Tail Strikes: Prevention

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Tail strikes can cause significant damage and cost operators millions of dollars in repairs and lost revenue. In the most extreme scenario, a tail strike can cause pressure bulkhead failure, which can ultimately lead to structural failure; however, long shallow scratches that are not repaired correctly can also result in increased risks. Yet tail strikes can be prevented when flight crews understand their causes and follow certain standard procedures.

Two vital keys to prevention are raising awareness of tail strikes among flight crews and including tail strike prevention in standard training procedures. It's also important to promote discussion about tail strikes among members of the flight crew as part of takeoff and landing briefings, particularly when strong wind conditions are present.

This article:

- Provides an overview of tail strikes and how Boeing is addressing them.
- Examines tail strike causes and prevention.
- Discusses operations in strong gusty winds.
- Reviews training recommendations and preventive measures.

TAIL STRIKES: AN OVERVIEW

A tail strike occurs when the tail of an airplane strikes the ground during takeoff or landing. Although many tail strikes occur on takeoff, most occur on landing. Tail strikes are often due to human error.

Tail strikes can cause significant damage to the pressure bulkhead. Failure of the pressure bulkhead during flight can cause a catastrophic event if the flight continues while pressurized.

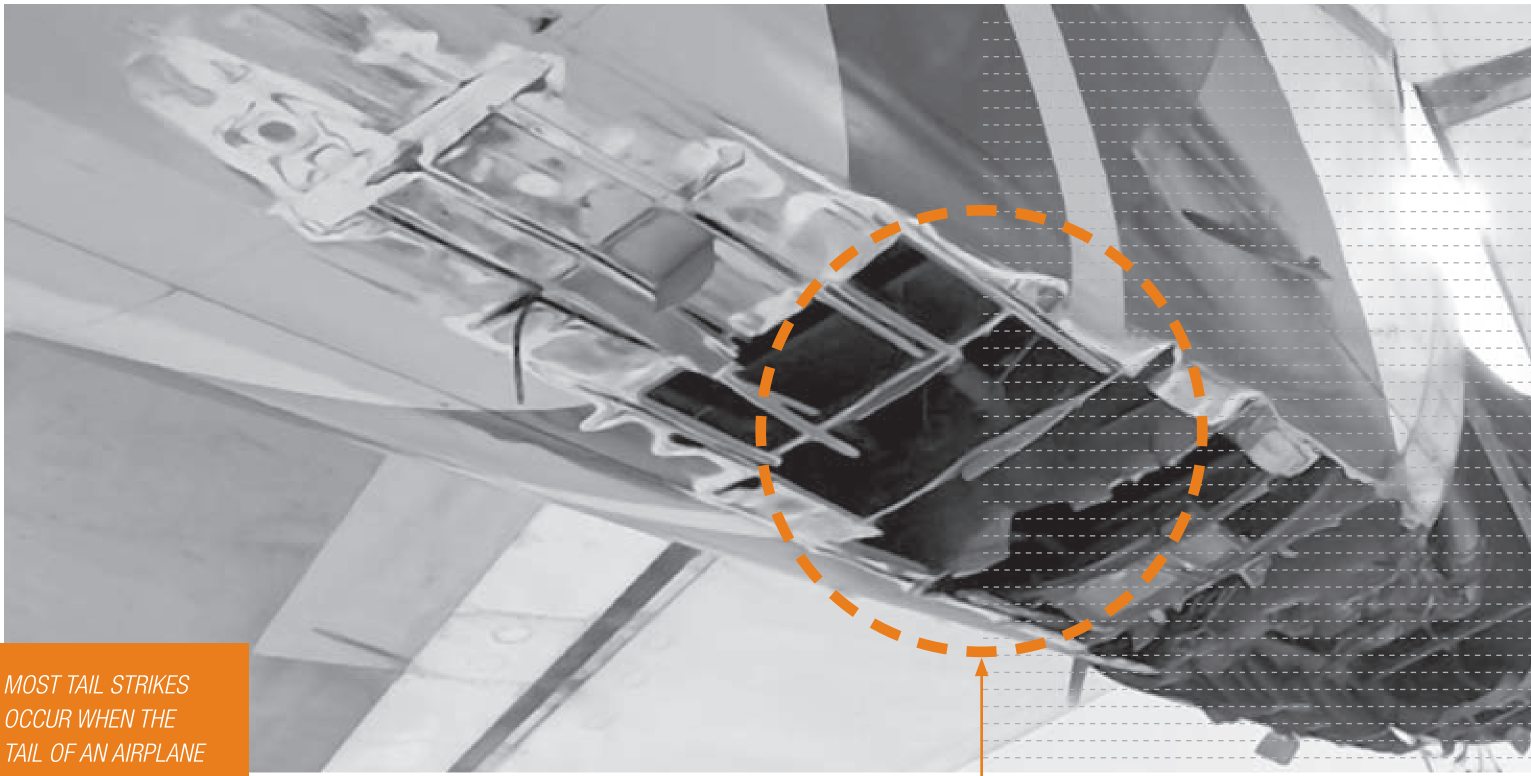
Tail strikes are expensive, too. During a safety investigation, one airline reported that a single tail strike cost its company $12 million in repair cost and loss of revenue during the repair.

