

Use of rudder on Boeing aircraft



According to Boeing the Primary uses for rudder input are in crosswind operations, directional control on takeoff or roll out and in the event of engine failure.

This Briefing Leaflet was produced in co-operation with Boeing and supersedes the IFALPA document 03SAB001 and applies to all models of the following Boeing aircraft: 707, 717, 727, 737, 747, 757, 767, 777, 787, DC-8, DC-9, DC-10, MD-10, md-11, MD-80, MD-90

Background

As part of the investigation of the American Airlines Flt 587 crash on Long Island, USA the United States National Transportation Safety Board (NTSB) issued a safety recommendation letter which called for pilots to be made aware that the use of “sequential full opposite rudder inputs can potentially lead to structural loads that exceed those addressed by the requirements of certification”. Aircraft are designed and tested based on certain assumptions of how pilots will use the rudder. These assumptions drive the FAA/EASA, and other certification bodies, requirements. Consequently, this type of structural failure is rare (with only one event over more than 45 years). However, this information about the characteristics of Boeing aircraft performance in usual circumstances may prove useful.

Rudder manoeuvring considerations

At the outset it is a good idea to review and consider the rudder and its aerodynamic effects. Jet transport aircraft, especially those with wing mounted engines, have large and powerful rudders these are necessary to provide sufficient directional control of asymmetric thrust after an engine failure on take-off and provide suitable crosswind capability for both take-off and landing. As the aircraft flies faster, less rudder is needed for directional control and therefore the available rudder deflection is reduced. This reduction is achieved by rudder limiting (discussed in more detail later). Manoeuvring the aircraft using rudder will result in yaw and a secondary roll response – with

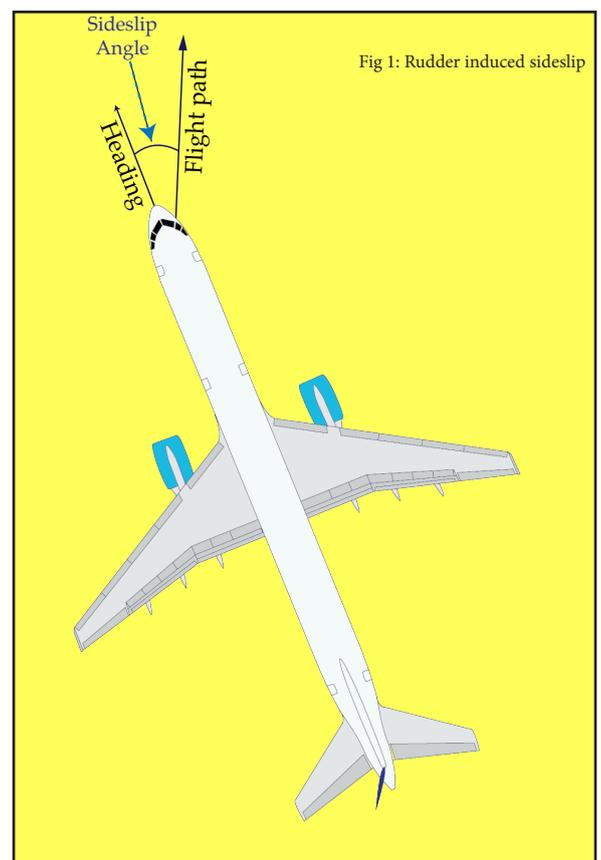
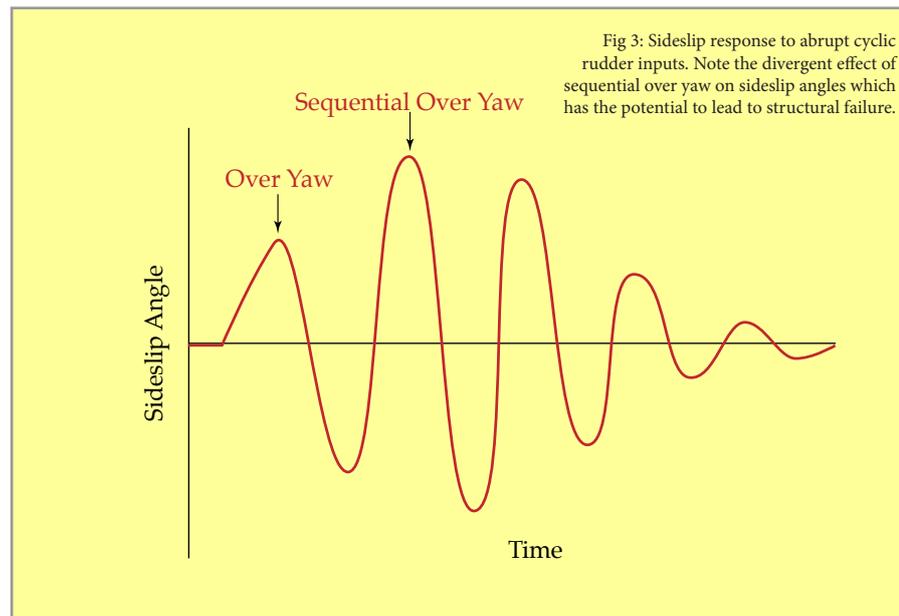
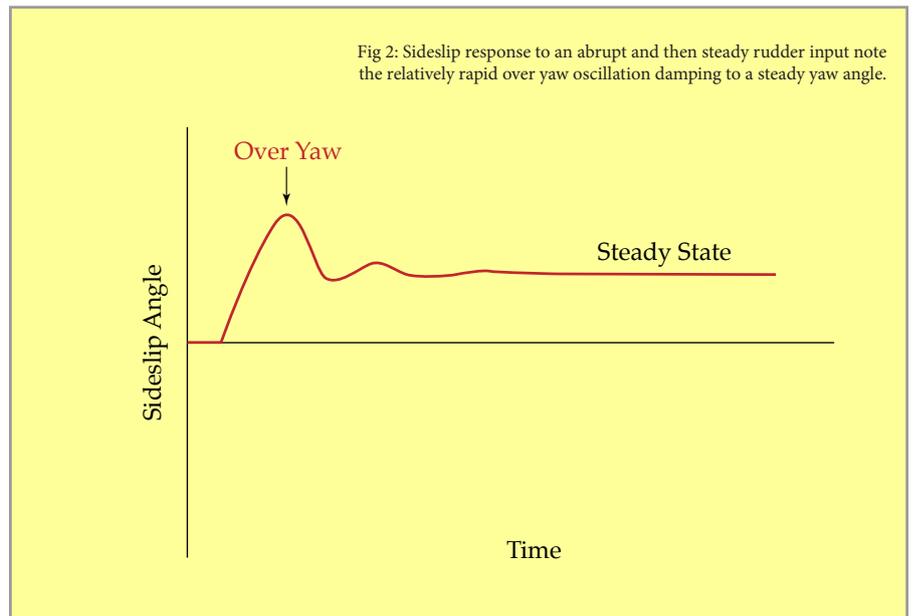


