Safety first

The Airbus Safety magazine

A Focus on the Takeoff Rotation

An appropriate takeoff rotation maneuver is a balance between good takeoff performance and sufficient margin versus tail strike, stall speed, and minimum control speeds.

Applying the 3°/s rotation rate requested in the SOPs is the key to ensure that the aircraft meets the expected takeoff performance. Flight data monitoring shows that the rotation rate values in service vary and a lower rotation rate is observed in some cases with the associated degradation of takeoff performance. This article describes both the takeoff rotation laws available on Airbus Fly-by-Wire (FBW) aircraft and the recommended rotation techniques that will enable flight crew to achieve consistent takeoff rotations at the requested rotation rate.

CASE STUDY: A340 LONG TAKEOFF

Event Description

A takeoff from a high altitude airport (8360 ft)

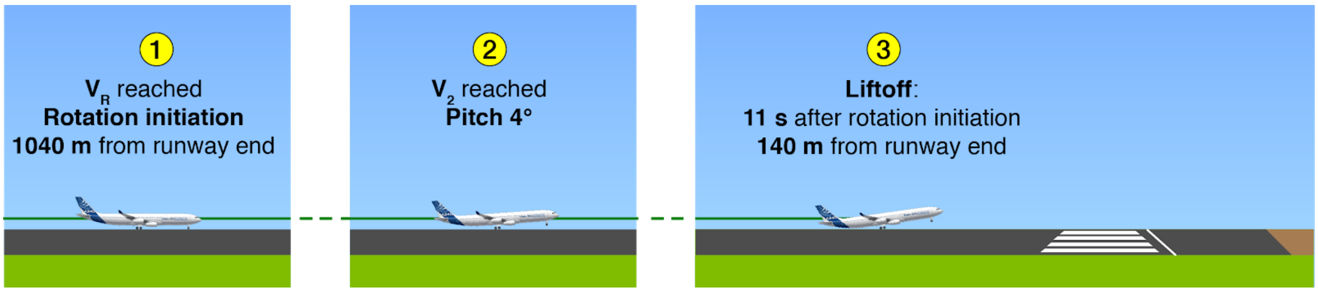
An A340-300 was performing a takeoff from a high altitude airport. A TOGA thrust takeoff in CONF2 was selected. The takeoff performance was calculated for a 4 kt tailwind and was limited by the runway length (takeoff run in One Engine Inoperative (OEI) condition). The gross weight of the aircraft was 236.9 t and was close to the Maximum Takeoff Weight of 237 t in the conditions of the day.

An uneventful takeoff roll

The aircraft reached **V_1** (128 kt) 54 s after brake release and TOGA thrust application. ① The Pilot Flying (PF) then initiated the rotation close to **V_R**. The nose landing gear lifted off the ground 1 s later and the pitch began to increase.

A late liftoff

② **V_2** (149 kt) was reached with the aircraft still on the ground. The main landing gear was still compressed and the aircraft had a pitch of 4° up. ③ Liftoff occurred 11 s after rotation initiation at 155 kt, and at only 140 m from the runway end with a recorded pitch of 9° up.

