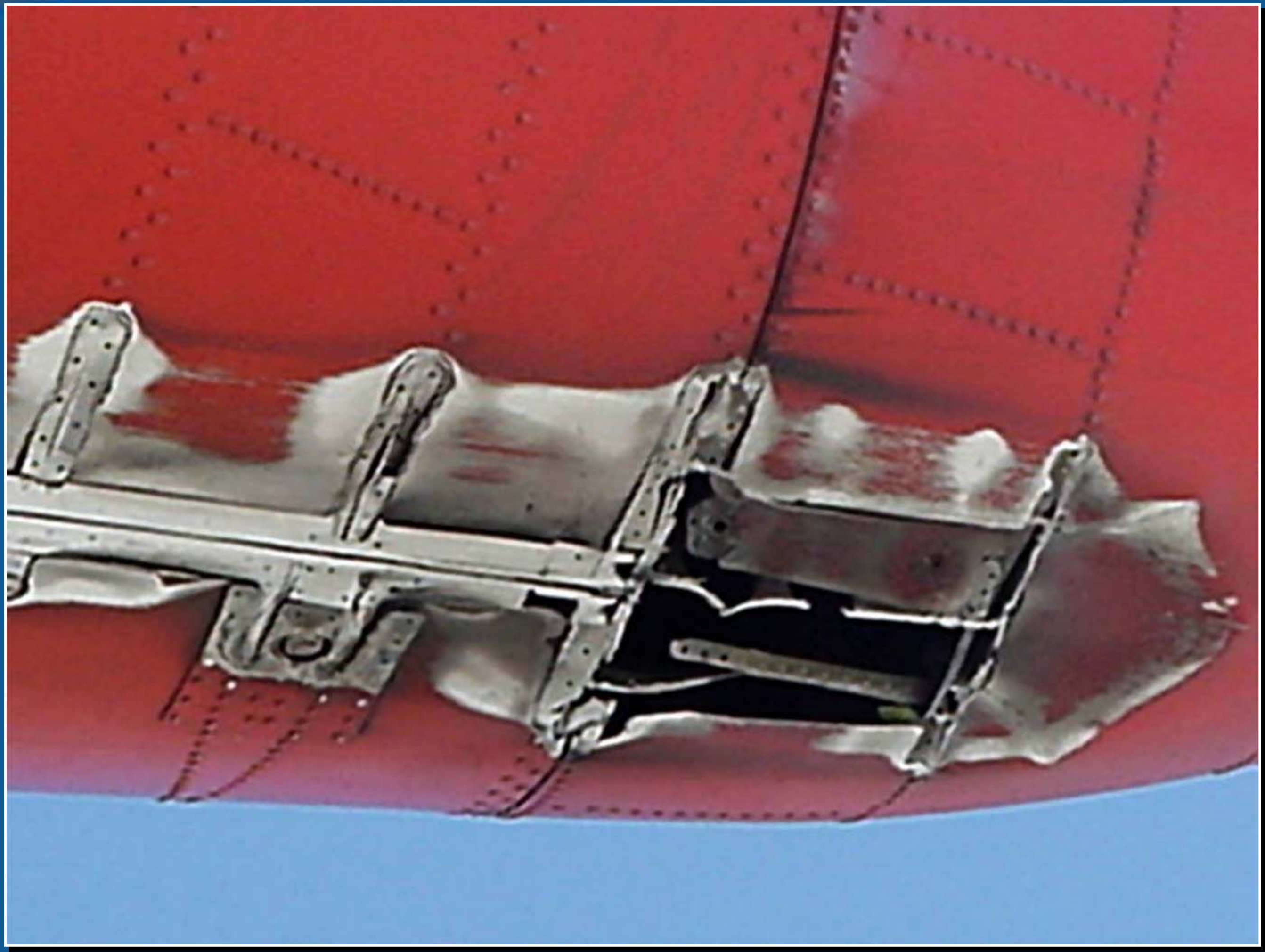
Tail Strikes and Strong Gusty Winds—Preventive Measures

Captain Dave Carbaugh
Chief Pilot, Boeing Flight Operations Safety
Boeing Commercial Airplanes

747 Classic Tail Strike



Tail Strikes Cost Millions of Dollars!

