In-Flight AIRPLANE VIBRATION and Flight Crew Response

Modern commercial jet airplanes provide smooth, comfortable travel that typically is free of vibration. Some types of vibration can be expected from time to time and are considered normal. However, isolated cases of abnormal vibration require prompt flight crew response and subsequent timely maintenance action.

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Occasional airplane vibration during flight is not unusual. There are many causes of airplane vibration, including landing gear extension and retraction, extension of speed brakes, free play in movable surfaces, and systems malfunctions. Flight crews need to understand the causes and effects of airplane vibration so that they can take appropriate action to maintain flight safety and prevent excessive wear or airframe damage. In addition, flight crews can contribute to accurate reports of in-service events that will facilitate troubleshooting and maintenance activities.

Understanding the possible sources of vibration and the information needed to isolate and correct vibration problems requires knowledge of the following:

1. Types of vibration and noise.
2. Causes of airplane vibration.
3. Detection of airplane vibration.
4. Flight crew response.
5. Maintenance troubleshooting.

1 TYPES OF VIBRATION AND NOISE

The following engineering definitions differentiate various forms and types of vibration and noise:

Vibration is oscillating, reciprocating, or any other periodic motion of a rigid or elastic body forced from a position or state of equilibrium. If the frequency and magnitude of vibration are constant, the vibration is said to be *harmonic*. When the frequency and magnitude vary with time, the vibration is *random*.

Buffet is a form of vibration usually caused by aerodynamic excitation. It usually is random and associated with separated airflow. For example, buffet may be felt during the extension of speed brakes or during air turbulence.

Flutter is an unstable condition in which unsteady aerodynamics excite the natural frequencies of the structure over which the air flows. The resulting vibrations can grow to a magnitude that causes the structure to fail.

Noise is a vibration that excites the air and can be heard. When the vibration is random, the noise is unmusical or confused. When the vibration is harmonic, the result is a tone like that produced by a musical instrument. It may sound like the whistling of a drain or a slight leak in a door.

2 CAUSES OF AIRPLANE VIBRATION

Normal and abnormal vibrations occur for several reasons. Aerodynamics, mechanical malfunctions, and external factors such as atmospheric turbulence can cause airplane vibration. All vibrations have associated frequencies and magnitudes that may be readily detected or barely perceptible to the flight crew and passengers. For some vibrations, such as those associated with engine operation, the flight crew has dedicated instrumentation to measure magnitude. Other vibrations are detected by sight, sound, or feel and may depend on flight crew experience for analysis.

Normal vibration.

Each airplane has a unique signature of normal vibration. This is a consequence of mass distribution and structural stiffness that result in vibration modes at certain frequencies. When external forces act on the airplane, such as normal airflow over the surfaces, very-low-level vibrations result. Typically, this is perceived as background noise. More noticeable, but also normal, is the reaction of the airplane to turbulent air, in which the magnitude of the vibration may be larger and thus clearly visible and felt. Engine operation at some spool speeds may result in increased vibration because spool imbalance excites the engine and transmits this vibration throughout the airframe. Finally, the operation of some mechanical components, such as pumps, may be associated with normal noise and vibration.

Most flight crews recognize these normal events, which become the experience base from which flight crews detect abnormal vibration events.

Abnormal vibration.

The most easily identified abnormal vibration is that which has a sudden onset and may be accompanied by noise. The vibration may be intermittent or steady with a distinct frequency, or it may be a more random buffet type. When the onset of abnormal vibration can be associated with a previous action or event, the source may be obvious. However, some vibrations initially are rather subtle and require diagnostic procedures to determine their probable causes.

Abnormal vibration usually is related to one or more of the following causes: engine rotor imbalance, malfunction of mechanical equipment, and airflow disturbances acting over doors or control surfaces that are misrigged or misfaired or that have excessive wear or free play. Abnormal vibration rarely is caused by a structural failure or an unstable power control system.

Flutter.

Aeroelastic instability, or flutter, very rarely causes abnormal vibration. Through design, extensive analysis, and certification tests, all configurations of commercial jet airplanes are free from flutter for all design conditions within the aeroelastic stability envelope. This envelope extends well beyond normal permissible operating speeds and applies to normal operation as well as failures, malfunctions,

and adverse conditions. However, when an airplane is operated in a configuration or condition that is beyond these criteria, flutter may result within the operational envelope. Flutter can be differentiated from buffet in that flutter can occur in smooth air; the vibration originates from the airplane rather than from the atmosphere. Closely associated with flutter is limit cycle oscillation (LCO). During LCO, the vibration is self-excited, but nonlinear effects such as friction, clearances, and free play (or backlash) limit the amplitude. LCO most often is caused by excessive free play within the flight control surfaces and associated components.

