Appendix F
Boeing-Recommended Design Changes

The design improvements Boeing has identified are based on lessons learned during extensive testing and thousands of hours of analysis. The company intends to improve upon an already safe and reliable control system by incorporating the following redesigns and new features:

- Rudder power control unit (PCU) valve redesign.
- New PCU input rod fasteners.
- Yaw damper system redesign.
- New hydraulic pressure reducer.
- Rudder input force transducer.

These changes are intended to protect against some highly unlikely failures, improve reliability, and aid in investigations in the event a future incident or accident should occur.

Rudder PCU Valve Redesign

Housed in the base of the vertical fin, the 737 main rudder PCU directs power from two independent hydraulic systems to deflect the rudder in response to rudder pedal inputs from the flight crew, and from yaw damper inputs. It does not receive commands from the 737 autopilot system.

For safety through redundancy, the 737 rudder PCU employs a dual concentric valve design. If either the primary or secondary valve slide jams (a highly unlikely event), the other slide moves to counteract its unwanted input.

Thermal shock tests performed in October 1996 revealed a previously unknown failure effect. A secondary valve slide seized when an unpressurized PCU, cold-soaked to -40°F, was suddenly hit with hydraulic fluid heated to 170°F, a temperature that is well outside the normal operating limits of the unit. In this test, the redundant features of the valve did not work as intended, resulting in a rudder movement to full authority in the direction opposite to the rudder pedal input.

In actual operations, however, PCUs are pressurized with warm hydraulic fluid and maintain an in-flight temperature no lower than 35°F—or some 75°F warmer than in this extreme test—while the hydraulic fluid temperature is normally not much warmer than the PCU. Even for hot weather or hydraulic system failure conditions, the system does not experience temperature extremes between the PCU and hydraulic fluid that would approach the conditions necessary to seize the valve.

All of the testing and data indicate that a thermal-induced secondary-slide jam is impossible in flight. Nevertheless, Boeing believes that it is prudent to eliminate the failure effect demonstrated in the thermal shock tests. Boeing issued service bulletin (SB) 737-27A1202 advising operators to test for any latent valve jams of this nature. Reinforced by FAA Airworthiness Directive (AD) 96-23-51, this examination of the world fleet is required every 250 flight hours. More than 2,500 737s have been inspected so far, with no evidence of a secondary slide jam. No such event has ever been recorded in the more than 80 million flight hours logged by 737s to date.

This inspection requirement will end once operators install a new rudder PCU dual valve in the current-generation 737 fleet (737-300, -400, and -500). This valve—which will be nearly identical to that used in the rudder PCU of Next-Generation 737s (737-600, -700, and -800)—restores the redundant features of the valve for any hypothetical jam condition.

New PCU Input Rod Fasteners

During routine in-service maintenance, two fractured outer bolts were discovered on 737 rudder PCU input rods. In both cases, the fracture was initiated when the shank of the bolt ran into the nut threads. Because this fastener is a dual-load-path design with inner and outer elements, either of which is sufficient to retain the input rod, these fractures did not affect system operation.

A fractured input rod fastener was not involved in the Flight 427 accident event. However, because any condition that could eliminate one of the redundant load paths in this 737 rudder control system linkage is undesirable, a new fastener has been designed to prevent the cause of these fractures. These fasteners were made available in August 1997 and may be retrofit concurrently with the PCU valve retrofit.

Yaw Damper System Redesign

A redesigned yaw damper is included in the enhancements to the 737 rudder control system. This new unit will reduce any flight-path upsets that could be caused by yaw damper system malfunctions.

The yaw damper serves to counteract Dutch roll, a natural flight oscillation characteristic of swept-wing airplanes. Because the 737 is less prone to Dutch roll than most jetliners, its design does not require a yaw damper. Nevertheless, one is included to improve ride comfort.

