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Use of Rudder on Transport Category Airplanes

(For Boeing Aircraft Only)

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INTERNATIONAL FEDERATION OF AIR LINE PILOTS' ASSOCIATIONS
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Published by the International Federation of Air Line Pilots' Associations
Gogmore Lane, Chertsey, Surrey, KT16 9AP, England
Telephone +44 1932 571711 Fax +44 1932 570920
globalpilot@ifalpa.org www.globalpilot.org

BOEING COMMERCIAL AIRPLANE GROUP

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER:

707	**717**	**727**	**737**	**747**
02-1	B-717-02-09	02-1	02-2	13
747-400	**757**	**767**	**777**	**DC-8**
50	68	68	10	DC-8-02-01
DC-9	**DC-10**	**MD-80**	**MD-90**	**MD-10**
DC-9-02-01	DC-10-02-01	MD-80-02-01	MD-90-02-01	MD-10-02-01
MD-11				
MD-11-02-01				

DATE: May 13, 2002

SUBJECT: Use of rudder on transport category airplanes

ATA NO:

APPLIES TO: All 707, 717, 727, 737, 747, 757, 767, 777, DC-8, DC-9, DC-10, MD-80, MD-90, MD-10 & MD-11

Background

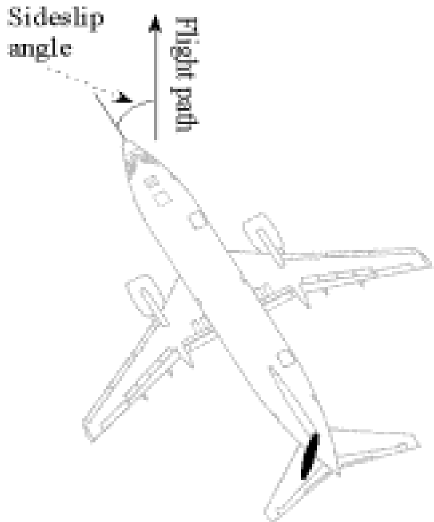
As part of the on-going accident investigation of American Airlines flight 587, an Airbus A300-600, the National Transportation Safety Board (NTSB) issued a Safety Recommendation letter on Feb. 8, 2002. The letter recommends that pilots be made aware that aggressive maneuvering using “sequential full opposite rudder inputs” can potentially lead to “structural loads that exceed those addressed by the requirements.” Airplanes are designed and tested based on certain assumptions on how pilots will use the rudder. These assumptions drive the FAA/JAA certification requirements and any additional Boeing design requirements. The net result of this approach is that there has been no catastrophic structural failure of a Boeing airplane due to a pilot control input in over 40 years of commercial operations involving more than 300 million flights. However, providing additional information to pilots about the characteristics of their aircraft in unusual circumstances may prove useful.

Rudder Maneuvering Considerations

Jet transport airplanes, especially those with wing mounted engines, have large and powerful rudders. These powerful rudders are necessary to provide sufficient directional control of asymmetric thrust after an engine failure on takeoff and to provide suitable crosswind capability for both takeoff and landing. As the airplane flies faster, less rudder is needed for directional control and the available rudder deflection is therefore reduced. This reduction in rudder deflection is achieved through rudder limiting (discussed later in more detail).

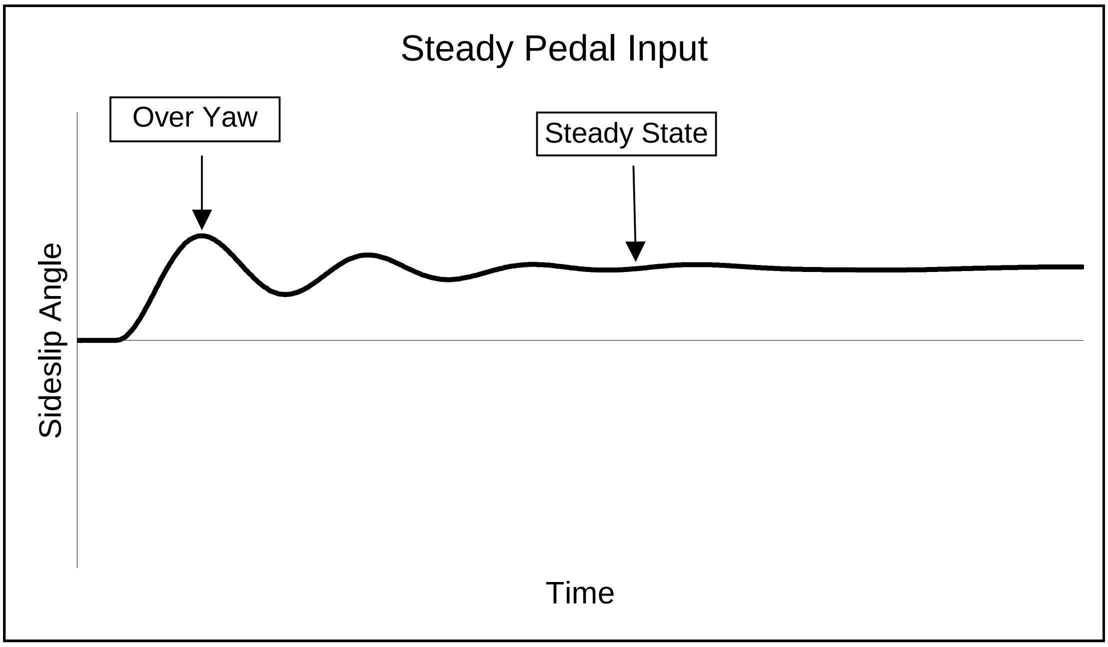
Maneuvering an airplane using the rudder will result in a yaw and roll response. The roll response is the result of sideslip. For example, if the pilot applies left rudder the nose will yaw left (Figure 1). This yawing response to the left will generate a sideslip (right wing forward). The resulting sideslip will cause the airplane to roll to the left (i.e., roll due to sideslip). The actual force on the vertical tail due to the rudder deflection tends to roll the airplane right, but as the sideslip moves the right wing forward, the net airplane roll rate is to the left.

