, the high aerodynamic speeds used at high altitude radically change the trajectories followed for given load factor applications. This means that

the pilot must anticipate to a greater extent the changes in the trajectories both vertically and horizontally. This is valid whatever the flight control law used, including the normal law.

The behaviour of the normal law differs from its behaviour at low altitude by the effect of the speed on the trajectory. This is sufficient to make it worth the effort to become familiar with the situation in the simulator. For degraded laws, or for aircraft with conventional flight controls, the characteristics specific to high altitude are more affected and must be known.

Normal and alternate laws

The normal law and the alternate law - so-called C* laws, or load factor flight control laws - function practically identically on the longitudinal axis as long as we remain within the operational flight envelope and we do not perform dynamic maneuvers leading the angle-of-attack to approach maximum values (which depend on the Mach number). Beyond these limits, the alternate law no longer ensures the protections and this is recalled by the “protection lost” message on the ECAM. The pull-out and turn

maneuvers, for a given longitudinal stick order, give the same load factor excursion. As the alternate law is not protected against excessive angles of attack, awareness of an approach to limiting angle-of-attack is ensured by the Stall Warning (SW) or, in certain cases, by the deterrent buffeting, to which the pilot must react immediately by releasing control. The SW directly alerts the crew of stall proximity but it also indirectly alerts it by indicating, during dynamic maneuvers, that it is approaching angles of attack

where the pitch-up phenomenon may start to develop; this phenomenon itself can lead to stall if the pilot does not immediately counter it by reacting to the SW. In practice, maneuvers a little too dynamic can fairly easily lead to the SW, especially if they are done close to the maximum cruise altitude (REC MAX) calculated by the FMS. For this reason and to make flying more comfortable, even outside of the RVSM space, when flying in degraded laws, it is recommended to maintain some margin in

altitude (around 4000 ft) below the REC MAX altitude.

According to the type of aircraft and type of failure, the alternate law may lead to lateral control being in direct law, i.e. a deflection of the ailerons according to the stick input and not according to a roll rate law, as is normally the case in normal law. This difference can be fairly significant, generally leading to roll responses a little more sharp than in normal law, but still easy to control.

Direct law

In direct law, as its name implies, the controls give direct orders to the control surfaces. In direct law, the aircraft becomes an “old aircraft” where no assistance is given to the pilot. The longitudinal trim must be used to zero forces on the stick and to balance the longitudinal effects of the engines. The ECAM and the Primary Flight Display (PFD) remind us of this by the “USE MAN PITCH TRIM” message. However, depending on the aircraft, very basic yaw or roll dynamic stabilisation functions may be included in the direct law. At high altitude, the trim law versus speed variations, and therefore the Mach number, is very “flat”. Pilots should therefore not be surprised that there is much

less need to use the trim than at low altitude.

During flight tests, Airbus test pilots try to adjust the kinematics of the direct law to make it as “placid” as possible at high altitude in all the weight and CG ranges. The aim is to have enough authority to efficiently do the basic maneuvers in the vertical and horizontal planes, but without trying to do specifically dynamic maneuvers. Here also, as with alternate law, the deterrent buffeting and/or the SW warn against excess angles of attack taking into account, if applicable, a pitch-up tendency. The same recommendations also apply concerning the flight altitude.

“ To make flying more comfortable, even outside of the RVSM space, when flying in degraded laws, it is recommended to maintain some margin in altitude (around 4000 ft) below the REC MAX altitude. ”

TRAINING FOR HIGH-ALTITUDE MANUAL FLYING

Representativeness of simulators at high altitude

The flight mechanics models used on the training simulators are established based on specific tests conducted during real flights. They generate what is called the “data package. These tests are long and many to obtain a model very close to reality. As I have done several thousands of hours of tests of all sorts on simulators before doing them in flight, I can confidently say that

the models supplied by the simulators are very close to reality. However, two important limits exist and must be known, which are the very high angles of attack and the representativeness of the cabin movements.

1) During flight tests, for each type of aircraft, hundreds of stalls are performed, beyond the SW and a little

“ Over the normal operating domain of commercial flying, simulators are perfectly representative of reality and utmost confidence can be placed in them, for both low and high altitude manual flight. ”

beyond the maximum lift coefficient (Cl) to clearly identify the loss of lift. In practice, the maximum Cl is exceeded by several angle-of-attack degrees, let us say four or five, but not more. This means that all maneuvers on the simulator that go beyond these known values enter a domain where the representativeness of the model becomes erroneous. Therefore, the exercises on the simulator must not go further than the excursions leading to the reactions to the SW which, according to regulations, are expected by the pilot. In practice, not more than 3 seconds after the appearance of the SW during a dynamic maneuver in cruise. This obviously concerns only the unprotected laws.

