BOEING COMMERCIAL AIRPLANES

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: 737-12-2
747-400-64
747-8-4
757-84
767-86
777-36
787-8

DATE: June 25, 2012

This bulletin provides information which may prove useful in airline operations or airline training. The information provided in this bulletin is not critical to flight safety. The information may not apply to all customers; specific effectivity can be determined by contacting The Boeing Company. This information will remain in effect depending on production changes, customer-originated modifications, and Service Bulletin incorporation. Information in this bulletin is supplied by The Boeing Company and may not be approved or endorsed by the FAA at the time of writing. Appropriate formal documentation will be revised, as necessary, to reflect the information contained in this bulletin. For further information, contact Boeing Commercial Airplanes, Chief Pilot – Flight Technical and Safety, P. O. Box 3707, Mail Code 20-95, Seattle, Washington 98124-2207; Phone +1 (206) 544-8024; or Facsimile +1 (206) 662-4747.

SUBJECT: Upset Recovery

ATA NO: 0200-00

APPLIES TO: All 737-200/300/400/500/600/700/800/900/BBJ, 747-400/8, 757, 767, 777, and 787 Airplanes

REASON: To provide increased flight crew awareness of the Upset Recovery non-normal maneuver and the requirement to disconnect automation as the first step.

BACKGROUND INFORMATION

An upset situation can generally be defined as unintentionally exceeding the following conditions:

- Pitch attitude greater than 25 degrees nose up, or
- Pitch attitude greater than 10 degrees nose down, or
- Bank angle greater than 45 degrees, or
- Within above parameters but flying at an airspeed inappropriate for the conditions.

Upset situations can be caused by a variety of issues, such as:

- External events, i.e., windshear, microburst, wake turbulence, etc.
- Airplane structural issues (primary and secondary flight control issues), bird impact, collision with another aircraft, etc.
- Airplane system(s) not operating correctly
- Incorrect or unexpected flight control inputs by the pilot

Several techniques are available for recovering from an upset. The Flight Crew Operations Manual (FCOM)/Quick Reference Handbook (QRH) Upset Recovery non-normal maneuver provides a technique that represents a logical progression for recovering the airplane from an upset situation.

Further information about upset recovery can be found in the Flight Crew Training Manual (FCTM).

OPERATING INFORMATION

There are multiple causes of upset situations, but because upsets occur so infrequently, crew recognition can be a challenge. Pilots are usually surprised or startled when an upset occurs. There can be a tendency to react too quickly before analyzing the situation or to fixate on only one indication. The primary flight instruments, in conjunction with airplane performance indications, should be used when analyzing an upset situation. It should be emphasized that recovery to a stabilized flight path should be initiated as soon as a developing upset condition is recognized and confirmed to prevent a more serious situation.

The Upset Recovery non-normal maneuver assumes that the airplane is not stalled. If the airplane is stalled, recovery from the stall must be done before upset recovery actions are taken. Stall recovery is accomplished by applying and maintaining nose down elevator until the stall recovery is complete and stick shaker activation ceases.

The crew should recover the airplane in accordance with the Upset Recovery non-normal maneuver as described in the QRH. In all cases, once an upset is recognized and confirmed, the first step is to disconnect the autopilot and autothrottle, and recover from the upset manually.

BOEING COMMERCIAL AIRPLANES

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: **787-7**
DATE: **February 14, 2012**

This bulletin provides information which may prove useful in airline operations or airline training. The information provided in this bulletin is not critical to flight safety. The information may not apply to all customers; specific effectivity can be determined by contacting The Boeing Company. This information will remain in effect depending on production changes, customer-originated modifications, and Service Bulletin incorporation. Information in this bulletin is supplied by The Boeing Company and may not be approved or endorsed by the FAA at the time of writing. Appropriate formal documentation will be revised, as necessary, to reflect the information contained in this bulletin. For further information, contact Boeing Commercial Airplanes, Chief Pilot – Flight Technical and Safety, P. O. Box 3707, Mail Code 20-95, Seattle, Washington 98124-2207; Phone (206) 544-8024; Facsimile (206) 662-4747; SITA: SEABO7X, Station 627.

SUBJECT: 787 Flight Deck Window Popping Noise

ATA NO: 5300-00, 5600-00

APPLIES TO: 787-8

REASON: This bulletin advises operators of a 787-8 flight deck window popping noise issue.

BACKGROUND INFORMATION

The flight deck window support structure has been designed with dimensional clearances to allow easy window replacement. As a result, when pressurization or temperature changes occur, the flight deck windows may create popping sounds as they seat themselves within the support structure.

The window edges have a Teflon coating to allow them to move within the support structure without popping noises. However, if the airplane has not flown for a significant period of time, the windows may re-seat themselves when the aircraft is pressurized or temperature changes during flight. The noise should subside during the flight or on a subsequent flight.

Window popping noises during normal operation do not indicate any deterioration or reduction of the structural integrity of the window, support structure, or attaching hardware.

OPERATING INFORMATION

No crew action is required. If the windows continue to produce popping noises on subsequent flights, the Teflon coating on the window edges may not be adequate, and can be reapplied by maintenance.

BOEING COMMERCIAL AIRPLANES

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: **787-6**

DATE: **January 9, 2012**

This bulletin provides information which may prove useful in airline operations or airline training. The information provided in this bulletin is not critical to flight safety. The information may not apply to all customers; specific effectivity can be determined by contacting The Boeing Company. This information will remain in effect depending on production changes, customer-originated modifications, and Service Bulletin incorporation. Information in this bulletin is supplied by The Boeing Company and may not be approved or endorsed by the FAA at the time of writing. Appropriate formal documentation will be revised, as necessary, to reflect the information contained in this bulletin. For further information, contact Boeing Commercial Airplanes, Chief Pilot – Flight Technical and Safety, P. O. Box 3707, Mail Code 20-95, Seattle, Washington 98124-2207; Phone (206) 544-8024; Facsimile (206) 662-4747; SITA: SEABO7X, Station 627.

SUBJECT: **787 GEnx-1B Engine Related Characteristics**

ATA NO: 72-00

APPLIES TO: 787

REASON: This bulletin advises operators of the 787 GEnx-1B Engine Characteristics.

BACKGROUND INFORMATION

The 787 GEnx-1B Engine exhibits a few unique characteristics during engine start and engine shutdown. The following is a list of items to familiarize the operator with these characteristics.

- Smoke During Engine Start
- Engine Vibration During Engine Start
- Fuel Venting From Engine After Engine Shutdown

Smoke During Engine Start

When starting a cold GEnx-1B engine at low ambient air temperatures, white smoke can be observed exiting the engine exhaust after fuel has been introduced. The smoke will continue until ignition completes and the engine accelerates toward idle. The smoke will dissipate as normal engine exhaust mixes with the smoke.

The smoke is a result of unburned fuel during the combustion process at engine start. It is limited to cold engine starts due to increased oil viscosity, which results in a prolonged duration in the inefficient combustion region. The starting portion of combustion is the most inefficient region, in which variables such as starter torque, fuel enrichment, igniter energy, and environmental effects play a larger role. Smoke has been observed during starts at ambient temperatures below 65 deg F (18 deg C). The amount of white smoke increases as ambient temperatures decreases.

While smoke during engine starts in cold ambient air temperatures occurs on other airplanes, the 787-8/GEnx-1B may exhibit more smoke than previous Boeing or GE legacy products. GE is evaluating potential design changes to reduce smoke during engine starting.

Engine Vibration During Engine Start

GEnx-1B engine starts occurring within approximately 30 minutes to three hours after engine shutdown may result in increased core (N2) vibration due to a very small deflection (bow) of the core rotor system. This is referred to as a bowed-rotor start. This results from hot air accumulating on the top part of the nacelle, causing the N2 rotor system components at the lower part of the engine to cool at a faster rate than the N2 rotor system components exposed to the warmer air at the top of the nacelle.

During the start higher than normal vibration indications may be observed. The indication may enter the engine vibration high band. The vibration may be accompanied by a “rumbling” sound, but it is not accompanied by tactile vibration. Core airflow during the start will alleviate the thermal gradient in the engine, and the bowed-rotor effect will typically subside as the engine reaches idle. This condition does not adversely affect engine operation or integrity.

Fuel Venting From Engine After Engine Shutdown

Fuel venting after engine shutdown has been observed on the GEnx-1B engine. It is exhibited by fuel vapors exiting the engine booster or the primary exhaust, accompanied by a fuel odor for up to thirty minutes following engine shutdown. The cause of the fuel venting is attributed to bulk fuel expansion.

Post-shutdown fuel vapor on the GEnx-1B is the byproduct of fuel seepage through fuel nozzle check valves at elevated fuel manifold pressures. The fuel that seeps from the nozzles contacts the combustion chamber walls and vaporizes. The amount of fuel emitted is equal to the expansion of fuel contained in the fuel system downstream of the fuel metering unit (FMU) high-pressure shutoff valve (HPSOV). Immediately following an engine shutdown, a fixed, static volume of fuel exists between the FMU HPSOV and the fuel nozzle check valves. Since the core ventilation system does not function after engine shutdown, heat is radiated from the hot engine structure and components to cooler components, such as the fuel system and static fuel. As the fuel temperature increases during this heat transfer, the pressure of the trapped fuel mass increases. Since liquid fuel is incompressible, the resulting expansion overcomes the fuel nozzle check valve cracking pressure and seeps into the combustor.

GE is evaluating potential design changes to eliminate post-engine-shutdown fuel vapor emissions. The design changes are currently scheduled for production incorporation by the end of 2012, with retrofit completion by the end of 2014.

OPERATING INFORMATION

The following is applicable operation information:

Smoke During Engine Start
No crew action is necessary for observed smoke during engine starting provided the engine operates normally.

Engine Vibration During Engine Start
No crew action is necessary to address high vibration indications during engine starting provided the engine operates normally.

Fuel Venting From Engine After Engine Shutdown
No action is required to address post-shutdown fuel venting. The vapor will dissipate in a short period of time.

BOEING COMMERCIAL AIRPLANES

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER:

707	**717**	**727**	**737**	**747**
02-1 R1	B-717-02-09 R1	02-1 R1	02-2 R1	13 R1
747-400	**757**	**767**	**777**	**787**
50 R1	68 R1	68 R1	10 R1	5
DC-8	**DC-9**	**DC-10**	**MD-80**	**MD-90**
DC-8-02-01 R1	DC-9-02-01 R1	DC-10-02-01 R1	MD-80-02-01 R1	MD-90-02-01 R1
MD-10	**MD-11**			
MD-10-02-01 R1	MD-11-02-01 R1			

DATE: November 18, 2011

These bulletins provide information which may prove useful in airline operations or airline training. The information may not apply to all customers; specific effectivity can be determined by contacting The Boeing Company. This information will remain in effect depending on production changes, customer-originated modifications, and Service Bulletin incorporation. Information in these bulletins is supplied by The Boeing Company and may not be approved or endorsed by the FAA at the time of writing. Appropriate formal documentation will be revised, as necessary, to reflect the information contained in these bulletins. For further information, contact Boeing Commercial Airplanes, Chief Pilot, Flight Technical and Safety, P. O. Box 3707, Mail Code 20-95, Seattle, WA, USA 98124-2207, Phone +1 (206) 544-8024, Facsimile +1 (206) 662-4747.

SUBJECT: **Use of rudder on transport category airplanes**

ATA NO: **02-00**

APPLIES TO: **All 707, 717, 727, 737, 747, 757, 767, 777, 787, DC-8, DC-9, DC-10, MD-80, MD-90, MD-10 & MD-11**

REASON: Revised to add information about the 787.

BACKGROUND INFORMATION

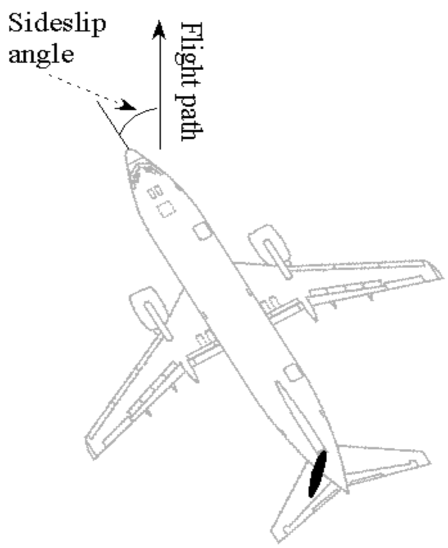
As part of the on-going accident investigation of American Airlines flight 587, an Airbus A300-600, the National Transportation Safety Board (NTSB) issued a Safety Recommendation letter on Feb. 8, 2002. The letter recommends that pilots be made aware that aggressive maneuvering using "sequential full 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).

