# SUBMISSION OF THE AIR LINE PILOTS ASSOCIATION

# TO THE NATIONAL TRANSPORTATION SAFETY BOARD

**REGARDING THE ACCIDENT INVOLVING**

# USAIR FLIGHT 427

**NEAR PITTSBURGH, PA**

**ON SEPTEMBER 8, 1994**

## TABLE OF CONTENTS

---

Back to Top

## I. Executive Summary

On September 8, 1994, USAir Flight 427, a Boeing 737-300, crashed while maneuvering to land at Pittsburgh International Airport. The airplane was being operated on an instrument flight plan under 14 CFR Part 121 on a regularly scheduled flight from Chicago, Illinois. The airplane was destroyed by impact forces and all 132 persons on board were fatally injured. Based on the evidence developed during the course of this accident investigation, ALPA believes that the airplane experienced an uncommanded full rudder deflection. This deflection was a result of a main rudder power control unit (PCU) secondary valve jam which resulted in a primary valve overstroke. This secondary valve jam and primary valve overstroke caused USAir 427 to roll uncontrollably and dive into the ground. **Once the full rudder hardover occurred, the flight crew was unable to counter the resulting roll with aileron because the B737 does not have sufficient lateral control authority to balance a full rudder input in certain areas of the flight envelope.**

---

Table of Contents

## II. B737 Flight Control System Design

This section will show that:

1. The B737 rudder control system design is unique among jet transport designs in that it utilizes a single panel rudder and a single rudder PCU.

2. Since the B737 received its original FAA Type Certificate in 1967, the aircraft has had a history of uncommanded yaw incidents.

3. The B737 rudder control system does not meet the current FAR requirements, FAR 25.671, with regard to malfunction probability and effects.

4. During the course of the investigations of UAL 585, USAir 427, and Eastwinds 517 a number of failure modes have been identified with the B737 main rudder PCU which can lead to uncommanded full rudder hardovers and rudder reversals.

5. The B737 main rudder PCU's design redundancy is ineffective if any of these failure modes occur and, as a result, the aircraft is not in compliance with the FARs.

6. Some secondary valve jams leave no witness marks.

7. USAir 427 experienced a secondary valve jam and reversal in the main rudder PCU that resulted in an uncommanded full rudder deflection.

The Boeing 737 directional control system is unique among jet transport aircraft because of its single rudder panel, single rudder power control unit (PCU) combination. Other Boeing aircraft either have split rudders or command input via multiple PCU's. In normal operation, two independent (A and B) hydraulic systems provided hydraulic power to the rudder through the main rudder power control unit (PCU) which in turn moves the rudder surface. In addition, the A and B hydraulic systems also provide hydraulic power for the pitch and roll control systems. For pitch and roll control there is also manual control available to command pitch and roll inputs if the aircraft experiences a hydraulic failure. The rudder system does not have manual backup. For redundancy, the rudder has a third hydraulic system (Standby) that can provide hydraulic power through the standby rudder PCU if needed.

For rudder input, pilot commands are transmitted via stainless steel control cables to the hydraulic power control unit. There is a direct correlation between the magnitude of the pilot input and the resulting control surface movement at all airspeeds.

The single PCU on the B737 attempts to provide redundancy by using dual components and dual load paths within the PCU. By eliminating one actuator there was a significant weight saving. Later twin jet transports like the B757 and B767 use tandem (two different) PCU's to provide redundancy.

The control of movement of the rods and linkage within the B737 rudder system is essential for it to operate normally. Any unexpected movement in the system could result in uncommanded movement of the rudder. The linkages are load path redundant so that a single failure should not result in loss of control.

Mechanical linkages connect the control rod movement to the primary and secondary valves within the PCU servo valve. The servo valve directs high pressure (3,000 psi) hydraulic fluid to the extend or retract side of the main rudder PCU actuator. Additionally, the servo valve determines the amount and duration of the fluid flowing to the actuator.

The intended design of the PCU was such that in the event of a jam of either the primary or secondary valve, opposing movement by the non-jammed valve would result in control of the rudder. As an example, if the primary valve jams in a position that results in one gallon per minute airplane nose left, the secondary valve will center at a position of one gallon per minute nose right. The result is a higher that normal leakage rate and some reduction in the maximum rate of rudder travel. Pilots maintain control of the rudder, in the event of a jam, by this redundant valve design.

The design of this servo valve does not use "O" rings. Instead it relies on very close tolerances to limit hydraulic leakage. The total movement of the primary or secondary valve from center to its extreme travel is about 0.0045 of an inch (about the width of a dime). The clearance between the primary valve and the secondary or the secondary to the valve housing is less than a human hair. Close tolerances required that consideration be given to the effects of a foreign object obstructing movement of the valves. Chip shear force is a measure of the ability of a valve to shear a foreign object. That is, to actuate normally in spite of the presence of foreign material. The chip shear of the primary valve of the B737 main rudder PCU is significantly less than that of other similar aircraft. This chip shear capability is about 40 pounds on the B737 while the DC-9 and MD-80 are a minimum of 100 pounds. As a result it may be easier to jam the B737 PCU. The secondary valve of the B737 has a somewhat higher chip shear than the primary valve.

The redundant features of the servo valve are only effective if both valves are free to move. If one valve does not move freely, then a subsequent single failure or jam can cause uncommanded movement of the rudder. **B737 pilots have no way to detect a jam of either a primary or secondary valve.**

Testing of the PCU conducted during the course of this accident investigation have shown that differential cooling or heating can impede critical, free, movement of the servo valves. These tests proved that thermal binding could impair or prevent movement of either valve. During such circumstances a rudder reversal (rudder deflection in the direction opposite to that commanded) can occur. **During post accident testing the PCU installed in USAir 427 has shown instances of reversal and binding.** The cause for this reversal was the failure of the servo valve to perform its intended design purpose. The mis-positioning of the primary valve due to a jam of the secondary valve results in the loss of the required redundancy. Forces applied to the internal linkage of the PCU result in bending, or linkage deformation, when there is a jam of the secondary valve. This then forces the primary valve out of its customary position. As a result, the primary valve no longer provides redundancy or the ability to oppose the jam. Therefore, the rudder will deflect fully in the direction of the jam of the secondary valve. A pilot applying pressure to a rudder pedal, while a jam exists in the secondary valve, can result in the rudder deflecting fully in the opposite direction to pilot command.

The USAir 427 Systems Group extensively tested and confirmed the reversal condition. Jamming of the secondary valve **for any reason** can cause a reversal, leaving no witness marks on the valve (NTSB Systems Group Factual Report). Tests also showed that once the reversal begins a pilot cannot overcome it. A jam of the secondary valve and the resulting reversal applies continuous, unrelenting, pressure on the rudder pedals while driving the rudder to full deflection. In fact, as documented in Section V of this submission, the harder a pilot applies pressure to the right rudder pedal, the more likely it becomes that the rudder reversal will not clear.

There are documented cases of jams that leave no witness marks on the valves. As demonstrated in Systems Group tests, the USAir 427 servo valves jammed by thermal binding, left no marks after the jam cleared. The lack of witness marks on the valve does not indicate that a jam did not occur. **The secondary valve in USAir 427's rudder PCU could have been jammed when the primary valve overstoked causing a rudder reversal.**

In August 1997, the Systems Group convened at Parker in Irvine, California. The group conducted tests to better understand primary valve reversal. These tests provided data on the rate of actuator movement and the force available to move the rudder with different positions of the secondary valve. The tests showed a correlation between secondary valve position and both rate of movement and force available.

Results of these tests show that when the secondary valve is at the neutral (or null) position there is full force available, however, no reversal can occur. As the secondary valve moves away from neutral the force available to the rudder during a reversal drops significantly. After the initial drop, the force available to the rudder rises quickly as the secondary valve moves farther from neutral. At the point where the secondary valve is fifty percent (50%) along its travel almost full force is again available to the rudder.

The significance of the relationship of secondary valve position and force available to the rudder is that above fifty percent (50%) secondary valve travel a reversal results in a full rudder hardover. The rate of rudder movement will be one half (1/2) the maximum rate due to the primary valve having no hydraulic fluid passing through it.

During the course of this investigation, the NTSB Systems Group identified a number of significant failure modes of the B737 main rudder PCU. These failure modes include:

1. A foreign object between the input crank and the external manifold stop

2. Overtravel of the primary valve

3. Overtravel of the secondary valve

4. Thermal binding of the primary valve to the secondary valve

5. Thermal binding of the secondary valve to the housing

6. Mis-positioning of the primary valve when the secondary valve is jammed

7. Uncontrollable actuator reversal due to mis-positioning of the primary valve

When each of these failure modes was tested by the NTSB Systems group using the USAir 427 main rudder PCU, the rudder either reversed or deflected to its maximum position.

Table of Contents

**a. Rudder Blowdown**

Unlike many jet transport aircraft, the B737 uses dynamic pressure, also known as blowdown, to determine the maximum rudder deflection possible when flying at high speeds. There is no mechanical limiting of rudder movement as a function of airspeed on the B737. Rudder movement is commanded via hydraulic pressure (3000 psi) in the rudder PCU. As the rudder moves, air load acts on the rudder panel, which results in a force that opposes rudder deflection. When the air load increases to the point that it equals the hydraulic pressure commanding rudder deflection, rudder movement will stop. This is known as the rudder blowdown limit. In the B737, the higher the airspeed the lower the maximum available rudder deflection possible. Unlike newer model aircraft, in the B737 there is no indication to the pilot in the cockpit of what the maximum rudder deflection available is.

B737 pilots can trim the rudder to relocate the neutral position. This is of use during engine out operation. The B737-1/200 uses manual cables to trim the rudder, while the B737-3/4/500 uses an electric motor to reposition the rudder's neutral position. The electric trim moves at 1/2 ° per second up to a maximum of 16° . There have been cases of failure of the electric trim system resulting in uncommanded movement of the rudder.

Table of Contents

**b. B737 Rudder Control System Certification**

The Boeing 737 received its original type certificate in 1967. Since that original FAA type certificate was issued there have been a number of B737 derivative models developed by Boeing and certified by the FAA. As far as the B737 flight control system was concerned, each derivative model was certified based on the FAR regulations in place at the time the original type certificate was issued, 1967. The FAA granted a derivative type certificate for the B737-300 in 1984, 17 years after the original type certificate was issued by the FAA.

The criteria applied in 1967, 14 CFR § 25.695 stated,

> "The failure of mechanical parts (cables, pulleys, piston rods, and linkages) and the jamming of power cylinders [such as hydraulic powered actuators] must be considered unless they are extremely remote."

The FAA at that time did not define "extremely remote". In their October 18, 1996 letter to Administrator Hinson, the NTSB referenced several FAA certification representatives who stated their belief that "extremely remote" is a failure rate of less than 1x $10^{-6}$ per flight hour.

In 1967 the FAA received failure analysis data from Boeing that showed that the B737's lateral control (roll) authority exceeded the rudder authority. Therefore pilots could use lateral control to overcome a hardover rudder. This was later shown to be inaccurate under certain conditions. The NTSB concluded that "the lateral control system may not be able to counteract the effects of a fully deflected rudder at certain airspeeds and flap settings."

Boeing acknowledged this condition in a September 20, 1991 letter from Mr. John W. Purvis (Boeing) to Mr. John Clark (NTSB). In that letter, Mr. Purvis states, "a full rudder hardover on a B737-200 Advanced airplane in level flight and flaps 10 could not be countered with wheel." This letter further explained, "the left rolling moment due to full left wheel is not enough to counter the right rolling moment due to sideslip."

Another Boeing letter (signed by K. K. Usui) sent to Mr. Donald L. Riggin (Manager of the FAA Seattle Aircraft Certification Office) on September 14, 1992 stated, "The B737 lateral control system capability exceeds the rolling moment due to a full rudder sideslip for all landings flaps at normal landing speeds ($V_{REF}$ + additives) and for flaps up at normal operational speeds. This is not true and conflicts with the September 20, 1991 letter from Boeing to NTSB on this subject. Further, testing conducted during the course of this investigation has proven that in certain areas of the flight envelop the B737 does not have sufficient lateral control authority to counter a full rudder input. As previously discussed with the FAA and NTSB during the investigation of the B737-200 ADV accident at Colorado Springs, the rolling moment produced by a full rudder sideslip exceeds the capability of the lateral system under the following conditions:

> 1) Flaps 1 to Flaps 10 at the low speed end of the flap operational envelope.
>
> 2) Flaps up and Flaps 15 if the aircraft is flown below normal operating speeds.

The 1967 certification requirements of 14 CFR § 25.695 required the B737 to consider only a single failure. Amendment 23 revised this FAR in 1970 to include undetected and multiple failures. The FAA did not and has not required the B737 to meet the updated FAR standards.

The "Control Systems, General" section of 14 CFR § 25.671 (c) requires that an airplane be capable of safe flight and landing after failure or jamming of a flight control system or surface without exceptional piloting skill or strength. If the probability of a malfunction is considered greater than $1x10^{-5}$ it must have only a minor effect on the control system and be readily counteracted by the pilot.

Also, subsection (3) states: "Any jam in a control position normally encountered during takeoff, climb, cruise, normal turns, descent, and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable." Tests on the B737 PCU servo valve have identified failure modes that do not meet the "extremely improbable" clause in this FAR. **As a result, ALPA concludes that the B737 does not meet the current requirements of 14 CFR § 25.671. ALPA recommends that in the future FAA and manufacturers evaluate derivative models against FARs in effect at the time of design.**

There has been some concern by NTSB over the ambiguity in the FAR terminology. Additionally, the NTSB agreed with the FAA Critical Design Review (CDR) team concern that existing regulations only considered control positions that were "normally encountered." The CDR team recommended that flight control systems be tested with a jam at any control position possible. ALPA shares the NTSB's concern and agrees with the CDR team's recommendation. ALPA also supports and agrees with the NTSB's belief "that the FAA should revise 14 CFR § 25.671 to account for the failure or jamming of any flight control surface at its design-limit deflection." **Further, ALPA believes that the FAA should re-evaluate all transport-category aircraft and ensure compliance with the revised criteria.**

The CDR team reports stated that there are "a number of ways where loss of rudder control and potential for a sustained rudder hardover may occur…Since full rudder hardovers (a control surface hardover is defined as an uncommanded, sustained deflection of the control surface to its full travel position) and/or jams are possible, the alternate means for control, the lateral control system, must be fully available and powerful enough to rapidly counter the rudder and prevent entrance into a hazardous flight condition." ALPA concurs with this CDR recommendation.

Table of Contents

### c. B737 Flight Control Incidents

Since the introduction of the B737, there have been recurring reports of flight control indents. On June 10, 1996 Eastwinds Airlines Flight 517, a B737-200, approached Richmond, Virginia. While descending for approach, the flight experienced at least two uncommanded rudder inputs. Other B737's have experienced uncommanded rudder inputs from the yaw damper. What made the Eastwinds flight notable was the magnitude of the rudder movement. The DFDR traces revealed that the rudder had deflected to near its blowdown limit. Another documented case of a rudder moving to its blowdown limit is USAir 427. The principle difference between the two events, and their outcome, was the airspeed at the time of the uncommanded rudder movement. Eastwinds 517 was operating at 250 knots with flaps up, which is well above crossover speed. USAir 427 was below crossover speed for its flap setting and weight. Recovery for the Eastwinds 517 flight crew proved difficult, for the flightcrew of USAir 427 recovery was impossible.

NTSB Chairman, Jim Hall, referred to Eastwinds 517 in a letter to FAA Administrator Hinson, "Under slightly different circumstances the Eastwinds incident could have been a third fatal B737 upset accident for which there was inadequate flight recorder information to determine the cause." ALPA agrees with Chairman Hall. The primary reason Eastwinds 517 did not result in a catastrophic accident is that Eastwinds 517 was above crossover speed when the rudder hardover occurred. The B737 crossover speed issue will be fully discussed in Section IV of this submission.

An NTSB investigation determined that one problem was that the Linear Variable Displacement Transducer (LVDT) had been mis-rigged which allowed the rudder to deflect to 4 1/2° . However, a second uncommanded rudder movement exceeded 4 1/2° and traveled to the blowdown limit (about 8° at 250 knots). As noted in the investigation, this airplane had experienced other rudder problems on May 14, 1996, June 1, 1996, and June 8, 1996. Eastwinds maintenance changed the main rudder PCU and the airplane returned to service.

A review of the B737 fleet record shows over 180 rudder related incidents since 1967. Explanation are yaw damper malfunctions, wake vortex encounters, or liquid contamination of the electronic boxes of the yaw damper. Some rudder event causes remain unknown.

Table of Contents

**d. FAA Critical Design Review Team**

On October 20, 1994, the FAA formed a Critical Design Review (CDR) team to review the design and certification of the B737 aircraft. On May 3, 1995 a report of the results of their review was issued. The members of the CDR team included FAA, Transport Canada, and US Air Force personnel.