Presentation Overview

- General Information
- Review causes and prevention
- Operations in strong gusty winds
- Training recommendations and preventative measures
- Summary

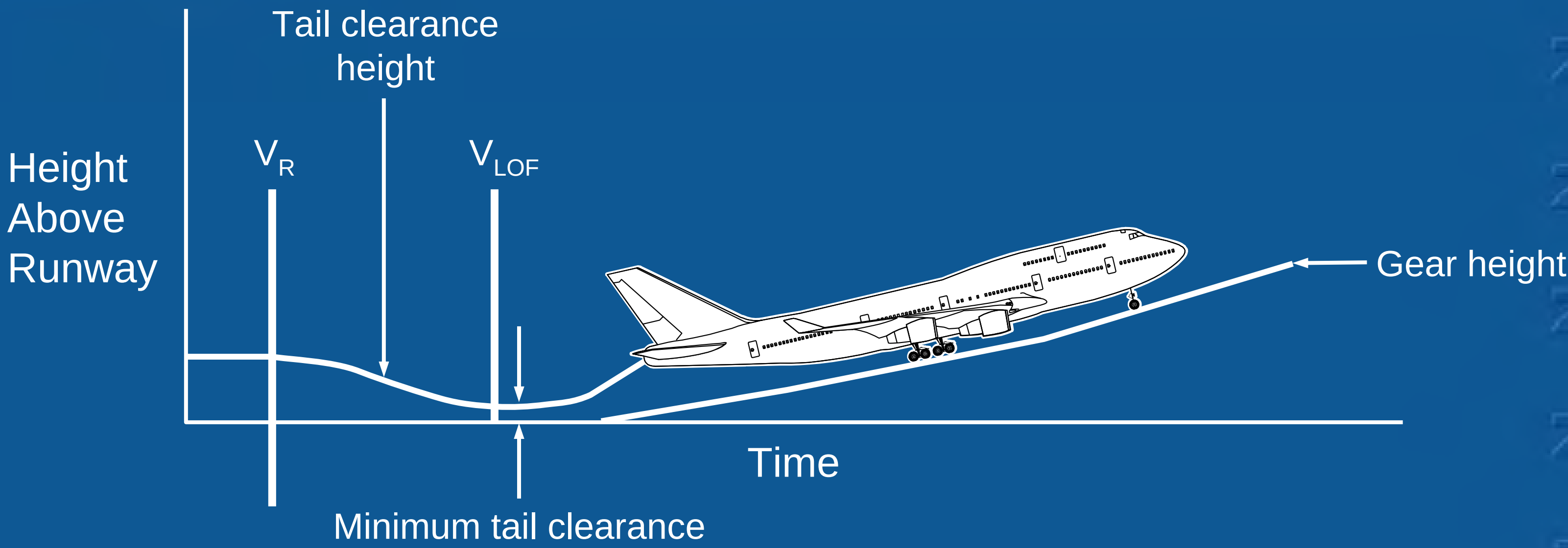
General Information

- Newer designs incorporate improved elevator feel systems and other design improvements
- Aircraft such as the 737-400, 737-800/-900, 767-300/-400, 777-300 have tail skids that prevents damage from takeoff tail strikes. Some provide landing protection also
- Longer bodied Boeing airplanes use relative higher speeds (speed additives to V1, VR, and V2, or approach speeds) to maintain equivalent tail clearance across models
- More tail strikes occur on landing than on takeoff on most models
- Tail strikes are cyclic