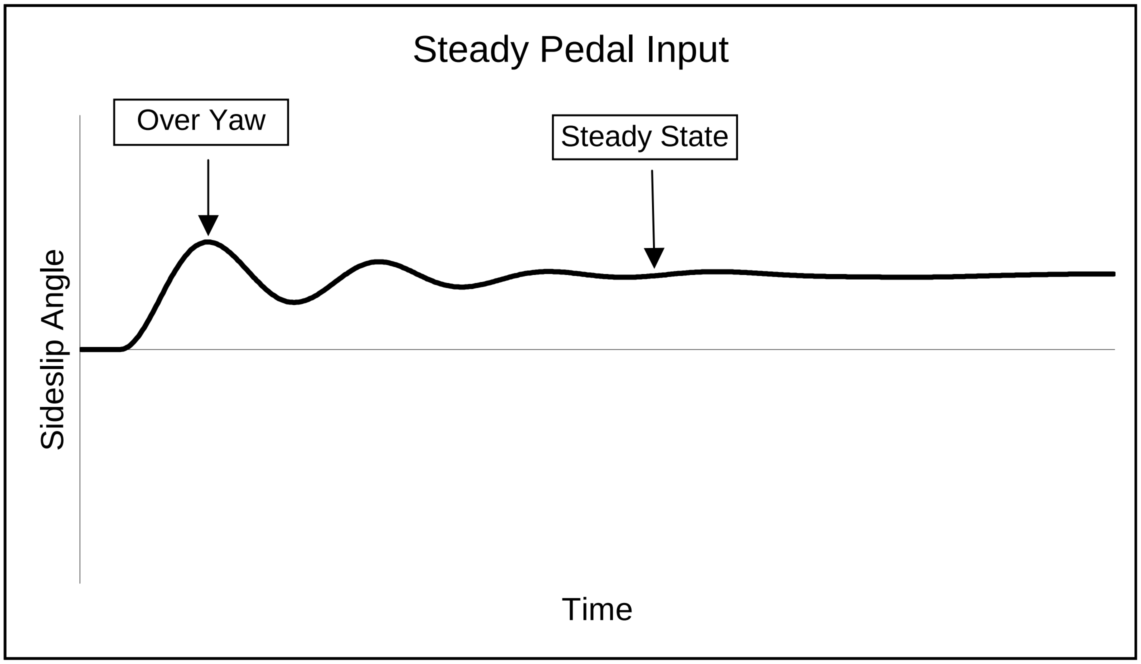
Maneuvering an airplane using the rudder will result in a yaw and roll response. The roll response is the result of sideslip. For example, if the pilot applies left rudder the nose will yaw left (Figure 1). This yawing response to the left will generate a sideslip (right wing forward). The resulting 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*



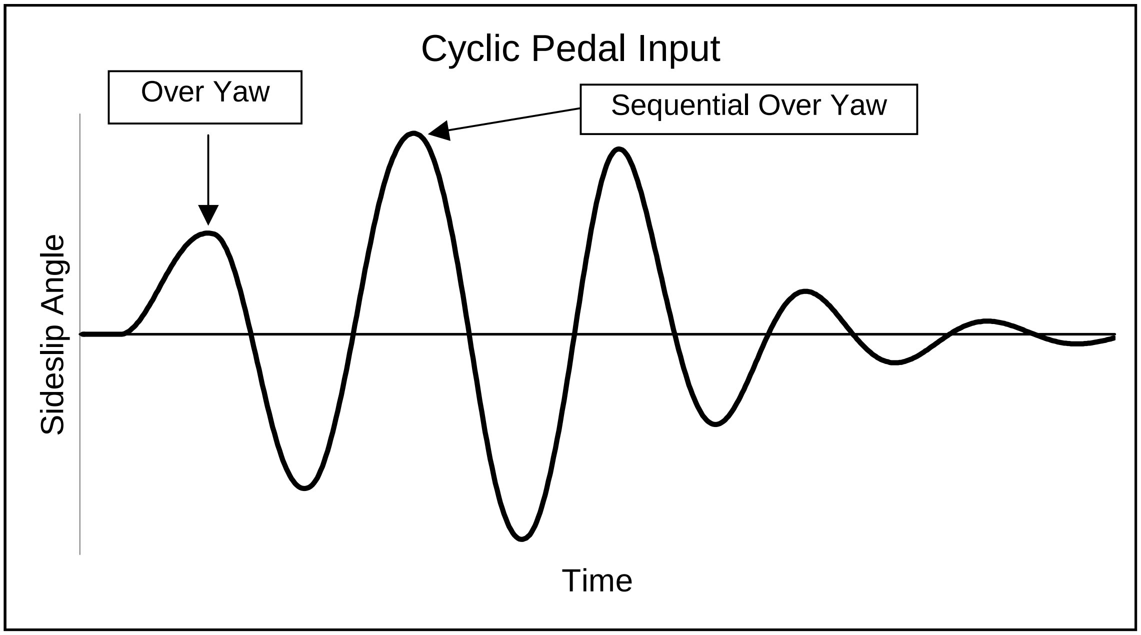
It is difficult to perceive sideslip and few modern transport airplanes have true sideslip indicators. In older transport instrument panels the “ball” was an indicator of side force or acceleration, not sideslip angle. Some newer models have electronic flight displays with a slip/skid indication, which 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

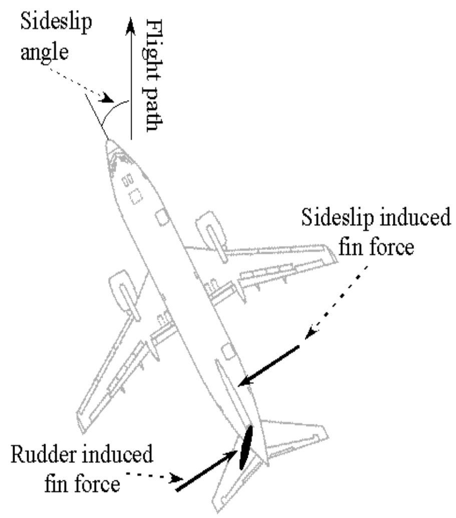
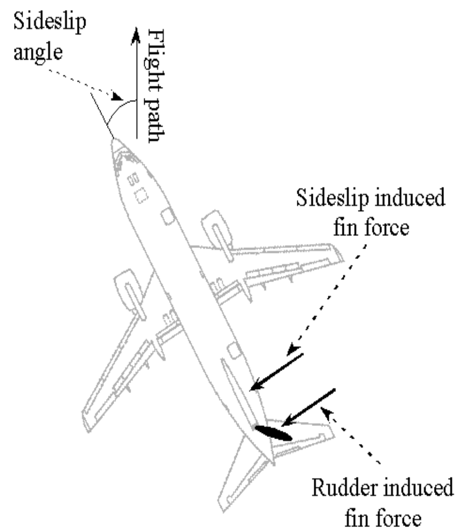


Figure 5 Rapid Rudder Reversal Forces



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.

Boeing has implemented a Fin Load Alleviation (FLA) function on the 777-200IGW and on the 787. Starting on the 777-200IGW, FLA was added to reduce vertical tail loads during rudder application with an engine failure. On the 787, Boeing has implemented a FLA function that is active over the full flight envelope and is designed to reduce vertical tail loads for all rudder checkback/reversal maneuvers.

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, & 787) 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 <u>available</u> 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 <u>available</u> 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
787	65	3.8	22	65	3.8	6	65	3.8	4
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 <u>high structural loads</u>." 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 and 787 have 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**.** The 787 features an even more extensive use of structural composites (approximately 50% by weight) including the entire fuselage monocoque, wing box, and empennage, in addition to the applications on previous Boeing models.

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.).

BOEING COMMERCIAL AIRPLANES

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: 737-11-1
747-400-62
747-20
757-81
767-83
777-32
787-4

DATE: April 15, 2011

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SUBJECT: Ice Crystal Icing

ATA NO: 0200-00

APPLIES TO: 737, 747, 757, 767, 777, 787

BACKGROUND

This bulletin summarizes current Boeing information about engine power loss and damage events associated with flight in ice crystal icing conditions. This problem most frequently affects aircraft flying over tropical regions but is not limited to those areas. In 2008, Boeing recorded three events in the United States, two near Chicago O'Hare airport and one near New York's Kennedy airport. All three were at high altitude in convective* weather associated with the remnants of tropical storms which had lost energy but were still producing heavy rain on the ground.

- * Convection occurs when warm moist air rises in an unstable atmosphere. As the air rises, it expands and cools, and water vapor within it condenses to form clouds. Thunderstorms are one type of convective weather that can lift moisture to the tropopause where winds spread the cloud into a recognizable anvil shape. Convective updrafts lift high concentrations of water above the freezing level where the water freezes, and grows to hailstones or falls as rain.

Ice crystal icing affects engine models differently. Engines on Boeing aircraft have experienced flameouts, surges, high vibrations, and compressor damage due to ice impacting the fan blades. Flight crews are not always aware that the engines have been damaged as a result of flight in convective weather containing ice crystals. Data gathered from pilot reports, flight data, and meteorological studies were used to develop the best practices summarized in this bulletin. Our understanding of the ice crystal icing phenomenon and its flight deck effects is evolving. This bulletin may be updated as more information becomes available.

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1.0 A New Threat

Until now, ice crystals at high altitude have not been thought of as a threat to aircraft because they do not lead to airframe icing. However, the industry has identified a condition in which solid ice particles can cool interior engine surfaces through melting and ice build-up. When the ice sheds, it can result in engine power loss or damage. Symptoms of a power loss can be a surge, flameout, or high vibration. Typically, the engine power loss has occurred at high altitude, in clouds, as the aircraft is flying over an area of convective weather where little or no weather radar returns were observed at the flight altitude. In other cases, flight altitude radar returns were observed and pilots followed standard thunderstorm avoidance procedures. Despite pilot avoidance of weather radar returns, engine power losses have occurred. Avoidance of ice crystals is a challenge because they are not easily identified.

2.0 Pilot Reports

Here is a sample report for an ice crystal icing event.

> **J502 YYJ288/30**
> **1420L, FL 350, B747**
> **Intermittent IMC to 330 then IMC up to and at 370.**
> **TAT approximately zero (0).**
> **Winds 330/19, light to moderate turbulence, no icing.**
> **Remarks: TAT indicator wrong. Rain on windscreen at 370 (impossible), suspect ice crystals due to the sound. Heavy returns 5 to 7000 feet below us. Saw tops above 41K before going IMC. No returns at our higher altitude. Got ATC reroute to pass north of heavy returns ahead and below. (passing waypoint) Turbulence increased, asked flight attendants to be seated. Appears Engine 1 rolled back briefly, then recovered.**

3.0 Indications of Ice Crystal Icing

Breaking down the above report and analyzing the weather in similar incidents has increased our confidence in the following traits associated with ice crystal icing:

3.1 In clouds at high altitude

- All pilots report being ***in clouds*** when the ice crystal-induced engine power loss events occur.
- More than 60% of these events occur in the Asia-Pacific region, in a tropical environment, where warm air can hold more moisture. This air rises and cools, forming clouds containing a great amount of ice ***at high altitude***.

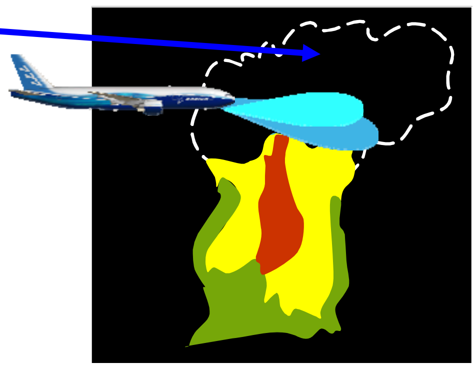
3.2 No weather radar returns at flight level

- This ice is thought to be concentrated in very small particles, the size of baking flour - a ***poor reflector of radar energy*** despite the density.

3.3 Heavy weather radar returns below flight level

- From event weather radar analysis, events consistently occur when the aircraft is in Instrument Meteorological Conditions ***(IMC) and over-flying an area which would be amber or red*** on the pilot's weather radar. Ice that has been lifted to high altitude eventually falls through the freezing level and begins to melt. These wet particles are much more reflective and therefore visible (amber or red) to radar. These clouds can be identified by pilots if they ***manually tilt the radar down*** to scan below the freezing level.

Potential for high concentrations of ice crystals



3.4 Traversing clouds with tops at high altitude

- Often these clouds lift condensed water to high altitude, even penetrating the tropopause. It is in these ***updraft areas*** where the highest ice crystal concentrations can be encountered.