3 DETECTION OF AIRPLANE VIBRATION

Detection of airplane vibration depends almost entirely on crew sensitivity. The only exception is vibration in the engines, which are equipped with dedicated accelerometers to measure spool vibration. All other airplane vibration is detected by the crew through sight, sound, and feel. It should be noted that flight crews may not sense vibrations in some areas of the airplane, such as the main cabin or tail section, although passengers or other members of the crew usually feel and report such vibrations.

Flight crews use various terms to describe their perception of an abnormal vibration in the flight deck environment. It is very difficult for a flight crew to distinguish among the engineering definitions for vibration, buffet, flutter, and noise. For example, crews often report vibrations as noise because they are carried by the fuselage structure to the flight deck where the crews can hear them. Vibration and buffet both can shake the whole airplane, so it can be difficult for crews to distinguish between them.

4 FLIGHT CREW RESPONSE

The response of flight crews to vibration is fundamentally an exercise in airmanship. Every vibration event is different, and flight crews retain the responsibility to deal with such problems, as they deem necessary. Some general guidelines follow.

When crew response is warranted.

The best tool for gauging the severity of an airplane vibration is the experience of the flight crew. In some cases, the lack of a certain vibration may indicate a malfunction. For example, when starting the auxiliary power unit (APU) while airborne in a 757, a slight vibration occurs when the APU door is opened. Lack of that signature vibration could indicate that the door did not open and the APU cannot start.

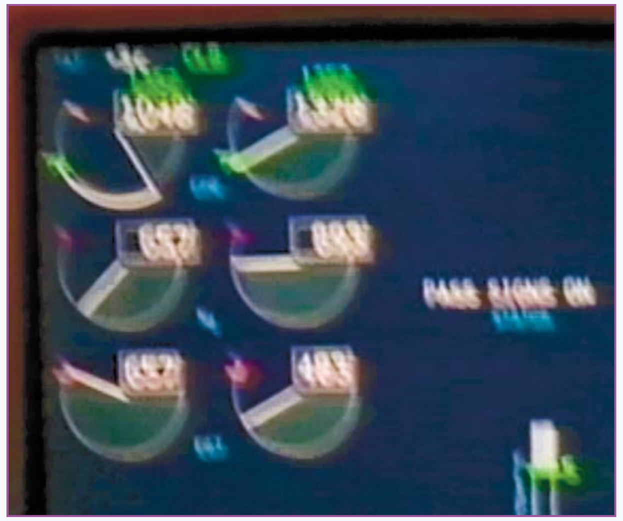
The presence of an abnormal vibration or noise usually is cause for flight crew attention. Experience provides flight crews with the ability to judge the severity of the vibration, distinct signatures, and most important, the immediate history of the flight conditions (i.e., the conditions of flight before the event and the parameter changes that occurred as the event occurred).

When unexplained vibrations occur, usually something has changed that is obvious to the crew (e.g., an abnormal engine indication, a change in flap or spoiler position, or a change in airspeed). This differs from the normal vibration felt as flaps come out or speed brakes move up — it is a change in the expected level of vibration. However, it is possible that something in the airplane can change without an obvious change in vibration; these situations are the most difficult to discern, describe, and avoid.

The best crew reaction to an unexplained vibration is to analyze the situation for a short period of time. When the vibration is extreme, the indications usually are clear. Analyses of situations may differ, but all must answer these key questions:

- What parameter just changed — airspeed, flight control, thrust setting?
- Is the vibration getting worse or is it constant?
- Will the current flight condition allow for a gradual change of parameters?
- What parameter can the flight crew feel or see that provides an idea of the cause?
- If the flight crew makes a small, planned change in a parameter, does the vibration or noise, or both, get worse or better?

After these data points are gathered and analyzed, the flight crew can formulate a plan of action to ensure the continued safety of the flight. After completion of the flight, the crew should fill out a vibration report (table 1, p. 6).