Tail Skid Contact

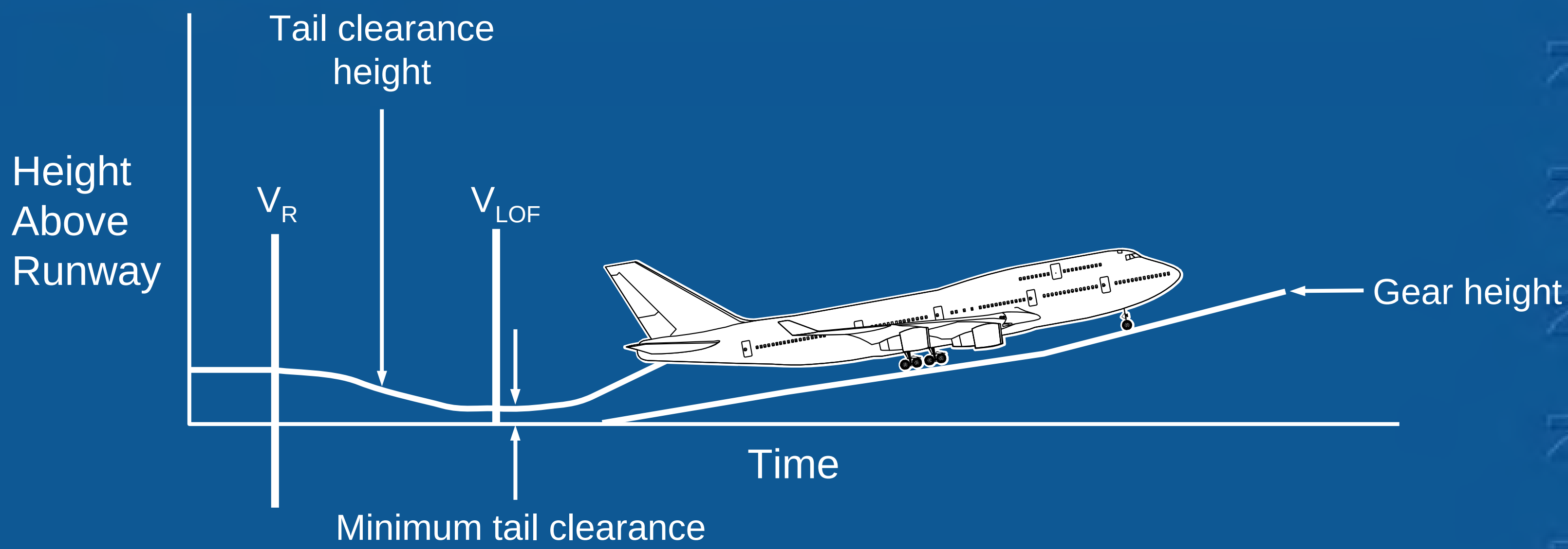
Tail Skid Crushable Cartridge

Typical Tail Clearance for T/O



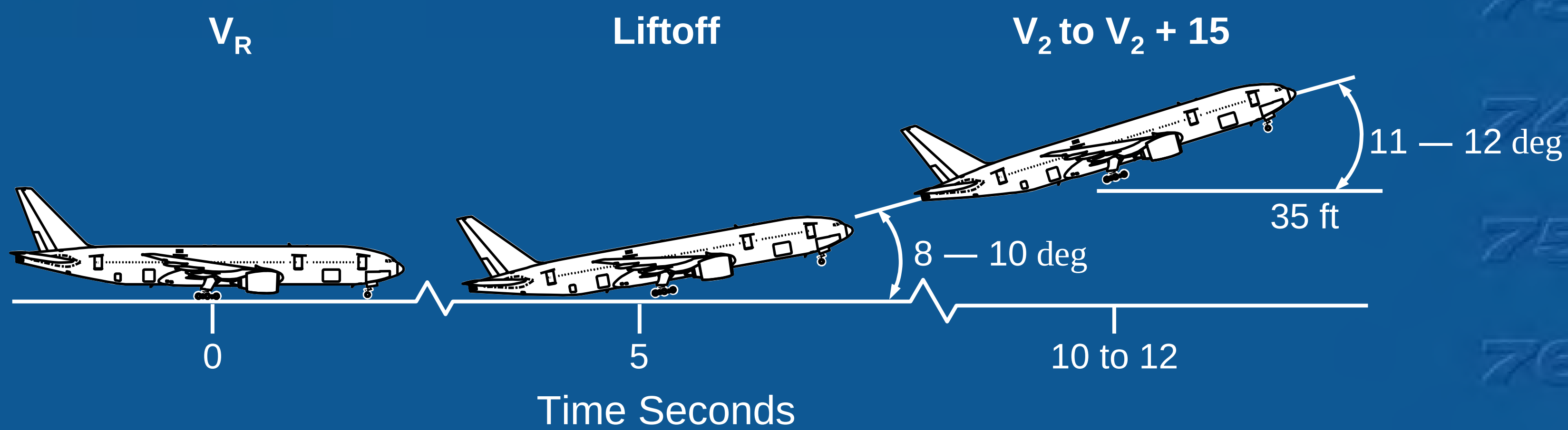
Model	Flap	Liftoff Attitude (deg)	Minimum Tail Clearance inches (cm)	Tail Strike Pitch Attitude (deg)
747-400	10 20	10.1 10.0	39 (99) 40 (102)	12.5 12.5