3.5 No airframe icing

- Ice crystals bounce off cold surfaces such as the airframe, which is why airframe icing is usually <u>not</u> noted. These small particles may accumulate in stagnation areas, so it is possible that a small concentration might be noted on the leading edge of the wiper post.

3.6 Appearance of rain

- Another key indicator of ice crystal conditions is the ***appearance of rain*** on the windscreen at high altitudes. From pilot reports and flight data we have concluded that when small ice crystals in high concentrations hit the heated windscreen, they melt and give the appearance of rain, even when the ambient temperature is too cold for liquid to exist. Several interviewed pilots explained that ice crystals ***sound different*** than typical rain.

3.7 TAT near zero

- For the engineer reviewing event data, the ***TAT anomaly*** (TAT reading near zero °C) is a good indication that an aircraft has flown through ice crystals. This unusual behavior is created when ice crystals collect in the area where the sensor element resides. Some ice crystals melt and the sensor measures ice-water at 0° Celsius. This effect depends on the aircraft model, where the TAT probe is installed on the fuselage, and how TAT is displayed in the cockpit. There are many variations in the Boeing fleet and some aircraft are more susceptible to the TAT anomaly than others.

3.8 Only light to moderate turbulence

- Meteorologists tell us that even though these clouds reach the tropopause, when they form in a tropical environment, they are not as powerful as those that form over land (which more commonly have lightning) and, therefore, they have lower updraft velocities, resulting in only **light to moderate turbulence**.

3.9 Other clues

Pilot reports from events vary and not all the symptoms noted above are reported in every event.

- Another effect which is associated with ice crystals striking the airframe is **St. Elmo's Fire**.
- Several reports referred to increases in **temperature and humidity** in the cockpit preceding the TAT anomaly. This was only present while in IMC and is likely another cue that ice crystals were present.

4.0 Industry Efforts

The industry is working to improve engine capability in ice crystals. There is still much to be understood, including the weather threat and the details of the ice formation inside the engines. Efforts to close the knowledge gap have long timescales, and the ability to apply practical technology to allow robust simulation of these conditions is many years away. Hence in the near term, there has been a focus on providing better information to flight crews in the cockpit to help with weather avoidance.

5.0 Research

Very few instrumented research flights have been made in convective clouds. Very little is known about the concentrations and sizes of ice crystals in these clouds. Knowing the severity of the atmosphere is a key to designing an engine to operate in these clouds. To address this need, a team of government and industry members known as the High Ice Water Content (HIWC) Partnership plans to conduct an instrumented flight program in 2012. At the same time, work is ongoing to better understand the physics of engine ice crystal icing, and develop test facilities where engines can be tested.

Recently, airlines have brought pilot reports and flight data to Boeing's attention where the aircraft TAT is in disagreement with the engine inlet temperature. We believe this can occur in ice crystal icing conditions. A study of TAT anomalies, as well as TAT and engine inlet temperature disagreement, may provide more insight into the type of convection that causes engine power loss and damage events. One interesting finding is that the TAT anomaly is occurring at a higher frequency than previously realized.

Boeing continues to enhance its understanding of what kind of weather causes engine events so the best information can be provided to flight crews. Each engine event is carefully evaluated from a meteorological and engine diagnostic standpoint so that, in the future, we can provide better information to operators.

6.0 Key Points for Flight Crews

6.1 Recognize weather conducive to ice crystal formation

Ice crystals are most frequently found in areas of visible moisture above altitudes normally associated with icing conditions. They are indicated by one or more of the following:

- Rain on the windscreen at temperatures too cold for liquid water to exist, due to ice crystals melting on the heated windows.
- Aircraft TAT remains near 0 degrees C.
- Areas of light to moderate turbulence.
- No significant radar returns at aircraft altitude.
- Heavy rain below the aircraft, identified by amber and red on weather radar.
- Cloud tops reaching above typical cruise levels (above the tropopause).

Note: There is no significant airframe icing. The icing conditions detection system (if installed) is not designed to detect ice crystal icing, only supercooled droplets.

6.2 Avoid ice crystal icing conditions

During flight in IMC, avoid flying directly above significant amber or red radar returns, even with no returns at aircraft altitude.

Use the weather radar manual tilt and gain functions to assess weather radar reflectivity below the aircraft flight path.

6.3 Ice crystal icing suspected

Exit ice crystal icing conditions. Request a route change to minimize time above red and amber radar returns.

7.0 More Information

For more general information please see the MyBoeingFleet web pages below:

- **Air France Training Module**
  Ice Crystals at High Altitude: Engine Powerloss, TAT and Pitot Anomalies
  [A 15 minute computer based training module for flight crews. Follow: “Flight Operations”, “Events, Training & Resources”, “Safety Tools & Training Aids”, “Ice Crystals at High Altitude”.]
- **Symposium Briefing**
  Ice Crystal Threat

["Flight Operations", "Past Flight Operations Conference Presentations", "More", "Regional Operations Conferences" (2008), "Ice Crystal Threat".]

– **AERO magazine**
  Engine Power Loss in Ice Crystal Conditions ["Archive", "2007, 4th Quarter"]
  Avoiding ConvectiveWeather Linked to Ice-crystal Icing Engine Events ["Archive", "2010, 1st Quarter"]

8.0 Ice Crystal Ice Threat - Frequently Asked Questions

Q1. How many engine events have been recorded?

There are more than 100 events in an industry database. This number includes events on Boeing aircraft, events involving engines on other manufacturers' aircraft, a commuter aircraft, and a business jet. In some cases, Boeing has been successful in making procedural changes which have eliminated engine power loss events on some engines.

Q2. How does ice form on warm engine surfaces?

The physics of ice crystal accumulation in the engine is not completely understood, but the mechanism is thought to be the following: Ice particles enter the engine and bombard a warm surface. Thus, a mixture of liquid and ice particles exist on the surface. The liquid slows down the incoming ice particles long enough for heat transfer to take place. Heat is removed from the metal until the freezing point is reached and ice begins to form. This phenomenon means ice accumulation can occur well behind the fan in the engine core. Ice shed from compressor surfaces can cause engine instability such as surge, flameout, or engine damage.

Q3. To date, what is the maximum internal engine surface temperature at which ice has formed?

Industry data has shown that an engine at cruise power, with engine surfaces near 100°F (38°C) before entry into cloud, was able to build up ice.

Q4. Are these events mostly at low power settings?

No. Engine power loss and damage events have been experienced both at high power, cruise conditions and low power, descent conditions.

Q5. Does increasing thrust help prevent ice build up?

Unlike conventional icing (supercooled liquid water), which builds up on cold engine surfaces, ice crystal icing can occur on engine surfaces that are initially warmer than freezing. When power is increased, the engine surfaces that are susceptible to the formation of ice change but ice formation is not eliminated. Further, if on descent, setting higher power would result in a slower descent and longer exposure to the threat.

Q6. In what temperature range do ice crystals exist?

Ice crystals exist from temperatures just below 0°C to well below -40°C. Note that convective storms have strong mixing effects so all supercooled liquid is efficiently converted to ice or ice crystals, even near freezing temperatures.

Q7. Explain the significance of ice crystal mass concentration compared to supercooled liquid?

For engine certification, the engine is exposed to a maximum of 2 g/m^3 (grams per cubic meter) of supercooled liquid droplets. In these conditions, ice builds up on the front of the engine – the fan, spinner, and core splitter fairing. When ice sheds, some of it will pass harmlessly through the fan duct. Measurements suggest that convective clouds can hold up to 8 g/m^3 of ice crystals. Not only is that four times the mass of supercooled liquid but ice is also able to form on core engine surfaces.

Q8. Why do some engines stall, some flameout, and some have damage?

The ice crystal icing phenomenon is not completely understood. Every engine also has different margins in its compressor and combustor, plus different geometry. The combination of design margins and geometry seem to result in different effects on each engine.

Q9. In these conditions, should engine anti-ice be turned on for all aircraft?

Not for all aircraft. Engine anti-ice supplies heat to the cowl and, in these conditions, that is not where ice is forming. Engine anti-ice also has other effects: Accelerating the engine to approach idle, providing ignition, and promoting a higher fuel-to-air ratio in the combustor. We have recommended using engine anti-ice for only those engines where we believe these effects are beneficial – those engines that have a power loss during low power. If the power loss or damage problem occurs during cruise, none of these effects prevent icing-related power loss.

Q10. What about turning on engine ignition?

On engines without auto-relight protection, continuous ignition could help the engine recover more quickly if the combustor flames out.

Q11. Would the relights be faster if the engine is at approach/high idle?

Yes, as long as ignition is available.

Q12. Are events still happening?

Yes. Across the industry, there is roughly one power loss and one damage event every four months.

Q13. At what altitudes have events been identified?

We have seen events from 9,000 feet up to 41,000 feet, all above the freezing level in a convective storm.

Q14. Are both large and small turbofan engines affected?

Yes. In the 1990s, commuter aircraft suffered rollbacks due to ice accumulation “blocking” the core. This phenomenon has not happened on large turbofan engines because the sizes of the engine passages make it more difficult to build up enough ice to block the core. Most of the large turbofan engine events are a result of ice building up and shedding, causing a surge, flameout or damage.

Q15. Do all engines recover?

As of today, all large turbofan engines have recovered. Commuter aircraft engines were not restarted until the ice melted at lower altitude. On large turbofan engines which have suffered power losses, all have been restarted quickly. Once the ice has shed, the engine is immediately able to restart.

Q16. Are both low and high bypass ratio engines affected?

Yes. We have events on older, low bypass engines as well as on brand new, large high bypass ratio turbofan engines.

Q17. Are deteriorated engines more susceptible?

Not necessarily, we have had events on old and new engines.

Q18. Why aren’t there flight crew procedures for all engine types?

Not all engines have ice crystal ‘problems' and the behavior of engines with problems differ. We provide engine-related procedures for only those engines where they are needed.

Q19. What is the TAT anomaly?

The aircraft Total Air Temperature (TAT) probe erroneously reporting zero °C can be an indication of ice crystals in the atmosphere.

This anomaly is due to ice crystals building up in the area near the sensor element, where ice crystals are partly melted by the heater, causing the zero °C reading. In some cases, TAT has “flat-lined” at zero during a descent and may be noticeable to pilots. In other cases, the error is more subtle and may not be a reliable indicator to provide early warning to pilots of high concentrations of ice crystals.

Although TAT is an engine control system parameter, the TAT anomaly has not been determined to be a contributor to the surge, stall or flameout events. Under these conditions, the engine control system compensates for the loss of TAT. Note that the 757 has never had a TAT anomaly event due to its location on the fuselage.

Q20. Can we tell flight crews to use the TAT anomaly to avoid iced crystal icing conditions?

The TAT anomaly is not a reliable indicator of ice crystal icing conditions because it does not occur on all aircraft and it sometimes occurs after the engine event.

Q21. Is anyone building an ice crystal detector?

Boeing and the industry are working to develop better methods of detecting ice crystals.

Q22. What is the industry doing to better understand this problem?

An industry committee has developed a Technology Plan which includes:

- Improved instrumentation to measure atmospheric conditions
- Flight trials to characterize ice crystals (particle size, concentration and extent)
- Fundamental physics testing of ice accumulation and shedding
- Improving engine test methods and facilities

Government and industry partnerships are funding this work.

Q23. What is the FAA doing to make sure engines are capable of operating in ice crystal icing?

The FAA is a partner in the technology plan mentioned above. In addition, the FAA has new regulations under review.

Q24. If I have had an ice crystal icing event, **would Boeing be interested in hearing about it, and receiving data?**

Boeing would greatly appreciate hearing details of the event. We have a questionnaire (included in this bulletin) you can fill out. In addition, if the flight data is still available, we have a standard request for engine and airplane data, including questions for the pilots. This would be very valuable to our continued investigation

9.0 Ice Crystal Encounter Pilot Questionnaire

Most information about ice crystal icing has been gathered from meteorological studies, airline-provided pilot reports, and flight data. If you suspect you've experienced an ice crystal encounter, even if it hasn't resulted in an engine event, we'd like to hear about it. In addition, it would be helpful to receive Flight Data Recorder (FDR) or Quick Access Recorder (QAR) data, if available.

Please complete the questionnaire on the following pages or online at http://vovici.com/wsb.dll/s/6640g3bab0. It should take less than 10 minutes of your time.

If you have had more than one encounter, please complete a questionnaire for each encounter.

Thank you in advance for your assistance.

Ice Crystal Encounter Pilot Questionnaire

Ice crystals have been associated with engine power loss, vibration, and damage. Power loss can be a surge, stall, flameout, or failure to respond to throttle input.