Responses to a vibration event.
There is concern that a drastic measure taken by the flight crew to rectify vibration could actually increase the severity of the problem. For this reason, the best flight crew reaction to an abnormal vibration is to smoothly extract the airplane from the operating region where the vibration occurs.

If performance considerations do not override the severity of the vibration, the flight crew should reduce airspeed and engine speed. Essentially, the crew should return to level flight at reduced airspeeds and avoid unnecessary stress on the airplane.

In-flight observations to assist in maintenance troubleshooting.
Identifying and correcting the cause of in-flight airplane vibration often is accomplished through trial and error, which can consume many maintenance hours. The causes of airplane vibration are numerous; however, flight crew observations and detailed reporting can provide very important clues to the potential source of the vibration.

Post flight, flight crews generally report two types of vibration. The first is a high-frequency tactile vibration (typically more than 25 Hz) that is felt in either the hands or feet. This vibration is sometimes associated with sound and usually relates to a small-mass component acting on the airframe, such as a loose door, access panel, or fairing. This type of vibration can be constant during all phases of flight, but it may vary with airspeed.

The other type of vibration is of a lower frequency (typically less than 20 Hz) that can be felt by the entire body. This type of vibration usually relates to a large-mass component acting on the airframe, such as the rudder, horizontal stabilizer, or elevator.

Typical crew reports often identify the direction of in-flight vibration as lateral, vertical, or oscillatory. Crews sometimes may indicate where the vibration is most evident within the airframe, such as in the forward cabin, overwing area, or aft cabin. Additionally, crews sometimes estimate the frequency of vibration and supply information regarding the airplane configuration at the time of vibration onset.

Information on the type, direction, and location of a vibration and the configuration of the airplane is extremely useful to maintenance crews in locating the source of the vibration. Because various factors can cause abnormal airplane vibration, a standardized process of elimination may be very helpful in pinpointing a specific cause. Flight crews can aid in correction efforts by reporting as much event information as possible. These data can then be used by the maintenance organization to correct the vibration source.

1 TABLE VIBRATION LOG

Flight Deck Vibration Event Log

To assist in the resolution of any vibration observed in the flight deck or in the cabin, please complete the following:

Date:________ Airplane:________ Model:________ Takeoff gross weight:________

Flight condition at approximate onset (please check applicable box):
☐ T/O roll ☐ Climb ☐ Cruise ☐ Hold ☐ Descent ☐ Landing
Altitude:________ Airspeed:________ Mach:________ Autopilot: ☐ On ☐ Off
Eng. #1, 2, 3, 4 _______%N1 _______%N2 Eng. vib: ☐ #1 ☐ #2 ☐ #3 ☐ #4

What event, if any, initiated the vibration?________

What event, if any, caused the vibration to stop?________

Was the vibration continuous or intermittent?________

How did the vibration start and stop? ☐ Started/stopped suddenly ☐ Started/stopped slowly

What was the magnitude of the vibration?
☐ Barely perceptible ☐ Clearly noticeable ☐ Annoying ☐ Uncomfortable

What were the characteristics of the vibration (please check one)?
☐ *Low frequency:* Motion could be felt by the whole body. Motion of sun visors or window heater cable might have been noticeable.
Direction: ☐ Mostly lateral ☐ Mostly vertical ☐ Vertical and lateral
☐ *Higher frequency:* Vibration could be felt tactilely with the hands or feet.

Where was the vibration noticeable, and where was it the strongest?
Noticeable: ☐ Flight deck ☐ Passenger cabin ☐ Aft galley
Strongest: ☐ Flight deck ☐ Passenger cabin ☐ Aft galley

Describe in detail the location(s) where the vibration was felt or not felt (use body station, seat row, component name, etc.):________

If a noise was associated with the vibration, describe the characteristic of the noise (e.g., drone, buzz, whine, whistle):________

Additional description of vibration and noise or other observations:________

Event information has proved to be so valuable for maintenance troubleshooting that a flight deck vibration event log has been attached to Boeing service letters for the 737 and 757 airplanes (table 1). The symptoms recorded on this form can be correlated with specific inspections and tests for applicable system and structure components. The tests and inspections are described in Boeing service letters and aircraft maintenance manuals. Table 1 shows a form that can be adapted to any Boeing airplane model for use in documenting vibration events and assisting engineering and maintenance organizations in resolving vibration problems.