Typical Tail Clearance Engine Out Takeoff



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

777 Flight Crew Training Manual—Takeoff and Initial Climb



- Retract the landing gear after a positive rate of climb is indicated on the altimeter
- Retract flaps in accordance with the technique described in this chapter

Boeing Does Testing for Certification Involving:

- Abuse Cases
- Early Rotation
- Rapid Rotation
- No Flare
- Long Flare

Cross Wind Takeoffs and Landings

Engine Out Takeoffs and Landings

Takeoff **Risk Factors**

- Mis-trimmed stabilizer
- Improper rotation techniques
- Improper use of the flight director
- Rotation prior to VR-either:
  - Early rotation: Too aggressive, misinterpretation
  - Early rotation: Incorrect takeoff speeds (Human Factors)
  - Early rotations: V1 – VR split differences
- Excessive initial pitch attitude
- Crosswinds

Review of Proper Takeoff Techniques

- Use normal takeoff rotation technique
- Do not rotate early
- Do not rotate at an excessive rate or to an excessive attitude
- Ensure takeoff V speeds are correct and adjusted for actual thrust used*
- Consider use of greater flap setting to provide additional tail clearance
- Manage gusty winds and use proper amount of flight controls during crosswinds

** Note: From a human factor perspective, a common error with a high level of consequence*

<u>Landing</u> Risk Factors

- Un-stabilized approach
- Holding airplane off the runway in the flare
- Mis-handling of crosswinds
- Over-rotation during go-around

Sometimes a go around is the correct option

Note: Tail strikes on landing generally cause more damage. The tail may strike the runway before the main gear damaging the aft pressure bulkhead

Proper Landing Techniques

- Maintain an airspeed of Vref + 5 knot minimum to start of flare and fly the approach at “Specified Target Airspeed”
- 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 appropriate amount of rudder/aileron during cross wind approaches and landing
- Immediately after main landing gear touchdown, release back pressure on control wheel and *fly* the nose wheel onto the runway
  – Do not allow pitch attitude to increase after touchdown
  – Do not attempt to use aero braking — *it does not work!*

Tail Strikes During Gusty Wind and Strong Crosswind Conditions

Boeing Flight Crew Training all model change

- Consider a thrust setting near or at maximum takeoff thrust
  - Note: Light wt 747-400 requires de-rate and others may have requirements with Vmcg or other issues
- Momentarily delay rotation during the gust
- Use normal rate of rotation
- Use just enough control wheel input to maintain wings level
- Avoid excessive control wheel displacement
- Smoothly transition from slip after liftoff

Details to Consider During Gusty Winds and Strong Crosswind/Tailwind Operation

- Tail clearance margins are less due to crosswind flight control inputs and gusty winds
- Avoid the tendency to “pop” the airplane off the ground during rotation
- Rotate on the conservative side of the gust
- Use normal rate of rotation
  (a bit slower is better than faster)
- If after reaching takeoff attitude and the airplane is NOT airborne avoid the tendency to increase rotation rate
  – Slow or momentarily stop rotation rate
  – Do not increase rotation rate