Please review the Engine Anomalies in Part 1 and the Conditions Associated with Ice Crystal Encounters in Part 2. If you have experienced an engine anomaly in IMC *or* one or more of the conditions, please answer the Questions about Ice Crystal Encounters in Part 3.

Part 1. Engine Anomalies

- Engine surge or stall (may have been momentary)
- Engine failed to respond to thrust lever inputs (may have been momentary)
- Engine flameout
- Engine vibration

Part 2. Conditions Associated with Ice Crystal Encounters

- No ice detected on Rosemount ice detector
- Aircraft in the vicinity of convective clouds or thunderstorms
- TAT anomaly (or TAT / T12 disagree)
- Flight above freezing level
- No weather radar returns at the event location
- Tropical atmosphere
- Visible moisture
- Light to moderate turbulence
- No observation of significant airframe icing
- Heavy rain or rain on the windscreen at SAT below -20°C
- St. Elmo's Fire
- Lightning
- Sounds of precipitation

Part 3. Questions about Ice Crystal Encounters

Please take a few minutes to provide as much of the following information as possible about your experience. Feel free to include any additional information you think may be of interest.

1. Did any of the following engine anomalies occur during the event?

	Yes	No / Don't know
Engine surge or stall (may have been momentary; engine may have recovered automatically)	☐	☐
Engine failed to respond to thrust lever inputs (may have been momentary; engine may have recovered automatically)	☐	☐
Engine flameout (may have been momentary)	☐	☐
Engine vibration	☐	☐
Other (please describe below)	☐	☐

Additional comments:

____

____

2. Please provide information about the event.

Aircraft Type ______________________________
Engine Type ______________________________
Date ______________________________
Time (UTC) ______________________________
Location (latitude/longitude, nearest waypoint or navaid) ______________________________
Altitude ______________________________
Temperature (SAT °C) ______________________________

3. Was the flight in the vicinity of convective clouds or thunderstorms?

☐ No / Don't know
☐ Yes (please indicate the location of the weather in relation to the aircraft)

Additional comments:

____

____

4. Was the flight through visible moisture or in Instrument Meteorological Conditions (IMC) at the time of the event?

- ☐ No / Don't know
- ☐ Yes (please describe)

Additional comments:

---

5. Was there rain on the windscreen or ice melting on the heated windscreen?

- ☐ No / Don't know
- ☐ Yes (please describe)

Additional comments:

---

6. If the aircraft was equipped with an ice detector, did it indicate ice?

- ☐ No / Don't know
- ☐ Yes
- ☐ Not equipped with an ice detector

Additional comments:

---

7. Was there a TAT anomaly (TAT reading zero or tending toward zero erroneously)?

- ☐ No / Don't know
- ☐ Yes (please explain)

Additional comments:

---

8. Were there any radar returns in the area?

☐ No / Don't know
☐ Yes (please provide the location [above or below, in front of, behind], size, color, and any additional information describing the returns)

Additional comments:

9. Were there any sounds of precipitation?

☐ No / Don't know
☐ Yes (please describe)

Additional comments:

10. Was there any visible airframe icing?

☐ No / Don't know
☐ Yes (please describe the icing type and severity)

Additional comments:

11. Was there any turbulence?

☐ No / Don't know
☐ Yes (please describe the turbulence)

Additional comments:

12. Was there any lightning?

- ☐ No / Don't know
- ☐ Yes

Additional comments:

____

____

13. Was St. Elmo's Fire visible?

- ☐ No / Don't know
- ☐ Yes

Additional comments:

____

____

14. Was the cockpit warmer or more humid than normal?

- ☐ No / Don't know
- ☐ Yes

Additional comments:

____

____

15. Was there any smell in the cockpit?

- ☐ No / Don't know
- ☐ Yes (please describe)

Additional comments:

____

____

16. Did the autothrottle automatically disconnect?

- ☐ No / Don't know
- ☐ Yes (please describe)

Additional comments:

____
____

17. Please provide any additional information about the event to help us better understand this weather phenomenon.

____
____
____
____

Thank you for taking the time to complete the questionnaire.

If you have any questions or would like to provide additional information, contact Jeanne Mason at jeanne.g.mason@boeing.com.

10.0 Information for Dispatchers

10.1 On IR satellite image

Look for large (>180KM) region of cloud tops at or above the altitude of the tropopause

Events typically happen in deep convection identified on an IR satellite image by a large round or oval "enhanced" region of cloud on the order of 180 km or greater. The enhanced region is where cloud tops are at the tropopause* temperature (obtained from nearest observed or forecast sounding see figure B) or colder. Approximately 80% of the events we've seen have occurred in mesoscale convective systems (MCS*).

10.2 Warm season thunderstorms

ISA +5 to +20C

The events are often found in MCSs with a tropical-like moist atmosphere. Events are occurring with equal frequency over land and water. A majority of the events tropical and subtropical regions, but they can occur anywhere convection is found. The temperature profiles are 5 to 20C warmer than ISA during events showing that this is a warm season or warm climate phenomena. The events recorded in 2008-2010 in the USA occurred in remnants of hurricanes and tropical storms.

10.3 Storm cloud top temperatures

Typically from -55C and colder (elevations above typical cruise altitudes)

Infrared cloud top temperatures were measured and recorded for each event location. As a result of the analysis, the median cloud top temperature was found to be -63C, the middle half of events had cloud top temperatures ranging from -55 C to -70 C, the maximum temperature was -44 C, and the minimum was -87 C

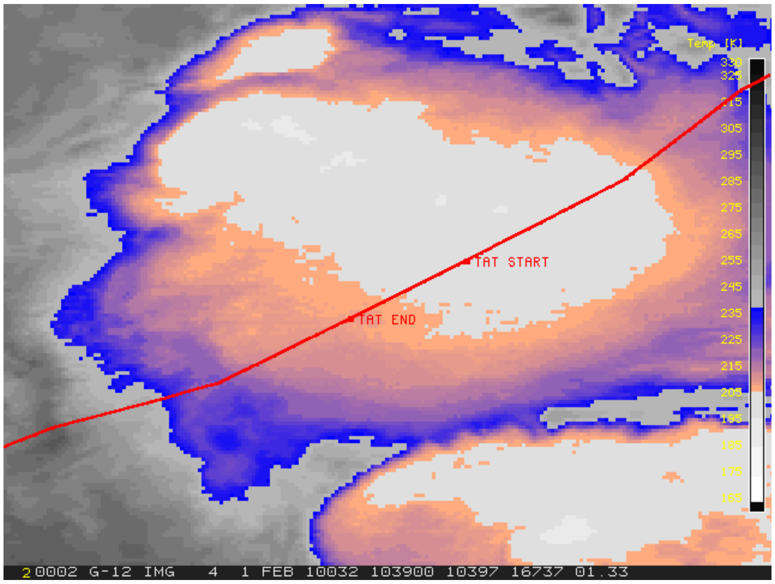


Figure A: Enhanced infra-red satellite image showing clouds at or above the tropopause in grey and white colors. The airplane track is shown in red. An engine damage event occurred during a TAT anomaly, noted by TAT start and TAT end notations. In the flight deck, the flight crew observed an auto-throttle disconnect associated with the TAT anomaly.

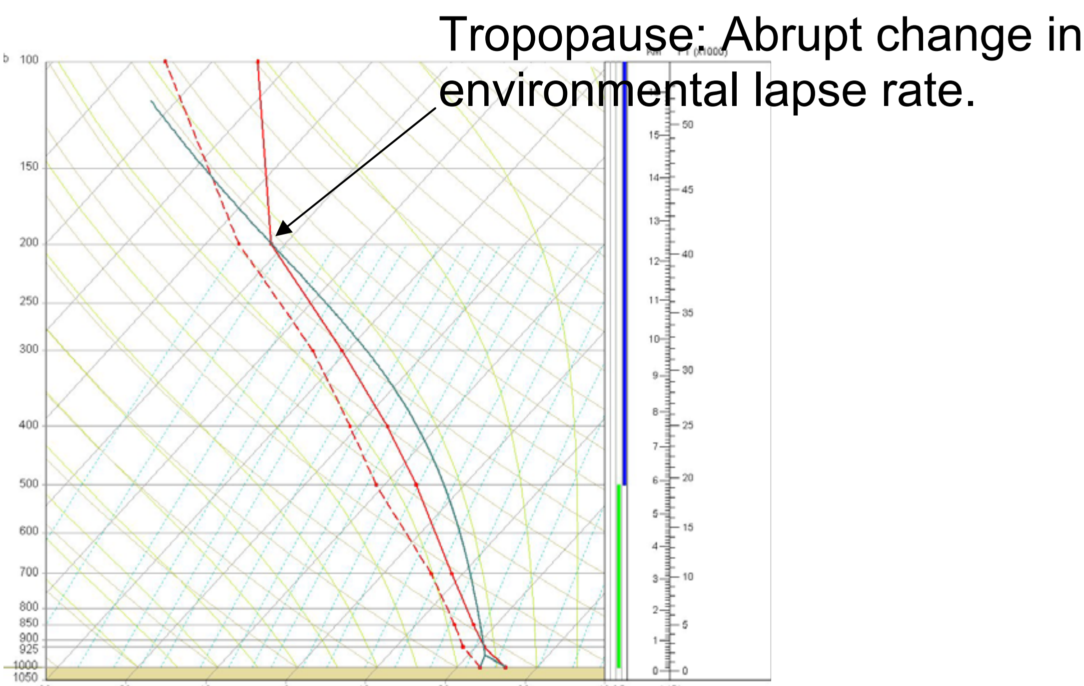


Figure B: An average sounding compiled from engine power loss and damage events up through 2009

10.4 Moderate and/or Heavy rain below the freezing level (> 30dbz)

Radar data from events show that below the aircraft there was heavy rain identified by greater than 5.5 mm/hr (30 dBZ) or amber or red on the on board weather radar (1 mm/hr = 23 dBZ, 10 mm/hr = 37 dBZ, and 100 mm/hr = 50 dBZ)

10.5 From the flight deck: Little or no radar at flight level (<20dbz)

Little to no radar reflectivity is typically detected at flight level during events. Reflectivity values have ranged from 10-25 dBZ at the engine event altitudes. Pilots can only detect 20+ dBZ, which make these areas mostly transparent to pilots.

10.6 Be aware of CAPE, Lifted Index* and Precipitable Water* values along the route*

A study of environmental parameters indicates engine events occur with moderate instability (median CAPE of 1,141 J/kg & median lifted index of -3.7), high moisture (median precipitable water of 2.3”) The highest risk areas will be MCS’s that occur within an environment that has PW values of 2” or greater.

10.7 Guidance for flight crews:

Avoid flying over the deepest convection in IMC, at temperatures below freezing. Pilots should also be advised to avoid flying down shear from convective cells in-cloud, at temperatures below freezing, especially if light returns (20-29 dBZ on aircraft weather radar).

10.8 Summary of Key Points for Dispatchers

- MCS with clouds over tropopause height 180km in size
- ISA +5 and greater
- Cloud top temps < -55
- Moderate and/or Heavy rain below the freezing level (> 30dbz)
- Precipitable Water values of 2” or greater

Forecasters should be aware of any MCS’s along the route and minimize (or avoid) routes through enhanced cold cloud top regions.

10.9 What the flight crews will notice and actions to take

- Little or no radar at flight level (<20dbz)
- Amber and red returns below the flight level

Advise pilots to tilt radar down and scan below airplane. Highest risk areas will have a combination of heavy rainfall below aircraft (likely no returns at flight level) and enhanced infrared region on satellite within MCS.

10.10 Glossary*

Tropopause: The boundary between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate. The change is in the direction of increased atmospheric stability from regions below to regions above the tropopause. Its height varies from 15 to 20 km (9 to 12 miles) in the Tropics to about 10 km (6 miles) in polar regions. In polar regions in winter it is often difficult or impossible to determine just where the tropopause lies, since under some conditions there is no abrupt change in lapse rate at any height. It has become apparent that the tropopause consists of several discrete, overlapping “leaves,” a multiple tropopause, rather than a single continuous surface. In general, the leaves descend, step-wise, from the equator to the poles.

Mesoscale Convective System (MCS): A cloud system that occurs in connection with an ensemble of thunderstorms and produces a contiguous precipitation area on the order of 100 km or more in horizontal scale in at least one direction. An MCS exhibits deep, moist convective overturning contiguous with or embedded within a mesoscale vertical circulation that is at least partially driven by the convective overturning.

Convective Available Potential Energy (CAPE): The maximum energy available to an ascending parcel, according to parcel theory. On a thermodynamic diagram this is called positive area, and can be seen as the region between the lifted parcel process curve and the environmental sounding, from the parcel's level of free convection to its level of neutral buoyancy.