In-flight observations to assist in determining vibration source.
In-flight observations can provide essential clues to the source of a vibration. Information about the airplane speed, flight conditions, engine power settings, and effects of changes made to airplane systems and flight controls on vibration can assist in identifying the source.

For example, a low-frequency vibration in the vertical direction that is felt in both the forward and aft cabin may be the result of excessive free play in the elevator or stabilizer surfaces. Pitch-control flight surfaces with excessive free play can cause the body to vibrate vertically, with the motion felt most strongly in the forward and aft locations of the airplane. Slight mistrimming of the airplane using the stabilizer and elevator may dampen out this type of vibration because the free play of the surface is removed with aerodynamic loading.

This same low-frequency vibration in the lateral direction may be the result of excessive free play of the rudder. A slight input made to the rudder system may be enough to remove the free play with aerodynamic loading. A low-frequency lateral vibration felt over the wing and in the flight deck at high engine power settings might be engine related. Reducing or increasing the power setting on each engine individually may isolate the vibration to an individual engine.

Vibration events that are caused by excessive free play in control surfaces are serious. These events must be investigated and remedied before further revenue flight.

A high-frequency vibration with associated sound that can be detected only in the flight deck when the flaps are up could be caused by unrestrained, or unlatched, landing gear doors or access panels located below the flight deck. High-frequency vibrations associated with sound over the wing or in the passenger cabin with the flaps up could be caused by the ailerons, main landing gear doors, trailing-edge flap fairings, or other wing components identified for each airplane model in its respective maintenance manual sections or service letters.

Table 2 (p. 8) lists other typical airplane vibration incidents. These are only a few examples, and operators are encouraged to review applicable airplane vibration service letters and maintenance manual sections to determine how other in-flight observations relate to potential sources of vibration.

5 MAINTENANCE TROUBLESHOOTING

Following a flight crew's report of a vibration incident, a comparison with previously reported incidents on the specific airplane or fleet may reveal the cause of the problem immediately. An important first step is to review service letters containing a compendium of previously reported vibrations. When this does not suggest an obvious problem, the next action should be a careful inspection of the entire airplane.

Control surfaces, spoilers, and flaps should be checked for free play and correct rigging. Doors and access panels must not be loose or out of contour. Landing gear doors must be checked to ensure that they are properly secured and faired with the gear retracted.

To continue the check of the control systems, the control surfaces should first be examined in neutral and displaced positions. Then, the control systems should be energized and the trailing edge of the associated control surfaces checked for rattles and possible bearing damage. If sustained oscillation can be detected, the system should be checked for linkage wear and replacement of the power control unit.

When ground checks fail to isolate the cause of vibration, the investigation should be extended to a nonrevenue flight check. If the cause cannot be determined after all recommended maintenance actions have been taken, Boeing should be contacted for further disposition.

SUMMARY

The effects of airplane vibration range from passenger and crew discomfort to flight safety issues. Appropriate flight crew response involves continuing the flight in a manner that avoids continued vibration and recording information that will assist in identifying the cause of the vibration. Crews' understanding of airplane vibration and response procedures is important because it can prevent continued exposure to events that may cause airframe damage and proper awareness can provide valuable information to facilitate maintenance troubleshooting. In all cases, of course, flight safety takes precedence over any in-flight analysis of vibration.

2 TABLE TYPICAL AIRPLANE VIBRATION INCIDENTS

Service letters (SL) and all-operator letters (AOL) by airplane model

717	Not available
727	727-SL-02-2, Nov. 16, 1987
737	737-SL-02-002-D, July 3, 2001
747	747-SL-02-005-D, Sept. 12, 1996
757	757-SL-02-019, March 16, 2001
767	767-SL-02-9, June 11, 1993
DC-9	AOL 9-1140, June 13, 1978
DC-10	AOL 10-1891A, July 17, 1990
MD-80	AOL 9-2029, Dec. 14, 1989