Example: Aft Body Clearance Breakdown—Tail Strike #1

Factor		FDR Data	Clearance Reduction (inches)	Clearance Reduction from the Nominal Clearance of 37 inches (%)
Airspeed (below liftoff speed) 2.8 inches/knot		4 - 6	11”- 17”	30% - 46%
-ΔCL (reduction in lift due to lateral controls) 14 inches per 0.1 of -ΔCL		.07 - .14	10”- 20”	27% - 54%
Pitch Rate				
	Average Pitch Rate (Δ above nominal average rate) 2.8 inches per 0.1 deg/second	N.A.	N.A.	N.A.
	Maximum Pitch Rate (Δ above 4.0 deg/second) 1.3 inches per 0.1 deg/second	2.4	31”	84%

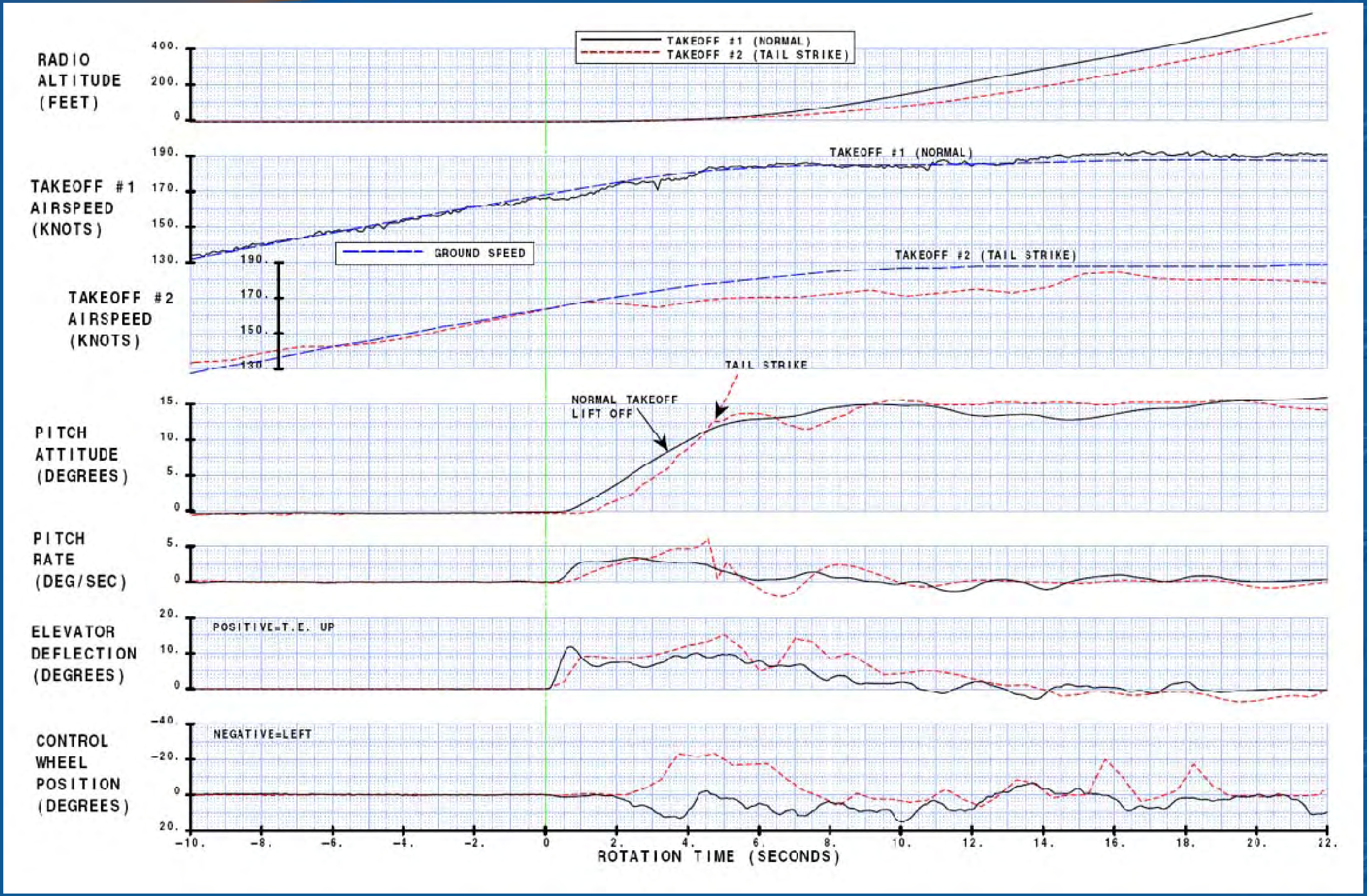
Note: Average pitch rate corrections are based on the maximum pitch rate being below 4.0 deg/sec. If maximum pitch rate is above 4.0 deg/sec then the maximum pitch rate correction should be used instead of the average pitch rate correction.	**Total Clearance Reduction**	52”- 68”	141% - 184%