Lifted Index (LI): is the temperature difference between an air parcel lifted adiabatically Tp(p) and the temperature of the environment Te(p) at a given pressure height in the troposphere (lowest layer where most weather occurs) of the atmosphere, usually 500 mb. When the value is positive, the atmosphere (at the respective height) is stable and when the value is negative, the atmosphere is unstable.

Precipitable Water: is the depth of the amount of water in a column of the atmosphere if all the water in that column were precipitated as rain. As a depth, the precipitable water is measured in millimeters or inches.

BOEING COMMERCIAL AIRPLANE GROUP

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: **777-31, 787-3**

DATE: **November 12, 2010**

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SUBJECT: **Approach to Stall or Stall Recovery Maneuver**

ATA NO: **0220**

APPLIES TO: **All 777/787 airplanes**

REASON: To provide background information about the new Approach to Stall or Stall Recovery Maneuver.

Background Information

An approach to a stall is a controlled flight maneuver; a stall is an out-of-control, but recoverable, condition. However, the recovery maneuver is the same for either an approach to a stall or a fully developed stall.

Most approach to stall incidents have occurred where there was altitude available for recovery. The incidents that progressed into accidents often occurred because the crew failed to make a positive recovery when the stall warning occurred, the condition progressed to a full stall, and the airplane impacted the ground in a stalled condition. For this reason, emphasis has shifted from a recovery with minimum loss of altitude to reducing the angle of attack below the wing stalling angle to complete a positive and efficient recovery.

A stall warning should be readily identifiable by the pilot, either by initial buffet or an artificial indication (stick shaker). During the initial stages of a stall, local airflow separation results in buffeting (initial buffet), giving a natural warning of an approach to stall. At cruise Mach speed, stick shaker activation occurs just after reaching initial buffet. Recovery from an approach to stall should be initiated at the earliest recognizable stall warning, either initial buffet or stick shaker.

An airplane may be stalled in any attitude (nose high, nose low, high or low angle of bank) or any airspeed (turning, accelerated stall). It is not always intuitively obvious that the airplane is stalled.

An airplane stall is characterized by one or more of the following conditions:

- Stall warning
- Buffeting, which could be heavy
- Lack of pitch authority
- Lack of roll control
- Inability to arrest descent rate.

Approach to Stall or Stall Recovery

To recover from a stall, the angle of attack must be reduced below the wing stalling angle. Smoothly apply nose down elevator to reduce the angle of attack until the wings are unstalled (buffet or stick shaker stops). Nose down stabilizer trim may be needed if the control column does not provide the needed response.

Application of forward control column (as much as full forward may be required) and the use of some nose-down stabilizer trim should provide sufficient elevator control to produce a nose-down pitch rate. It may be difficult to know how much stabilizer trim to use, and care must be taken to avoid using too much. Pilots should not fly the airplane using stabilizer trim, and should stop trimming nose down when they feel the g force on the airplane lessen or the required elevator force lessen. The use of too much trim may result in the loss of control or high structural loads.

If an attempt is made to roll to wings level before the wings are unstalled, the ailerons and spoilers are ineffective. Unloading the wing by maintaining continuous nose-down elevator pressure keeps the wing angle of attack low making the normal roll controls more effective. After the stall is broken, normal roll controls, up to full deflection of ailerons and spoilers, may be used to roll in the shortest direction to wings level, if needed. The use of rudder is normally not needed.

Normally the AFDS and flight controls protection reduces the likelihood of inadvertently exceeding the wing stalling angle. However, even though the autopilot and autothrottle are operating correctly, the airplane could fly into a condition where an approach to stall is momentarily experienced. The AFDS is designed to recover the airplane from this condition. The Approach to Stall or Stall Recovery maneuver calls for the crew to disengage the autopilot and autothrottle if the response is not acceptable. The following indications are examples of unacceptable performance:

- An approach to a stall is encountered and in the pilot's judgment the AFDS is not responding correctly or rapidly enough
- The airplane enters a fully developed stall
- The airplane enters an upset condition.

The Approach to Stall or Stall Recovery maneuver calls for the crew to advance the thrust levers as needed. Under certain conditions, where high thrust settings are already applied such as during takeoff or go-around, it may be necessary to reduce thrust in order to prevent the angle of attack from continuing to increase. This is because airplanes with underwing-mounted engines have an upward pitch moment relative to increased thrust.

Note: Use care during recovery from a nose low attitude after the buffet and/or stick shaker have stopped. If the pull up is too aggressive, a "secondary" stall or sustained stick shaker may result.

In extreme cases where the application of forward control column coupled with some nose-down stabilizer trim and a thrust reduction do not stop an increasing pitch rate in a nose high situation, rolling the airplane to a bank angle that starts the nose down may be effective. If normal roll control is ineffective, careful rudder input in the direction of the desired roll may be required. Bank angles of about 45°, up to a maximum of 60°, could be needed. Too much rudder applied too quickly or held too long may result in loss of lateral and directional control.

Do not change gear or flap configuration during the recovery, unless a stall warning indication is encountered during liftoff and the flaps were inadvertently positioned up for takeoff. In this case, extend flaps 1 as directed in the Approach to Stall or Stall Recovery maneuver.

Stall Protection Demonstration

The objective of the stall protection demonstration is to familiarize the pilot with stall warning and the correct recovery technique for conditions that are approaching stall, both with and without the autopilot.

Begin the stall protection demonstration in level flight with flaps up at flaps up maneuvering speed. Select a speed in the IAS/MACH window that is below the minimum speed indication on the speed tape. Disengage the autopilot and autothrottle and retard the thrust levers to idle. As the speed decreases into the amber band, the PLI appears on the PFD. When the speed decreases approximately half way through the amber band, the AIRSPEED LOW caution message appears. The autothrottle wakes up, automatically engages in the SPD mode, and returns the airplane to the minimum maneuvering speed.

For the second part of the stall protection demonstration, select VREF 30 on the CDU. Disengage the autopilot, turn the autothrottle arm switches off, and select a speed in the IAS/MACH window that is below the minimum speed indication on the speed tape. Maintain heading and altitude, and retard the thrust levers to idle. As the airplane decelerates, continue trimming and select flaps 20 on schedule. The PLI appears on the PFD when the flaps are extended. The airplane can be trimmed until the airspeed is approximately equal to the minimum maneuver speed. Below this airspeed, nose up trim is inhibited. After the airspeed decreases into the amber band, use only control column inputs to maintain level flight. The stick shaker activates at minimum speed. If the airspeed reduces to slightly less than minimum speed, increased control column force is required to maintain level flight. Recover from the approach to stall in accordance with the Approach to Stall or Stall Recovery maneuver. Lateral control is maintained with ailerons and spoilers. Rudder use is not recommended because it causes yaw and the resultant roll is undesirable. After recovery, accelerate to flaps up maneuvering speed while retracting the flaps.

To demonstrate autopilot stall protection, ensure that the pitch mode is ALT, turn the autothrottle arm switches OFF and then retard thrust levers to idle. As the speed approaches the minimum speed, the AUTOPILOT caution message appears, an amber line is drawn through the selected pitch mode and the flight director pitch bar is removed. At minimum speed, the stick shaker activates. Shortly after the stick shaker activates, the autopilot begins to descend from the selected altitude. The autopilot maintains a descent at a speed that is slightly above the minimum speed. To recover, engage the autothrottle with a higher speed selected or manually advance the thrust levers. Select a new pitch mode or disengage the autopilot and manually fly the airplane back to the starting altitude.

Sample Maneuver:

Maneuvers — **Chapter Man**
Non - Normal Maneuvers — **Section 1**

Approach to Stall or Stall Recovery

All recoveries from approach to stall should be done as if an actual stall has occurred.

Immediately do the following at the first indication of stall (buffet or stick shaker):

Note: Do not use flight director commands during the recovery.

Note: If autopilot response is not acceptable, it should be disengaged.

Note: If autothrottle response is not acceptable, it should be disengaged.

Pilot Flying	Pilot Monitoring
• Initiate the recovery: • Smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops	• Monitor altitude and airspeed • Verify all required actions have been done and call out any omissions • Call out any trend toward terrain contact
• Continue the recovery: • Roll in the shortest direction to wings level if needed * • Advance thrust levers as needed • Retract the speedbrakes • Do not change gear or flap configuration, except • During liftoff, if flaps are up, call for flaps 1	• Monitor altitude and airspeed • Verify all required actions have been done and call out any omissions • Call out any trend toward terrain contact • Set the FLAP lever as directed
• Complete the recovery: • Check airspeed and adjust thrust as needed • Establish pitch attitude • Return to the desired flight path • Re-engage the autopilot and autothrottle if desired	• Monitor altitude and airspeed • Verify all required actions have been done and call out any omissions • Call out any trend toward terrain contact

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WARNING: * Excessive use of pitch trim or rudder may aggravate the condition, or may result in loss of control or in high structural loads.

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ADVANCES IN

VOCANIC ASH

AVOIDANCE AND RECOVERY

A commercial airplane encounter with volcanic ash can threaten safety of flight because of resulting conditions that range from windshield pitting to loss of thrust in all engines. Developments in technology and communication networks have significantly decreased the probability of such an encounter in the last several years. Despite these developments, however, a 737-700 recently flew through a volcanic ash cloud. Updated information about advancements made in ensuring safe operations and minimizing damage to the airplane during a volcanic ash encounter is now available to flight crews.

SAFETY

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In the past 30 years, more than 90 jet-powered commercial airplanes have encountered clouds of volcanic ash and suffered damage as a result. The increased availability of satellites and the technology to transform satellite data into useful information for operators have reduced the number of volcanic ash encounters. However, further coordination and cooperation, including linking operators and their dispatchers to the network of government volcano observers, is required throughout the industry. Boeing has always advocated that flight crews avoid volcanic ash clouds or exit them immediately if an encounter occurs. The company also recommends specific procedures for flight crews to follow if they cannot avoid an encounter.

Flight crews will be better prepared to avoid volcanic ash clouds and take the appropriate actions during an encounter if they understand the following information:

1. Results of past events involving volcanic ash.
2. Resources available to help avoid ash encounters.
3. Specific flight crew actions required in response to encounters.

1 RESULTS OF PAST EVENTS INVOLVING VOLCANIC ASH

Significant ash encounters from the past include those involving such well-known volcanoes as Mt. Pinatubo, Mt. Redoubt, and Mt. St. Helens. The airplanes that encountered volcanic ash during these events and in the other events listed chronologically experienced varying degrees of damage.

Mt. St. Helens, United States, 1980.

A 727 and a DC-8 encountered separate ash clouds during this major eruption. Both airplanes experienced damage to their windshields and to several systems, but both landed safely despite the windshield damage.

Galunggung volcano, Indonesia, 1982.

Several 747s encountered ash from this eruption. One airplane lost thrust from all four engines and descended from 36,000 ft to 12,500 ft before all four engines were restarted. The airplane, on a flight from Kuala Lumpur, Malaysia, to Perth, Australia, diverted to Jakarta and landed safely despite major engine damage. This airplane subsequently had all four engines replaced before returning to service. A few days after the initial encounters, another 747 flew into the ash cloud and suffered significant engine damage. This airplane also diverted to Jakarta and subsequently performed a successful two-engine landing.

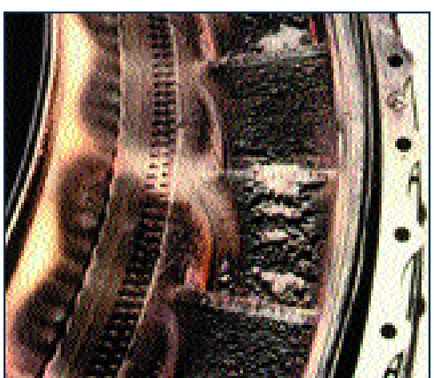
Mt. Redoubt, United States, 1989.

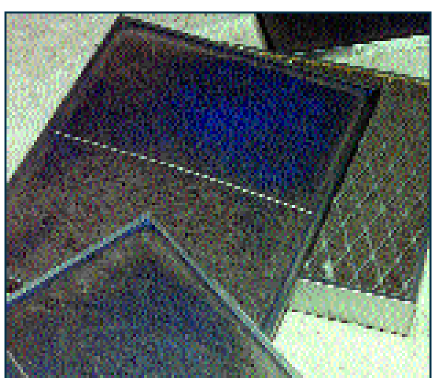
On a flight from Amsterdam to Anchorage, Alaska, a new 747-400 (only three months old with approximately 900 hr total flying time) encountered an ash cloud from the erupting Mt. Redoubt near Anchorage. All four engines ingested ash and flamed out. The crew successfully restarted the engines and landed safely at Anchorage.