Team members defined their objectives as:

> 1. Identify those failure events, both single and multiple, within certain flight control systems that result in an uncommanded deflection or jam of a flight control surface.
>
> 2. Identify latent failures in each axis of flight control.
>
> 3. Review the service history of the failed or malfunctioning component or subsystem through a review of ADs, Service Bulletins (SBs), Service Letters (SLs), Service Difficulty Reports (SDRs), NTSB recommendations, NASA Aviation Safety Reporting System (ASRS) reports, and other reports.
>
> 4. Identify and review the maintenance or inspection requirements (task and inspection interval), as provided by the manufacturer's Maintenance Planning Document (MPD), Maintenance Review Board (MRB) report, or maintenance manual for each identified component or subsystem with critical failure potential.

A review of 17 ADs, 54 SBs, and 37 SLs and visits to Boeing and other repair facilities (FAR Part 145) resulted in the following observations:

1. Valve chip-shearing forces (as low as 37 pounds) on the PCU actuator appeared to be low.

2. There is no adequate means for testing the dual spool servo valve for proper operation on the airplane.

3. The dual spool servo valve is a complex assembly and is a critical component of the rudder and aileron power control units and, therefore, critical to flight safety. Any facility authorized by the FAA to perform repair and maintenance or manufacture this component must assure the FAA of having the necessary equipment, personnel, and data (design, manufacture, qualification and acceptance tests procedures), including access to the latest revisions to the data provided by the Original Equipment Manufacturer (OEM).

After the team visited Douglas Aircraft Company (DAC) to compare their design and manufacturing practices to that of Boeing, the team published the following observations:

1. The earlier DAC airplanes employ direct cable-driven surface tabs as the primary control mechanism for many of the flight control systems.

2. The airplanes that have a hydraulically powered rudder have a built-in hardover protection with the use of split surfaces, or manual reversion via hydraulic shut-off lever. Earlier airplanes use rudder limiting devices with airspeed inputs. Later airplanes use aerodynamic (blowdown) limiting.

3. After breakout, the resulting prolonged forces required to control the airplane after a jam in the lateral control system are significantly lower than those of the B737.

4. The DAC minimum chip-shearing capability for hydraulic servo valves (100 pounds) is significantly higher than that of the B737 rudder PCU servo valve (minimum 37 in service, and 39 design).

5. DAC has more restrictive contaminated hydraulic fluid inspection requirements than the B737.

6. DAC performs flight tests of "rudder kicks" to determine structural strength issues; flight tests of rudder hardovers to determine lateral versus directional authority are not performed.

7. DAC employs a safety, reliability, and ergonomics group to perform hazard analysis on newer airplane models.

8. DAC's Failure Modes and Effects Analysis (FMEA) process is comprehensive and crosses engineering and operational disciplines.

9. In the DAC FMEA process for analyzing latent failures, DAC takes credit for the inspection interval of the identified failure, but does not make this inspection a Certification Maintenance Requirement.

A visit to Honeywell/Sperry by a CDR team representative resulted in two observations:

1. A 12-month accumulation of 200 failed Yaw Damper units were reviewed by the group in an effort to identify failure trends. Of the 200 failed units reviewed, 130 were due to rate gyro failures, and all of those were caused by damage to the rate gyro rotor bearings. Of the remaining 70 failures, 42 were confirmed as "No Fault Found", and the remaining 28 failures were considered "typical" (i.e. failed components, cold solder joints, etc.). The review suggests that the reason for the excessive frequency of rate gyro failures is due to a Boeing engine change. Boeing requested that Honeywell approve the existing Yaw Damper in the new vibration environment. That new vibration environment was a direct result of the engine change, which is the principle difference between the model -200 and the -300 aircraft. Honeywell has an action item to review those failures with Boeing.

2. There are a number of failure modes that could cause the Yaw Damper to command a rudder deflection to the Yaw Damper authority:

a. Electrical shorts of grounds,

b. Open feedback circuit, and

c. A condition involving an intermittent connection to the transfer valve and an integration circuit in the coupler where the Yaw Damper could command a rudder to deflect 3° for up to 120 seconds. Honeywell was not aware of this condition. Further investigation is being initiated by Honeywell.

The CDR team issued the following recommendations:

1. To develop a national policy for transport category airplane certification which includes consideration of a flight control jammed and any position including full deflection.

2. To develop a national policy requiring that when an alternate means of flying an airplane is employed they shall not require exceptional pilot skill and strength and that a pilot can endure the forces for a sufficient period of time to ensure a safe landing.

3. Require transport airplanes to have redundancy in the directional control system to maintain control in the event of a rotor burst for the most critical phase of flight.

4. Develop a national policy for transport airplanes requiring the determination of critical hydraulic flight control system and components sensitive to contamination, requirements for sampling hydraulic fluid, and requirements for actuator components to eliminate or pass (shear) particulate contamination.

5. Develop additional guidance for transport airplane failure analysis of flightcrew action items in response to failure conditions.

6. Establish a requirement for flightcrew action items to be developed and implemented or the failure analysis evaluated in order to justify no flight crew action items.

7. Review the adequacy of the B737 aileron transfer mechanism. Maintain a safe margin so that a pilot could continue a safe flight and land in a crosswind or go-around if necessary.

8. Ensure the B737 lateral control system is able to provide directional control throughout the airplane envelope with a jammed or hardover rudder, unless these type of failures are shown to be extremely improbable by the most rigorous methodology available.

9. Determine feasibility of improving the protection of the B737 main wheel well from the effects of environmental debris.

10. Ensure B737 wheels are based on TSO-C26 Revision C or later.

11. Require a failure analysis of the B737 yaw damper to identify all failure modes, malfunctions and potential jams.

12. Require corrective action(s) for those failure modes found in #12 that are not shown to be extremely improbable.

13. Require action to reduce the number of B737 yaw damper failures to an acceptable level.

14. Require action to correct galling of the standby rudder PCU input bearing.

15. Review and revise identified latent failures.

16. Require inspections of identified latent failures.

17. Revise the B737 MPD for inspection of latent failures of the Aileron Transfer Mechanism, Aileron Spring Cartridge, and the Standby Hydraulic System including Rudder Function.

18. Revise the B737 flightcrew training to include proper procedures for recovery from upsets caused by flight control system malfunctions.

19. Require that replacement parts of primary elements of flight control system (hydraulic servos and bypass valves) provided by sources other than the Original Equipment Manufacturer (OEM) have undergone qualifications of the OEM part so that the non-OEM part is equivalent under all design tolerance conditions.

20. Require the responsible FAA Aircraft Certification Office to concur with any non-OEM vendor.

21. Assess the repair procedures of every B737 PCU repair station in the US.

22. Evaluate the adequacy of the B737 maintenance manual actions addressing flight control cable inspection, rigging procedures and replacement criteria.

23. Require control cable service life limits unless acceptable inspection and/or test procedure are developed and utilized that can determine the continuing serviceability of the control cables.

24. Determine the degree of incorporation of the following SBs: B737-27-1060, B737-27-1033, B737-27-1081, B737-27-1125, B737-27-1134, B737-27-1152, B737-27-1154, B737-271155, B737-29-1062 and Report No. 95-04-2725.

> 25. Determine the degree of incorporation of the following SLs: B737-SL-27-16, B737-SL-27-24, B737-SL-27-30, B737-SL-27-57, B737-SL-27-71A.
>
> 26. Request NTSB to form a special accident investigation team to begin a new investigation of the B737 accidents at Colorado Springs and Pittsburgh.

Table of Contents

**e. NTSB Safety Recommendations and FAA Actions**

Prior to the accident involving USAir 427 there was some concern about the aircraft's rudder control system. In August 1991 the NTSB sent then FAA Administrator, James Busey a letter containing Safety Recommendation A-91-77. This recommendation called for an Airworthiness Directive (AD) to require inspection for galling (defined as the transfer of metal from one surface to another surface) in bearings of the standby rudder PCU control rod. The FAA first issued a Notice of Proposed Rulemaking (NPRM) for an AD but later withdrew it on April 19, 1993. The NTSB reiterated their recommendation in its report on the United Airlines 585 accident issued December 8, 1992. They classified A-91-77 as "Open--Unacceptable Action."

During the investigation of the UAL 585 accident a B737-300 experienced a rudder control system anomaly during a preflight rudder test on July 16, 1992. Bench tests identified a failure mode that could result in a rudder reversal. This failure mode involved the mis-positioning of the secondary slide by the internal summing linkage which would cause it to move too far or over-travel within the control valve.

On November 10, 1992, the NTSB issued Safety Recommendations A-92-118 through -121. These recommendations included maintenance and preflight tests to insure proper rudder operation. Additionally, the NTSB recommended that an AD be issued to require incorporation of design changes to preclude the possibility of rudder reversal and to conduct a design review of similar servo valves. The FAA agreed with these safety recommendations and in their response to NTSB stated,

> "The problem was found to exist in the main rudder power control unit only on the Boeing 737 model airplanes."

In this response the FAA acknowledged the uniqueness of the B737 rudder control system and its susceptibility to malfunctions resulting in rudder reversal. In order to correct this possible failure mode and rudder reversal, the FAA then issued NPRM 93-NM-79-AD on August 9, 1993 followed by AD 94-01-07 on March 3, 1994. That AD required an inspection of all main rudder PCU's within 750 flight hours and mandated the replacement of the main rudder PCU with an updated PCU that contained internal mechanical stops to prevent secondary valve over-travel.

In early 1996 a B737 operator discovered that an incorrect bolt had been installed in a main rudder PCU during overhaul. Installation of incorrect bolts can cause cracking of bearings which can result in an uncommanded rudder hardover. As a result, the FAA issued AD 97-05-10 Effective March 19, 1996. This AD required that all B737 PCU's be inspection within 90 days to confirm proper operation. Additionally, a B737 operator found incomplete testing of PCU's after overhaul resulted in uncommanded actuator movement. These are two cases where repair facilities not meeting OEM standards introduced rudder anomalies through faulty overhaul procedures.

The complex nature of the PCU requires careful maintenance. An intricate mechanism of this type requires special training of personnel and approval of the FAA before any repair station undertakes repair. ALPA believes history shows that the current practice of allowing a Principle Maintenance Inspector (PMI) to permit a repair station to perform work on a component as complex as a PCU without meeting the same standard as the OEM is a degradation in safety.

Examples of the safety implications of this practice are two cases where repair stations performed FAA approved work on PCU's. The work, however, was not airworthy. The FAA issued Airworthiness Directives (ADs) to correct the work. The PMI of each repair station had approved the methods used in the repairs. While the FAA later determined these methods were unairworthy. One repair facility did not use a proper test fixture for the PCU while the other installed a bolt that did not comply with the manufacture's specifications. **Holding repair stations to the same standard as the OEM will prevent occurrences like these from happening in the future.**

The NTSB's investigation of USAir 427 provided investigators with an opportunity to expose weaknesses in the maintenance of hydraulic flight components. While the issue of allowing PMI's to approve work that does not meet the same standard as the OEM did not directly affect USAir 427, there is now recognition of the problem potential serious consequences of this practice. **ALPA recommends that the FAA require all FAA approved repair stations meet the same standards as the OEM.**

On August 22, 1996, the FAA issued several NPRMs for ADs. These ADs included inspections for galling of the standby rudder PCU (96-NM-147-AD), inspections of the bores on aileron, elevator, and rudder PCU's for chrome plating separation (96-NM-150-AD), and verification of the integrity of the yaw damper system within 3000 flight hours and every 6000 flight hours thereafter (96-NM-151-AD).

The NTSB Systems Group conducted tests in August and September 1996 which showed that binding and reversal was possible in the main rudder PCU servo valve. As a result, on November 1, 1996, the FAA issued Telegraphic AD T96-07-51. This AD required repetitive tests within 10 days and every 250 flight hours thereafter for correct operation of the secondary and primary valves. In coordination with this AD was Boeing Alert Service Bulletin 737-27A1202.

On October 18, 1996, proceeding the November 1, 1996 Telegraphic AD, the NTSB issued Safety Recommendations A-96-107 through A-96-120. ALPA concurs with these far-reaching Safety Recommendations aimed at addressing the many areas of concern including:

A-96-107 - Development of "operational measures and long term design changes to preclude the potential for loss of control from and inadvertent rudder hardover. Once operational measures and design changes have been developed, issue respective airworthiness directives to implement this actions."

A-96-108 - Revise 14 CFR 25.671 to account for fully deflected failed or jammed flight controls.

A-96-109 - Require the installation of a rudder surface position indicator.

A-96-110 - Redesign the yaw damper system to "eliminate the potential for sustained uncommanded yaw damper control events." Require installation of the improved yaw damper on all B737.

A-96-111 - Prohibit any operator from removing and replacing the LVDT without testing of proper operation.

A-96-112 - Establish inspection intervals and service life for the main rudder PCU.

A-96-113 - Devise a method for detecting a jam of the primary or secondary slide.

A-96-114 - Test the adequacy of chip shear capability of all sliding control valves.

A-96-115 - Require modification of the input rod bearing of the standby rudder actuator to prevent galling by August 1, 1997.

A-96-116 - Define standards for hydraulic fluid cleanliness and sampling.

A-96-117 - Conduct a design review of dual concentric servo valves for malfunction and/or reversals because of improperly positioned servo slides.

A-96-118 - Require pilots to memorize the procedure for disengaging the yaw damper in the event of uncommanded yaw.

A-96-119 - Require development of procedures and training for B737 pilots to effectively deal with uncommanded rudder movement to the limit of its travel for any flight condition within the operational envelope.

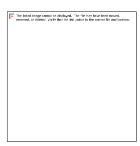
A-96-120 - Require pilot training to recognize and recover from unusual attitudes and upsets that can occur from flight control malfunctions and uncommanded flight control surface movement.

On January 2, 1997, the FAA issued an AD (96-NM-266-AD, 96-26-07) requiring a revision the B-737 FAA-approved Airplane Flight Manual (AFM). This AD required inclusion of a procedure for a flight crew action during uncommanded yaw or roll and to correct a jammed or restricted rudder.

At a press conference with Vice President Gore on January 15, 1997, the FAA announced four ADs for the B737. These ADs included: (1) a redesign of the main rudder PCU to eliminate any possibility of uncommanded rudder motion including rudder reversals; (2) an agreement to replace the mechanical yaw damper rate gyros with solid state rate gyros similar to the B747-400, B757, and B767; (3) incorporating a rudder limiter to decrease rudder movement and significantly improve a flight crew's ability to control a B737 experiencing a rudder hardover; and (4) redesign of bolts in the control rod that links the feel centering unit with the main rudder PCU so as to maintain a dual path. On March 14, 1997, the FAA issued NPRMs for these ADs (97-NM-28-AD and 97-NM-29-AD). It is important to point out that each of these 4 Airworthiness Directives requires the replacement of existing rudder control system components with new, improved components, not simply modifying existing components.

ALPA supports the NTSB and the FAA in their efforts to improve the B737. The changes to the B737 will help insure the highest level of safety for passengers and flight crew members. ALPA believes that the industry needs a maximum effort to hasten the replacement of the PCU's.

Table of Contents



## III. Aircraft Performance

This section will show that:

1. The lack of detailed flight data recorder information hampered the accident investigation. As a result, new investigative techniques had to be developed in order to supplement the data recorded.

2. The Kinematic analysis conducted, while not 100% conclusive, resulted in one scenario that matched the recorded FDR data. That match involved a full rudder hardover, in magnitude and input rate, which was consistent with a rudder PCU secondary valve jam with a primary valve overstroke.

During the field phase of the investigation, readout of the accident aircraft's CVR and FDR revealed that Flight 427 had experienced a sudden, uncontrollable roll and dive into the ground while maneuvering for landing. Because the B737 had a history of past rudder control system anomalies that can result in unwanted rudder deflection, the rudder became suspect almost immediately. Unfortunately, in the case of USAir 427, only eleven (11) parameters were recorded by that aircraft's Flight Data Recorder. While the FDR did yield information concerning pitch attitude and bank angle during the accident upset, information regarding flight control surface movement and flight control inputs, with the single exception of control column, was not recorded.

Because of the extremely limited amount of data available from the USAir 427 FDR, the FDR data was taken to the Boeing Seattle facility for study using the Boeing multi-purpose (MCAB) simulator. It was hoped that by feeding the FDR data into the Boeing B737 simulation and observing the MCAB simulator results would yield additional clues concerning the cause of the accident.