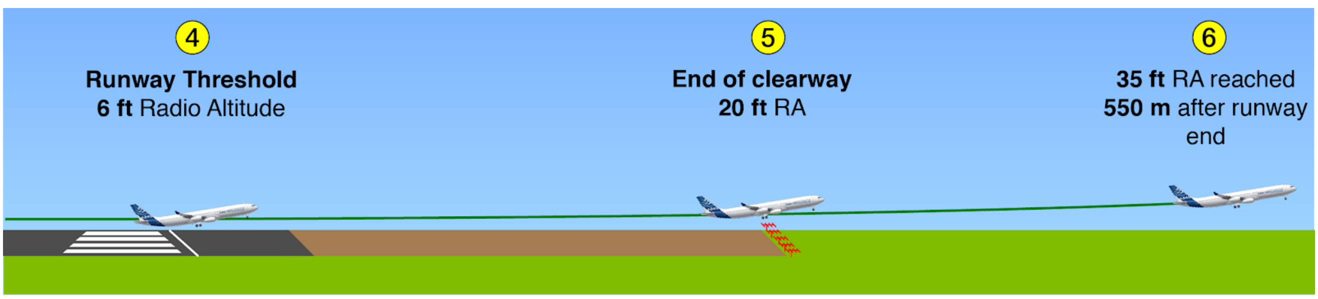


(fig.1) Sequence of events from V_R to liftoff

Runway end overflown at 6 ft radio altitude

④ The aircraft flew over the runway end at 6 ft Radio Altitude (RA), and then ⑤ overflew the end of the clearway at 20 ft RA and avoided the LOC antennas by only 12 ft. ⑥ The aircraft eventually reached 35 ft RA 550 m after the runway end. The landing gear was selected up 3 s later at 135 ft RA with a vertical speed of 1300 ft/min, pitch at 12°, and speed at 160 kt. The aircraft continued its climb and completed its flight uneventfully.

Despite what seemed to be a standard takeoff roll, the aircraft lifted off the runway very late, overflying the LOC antennas located at the end of the clearway with very little clearance. How did this happen?



(fig.2) Sequence of events from runway threshold to 35 ft RA

Event Analysis

A nominal aircraft acceleration performance until V_R

The analysis of the DFDR data showed that the aircraft acceleration was in accordance with the expected performance in the conditions of the day reported as wet runway with 4 kt tailwind.

A slow rotation rate during takeoff

The sidestick inputs ordered by the PF during the rotation resulted in an average rotation rate of 1°/sec. Airbus SOPs request a 3°/s rotation rate. This slow rotation rate resulted in degraded takeoff performance leading to a significant increase in the takeoff distance.

THE REQUESTED TAKEOFF ROTATION RATE VALUE

The origin of the requested rotation rate

The rotation rate that is used to compute the takeoff performance was determined during the takeoff performance flight test campaign together with the Airworthiness Authorities. This value is the average of the rotation rates recorded during all of the test aircraft takeoffs performed in a variety of operating conditions.

The requested 3°/s rotation rate was the value selected and is applicable to all Airbus aircraft except for the A220, which has a 3 to 5°/s rate requested in its FCOM. This value ensured that the actual takeoff distance is closest to the computed distance. If the PF applies a rotation rate that is lower than the requested rotation rate, the aircraft may not take off according to the computed performance, leading to an increased takeoff distance and a decreased obstacle clearance.

"The requested 3°/s rotation rate was the value selected and is applicable to all Airbus aircraft except for the A220, which has a 3 to 5°/s rate requested in its FCOM."

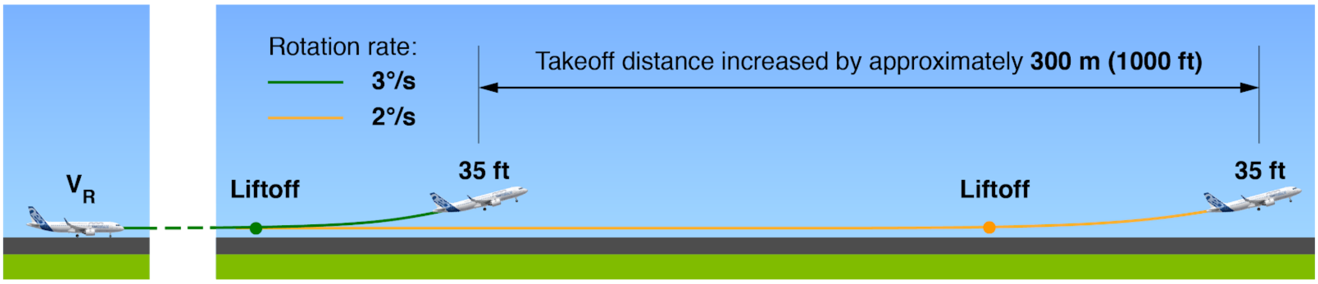
Rotation rate too low in some takeoffs

Flight data monitoring shows that the rotation rate values recorded in service vary. A low rotation rate with an associated takeoff performance degradation was observed in some cases. Safety margins used in takeoff performance computation prevent any significant problems in most cases. However, these margins may not be sufficient in certain situations as can be seen in the event described above. It is why flight crews should always perform the takeoff rotation at a rate as close as possible to the requested rotation rate, and this is especially important in conditions where performance is limited by runway length or obstacle clearance.