Fig 1: Rudder induced sideslip

the roll developed as a result of sideslip. For example, if the pilot applies left rudder the nose will yaw left (see Fig 1), this yaw will generate a sideslip (right wing forward) this sideslip will cause the aircraft to roll to the left. The actual force on the vertical stabiliser due to rudder deflection would naturally induce a roll in the opposite direction but as the sideslip blankets the left wing the net roll is to the left.

It is difficult to perceive sideslip and few modern aircraft have true sideslip indicators. In the instrument panels of older aircraft the “ball” was an indicator of side force or acceleration rather than sideslip angle. Some newer aircraft have electronic flight displays with a slip/skid indication (“the brick”) but these are still an indication of side force or acceleration, not sideslip angle. As more rudder is applied, more sideslip is generated

and a greater roll response will be induced. Large abrupt rudder inputs can generate very large sideslip angles – much larger than encountered in a steady state sideslip (that is one which is reached with a slow pedal input and held for a period of time). This is due to the dynamic response characteristics of the aircraft (see Fig 2). This “overyaw” can amplify the roll rate and therefore it is important to use the rudder carefully so that unintended large sideslip angles and resulting roll rates do not develop. The key consideration to remember is that the amount of roll rate induced by yaw is proportional to sideslip angle not rudder deflection.