During the course of this accident investigation, the Boeing MCAB simulator has been an invaluable tool. An initial simulator session was conducted immediately following the accident. During this session it became evident from the FDR data that there was a large heading change, both in magnitude and rate, during the initial accident upset. During that initial simulator session, a number of simulator "runs" were conducted, simulating a variety of aircraft malfunctions and pilot reactions, in an attempt to replicate the FDR data recorded in the accident sequence. Aircraft malfunctions studied included: (1) rudder, yaw damper and spoiler hardovers; (2) leading edge slat malfunctions; (3) trailing edge flap malfunctions; (4) engine failures and; (5) hydraulic system failures. In addition, because of the separation distance of USAir 427 behind a preceding B727 aircraft, the possibility of a wake vortex encounter was also explored. During this early testing, however, it was recognized that limitations in the B737 simulation fidelity would have to be resolved before certain scenarios could be focused on or ruled out. These limitations included:

1. Aerodynamic data package at high angles of attack ( $\alpha$ ) and sideslip angle ($\beta$ ).
2. Modeling of wake vortex effects from the preceding B727, including limited knowledge on the behavior of the vortex itself.
3. Lateral and directional control effectiveness at high angles-of-attack ( $\alpha$ ) and sideslip ($\beta$ ).
4. Maximum rudder control deflection (blowdown) as a function of altitude, airspeed and sideslip angle.

In order to quantify these limitations and improve the simulator's fidelity, a number of activities were undertaken during the course of the investigation. These activities included wind tunnel and flight-testing in order to obtain actual aerodynamic data at high angles-of-attack and sideslip and to improve the modeling of control system and control surface effectiveness. Once these limitations were mitigated to the extent possible, analysis showed that the rudder hardover scenario was the **only** scenario that could produce enough yaw to match the FDR data from the accident flight.

Table of Contents

**a. Simulator Validation Testing**

In order to improve the MCAB simulator's fidelity, wind tunnel and flight testing was conducted in order to obtain aerodynamic data at high angles-of-attack and sideslip. In addition, this testing was also aimed at obtaining data so that the simulator model could be modified in order to more accurately model B737 rudder blowdown characteristics. During the course of this testing, it was discovered that the B737-300 was capable of more rudder deflection at Flaps 1 and 190 KIAS than originally believed. This increase in rudder deflection capability further supported the hypothesis that a full rudder hardover had caused the USAir 427 accident.

Table of Contents

**b. Flight Kinematics Study**

In order to better understand the accident upset involving USAir 427, the Aircraft Performance Group initiated a Flight Kinematics Study. This was a study using the kinematic equations of motion and the accident aircraft FDR data in order to approximate or estimate other flight parameters which were not directly recorded on the FDR such as angle- of-attack and sideslip angle. This data was further resolved into estimates of aircraft aerodynamic force and moment coefficients. Assuming that these aerodynamic force and moment coefficients were due to flight control surface inputs, these forces and moments could then be equated to flight control surface positions. A major limitation in this process however is that the analysis assumes "calm" air in order to be reasonably accurate. Other limitations include the accuracy of the FDR data itself and the accuracy of the simulator aerodynamic model.

In January 1995, the results of the first kinematic study were provided to the NTSB (Exhibit 13G). The results of this first study presented "equivalent control positions" for both rudder and wheel derived from the estimated roll and yawing moment coefficients. These results included the combined effects of data errors and the unknown external forces acting on the aircraft, including wake turbulence.

An updated version of this Kinematic Study was presented to the NTSB in June 1995 (Exhibit 13X-D). This version differed from the first in that it considered the effect of a wake encounter by USAir 427. A B727 preceded USAir 427 in the approach into Pittsburgh. The B727 was 4.2 miles or 69 seconds ahead of USAir 427 at the time of the accident. Recorded ATC radar data shows that the tracks of the two aircraft cross at approximately the point of USAir 427's accident upset. In addition, regarding the vertical separation between the two flight paths, USAir 427 was approximately 300 feet below the B727. This is consistent with the theoretical wake descent rate of 300 feet per minute. Further, there were obvious abnormalities in the kinematically derived lift and pitching moment coefficients. These coefficients showed a loss in lift and an airplane nose up pitch, as well as a sudden increase in turbulence. The performance group concluded that USAir 427 did encounter the wake from the preceding B727.

In order for this analysis to be accurate "calm" atmospheric conditions must exist. Since the actual conditions were not calm considering the wake encounter, the next step in refining the results of the kinematic study was to create an accurate wake turbulence model. This allowed estimation of the effects of the wake during the encounter. Developing this wake model required that many assumption be made. These assumptions include:

1. wake circulation or strength,
2. wake vortex core diameter,
3. wake span,
4. disruption of the wake due to interaction with the aircraft,
5. instability of the wake,
6. the oscillatory nature of the wake vortex pair (Crow instability), and
7. the position of the wake relative to the aircraft throughout the encounter.

This effort was undertaken and the estimated rolling and yawing moments due to the wake encounter were subtracted out of the airplane motion derived in the first kinematic study and new "equivalent control deflections" for control wheel and rudder were calculated.

The estimated wheel and rudder positions shown in this analysis were intriguing in two respects. First, the wheel trace showed the wheel turning in the same direction as the roll caused by the wake. This is contrary to the expectation that the flight crew would input wheel to oppose the roll due to the wake. Second, the derived rudder position showed rudder deflection greater than what was believed to be the blowdown limit.

Finally, a third kinematic study was prepared by Boeing and presented to the Aircraft Performance Group in September 1996. While the two previous studies were conducted in close coordination with the group, this third study was conducted solely by Boeing with minimal input from the Performance Group. During the meeting in which Boeing presented the results of this study, numerous questions were raised by group members regarding the analysis of the wake encounter and derivation of the rudder and wheel time histories. First, Boeing determined that the effects of the low sample rate of the FDR had to be "corrected" and rather than use a linear interpolation or another curve-fit methodology to fair the heading data, Boeing chose to fit an unorthodox non-linear interpolation through the data. Second, based on the Boeing curve fit, Boeing compared their results with hypothetical rudder system malfunctions or failures. The Aircraft Performance Group does not agree with the Boeing curve fit, and this remains an open issue with this third draft report.

In addition, the wake model was substantially changed from the previous study. These changes were based on the results of the wake vortex flight testing which was conducted in Atlantic City in September 1995. Unfortunately the data acquired during this flight testing was arbitrarily applied by Boeing to the new wake model. For instance, while Crow instability [movement of the wake vortices up and down relative to the flight path of the aircraft] was evident during the majority of the testing, Boeing only applied this motion to the wake vortex pair when it was needed to match lift and pitching moment. This self serving use of the wake vortex test data was also apparent when a problem with the estimated rudder position at FDR time 135 to 136 seconds arose. When Boeing presented the results of this study in September 1996 the rudder position during the 135-136 time period should have been 3 degrees airplane nose right assuming a functioning yaw damper. However, the rudder position predicted by the Boeing kinematic study, based on non-linear interpolation, was 2 degrees airplane nose left, a difference of 5 degrees of rudder travel. **Boeing had changed the predicted rudder value significantly by altering the wake vortex effects and changing the curve fit through the FDR heading data.**

As part of their presentation of the results of the third kinematic study, Boeing demonstrated the effect of data sampling rate on the results of the study and the estimates of rudder position. The sample rate for aircraft heading on the FDR was 1 sample per second. Therefore in a dynamic situation, such as the accident sequence, aircraft heading is only known for the recorded intervals. There is no way to precisely determine aircraft heading between sample intervals. Since the estimate of rudder position is dependent on the determination of sideslip angle, which is calculated from FDR heading, the greater the sampling rate for heading, the more accurate the estimate of rudder position. Sample rates investigated by Boeing included 20, 4, 2, and 1 samples per second. Boeing's analysis showed that the rudder results based on heading sampled once per second were very "noisy," while the sample rates of 2, 4, and 20 were relatively accurate and consistent. Therefore Boeing **unilaterally** decided to perform a non-linear interpolation of the heading data in an attempt to generate the 2 samples per second accuracy from the 1 sample per second FDR data. In this case, the results of the study are influenced by the curve drawn through the FDR data. Variations in the curve fit produce variations in the resulting rudder trace. **Boeing's interpolation through the heading data is not the only one that will fit.**

All of the kinematic analyses conducted during the course of this investigation are based on the computed aerodynamic forces and moments using the Boeing B737-300 simulator database. Therefore any results are limited by the accuracy of the aerodynamic data in the simulator database. As mentioned previously, there are known limitations in the simulator aerodynamic data at high angles-of-attack and sideslip. These limitations will introduce errors in the results of the kinematic study. In addition, the kinematic analysis conducted is most accurate in calm wind conditions. USAir 427 encountered the wake turbulence from the preceding B727 4.2 miles or 69 seconds in front of them. As a result, an attempt was made to account for the wake effects of the B727 on USAir 427. There is no conclusive way of knowing whether those effects were accurately accounted for. Further, limitations in the recorded FDR heading data introduce additional potential errors in the estimates of rudder position. However, the results of each of the three phases of the overall kinematic study have consistently shown a **full** airplane nose left rudder input at the initiation of the upset. **In addition, analysis of the rate of rudder input based on these kinematic results reveals that the rate and magnitude are both consistent with a secondary valve jam with a primary valve overstroke in the main rudder PCU.**

As mentioned earlier, the lack of detailed flight data recorder information in this investigation lead to the development of new and innovative investigative techniques. The flight kinematics study was one such technique, however this study literally took years to complete. If there been detailed flight data recorder data available following this accident this kinematic analysis would not have been needed and conclusions regarding flight control positions during the accident sequence would have only taken days. ALPA applauds the NTSB's actions regarding improved flight data recorder standards. The NTSB's recommendations in this area have lead to new FAR requirements regarding the minimum number of parameters required to be recorded. ALPA is confident that these new standards will benefit the industry by leading to more thorough accident investigations in the future.

---

Table of Contents

## IV. B737 Lateral vs. Directional Control Authority

This section will show that:

1. The B737 has limited lateral control authority which, at certain airspeeds and aircraft configurations, is unable to counter the roll due to sideslip caused by a full rudder hardover.
2. In the case of USAir 427, the lateral control authority available was not sufficient to maintain a wings level attitude once the flight experienced the full rudder hardover.

The B737 has insufficient lateral control at some airspeeds and flap settings to counter a fully deflected rudder. During the investigation of the UAL 585 accident at Colorado Springs, Boeing produced data which indicated that in certain aircraft configurations below certain airspeeds there was not enough lateral (roll) control authority to balance or counter the roll due to sideslip as a result of full rudder deflection. At that time Boeing stated that the aircraft configurations affected were Flaps 1 through Flaps 10. This information was relayed to the NTSB in a September 20, 1991 letter to Mr. John Clark (NTSB) from Mr. John Purvis (Boeing).

During the investigation of USAir 427 simulator validation flight testing was conducted and maneuvers were flown in order to examine the balance between lateral and directional control on the B737. During the course of this flight testing, Boeing and NTSB confirmed the data Boeing had provided during the UAL 585 investigation. For a B737-300 at Flaps 1 and weights above 110000 lbs, at speeds below 190 knots there was not enough lateral control authority to balance a full rudder hardover to the blowdown limit. **The speed at which full lateral (roll) control is needed to balance the roll due to sideslip caused by full rudder deflection is referred to the "Crossover" speed.** At the point of the USAir 427 upset, the aircraft was configured at Flaps 1 and was at a speed of 190 kts. It was determined that crossover speed is also affected by aircraft "g" loading such that an increase in "g" loading resulted in an increase in crossover speed for a given aircraft configuration. During the course of simulator validation flight testing, the investigation documented the exact speed at which crossover occurred. A review of the data found that this speed was significantly higher than Boeing had predicted. It was also within 3 knots of the Boeing suggested minimum maneuvering speed. At a Flap 1 setting and an aircraft weight of 110,000 lbs, flight tests found the crossover speed to be 187 knots. The Boeing suggested minimum maneuvering speed for this flight condition is 190 knots.

ALPA believes that this is an inadequate margin of safety. Adding 10 knots to the Boeing suggested minimum speed improves lateral control significantly. This increase in lateral control helps return the airplane to wings level flight much more rapidly in the event of a rudder hardover.

At the time of the upset, USAir 427 was operating at the Boeing recommended minimum maneuvering speed of 190 knots with the flaps set to "1". As the flight encountered the wake vortex of the preceding Delta Air Lines B727-200, the autopilot increased the pitch of the B737 to hold altitude when the aircraft rolled due to encountering the vortex. This slight increase in "g" load or angle-of-attack ($\alpha$) resulted in an increase in the crossover speed. Therefore, when the rudder went hardover there was insufficient lateral control to bring the airplane back to a wings level attitude. As the "g" load increased during the upset, the crossover speed continued to increase. As a result, the rate and magnitude of the roll increased.

Five seconds after the momentary five knot increase in airspeed that signifies that the airplane had encountered the wake of the B727, the bank angle was greater than 30° and increasing. Boeing charts predict that the crossover speed for a 110,000 lbs B737-300 in a 30° bank to be above 195 knots. USAir 427 was below the crossover speed and, due to the specific flight characteristics of a Boeing 737, lacked lateral control to return to wings level flight. **Throughout its remaining short flight, USAir 427 was never above the crossover speed.** As expected, the airplane continued to roll uncontrollably until impact.

During the course of this investigation much discussion and debate has taken place regarding the increase in "g" loading USAir 427 experienced during its accident upset and whether or not the upset was recoverable. ALPA believes that the increase in "g" loading experienced by USAir 427 during the upset was a combination of two factors. First, the natural stability of the aircraft would have caused an increase in "g" loading during the rollover and dive since the aircraft would have a desire to maintain its "trimmed" airspeed. Second, some time after the initiation of the upset and during the dive, the flight crew applied back pressure on the control yoke (airplane nose up elevator) instinctively trying to avoid impacting the ground.

As to whether this upset was recoverable or not, it is important to realize that we, in the investigation, are just now beginning to understand the concept surrounding B737 crossover speeds and the lateral control authority issue. This accident investigation has taken three years. Prior to this accident the B737 crossover speed issue and the effect of "g" loading and angle-of-attack on crossover speeds were unknown. The flight crew of USAir 427 had no way of determining what was wrong with their aircraft and why they could not regain or maintain control of their aircraft during the upset. This flight crew was helpless and the stall of the airplane experienced at the end of the accident upset is immaterial. **So long as the airplane remained below crossover speed, recovery from the roll due to sideslip caused by the hardover rudder was impossible.**

In the case of USAir 427, the crossover speed increased to the point that it was unattainable. The specific flight characteristics of the B737 and crossover speeds were not explored in detail and understood fully until this accident investigation. This knowledge has still not been passed on thoroughly to the piloting community. While ALPA applauds the initiative of the industry for the development of "Unusual Attitude" and "Aircraft Upset" training, we do not believe that enough has been done in the way of pilot education and the development of pilot operating procedures in order to prevent a loss of control accident.

In June 1997, Boeing undertook some additional flight testing on their own in order to further explore this crossover speed issue. During this flight testing, it was discovered that operations with flaps up was also impacted by crossover speed. Further, during this flight testing full rudder hardover malfunctions were conducted in order to quantify B737 handling characteristics and recovery techniques with full rudder deflections. It was determined that for the Flaps 1, 190 knot case, once a full rudder hardover was experienced, the aircraft had to accelerate to well above crossover speed before sufficient lateral control margin was reached and the aircraft could be recovered.

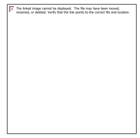
This idiosyncrasy of the B737 means that ALPA's recommended speeds would result in a flight crew having the ability to return to wings level flight over a much greater part of the flight envelope. Using ALPA's recommended speeds provides a greater margin of safety in the event of a hardover rudder, than the Boeing minimum maneuvering speeds for flap settings of "1" through "10".

During the course of this investigation, when the issue of crossover speed was confirmed, the NTSB issued Safety Recommendation A96-119. This recommendation called for the development of B737 operating procedures so that the aircraft could be safely operated in the event the aircraft experienced a full rudder hardover in any area of the flight envelope. To date, a number of B737 operating procedures have been developed aimed at eliminating a full rudder hardover should one occur in flight. However, a procedure aimed at providing a flight crew with more time in which to react and respond to a full rudder hardover has not yet been mandated by FAA. This procedure is relatively simple: increase the aircraft's minimum maneuvering speed to the Boeing recommended "Block" speed plus 10 knots. ALPA has been advocating this procedure during the past 2 years. Some airlines have adopted this procedure. Even though the FAA has not mandated this increase in minimum maneuvering speeds, they have however endorsed this concept of increasing the B737 minimum maneuvering speeds to "Block" speed plus 10 knots. In a June 4, 1997 letter to ALPA, the FAA stated:

> "The Federal Aviation Administration (FAA) has reviewed your proposal and agrees that the approach recommended in this bulletin certainly does have merit. The
>
> techniques recommended in Bulletin 95-3 would definitely result in a more expeditious and easier recovery from any uncommanded directional control system failure."

**ALPA urges the NTSB to recommend that B737 operators increase B737 minimum maneuvering speeds to Boeing's recommended "Block" speed plus 10 knots.** This would be the safest course of action until the FAA mandated changes in the B737 rudder PCU are completed in order to provide a margin of safety in the event of a rudder hardover.