All four engines were replaced and many airplane systems also had to be repaired or replaced. For example, the airplane environmental control system was replaced (see below), the fuel tanks were cleaned, and the hydraulic systems were repaired. Several other airplanes encountered ash from this eruption, but most damage was minor because operators had been notified of the eruption. Some operators, such as Alaska Airlines, continued scheduled flights once they developed processes to safely identify where ash might be encountered. Although information was available about the Mt. Redoubt eruption, the channels for sharing this information were not well developed at the time (see "Alaska Airlines Procedures for Operating in Volcanic Ash Conditions" on p. 25).

Mt. Pinatubo, Philippines, 1991.

More than 20 volcanic ash encounters occurred after the Mt. Pinatubo eruption, which was the largest volcanic eruption of the past 50 years. The ability to predict where ash was to be found was challenging because of the enormous extent of the ash cloud. Commercial flights and various military operations were affected; one U.S.


Engine damage from ash ingestion


Environmental control system damage

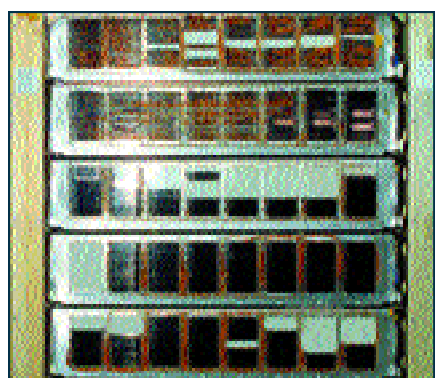
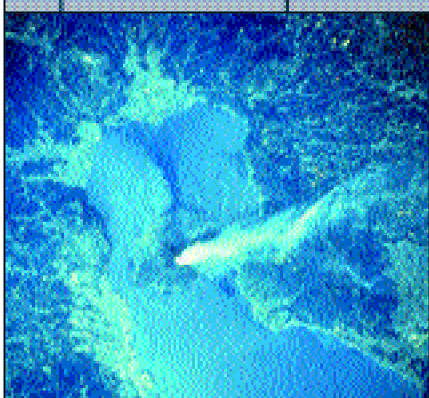

Electrical panel damage

FIGURE 1 VAAC REGIONS



Space shuttle image of volcanic eruption

operator grounded its airplanes in Manila for several days.

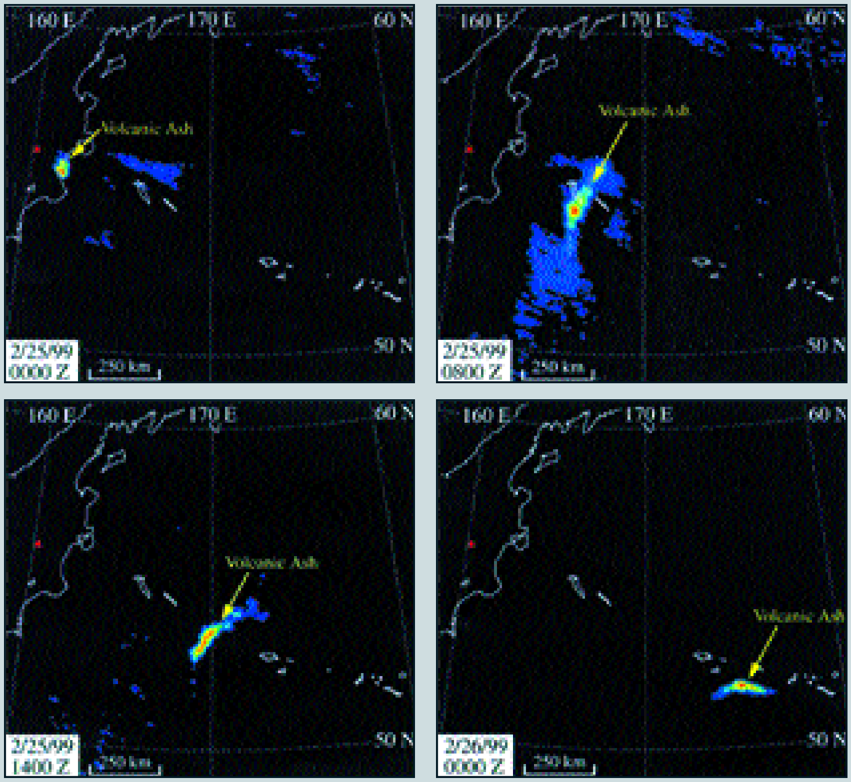
Mt. Popocatepetl, Mexico, 1997. This volcano affected several flights in 1997 and 1998. Although damage was minor in most cases, one flight crew experienced significantly reduced visibility for landing and had to look through the flight deck side windows to taxi after landing. In addition, the airport in Mexico City was closed for up to 24 hr on several occasions during subsequent intermittent eruptions.

2 RESOURCES AVAILABLE TO HELP AVOID ASH ENCOUNTERS

Although some information about volcanic eruptions has been available for many years, the aviation industry and volcanological community began a joint effort to find ways to avoid future encounters after the Mt. Redoubt eruption. At an international conference in Seattle, Washington, in July 1991, aviation industry members, meteorologists, and volcano scientists gathered to determine what volcano event information the aviation industry needed, how this information could be distributed, and who or which agencies should distribute it. The International Civil Aviation Organization (ICAO) had laid much of the foundation for the volcanic ash issue through its Volcanic Ash Warnings Study Group; see "ICAO Activities on Volcanic Ash" on page 26.

One of the outcomes of this initial meeting is the availability of today's Volcanic Ash Advisory Centers (VAAC). The VAACs provide an important link among volcano observatories, meteorological agencies, air traffic control centers, and operators. A total of nine VAACs observe and report on a particular region of the world (fig. 1).

One product of the VAACs is the Volcanic Ash Advisory Statement (VAAS). Below is an example of a VAAS for a recent event in 1999.



Geostationary operational environmental satellite detection and tracking of volcanic ash cloud from an eruption of Bezymianny volcano, Russia, that began at 7:00 a.m. on Feb. 24, 1999. The red triangle indicates the volcano location. Highest ash concentrations are indicated in orange and yellow. The blue areas on 0000Z and 0800Z are noise and do not indicate ash. The cloud was tracked at 15-min increments for 1,500 km until it dispersed beyond the limits of detection.

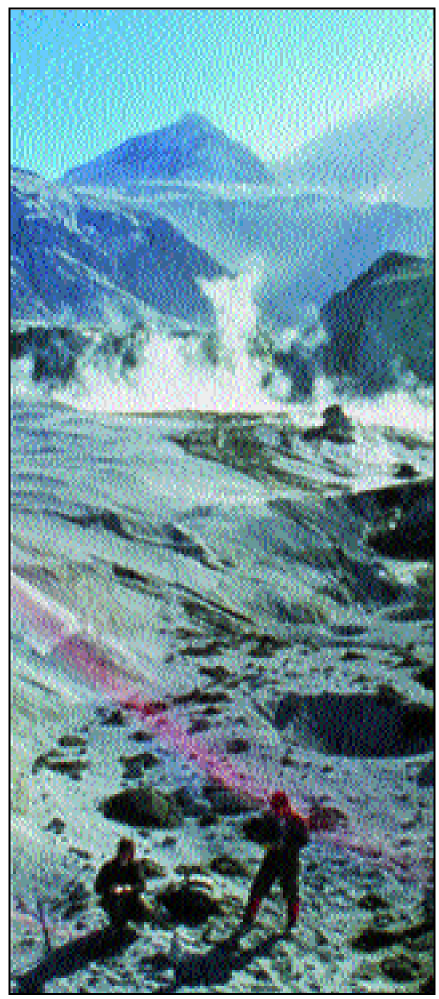
In addition to providing VAASs directly to the airlines, the VAACs also provide information to appropriate meteorological organizations that subsequently issue significant meteorological information (SIGMET) and other reports. The ICAO publication "International Airways Volcano Watch"(ICAO annex III) contains further information and contact names and numbers. Detailed information on the VAACs, including contacts for each of the nine centers, is available at http://www.ssd.noaa.gov/VAAC/.

Operators rely on the VAACs for information, and many operators maintain direct contact with volcano observatories within their flight domains. For instance, the Alaska Volcano Observatory (AVO) in Anchorage, with links to Fairbanks, issues a weekly bulletin by e-mail and fax detailing the activity of key volcanoes in Alaska. During periods of volcanic unrest and eruption, bulletins are issued frequently as conditions change. Anyone can request to be placed on distribution for the bulletins. The AVO web site (http://www.avo.alaska.edu/) also provides updated information. For those without Internet access or unable to access the site if it is overloaded during a crisis, the AVO daily telephone recording at 907-786-7477 provides brief updated information for air carriers. Finally, many operators maintain personal relationships with individuals in the volcano observatories that monitor volcanoes within a particular flight domain. For instance, Alaska Airlines maintains contact with key individuals at the AVO because a significant portion of Alaska's flight domain could be affected by Alaskan volcanoes.

Reports can indicate whether the activity is steam, as shown above, or ash.

Right: Geologists from the AVO examine fresh pyroclastic flow from Mt. Redoubt, Mar. 23, 1990.

Many other web sites provide information and links to other sources of volcano information (see "Volcanic Ash Resources" on p. 27). A wealth of printed information, such as the *Bulletin of the Global Volcanism Network* through the Smithsonian National Museum of Natural History in Washington, D.C., is also available. However, the information about current volcanic activity in these printed sources is often two to three months old.



3 SPECIFIC FLIGHT CREW ACTIONS REQUIRED IN RESPONSE TO ENCOUNTERS

Despite ongoing avoidance efforts, operators can still experience volcanic ash encounters. Guidance on the operational issues surrounding volcanic ash is divided into three aspects: avoidance, recognition, and procedures. The following information is general; flight crews should refer to their respective company's operating manuals for details.

Avoidance.

Preventing flight into potential ash environments requires planning in these areas:

- Dispatch needs to provide flight crews with information about volcanic events, such as potentially eruptive volcanoes and known ash sightings, that could affect a particular route (see sidebar at bottom of p. 26).
- Dispatch also needs to identify alternate routes to help flight crews avoid airspace containing volcanic ash.
- Flight crews should stay upwind of volcanic ash and dust.
- Flight crews should note that airborne weather radar is ineffective for distinguishing ash and small dust particles.

Recognition.

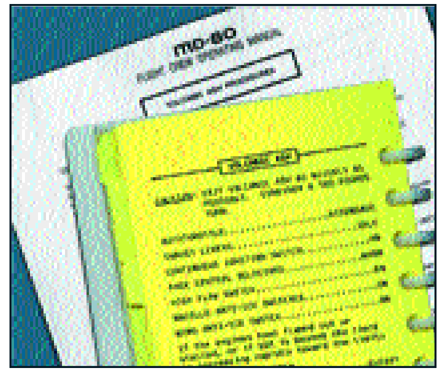
Indicators that an airplane is penetrating volcanic ash are related to odor, haze, changing engine conditions, airspeed, pressurization, and static discharges.

- **Odor.** When encountering a volcanic ash cloud, flight crews usually notice a smoky or acrid odor that can smell like electrical smoke, burned dust, or sulfur.
- **Haze.** Most flight crews, as well as cabin crew or passengers, see a haze develop within the airplane. Dust can settle on surfaces.
- **Changing engine conditions.** Surging, torching from the tailpipe, and flameouts can occur. Engine temperatures can change unexpectedly, and a white glow can appear at the engine inlet.
- **Airspeed.** If volcanic ash fouls the pitot tube, the indicated airspeed can decrease or fluctuate erratically.
- **Pressurization.** Cabin pressure can change, including possible loss of cabin pressurization.
- **Static discharges.** A phenomenon similar to St. Elmo's fire or glow can occur. In these instances, blue-colored sparks can appear to flow up the outside of the windshield or a white glow can appear at the leading edges of the wings or at the front of the engine inlets.

Procedures.

The following nine procedures are general recommendations. Each operator's flight operations manuals will include more specific directions.

1. **Reduce thrust to idle immediately.** By reducing thrust,engines may suffer less buildup of molten debris on turbine blades and hot-section components. Idle thrust allowsengines to continue producing electrical power, bleed air for pressurization, and hydraulic power for airplane control.
2. **Turn the autothrottles off.** This prevents the engines from increasing thrust above idle. Ash debris in the engine can result in reduced surge margins, and limiting the number of thrust adjustments improves the chances of engine recovery.
3. **Exit the ash cloud as quickly as possible.** A 180-deg turn out of the ash cloud using a descending turn is the quickest exit strategy. Many ash clouds extend for hundreds of miles, so assuming that the encounter will end shortly can be false. Climbing out of the ash could result in increased engine debris buildup as the result of increased temperatures. The increased engine buildup can cause total thrust loss.
4. **Turn on engine and wing anti-ice devices and all air-conditioning packs.** These actions improve the



engine stall margins by increasing the flow of bleed air.