Boeing has done design work to reduce tail strikes, including implementing an improved elevator feel system in some airplanes. For example, the 747-100/-200/-300 has varied feel (column forces) throughout the center of gravity (CG) and weight envelope. The newer 747-400's elevator feel system design provides a constant feel elevator pressure, which has reduced the potential of varied feel pressure on the yoke contributing to a tail strike. The 747-400 has a lower rate of tail strikes than the 747-100/-200/-300.

In addition, some 777 models incorporate a tail strike protection system that uses a combination of software and hardware to protect the airplane. And some models of the 737, 767, and 777 have a tail skid that prevents damage from most takeoff tail strikes. However, these devices do not guarantee protection for landing tail strikes and some takeoff tail strikes. They also reduce tail clearance distances.

Many of the longer-bodied Boeing airplanes use relatively higher speeds than their shorter-bodied major models (e.g., the 757-300 versus the 757-200). The subsequent higher V_1, V_r, and V_2 speeds, or approach speeds, are designed to improve the tail clearance. Higher speeds make the tail clearance equivalent to the shorter-bodied equipment of the same model.

Regardless of airplane model, tail strikes can have a number of causes, including gusty winds and strong crosswinds. But environmental factors such as these can often be overcome by a well-trained and knowledgeable flight crew following prescribed procedures. Boeing conducts extensive research into the causes of tail strikes and continually looks for design solutions to prevent them, such as an improved elevator feel system. Enhanced preventive measures, such as the tail strike protection feature in some Boeing 777 models, further reduce the probability of incidents.



MOST TAIL STRIKES OCCUR WHEN THE TAIL OF AN AIRPLANE STRIKES THE GROUND DURING LANDING AND ARE PREVENTABLE.