Table of Contents



## V. Human Performance

The NTSB conducted a very extensive Human Factors investigation with regard to flight crew actions during the USAir 427 accident upset. Based on this analysis, flight crew actions were not causal to the accident.

Table of Contents

### a. Flightcrew General: Health and Background

This section will show that:

1. The crewmembers of this flight were healthy, both physically and mentally, and were fit for flight.
2. No evidence exists of any medical conditions that would have affected the performance of the flightcrew.

The captain was 45 years old and the first officer was 38 years old. (Human Performance Group Chairman’s Factual Report, October 31, 1994)

The captain’s height was 5’11" and his weight was 210 pounds, according to his FAA medical records. The first officer was 6’3" and weighed 210 pounds according to his FAA medical records. (Human Performance Group Chairman’s Factual Report, October 31,1994)

According to the captain’s wife, she characterized her husband’s health as "very good." The first officer’s health was characterized as "excellent" by his wife. (Human Performance Group Chairman’s Factual Report, October 31, 1994)

According to the Human Performance Group Factual Report dated October 31, 1994, "The captain had undergone back surgery in March, 1994 to remove a ruptured disk. He returned to flying in May 1994 and, according to his wife, did not complain of further back pain [following the operation.]" The crew’s chief pilot indicated that neither of these pilots abused their sick leave. (Operations Group Factual Report, October 27, 1994)

The captain and first officer held valid FAA first class airman medical certificates dated 7/9/94 and 7/13/94, respectively. (Human Performance Group, October 31, 1994)

The captain and first officer had no restrictions placed on their FAA medical certificates. According to the Human Performance Group Factual Report dated October 31, 1994, the captain’s "distant vision was listed as 20/20 in each eye without correction, and near vision was 20/60 corrected to 20/20 in each eye." The first officer’s "distant vision was listed as 20/15 in each eye without correction, and near vision as 20/30 in each eye without correction."

Each pilot’s medical insurance claim record was reviewed by members of the Human Performance Group, looking at the immediate 5-year period prior to the accident. The following is extracted from the Human Performance Group Factual Report, Second Addendum,

> "A review was conducted by committee members (MB, PL, CD) of the medical claims records of the company-sponsored insurance carrier. During the five years prior to the accident, the first officer submitted no medical claims. During the same period, the claims submitted by the captain indicated no significant illness or hospitalization with the exception of back surgery as described in the Human Performance Factual Report. The investigation revealed no evidence of any active or pre-existing medical conditions that would have affected the performance of the flightcrew."

According to the Human Performance Group Factual Report, Second Addendum, "A telephone interview was conducted with the captain’s allergist. The doctor reported that the captain received regular allergy shots for environmental allergens. He stated that the captain’s clinical symptoms, consisting of sneezing, runny nose, and post-nasal drip, were mild and responded well to treatment. The captain’s last allergy shot was administered in August, 1994, and his treatment was current at the time of the accident."

The Human Performance Group Factual Report dated October 31, 1994 indicated that the captain’s, wife told investigators that her husband took no medication other than allergy shots. Further, the first officer’s wife indicated that her husband took no medication. Further, a medical insurance claim review showed that the first officer had no medical insurance claims for medication, as discussed in the NTSB’s Human Performance Group meeting, July 12, 13, 1995.

Postmortem toxicological tests showed no evidence of drug, alcohol or medication usage by either crewmember.

According to Dr. Scott Meyer, a physiologist who reviewed the Cockpit Voice Recorder audio tapes at the request of the Human Performance Group, "There were no indications from the normal communications throughout the tape that either crew member was physically incapacitated or hampered in the performance of their duties by a lingering injury. Both the breathing and physical responses of the PIC and F/O appear to be within normal limitations and not major contributing factors to this accident." (Speech Examination Factual Report, May 5, 1997.)

Table of Contents

**b. Flightcrew Psychological and Psychosocial Factual Information**

According to the Human Performance Group Factual Report dated October 31, 1994, the captain was "married for 19 years and had two young children." Several colleagues indicated that "the captain appeared to be happily married and devoted to his family." This report further stated that the first officer was "married for almost two years and had no children." Several colleagues indicated that "the first officer appeared to be happily married."

There were no indications that either crewmember had any major changes in personal or financial situations in the twelve months prior to the accident. (Human Performance Group, October 31, 1994)

The captain had no history of automobile accidents in the preceding three years; he received a traffic violation in January 1993 for "failure to give a proper signal." The first officer had no history of automobile accidents or violations in the preceding three years. (Human Performance Group, October 31, 1994)

Neither crewmember had any record of aviation accidents or enforcement actions, and further, there were no records of any criminal history. (Human Performance Group, October 31, 1994)

The captain's wife indicated that her husband rarely drank alcohol. The first officer's wife stated that he was a moderate, occasional drinker. (Human Performance Group, October 31, 1994)

Interviews with station gate agents who interacted with the crew stated that the crew seemed alert, happy and in a good mood. (Human Performance Group, October 31, 1994)

A USAir captain rode on the cockpit jumpseat with this crew on the flight prior to the accident flight. This jumpseating pilot indicated that the crew did not appear tired or stressed. (Operations Group, October 27,1994)

All of the captain's training records indicate satisfactory performance. Approximately 5 months prior to the accident the captain had a simulator check. The check airman who administered the check stated that the training session "went well with no problems." Further it was noted that the captain was "prepared for the training and it went smoothly." (Operations Group, October 27, 1994)

According to the Operations Group Factual Report dated October 27, 1994, another check captain flew a three day trip with the captain in order to requalify him following his back surgery. The check captain stated that the captain was "meticulous...very professional...he paid attention to detail...ran completed checklists...followed all procedures."

When Captain Germano transitioned from BAC 1-11 First Officer to B737 First Officer in September 1987, his training record indicated a remark by his instructor that stated, "I would place at end of training, Mr. Germano in lower 10 percent." This is inconsistent with other characterizations of the Captain's proficiency. On October 8, 1996 the NTSB's Operations Group for this accident interviewed Captain Michael Rush, the instructor who made this comment. According to the Operations Group Factual Report, Addendum 3, dated June 19, 1997, "[Captain Rush] stated that he did not have a clear recollection of Captain Germano. He had never flown with Germano on the line. He could not estimate the number of check rides he had administered. Regarding the 'lower 10 percent' comment he had entered in Germano's training record, Rush stated that at the time the USAir manual suggested commenting 'Top 10 percent' if the pilot being checked had done a good job. He did not specifically remember the check ride after which he had written this comment for Germano, but he interpreted the comment to mean that Germano met all of the requirements but 'his methods may not have been as fast or polished as other pilots.' He stated that he did not 'recall my motivation at the time.' He compared these ratings to those given to Olympic athletes; some successful athletes received lowed marks. He said that he had probably written similar comments on other pilots' training forms." Captain Rush also added that if he 'would have had no doubts about grading Germano as Unsat[isfactory] had that been warranted. He said that, as both a check airman and designated examiner, he had graded some other pilots as Unsat.'

ALPA considered the testimonies of Captain Rush and other check airmen who had evaluated Captain Germano's performance more recently. From the record, Captain Rush clearly stated that he found Captain Germano's performance to be satisfactory, but felt that he lacking some "polish." Whether or not Captain Germano was having difficulty at that time (1987) should be countered by his performance closer to the time of the accident, some seven years later. As cited above, five months prior to the accident a check airman stated that training Captain Germano "went well with no problems" and that the Captain was "prepared for the training and it [the training] went smoothly." Further, a check airman who flew with the captain in order to requalify him following his extended sick leave absence stated that Captain Germano was "meticulous...very professional...he paid attention to detail...ran completed checklists...followed all procedures." From weighing these comments, ALPA concludes that the issue is not how well Captain Germano may have performed during First Officer transition training seven years prior to the accident. Instead, a more accurate predictor of his performance during the accident flight would have been those more recent comments concerning Captain Germano, while he was being observed in actual line operations and while acting as Pilot-in-Command, which is the same role that he was performing on the accident flight.

All of the first officer's training records indicate satisfactory performance. Approximately 5 months prior to the accident the first officer received a simulator check. The check airman who conduced the check stated that the first officer was "well prepared...he was a sharp guy...in both the oral and the simulator check." He had no negative comments concerning the first officer's training. (Operations Group, October 27, 1994)

Table of Contents

### c. Crew Communications - Intra-cockpit

*This section will show that:*

1. *The type and quality of intra-cockpit communications are predictors of crew performance.*

2. *The crew of this flight communicated amongst themselves in a manner that is consistent with a high degree of professionalism and good crew coordination.*

Previous human factors research has shown that the type and quality of communications among flight crews are important predictors of crew performance.' During the NTSB's investigation of this accident, the Human Performance Group sought the expert assistance of NASA scientist Barbara Kanki, Ph.D., for the purpose of conducting a speech analysis. Her completed report is attached to the Factual Portion of Speech Analysis Report, dated October 22, 1996.

According to Dr. Kanki's report, "Because verbal communication is so often the means by which flightcrews perform their tasks, patterns of speech are potential indicators of how crewmembers coordinate their work, how they relate to each other and others in the system." This statement is consistent with Foushee and Manos's (1981) observation: "At the very best, communication patterns are crucial determinants of information transfer, but research has shown that they are also related to such factors as group cohesion (important from a crew coordination standpoint), attitudes toward work, and complacency."

Dr. Kanki looked at three aspects of speech acts: 1) task-related speech, which describes crew coordination during routine flight conditions, as well as problem-solving during the emergency conditions; 2) procedural speech, which describes adherence to regulations, policies and protocol; and, 3) non-task-related speech, which describes general cockpit atmosphere and interpersonal relationships among crewmembers.

Table of Contents

### d. Task-Related Speech

Dr. Kanki states that during the routine portion of flight, patterns of request for information and their responses are analyzed as an indicator of how the crew coordinates their task activities and obtains the information they need. According to Dr. Kanki's report:

> At a simple descriptive level, much of the captain's speech is devoted to air traffic control (ATC) communications. However, in addition to ATC speech, the remainder of his task-related speech consists of six task observations, one statement of intent and one suggestion/directive. Responses by the first officer to these statements are exceptionally high (i.e., no completed speech by the captain is left hanging or un-acknowledged). There are fewer first officer speaking turns since he is not handling ATC. Thus, his entire pattern of task-related speech consists of three task observations, five questions/verifications, one statement of intent and one suggestion/directive. Consistent with the first officer, the captain responses are high, especially in cases of question/verifications.

> *Crew Coordination:* One indicator of crew coordination is the pattern shown by the pilots in their requests for information and verification. Since these are potential areas of miscommunications, the completion of these task-related communication sequences is important. From this transcript, the following general pattern is shown: when a question or request for verification is initiated, the other responds immediately, except for outside interruptions. On task-related topics, the first officer (F/O) initiates questions to the captain (C) 5 times, and the C initiates questions to the F/O once. Since all of the questions are requests for clarification or verification regarding ATC instructions or ATIS, and C is handling radio communications, it is reasonable that he is the responder more often than the initiator. Both C and F/O resolve the questions in all cases, and ATC is considered an integral part of the communication loop. There is no apparent reluctance to seek or incorporate information from each other or ATC. Assessing these patterns on the basis of pilot and ATC roles in routine operation, level of coordination and communication appears to be adequate for accomplishing the task. At the point at which the emergency begins, there is no question or verification issue left unresolved.

Dr. Kanki summarized her thoughts concerning task-related speech during the routine phase of flight: "While there is not an abundance of data (speaking turns), this aspect of crew performance can be described as complete, cooperative interactions among the flightcrew members and air traffic control (who is also part of the communications loop)."

Regarding the emergency period, Dr. Kanki states: "Because the pilots seem to have been cooperative and responsive to each other within the last 30 minutes, there would not seem to be any interpersonal barrier to their being in tune with each other at this time. On the other hand, the emergency conditions themselves may be pulling their attention in different directions. In either case, the communications and actions may be altogether appropriate."

Table of Contents

**e. Procedural Speech**

According to Dr. Kanki, "Procedural speech is interpreted as an indicator of crew adherence to regulations, policies and protocol. Throughout the transcript, procedural speech (ATC communications, checklist and PA announcements) generally appear to fall within expectations."

**f. Non-Task-Related Speech**

Dr. Kanki states, "Non-task-related speech is interpreted as an indicator of the cockpit atmosphere and interpersonal relationships among the flightcrew members. Instances of non-task-related speech, or social communications are normal and responsive. There is a casual, friendly interaction among both pilots and flight attendants, implying that, as least on a professional level, there is no particular social barrier or problem that would impede their working together during the emergency." She adds, "Non-Task conversation is curtailed when task activities accelerate."

Table of Contents

**g. Crew Communications - ATC**

*This section will show that:*

1. *The captain of USAir 427 acknowledged each ATC radio transmission in accordance with accepted practices.*
2. *100 percent of the captain's clearance or frequency change readbacks contained both the full clearance readback and the complete aircraft call sign, compared to a recent FAA study that found that only 37 percent of pilot readbacks contain both the clearance readback and complete aircraft call sign.*
3. *The captain's careful attention to ATC communications indicates that he was attentive during flight and that his professionalism towards ATC communications was likely a reflection of his professional approach to flying.*

Using the Cockpit Voice Recorder Specialist's Factual Report of Investigation, ALPA conducted an analysis of pilot-to-controller communications between the crew of the accident aircraft and ATC facilities along their route.

In establishing a baseline for this analysis we consulted the Aeronautical Information Manual (AIM) to identify traits associated with good radio discipline. Section 5 of the AIM, *Pilot/Controller Roles and Responsibilities* mentions four pilot actions that are important in receipt of ATC clearances.

Each of these areas are listed below, along with ALPA's analysis.

1) Acknowledge receipt and understanding of an ATC clearance.

> ALPA findings: During the 30 minutes beginning at 1832:29 EDT (the beginning of the CVR transcript) and ending at 1902:32.0 (the last radio transmission from USAir 427 before the upset event), ATC issued 14 clearance or frequency change transmissions. The captain, the pilot-not-flying, answered 100 percent of these transmissions immediately, and in each case correctly utilized the aircraft call sign. There was never the need for ATC to repeat a transmission, and information contained in the captain's readback was consistently correct.
>
> By way of comparison, in a recent FAA study researchers analyzed 48 hours of ATC-pilot communications. Of the 13,089 transmissions reviewed by researchers, only 37 percent of pilot

readbacks contained full readbacks and complete aircraft call signs. The USAir 427 crew exceed this performance by a factor of almost three.

2) Readback any hold short of runway instructions imposed by ATC.

ALPA finding: This was not relevant, as the aircraft was airborne during the time that covered the CVR transcript .

3) Request clarification or amendment, as appropriate, any time a clearance is not fully understood or considered unacceptable from a safety standpoint.

ALPA findings: At 1856:16 ATC requested that USAir 427 reduce speed to 210 knots. The captain acknowledged that he would comply with the speed request, but that an altitude clearance that was previously assigned (CUTTA Intersection at 10,000) would be difficult to make. The controller then replied that the speed reduction was paramount, and that the altitude restriction was no longer needed.

At 1857:23 the Pittsburgh Approach controller made a lengthy transmission to USAir 427 ("USAir four twenty-seven, Pittsburgh Approach, heading one six zero vector ILS runway two eight right final approach course, speed two one zero.) Before the captain could readback the clearance, the first officer asked the captain, "what kind of speed?" followed by the captain’s clearance readback. However, because of the distraction of the first officer’s request for speed verification the captain became unsure of the runway assignment, which was embedded among other bits of the controller’s transmission. The captain later asked ATC, "did you say two eight left for USAir four twenty-seven?" followed by the controller providing the correct runway assignment.

4) Promptly comply with an air traffic control clearance upon receipt except as necessary to cope with an emergency. Advise ATC as soon as possible and obtain an amended clearance, if deviation is necessary.

ALPA finding: Each of the 14 clearances or frequency changes were immediately executed by the flightcrew.

ALPA concludes that the crew’s performance regarding ATC communications was in accordance with accepted practices. During the final 30 minutes of flight the captain correctly acknowledged each ATC transmission and correctly used the full aircraft call sign in each instance. This performance is considerably better than the average performance of pilots in a recent FAA study, where only 37 percent of pilot readbacks contained full readbacks and aircraft call signs. From this ALPA concludes that the captain was attentive during the flight, and further that he was disciplined in his approach to flying, which prompted careful attention to his radio usage. The aircraft was flown in compliance with all ATC clearances.

