Boeing supplements the standard procedures in its aircraft maintenance manuals (AMM) with conditional maintenance inspection procedures. These procedures address unscheduled maintenance situations that result from non-normal flight and landing conditions. The procedures are continually being updated to standardize inspection procedures across all models and to provide more explicit inspection content. Currently, quantitative vertical acceleration thresholds are being added to all Boeing-designed airplane conditional inspections to assist operators in deciding whether to initiate hard landing inspections. Similar information is being added to the AMMs for Douglas-designed airplanes. Boeing also is adding qualitative data to the 737 AMM conditional inspection maintenance procedures based on operators’ requests and service experience. Although specific to 737-100/-200/-300/-400/-500, the rationale and some of the data may be applied to other Boeing airplane models.
Boeing is updating its recommended maintenance procedures for 737 non-normal landings, such as a hard landing, a high-drage load or side-load landing, an off-runway excursion, or a tail strike. The changes are based largely on airline service experience (see “Non-Normal Landing Service Experience” on p. 20) and are part of an ongoing effort by Boeing to update recommended unscheduled inspections after non-normal events for all its models. The changes involve:

1. Determination of non-normal landings.
2. More explicit inspection procedures.

**Vertical acceleration values.** Using vertical acceleration values as the sole criterion for initiating unscheduled inspections is generally not advisable because of the location and design considerations of the FDRs and accelerometers. In most instances, there is no absolute way of knowing whether the recorded accelerations are a minimum, maximum, or some intermediate value relative to the entire airplane structure. This is because the onboard accelerometer located near the airplane CG is limited in its capability to capture actual loads that may be occurring in the entire airplane structure during the landing impact.

Several accelerometers placed throughout the airplane have shown significant variations in both time and magnitude of vertical acceleration values, or structural loads. These variations are the result of airplane weight, CG, motion (e.g., sink rate; forward and side velocity; roll, pitch, and yaw angles; and corresponding rates), external forces (e.g., gust loads, ground effect, and runway contact loads), and structural dynamics (e.g., vibrations and harmonics). Also the sampling frequency of the recorded vertical acceleration data—which is subject to the specific flight recorder installation and varies from 4, 8, or 16 samples per second—can cause wide variation in recorded peak vertical acceleration values.

After reviewing some limited data generated by operators, Boeing decided to perform more extensive analysis to correlate vertical acceleration with the design sink rate. Figure 1 shows an example comparing the recommended inspection threshold to analytical digital FDR accelerations (based on an eight-samples-per-second digital FDR) for the 737 family at the design sink rate of 10 ft/s. The figure shows the peak CG acceleration to the filtered digital FDR sensor acceleration (both the calculated peak and the lowest possible recorded peak value at eight samples per second). The inspection threshold is slightly less than the lowest data point to minimize the number of nuisance inspections without exceeding the design sink rate.

With this information, Boeing developed vertical acceleration thresholds to trigger operator review of flight data when these acceleration values are exceeded in service. The thresholds, in addition to flight crew judgment, give operators the option of initiating AMM inspections after review of FDR data.

**1. Determination of non-normal landings**

**Flight crew judgment.** Boeing commercial airplanes have been designed for a 10-ft/s sink rate at or below the maximum design landing weight and a 6-ft/s sink rate at more than the maximum design landing weight. A hard landing inspection is recommended if these values are approached or are exceeded. Because the sink rate is not directly measured, however, the flight crew must rely on its own judgment or peak vertical center-of-gravity (CG) acceleration from the flight data recorder (FDR) after the flight to determine whether an inspection is warranted.

Service experience indicates that most flight crews report a hard landing when the sink rate exceeds approximately 4 ft/s. Past experience also indicates that the flight crew’s determination of a hard landing is the most reliable criterion because of the difficulty in interpreting recorded acceleration values at the CG of the airplane.
Operators review these data to see whether changes in operation coincide with changes in frequency of conditional maintenance. For instance, in the absence of flare during landing, there is a tendency for three-point landings and generally higher sink rates at touchdown. If severe enough or done often, this can damage or wear nose landing gear components. This damage or wear usually is found at scheduled gear overhaul. Initial touchdowns on the main gear during flared landing allow the airplane to straighten out before nose gear contact, such as in crosswind conditions. This will avoid putting side loads on the nose gear at high speeds and create less wear on some nose gear components, such as tires, steering components, and internal shock strut components, including upper and lower bearings, centering cam components, and their anti-rotation devices.