5. **If possible, start the auxiliary power unit (APU).** The APU can power systems in the event of a multiple-engine power loss. It can also be used to restart engines through the use of APU bleed air.
6. **If volcanic dust fills the flight deck, the crew may need to use oxygen.** Use flight deck oxygen at the 100 percent setting. Manual deployment of the passenger oxygen system is not required because it will deploy automatically if the cabin altitude exceeds 14,000 ft.
7. **Turn on the continuous ignition.** Confirm that autostart is on, if available. In the event that the engines flame out or stall, use appropriate procedures to restart the engines. During restart, the engines may take longer than normal to reach idle thrust due to the combined effects of high altitude and volcanic ash ingestion. If an engine fails to start, try restarting it again immediately. Flight crews should remember that the airplane may be out of the airstart envelope if the encounter occurs during cruise.
8. **Monitor engine exhaust gas temperature (EGT).** Because of potential engine debris buildup, the EGT can climb excessively. The flight crew should prevent EGT exceedances. Shut down the engine and restart it if the EGT is approaching limits similar to a hung start.
9. **Fly the airplane by monitoring airspeed and pitch attitude.** If necessary, follow the procedure for flight with unreliable airspeed.

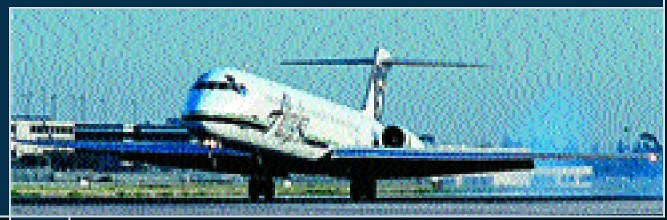
SUMMARY

Though the number of commercial airplane encounters with volcanic ash clouds has decreased significantly over the past several years, the potential for this type of event still exists. Efforts to advance knowledge about how to avoid and recover from these encounters have resulted in improved capability in these areas. By working with members of the volcanological community, the aviation industry has developed procedures to share information about events with flight crews, dispatchers, volcano scientists, and others. Volcano observatories that provide daily updates through e-mail messages or phone recordings have been established. In addition, a variety of Internet sources provide information that operators can tailor to their specific flight domains. Finally, flight operations procedures are documented and available to flight crews to help them respond immediately and appropriately to maintain the highest possible level of flight safety.

ALASKA AIRLINES PROCEDURES FOR OPERATING IN VOLCANIC ASH CONDITIONS

Alaska Airlines has many active volcanoes within its flight domain. To prepare for an eruption and resulting encounter with volcanic ash, the airline has developed focused guidelines for flight operations when eruptions interfere with its route structures:

1. When in doubt, don't fly.
2. Use facts and data.
3. Identify the location of both the ash and clear areas.
4. Stay focused.

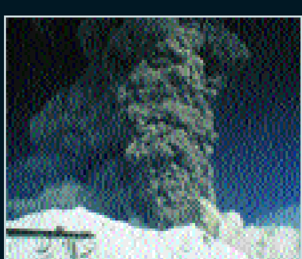


1 WHEN IN DOUBT, DON'T FLY

The fundamental principle by which Alaska Airlines operates is knowing where to find the ash after a volcanic eruption. If unsure of the ash location, it will not allow its flight crews to fly through the eruption area. Though this approach is conservative, Alaska Airlines successfully and safely operated after the 1989 Mt. Redoubt eruption and other volcanic eruptions.

2 USE FACTS AND DATA

Alaska Airlines has selected several information sources, uses Volcanic Ash Advisory Statements from the Volcanic Ash Advisory Centers, and is in direct communication with the Alaska Volcano Observatory. During a major eruption, Alaska Airlines will interview its own pilots as well as other operators' pilots about their observations on ash location. It has also established contacts on the ground that it can call for additional intelligence. These individuals include mayors and police officers in villages and towns near the airline's flight paths. If Alaska Airlines receives inconsistent information, it double-checks and continually validates what appears to be correct.



3 IDENTIFY THE LOCATION OF BOTH THE ASH AND CLEAR AREAS

Alaska Airlines tracks the ash by asking a number of questions:

- Where is the ash itself?
- Where is the volcanic source of the ash?
- What are the winds doing?
- What information is available from the volcanological community?
- What information do the reports from the pilots, selected contacts, and others contain?

Alaska Airlines then provides its pilots with information on where to fly and the reasons for not flying in certain areas.

4 STAY FOCUSED

Ed Haeseker, manager of air traffic control for Alaska Airlines, worked during the Mt. Redoubt event with Tom Cufley, then chief pilot at Alaska Airlines. They found that a small team worked better than a large team, especially if the chief pilot provided information directly to the flight crew in the early days of the event. In addition, a small team can travel more quickly to the site where the greatest assistance is needed and remain focused on the key task: identifying where the ash is.

ICAO ACTIVITIES ON VOLCANIC ASH

The International Civil Aviation Organization (ICAO) initiated a volcanic ash effort in 1982 after multiple volcanic ash encounters by 747 airplanes near Jakarta, Indonesia. The resulting organization, the Volcanic Ash Warnings Study Group, has worked since then to standardize the information provided to flight crews about volcanic eruptions.

In addition, ICAO formed the International Airways Volcano Watch (IAVW) in 1987. This effort formalized the international arrangements for monitoring and providing warnings to airplanes about volcanic ash in the atmosphere. ICAO annex III and the World Meteorological Organization (WMO) Technical Regulation C.3.1 introduced a requirement to disseminate information about volcanic ash to airplanes in the form of significant meteorological information (SIGMET) and notice to airmen (NOTAM).

The first WMO/ICAO workshop on volcanic ash hazards was held in Darwin, Australia, in 1995. Since then, a number of the designated Volcanic Ash Advisory Centers (VAAC) have come into full operation. A second workshop in Toulouse, France, in 1998 focused primarily on VAAC responsibilities and procedures

More information about ICAO activities related to volcanic ash avoidance and encounters is available in the organization's document titled "Operational Procedures And List Of Operational Contact Points Between Vulcanological Agencies, Meteorological Watch Offices And Area Control Centres," or from the address to the right.

T. Fox

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VOLCANO ERUPTION WARNING COLOR CODES

Eruption warnings are issued in the form of color-coded information releases. Over the past 10 years, this method has proved to be effective for alerting the aviation community to potential volcanic ash.

ALERT COLOR CODE	VOLCANO ACTIVITY STATUS
Red	Volcanic eruption in progress. Ash plume or cloud reported above FL 250.
	Volcano dangerous, eruption likely, with ash plume or cloud expected to rise above FL 250.
Orange	Volcanic eruption in progress but ash plume or cloud not reaching nor expected to reach FL 250.
	Volcano dangerous, eruption likely, but ash plume or cloud not expected to reach FL 250.
Yellow	Volcano known to be active from time to time and volcanic activity has recently increased significantly, volcano not currently considered dangerous but caution should be exercised.
	After an eruption, i.e., change in alert to yellow from red or orange, volcanic activity has decreased significantly, volcano not currently considered dangerous but caution should be exercised.
Green	Volcanic activity considered to have ceased and volcano reverted to its normal state.

The responsible volcanological agency in the region where the volcano erupts should provide the area control center with (1) the color code for the level of alert indicating the status of activity of the volcano and (2) any change from a previous status of activity (e.g., "Red alert following yellow" or "Green alert following orange"). Source: ICAO—International Airways Volcano Watch.

VOLCANIC ASH RESOURCES

Volcanic ash resources are available worldwide and in many forms accessible to operators. Volcano observatories are located throughout the world, including the Alaska Volcano Observatory for information about North Pacific volcanoes and the Nordic Volcanological Institute for information about volcanic activity that could affect North Atlantic routes. Many of these observatories provide immediate eruption and volcanic ash updates to operators by fax, e-mail, telephone, or teletype. Information is also available on the World Wide Web at the following sites:

The Smithsonian National Museum of Natural History Global Volcanism Program: http://www.volcano.si.edu/gvp/

The U.S. Geological Survey: http://www.usgs.gov/themes/volcano.html

The Airline Dispatcher Federation (a detailed paper about volcanic ash written by Leonard J. Salinas of United Airlines, Chicago, Illinois):
http://www.dispatcher.org/library/VolcanicAsh.htm

The Committee on Earth Observation Satellites Disaster Management Support Project/Volcanic Hazards Management (an effort by the U.S. National Oceanic and Atmospheric Administration; information on tracking ash clouds):

The Istituto Internazionale di Vulcanologia (a summary of volcanoes in Italy): http://www.iiv.ct.cnr.it/

The Nordic Volcanological Institute (information about volcanoes in and around Iceland): http://www.norvol.hi.is/index.html

The Volcanological Society of Japan (eruption information, live images of Japanese volcanoes, and other information):
http://hakone.eri.u-tokyo.ac.jp/kazan/VSJ1E.html

Current Eruptions in Japan (additional current information):
http://hakone.eri.u-tokyo.ac.jp/vrc/erup/erup.html

Other sources of information include the following:
The Boeing Company, *Airliner* magazine ("Vulcan's Blast," April-June 1990, and "Vulcan Returns: Volcanic Ash Effects on Airplanes Revisited," October-December 1991) and video ("Volcanic Ash Avoidance: Flight Crew Briefing").

U.S. Federal Aviation Administration, *Aviation Safety Journal* reprint ("The Volcano Threat to Aviation Safety").

Casadevall, T. J., ed. 1994. The First International Symposium on Volcanic Ash and Aviation Safety: Proceedings Volume: U.S. Geological Survey Bulletin 2047.

Casadevall, T. J., T. B. Thompson, and T. Fox. 1999. World map of volcanoes and principal air navigation features. U.S. Geological Survey Map I-2700.

THE PRIMARY SOURCE FOR ANY VOLCANIC ERUPTION AND ASH INFORMATION IS A VOLCANIC ASH ADVISORY CENTER. THE OTHER SOURCES LISTED HERE MAY OFFER MORE DETAILED INFORMATION ON A PARTICULAR ERUPTION. – ED.

BOEING COMMERCIAL AIRPLANES

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: 707-10-1
727-10-1
737-10-1
747-18 (747-100/200/300)
747-59 (747-400/-8)
757-78
767-80
777-28
787-2

DATE: April 21, 2010

This bulletin provides information which may prove useful in airline operations or airline training. The information provided in this bulletin is not critical to flight safety. The information may not apply to all customers; specific effectivity can be determined by contacting The Boeing Company. This information will remain in effect depending on production changes, customer-originated modifications, and Service Bulletin incorporation. Information in this bulletin is supplied by The Boeing Company and may not be approved or endorsed by the FAA at the time of writing. Appropriate formal documentation will be revised, as necessary, to reflect the information contained in this bulletin. For further information, contact Boeing Commercial Airplanes; Chief Pilot -Flight Technical and Safety; Training and Flight Services; P.O. Box 3707; Mail Code 14-HA; Seattle, Washington 98124-2207; Phone (206) 544-9700; Facsimile (206)544-9687; SITA: SEABO7X Station 627.

SUBJECT: Specific Flight Crew Actions Required in Response to Volcanic Ash Encounters

ATA NO: 05-50

APPLIES TO: All 707, 727, 737, 747, 757, 767, 777, 787, DC-8, DC-9, DC-10, MD-10, MD-11, MD-80, and MD-90 Airplanes

REFERENCES:
/A/ Boeing Multi-Operator Message MOM-MOM-10-0277-01B Dated 16 April 2010 GMT
/B/ AERO Magazine No. 9, 1st Quarter 2000
/C/ Boeing Multi-Operator Message MOM-MOM-10-0280-01B Dated 19 April 2010 GMT
/D/ Boeing Multi-Operator Message MOM-MOM-10-0281-01B Dated 21 April 2010 GMT

BACKGROUND:

As a result of volcanic ash from the Eyjafjallajoekull, Iceland area, all flights in and out of the United Kingdom and several other European countries have been suspended. Flight operations may be impacted for several months. The Reference /A/ message is a guide to operators and covers both airplane protection during this event and the actions necessary to return airplane to service following potential volcanic ash contamination.