A significant impact on takeoff performance

A rotation rate lower than the requested 3°/s in the SOPs significantly increases the takeoff distance. For example, a takeoff performed with a 2°/s rotation rate increases the takeoff distance by approximately 300 m (1000 ft) compared to a 3°/s rotation rate.

(fig.3) Impact of a lower rotation rate on the takeoff distance



Takeoff Distance (TOD) margins

The regulatory Takeoff Distance (**TOD**) on a dry runway is calculated by taking the greatest value of:

- the **TOD** computed with one engine failure happening just prior to reaching V1 (**TOD_{N-1}**), or
- the **TOD** computed with all engines operative (**TOD_N**) with an additional margin of 15 %.

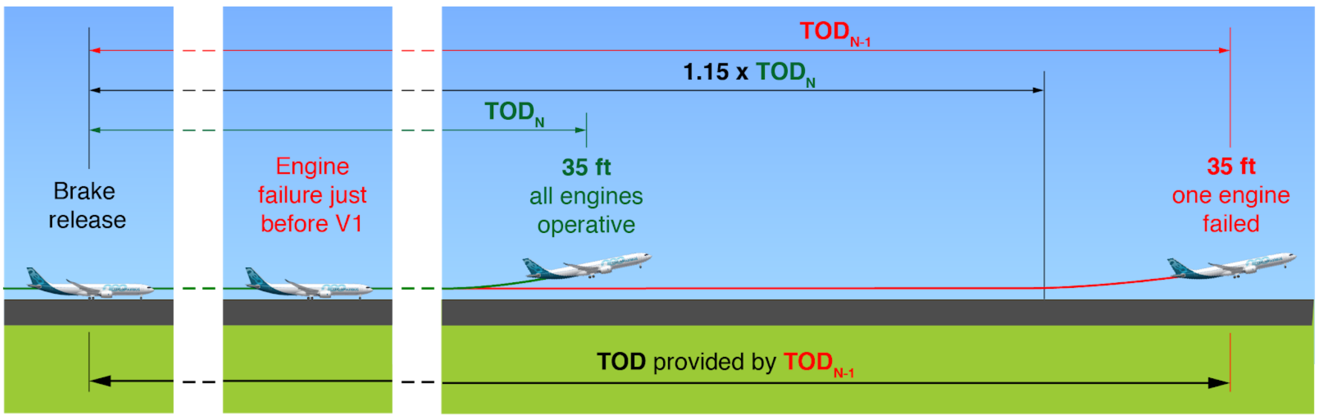
$$TOD_{dry} = \max \text{ of } \{ TOD_{N-1} ; 1.15 \times TOD_N \}$$

Twin-engine aircraft

On a twin-engine aircraft, the **TOD** is often provided by the **TOD_{N-1}** because the loss of half of its thrust strongly impacts the takeoff distance. This calculation provides additional margin for a takeoff with both engines operative.

While the PF should perform the requested rotation rate of 3°/s in all conditions, it is even more important in case of engine failure during takeoff, because there is no additional margin for the calculated **TOD**.