Figure 1 Rudder Induced Sideslip



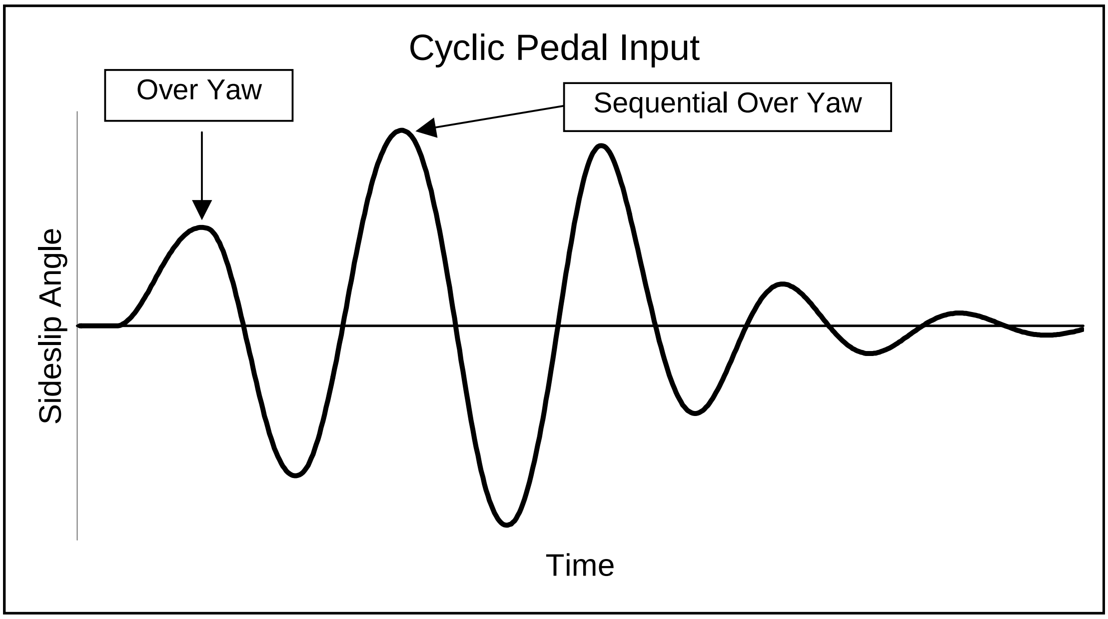
It is difficult to perceive sideslip and few modern transport airplanes have true sideslip indicators. In older transport instrument panels the "ball" was an indicator of side force or acceleration, not sideslip angle. Some newer models have electronic flight displays with a slip/skid indication, which is still an indication of side force or acceleration; not sideslip. As the pilot applies more rudder, more sideslip is generated and a greater roll response will result. Large, abrupt rudder inputs can generate very large sideslip angles, much larger than encountered in a steady state sideslip (that 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 airplane (Figure 2). This “over yaw” can amplify the roll rate. It is important to use the rudder carefully so that unintended large sideslip angles and resulting roll rate do not develop. The amount of roll rate that is generated by using the rudder is typically proportional to the amount of sideslip, NOT the amount of rudder deflection.

