Control your speed... at take-off

One of the most critical decisions that every line pilot may potentially encounter during every take-off is to continue or abort the procedure; hence the essential need to properly monitor the airspeed during this phase.

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Overlooking the airspeed during take-off or conducting a take-off with an inappropriate speed are directly associated to the following main risks: a lateral or longitudinal runway excursion, maximum brake energy exceedance resulting in a brake fire, tail strike, lack of lateral control once the aircraft is airborne, or obstacle clearance trespassing.

This article aims at providing some reminders on the ways the various take-off characteristic and limit speeds are elaborated from the certification requirements to the flight test validation, and how they can be implemented in daily operations.

We will offer a series of articles on this topic, in the present and future issues of our magazine, aiming to detail everything you always wanted to know about speeds… but were afraid to ask. The lines that follow are focusing on the take-off phase.

SECURING YOUR TAKE-OFF: UNDERSTANDING SPEEDS

Characteristic speeds are intended to provide reference points that can be used by pilots as a guide in making judgement in a very dynamic situation. In this respect, they need close supervision. What speeds exactly should be monitored? What do these speeds mean and where do they come from? What happens if such speeds are exceeded?

Our objective is to highlight the design and operational considerations underlying all recommendations Airbus has issued to flight crews regarding speed monitoring during take-off.

Take-off operating speeds V1, VR and V2 very precisely frame the aircraft take-off performance limits and the margins that exist in the event of a failure **(fig.1).**

For every aircraft type, V1, VR and V2 are computed by Airbus on the basis of design speeds and evidence collected during the certification testing of the airplane.

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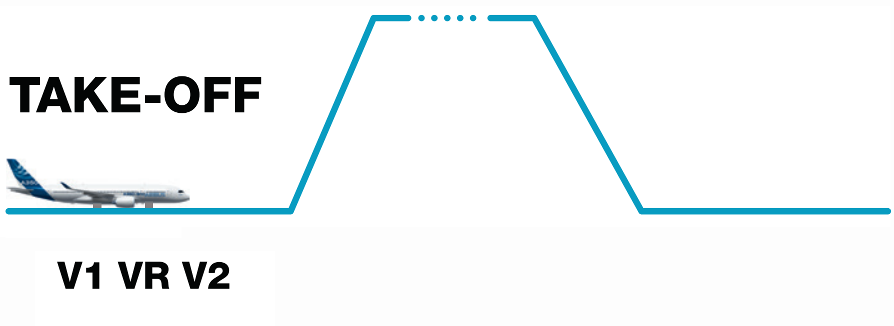


(fig.1)
V1: Decision speed
VR: Rotation speed
V2: Take-off safety speed

V1: Decision speed

» Definition

V1 is the maximum speed at which a rejected take-off can be initiated in the event of an emergency.

V1 is also the minimum speed at which a pilot can continue take-off following an engine failure.

This speed is entered by the crew in the MCDU during flight preparation, and it is represented by a "1" on the speed scale of the PFD during take-off acceleration **(fig.2).**

» How is V1 determined?