Table of Contents

**h. Crew Interactions**

*This section will show that:*

1. *CRM trains crews to operate more effectively and better cope with non-routine situations.*
2. *USAir's CRM program was well developed and that CRM principals were constantly reinforced during training with USAir flightcrews, including the accident crew.*
3. *Evidence gathered by a number of NTSB investigative groups indicates that the crew of USAir 427 performed in a manner that is consistent with good CRM during prior trips, as well as during the accident flight.*
4. *The crew's use of CRM practices helped foster a healthy crew concept, and this positive crew interaction well prepared them to deal with the emergency had it been a recoverable situation.*

According to FAA Advisory Circular AC 120-51B *Crew Resource Management Training:*

> Investigation into the causes of air carrier accidents have shown that human error is a contributing factor in 60 to 80 percent of all air carrier incidents and accidents. Long term NASA research has demonstrated that these events share common characteristics. Many problems encountered by flightcrews have very little to do with the technical aspects of operating in a multi-person cockpit. Instead, problems are associated with poor decision making, ineffective communication, inadequate leadership, and poor task or resource management.

The AC states, "CRM-trained crews operate more effectively as teams and cope more effectively with non-routine situations." The AC further states:

Good training for routine operations can have a strong positive effect on how well individuals function during times of high workload or high stress. During emergency situations, when time pressure might exist, a crewmember probably would not take the time to reflect upon his or her CRM training in order to choose the appropriate behavior. But practice of desirable behavior during times of low stress increases the likelihood that emergencies will he handled effectively.

Effective airline CRM programs, according to AC 150-51B, contain at least the following components:

- Initial indoctrination to CRM principals;

- Recurrent ground training to reinforce CRM principals and concepts;
- Combined training with cabin and flight crews;
- Instructor/check airman CRM evaluation techniques;
- Line Oriented Flight Training (LOFT) supplemented by use of video tape technique to capture positive and negative CRM usage; and
- Reinforcement and critique of CRM during line operation evaluations.

At the time of the accident, USAir's flight training program incorporated each of the above components. Their program was developed by Dr. Robert Helmreich, a well known CRM expert who has been tasked by NASA and FAA to research CRM issues. The crew of USAir 427 received initial and recurrent training in CRM concepts.

The following items are paraphrased from Advisory Circular AC 120-51B, which identifies "clusters" that are markers of effective CRM performance:

1) Communications Processes and Decision Behavior Cluster

- briefings - set open /interactive communications, for example, the captain calls for questions or comments.
- inquiry/advocacy/assertion - crewmembers speak up and state their information with appropriate persistence, crewmembers are encouraged to question the actions and decisions of others.
- communications/decisions - relate to free and open communication. They reflect the extent to which crewmembers provide necessary information at the appropriate time (For example, initiating checklists and alerting others to developing problems.)

2) Team Building and Maintenance Cluster

- leadership followship/concern for tasks - group climate appropriate to the operational situation is continually monitored and adjusted (for example, social conversation may occur during low workload, but not high).
- interpersonal relationships/group climate - "tone" of cockpit is friendly, relaxed, and supportive.

3) Workload Management and Situational Awareness Cluster

- preparation/planning/vigilance - monitoring weather and traffic and sharing relevant information with the rest of the crew, active monitoring of all instruments and communications and sharing relevant information with the rest of the crew.
- workload distribution/distractions avoided - how well the crew manages to prioritize tasks.

Evidence gathered by a number of NTSB investigation groups indicates that the crew of USAir 427 performed in a manner that is consistent with good measures of Communications Processes and Decision Behavior, Team Building and Maintenance, and Workload Management and Situational Awareness. For example, according to the Human Performance Group Chairman’s Factual Report dated October 31, 1994, a deadheading USAir pilot rode on the cockpit jumpseat with this crew on the leg prior to the accident flight. He described the accident crew as "amiable and alert." He stated that the captain "provided a thorough jumpseat briefing, and invited input from the first officer and the jumpseat rider concerning ORD [Chicago O’Hare Int’l Airport] since he had not landed there recently." The Operations Group Chairman’s Factual Report dated October 27, 1994 states that the jumpseat rider said that "the crew interaction was routine. He found both pilots friendly and in good spirits." He described the conduct of the flightcrew as "professional."

According to the Human Performance Group Factual Report dated October 31, 1994, "Two first officers who had flown recently with the captain indicated that his greatest strength as a pilot was an ability to get along with the entire crew and bring first officers and flight attendants into the operation. One co-pilot described a recent flight in which the captain attempted a VOR approach in bad weather into an airport neither pilot had landed at before. He said the captain provided a long briefing and flew the approach well."

According to the Operations Group Factual Report dated October 27, 1994, an interview was conducted with the flight crew’s chief pilot. The chief pilot stated that "as far as he knew, Captain Germano conducted his trips in a professional manner. He knew of no discipline actions against him. He stated that there had been no reported difficulty between Captain Germano and the first officers who flew with him. [Captain Germano] was ‘extremely well liked.’"

According to the Operations Group Factual Report dated October 27, 1994, the chief pilot stated that the first officer was a "very dedicated, professional, dependable person." The chief pilot further stated that he had personally flown with the first officer and that his performance was "extremely professional."

According to the Operations Group Factual Report dated October 27, 1994, interviews were conducted with pilots who had flown with Captain Germano and First Officer Emmett within the 60 days prior to the accident. A sample of their comments follows: [Note: Quoted verbatim from report]

- Captain Germano was very good to fly with...he was very proficient...excellent CRM.
- Captain Germano was very personable...very thorough...not excitable;
- Captain Germano flew by the book...used all checklists...no non-standard maneuvers
- First Officer Emmett had exceptional piloting skills;
- [First Officer Emmett] was the kind of first officer you’d want to fly with. We had an hydraulic problem on the trip and he did a great job.
- [First Officer Emmett’s] performance was outstanding...well qualified." [End of direct quote]

During the trip sequence, the first officer telephoned his wife where he indicated that he was flying with a "good crew." (Human Performance Group, October 31, 1994)

The evening before the accident the crew deplaned their aircraft at the end of the day. According to the customer service agent (CSA) who met the flight, the crew seemed cheerful. The crew sang "happy birthday" to one of the flight attendants and kidded as they left the airplane together. (Human Performance Group, October 31, 1994)

The CVR indicates that the crew talked very little amongst themselves during the cruise and descent portion of the accident flight. There were a few lighthearted moments of laughter on the CVR. According to the Operations Group Factual Report dated October 27, 1994, "Conversation within the cockpit was routine and indicated an appropriate checklist reading."

**From the foregoing information, the Air Line Pilots Association concludes that the crew's performance on prior trips, as well as this during the accident flight, was consistent with good CRM practices and this healthy crew interaction well prepared them to deal with the emergency had it been a recoverable situation.**

Table of Contents

### i. Observance of Sterile Cockpit Procedures

This section will show that:

1. When the flight reached 10,000 feet MSL, all extraneous cockpit conversation ceased, and all future comments were related to the operation of the aircraft.
2. Because the crew was occupied with completing the Preliminary Landing Checklist, and because the first officer had to wait for the flight attendant to complete the "Fasten Seat Belt" announcement, the cockpit pre-arrival PA announcement was not
3. made until one minute and fifty seconds after the aircraft descended below 10,000 feet.
4. When the pre-arrival announcement was made by the first officer, it was conducted in accordance with the suggested model contained in the USAir Flight Operations Manual.

The FAA "Sterile Cockpit Rule" (FAR 121.542) prohibits crewmembers from performing non-essential duties or activities while the aircraft in a "critical phase of flight." Critical phase of flight is defined as all ground operations involving taxiing, takeoff and landing and all other flight operations conducted below 10,000 feet MSL, except cruise flight.

According to the *Federal Register*, "Critical phases of flight...are the phases of a flight in which the flight crew is busiest, such as during takeoff and landing and instrument approaches. When many complex tasks are performed in a short time interval, distracting events could cause errors and significant reductions in the quality of work performed. The performance of a non-safety related duty or activity when flight crew workload is heavy could be the critical event which precludes a flight crewmember from performing an essential task such as extending the landing gear prior to touchdown."

*ASRS Directline*, a publication of NASA's Aviation Safety Reporting System (ASRS) states, "It's unrealistic to expect a crew to fly together for several days and never discuss anything except items related to flying the aircraft. In fact, experts have demonstrated that in order to be most effective, crews need to talk - even if it is just merely 'get to know you' sort of chat. The sterile cockpit rule is a good rule because it clearly defines when it is time to set aside non-essential activities and tend strictly to the task at hand - that of safely operating the aircraft."

According to Flight Safety Foundation's *Flight Safety Digest*, "The FARs never intended to prohibit functions that are necessary for flight safety. Items that must never be stifled include: accomplishment of checklists, crew callouts, procedural discussions, voicing safety concerns and crew interactions such as acknowledgments and commands."

Flight Safety Digest further states, "Because the cockpit should remain sterile below 10,000 feet MSL, cabin crews need some way of determining whether the aircraft is above or below 10,000 feet. However, a 1988 U.S. Department of Transportation (DOT) report highlighted flight attendant difficulties with trying to determine precisely when sterile cockpit procedures should be in effect... Association of Flight Attendants (AFA) safety representative Noreen Koan said that the ideal notification tool is a PA announcement from the flight deck as the aircraft climbs and descends through 10,000 feet. The DOT report acknowledges that this may be a good technique, but said, 'The success of this method depends entirely on the reliability of the announcement. Even in cases where the announcement is company policy, it is not always made.'

USAir's policy at the time of the accident was for flightcrews to make a pre-arrival announcement at or before 10,000 announcement to alert the cabin crew that a sterile cockpit environment would soon be entered. The USAir Flight Operations Manual (FOM) contains a sample pre-arrival announcement that states:

> We will be descending through 10,000 feet momentarily. Our location is 30 miles from Charlotte and we anticipate landing in approximately 10-12 minutes. I would like to take this opportunity to ... (personal comment). At this time I would like to request that the Flight Attendants prepare the cabin for arrival. Thank for you flying USAir.

In essence, the FOM suggests that pre-arrival announcement contain several elements. Among these elements are: the amount of time before the aircraft lands, a personal comment to extend appreciation for flying USAir, a statement for the flight attendants to prepare for landing, and in closing, a final "thank you."

This discussion is relevant to the crew of USAir 427. ,As the aircraft was descending into the Pittsburgh terminal area, the CVR reflects that while still above 10,000 MSL, the cockpit crew engaged in a casual conversation with a flight attendant concerning a "fruity punch" soft drink that the flight attendant had made. The flight had been initially cleared to 10,000 feet. At 1854:24 the CVR recorded the sound of the aural altitude alerter, signifying that the aircraft was approximately 750 feet above the level-off altitude of 10,000 feet. One second later the flight attendant stated, "**OK, back to work," followed by the sound of the cockpit door opening and closing. ALPA believes that the altitude alerter directed the flight attendant's attention to the altimeter and upon seeing that they were approaching 10,000 feet, she knew that the cockpit would soon become sterile.

At 1858:33, four seconds after the flight attendant closed the cockpit door, the flightcrew was issued a decent clearance to 6000 feet. At 1858:50 the first officer made a final remark concerning the fruity punch beverage. At 1858:56, concurrent with the aircraft reaching 10,000 MSL, the captain remarked, "cranberry, orange and sprite," a statement in reference to the drink's content. After this point all further remarks by the flight crew were related to the operation of the aircraft.

From 1859:04 to 1859:31 the crew became involved with accomplishing the Preliminary Landing Checklist. Due to their involvement with accomplishing this checklist, at 1900:26 the crew realized that they had not made the pre-arrival announcement at precisely 10,000 feet. The first officer then stated, "Oops, I didn't kiss 'em 'bye." He then had to wait for the flight attendant to finish his "Fasten Seat Belt" announcement before making the pre-arrival announcement at 1900:44.

In accordance with the USAir FOM suggested pre-arrival announcement as outlined above, the first officer stated:

> Folks, from the flight deck, we should be on the ground in 'bout 10 minutes. Uh, sunny skies, little hazy. Temperature, temperature's, ah, 75 degrees. Winds out of the west around 10 miles per hour. Certainly 'ppreciate you choosing USAir for your travel needs this evening. Hope you've enjoyed the flight. Hope you come back and travel with us again. This time we'd like to ask our flight attendants please prepare the cabin for arrival. Ask you to check the security of your seat belts. Thank you.

This pre-arrival announcement contained the FOM suggested elements that were cited above.

From this discussion, ALPA concludes that the flight crew complied with the spirit of the sterile cockpit rule. As the aircraft descended through 10,000, all extraneous conversation terminated. Required checklists were completed. Because the crew was occupied with completing the Preliminary Landing Checklist and because the first officer had to wait for the flight attendant to complete the "Fasten Seat Belt" announcement, the cockpit pre-arrival PA announcement was not made until one minute and fifty seconds after the aircraft descended below 10,000 feet. When it was made, however, it was conducted in accordance with the suggested model contained in the USAir Flight Operations Manual.

Table of Contents

**j. Spatial Disorientation Studies**

This section will show that:

1. A NASA expert in spatial disorientation evaluated the possibility of the crew becoming spatially disoriented.
2. The expert concluded that there was no compelling evidence to conclude that the pilots were disorientated, nor was there any evidence to believe that they applied incorrect control inputs in an attempt to overcome their disorientation, and thereby caused the accident.

Dr. Malcolm Cohen, an expert in human spatial orientation at the NASA-Ames Research Center, was asked to provide an opinion concerning the possibility that disorientation could have played a factor in the pilot's actions during the upset sequence. Dr. Cohen examined relevant information from the investigation. In conjunction with the Human Performance Group, he underwent repeated simulations of the upset sequence on the NASA Vertical Motion Simulator (VMS). The VMS used large physical motions to produce a high fidelity reconstruction of the acceleration forces in the upset sequence. Dr. Cohen experienced the simulations in a variety of formats, including an initial one in which he was exposed to motion cues only with no visual cues. Dr. Cohen's findings were:

> On the basis of my review of the circumstances leading up to the accident, the cockpit data recordings of various flight parameters, the transcript of the pilot's comments preceding the event, and on my participation in the Vertical Motion Simulator reconstruction of the accident at NASA-Ames Research Center on July 11, 1995, I am fairly confident that pilot disorientation was not a major causal factor in the crash.
>
> In my opinion, the accident situation did not provide any obvious evidence of factors that are normally associated with disorientation due to abnormal vestibular stimulation. These factors typically include degraded out-of-the-cockpit vision (e.g., night or instrument flight conditions) that is coupled with changes in linear or angular accelerations, which are either sudden, violent, and supra-threshold, or subtle, gradual, and sub-threshold. It is also possible that, under degraded visual conditions, false or inaccurate instrument reading could lead to disorientation.
>
> In contrast, this accident occurred during clear, daytime, visual flight conditions, where there would be ample opportunity for visual information to override any
>
> vestibularly-induced disorientation. The motion of the aircraft, from the initial encounter with the turbulence to the point where it probably was out of control and no longer recoverable, did not display obvious evidence of the types of acceleration that would be conducive to disorientation. Rather, except for the initial upset

from the turbulence, the motions of the aircraft appeared to have been relatively gradual, supra-threshold, and nearly continuous. Under these circumstances, I believe that the pilots probably would have experienced little difficulty in maintaining an accurate perception of their orientation, even during any brief periods when they may have lost sight of the visual horizon due to the pitch down attitude of the airplane. **In addition, perturbations of the flight path generally appear to have been followed by verbal comments from the pilots, indicating that they were aware of their trajectory, and that they were not able to change it. On balance, there does not appear to be any compelling evidence to conclude that the pilots were disorientated, nor is there any evidence to believe that they applied incorrect control inputs in an attempt to overcome their disorientation, and thereby caused the accident.**

Whether the control inputs were appropriate, or inappropriate, it is most unlikely that they were caused by pilot disorientation. Thus, although I cannot completely exclude the remote possibility, it does not appear at all likely that pilot disorientation due to abnormal vestibule stimulation provided a major contribution to this accident.

Table of Contents

### k. Biomechanics Associated with Attempting to Move Blocked or Jammed Rudder Pedals

This section will show that:

1. In June 1997, Boeing Commercial Airplane Group conducted a ground demonstration to evaluate rudder pedal movement during simulated rudder Power Control Unit (PCU) secondary servo valve slide jams at different positions.
2. The NTSB Human Performance Group Chairman for this accident participated in these tests, and confirmed that the jam caused uncommanded rudder reversals.
3. The Human Performance Group Chairman stated that once a rudder reversal was initiated, stepping of the opposite rudder pedal would not stop the reversal. He used the word "unrelenting" to describe that no matter how hard he pushed on the opposite rudder pedal, the rudder continued to move in the uncommanded direction.
4. A secondary slide jam that occurred during the wake encounter could result in an uncommanded rudder movement to the left.
5. The natural and correct tendency of an experienced pilot who faced a rapid rolling movement (such as that associated with wake turbulence) would be to try to counter the roll with a combination of aileron (through control wheel input) and rudder (through the rudder pedals).
6. As the roll rate began to intensify to the left, the first officer likely applied considerable pressure to the right rudder pedal to counter the roll.