(fig.4) Example of a TOD computation for a twin-engine aircraft

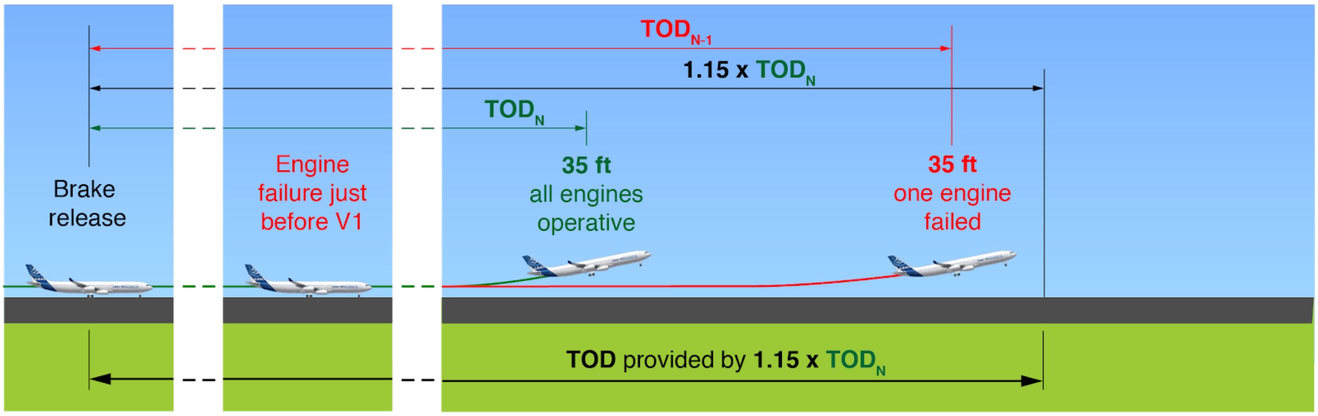


Four-engine aircraft

On a four-engine aircraft, the **TOD** is often sized by the factored **TOD_N** because the **TOD_{N-1}** is often the shortest as it is computed with a loss of thrust limited to a quarter of the total available thrust.

Achieving the requested rotation rate of 3°/s is especially important in daily operations (i.e. when all four engines are operative), because this condition is usually the sizing one, and therefore, does not provide additional margin on top of the **1.15** factor.

(fig.5) Example of a TOD computation for a twin-engine aircraft



TAKEOFF ROTATION LAWS AVAILABLE ON FBW AIRCRAFT

The takeoff rotation law helps the flight crew to perform the optimum takeoff rotation. The takeoff rotation law consists of both the rotation law and tail strike prevention functions.

There are different types of takeoff rotation law depending on the aircraft model.

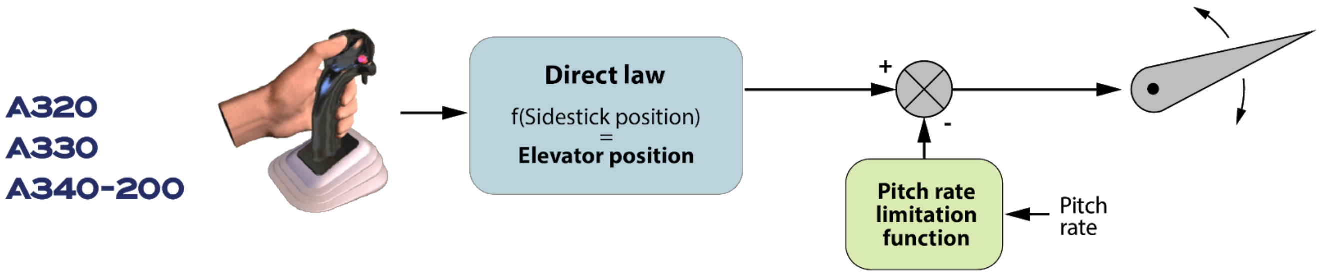
Rotation assistance on A320ceo, A330ceo, and A340-200/300 aircraft

Rotation law: Direct law

There is a direct relationship between the sidestick deflection and the elevator deflection on these aircraft models. The rotation rate obtained by a fixed sidestick deflection value may vary noticeably with different operating conditions such as aircraft weight, center of gravity position, slats/flaps configuration, engine thrust, and takeoff speeds.

Tail strike prevention: Pitch rate limitation function (A320ceo, A330ceo, A340-200)