Precise roll control using rudder is difficult because sideslip must build up to generate a roll moment, there is a time lag between the input and the perception of a roll. This lag has caused pilots to be surprised by an abrupt roll onset and have, in some cases, interpreted the seemingly un-commanded roll as due to outside forces not related to their rudder input. This misinterpretation led to another large rudder input in the opposite direction that in turn has led to large amplitude oscillations in roll and yaw. This type of cyclic rudder pedal inputs can lead very large amplitude sideslip oscillations (See Fig 3). The sideslip angle that is momentarily reached with this type of sequential over yaw can be much larger than that seen as the result of a single abrupt rudder input. Furthermore, when the rudder is reversed at this sequential over yaw sideslip angle the rudder-induced

forces on the vertical stabiliser fin are added to the sideslip induced fin forces (see Figs 4 & 5). The resulting structural loads can exceed limit loads¹ and possibly ultimate loads² – leading to structural damage.

Design manoeuvring speed

A structural design manoeuvring speed or V_a is defined for evaluating aircraft structural design. At or below this speed, Boeing aircraft are capable of sustaining a single maximum deflection input to any control surface – elevators, ailerons or rudders (as limited by control surface limiters, blowdown or control stops). It should be noted that these control surface inputs are to be in one axis (i.e. not in combination) and do not include control input reversal or oscillatory inputs. In addition Boeing have evaluated the effect of full rudder deflection to the maximum operating speed (V_{mo}/M_{mo}) and on certain models out to the design speed V_d/M_d (typically 30kts/0.5-0.7M faster than V_{mo}/M_{mo}).

As a result, pilots need not be concerned with how hard or fast to push the rudder in one direction from zero to full deflection in a single direction, anywhere within the flight envelope (from a structural point of view).

V_a is provided in most FAA/EASA approved flight manuals within *Section 1 – Limitations* under the heading *Maximum Airspeed Limits* and is usually shown for the most critical gross weight. The more commonly known Turbulent Air Penetration Speed gives

Note 1: Limit loads are the maximum loads expected in service

Note 2: The ultimate load is the limit load multiplied by the safety factors typically 1.5.