7. From the observations made by the Human Performance Group Chairman concerning uncommanded rudder pedal movement during secondary slide jams, ALPA concludes that the more pressure that the first officer applied right rudder pedal, the more likely it became that the rudder reversal would not clear, resulting in the aircraft continuing to roll rapidly and uncommandedly to the left.

By definition, biomechanics is the study of how parts of the body normally move, and the forces which they can apply. On June 5 and 6, 1997, Boeing Commercial Airplane Group conducted a ground demonstration to evaluate rudder pedal movement during simulated rudder Power Control Unit (PCU) secondary servo valve slide jams at different positions.

This section will discuss the biomechanics associated with applying foot forces to the rudder pedals under those conditions.

Malcolm Brenner, NTSB Human Performance Group Chairman for this accident, participated in the Boeing-conducted tests. According to his June 12, 1997 memo, Dr. Brenner stated that he occupied the right cockpit seat during these tests while wearing his seat belt. He stated that he was required to position his seat in the "full back position for leg room comfort." He noted that he is the same height as was the first officer of USAir 427 (6’3"). According to Dr. Brenner’s memo, "It should be noted that my leg inseam (34) is 2-3 inches shorter than that of the [USAir 427] first officer (36-37)." Prior to beginning the demonstration, Dr. Brenner stated that they sat in a newly manufactured B737 airplane and manipulated the rudder pedals to gain experience with the feel of a normally functioning B737 rudder system. According to Dr. Brenner’s June 12, 1997 memo:

> The first demonstration in the test airplane represented a jam of the secondary slide at about 25 percent off neutral position. I pushed the respective rudder pedals slowly to their full down positions as though I were performing a slow rudder system check. The right pedal seemed easier to push down than the left pedal, although the difference seemed subtle. I then performed about 7 tests in which I inputted a hard left rudder. With one or two exceptions, this input triggered a rudder reversal in the pedals. Immediately after my input, the left rudder pedal began moving outwards until it reached the upper stop. The motion was slightly slower than an input I would expect from a human. The motion was steady and continued without pause no matter how hard I pushed to counter it ("unrelenting" was a description that, at the time, seemed to capture my impression). After the left pedal reached the upper stop, I released my own pressure on the pedal (i.e., "stopped fighting" the motion.) The action of the rudder system ended almost immediately and the rudder pedals returned to the neutral position. On subsequent trials, I "stopped fighting" the rudder motion earlier, before the left pedal had reached the upper stop. Again, the rudder motion stopped almost immediately as soon as I

> stopped applying pressure, no matter where the pedal was located, and the pedals returned to neutral.

Dr. Brenner’s memo continued:

> The third demonstration represented a jam of the secondary slide at about 50% off neutral position. I performed about 9 trials. When I moved the pedals slowly and steadily, I was generally able to move the pedals to their stops without starting a reversal. Sometimes, however, even a slow input initiated a rudder reversal situation (this time with the right pedal moving to the upper stop.) Any abrupt motion on the pedals initiated an immediate rudder reversal situation. The rudder reversal motion was faster than was the case with the jam in a 25% position, perhaps similar to a relaxed or slow input speed by a human operator. Again, it was impossible to stop the motion by physically pushing against the rudder pedal. On several trials, I tried relaxing my input momentarily before the rudder pedal reached the upper stop. I found that the rudder reversal motion continued. This had not been true with the 25% jam, when the relaxation of pressure seemed to automatically stop the reversal motion. This motion was faster, easier to initiate, and more difficult to stop.

To summarize, Dr. Brenner found that when the slide jams were introduced, pressing on the opposite rudder pedal did not resolve the jam. He stated that the movement against his foot pressure was "unrelenting," meaning that no matter how hard he pushed on the pedal, the harder it seemed that the pedal was being forced against his foot. In one case (the 25% off neutral simulated jam), the only way to neutralize the rudder and return it to its normal state of usage was to release all rudder pedal pressure. In another simulated jam (the 50% off neutral jam), Dr. Brenner found that releasing rudder pedal pressure had no effect on stopping the uncommanded rudder movement.

Pilots are trained to "coordinate" inflight turns by combining aileron movement with the appropriate amount of rudder pedal input. While maneuvering an aircraft to the right, for example, a pilot would roll the control wheel until the desired bank angle was reached while simultaneously applying enough right rudder to keep the turn coordinated. Too much rudder results in a "skidding" turn, while too little rudder leads to a "slipping" turn. The act of making coordinating turns is something that is literally taught on the first day of fight training; it is something that every pilot instinctively strives to do on every flight. In smaller aircraft like a Cessna 172 the need for rudder is greater than that of a larger aircraft like a Boeing 737. Like other large transport category aircraft, the B737 uses a yaw damper to operate the rudder while in shallow turns. Pilots adapt to the yaw damper’s actions and learn that pilot input is usually not needed for relatively shallow turns. There are cases however, where experienced pilots routinely revert to rudder usage. A few of those cases are engine failures (where the asymmetric thrust tends to rapidly turn the aircraft), crosswind takeoff and landings, and cases where rapid turns are required or those where the pilot perceives that roll control alone will be insufficient to maneuver the aircraft (as in the case of a wake turbulence encounter).

The correct pilot response for an aircraft encountering wake turbulence with a rolling movement to the left is to stop the roll with a right control wheel movement, along with the simultaneous application of the right rudder pedal. As this relates to the USAir 427 accident, ALPA believes that a secondary valve jam with a primary valve overstroke

occurred during the wake encounter, resulting in an uncommanded rudder movement to the left. As the roll rate began to intensify to the left, the first officer correctly applied right rudder to counter the roll. However, using Dr. Brenner's remarks from above, ALPA concludes that the more pressure that the first officer applied to the right rudder pedal, the more likely it became that the rudder reversal would not clear. The situation was perilous; the more the aircraft turned to the left, the stronger the first officer's tendency to apply increased right rudder pedal pressure; the harder he pushed on the right rudder pedal, the more certain it became that the jam would not clear. Thus the upset sequence became inevitable. **ALPA therefore concludes that following the encounter with wake turbulence, the first officer manipulated the rudder pedals and control wheel properly and in accordance with his prior training. Had the aircraft responded properly at this point, the accident would not have occurred.**

Table of Contents

**l. Analysis of CVR - Speech and Physiological Aspects**

This section will show that:

1. The NTSB Human Performance Group for this accident sought independent experts to assist with analyzing the flightcrew's speech and breathing patterns and muscular exertion.
2. These analyses allowed investigators to evaluate crewmember levels of stress and physical exertion during the upset event.
3. Although evidence suggests that the captain and first officer were surprised by the sudden and unexpected rolling of the aircraft, evidence indicates that the element of surprise immediately invoked an increased level of arousal within the captain which would have aided him with problem solving.
4. The captain's level of stress was at Stage 1 or 2 until the aircraft was clearly unrecoverable, and these Stages are associated with increased performance due to the increased arousal factor.
5. Not until after the point where the aircraft was clearly unrecoverable, did the stress level of both crewmembers increase to Stage 3, the highest level. Considering that death was clearly imminent, this response is understandable and predictable.
6. Evidence suggests that the first officer was attempting to operate the flight controls throughout the upset period, and that the captain did not attempt to take over controls until the aircraft was clearly unrecoverable.

7. Because the captain was not task saturated in attempting to control the aircraft, it likely allowed more of his cognitive resources to be devoted to trying to decipher the emergency situation and invoke a plan for recovery.
8. To better understand the first officer's attempted flight control manipulations ALPA superimposed information from the reports from the experts, the CVR transcripts, the FDR data and data from the Performance Group's Kinematic Study.
9. While listening to the Cockpit Voice Recorder (CVR) the experts noted three grunts or explosive exhalations from the first officer.
10. ALPA cross referenced these exhalations with the kinematic study and found that the first one corresponded with the control wheel being rotated sharply to the right. ALPA concluded that this grunt occurred when the first officer exerted force to override the autopilot "command" mode.
11. The second grunt corresponded to a left rudder deflection that was denoted by the kinematic study. FDR data indicated that at this point the aircraft rolled left at a very high rate.
12. In order to counter this abrupt rolling moment, the first officer's response would have likely been to apply considerable control forces to turn the control wheel to the right and attempt to push the right rudder pedal. The forces exerted on these controls likely resulted in the grunting that was heard on the CVR.
13. The final grunting sound coincides with the kinematic analysis depicting that the control wheel was once again being turned through approximately 35 degrees and then increasing rapidly towards a full right direction. One of the experts compared this grunting to previous grunts by saying that this one was "was louder and more forceful; representative of the use of increased muscular force."
14. It is likely that this grunting "was louder and more forceful representative of the use of increased muscular force" because the first officer was desperately struggling to press the right rudder pedal, attempting unsuccessfully to oppose the uncommanded left rudder movement.

The NTSB Human Performance Group for this accident sought independent experts to assist with analyzing the flightcrew's speech and breathing patterns and muscular exertion. These analyses were performed using the actual Cockpit Voice Recorder (CVR) audio recording from the accident flight. With the concurrence of the Group, two experts were chosen.

Dr. Scott Meyer, Ph.D. performed analysis of the pilots' breathing and muscular exertion. Dr. Meyer is Head of the Aviation and Operational Medicine Department at the U.S. Naval Aerospace Medical Research Laboratory (NAML) in Pensacola, FL. He has conducted aerospace medical research for 14 years at NASA and NAML, and his work has focused on the cardiopulmonary and musculo-skeletal aspect of aviation physiology.

Dr. Alfred Belan, M.D. conducted a speech analysis. In 1987 Dr. Belan joined the Interstate Aviation Commission, the aircraft accident investigation authority of Russia. He previously completed graduate training in medicine and psychology and served as Chief of the Human Factors Laboratory of Aerospace Medicine in Moscow. He has participated in more that 250 accident investigations, specializing in medical and psychological aspects, and especially in the psychological analysis of speech.

Although these experts conducted their analyses independently, their analyses complemented one another. Therefore, in this submission ALPA will discuss them together.

Table of Contents

**m. Speech Analysis Background**

The purpose of the speech analysis was to obtain evidence relevant to the actions and psychological state of the pilots during the final upset sequence. While the NTSB has used speech analysis during the course of investigating only a few transportation accidents, the work has seen extensive use in the Commonwealth of Independent States (CIS), where over 300 aircraft accidents investigations have incorporated it.

The Russian methodology divides speech into four categories: 1) *acoustic measures*, which includes fundamental frequency (a measure of voice pitch), fundamental frequency range (a measure of the variations in the voice pitch, from lowest to highest), amplitude (loudness of voice), and relative energy distributions among formats; 2) *timing measures,* which includes speaking rate, and measures such as relative speaking/silence time and latency to respond; 3) *contour measures,* which relate to the relative shape of the speech energy waveform when plotted over time; and 4) *psycholinguistic measures,* which include phonetic measures such as changes in articulation of works.

Brenner, Meyer and Cash (1996) state that the Russian work classifies stress in three categories, which are listed below. However, it should be noted that while humans have very little or no stress, they are at their "baseline," which is essentially "Stage 0." Although not specifically stated, it is implicit in Dr. Belan's classification.

Stage 1 - a working stress that improves performance, a constructive mobilization of attention and resources in reaction to an unusual event. The speaker is in control of speech, communications are accurate and there are no logical or semantic disturbances evident in speech. The pilot's performance in the cockpit shows no procedural errors. When compared to relaxed (or baseline) levels, Stage 1 is characterized by about a 30 percent increase in fundamental frequency of speech, 10 percent increase in amplitude, and 5-10 percent increase in speaking rate.

Stage 2 - stress is increased, but the pilot can still do the job and make decisions. The pilot does not make gross mistakes. Movements can become sharper but still under control. Speech is still adequate for the situation, but emotional stress is clearly seen. Speech is fast, strained, brief and accented. Occasionally, phrases are not completed, and there is a reduction in nonessential speech. Compared to baseline levels, Stage 2 is characterized by a 50-150 percent increase in fundamental frequency, amplitude increases by 15-20 percent, and speaking rate increases by more than 50 percent. Other signs of stress include an increase in the fundamental frequency range and contour changes. Measures of pulse and respiration show increases.

State 3 - stress is elevated to very high levels which renders the pilot unable to think or act clearly. Incomplete articulation and unvoiced syllables are typical, along with poor word choice and improper grammar. Fundamental frequency increases 100-200 percent over baseline levels, amplitude increases 30-50 percent and speech rate can oscillate largely, including increases of 50-200 percent.

Table of Contents

**n. Breathing Patterns and Muscular Exertion Background**

Dr. Meyer based his expert observations of the pilots' breathing and muscular exertion on the circumstances leading up to the accident, the transcript of the pilots' comments preceding the crash, a video tape reconstruction of the accident, and the digital audio recordings from the CVR. In his report to Dr. Malcolm Brenner, Chairman of the NTSB's Human Performance Group for this accident, dated March 29, 1996, Dr. Meyer explained:

> ...The mechanics of breathing, or ventilation, are usually regulated by neural and hormonal factors for the purposes of oxygen and carbon dioxide exchange, the control of blood acidity, and oral communication. In normal, healthy individuals at rest, inhalation is an active muscular movement while exhalation is a passive response. The rapidity and depth of breathing affect the amount of oxygen and carbon dioxide exchanged between atmosphere and the body...

Table of Contents

**o. Crew Psychological Stress During the Upset Event**

According to Dr. Meyer's report:

> The sounds of breathing (through the mouth) of the Pilot-in-Command (PIC) are audible periodically throughout the tape. At several points during the first twenty-seven minutes of the tape, the breathing rate of the PIC was measured at thirty breaths per minute. The depth of breathing appeared to be normal at those times... After the onset of the emergency period, the rate of breathing increased and, at one point, was close to sixty breaths per minute. However, the depth of each breath did not seem to increase noticeably. There was an initial, large exhalation with the utterance "jheez" in response to the emergency sequence. That was followed shortly by a deep, rapid inhalation before "whoa" was heard from the PIC, almost as if he was startled by the sudden departure of the aircraft. The breathing responses of the PIC after the onset of the emergency appear to have been a sympathetic nervous system response that included increased heart rate, breathing rate, body temperature, and blood pressure commonly observed in emergency

> situations. During the emergency period, his breathing was not strained or impaired by the occurrence of the events.

Stated Dr. Belan:

> The captain demonstrated the distinct and recognizable symptoms of sudden surprise (psychological orientation reaction of the "what is that ?!" type) beginning at the time 1902:57.5. This response was expressed by the words "sheeez" and "whoa." There was an explosive exhaling during "sheeez" and an inhaling/exhaling quickly one time before the word "whoa," showing disruptions of breathing consistent with sudden surprise. While they might occur in response to visual or auditory events, these physiological reactions are characteristic of a human response to sudden motion or to a physical disturbance, for example, as results from a mechanical effect during variable vibrations of the airplane.
>
> Beginning at that time, the captain's psychological stress continually increased. The symptoms of that stress response are:
>
> - increased amplitude and fundamental frequency of speech
> - increased frequency of breathing
> - psycho linguistic criteria, such as the reduction of the information contained in a speech statement
>
> The audible breathing noises from 1902:58-1903:15.0 indicate that the captain experienced frequent breathing (more that 40 cycles per minute), the beginning of hyperventilation...

Dr. Belan also stated:

> At the beginning of the accident sequence (1902:57.6), the first officer also expressed sudden surprise. He stated "zuh" while the captain said "sheeez." The word "zuh" has no meaning, increasing the likelihood that it was an involuntary exclamation due to surprise rather than an intended statement

ALPA notes that both experts independently state that the captain and first office were surprised at the onset of the event. This is an understandable response. To this point the flight had been quite smooth and routine, and this sudden rolling movement would have been unexpected, thus creating an element of surprise.

ALPA was interested to learn whether this element of surprise may have caused the crew to panic and misapply the flight controls, which may have led to departure from controlled flight. To assist with this determination, we analyzed the captain's speech patterns using Dr. Belan's classification of levels of stress. A similar analysis of the F/O's speech was not possible due to his lack of spoken words during the upset event.

To determine the captain's baseline (or "Stage 0," as explained above) fundamental frequency, we looked at the fundamental frequency values of the 18 transmissions to ATC where the captain used the phrase "USAir four twenty seven" prior to the upset period. These phrases were selected because the aircraft call sign was used in each transmission, and therefore should have allowed some consistency in the averaging of these values. The values ranged from a low of 130 Hz to a high of 169 Hz, with an average of 149 Hz. This average figure represents the captain's baseline fundamental frequency value. It can be used to compare fundamental frequencies of other phrases made by the captain when trying to determine his increased level of stress.