Example: Aft Body Clearance Breakdown—Tail Strike #2

Factor	FDR Data	Clearance Reduction (inches)	Clearance Reduction from the Nominal Clearance of 37 inches (%)
Airspeed (below liftoff speed) 2.8 inches/knot	7 - 9	20”- 25”	54% - 68%
-ΔCL (reduction in lift due to lateral controls) 14 inches per 0.1 of -ΔCL	.05 - .06	7”- 8”	19% - 22%
Pitch Rate			
Average Pitch Rate (Δ above nominal average rate) 2.8 inches per 0.1 deg/second	N.A.	N.A.	N.A.
Maximum Pitch Rate (Δ above 4.0 deg/second) 1.3 inches per 0.1 deg/second	2.0	26”	70%

Note: Average pitch rate corrections are based on the maximum pitch rate being below 4.0 deg/sec. If maximum pitch rate is above 4.0 deg/sec then the maximum pitch rate correction should be used instead of the average pitch rate correction.	**Total Clearance Reduction**	53”- 59”	143% - 160%

Tail Strike Comparison



Example: Aft Body Clearance Breakdown

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 to10 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 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 <u>increase</u> in liftoff speed by 1 knot would <u>increase</u> the aft body clearance by 2.8 inches, and each 0.1 deg/sec of average pitch rate <u>below</u> 2.5 deg/sec would <u>increase</u> aft body clearance by 2.8 inches*

Tail Strikes

IS THERE A TRAINING STRATEGY TO PREVENT THEM?

Threat and Error Management
Strong Gusty X-Wind Example

Note: With regards to managing threats and errors, crews can get complacent during routine ops.

Does the crew say nothing or do they discuss the…

THREAT?

Threat and Error Management
Strong Gusty X-Wind Example

Identify and discuss the threat (before Takeoff/Landing Briefing)

- Plan and brief strategies
  - Review appropriate x-wind takeoff procedure and techniques for operating in strong gusty winds (e.g. Boeing FCTM)
  - PF reviews with PM the threat strategy for takeoff and landing
  - PM monitors airspeed versus rotation callout to PF as well as airspeed stagnation during rotation to takeoff target pitch attitude
  - Captain monitors FO pitch rate and attitude during FO takeoff

Tail Strike Big Concerns

- Tail strike damage can cause pressure bulkhead failure
- Short term, if damage is not corrected or flight is continued-risk of structural failure, hence crews need to follow the QRH guidance to depressurize
- Long term, if repair was not properly corrected-risk of structural failure

Maintenance Issue

- Post tail strike flight-ensure maintenance inspection prior to next flight
  - Maintenance inspection must be accomplished by qualified maintenance personnel
  - Aircrews are ***not*** qualified to conduct this inspection

Training Recommendations

As the crew member:

- Assess yourself in training or during your next operational takeoff and landing
- Assess each other's rotation rates and techniques
- When training in the simulator, check your tail clearance if this function is installed

As the trainer or check airmen:

- Evaluate tail clearance during takeoffs and landings
  - 1st experiences are the most valuable
  - In training, build good takeoff rotation and landing techniques
  - Evaluate rotation rates and landing techniques during all recurrent training and line evaluations

Example of an Airline Tail Strike Prevention Program

- Reduced operational tail strikes to almost nil
- Use of a crew *self* monitoring tail strike clearance tool
  - Pitch report for every takeoff and landing available for crew review
  - If within 2 degrees of maximum, it auto prints
  - Other airlines are adopting

Training—To Prevent Tail Strikes

Crew members:

- Adhere to proper takeoff and landing techniques
- Apply the lessons learned. Know the pitfalls.
- Don’t assume! Double check the takeoff data, especially if something doesn’t look right. Coordinate insertion of the ZFW with another crew member. Double check data with the load sheet.
- Know your airplane! Have an idea about the approximate T/O and Approach speeds. When setting airspeed bugs always do a “Reasonable Check!”
- Must be aware of the differences between models and types, especially when transitioning from other equipment
- If a tail strike occurs, follow the CHECKLIST!