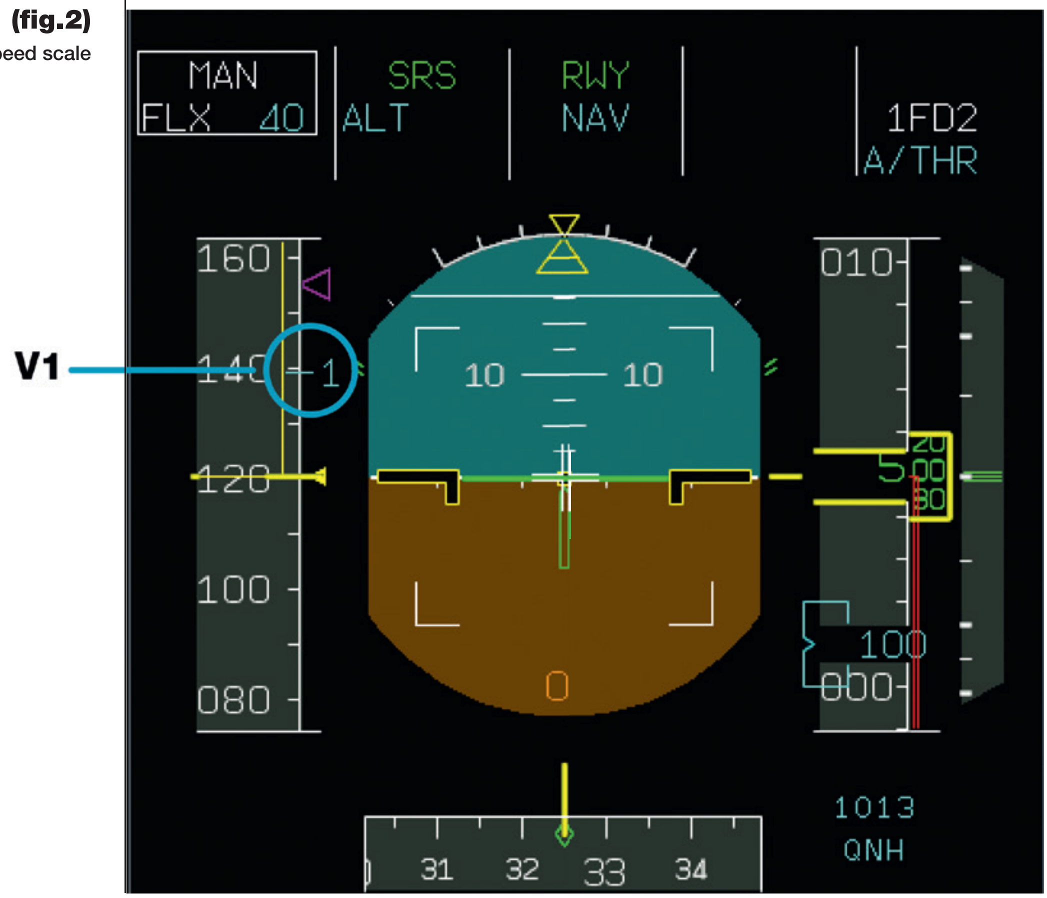
If take-off is aborted at V1, the aircraft must be able to be stopped before the end of the runway, without exceeding the maximum energy the brakes can absorb.

In addition, if an engine failure occurs after V1, then the aircraft must be able to achieve safely take-off with TOGA or derated power (enough lateral control).

These two conditions require identifying:

- The ground speed at which maximum energy is put into the brakes, when a RTO is performed at MTOW. This limit speed is defined during Airbus flight tests and is called **V_{MBE} = Maximum Brake Energy speed.** V1 must be lower than V_{MBE}.
- The minimum speed during take-off roll at which the aircraft can still be controlled after a sudden failure of one engine (be it a two or four-engine airplane).

(fig.2)
V1 on the PFD speed scale



In such a case, and if the take-off is continued, only the rudder will be able to counteract the yaw moment that is generated by asymmetric engine(s) thrust. Therefore if a failure occurs before reaching this minimum speed, the take-off must be interrupted to maintain control of the aircraft. This limit speed is determined during Airbus flight tests and is called **V_{MCG} = Minimum Control speed on the Ground.** V_{MCG} mainly depends on engine(s) thrust and pressure altitude. V1 must be greater than V_{MCG}.

• The maximum aircraft speed at which the most critical engine can fail without compromising the safe completion of take-off after failure recognition. This design speed is called **V_{EF} = Engine Failure speed.**

Considering that it is generally assumed humans have a reaction time to an unexpected event (such as a failure) of 1 second, V1 must be greater than V_{EF}.

In addition, if an engine failure happens at V_{EF}, then it must be possible to continue and achieve safely take-off with TOGA power. This means that V_{EF} must be greater than V_{MCG}.

$$V_{MCG} \leq V_{EF} \leq V1 \leq V_{MBE}$$

» What are the operational implications of not respecting V1?

Supposedly, there are two different ways of "disrespecting" the V1 speed criteria:

1. **The crew decides to continue take-off while an engine failure occurred before V1.** Standard procedures encourage the crew to reject take-off if an engine fails before V1. If take-off is continued despite this recommendation, then the aircraft can potentially exit the runway laterally, or be unable to take-off before the end of the runway.