At 1902:57.5, the onset of the upset event, the captain's remark of "sheez" had a fundamental frequency of 210 Hz. This value is 41 percent higher than his baseline fundamental frequency value. According to Dr. Belan's classification scheme, this percentage increase indicates that the captain was at the high end of Stage 1 level of stress. ALPA's analysis is consistent with Dr. Belan's analysis, which indicates that the captain's stress level did not elevate to Stage 2 until 1903:10.6, when the captain remarked "oh god." Dr. Belan further stated, "However, during this time period, the captain still had adequate responses. He recognized the air traffic call to 'USAir' and tried to respond (1903:15.0). However, his answer was incomplete and it is obvious that the situation was unclear for him."

Noted Dr. Belan:

> Psychological stress, at low levels, can improve a person's performance by providing a constructive mobilization of attention and resources (first stage). As the person's stress increases, the performance often displays hasty or premature actions. However, they can still accomplish their task (second stage). It is only at the highest levels of stress (third stage, or "panic") that the person cannot think or perform clearly.

Dr. Belan states that once the captain entered Stage 2 at 1903:10.6 he remained at that level until 1903:18.1. At this point, the aircraft was unrecoverable, and according to Dr. Belan, "...the captain entered into the highest (third) stage of emotional stress. He could not act and react in accordance to the situation. This state is confirmed by the highest intensity and fundamental frequency of his speech, his issuing a command that was inadequate to the situation ('pull') and finally, screaming."

From this analysis, ALPA concludes that the captain's stress level appropriately increased at initiation of the upset event, and remained at an increased level until the aircraft was clearly unrecoverable. This increased level of stress from baseline (Stage 0) to Stage 1 lasted 13.1 seconds. Dr. Belan states that during Stage 1 a person's performance is typically improved due to increased arousal and "constructive mobilization of attention and resources" to the task or problem at hand. By the time the captain had increased to Stage 2 (1903:10.6), the aircraft was already in at least a 30 degree nose down attitude, with approximately 85 degrees of left roll. It should be noted, however, that even at Stage 2, by definition, a person is capable of clear decision making and avoiding gross mistakes.

We conclude that the captain was likely surprised by the sudden and unexpected rolling event. However, the effect of this surprise acted to quickly arouse the captain into a state of heightened awareness and to employ to this hypervigilance to try to assess a situation for which there was no logical explanation.

Table of Contents

**p. Crew Physical Activity During the Upset Event**

ALPA was very interested to understand the actions of the crewmembers during the upset event. Of particular interest were questions concerning which crewmember was operating the controls during the attempted recovery and how that pilot attempted to manipulate those controls. Dr. Meyer stated:

> Similar to the PIC, the F/O did not appear to be straining during any of the routine portion of the tape. Unlike the PIC, there were fewer words spoken during the first part of the emergency period. The two grunting sounds of the F/O heard after the onset of the emergency are indicative of muscular exertion or physical straining. It is impossible from the grunting sounds alone to determine the muscles involved in the exertion...
>
> There were no indications from the normal communications throughout the tape that either crew member was physically incapacitated or hampered in the performance of their duties by a lingering injury. Both the breathing and physical responses of the PIC and F/O appear to be within normal limitations given the events of the emergency and not contributing factors to this accident.

According to Dr. Belan:

> ... The [captain’s] breathing was rapid and shallow. There were no indications, such as forced inhalations, that the captain experienced high physical loads during this time period.
>
> A person making a great physical effort develops a musculo-skeletal "fixation" (of the chest), which leads to deterioration of the normal expansion and ventilation of the lungs (inhaling and exhaling). These changes are manifested during speech. Sounds such as grunting and strain appear in speech as the person tries to minimize the outflow of air. Inhaling and exhaling become forced and rapid. None of these effects appear in the captain’s speech

> during this period. Based on all the above evidence, it could be concluded that the captain did not apply high physical loads to the controls. His actions were limited to the commands and attempt to evaluate the situation. The statements were brief and had low informational content or saturation. This is shown in the ambiguous expression "hang on" and the stereotype expression "oh god." All these speech indications, along with the increased amplitude and fundamental frequency, are signs of psychological stress. The sense of his statement "hang on" indicates that the captain was trying to understand the situation. The statement "what the hell is this" confirms that he was unable to understand it.
>
> ...At 1903:18.1, the captain most likely started to participate in the control of the airplane. This was shown by his command "pull...pull...(pull)" which, most likely, would be performed by himself as well as by the first officer. There was evidence of short, forced inhalations after each command that are characteristic of high physical loads (such as those produced by pulling the yoke against the stops)...However, this conclusion is not definite since strong mechanical motions of the airplane, related to attitude or g-forces, might also produce this type of breathing disturbance.

Dr. Meyer commented:

> The muscles of the arms, shoulders, back, chest, abdomen, and legs have been connected with routine movements of the aircraft controls. However, the physical act of manipulating the control surfaces of modern aircraft under normal conditions does not usually require excessive muscular force... Nevertheless, during emergency situations, increased muscular force may be needed to manipulate the controls of an aircraft. Generally, during increased muscular exertion, it is common for the individual performing the movement to apply a considerable exhalatory force against a closed or partially closed glottis in the throat. When the breath is finally exhaled, it is forceful and quick and usually accompanied by a grunting sound. The forceful movements of weight lifting and other short duration, high intensity physical activities are routinely accompanied by grunting. When the arms are used for pushing, pulling, or turning a wheel in an upright sitting position, the mechanics of the movements require the body to be stabilized to exert maximal force. This is usually accomplished by securing the torso to a chair or bench and bracing the body with the legs. Likewise, when legs are employed to exert a pushing movement, the upper body is usually braced. When these movements are made suddenly in reaction to an unexpected event, the body's mechanical reaction is usually reflexive.

> It is difficult to determine with certainly from the tape whether the PIC used increased muscular force on the controls during the emergency period. There was no audible grunting or straining indicative of muscular exertion heard. There was no audible grunting or straining indicative of muscular exertion heard. There was no indication of muscular strain during any of the verbal communications from the PIC heard on the tape. His initial comments were calm and controlled. His nonverbal breathing was unobstructed. That is not to say that the PIC was not on the controls, but only that he did not appear to be exerting increased muscular force during that time...

Concerning the first officer's actions, Dr. Meyer stated the following:

> The breathing of the first officer (F/O) was inaudible throughout the routine portion of the tape. The emergency period starts with the F/O having just remarked that he had located the aircraft traffic. Immediately following his statement and coincidental with the initial unusual movement of the aircraft was the remark "Zuh." This appeared to be an attempt to continue speaking that was abruptly halted with the abnormal departure (pitch, roll, or yaw) of the aircraft. He may have been responding to the situation by seizing the controls to correct the movement and reflexively stopped speaking to concentrate on his duties. After the onset of the emergency, two rapid grunting exhalations were heard. The first grunting sound was soft and indicated some submaximal muscular exertion. The second grunting sound was louder and more forceful representative of the use of increased, but probably submaximal, muscular force. The grunts suggest that the F/O was straining possibly in an attempt to manipulate the controls of the aircraft to override the autopilot. Following the second sound, no further grunting was apparent, but deep, rapid breathing was audible from the F/O. Again, these breathing sounds would not be out of the ordinary in the given situation. It is apparent that he was at the controls and focused on correcting the situation...

According to Dr. Belan:

> The first officer, from the moment 1902:59.5 most likely was actively involved in the control of the airplane. Beginning at this time, and continuing for several seconds, speech disruptions could be observed that included grunting and forced exhalations (1902:59.5; 1903:01.1; and 1903:02.0)...These are signs of high physical loads.

> Normal use of the cockpit controls should not produce the types of sounds shown in this period. These sounds indicate that the first officer was struggling unusually hard, (e.g. pushing a control against its stops or experiencing an unusual resistance in the use of a control.) The breathing information, by itself, does not permit a conclusion as to what type of physical motion was applied by the first officer, such as whether by the upper or lower body. Both would produce the same type of sounds.

Dr. Belan concluded from his analysis, "From the beginning of the accident sequence until the time 1903:17.4 the captain did not apply high physical loads to the controls and, most likely did not participate in the control. The first officer applied physical loads and controlled the airplane."

From information presented above, ALPA concludes the first officer had his hands and feet on the respective controls during the upset period and was attempting to manipulate them, and the captain did not attempt to take over controls until the aircraft was clearly unrecoverable. We agree with Dr. Belan's statement that at that point where the aircraft was in an unrecoverable attitude and bank, it is likely that the captain attempted to pull on the control wheel. We conclude that because the captain was not task saturated with attempting to fly the aircraft during the early upset period, this likely allowed him to have more cognitive resources devoted to trying to decipher the emergency situation and invoke a plan for recovery.

Table of Contents

**q. In-depth Examination of Attempted Flight Control Manipulations**

Having established that the first officer was the crewmember operating the controls during the upset, we focused our attention on understanding precisely how he attempted to manipulate the controls. To facilitate this understanding, ALPA superimposed information from Dr. Belan's and Dr. Meyer's reports, the CVR transcripts, FDR data and data from the Performance Group's Kinematic Study.

Dr. Belan referred to the first officer's "grunting and forced exhalations" at CVR time 1902:59.5; 1903:01.1; and 1903:02.0. He stated that "these are signs of high physical loads." He further stated, "These sounds indicate that the first officer was struggling unusually hard, (e.g. pushing a control against its stops or experiencing an unusual resistance in the use of a control.)" Dr. Meyer referred to "two rapid grunting exhalations" that were heard from the first officer. Stated Dr. Meyer, "The first grunting sound was soft and indicated some submaximal muscular exertion. The second grunting sound was louder and more forceful representative of the use of increased muscular force. The grunts suggest that the F/O was straining possibly in an attempt to manipulate the controls of the aircraft to override the autopilot."

As the aircraft rolled to the left the first officer likely tried to turn the control wheel to the right to "help" the autopilot correct for the left bank. As he did this he would have exceeded the force value necessary to enter Control Wheel Steering (CWS). (When the autopilot is used on the 737-300, the "command" mode of the autopilot is the mode normally selected for climb, cruise, descent and approach.) Control wheel steering (CWS) can be overridden when approximately **18** pounds of force are applied to the control wheel, and at approximately 25 degrees of control wheel deflection. Once this detent is overridden, the autopilot remains engaged, but is now in the Control Wheel Steering (CWS) mode.

ALPA correlated the first officer’s grunting at 1902:59.5 CVR time (which equates to approximately 136.55 FDR time), with that of his overriding the command detent. This is consistent with Dr. Meyers’s earlier comments that stated, "[T]he physical act of manipulating the control surfaces of modern aircraft under normal conditions does not usually require excessive muscular force... Nevertheless, during emergency situations, increased muscular force may be needed to manipulate the controls of an aircraft. Generally, during increased muscular exertion, it is common for the individual performing the movement to apply a considerable exhalatory force against a closed or partially closed glottis in the throat, when the breath is finally exhaled, it is forceful and quick and usually accompanied by a grunting sound."

The kinematic analysis corroborates that the first grunting sound coincided with the autopilot detent being overridden. Between FDR time 135.5 and 136.0 the kinematic study indicates that the control wheel position went from approximately 35 degrees (CWS) to full control wheel travel. This was a very rapid rate of control wheel movement - roughly 50 degrees in a half of a second. Dr. Meyer’s remarks corroborate these findings, "The first grunting sound was soft and indicated some submaximal muscular exertion... The grunts suggest that the F/O was straining possibly in an attempt to manipulate the controls of the aircraft to override the autopilot."

The next grunting sound referenced by Dr. Belan occurred at 1903:01.1 (approximately FDR time 137.0). This coincides with the kinematic analysis which shows that between 136.5 and 136.87 the rudder swung abruptly from the neutral position to a left deflection. ALPA believes that this was the beginning of the rudder’s uncommanded movement. This rudder input resulted in the aircraft rolling at a very high rate. In order to counter this abrupt rolling moment, the first officer’s response would have likely been to apply considerable control forces to turn the control wheel to the right and attempt to push the right rudder pedal. The forces exerted on these controls likely resulted in the grunting that was heard on the CVR at 1903:01.1 (FDR time 137.0).

The final grunting sound that was referred to by Dr. Belan was at 1903:02.0 (approximately FDR time 138.1). This coincides with the kinematic analysis depicting that the control wheel was once again being turned through approximately 35 degrees to full control wheel travel within approximately a 0.65 second interval. When comparing this grunting sound to the first grunting sound, Dr. Meyer stated that is "was louder and more forceful representative of the use of increased muscular force".

ALPA concludes that it is logical to assume that the first officer’s grunting would have denoted "increased muscular force". The kinematic analysis indicates that the rudder deflection was increasing rapidly towards full left. It is highly likely that the first officer would have attempted to depress the right rudder pedal in an effort to stop the turning moment that resulted from the uncommanded rudder movement. However, as discussed by Dr. Brenner in the previous section, in a rudder reversal situation, pushing on the opposite rudder has absolutely no effect on clearing the jam, and in fact, may only aggravate the situation. It is therefore quite likely that the grunting noted by Dr. Belan and Dr. Meyer at 1903:02.0 "was louder and more forceful representative of the use of increased muscular force" because the first officer was desperately struggling to press the right rudder pedal, attempting unsuccessfully to oppose the uncommanded left rudder movement.

Table of Contents

**r. Pilot Responses To Uncommanded Upsets**

*This section will show that:*

1. *The NTSB's Human Performance Group for this accident turned to the NASA Aviation Safety Reporting System (ASRS) to learn more about how pilots have reacted to uncommanded upsets.*
2. *ASRS conducted a special "structured callback" to assist with this understanding.*
3. *Altogether, information from 589 turbojet loss of control events was analyzed.*
4. *In many cases reporters acknowledged that the events startled them, and many perceived that the events were quite severe.*
5. *Although the events may have startled the pilots, and although they may have been severe events, in no case did the aircraft crash. In every case, regardless of how much the event surprised them, and regardless of how severe they perceived the event, crews were able to recover the aircraft and safely land it.*

The NTSB's Human Performance Group for this accident sought to learn more about pilot responses during unexpected rolling moments, such as that encountered by the crew of USAir 427. To facilitate this understanding, the NTSB sought the assistance of NASA's Aviation Safety Reporting System (ASRS). Established in 1976, ASRS is a confidential incident reporting system where those involved in aviation can report potential safety problems. To date the system has received approximately 350,000 reports, and about 75 to 80 percent of these reports are submitted by air carrier pilots.

At the request of the NTSB, in the summer and early fall of 1995, ASRS conducted a "structured callback" of 33 incidents involving multi-engine turbojet uncommanded flight control movements. As ASRS incident reports were submitted to ASRS by pilots, each report was screened to see if it met the scope of this study. For those cases that met the scope, a detailed follow-up telephone call, or "callback" was conducted between ASRS investigators and the pilots submitting the reports. Callbacks involve the investigators asking a set of pre-established questions. All 33 cases examined involved air carrier pilots, and involved reports that were submitted to ASRS between May 1, 1995 and October 31, 1995.

The ASRS study, "ASRS Multi-Engine Turbojet Uncommanded Upsets Structured Callback Summary," dated November 8, 1995 contained several findings. Apart from the results of the structured callbacks themselves, the report contained statistics concerning the overall ASRS database as they relate to the subject. Overall, looking at data submitted to ASRS between January 1987 and May 1995, the ASRS database contains 556 incident reports involving multi-engine turbojet loss of control incidents." In 297 of these incidents, ASRS analysts identified factors that contributed to the loss of control. Aircraft wake turbulence was cited in 96 reports, severe weather turbulence in 46, aircraft icing in 38, autopilot in 29, flaps in 24, windshear in 21, rudder in 18, aileron in 8, yaw damper in 5, and microburst in 4 reports. One incident could contain more than one of the above factors.

ALPA obtained a number of ASRS reports that involved upsets and conducted their own analysis. Several involved encounters with wake turbulence. In some of reports, pilots remarked in their ASRS report submissions that they were surprised by the upset. Some descriptors of the wake turbulence were "violent," "sudden," "severe." In one case, a B737 pilot unexpectedly encountered wake turbulence and rapidly rolled 18 degrees was reported to be "visibly shaken." Another pilot stated that wake turbulence "surprised me...Had I been distracted by looking at a chart or checking engine instruments...I could have very easily ended up on my back.

In the ASRS structured callback, pilots were asked to rate the severity of the upset event on a scale of 1-5, with 1 being "minor" and 5 being "severe." In 13 of the 33 reports (33 percent), pilots rated the upset as being either a 4 or 5.

To summarize, between January 1987 and May 1995, ASRS received 556 incidents referencing multi-engine turbojet loss of control incidents. The structured callback carefully evaluated another 33 cases, for a total of 589 such incidents in the ASRS database. In many cases reporters acknowledged that the events startled them, and many perceived that the events were quite severe.