This message is for dispatchers, flight followers, and flight crews and is a synopsis of the Reference /B/ article. Further, ground operation considerations and precautions have been added. The following information is general in nature; flight crews should refer to their company's operating manuals for more details.

OPERATING INFORMATION:

Operational guidance about volcanic ash is divided into three parts: Avoidance, Recognition, and Procedures.

1. Avoidance

Preventing flight into potential ash environments requires planning in these areas:

- Dispatch needs to provide flight crews with information about volcanic events, such as potentially eruptive volcanoes and known ash sightings, that could affect a particular route.
- Dispatch needs to identify alternate routes to help flight crews avoid airspace containing volcanic ash.
- Dispatch also needs to identify escape routes in the event of an unplanned descent due to an engine failure or cabin depressurization.
- Flight crews should stay upwind of volcanic ash and dust.
- Flight crews should remember that airborne weather radar is ineffective in distinguishing ash from small dust particles.

2. Recognition

Indicators that an airplane is penetrating volcanic ash are related to odor, haze, changing engine conditions, airspeed, pressurization, and static discharges.

- **Odor.** When encountering a volcanic ash cloud, flight crews usually notice a smoky or acrid odor that can smell like electrical smoke, burned dust, or sulfur.
- **Haze.** Most flight crews, as well as cabin crews and passengers, see a haze develop within the airplane. Dust can settle on surfaces.
- **Changing engine conditions.** Surging, torching from the tailpipe, and flameouts can occur. Engine temperatures can change unexpectedly and a white glow can appear at the engine inlets.
- **Airspeed.** If volcanic ash fouls the pitot tube, the indicated airspeed can decrease or fluctuate erratically.
- **Pressurization**. Cabin pressure can change, including possible loss of cabin pressurization.
- **Static discharges.** A phenomenon similar to St. Elmo's fire or glow can occur. In these instances, blue-colored sparks can appear to flow up the outside of the windshield or a white glow can appear at the leading edges of the wings or at the front of the engine inlets.

3. Procedures

Procedures are divided into two parts: In-flight Operations and Ground Operations at Airports Impacted by Volcanic Ash.

A. In-flight Operations

Flight crews should do the *Volcanic Ash* non-normal checklist in the Quick Reference Handbook (QRH). This checklist includes the following information:

- **Exit the ash cloud as quickly as possible.** A 180-degree turn out of the ash cloud using a descending turn is the quickest exit strategy. Many ash clouds extend for hundreds of miles, so assuming that the encounter will end shortly can be false. Climbing out of the ash could result in increased engine debris buildup as the result of increased temperatures. The increased engine buildup can cause total thrust loss.
- **If volcanic dust fills the flight deck, the flight crew may need to use oxygen.** Use flight deck oxygen at the 100 percent setting. If requested by the cabin crew, the flight crew may consider manual deployment of the passenger oxygen system. Flight crews should remember that the passenger oxygen system will deploy automatically if the cabin altitude exceeds 14,000 ft.
- **Turn the autothrottle(s) off.** This prevents the autothrottle(s) from increasing thrust. Ash debris in the engine can result in reduced surge margins and limiting the number of thrust adjustments improves the chances of engine recovery.
- **If conditions allow, reduce thrust to idle immediately.** By reducing thrust, engines may suffer less buildup of molten debris on turbine blades and hot-section components. Idle thrust allows engines to continue producing electrical power, bleed air for pressurization, and hydraulic power for airplane control.
- **Turn on continuous ignition, if available.**
- **If an engine flames out or stalls, attempt to restart the engine(s).** Confirm that autostart is on, if available. During restart, the engines may take longer than normal to reach idle thrust due to the combined effects of high altitude and volcanic ash ingestion. If an engine fails to start, immediately try restarting it again. Flight crews should remember that the airplane may be out of the airstart envelope if the encounter occurs during cruise.
- **Turn on engine and wing anti-ice devices, and all air conditioning packs.** These actions improve the engine stall margin by increasing the flow of bleed air.
- **Start the Auxiliary Power Unit (APU), if available.** The APU can power systems in the event of a dual/multiple engine power loss. It can also be used to restart engines using APU bleed air. Flight crews should remember that multiple APU start attempts can shorten battery life.
- **Monitor engine Exhaust Gas Temperature (EGT)**. Because of potential engine debris buildup, the EGT can climb excessively. The flight crew should prevent EGT exceedances. Shut down the engine and restart it if the EGT is approaching limits similar to a hung start.
- **Monitor airspeed and pitch attitude.** Watch for abnormal indications from pitot static system indicators. If necessary, follow the non-normal checklist for flight with unreliable airspeed.

B. Ground Operations at Airports Impacted by Volcanic Ash

- **Protect the airplane from ash.** For ground operations originating at airports impacted by volcanic ash, the Reference /A/ message advises operators to take special precautions to protect airplanes from the adverse effects of volcanic ash.

- **Remove ash from the airplane prior to flight.** Prior to flight, the operator must ensure that critical components such as inlets, probes, and static ports are free of volcanic ash. Volcanic ash will be similar in appearance to talcum powder. If ash is detected on or in the vicinity of a parked airplane, Boeing suggests that operators clean the areas of the airplane where ash is present, including the fuselage crown, horizontal surfaces, inlets, and exposed chrome common to the landing gear, to remove all traces of ash. Boeing strongly advises against water or detergent washing of the engine gaspath as this can cause accumulation of foreign material in the engine cooling flow passages. Operators should follow the engine manufacturer's recommendations for engine gaspath cleaning. Operators should pay special attention to the removal of volcanic ash from engine and APU inlets; areas around probes, ports, vents and drain holes; as well as ram air ducts and all windows. Operators should be aware that airplane washing processes, without proper sealing of ports and tubes, can introduce ash debris or water into pitot static systems. If there are no signs of volcanic ash, normal operations may be conducted.
- **Remove all covers and blanking material prior to flight.** Flight crews should ensure that all materials used to mask or blank inlets, probes, and ports are removed.
- **Determine safe ground routing.** After an airplane is free from any volcanic ash contamination, the operator should coordinate with the local airport authority to determine which ramps, taxiways and runways are clear of ash contamination. This information must be passed to flight crews prior to beginning ground operations.
- **Prior to departure, flight crews should review the airspeed unreliable, volcanic ash, single engine failure, dual/multiple engine failure, and engine in-flight start non-normal checklists.**

Flight Operations Technical Bulletin

The Boeing Company
Seattle, Washington 98124-2207

Number:

N/A	N/A	737	757	767	777	N/A	747-400
		99-5R1	62R1	62R1	4R1		45R1

Date: September 15, 2006

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Subject: Cold Temperature Altitude Corrections

ATA Number: 01

Applies To: All Airplanes

Background Information

The contents of this bulletin have been incorporated into the FCOM, Supplementary Procedures, Adverse Weather section.

BOEING COMMERCIAL AIRPLANE GROUP

FLIGHT OPERATIONS TECHNICAL BULLETIN

NUMBER: **707-06-1**
727-06-1
737-06-1
747-15
747-400-55
757-75
767-75
777-21
787-1

DATE: **August 1, 2006**

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SUBJECT: **Convective Weather Containing Ice Crystals Associated with Engine Power Loss and Damage**

ATA NO: 30-00

APPLIES TO: 707, 727, 737, 747, 747-400, 757, 767, 777, and 787 Airplanes

REASON: To explain the role of ice crystals in engine power loss and damage events, and to provide recommendations for avoiding ice crystal encounters associated with convective weather.

BACKGROUND INFORMATION:

Icing conditions are defined as temperatures below 10 degrees C with visible moisture. This definition describes conditions where supercooled liquid drops adhere to airframe surfaces, typically at 22,000 feet and below.

Recently, several engine power loss and damage events have occurred in convective weather above the altitudes typically associated with icing conditions. Research has shown that convective weather can contain very small crystals of frozen water, perhaps as small as 40 microns (the size of flour grains). The industry is using the phrase "ice crystal icing" to describe this condition.

Ice crystals do not adhere to airframe surfaces, only to engine surfaces, because the ice crystals bounce off cold surfaces, but partially melt and stick to relatively warm engine surfaces. "Glaciated conditions" refers to atmospheric conditions containing only ice crystals and no supercooled liquid. "Mixed phase conditions" refers to atmospheric conditions containing both ice crystals and supercooled liquid. Both glaciated and mixed phase conditions occur in convective clouds and have been present during engine power loss and damage events.

<u>The nature of deep convection and its importance in engine power loss and damage events</u>

Deep convective weather is characterized by significant lifting (thousands of feet) and condensation of water vapor in an unstable atmosphere. Some or all of the following can be found in areas of convection: strong windshear; turbulence; lightning; and high condensed water content, mainly in the form of ice crystals but occasionally in the form of heavy precipitation or hail. Convective weather can range in size from small to large: isolated thunderstorms or cumulonimbus clouds, to convective complexes or squall lines, and finally to tropical storms or hurricanes. Convective weather can extend hundreds of miles laterally and above 50,000 feet vertically.

Engine power loss and damage events have occurred in the periphery of convective weather of all sizes at altitudes between 11,500 feet and 36,000 feet. Typically, the event airplanes were diverting around isolated thunderstorms or crossing the cloud anvils of convective storms, convective complexes or tropical storms. The following properties of clouds away from the convective core appear to be important in the formation of ice on the engine surfaces:

- Small crystal sizes

  Research suggests that most of the mass is concentrated in very small crystals. These small crystals may play a key role in ice formation in the engine because they can melt quickly and provide a liquid film on surfaces that can capture more ice crystals.

- High ice crystal concentrations

  Deep convection is thought to contain very high ice crystal concentrations, analytical estimates are up to 9 grams per meter^3 (g/m^3). In comparison, the current standard for the maximum concentration of supercooled liquid for engine icing certification is 2 g/m^3. If a 9 g/m^3 concentration was associated with a conventional icing encounter, it would be extremely severe.

- Ice crystals above the freezing level; usually little or no supercooled liquid present

  The strong circulation associated with the periphery of deep convective clouds can efficiently mix water rising from below the freezing level with ice crystals above the freezing level, causing the mass above the freezing level to quickly become glaciated (converted to ice crystals). This means that, at an altitude above the freezing level, in a mature convective cloud, the majority of the water is likely to be ice crystals.

We know that near the convective core, water and large hail can rise above the freezing level. This mass is detectable by airborne radar. However, at the locations of the engine power loss and damage events, pilots did not report radar returns and reported only light to moderate turbulence. Thus, the conclusion is that the airplanes were not crossing the convective precipitation core at the time of the engine events and were likely encountering ice crystals.

<u>Use of on-board weather radar to detect ice crystals</u>

On-board weather radar can detect large particles such as hail, rain and large ice crystal masses (snowflakes). Small particles, such as ice crystals in high concentrations near thunderstorms, are invisible to on-board weather radar, even though they may comprise the majority of the total mass of a cloud.

Sophisticated satellite radar technology has been used to detect crystals smaller than the lower limit of on-board weather radar. Above the freezing level, where icing can occur in a deep convective cloud, satellite radar has confirmed that large particles, which can be detected by on-board weather radar, are only found near the convective precipitation core. Away from the convective precipitation core, satellite radar has confirmed that small ice crystals, which are invisible to on-board weather radar, exist.

For this reason, flight in visible moisture near deep convective weather, even without radar returns, and at temperatures below freezing is very likely to be in ice crystal conditions.

<u>Recognizing high ice crystal conditions</u>

High ice crystal concentrations can be found under the following conditions:

- Areas of visible moisture above the altitudes typically associated with icing conditions, indicated by:
  - No significant airframe icing
  - The ice detector (when installed) not detecting ice, due to the ice detectors ability to only detect supercooled liquid, not ice crystals

- Areas above heavy rain
- Areas of light to moderate turbulence
- When rain appears on the windshield above the freezing level, due to ice crystals melting on the heated flight deck windows
- When airplane Total Air Temperature (TAT) is significantly different than expected, often near zero degrees C.

OPERATING INFORMATION:

Since ice crystals may not be detected by existing on-board weather radar systems, it is not possible to avoid all ice crystal conditions. However, normal thunderstorm avoidance procedures may help in avoiding high ice crystal content conditions. These include:

- Plan a flight path that avoids reflective regions of storm cells by at least 20 nautical miles
- Use the radar antenna tilt function to scan the reflectivity of storms ahead. Assess the height of the storms. Recognize that heavy rain below, typically, indicates high concentrations of ice crystals above
- Fly upwind of storms when possible
- The most effective procedure is to avoid flying over storm cells. Visible moisture at high altitude must be considered a threat since intense storm cells may produce high concentrations of ice crystals at cruise altitude. Storm cells that do not produce visible moisture at cruise altitude may be overflown safely.