Airplane	Flight conditions	Symptom	Diagnosis	Maintenance action
717	Not available	Not available	Not available	Not available
727	High-speed descent	Airframe vibration similar to Mach buffet	Check for worn, loose, or misrigged trailing-edge flap components	Adjust eccentric bushings and clearance between aft flap track and roller
	210 kias/4,000 ft	Lateral vibration throughout airplane	Stops when side engine is cut back to idle	Replace engine vibration isolators
	350 kias	Vertical vibration in fuselage; vibration in control column	Vibration stopped when elevator hydraulic power is off	Replace elevator power control unit and reaction links
737-300/-400/-500	All phases of flight	High-frequency vibration and noise; vary with speed	Check seals, doors, panels	Repair or adjust
	Takeoff and approach	Vibration and noise in the wing root area	Check leading-edge (LE) slat and trailing-edge flaps for wear and deterioration	Repair and replace
	Climb and level flight	Low-frequency vibration felt in flight deck	Alternately reduce power on engines; vibration stops after power is reduced on a specific engine	Remove and replace the main engine fuel control of the suspect engine
737-600/-700/-800/-900	All phases of flight	Vibration in rudder pedals	Vibration stops with rudder input	Add seal at rudder to fuselage interface
	Descent above 15,000 ft	At idle power, clear audible tone and vibration; loudest in mid cabin	Slight throttle increase minimizes tone	Check engine high-pressure compressor vibration level
	High-speed descent	Moderate to severe vibration in aft fuselage and stabilizer when speed brakes are deployed	Check elevator tab for free play	Restore elevator tab free play within limits
747	Takeoff	Vibration in nose area	Check nose wheels and tires for imbalance	Replace nose wheels and tires
	Climb, 17,000 to 31,000 ft	Vibration	Check inboard elevator power control package (PCP) rod end bearing for wear	Replace PCP per Airplane Maintenance Manual (AMM) 27-31-07
	Cruise	Flight deck rumble	Check for loose stanchions in electrical/electronics bay	AMM 53-41-00
757	All phases of flight	Constant audible rumble and squeal from flight deck floor	Check nose radome seal	Ensure correct installation of radome and seal in accordance with AMM 53-12-01
	Cruise	Lateral low-frequency vibration in flight deck	Sensitive to engine no. 1	Change engine fuel flow governor
	Cruise	Moderate to severe vibration in aft fuselage	Vibration decreases with airspeed; check elevator for free play	If free-play check fails, replace elevator power control actuator and link bearings
767	All phases of flight	Control column vibration	Auxiliary power unit (APU) inlet door remains open in flight with APU off	Replace APU control unit
	Cruise	Noise and vibration near seat rows 10 and 11	Check seals at the forward edge of wing-to-body fairing	Replace or adjust seals
	Descent	Rudder pedal vibration with flaps 5 to 20	Yaw damper module defective	Replace yaw damper module and servo
777	All phases of flight	Vibration in aft galley floor	Vibration stops when aft chiller is turned off	Replace chiller
	All phases of flight	Wind noise at doors	Check door frame and seals	Repair or replace acoustic liner
	Taxi and takeoff	Loud grinding noise and vibration at door 2 area floor	Check air distribution duct ice screen	Clear or replace main air distribution duct ice screen
	Climb	Strong vibration felt through floor near seat row 19	Check ram air inlet door	Repair and adjust ram air inlet door
DC-9	Takeoff roll, climb	Noise and vibration in flight deck floor	Check clearance between new-look-interior door and deflectors	Adjust clearance of nosegear spray deflectors
	Climb, descent	Noise and vibration in wing area	Check LE slats for rig and waviness of trailing edge	Adjust, rig, and lubricate LE slats
	Climb, descent	Vibration in wing area	Install felt pad to underside of wing trailing edge above the forward vanes; vibration stops	Adjust and rig wing flap and movable vane systems in accordance with AMM chapter 27
DC-10	All phases of flight	High-level vibration and noise in cabin near wing; varies with airspeed	Check electrical bonding straps in the wing root LE; check hydraulic and electrical standoffs in the wing LE fillet area	Secure and repair
	Climb	Buzz in floor and sidewall on left side of airplane forward of the wing	Check for loose or damaged butterfly valve seal on the cabin pressure outflow valve	Replace seal or valve assembly in accordance with AMM 21-30-08
	Climb	Low-frequency vibration in cabin adjacent to LE of wing	Check outboard slats for wear and rig	Repair and rig in accordance with AMM 27-80-00
MD-80	All phases of flight	Vibration in forward galley area	Check lower horizontal stabilizer fairing	Replace if damaged
	Takeoff	Aft cabin vibration and associated whining noise	Check power plants for oil contamination	Replace affected engine
	Cruise	Cabin vibration	Check 13th stage duct for chafing against the engine burn-through barrier	Reposition duct