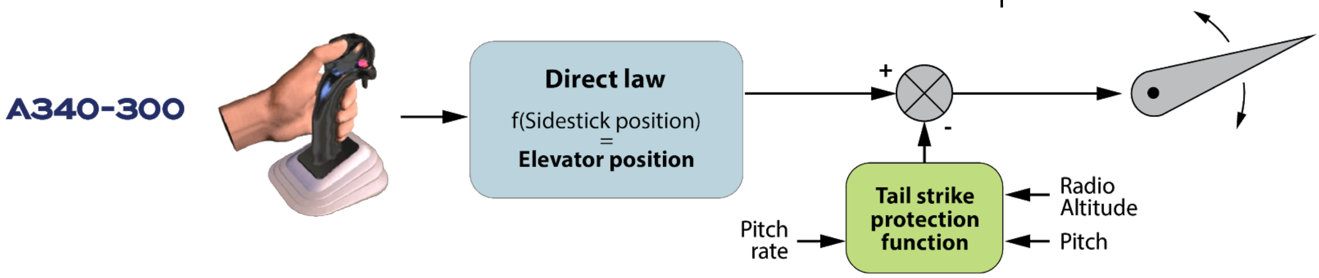
A limitation function reduces the pitch-up command sent to the elevators to reduce the risk of tail strike in case of excessive pitch rate. **This pitch rate limitation function does not provide tail strike protection**: If a nose-up input is maintained on the sidestick, a tail strike can still occur.



(fig.6) Rotation law on A320ceo, A330 and A340-200 aircraft

Tail strike protection function (A340-300 only)

A tail strike protection function estimates the rear fuselage clearance margin based on radio-altimeter height and pitch attitude. This function modulates the nose-up input order sent to the elevator whenever the clearance of the tail to the ground becomes too small. **The function protects the aircraft against tail strike for average sidestick deflection values until the sidestick deflection reaches approximately ¾ of nose-up order.** The PF can override this protection by pulling back on the sidestick beyond ¾ of nose-up.



(fig.7) Rotation law on A340-300 aircraft

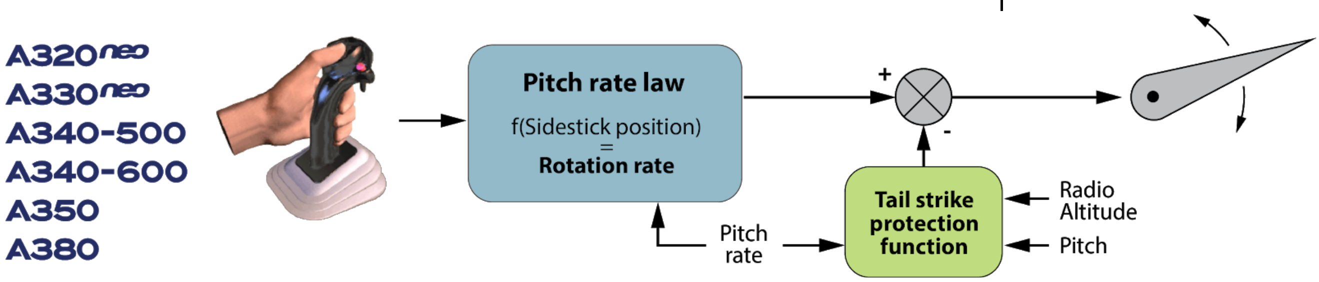
Rotation assistance on A320neo, A330neo, A340-500/600, A350, and A380 aircraft

Rotation law: Pitch rate target

On these aircraft, the rotation law ensures that an equivalent and repeatable rotation rate is achieved for a given sidestick deflection, and independent of the variable operating conditions such as aircraft weight, center of gravity position, slats/flaps configuration, engine thrust, and takeoff speeds.

Tail strike protection function

A tail strike protection function similar to the one available on A340-300 is also available on these aircraft.



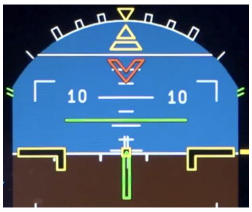
(fig.8) Rotation law on A320neo, A330neo, A340-500/600, A350 and A380 aircraft

Tail strike pitch limit indication at takeoff (A330/A340 family and A380 aircraft)

The tail strike pitch limit indication is currently displayed at takeoff and landing on all A340 and A380 aircraft. The tail strike pitch limit was an option on the earlier models of the A330ceo, but was later installed as standard for all A330ceo produced after mid-2013.

A320, A321, A330neo, and A350 aircraft also have a tail strike pitch limit, but it is only displayed on landing, because it is not necessary at takeoff. There is no tail strike pitch limit indication on A318 and A319 aircraft, because these aircraft have shorter length fuselage and less risk of tail strike.