BEST PRACTICE

In the event of an engine failure at low speed, any delay in reducing the thrust of the good engine(s) will lead to a loss of directional control and a very quick lateral deviation. Max rudder pedal and max manual differential braking may be required (refer to the new FCTM recommendation AO-020 "Low speed engine failure").

2. **An RTO is initiated above V1.** Virtually, any take-off can be "successfully" rejected, on the proviso that the reject is initiated early enough and is conducted properly. In this respect, the crew must always be prepared to make a GO/ NO GO decision prior to the aircraft reaching V1. Doing otherwise exposes the aircraft to an unsafe situation where there either may not be enough runway left to successfully stop the aircraft - therefore resulting in a longitudinal runway excursion-, or maximum brake energy is exceeded and brakes catch fire.

BEST PRACTICE

As speed approaches V1, the successful completion of an RTO becomes increasingly more difficult. After V1, the crew must continue take-off and consider using TOGA thrust except if a derated take-off was performed (refer to FCOM PRO-ABN-10 operating techniques).

V1 IN A NUTSHELL

Do not continue take-off in the event of an engine failure below V1.
Do not initiate an RTO at speeds in excess of V1.

VR: Rotation speed

» Definition

VR is the speed at which rotation can be initiated at the appropriate rate of about 3° per second. VR ensures that V2 is reached at 35 feet above the runway surface at the latest, including in the event of an engine failure at V_{EF}. Therefore at 35 feet, the actual speed is usually greater than V2.

» How is VR determined?

In principle, VR shall not be lower than V1.
In addition, whenever pilots initiate the rotation at VR, they must be assured that the aircraft will be controllable once airborne, including when the most adverse engine has failed after V_{EF}.

On the upper end, if the rotation of the aircraft is started at VR at maximum practicable rate, lift-off must be possible at the end of the maneuver.

These concepts involve understanding the following limit speeds:

• The minimum speed in the second segment (take-off) at which the pilot is still able to maintain lateral and directional control when the most adverse engine fails.
This limit speed is demonstrated by Airbus flight tests and is called **V_{MCA} = Minimum Control speed in the Air.** VR shall not be lower than 1.04 or 1.05 V_{MCA}, the factors 1.04 and 1.05 being defined by Airworthiness Authorities to ensure a safety margin.

• The minimum speed at which the aircraft becomes able to lift off and escape ground effect.
This limit speed is based on evidence collected during certification tests and is called **V_{MU} = Minimum Unstick speed.** V_{MU} is achieved by pitching the aircraft up to the maximum (tail on the runway, for aircraft that are geometrically limited) during the take-off roll. The speed at which the aircraft first lifts off is V_{MU}; therefore lift-off is not possible prior to V_{MU}.

V_{MU} is different from the design lift-off speed V_{LOF}, which applies to general case scenarios and is necessarily greater than V_{MU}, according to the following criteria:

$$1.04 \text{ or } 1.05\, V_{MU\,(N-1)} \leq V_{LOF}$$
$$1.08\, V_{MU\,(N)} \leq V_{LOF}$$

NOTE

The multiplicative factors that were applied were specified by Airworthiness Authorities, in consideration of safety margins.

In turn, V_{LOF} is limited by the design speed V_{TIRE}, which corresponds to the maximum tyre speed (tyre structural limit).

$$V_{LOF} \leq V_{TIRE}$$

Coming back to VR, if we consider that when a rotation is initiated at VR at the maximum practicable rate, it has to result in a satisfactory lift off speed, then VR must be limited by V_{LOF}.

$$V1 \leq VR$$
$$1.05\ V_{MCA} \leq VR$$
$$VR \leq V_{LOF}$$

» What are the operational implications of not respecting VR?

One direct consequence of initiating a rotation before VR is a tail strike.
Second, if the rotation is done at VR but too slowly, or if the rotation is initiated after VR, then the aircraft intrinsic performance will very likely not allow it to reach 35 feet at the end of the runway, and/or not respect the clearway if the take-off speeds were limited by the runway length or obstacles.