The 737 yaw damper is mechanically limited. It can deflect the rudder no more than three degrees either way in current-generation 737s, and from two to four degrees in earlier models (737-100, -200, and -200ADV).

As a result, a malfunctioning yaw damper is controllable by the flight crew, and will not affect safety of flight. The flight path upsets that may result from such a malfunction can startle the flight crew, however, and can potentially lead to injuries among passengers and cabin crew.

The Flight 427 accident investigation found no evidence that a yaw damper malfunction occurred during the event. However, an investigation into the service history of this yaw damper system showed opportunities to significantly improve its reliability using technologies available today. The resulting redesigned system:

- Replaces the current system's single electro-mechanical rate gyro with a dual solid-state rate sensor that is more reliable and free of mechanical wear problems.
- Retains the form and fit of the existing yaw damper coupler to simplify incorporation on in-service airplanes.
- Adds control and indication electronics for the new rudder PCU pressure reducer.
- Provides detailed system monitoring and fault analysis through improved built-in test equipment.
- Includes improved wire shielding and isolation to eliminate problems caused by electrical interference.

This new system is scheduled to be incorporated into current-generation 737 production in July 1998, when retrofit kits will be available.

New Hydraulic Pressure Reducer

Excessive rudder deflections at high speed can damage the vertical stabilizer on many airplanes. To avoid the risk of excessive loads on the vertical fin, these airplanes have rudder ratio changers or pressure reducers to limit rudder travel at higher speeds, when the rudder is proportionately more effective. Because these potentially damaging loads are not present in the current-generation 737 family, a rudder authority limiter is not required in its design.

However, Boeing decided to incorporate a hydraulic pressure reducer that reduces the amount of rudder available to the flight crew. Incorporation of a pressure reducer will reduce available rudder authority by about one-third during those phases of flight when large rudder deflections are not required. This reduced authority will further enhance 737 safety by reducing the airplane's reaction to full rudder inputs, giving flight crews more time to recover from any excessive rudder deflections. It will also make 737 lateral controls (ailerons and spoilers) proportionately more effective in countering excessive rudder inputs.

The new hydraulic pressure reducer does not adversely affect airplane handling characteristics. This system is inactive in the three situations when full rudder authority is desirable:

- Below 1,000 feet above ground level (AGL) during takeoff climb.
- Below 700 feet AGL during landing approach.
- When one engine has failed, regardless of altitude (737-300, -400, and -500 only).

Added to the "A" hydraulic system near the rudder PCU, this reducer unit lowers the hydraulic pressure from 3,000 psi (737-300, -400, and -500) or 1,400 psi (737-100, -200, and -200ADV) during conditions other than those listed above. It does not interfere with the yaw damper, which makes inputs to the servo valve controlled by the "B" hydraulic system. Because the control and indication logic for the hydraulic pressure reducer will reside in the new yaw damper, these two changes will be implemented together.

Rudder Input Force Transducer

FAA Notice of Proposed Rulemaking (NPRM) 96-7 mandates additional flight data recording parameters, including rudder-surface and pedal positioning. This change applies to new-production 737s and requires retrofit to 737s already in service.

Rudder pedal force—another valuable flight data recorder parameter —is part of NPRM 96-7 for new-production airplanes only. The FAA encourages, but does not mandate, the retrofit installation of pedal-force sensors to the 737 fleet.

Recording rudder input force on all 737s will benefit operators, manufacturers, and certification and investigation agencies. Because this parameter records crew input forces through the rudder pedals, not just pedal positioning, it will help the industry better understand possible future rudder-related incidents.

Had Flight 427 been equipped with a rudder input force transducer, accident investigators would have been able to quickly determine whether the questioned rudder deflection was airplane-caused or crew-commanded.

The aft quadrant control rod is being designed with a force transducer to record this parameter. A service bulletin and retrofit kit for the world fleet may be available as early as May 1998. Also at that time, the identical installation will be incorporated in current-generation 737 production. A similar design is in development for Next-Generation 737 models.