VII. Recommendations

Boeing recommends, and is pursuing, several actions to improve an already safe rudder system, and enhance flight crew recovery technique and preparedness. This section of the document:

- Summarizes these improvements, which are being taken in the areas of flight crew training, flight crew procedures, rudder system design, and flight data recording.
- Assesses the relevance and adequacy of these improvements.
- Refers readers to Appendix E, Boeing-Recommended Training and Procedures, and Appendix F, Boeing-Recommended Design Changes, for specific details of these improvements

A. Improvements Made

Exhaustive analysis shows that the vast majority of in-flight upsets are caused by either *external* sources (wake vortices, turbulence, windshear) or *internal* sources (yaw damper, autopilot, and autothrottle malfunctions; asymmetric flap/slat deployment; crew action/inaction). Highly unlikely but hypothetically possible rudder system malfunctions may also cause such events, although there is no recorded instance of such an event ever occurring in the more than 78 million hours logged by 737s since the late 1960s. The improvements being pursued by Boeing reflect the understanding gained from this fact-based analysis.

Flight Crew Training and Procedures

The known and likely causes of unanticipated yaw and roll events, listed above, will continue to exist. Throughout these events, the 737 remains controllable. Nevertheless, the potential for these events to startle flight crews is well documented, as are instances of improper control inputs made in response to upset events.

The preparedness of today's flight crews to deal with upset events can be improved. Pilots have highly varied backgrounds and experience. Many have never experienced attitudes in excess of those associated with normal line flying and typical training maneuvers. Moreover, precisely what constitutes appropriate knowledge and skill for airplane upset recovery is today neither well defined nor universally agreed upon.

Therefore, Boeing supports enhanced training to ensure that flight crews are provided with the knowledge and skill they need to effect beneficially the outcome of unanticipated yaw and roll events. To this end, Boeing has worked with the industry to develop an upset training aid that will provide increased awareness of all types of in-flight upsets, as well as their recommended recovery techniques.

Additionally, Boeing has made changes to its flight procedures to provide more specific guidance to the flight crew for response to an uncommanded yaw or roll, and a confirmed jammed rudder. Mandated by FAA Airworthiness Directive 96-26-07 in January 1997, these enhanced procedures are:

- A revision of the existing *Uncommanded Yaw or Roll Procedure.*
- A new *Jammed or Restricted Rudder Procedure.*

See Appendix E for a detailed overview of the new Upset Recovery Training Aid, and these revised and new procedures.

Rudder System Changes

Despite exhaustive investigation, Boeing, the NTSB, and the FAA have been unable to find any evidence that a failure of the 737 rudder control system caused an accident, or that an uncommanded full rudder deflection has taken place in the history of the 737.

Nevertheless, investigations and design reviews did identify possible areas where the 737 rudder system could be improved. In addition, extremely unlikely failure modes were identified that could hypothetically result in unwanted rudder deflections.

Therefore, Boeing recommends and is making rudder system changes to preclude these extremely unlikely system failures, better meet the original design intent, and improve overall system reliability. These changes improve on an already safe and reliable system by drawing from lessons learned through exhaustive testing, service experience, and analysis. The design changes being pursued include:

- **Rudder PCU valve redesign**—eliminates PCU failure effect associated with PCU servo valve secondary slide jam and primary valve over-stroking.
- **New PCU input rod fasteners**—redesigned outer bolts eliminate a failure condition that can compromise dual-load-path redundancy but, by itself, cannot affect rudder system operation.
- **Yaw damper system redesign**—uses updated technology to make the yaw damper significantly more reliable.
- **Hydraulic pressure reducer**—reduces rudder authority by about one-third during those phases of flight when large rudder deflections are not required, to lessen the effects of an excessive full rudder deflection, however initiated.
- **Rudder input force transducer**—allows the flight crew's rudder inputs to be recorded as a separate parameter by the flight data recorder. This will enhance future incident or accident investigations by facilitating an understanding of flight crew/rudder system interaction.

The first four of these changes have been mandated by the FAA by AD97-14-04 (PCU changes) and AD97-14-03 (yaw damper and pressure reducer). See Appendix F for a description of these Boeing-recommended and initiated design and retrofit changes.

B. Assessment of Relevance and Adequacy

It is the Boeing belief that the above actions adequately and effectively address the key findings from the investigation of the Flight 427 accident. Specifically, they address theoretical failure conditions that were not present in this accident, and are not known to have ever occurred in the service history of the 737. This judgment is supported by the exhaustive analysis of facts and data assessed by the NTSB and the other parties over a period of three years.

Based on this extensive industry effort, the Boeing-recommended corrective actions cover the spectrum of improvement areas to yield safety benefits on these four fronts:

- **Airplane design**—the changes will make the 737 rudder flight control system even more reliable and robust than it already is, resulting in fewer airplane-initiated yaw and roll events.
- **Improved training**—the changes will help assure that flight crews have the knowledge and skill to properly respond to startling in-flight upsets, whatever their cause.
- **New procedures**—the changes will provide flight crews with specific procedures for handling directional/lateral upsets and rudder jams.
- **Future incident/accident analysis**—the changes will ensure that the flight data recorders of the 737 world fleet have parameters for rudder positioning and rudder pedal inputs. This will facilitate a definitive understanding of flight crew/rudder system interaction in any future investigation.

C. Additional Recommendations

Analysis performed in the course of this investigation confirms the need to better understand the varying reactions of flight crews to upset events. Documented incidents highlight the industry's current lack of knowledge regarding crew behavior in upset situations.

In August 1997, for example, a 737 encountered wake turbulence during its descent for landing. The flight crew reacted to the roll oscillation by disengaging the autopilot, the yaw damper, and both flight control hydraulic systems in a period of less than 10 seconds. This extreme response is not a technique for recovering from lateral upsets, but is the final recommended procedure in the event of a firmly jammed or restricted rudder that is significantly deflected.

It seems likely that the flight crew acted on the incorrect, uninvestigated supposition that the roll oscillation was caused by anomalies in the airplane's flight control system. If an actual failure in a lateral flight control system had occurred, this incorrect flight crew response might have been catastrophic.

Therefore, Boeing makes the additional recommendation that the appropriate organizations within the industry take steps to improve industry understanding of possible flight crew responses to wake vortex encounters and other upset events. Boeing believes that such an effort would be valuable to training organizations worldwide.