Figure 2 “Sideslip Response to Abrupt Steady Rudder Input”



Precise roll control using rudder is difficult and therefore not recommended. Because sideslip must build up to generate the roll, there is a time lag between the pilot making a rudder input and the pilot perceiving a roll rate. This lag has caused some pilots to be surprised by the abrupt roll onset and in some cases to interpret the rapid onset of roll as being caused by an outside element not related to their rudder pedal input. If the pilot reacts to this abrupt roll onset with another large rudder input in the opposite direction, large amplitude oscillations in roll and yaw can result. Cyclic rudder pedal inputs can result in very large amplitude sideslip oscillations (See Figure 3).

Figure 3 “Sideslip Response to Abrupt Cyclic Rudder Input”



The sideslip angle that is momentarily reached with such “sequential over yaw” can be much larger than the over yaw associated with a single, abrupt rudder input (See Figure 2 & 3). When the rudder is reversed at this sequential over yaw/sideslip angle, the rudder induced fin force is added to the sideslip induced fin force (See Figure 4 & 5). The resulting structural loads can exceed the limit loads and possibly the ultimate loads, which can result in structural damage.

Note: Limit loads are the maximum loads to be expected in service.
Ultimate loads are the limit loads multiplied by prescribed factors of safety, normally 1.5.

Figure 4 Rudder Induced Sideslip Forces

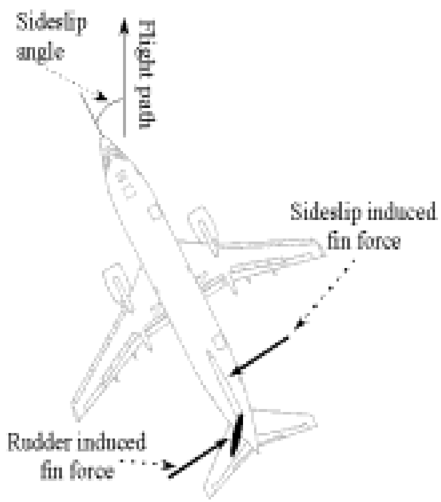
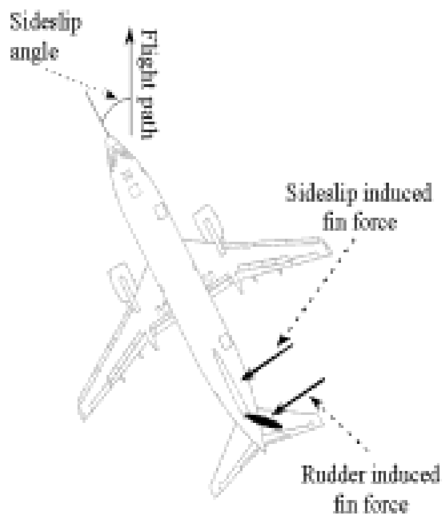


Figure 5 Rapid Rudder Reversal Forces



Design Maneuvering Speed - Va

A structural design maneuvering speed, Va, is defined for evaluating airplane structural design. At or below this speed, Boeing airplanes are capable of sustaining a single input to any set of control surfaces (elevators, ailerons, rudder(s)) to their maximum available authority (as limited by control surface limiters, blowdown, or control stops). These control surface inputs are to be in one axis (not in combination) and do not include control input reversal or oscillatory inputs. In addition, on Boeing airplanes at speeds above Va, full rudder input is evaluated out to the maximum operating air speed, Vmo/Mmo, and for some models, out to the design dive speed, Vd/Md (where Vd/Md is typically 30-60 knots/.05-.07 Mach higher than Vmo/Mmo). Therefore the pilot does not have to be concerned about how fast or how hard to push the rudder pedal in one direction, from zero to full available pedal deflection throughout the flight envelope (from a structural capability standpoint).

The maneuver speed is provided in most FAA/JAA approved Flight Manuals in the Section 1 Limitations under Maximum Airspeed Limits, and is usually shown for the most critical gross weight. The more commonly known Turbulent Air Penetration Speed gives a rough approximation to maneuver speed. It should be pointed out, for reasons discussed in the next section, that many aircraft have structural capability beyond that required by the minimum structural design criteria of the FARs or JARs.

Design maneuver speed should not be confused with the “minimum” or “recommended” maneuver speed supplied for each flap setting to be used in daily operation. These speeds are based on aerodynamic margins: margins to stick shaker, flap placard, and acceleration and deceleration capability during flap changes.

NTSB Recommendations

A. Explain to Flight Crews the structural certification requirements for the rudder and vertical stabilizer on transport category airplanes.

Response: The FAA/JAA have three rudder maneuver structural load design requirements, that the rudder and vertical fin must meet in order to be certified. These requirements are met for all airspeeds up to the design maneuvering speed. In addition, newer airplane designs meet these requirements up to the design dive speed.

Note: The following conditions are engineering design conditions that may be physically impossible to fly.