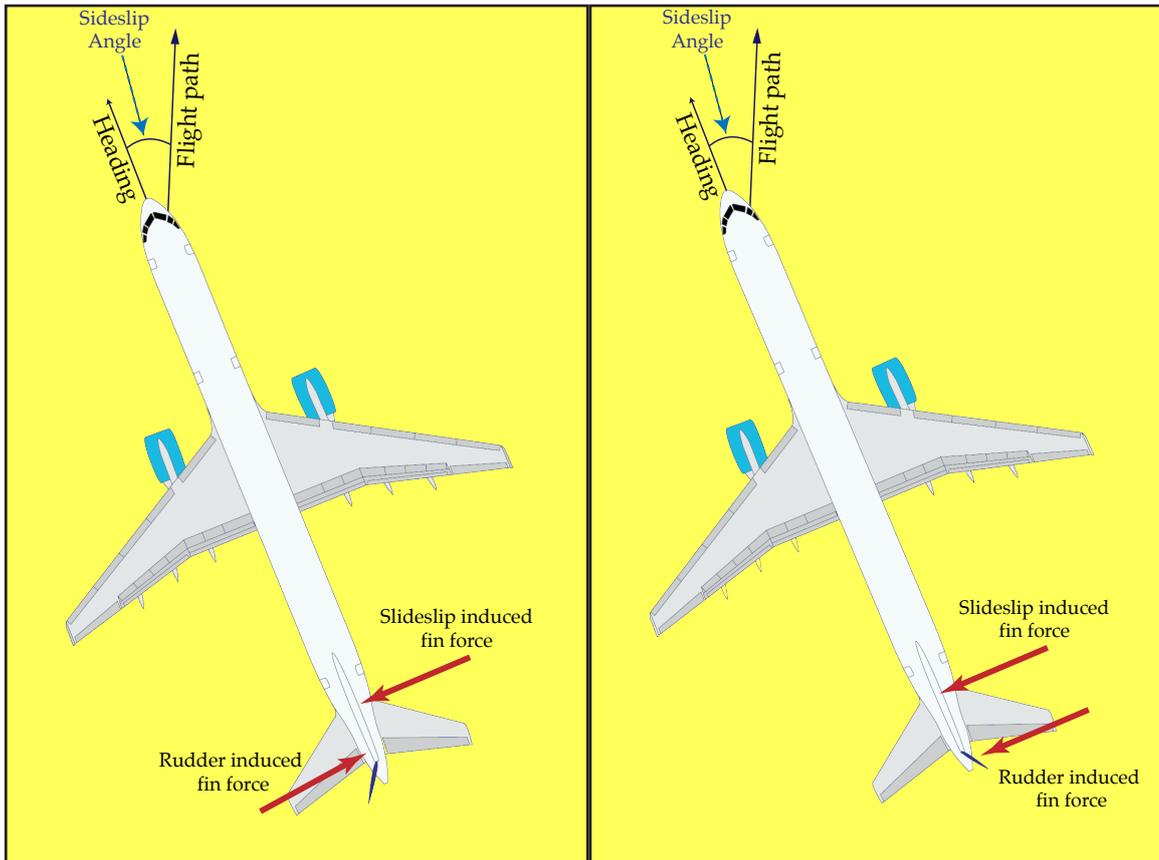


Fig 4 & 5: The loading effects of rudder induced sideslip forces and rapid rudder reversal forces. Note the torsional loads imposed on the vertical stabiliser as a result of cyclic application of rudder.

a rough approximation to V_a . It should be pointed out that many aircraft have a structural integrity well beyond that required by the minimum structural design criteria set out by the regulators. V_a should not be confused with the minimum or recommended manoeuvre speed for each flap setting used in daily operations. Those speeds are based on aerodynamic margins to stickshaker, flap placard and acceleration/deceleration capability during flap changes.

NTSB Recommendations

Following on from its investigation of the AA587 crash the NTSB made a series of recommendations concerning rudder use and its limitations, these recommendations and Boeing's response are set out below:

1. Explain to Flight Crews the structural certification requirements for the rudder and vertical stabiliser on transport category aircraft.

The FAA/EASA have three rudder manoeuvre structural load design requirements, which the rudder and vertical fin must meet in order to be certified³. These requirements are met for all airspeeds up to the design manoeuvring speed. In addition, newer aircraft designs meet these requirements up to the design dive speed.

- ▶ At a zero sideslip condition; the aircraft must be able to withstand a rapid rudder input to full rudder deflection. A Safety Factor of 1.5 is then applied. This means the structure must have at least a 50% safety margin over the maximum load generated by this manoeuvre.
- ▶ Starting from a zero sideslip condition, the aircraft must be able to withstand a rapid rudder input to full deflection that is held at full deflection until the maximum sideslip angle (over yaw) is achieved. The aircraft will exceed the maximum steady state sideslip due to the dynamic response characteristics of the aircraft. A Safety Factor of 1.5 is then applied.
- ▶ Starting from a maximum steady heading sideslip condition, the rudder is rapidly returned to neutral while maintaining the sideslip angle. A Safety Factor of 1.5 is then applied.

During certification, Boeing does not flight test these exact conditions, but gathers flight test data to validate structural loads analysis. This analysis, combined with ground structural load testing, ensures that the structure meets design requirements.

The FAA/EASA impose structural load design requirements in addition to these rudder manoeuvre requirements. These include requirements for loads due to gusts, engine failure dynamics, and lateral control induced rolling conditions. Boeing aircraft vertical fins can also sustain loads if the rudder is rapidly returned to neutral from the over yaw sideslip or the rudder is fully reversed from a full steady state sideslip.

Note 3: These conditions are engineering design conditions that may be physically impossible to fly.

2. Explain to Flight Crews that a full, or nearly full, rudder deflection in the opposite direction, or certain combinations of sideslip angle and opposite rudder deflection can result in potentially dangerous loads on the vertical stabiliser, even at speeds below the design manoeuvring speed.

Boeing aircraft are designed to withstand the structural loads generated by a full rudder input out to the aircraft's maximum operating airspeed, V_{mo}/M_{mo}. Some Boeing aircraft meet these requirements out to the design dive speed. This means the structure has at least a 50% safety margin over the maximum load generated by this kind of manoeuvre. As previously mentioned, Boeing aircraft vertical fins can also sustain loads if the rudder is rapidly returned to neutral from the over yaw sideslip or the rudder is fully reversed from a full steady state sideslip.

Boeing aircraft are not designed to a requirement of full authority rudder reversals from an "over yaw" condition. Sequential full or nearly full authority rudder reversals may not be within the structural design limits of the aircraft, even if the airspeed is below the design manoeuvring speed. There are no Boeing Procedures that require this type of pilot input. It should also be pointed out that excessive structural loads may be generated in other areas of the aircraft, such as engine struts, from this type of control input. In addition, large sideslip angles may cause engine surging at high power settings. It is important to note that use of full rudder for control of engine failures and crosswind takeoffs and landings is well within the structural capability of the aircraft.