VR IN A NUTSHELL

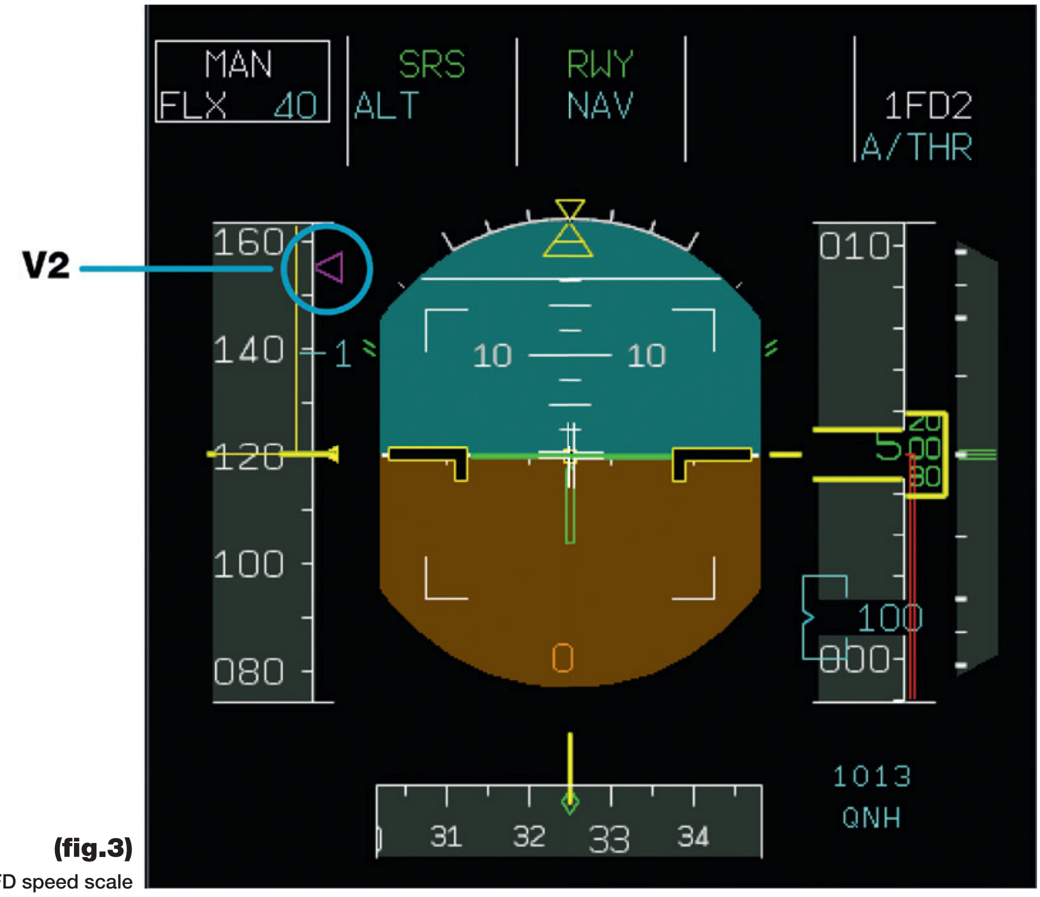
Do not start rotation below or above VR.

V2: Take-off safety speed

» Definition

V2 is the minimum take-off speed that the aircraft must attain by 35 feet above the runway surface with one engine failed at V_{EF}, and maintain during the second segment of the take-off.

This speed must be entered by the crew during flight preparation, and is represented by a magenta triangle on the PFD speed scale **(fig.3).**



(fig.3)
V2 on the PFD speed scale

» How is V2 determined?

V2 is always greater than V_{MCA} and facilitates control of the aircraft in flight.

On the upper end, Airworthiness Authorities have agreed that all operating speeds must be referenced to a stall speed that can be demonstrated by flight tests. This speed is designated V_{S1g}. V2 must obviously be greater than this stall speed.

$$1.13\ V_{S1g} \leq V2$$
$$1.10\ V_{MCA} \leq V2$$

NOTE

The multiplicative factors that were applied were specified by Airworthiness Authorities, in consideration of safety margins.