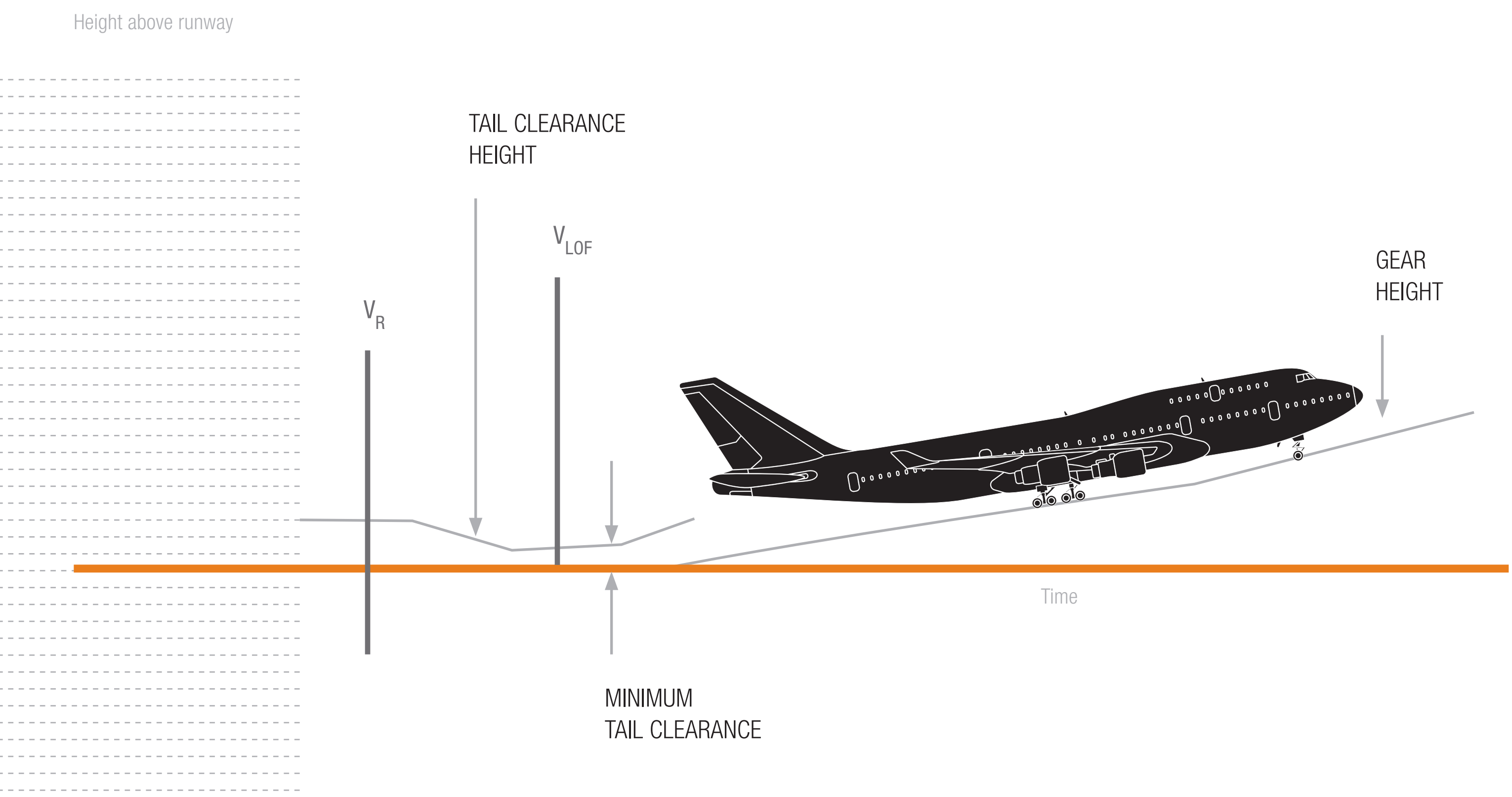
IN THIS INCIDENT, THE CREW MADE AN ERROR AND CALCULATED TAKEOFF DATA INCORRECTLY. THIS RESULTED IN AN EARLY ROTATION.

TYPICAL TAIL CLEARANCE FOR TAKEOFF

Figure 1

Model	Flap	Liftoff Attitude (deg)	Minimum Tail Clearance [inches (cm)]	Tail Strike Pitch Attitude (deg)
747-400	10	10.1	39 (99)	12.5
747-400	20	10.0	40 (102)	12.5

This diagram indicates the effect of flap position on liftoff pitch attitude as well as minimum tail clearance during takeoff. The minimum tail clearance depicted is predicated on a no-wind, no-crosswind control, and constant rate of 2 to 3 degrees per second rate of rotation.