3. Explain to Flight Crews that on some aircraft, as speed increases, the maximum available rudder deflection can be obtained with comparatively light pedal forces and small pedal deflections.

Implementation of the rudder limiting function and associated forces vary from model to model. The force a pilot feels when pushing on the rudder pedals of a Boeing aircraft is analogous to that of a force generated by a spring. The more the pedal is displaced the greater the required force. All modern transport aircraft limit rudder deflection as airspeed increases. Engine out take-off and crosswind landing requirements define the maximum rudder deflection (authority). As the aircraft flies faster, less deflection is needed and rudder authority is therefore reduced. Some Boeing models (747, 757, 767, 777 & 787) have rudder limiters that reduce the rudder authority by changing the gearing between the rudder and the rudder pedals. As the aircraft speeds up, the pilot must continue to fully deflect the rudder pedal to command full available rudder, even though the maximum available rudder deflection has been reduced. This means the pilot will have to apply the same force to the rudder pedal to achieve maximum available rudder deflection throughout the flight envelope.

On other Boeing models (707, 717, 727, 737, DC-8, DC-9, MD-80, MD-90, DC-10 & MD-11), as the aircraft speeds up, the rudder authority is limited, but the gearing between the rudder and the rudder pedal does not change. Since rudder authority is limited, rudder pedal travel is also limited; i.e. full rudder pedal deflection is not required to get full available rudder deflection. Rudder pedal force is a function of rudder pedal deflection, so less force will be required to achieve maximum available rudder deflection as airspeed increases

	V ₁ (135kts)			250kts			FL330 - M _{Mo}		
	Pedal Force (lbs)	Pedal Travel (in)	Rudder Deflection (deg)	Pedal Force (lbs)	Pedal Travel (in)	Rudder Deflection (deg)	Pedal Force (lbs)	Pedal Travel (in)	Rudder Deflection (deg)
707	70	2.3	24	100	1.3	9	100	1.1	7
717	75	3.3	29	65	1.6	13	40	0.5	4
727	80	3	18	50	1.3	7	45	1.3	6
737	70	2.8	18	50	1.0	4	50	1.0	4
747	80	4	30	80	4	12	80	4	8
757	80	4	26	80	4	6	80	4	5
767	80	3.6	26	80	3.6	8	80	3.6	7
777	60	2.9	27	60	2.9	9	60	2.9	6
787	65	3.8	22	65	3.8	6	65	3.8	4
DC-8	85	3.6	32	65	1.5	13	60	1.0	8
DC-9	75	2.6	22	60	1.1	8	30	0.4	3
DC-10	80	3.8	23	65	2	14	55	1.5	9
MD80	75	2.6	22	60	1.1	8	30	0.4	3
MD-90	75	3.3	29	65	1.6	13	40	0.5	4
MD-11	80	3.8	23	65	2.2	15	60	1.7	11

Table 1 contains approximate values for rudder pedal force, rudder pedal travel and rudder deflection for the models listed. Three flight conditions (airspeeds) are presented: V₁ (135 knots), 250 knots, and M_{mo} at FL390. Source: Boeing

Aircraft do vary on the amount of rudder pedal force and displacement required to achieve maximum available rudder as airspeed changes. It is important that pilots understand their aircraft's feel and response characteristics to flight control inputs. By understanding and becoming familiar with the aircraft's characteristics, pilots will learn to apply the appropriate control input in response to various flight situations.

4. Carefully review all existing and proposed guidance and training provided to pilots of transport-category aircraft concerning special manoeuvres intended to address unusual or emergency situations and, if necessary, require modifications to ensure that flight crews are not trained to use the rudder in a way that could result in dangerous combinations of sideslip angle and rudder position or other flight parameters.

Boeing agrees that additional and more comprehensive dissemination of information to flight crews about aircraft characteristics and capabilities may prove useful. For example, Boeing strongly supports industry efforts to improve training of airline flight crew in:

- ▶ Techniques of large aircraft upset recovery
- ▶ Appropriate response to wake vortex encounters
- ▶ Consequences of pilot initiated security related in-flight manoeuvres.