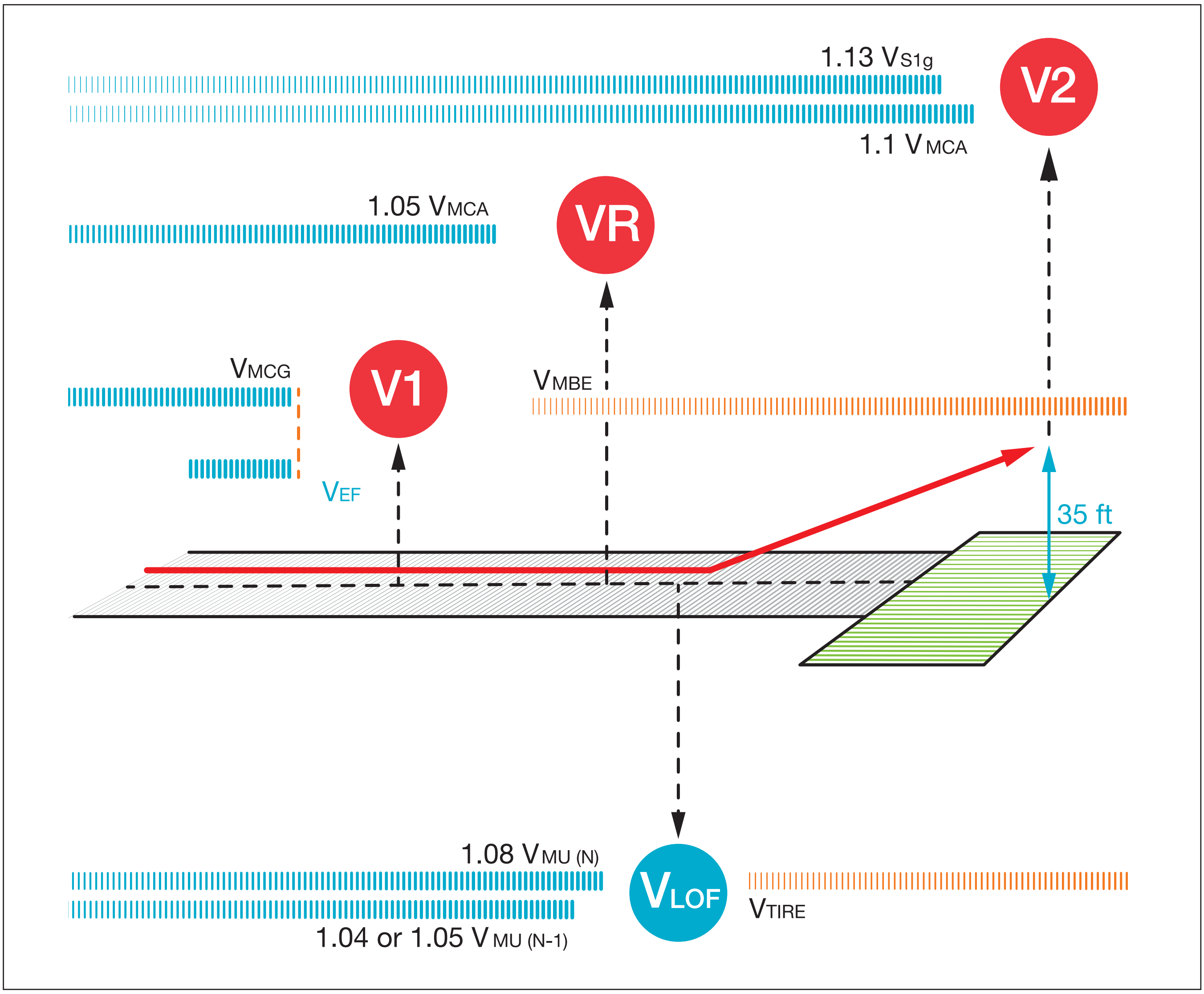
» What are the operational implications of not respecting V2?

Supposedly, there are two different ways of "disrespecting" the V2 speed criteria:

1. **Flying below V2 in case of an engine failure.**
The drag increase below V2 may lead to a situation where the only way to recover speed is to descend. If the speed further decreases and V2 is not recovered, then the high angle of attack protection may be reached, and the aircraft may ultimately enter into an unrecoverable descend trend. In particular, if the speed decreases below V_{MCA}, the aircraft might not be recoverable due to lack of lateral control.