Tail Strike Prevention (continued)

Management should:

- Ensure instructors and evaluators stress proper landing and takeoff techniques during all training and evaluations
- In training-stress differences
- Make “Tail Strike Prevention” part of the safety program
  - Posters, Briefings, Videos, CBT, CDs, etc.
- Make available in the simulator tail clearance measuring tools for all takeoffs and landings during simulator training and evaluations, (provide feedback to crews)
- Use a self measuring tail strike operational tool in the airline’s fleet

Note: Ensure that FOQA is not used as a punitive device

New Preventive Measures

Future strategy discussions at Boeing

- TSP (Tail Strike Protection) in 777
- Smarter FMCs

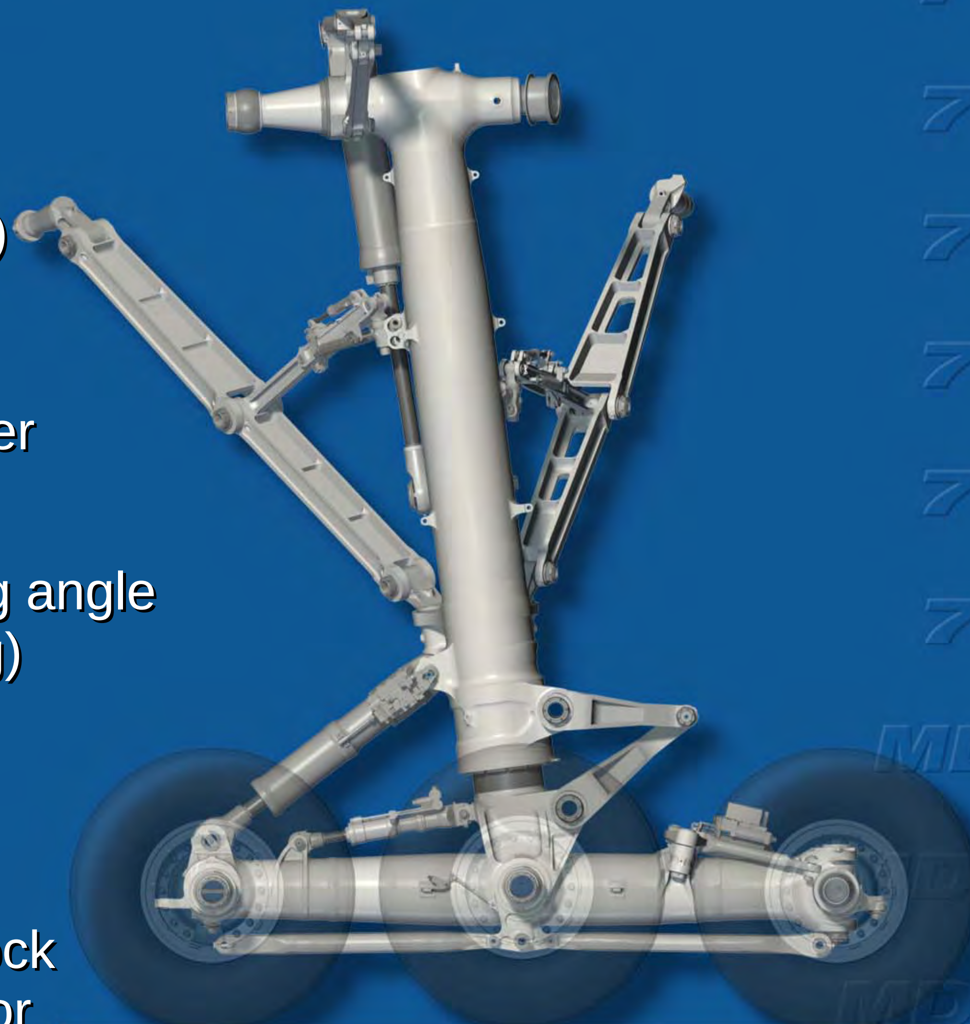
Tail Strike Prevention Items 777-300ER

Tail Strike Protection (TSP)