To aid in pilot education, a significant amount of material is currently available and should be incorporated and stressed in pilot training programs. For example, Boeing Flight Crew Training Manuals and Flight Crew Operating Manuals contain material on upset recovery guidance that includes guidance on the proper use of the rudder. The Quick Reference Handbook (QRH), in the *Non-Normal Maneuvers* section under Upset Recovery contains the Warning: **“Excessive use of pitch trim or rudder may aggravate an upset situation or may result in loss of control and/or high structural loads.”** In addition, Boeing has published related information such as the article *“Aerodynamic principles of large aircraft upsets”* in its *AERO* magazine (Vol. 3 1998) and the Aircraft Upset Recovery Training Aid in which similar guidance was provided in a much more detailed format. Boeing supports efforts that will assure that this information and other similar materials reliably reach pilots in line operations.

Additionally, there may be misconceptions among transport pilots about the use of flight controls, how aircraft may be manoeuvred, and what are the structural load capabilities of transports. These misconceptions may be due to previous experience with other aircraft classes or configurations (e.g., tactical military aircraft, small General Aviation {GA} aircraft). Such misconceptions could lead transport pilots to attempt manoeuvres in unusual situations that could make the situation worse and introduce excessive risk. The issue is further compounded by the limitations in simulator fidelity that may cause pilots to assume some manoeuvres are feasible and repeatable.

Boeing recommends that:

- ▶ Transport pilots should be made aware that certain prior experience or training in military, GA, or other non-transport aircraft that emphasizes use of rudder input as a means to manoeuvre in roll typically does not apply to transport aircraft or operations.
- ▶ Transport pilots should be made aware that certain prior experience or training in military, GA, or other non-transport aircraft types emphasizing the acceptability of unrestricted dynamic control application typically does not apply to transport aircraft or operations. Excessive structural loads can be achieved if the aircraft is manoeuvred significantly differently than what is recommended by the manufacturer or the operator's training program. Finally, as background information, crews should “optionally” be able to learn more about their aircraft, such as how certain regulatory certification practices are accomplished. This could help them better understand what their aircraft have been tested for, the manoeuvres their aircraft have been shown to be capable of safely doing, and conditions that have not specifically been tested. For example, a manufacturer is required to demonstrate full stall and stall recovery characteristics. The FAA assesses whether the characteristics during a full stall are acceptable and that the recovery does not require any unusual pilot technique. Note that these stalls are not done in large dynamic yaw rate or sideslip conditions. Boeing aircraft have demonstrated entry and recovery from full stalls without the need for rudder. Boeing strongly recommends that the rudder not be used in a stall recovery, and that stall recovery should be accomplished before proceeding with any unusual attitude recovery. Once the stall recovery is complete, the ailerons/spoilers should provide adequate rolling moment for unusual attitude recovery. Unless a transport aircraft has suffered significant loss of capability due to system or structural failure (such as a loss of a flap or thrust reverser deployment), rudder input is generally not required.

In simple pilot terms, if you are in a stall, don't use the rudder; if you are not in a stall, you don't need the rudder. The rudder in a large transport aircraft is typically used for trim, engine failure, and crosswind takeoff and landing. Only under an extreme condition, such as loss of a flap, mid air collision, or where an aircraft has pitched to a very high pitch attitude and a pushover or thrust change has already been unsuccessful, should careful rudder input in the direction of the desired roll be considered to induce a rolling manoeuvre to start the nose down or provide the desired bank angle. A rudder input is never the preferred initial response for events such as a wake vortex encounter, windshear encounter, or to reduce bank angle preceding an imminent stall recovery.

Finally, after 9/11, there was much discussion about aggressively manoeuvring the aircraft to thwart a hijacking attempt. The Boeing recommendation in this situation has been to rely on manoeuvres that do not apply inputs to the rudder. The issues discussed in this bulletin have shown the risks associated with large rudder inputs. The use of ailerons and elevators in this situation has limitations as well. Elevators and ailerons are not designed for abrupt reversals from a fully displaced position. In all cases the manufacturer's specific recommendations for aggressive manoeuvring should be followed. Random unplanned manoeuvres outside the manufacturer's recommendations can lead to loss of control and/or structural damage.

(For more information about aggressive manoeuvring as an anti-hijacking tactic see the IFALPA Briefing Leaflet 03ADOBL01 [click here](#) to access)

Boeing's rudder usage FAQs

1. The NTSB recommendation mentions that any new rudder training should not compromise the substance or effectiveness of existing training regarding proper rudder use (i.e. engine out during takeoff, crosswind landings). Please provide Boeing comments about this.