2. **Flying above V2 in case of an engine failure.**
In case of excessive speed, the required climb performance may not be reached, thus increasing the chance to trespass the obstacle clearance. ■

Take-off speeds in a nutshell



SECURING YOUR TAKE-OFF: THE ROLE OF THE PILOT MONITORING (PM)

The take-off phase is a very dynamic and demanding one, during which the PM plays a central role for a timely monitoring from cockpit preparation, all the way through take-off speeds computation and utilization.

Clearly flight crews are expected to be able to rapidly scan the essential and relevant parameters that support key decisions, such as continue or abort a take-off essentially. Doing so, the PM must be able to differentiate between situations that are detrimental to operational safety, and those that are not.

In this respect, he/she must be prepared to adapt his/her monitoring to the level of the threat and reach out in a communication sense to the PF to encourage action if necessary, by making callouts as per SOP. Callouts coupled to responses are a very effective means indeed to cope with demanding situations, and allow the crew to act as a well coordinated team.

Second, he/she must be aware of the primary threats to the safe completion of take-off in order to actively help to prevent take-off speed errors. Take-off speed calculation errors are often due to a combination of two factors:

- Error in parameter entry
- Poor crosschecks by other crewmember.

Prevention strategies should therefore be developed to ensure efficient crosschecks, particularly after last-minute changes (runway change, loadsheet modification, etc).

For this purpose, we want to highlight the main factors often observed when analysing take-offs in which speeds were not respected:

» Errors in take-off speed computation

• Data issued from a computerized system is rarely challenged. However, incorrect inputs may occur, thus resulting in inadequate take-off speed values computation.

• In take-off speed calculations, Zero Fuel Weight (ZFW) is sometimes mistaken for Gross Weight (GW). This is particularly true when a last minute change occurs in cargo loading, or when time pressure and workload are high. Therefore calculated speeds will be much lower than expected, and will potentially lead to tailstrikes, “heavy aircraft” sensation, and high-speed rejected take-offs.

• Take-off speeds calculations are based on specific configurations. Any change in the parameters of these configurations will invalidate take-off speeds. Examples of such parameters include a runway change, a wet runway that becomes contaminated, or a take-off from an intersection.

Errors in take-off speed utilization

• When a last minute change occurs, take-off speeds are sometimes modified and crosschecked during push-back or taxi. During such phases of flight, the PF workload is high. As a result, the PF may not have sufficient time or resources to perform efficient crosschecks.

• If an incident occurs before V1, the PM's attention may be focused on trying to assess the situation and may forget the V1 announcement.

• In the event of an engine failure after take-off, and in an attempt to climb faster, there may be a tendency to set a pitch attitude too high if FD bars are not followed. The aircraft is then flown below V2, and climb performance cannot be maintained.

OPERATIONAL RECOMMENDATIONS FOR THE PM

- **Compute/crosscheck V1, VR and V2.**
- **Enter V1, VR and V2 in the FMS, and ensure these data are re-inserted during taxi as per SOP in case of last minute changes. Attention should be paid to keystroke errors.**

- **Crosscheck information set or used by the PF.**
- **Ensure a take-off briefing is conducted that highlights take-off speeds (particularly if they were changed during taxi), slats/flaps configurations and weight.**
- **For aircraft that are not equipped with a V1 auto-callout: pay a close attention to the V1 standard callout.**

Understanding the implications of take-off speeds is paramount to enable pilots to sense instantly the available margin of maneuver they have left to preserve safety of flight, and make a wise GO/NO GO decision.

In practice, crew coordination and the PM's involvement in the take-off phase preparation and execution are essential parameters to satisfactorily manage the risks associated to this particular phase of flight, such as: a lateral or longitudinal runway excursion, maximum brake energy exceedance causing a brake fire, tail strike, lack of lateral control once the aircraft is airborne, or obstacle clearance trespassing.

Whatever the flying conditions, it is essential that flight crews number one objective remains to fly the aircraft according to the 4 Golden Rules for Pilots.

DID YOU KNOW

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