TYPICAL TAIL CLEARANCE FOR ENGINES-OUT TAKEOFF

Figure 2

Model	Flap	Liftoff Attitude (deg)	Minimum Tail Clearance [inches (cm)]	Tail Strike Pitch Attitude (deg)
747-400	10, 20	10.6	34 (86)	12.5

When operating with an engine failed at V_1 with only 75 percent of thrust available for a four-engine airplane or 50 percent of thrust available for a two-engine airplane, minimum tail clearance is reduced. If there is a crosswind, the aileron/spoiler displacement will further reduce minimum tail clearance. In all cases, whether operating in one-engine or two-engine configuration during the rotation, a high average rate of rotation above what is recommended will further reduce minimum tail clearance.

Boeing also works to reduce tail strikes through exhaustive takeoff testing, which is a part of certification for any new airplane program. During flight testing, takeoff test conditions are specifically designed to investigate the impact of early rotation, rapid rotation, no flare during landing, and long flare. During this testing, an acceptable margin per certification criteria is established for the design operational use of the airplane. In all cases, Boeing commercial airplanes meet or exceed the design certification criteria for takeoffs and landings, as well as for crosswind takeoffs and landings (see fig. 1). Criteria for engine-out takeoffs and landings are also evaluated (see fig. 2).

CAUSES AND PREVENTION

Takeoffs. A number of factors increase the chance of a tail strike during takeoff, including:

- Mistrimmed stabilizer.
- Improper rotation techniques.
- Improper use of the flight director.
- Rotation prior to V_r:
  - Early rotation: Too aggressive, misinterpretation.
  - Early rotation: Incorrect takeoff speeds.
  - Early rotations: Especially when there is a significant difference between the V_1 and V_r.
- Excessive initial pitch attitude.
- Strong gusty winds and/or strong crosswinds may cause loss of airspeed and/or a requirement for lateral flight control inputs that can deploy some flight spoilers, reducing the amount of lift on the airplane.

These factors can be mitigated by using proper takeoff techniques (refer to your operations manual for specific model information), including:

- *Normal takeoff rotation technique.* For current production airplanes, the feel pressure should be the same as long as the CG/weight and balance are done correctly. For most cases, there is no reason to be aggressive during rotation.
- *Rotating at the appropriate time.* Rotating early means less lift and less aft tail clearance.
- *Rotating at the proper rate.* Do not rotate at an excessive rate or to an excessive attitude.
- *Using correct takeoff V speeds.* Be sure to adjust for actual thrust used and be familiar with quick reference handbook and airplane operations manual procedures for takeoff speed calculations.
- *Consider use of greater flap setting* to provide additional tail clearance on some models.
- *Use the proper amount of aileron* to maintain wings level on takeoff roll.

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Approximately two years ago, Boeing revised wording in all production model flight crew training manuals (FCTM) to incorporate input from industry and safety professionals regarding tail strikes during strong and gusty winds. The Boeing FCTM recommends that crews use thrust settings higher than the minimum required. The use of a higher takeoff thrust setting reduces the required runway length and minimizes the airplane exposure to gusty conditions during takeoff roll, rotation, liftoff, and initial climb.

Landings. Tail strikes on landing generally cause more damage than takeoff tail strikes because the tail may strike the runway before the main gear, damaging the aft pressure bulkhead. These factors increase the chance of a tail strike during landing:

- Unstabilized approach.
- Holding airplane off the runway in the flare.
- Mishandling of crosswinds.
- Overrotation during go-around.

Techniques that can reduce the chance of a tail strike during landing include:

- Maintain an airspeed of V_{ref} + 5 knot minimum to start of flare and fly the approach at the "specified target airspeed."
- The airplane should be in trim at start of flare; do not trim in the flare or after touchdown.
- Do not "hold the airplane off" in an attempt to make an excessively smooth landing.
- Use only the appropriate amount of rudder/aileron during crosswind approaches and landing.
- Immediately after main landing gear touchdown, release the back pressure on the control wheel and fly the nose wheel onto the runway.
- Do not allow pitch attitude to increase after touchdown.
- Do not attempt to use aerodynamic braking by holding the nose off the ground.