(fig.9) Example of a tail strike pitch limit indication on an A330 aircraft



Removing the tail strike pitch limit for takeoff

In-service experience showed that when the tail strike pitch limit indicator appears on the display, it may cause the PF to unnecessarily reduce the rotation rate of the aircraft during takeoff and prevent the aircraft from reaching the requested 3°/s rotation rate. As a result, Airbus decided to deactivate the tail strike pitch limit indicator at takeoff and to keep it activated only on landing for all aircraft models.

The tail strike protection function proved to provide A340-300, A340-500/600, and A380 aircraft with sufficient tail strike protection.

The pitch rate limitation function on A330ceo aircraft, combined with its tail strike margin is sufficient protection against the risk of tail strike.

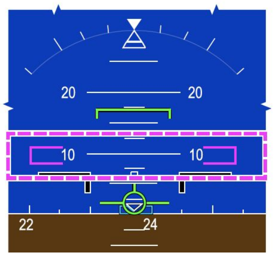
Deactivation of the tail strike pitch limit indication for takeoff will be performed at the opportunity of a next A330/A340 Flight Management Guidance and Envelope Computer (FMGEC) or A380 Flight Control and Guidance Computer (FCGC) update.

Rotation assistance on A220 aircraft

Rotation law: Direct law

There is a direct relationship between the sidestick deflection and elevator deflection with a compensation for forward or aft center of gravity conditions on A220 aircraft.

(fig.10) Pitch Target Marker (PTM) on the PFD of an A220 aircraft



Pitch Target Marker (PTM)

The Pitch Target Marker (PTM) on the PFD provides the initial pitch for the flight crew to target during the takeoff rotation until FD guidance is available.

Tail strike prevention: Pitch rate reduction

A limitation function will reduce the pitch-up command sent to the elevators in case of excessive pitch rate, and will reduce the risk of tail strike. **The flight crew should be aware that this pitch rate limitation is not protection against tail strike**: A tail strike event can still occur if a nose-up input is maintained on the sidestick.

A tail strike symbol is displayed on the Head-Up Display (HUD) during rotation when the PTM is not displayed and the aircraft pitch angle approaches the tail strike angle by less than 3 degrees or when the pitch rate is excessive.

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THE TAKEOFF ROTATION TECHNIQUE

A technique common to all FBW and non-FBW aircraft

A similar technique is used on all Airbus aircraft. It can be found in the FCOM SOPs, and additional information is provided in the Flight Crew Techniques Manual (FCTM).

Step 1: Initiate Rotation

When the aircraft reaches V_R, the PF should apply a ① **positive backward sidestick (or control column) input** to initiate the rotation.

Step 2: Use outside visual references to achieve & maintain rotation rate

After the PF initiates the rotation, they should ② **use outside visual references to achieve and maintain the rotation rate**.