1. At a zero sideslip condition, the airplane 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 maneuver.

2. Starting from a zero sideslip condition, the airplane 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 airplane will exceed the maximum steady state sideslip due to the dynamic response characteristics of the airplane. A Safety Factor of 1.5 is then applied.

3. 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 airplane 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/JAA impose structural load design requirements in addition to these rudder maneuver requirements. These include requirements for loads due to gusts, engine failure dynamics, and lateral control induced rolling conditions. Boeing airplane 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.

B. 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 stabilizer, even at speeds below the design maneuvering speed.

Response: Boeing airplanes are designed to withstand the structural loads generated by a full rudder input out to the airplane's maximum operating airspeed, Vmo/Mmo. Some Boeing airplanes 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 maneuver. As previously mentioned, Boeing airplane 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 airplanes 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 airplane, even if the airspeed is below the design maneuvering 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 airplane, 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 airplane.

C. 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.

Response: 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 airplane 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 airplanes limit rudder deflection as airspeed increases. Engine out takeoff and crosswind landing requirements define the maximum rudder deflection (authority). As the airplane flies faster, less deflection is needed and rudder authority is therefore reduced.

Some Boeing models (747, 757, 767, & 777) have rudder limiters that reduce the rudder authority by changing the gearing between the rudder and the rudder pedals. As the airplane 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 airplane 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

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 Mmo at FL390.

Table 1 *Rudder Deflection and Force Required*

	V_1 (135)			250 kts			FL390 MMo		
	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)
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
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
DC8	85	3.6	32	65	1.5	13	60	1.0	8
DC9	75	2.6	22	60	1.1	8	30	0.4	3
MD 80	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
DC 10	80	3.8	23	65	2	14	55	1.5	9
MD 11	80	3.8	23	65	2.2	15	60	1.7	11

Airplanes 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 airplane's feel and response characteristics to flight control inputs. By understanding and becoming familiar with the airplane's characteristics, pilots will learn to apply the appropriate control input in response to various flight situations.

D. Carefully review all existing and proposed guidance and training provided to pilots of transport-category airplanes concerning special maneuvers 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.

Response: 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 maneuvers.

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- Airplane Upsets" in its AERO magazine (Vol. 3 1998) and the Airplane 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 maneuvered, 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 maneuvers 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 maneuvers 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 maneuver 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 maneuvered significantly different 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 maneuvers 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 airplanes 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 airplane 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 airplane 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 airplane 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 maneuver 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, following the events of September 11, there has been much discussion about aggressively maneuvering the airplane to thwart a hijacking attempt. The Boeing recommendation in this situation has been to rely on maneuvers 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 maneuvering should be followed. Random unplanned maneuvers outside the manufacturer's recommendations can lead to loss of control and/or structural damage.

Summary

- There has been no catastrophic structural failure of a Boeing airplane due to a pilot control input in over 40 years of commercial operations involving more than 300 million flights.

- Jet transport airplanes 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 airplane.

- As the airplane flies faster, less rudder authority is required. Implementation of the rudder limiting function varies from model to model.

- Airplanes 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.

- The pilot should be aware that the airplane 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 airplane reaches an “over yaw” sideslip angle may be beyond the structural design limits of the airplane. There are no Boeing flight crew procedures that would require this type of rudder input.

Attachment One

COMMONLY ASKED QUESTIONS REGARDING RUDDER USEAGE

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.**

   A- 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 stabilizer?**

   A- No, such a maneuver 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 airplane?**

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

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?**

   A- The point of maximum stress will depend on the airplane type, configuration, and specific maneuver. However, from a zero sideslip condition the maximum available rudder can be applied in one direction out to the maximum operating speed, Vmo/Mmo, and for some models, out to the design dive speed, Vd/Md.

5. **At high angles of attack, beyond stick shaker, the roll effectiveness of the ailerons and spoilers is decreased. On some airplanes 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?**

A- If the airplane 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 centered.

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?**

   A- 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 ½ of it out and hold. Does that put undue stress on the tail?**

   A- 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?**

   A- The first action to take is to unload the airplane 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 airplane. 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?**

   A- 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 airplanes (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?

A- 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 Airplane 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 airplane performance. Simulators flown outside the limits of valid data can present misleading airplane response. Airlines should use caution when activating pre-loaded 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?

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

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

A- 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 airplane rapidly decompressed. Additionally, structural damage has occurred due to lighting 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?

A- 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 airplane, with fin attached, is tested for static strength to prove ultimate load capability. A separate full-scale airplane 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 airplane 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?

A- The 777 has a vertical tail made of composites.

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

A- Composite materials were used on secondary structure on the 727 (fairing, radome, trailing edges). As technology advanced, more composites were used on new airplane 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**.**

16. Are composite tails as strong as metal tails?

A- Yes. If one were to go through the design process for a metal or composite tail for the same airplane, 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.).