- ▶ *Service history and previous investigations demonstrate that pilots must be willing to use full available control authority in certain specific situations such as engine out during takeoff. We agree with the NTSB that any new guidance that is developed must not undermine this training.*

2. During an engine failure situation, would an initial input of rudder in the wrong direction followed by a rapid full input in the opposite direction cause structural problems with the rudder or vertical stabiliser?

- ▶ *No, such a manoeuvre does not result in excessive loads being produced.*

3. Some non-normal procedures call for using maximum force to overcome jammed controls. If I have a jam in one direction and do the procedure and the jam frees itself will I overstress the aircraft?

- ▶ *If the rudder is jammed off neutral, the aircraft will establish itself in a steady state sideslip. The removal of the jam condition will not overstress the aircraft.*

4. At what point are the stresses on the tail at the maximum if I put in full rudder? Right before the limiter starts reducing the travel? Maximum speed?

- ▶ *The point of maximum stress will depend on the aircraft type, configuration, and specific manoeuvre. However, from a zero sideslip condition the maximum available rudder can be applied in one direction out to the maximum operating speed, V_{mo}/M_{mo} , and for some models, out to the design dive speed, V_d/M_d .*

5. At high angles of attack, beyond stick shaker, the roll effectiveness of the ailerons and spoilers is decreased. On some aircraft this is more pronounced than others. Should I use rudder, up to full authority, to assist in maintaining wings level, especially if I encounter a back and forth rolling motion?

- ▶ *If the aircraft is stalled the use of rudder for roll control is not recommended. Precise roll control using rudder is difficult, and the use of rudder could aggravate the situation. If after applying full nose down elevator and reducing thrust, a pitch down response does not occur, apply a small amount of rudder to initiate a roll and resultant pitch down. As roll control is regained, the rudder should be centred.*

6. During a wind shear recovery, large control wheel inputs can cause the spoilers on one wing to deflect, with a resultant reduction in lift and increase in drag. Should I keep the control wheel level and use rudder to control roll?

- ▶ *In wind shear recovery the use of rudder is not recommended. Precise roll control using rudder is difficult, and the use of rudder could aggravate the situation. Additionally, from a human factors standpoint, it is not reasonable to expect pilots to maintain a level control wheel in these conditions as a reaction to roll upsets. Lift loss and drag produced from spoiler deflection during upset recovery is momentary.*

7. In the 747 with an engine failure at V1 I am taught the technique of full rudder then take 1/2 of it out and hold. Does that put undue stress on the tail?

- ▶ *This technique for rudder movement does not put undue stress on the tail structure.*

8. If my aircraft is upset and in a 90-degree bank and the ailerons appear to be ineffective, should I smoothly put in rudder or can I aggressively put it in? What should I do when it rapidly reverses the roll?

- ▶ *The first action to take is to unload the aircraft to the point of being "light in the seat" to improve roll capability. If this*

does not improve roll control then the smooth application of small amounts of coordinated rudder in the direction of the desired roll can assist in rolling the aircraft. Aggressive rudder application could cause a rapid roll. If this occurs, the rudder should be moved to neutral and aileron control used to complete the recovery.

9. What pilot action should I take to recover when I encounter wake turbulence?

- ▶ *Normal piloting actions for roll control are sufficient for large commercial jet transports. If a roll off does occur, the normal use of ailerons and spoilers should be sufficient to recover. The use of rudder is not recommended. The induced roll from the vortex will be more severe for short span aircraft (relative to the aircraft that generated the vortex) but the recovery procedures are the same. Crews should perform the upset recovery procedures if bank angles of greater than 45 degrees are encountered.*

10. Does Boeing have pre-planned upset recovery scenarios that can be plugged into the simulator and activated by the instructor?