Sometimes the best option for the approach is a go-around. It is important that the culture within the airline promote go-arounds when needed without punitive measures.

OPERATIONS IN STRONG, GUSTY WINDS

Tail clearance is reduced during takeoffs performed in strong gusty winds and crosswinds because of the lift loss incurred by flight control inputs, primarily spoilers. With very large inputs, this loss can be significant (see figs. 3 and 4).

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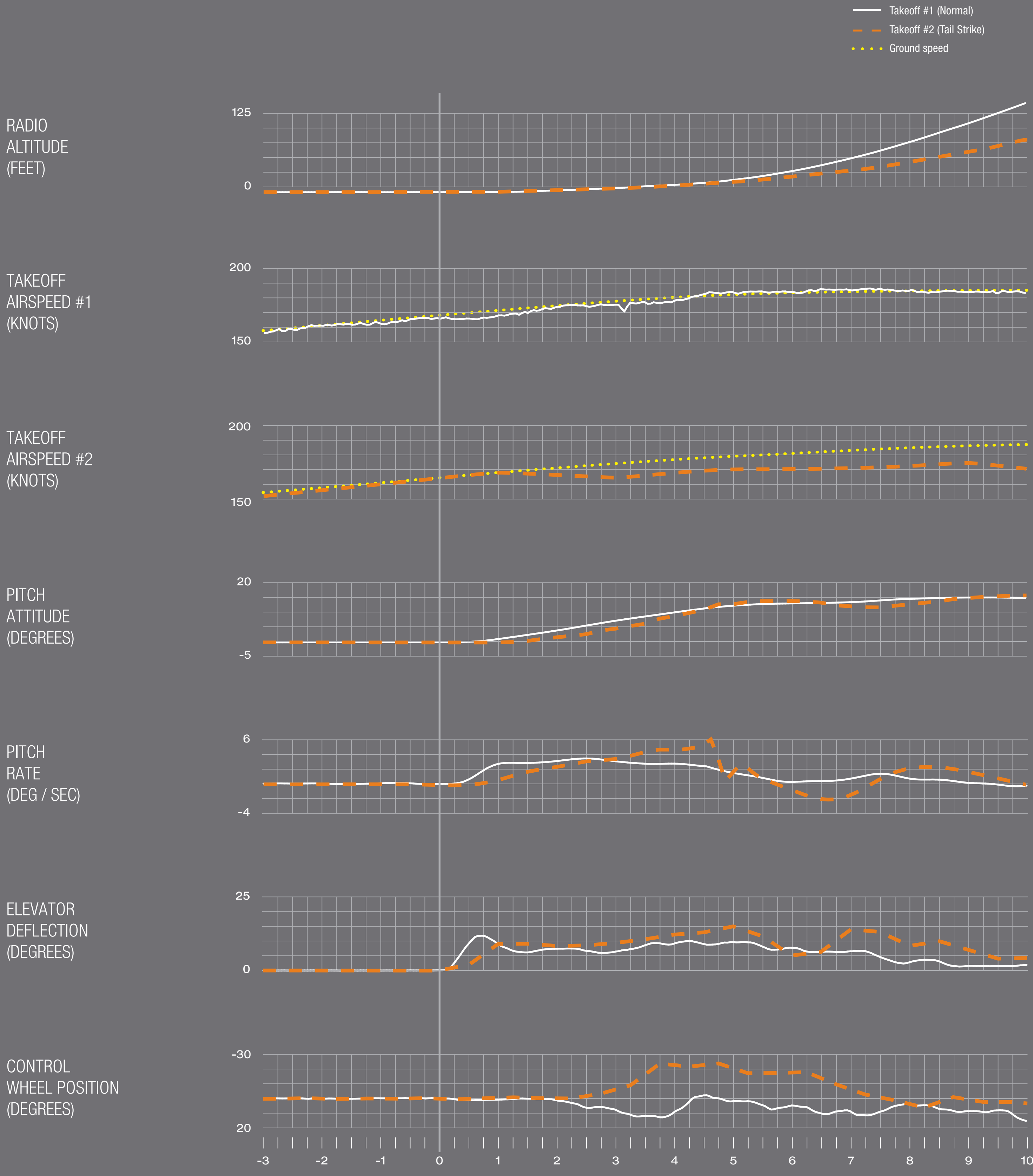
Pilots can take a number of steps to reduce the possibility of tail strikes during takeoff in gusty winds or strong crosswinds, including:

- Momentarily delaying rotation during the gust. As airspeed fluctuates back and forth (what is sometimes referred to as "bounce"), ensure that the airplane starts rotation at a speed that averages above rotate speed.
- Using a normal rate of rotation, but not a greater rate of rotation than normal. This faster rate may be a tendency if the airplane is slow to liftoff due to airspeed stagnation.
- Limiting wheel input to that necessary to maintain wings level. Pre-setting too much aileron increases drag and reduces lift with higher probability of cross control and reduced tail clearance margins. When safely airborne, smoothly transition from the slip by slowly releasing the rudder while maintaining desired track.
- Avoiding the tendency to quickly rotate the airplane off the ground during rotation in these wind conditions. Gusts up to 20 knots have been noted in the review of tail strike incidents.
- Rotating on the conservative side of gusts. Use normal rate of rotation a bit on the side of a slower versus faster rotation, similar to the engine-out case noted earlier.

TAIL STRIKE COMPARISON
Figure 3

This is a comparison of a normal takeoff and a tail strike takeoff in gusty wind conditions. Note that takeoff #2 suffers a 9- to 10-knot airspeed loss during the rotation. The pitch attitude increases at an increasing rate until the tail strike. This is primarily due to the continued elevator increased deflection during rotation.



AFT BODY CLEARANCE BREAKDOWN
Figure 4

Guidelines that relate to Boeing airplanes show that airspeed loss, lateral control deflection, a greater than average pitch rate, and a maximum pitch rate in excess of 4 degrees per second all contribute to reduced tail clearance margins. The numbers change, but the concepts hold true for other models.

Factor		Incremental Difference from Nominal	Reduction in Aft Body Clearance
Airspeed loss		Each 1 knot below the nominal liftoff speed	=2.8 inches †
-ΔCL from lateral controls		Each 0.1 of (-ΔCL) from lateral controls	=14 inches
Pitch rate*			
Either/Or	Average pitch rate to 10 degrees pitch attitude	Each 0.1 deg/sec in the average pitch rate above 2.5 deg/sec	=2.8 inches †
	Maximum pitch rate	Each 0.1 deg/sec above 4.0 deg/sec	=1.3 inches

* *If the maximum pitch rate up to the point of contact was less than 4.0 deg/sec, the average pitch rate corrections are used. If the maximum pitch rate up to the point of contact was above 4.0 deg/sec, then the maximum pitch rate correction should be used. In all cases, only one method or the other is employed.*

† *For these increments, the relationship holds for both positive and negative contributions, i.e., an* increase *in liftoff speed by 1 knot would* increase *the aft body clearance by 2.8 inches, and each 0.1 deg/sec of average pitch rate* below *2.5 deg/sec would* increase *aft body clearance by 2.8 inches.*

If, after reaching the normal takeoff attitude, the airplane is not airborne, avoid the tendency to increase rotation rate. Either slow or momentarily stop rotation rate. Many tail strikes on takeoff occur when or just after the main gear is airborne.

TRAINING RECOMMENDATIONS AND PREVENTIVE MEASURES

Tail strikes can be prevented. The most effective means of prevention is a training program that reinforces proper takeoff and landing procedures. There are a number of steps both management and flight crews can take to help prevent tail strikes.