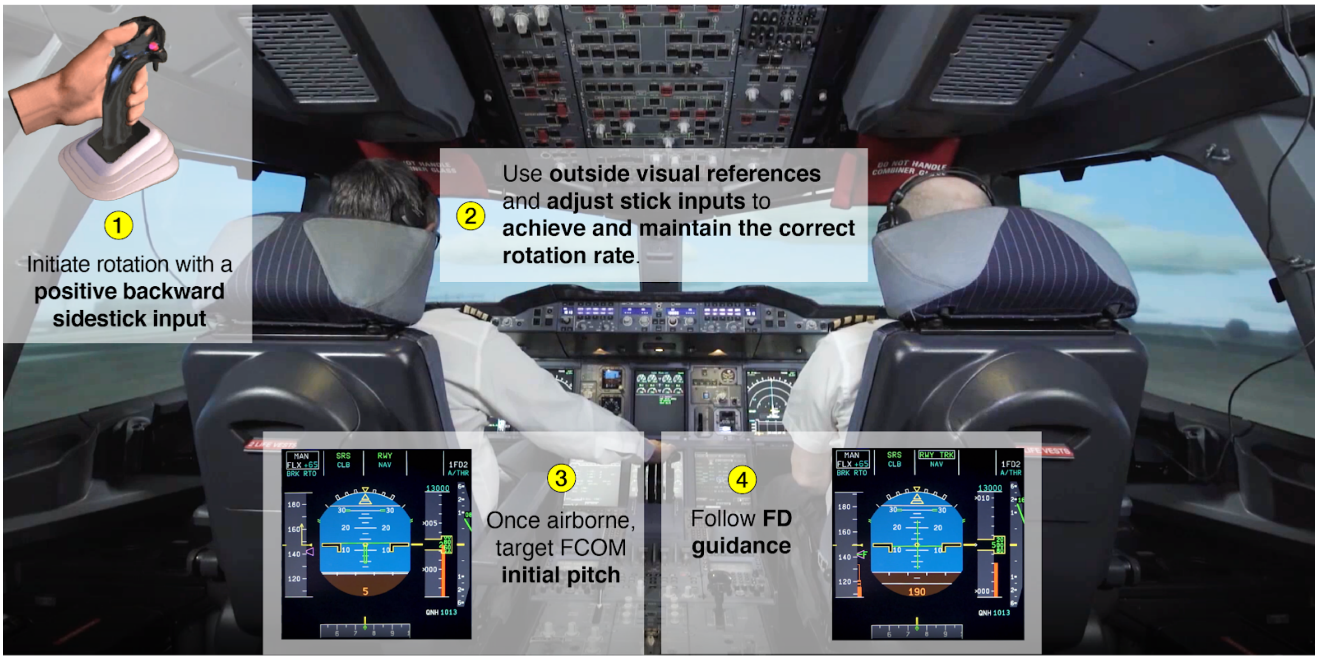
Adjustments may be necessary to achieve and maintain the required rotation rate. On aircraft with direct rotation law or non-FBW aircraft, the flight crew should adapt to the takeoff conditions on the day. On aircraft that have the pitch rate rotation law, the law assists the flight crew to achieve an equivalent rotation in all conditions.

With a suitable rotation rate, the aircraft typically lifts off approximately 4 to 5 s after the PF initiates the rotation and when the pitch reaches approximately 10°.

Step 3: Target initial pitch attitude after liftoff then follow FD guidance

When the aircraft is airborne, the PF should ③ **adjust the pitch toward the initial pitch target** provided in the FCOM (e.g. 15° or 12.5° if one engine failed on A320 aircraft). On A220 aircraft, the Pitch Target Marker (PTM) provides a visual indication of the initial target pitch. The PF should then ④ **follow the FD guidance**.

"A similar technique is used on all Airbus aircraft"



(fig.11) Recommended rotation technique

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INFORMATION

The "What about rotation technique?" video is available on the Worldwide Instructor News (WIN) website and provides a step-by-step review of a full takeoff sequence performed in an A380 simulator.

NOTE

Training Areas of Special Emphasis (TASE) for A340 family aircraft

An EASA Safety Information Bulletin (SIB 2017/20) was published in 2017 following the incident described in this article. In 2018, a Training Areas of Special Emphasis (TASE) was included in the A340 Operational Suitability Data (OSD) for flight crew in response to the SIB. The TASE emphasizes the need to ensure flight crews know how to perform the correct takeoff rotation technique during initial and recurrent training. This includes:

- How to initiate the rotation
- How to achieve and maintain the rotation rate
- How to achieve the pitch attitude after liftoff.

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Flight data monitoring shows that the takeoff rotation rates recorded in service vary and that a lower rotation rate is observed in some cases, with the associated degradation of takeoff performance.

Achieving an appropriate rotation rate is essential to ensure takeoff performance, while maintaining a sufficient margin with tail strike, stall speed, and minimum control speeds.

Airbus aircraft are designed, tested, and certified to achieve the necessary rotation rate, while having sufficient margins against the tail strike. Flight control laws include features that reduce the risk of tail strike.

The flight crew should apply the FCOM procedures and FCTM techniques to achieve the requested rotation rate:

After the rotation is initiated with a positive nose-up input, the flight crew should use outside visual references to achieve and maintain the rotation. The flight crew should fly the rotation, and make any necessary adjustments to achieve and maintain the required rotation rate. When the aircraft is airborne, the PF adjusts the pitch toward the initial FCOM pitch target and then follows the FD guidance.

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