- ▶ *Boeing does not have pre-planned system failure upset recovery scenarios. Simulator manufacturers have assisted some carriers in activating such scenarios. Boeing does provide Simulator Training Exercise in the Aircraft Upset Recovery Aid. These exercises demonstrate techniques for recovering from an upset regardless of the cause. The training recommended in the Training Aid has been researched and test flown to ensure that sideslip and angle of attack limits are not exceeded. Additional simulator envelope information is provided in the Appendix to the Training Aid. Therefore, simulator action correctly mimics real aircraft performance. Simulators flown outside the limits of valid data can present misleading aircraft response. Airlines should use caution when activating preloaded scenarios such that data limits are not exceeded and that poor habit patterns are not instilled that will have negative consequences.*

11. How much force are Boeing tails designed to withstand?

- ▶ *The tail structures of Boeing aircraft are designed to withstand at least 1.5 times the maximum forces aircraft are expected to encounter in service.*

12. Has the vertical tail of a Boeing commercial jet ever failed in flight?

- ▶ *No vertical tail has ever broken off a Boeing commercial jet in revenue service due to rudder movements. There was a 747 accident in 1985 in which significant damage occurred to the vertical tail when the aft pressure bulkhead failed and the aircraft rapidly decompressed. Additionally, structural damage has occurred due to lightning strikes, midair collisions, and engine failures. Damage has also occurred in flight test but the damage was not due to use of controls.*

13. What kind of tests do you do to ensure the vertical tail is strong enough?

- ▶ *There are numerous tests that directly verify structural integrity, or support analytical methods:*
 - *Element testing for mechanical properties (e.g., strength, stiffness, uniformity) of raw materials, fasteners, bolted-joints, etc. This includes the effects of environment and manufacturing flaws.*
 - *Subcomponent tests to validate concepts, to verify analytical methods, provide substantiating data for material design values, demonstrate repairs, and show compliance with strength requirements in configured structure. These tests include ribs, spars, skin panels, joints and fittings.*
 - *The full-scale aircraft, with fin attached, is tested for static strength to prove ultimate load capability. A separate full-scale aircraft with fin attached is tested under simulated service loads for 3 lifetimes to show durability and lack of widespread fatigue damage. A separate full-scale horizontal stabilizer is tested for static strength and fatigue also.*
 - *Boeing then flight tests the aircraft to gather flight test data to validate structural loads analysis. This analysis, combined with ground structural load testing, ensures that the structure meets design requirements.*

14. Which Boeing models have composite vertical tails?

- ▶ *The 777 and 787 have a vertical tail made of composites.*

15. Where else has Boeing used composites in its aircraft?

- ▶ *Composite materials were used on secondary structure on the 727 (fairing, radome, trailing edges). As technology advanced, more composites were used on new aircraft models such as the 737, 757, 767 and 777. Composites also were*

used on the MD-80, MD-90, MD-11 and 717. Many other components on the 777 contain composite materials. Examples include fairings, floor beams, engine nacelles, rudder and elevator, movable and fixed wing trailing edge surfaces, and gear doors. The 777 is similar to other Boeing models in that elevators and rudders are made of composite materials (the skins, ribs and spars). There are metal ribs and fittings that attach the rudder/elevator to the stabilizer structures. Of course composite use on the 787 is much higher (50%), with major elements like the fuselage barrel being constructed using composites.

16. Are composite tails as strong as metal tails?

- ▶ Yes. If one were to go through the design process for a metal or composite tail for the same aircraft, then the same requirements would be applied. Similar engineering activities would occur (i.e., aerodynamic analysis, external loads, structural design, stress analysis, material qualification, manufacturing verification, testing, validation, maintenance & inspection planning, certification, in-service monitoring, etc.).

Summary

-  Jet transport aircraft have large and powerful rudders.
-  The use of full rudder for control of engine failures and crosswind takeoffs and landings is well within the structural capability of the aircraft.
-  As the aircraft flies faster, less rudder authority is required. Implementation of the rudder limiting function varies from model to model.
-  Aircraft are designed and tested based on certain assumptions about how pilots will use the rudder. These assumptions drive the FAA/JAA certification requirements and any additional Boeing design requirements.
-  Pilots should be aware that the aircraft has been designed with the structural capability to accommodate a rapid and immediate rudder pedal input when going in one direction from zero input to full.
-  It is important to use the rudder in a manner that avoids unintended large sideslip angles and resulting excessive roll rates. The amount of roll rate that is generated by using the rudder is proportional to the amount of sideslip, NOT the amount of rudder input.
-  If the pilot reacts to an abrupt roll onset with a large rudder input in the opposite direction, the pilot can induce large amplitude oscillations. These large amplitude oscillations can generate loads that exceed the limit loads and possibly the ultimate loads, which could result in structural damage.
-  A full or nearly full authority rudder reversal as the aircraft reaches an “over yaw” sideslip angle may be beyond the structural design limits of the aircraft. There are no Boeing flight crew procedures that would require this type of rudder input.