- New semi-levered main gear
- New wheels, tires and brakes
- Retract actuator size increased

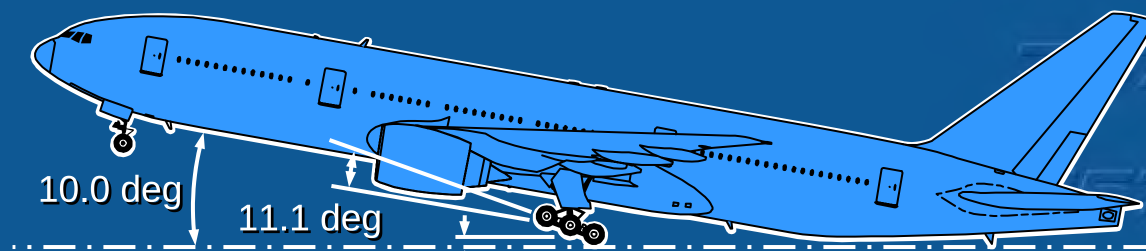
777-300ER Main Landing Gear

- New shock strut (1 inch larger diameter)
- New 52x21r22 radial tire (current 777 tire is 50x20r22)
- New wheel and brake
- New truck beam (1 inch larger diameter, 1.2 inches longer)
- Maximum main gear steering angle 6.5 deg (current 777 is 8 deg)
- New semi-lever gear
- Adjustable side struts
- New retract actuator, downlock actuator and steering actuator



Semi-Lever Main Landing Gear (SLG)

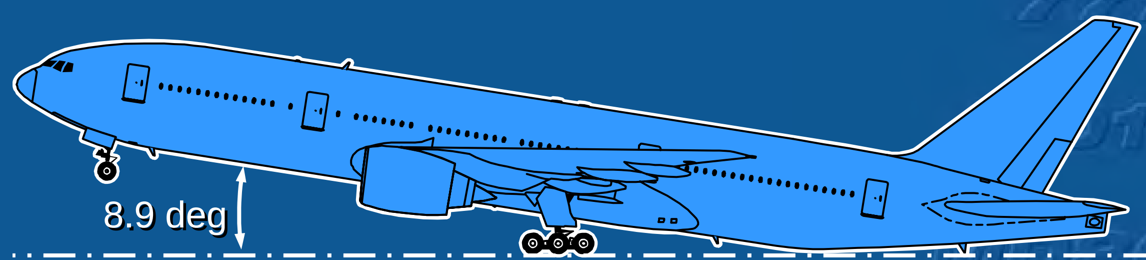
- Effectively lengthens the main landing gear providing increased angle of attack on takeoff rotation (~ 1.1 deg)
- Increased angle of attack provides more lift (~ 15,000 lb) for same field length



Vmu Takeoff With SLG

or

- Increased angle of attack provides less field length (~ 600 ft) for same aircraft gross weight



Vmu Takeoff Without SLG

Semi-Lever Gear Takeoff Mode

- SLG hydraulic strut attaches forward end of truck beam to outer cylinder
- SLG hydraulic strut locks hydraulically during takeoff roll
- Increased shock strut precharge provides additional energy required for improved takeoff performance

Tail Strike Protection

- A pilot over-rideable, protective control law in Normal Mode, comparable to stall and overspeed protection
- Purpose is to reduce the frequency and severity of tail strikes without interfering with normal takeoffs
- Computes tail skid height above the runway and tail skid closure rate to determine potential tail strikes
- Reduces a nose-up elevator command if skid height and rotation rate indicate an impending contact
- Tail Strike Protection elevator command limited to 10 degrees with no feedback to the control column

Summary

- Tail strikes are preventable
- Standard recommendations when followed are successful
- Strong and gusty winds provide additional challenges and solutions
- Training is key to prevention
- Technology is also helping


Thank You