Management:

- Ensure instructors and evaluators stress proper landing and takeoff techniques during all training and evaluations.
- Make "tail strike prevention" part of the safety program through posters, briefings, videos, computer-based training, and other elements which are available from Boeing Field Service representatives.
- Make tail clearance measuring tools available in the simulator for all takeoffs and landings during simulator training and evaluations and provide feedback to crews.
- Use a self-measuring tail strike operational tool in the airline's fleet (see "Crew" section).
- Ensure that flight operational quality assurance programs are not used as a punitive device.

Crew:

- Adhere to proper takeoff and landing techniques.
- Never assume—double-check the takeoff data, especially if something doesn't look right. Coordinate insertion of the zero fuel weight (ZFW) in the Flight Management Computer with another crew member. Double-check data with the load sheet. Inaccurate (low) ZFW entries have caused significant tail strikes.
- Know your airplane—have an idea about the approximate takeoff and approach speeds.
- When setting airspeed bugs, always do a "reasonable check."
- Be aware of the differences between models and types, especially when transitioning from other equipment.
- If a tail strike occurs, follow the checklist.

Crew resource management should be an integral part of training. Crews can get complacent during routine operations, yet a real threat exists during operations in strong gusty crosswinds. How the crew plans for and mitigates the threat can make the difference between a safe takeoff or landing and one that results in a tail strike. Every crew should have a plan for identifying and discussing the threat.

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  - The entire crew should review appropriate crosswind takeoff procedures and techniques for operating in strong gusty winds.
  - The pilot flying (PF) should review threat strategy for the takeoff or landing with the pilot monitoring (PM).
  - The PM should monitor airspeed versus rotation callout to the PF and identify airspeed stagnation during the rotation phase to takeoff target pitch attitude.
  - If the first officer is making the takeoff, the captain should monitor pitch rate and attitude and call out any deviations and be prepared to intervene.

Other approaches include a self-monitoring tail strike analysis tool that provides a pitch report for every takeoff and landing. If the tail gets within 2 degrees of a potential tail strike, an auto printout is provided to the crew after the respective takeoff or landing. Airlines that have adopted this program have had significant drops in tail strike rates.

Preventive measures. Boeing is actively developing tail strike preventive measures.

Some 777s have two additional features that help prevent tail strikes: the semi-levered main gear and tail strike protection.

Boeing 777 semi-levered main gear. Because the vast majority of the weight of the airplane is borne by the lift of the wings at the time of rotation, the semi-levered gear acts as if it were "pushing" down like a longer gear. This allows a higher pitch attitude for the same tail clearance or more clearance for the same pitch attitude. A hydraulic strut provides the energy to provide this increased takeoff performance. Although designed to increase takeoff capability, the system provides increased tail clearance for the same weight and thrust as nonequipped airplanes.

Boeing 777 tail strike protection. Timely elevator input can help avoid tail strikes on both takeoff and landing. The tail strike protection command (TSP CMD) is summed with the pilot's input to form a total elevator command. The TSP CMD is limited in size to 10 degrees, which allows the pilot to overcome its effects, if desired, by pulling the column farther aft. The size of the TSP CMD is controlled by excessive tailskid rate relative to a nominal threshold of tailskid rate, and by excessive nearness of the skid to the runway, relative to a nearness threshold. Different thresholds are used for takeoff and landing. The TSP CMD is limited to commanding nose down increments only. Tailskid height and rate are computed from radio altimeter signals, pitch attitude, pitch rate, vertical speed, and the length between the radio altimeter location and the tailskid location. A complementary filter is used to provide acceptably smooth rate and height signals. Provisions are included to account for the bending of the forward fuselage when the nose wheel gear lifts off the ground.

SUMMARY

Tail strikes are preventable. If standard recommendations are followed for all Boeing models, the chance of tail strikes is greatly reduced. There are additional challenges and solutions when operating during strong crosswinds and gusty winds. Training is the key to preventing tail strikes. Technology enhancements can also contribute to solutions for Boeing production airplanes. For more information, contact Capt. Dave Carbaugh at dave.c.carbaugh@boeing.com.