2) The movements of mobile simulator cockpits are intended to trick the sensory channels of the pilots to make them believe that what they perceive corresponds to a real flight. This operates fairly well when the simulated movements remain low. Simply, let us say that the feelings are not too false whilst the movements of the aircraft are those that the Auto Pilot would command. Whenever significant dynamic movements are done, the feelings become very false and

can clearly have counterproductive training effects as the pilots then perceive sensations contrary to what they would experience in reality. This can be asserted based on a comparison between the basic rotation speed and acceleration parameters on the three aircraft axis (i.e. p, q, r, nx, ny, nz of the flight mechanics) with the same parameters measured in the cockpit of a mobile simulator during somewhat dynamic maneuvers. For this reason, during the flight tests, cockpit movements are never used to fine tune the flight controls knowing that the sensations experienced are, essentially false, and can therefore seriously alter test pilots assessment of these.

Clearly these two limits can be considered as such only when certification flight tests maneuvers are performed very close to – if not beyond – the limits of the aircraft flight envelope. Over the normal operating domain of commercial flying, simulators are perfectly representative of reality and utmost confidence can be placed in them, for both low and high altitudes. For this reason, flying in a simulator is the best option for pilots to experience and train for manual flying at any altitude.

Some ideas for high-altitude manual flying training

Simulation training exercises must show pilots that at high altitudes and high Mach numbers, it is very important to adopt an especially calm, flexible flying attitude without aggressiveness. At the same time, the exercises suggested here will allow pilots to reinforce the necessary confidence in themselves. To gain this competence, it is important that they do maneuvers which go a little beyond those that they may have to do in flight. Here are several personal ideas of exercises to reach this objective. Within the same frame of mind, others can of course be proposed.

1) Normal law, AP engaged, weight = MLW + 2 hours of fuel consumption, REC MAX altitude and cruise Mach according to airline Cost Index. Loss

of AP, FD and ATHR, return to alternate law. Keep level flight. Reduce Mach to alternate law limit (if applicable). Do a turn with a bank angle of 30° (that is 1.15 g) in level flight at constant Mach. Resume straight line flight. Descent with engines at idle to first level outside of the RVSM space, still at constant Mach. Temporarily stabilise at REC MAX – 4000 ft, maintaining the Mach. Observe the response of the aircraft, resume descent.

2) Normal law, AP engaged, weight = MLW + 2 hours of fuel consumption, REC MAX altitude. Loss of AP, FD and ATHR, return to direct law. Use the trim. Keep level flight. Reduce Mach to direct law limit (if applicable). Make a turn with a bank angle



of 25° (that is 1.1 g) in level flight at constant Mach. Resume straight line flight. Descent with engines at idle to first level outside RVSM space, still at constant Mach. Temporarily stabilise at REC MAX – 4000 ft, maintaining the Mach. Observe the response of the aircraft, resume descent.

As a passenger, I would be very happy to fly with an airline which gives its pilots the instruction to place themselves in the easiest situation at all times. Pilots should be instructed to use all the piloting aids placed at their disposal to facilitate their tasks as far as possible. In practice, this perfectly respectable policy leads the pilots to almost never manually fly the aircraft, except on take-off for a short period and for certain landings between the minima and the ground when automatic landing is impossible. This means that the pilots of such an airline acquire or maintain almost no

manual flying training. But, again as a passenger, I at the same time require that these same pilots have all the manual flying skills that we have discussed and which they require to face up to failure cases where the piloting aids are no longer available, whether at high or low altitude.

These two requirements are contradictory only in appearance. Indeed, even as is the case in many airlines, the pilots are authorised to manually fly aircraft under certain conditions. During commercial flights, they could never fly manually at high altitude due to the RVSM rules, or under degraded flight control laws for obvious reasons, which deprives them of all knowledge of the reactions of their aircraft under these conditions.

The only solution to cover this need is therefore the intensive use of training simulators and this in perfect compliance with the limits of their representativeness. ■

“ At high altitudes and high Mach numbers, it is very important to adopt an especially calm, flexible flying attitude without aggressiveness. ”

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