**MORE EXPLICIT INSPECTION PROCEDURES**

In addition to vertical acceleration thresholds being added to the AMMs, the conditional maintenance inspections are being updated in the 737 AMM to provide more explicit inspection procedures. The conditional inspections are constantly being updated and geared toward ensuring continued serviceability and structural integrity of the airplane. Changes to the 737 AMM, section 05-51, involve the conditional maintenance inspections for hard, high-drag-load, and side-load landings, as well as off-runway excursions. These changes will permit operators to make the most effective use of the two-phased conditional maintenance inspection process. The changes also will keep phase I inspections as simple as possible with minimal access and disassembly requirements.

The two-phased inspection starts with a close visual inspection of various structural components, especially those most vulnerable to damage, to determine whether further inspections are warranted. A second phase of inspections is conducted if any damage is found during phase I.

In some instances, operators may request that Boeing review their findings if structural damage or fuel or hydraulic leakage is detected during phase I or phase II inspections. Boeing also may be asked to review flight recorder data. (See “Analyzing QAR Data” on p. 23.) The reviews may indicate that further inspections are warranted.

AMM changes for non-normal landings. Changes to the unscheduled maintenance procedures in the 737-100/-200/-300/-400/-500 AMM will involve both phase I and II structural inspections. The most significant changes will involve inspection of the main and nose landing gear and supporting structure. These changes are as follows:

During the phase I inspections of the main landing gear, operators should check for shock strut leakage and examine the inside diameter of the fuse pins of the drag strut and the outboard end of the main landing gear beam for distortion. This involves checking for visible damage to the specific component without removing it. Operators also should examine the main landing gear beam to the inboard rear spar stabilizing link for damage to the link or the crank shafting of the forward and aft attach bolts (figs. 2 and 3). This is accomplished by loosening the nut on the stabilizing link bolt and turning the bolt to determine whether it is deformed or crank-shafted.

Damage at this location will warrant further action during phase II inspections; specifically, the trunnion link should be removed in accordance with the AMM and the forward trunnion fuse bolt inspected (fig. 4).
On the outboard attach fuse pin for the main landing gear beam, the retention bolt should be removed and the pin rotated to check for crank shafting.

During phase II inspections of the main and nose landing gear, operators should ensure proper hydraulic fluid levels are in the shock struts by performing a two-point service check, or by completely servicing the shock struts in accordance with the AMM. Operators also should remove the landing gear inner cylinders if shock strut servicing was found to be incorrect or if both a hard and a high-drag-load or side-load landing occurred at the same time. The barrel of the inner cylinders and axles also should be dimensionally checked for distortion or bending and examined for cracking. Airline technical and operational staff may be consulted following phase I and II inspections, depending on inspection findings. Boeing is often requested to provide technical assistance during such reviews.

AMM changes for off-runway excursions. Off-runway excursions occur either on hard, even surfaces that do not create higher-than-normal loads or on uneven surfaces with depressions and obstructions that also may include soft and muddy conditions. The latter situation can create high vertical, high drag, and side loads when the gear goes over rough terrain or when the airplane stops suddenly in soft terrain.

Maintenance procedures for off-runway excursions are being added to the AMM for the 737-300/400/500 and revised for the 737-100/200 AMM as follows.

Travel onto surfaces with depressions or obstructions will generally require close inspection of all fuse pins during the two-phased inspection process outlined in the AMM. The gear then may be removed for closer inspection depending on flight crew judgment, FDR/QAR data review, consultation between the operator and technical experts, or the discovery of any structural anomalies. In addition to fuse pin deformations, axle and truck deformations may be discovered during close inspection of the gear.

When an airplane goes into soft or wet turf or the gear picks up debris (fig. 5), in addition to high-drag-load conditional inspections, the wheel and tire assemblies should be replaced because water or dirt may have contaminated the wheel bearings. Also, the wheel speed transducers should be removed and inspected; brakes should be washed, examined for obvious damage, and operationally checked; and the entire gear should be cleaned of debris, especially under the axle sleeves, and relubricated.

In one instance, an axle fracture was attributed to moisture and mud under the axle sleeve following an off-runway excursion. According to the maintenance records, no inspection or cleaning was done, and the contamination resulted in corrosion and crack initiation.

SUMMARY

Operators need adequate data after a non-normal flight or landing or an off-runway excursion to determine whether to conduct an unscheduled inspection of the airplane. Operators are being provided information to supplement flight crew reports of such conditions in the Boeing AMM. This supplemental information includes vertical acceleration thresholds for unusual landings, which will be available in the AMMs for all Boeing- and Douglas-designed airplanes later this year.

Also, more explicit procedures for airline maintenance crews to use in initiating conditional structural inspections will be added to the 737-100/200/300/400/500 AMM by third-quarter 2001. Boeing is standardizing these inspections across all models to the extent possible, given differences in structure that will require different inspections in some instances.