In early 1994 the NTSB completed a Special Investigation Report entitled *Safety Issues Related to Wake Vortex Encounters During Visual Approach to Landing.* In this report the Safety Board refers to an MD88 that encountered wake turbulence at approximately 110' AGL during approach at Orlando, Florida. According to the NTSB's report, "The crew of the MD88 reported that the airplane suddenly rolled right about 15 degrees, and the pilot rapidly deflected both the wheel and rudder pedal to correct the uncommanded roll... The crew regained control and the approach was continued to an uneventful landing." In another case the Safety Board discussed a B737 wake turbulence encounter at Denver's Stapleton International Airport. Stated the Safety Board, "The flightcrew reported that about 1000 feet AGL, the airplane rolled left violently with no yaw, the pitch decreased 5 degrees, and the airplane lost 200 feet altitude. To correct the uncommanded roll, the pilot rapidly deflected the wheel and rudder about 60 degrees and 7 degrees, respectively, according to the DFDR. A go-around was initiated, and the airplane landed without further incident." ALPA feels that there is a very important point here: **in not one of these cases did the aircraft crash.** In each any every case, regardless of how much the event surprised them, and regardless of how severe they perceived the event, crews were able to recover the aircraft and safely land it.

Table of Contents

**s. Unintended Acceleration**

This section will show that:

1. Unintended acceleration has no relevance in explaining this accident scenario

During the course of the NTSB's investigation of this accident, the Human Performance Group was made aware of a situation known as unintended acceleration (UA) by Boeing, which occurs when the driver of an automobile accidentally depresses the accelerator instead of the brake pedal. Boeing suggested that the literature concerning UA could partly explain how a crew could unknowingly depress a rudder pedal, which would lead to an accident scenario, such as that of the USAir 427 accident. ALPA conducted a literature review of UA and concluded that this material had no applicability to this investigation. The discussion below summarized these findings.

According to Boeing, UA is the act of an having an automobile accelerate unexpectedly at the "beginning of the driving cycle." In other words, it occurs when a driver first gets into an automobile, starts the engine, and then places the car into Drive or Reverse. According to the literature, this is attributed to the driver placing his or her foot on the gas pedal instead of the brake before shifting into gear. It should be noted that the definition of UA <u>does not</u> involve cases where drivers are operating a vehicle that is moving at higher speeds (such as driving a car down a road or highway), but instead only involves unintended acceleration that occurs when the car was first started.

The literature suggests that there are a number of reasons why UA could be problematic to drivers who are just getting situated in a car "at the start of a driving cycle." Schmidt (1989) refers to research by Perel (*Vehicle familiarity and safety*, 1983) where "at least some of this problem is unfamiliarity with the foot controls." Schmidt mentioned that many of these accidents involved people attempting to drive borrowed or rented vehicles, those with newly-obtained vehicles, and "occasional users such as parking lot attendants or rental car patrons who are relatively unfamiliar with the controls in a particular vehicle." Schmidt concluded that "there is strong evidence that drivers new to vehicles tend to have more unintended accelerations episodes." ALPA notes that the flight crew of USAir 427 had literally thousands of flight hours in this exact type of aircraft, and that unfamiliarity was not a factor. Further, the crew had been seated in the accident aircraft for several hours that day, including at least the final 30 minutes of flight.

Reinhart (1994) states that "pedal misapplications are more likely to occur when the driver attempts to make the first brake application after entering the car..." Schmidt referred to this as an "aiming accuracy" problem, and explained that this is due, in part, to the close distance between the gas and brake pedals. He states that once the driving cycle has began, the likelihood of such error "would be considerably smaller" (Schmidt, p. 352) because the foot is positioned closely to the appropriate pedals. From an aviation perspective, ALPA notes that for a pilot seated in a 737 cockpit, positioning a foot on the incorrect rudder pedal is almost physically impossible due to a structural divider between the two pedals. This applies to cases where the pilot's foot was placed directly on the rudder pedal, as well as to cases where the foot was placed directly behind the rudder pedals.

Schmidt also refers to several laboratory simulations of driver behavior to document the frequency of foot placement errors. One study, in particular, was research by Rogers and

Wierwille (*An investigation into the occurrence of accelerator and brake pedal actuation errors during simulated driving*, 1988). Schmidt summarizes that laboratory simulation by saying, "Pressing the accelerator instead of the brake was relatively rare, occurring in only two instances in the entire experiment. When this error was made, the driver always corrected it immediately..." Reinhart and Schmidt both state that a disproportionate number of UA accidents involve elderly drivers. According to Schmidt, "The accidents occur much more frequently as the driver age increases: there is a 100% - 600% over involvement of drivers older than 60 years..." ALPA notes that the captain of USAir 427 was 45 and the First Officer was 38 years old.

Schmidt further describes other attributes of people involved with UA errors: "There are also slight tendencies for these accidents to occur more frequently among women than among men, and among people shorter than average. The pilots of USAir 427 were men. The captain was 5’11" tall and the first officer was 6’3" tall.

Based on the above information ALPA feels that unintended acceleration has no relevancy in explaining this accident scenario. In retrospect, this information was obtained and evaluated but clearly was not applicable.

Table of Contents

**t. Rudder Pedal Damage**

This section will show that:

1. Two medical experts formed differing opinions concerning interpretation of rudder pedal damage.
2. Due to this conflicting interpretation, information concerning rudder pedal damage is inconclusive and therefore should be disregarded.

According to the NTSB Metallurgist’s Factual Report dated December 27, 1994, damage to the rudder pedal structures, as observed in the wreckage, included a shearing of the shafts for the left rudder pedals used by both pilots. There was no such shearing for the right pedals. In attempting to learn more about the potential implications of these fractures, the NTSB’s Human Performance Group consulted with the Armed Forces Institute of Pathology (AFIP). In a January 22, 1996 letter, David Hause, MD stated:

> Pursuant to our discussions, below is my elaboration of the opinions I offered to the Human Performance Group concerning considerations of possible control inputs by the crew of USAir Flight 427.
>
> With the information from the metallurgical analysis that both the pilot’s and co-pilot’s left rudder pedals were fractured in a similar pattern, I infer the possibility that both flight officers were symmetrically applying pressure to their respective left rudder pedals at the time of ground impact. The metal fractures implies

> such a strong pressure that I find that the most likely body position to do this would be with the majority of the body weight concentrated on the left foot, (e.g. with the left knee locked). This sort of positioning sometimes produced characteristic "control injuries" (which would probably be mid-foot fractures, telescoping/ collapsing fractures of leg bones, and/or hip fractures). Unfortunately, in this case, the extent of body disruptions from the crash, the quantities of remains, did not yield these body parts of the flight crew for examination. This makes this scenario a "possible explanation" rather than an opinion with quantifiable probability.

It must be noted that there was significant disagreement within the Human Performance Group concerning this letter. Notably, Dr. Hause, a forensic pathologist, has formed this opinion not on the basis of an examination of the forensic evidence, but rather on the basis of the NTSB's metallurgical examination. Dr. Hause admits that he examined no body parts before forming his conclusion.

Dr. Chuck DeJohn, a medical doctor with a masters degree in aeronautical engineering and a member of the NTSB's Human Performance Group serving as representative of FAA's Civil Aeromedical Institute (CAMI), wrote to object to Dr. Hause's conclusion. According to Dr. DeJohn's November 15, 1996 letter,

> ... Although LTC Hause states in his last sentence that the scenario he described is only a possible explanation due to the extent of disruptions of the remains, the major portion of his letter is devoted to describing a situation that cannot be supported by the investigation.
>
> ... I have been concerned that his letter could be misinterpreted and that the wrong conclusions could be drawn by the press and the public. I believe that it is possible to read his letter and come to the conclusion that the scenario LTC Hause described in the first part of his letter is in fact what actually occurred, when in reality there is inconclusive forensic evidence to support this.

In this case, ALPA notes that two medical experts had totally opposing views. We feel that the information gleaned from Dr. Hause's letter, in view of his lack of qualification in metallurgy, is inconclusive, and therefore should be disregarded by the investigation. It also should be noted that a secondary valve jam would produce a full left pedal deflection with some external force applied. It could not be determined from a metallurgical standpoint whether the applied force was mechanical or due to pilot input.

Table of Contents

**u. Seat Track Damage**

This section will show that:

1. Information concerning seat position could not be determined from seat track damage.
2. The lack of seat track damage has no relevancy to this investigation, because due to the first officer's height, he would have had full and unobstructed use of all flight controls, regardless of seat position.

The Human Performance Group Chairman's Factual Report, Second Addendum dated October 5, 1995 stated: "Identifiable sections of the seat tracks for both the captain and first officer were obtained from the wreckage and were examined by the Structures Group. No determination could be made of the actual seat position for either pilot."

ALPA agrees that no conclusions can be drawn from the seat track information. However, we note the independent observations of Dr. Malcolm Brenner, Chairman of the NTSB's Human Performance Group. Dr. Brenner told the Human Performance Group that he is 6'3" tall, the same height as was the first officer from the accident flight. Dr. Brenner stated that following the accident, he sat in the right seat of a Boeing 737-300 and adjusted the seat and rudder pedals through various extreme positions. He noted that regardless of seat position, he still had full use of all controls, including the rudder pedals. From this verbal report of Dr. Brenner's, we conclude that although we may never know the seat position of either pilot, this information is probably not relevant because regardless of seat position, the first officer would have had full use of all flight controls.

---

Table of Contents

## VI. Conclusions

The investigation into the cause of this accident focused in three primary areas:

- Aircraft Performance,
- Flight Crew Human Factors,
- B737 Rudder Control System.

Based on evidence collected during the course of this investigation ALPA concludes that the accident was the result of a PCU secondary valve jam resulting in primary valve overtravel which caused unwanted full airplane nose left rudder movement. The flight crew was unable to counter this full left rudder due to insufficient lateral control authority available to balance the roll due to sideslip caused by full left rudder.

Aircraft performance analysis revealed that the maneuver of USAir 427 is consistent with full nose left rudder travel. As for the cause of the rudder travel, the Human Factors analysis was unable to identify a possible reason the flight crew would command full left rudder. There was no evidence of any event or abnormality that would have adversely affected the airmanship abilities of either pilot. Further, the initial portion of the upset was found to not be disorienting. The flightcrew of USAir 427 properly and professionally performed their duties before and during the upset period. There is no evidence to support the hypothesis that the flightcrew mishandled the flight controls following the upset event, or that this control mishandling led to the accident.

As for the B737 rudder control system however, during the course of this investigation a number of failure modes have been identified which could result in an uncommanded full rudder input. It was also discovered that at least one failure mode, secondary valve jam resulting in primary valve overtravel, would not leave witness marks. In addition, this failure mode resulted in rudder movement that matched the rudder time history, in both magnitude and input rate, determined from the aircraft performance study necessary to match the maneuver.

**B737 Flight Control System**

- Tests have shown that a jammed PCU secondary valve may not leave detectable witness marks.
- A B737 flightcrew has no way to detect a jammed secondary valve.
- When the secondary valve jams, the primary valve may not perform its designed function of providing redundancy.
- Failure of the primary valve to perform its designed function can result in the main rudder power control reversing rudder direction from the pilot’s command without warning.
- The industry and the flightcrew of USAir 427 were unaware of the potential for the main rudder power control unit to lose redundancy with a jammed secondary valve.
- The industry and the flightcrew of USAir 427 were unaware of the potential for rudder reversal.
- The industry and the flightcrew of USAir 427 were unaware of the lack of sufficient lateral control on B737 aircraft to counter a fully deflected rudder.
- A redesign of the main rudder power control unit is needed to prevent loss of redundancy.
- The industry and the flightcrew of USAir 427 were not aware of all possible failures of the main rudder power control unit.
- The FAA’s certification of the Boeing 737 did not adequately evaluate the rudder control system.
- The FAA did not require retesting of the Boeing 737 rudder system during certification of later B737 derivative models.
- The B737 main rudder power control unit does not meet current FAA standards with regard to FAR 25.671.
- The FAA was aware of main rudder PCU problems.

- The FAA policy of allowing a principle maintenance inspector to solely supervise a repair station repairing B737 main rudder power control units is inadequate.
- USAir 427 flight profile is consistent with a rudder reversal due to secondary valve jam and primary valve failure and mis-positioning of the primary valve.
- Eastwinds 517 flight profile is similar that of USAir 427 except for the airspeed at the time of the reversal, which allowed Eastwinds 517 to recover due to being above the crossover speed.

**<u>Aircraft Performance</u>**

- The flight profile of USAir 427 is consistent with a hardover rudder.

**<u>Lateral vs. Directional Control</u>**

- The B737 has limited lateral control authority which, at certain airspeeds and aircraft configurations, is unable to counter the roll due to sideslip caused by a full rudder hardover.
- In the case of USAir 427, the lateral control authority available was not sufficient to maintain a wings level attitude once the flight experienced the full rudder hardover.
- The industry and the flightcrew of USAir 427 were unaware of the crossover speed being so near Boeing's recommended minimum maneuvering speed.
- An increase of 10 knots in minimum speed will increase controllability during flight with a hardover rudder at flap settings of "1" through "10".

**<u>Human Performance</u>**

Flightcrew General: Health and Background

- The crew members of this flight were healthy, both physically and mentally, and were fit for flight.
- No evidence exists of any active or pre-existing medical conditions that would have affected the performance of the flightcrew.

Crew Communications - Intra-cockpit

- The type and quality of intra-cockpit communications are predictors of crew performance.
- The crew of this flight communicated amongst themselves in a manner that is consistent with a high degree of professionalism and good crew coordination.

Crew Communications - ATC

- The captain of USAir 427 acknowledged each ATC radio transmission in accordance with accepted practices.
- 100 percent of the captain's clearance or frequency change readbacks contained both the full clearance readback and the complete aircraft call sign, compared to a recent FAA

study that found that only 37 percent of pilot readbacks contain both the clearance readback and complete aircraft call sign.
- The captain’s careful attention to ATC communications indicates that he was attentive during flight and suggests that his professionalism towards ATC communications was likely a reflection of his professional approach to flying.

Crew Interactions

- CRM allows crews to operate more effectively and better cope with non-routine situations.
- USAir’s CRM program was well developed and CRM principals are constantly reinforced during training with USAir flightcrews, including the accident crew.
- Evidence gathered by a number of NTSB investigative groups indicates that the crew of USAir 427 performed in a manner that is consistent with good CRM during prior trips, as well as during the accident flight.
- The crew’s use CRM practices helped foster a healthy crew concept, and this positive crew interaction well prepared them to deal with the emergency had it been a recoverable situation.

Spatial Disorientation Studies

- A NASA expert in spatial disorientation evaluated the possibility of flight crew disorientation and concluded that there was no compelling evidence that the pilots were disorientated, nor was there any evidence to believe that they applied incorrect control inputs in an attempt to overcome their disorientation, and thereby caused the accident.

Biomechanics Associated with Attempting to Move Blocked or Jammed Rudder Pedals

- In June 1997, Boeing Commercial Airplane Group conducted a ground demonstration to evaluate rudder pedal movement during simulated rudder Power Control Unit (PCU) secondary servo valve slide jams at different positions.
- The NTSB Human Performance Group Chairman for this accident participated in these tests, and confirmed that the jam caused uncommanded rudder reversals.
- The Human Performance Group Chairman stated that once a rudder reversal was initiated, stepping on the opposite rudder pedal would not stop the reversal; he, used the word "unrelenting" to describe that no matter how hard he pushed on the opposite rudder pedal, the rudder continued to move in the uncommanded direction.
- A secondary slide jam that occurred during the wake encounter could result in an uncommanded rudder movement to the left.
- The natural and correct tendency of an experienced pilot who faced a rapid rolling movement (such as that associated with wake turbulence) would be to try to counter the roll with a combination of aileron and rudder.
- As the roll rate began to intensify to the left, the first officer likely applied considerable pressure to the right rudder pedal to counter the roll.
- However, from the observations made by the Human Performance Group Chairman concerning uncommanded rudder pedal movement during secondary slide jams, ALPA

concludes that the more pressure that the first officer applied right rudder pedal, the more likely it became that the rudder reversal would not clear, resulting in the aircraft continuing to roll rapidly and uncommandedly to the left.

Analysis of CVR - Speech and Physiological Aspects

- The NTSB Human Performance Group for this accident sought independent experts to assist with analyzing the flightcrew's speech and breathing patterns and muscular exertion.
- These analyses allowed investigators to evaluate crewmember levels of stress and physical exertion during the upset event.
- Although evidence suggests that the captain and first officer were surprised by the sudden and unexpected rolling of the aircraft, evidence indicates that the element of surprise immediately invoked an increased level of arousal within the captain which would have aided him with problem solving.
- The captain's level of stress was at Stage 1 or 2 until the aircraft was clearly unrecoverable, and these Stages are associated with increased performance due to the increased arousal factor.
- Not until after the point where the aircraft was clearly unrecoverable, did the stress level of both crewmembers increase to Stage 3, the highest level. Considering that death was clearly imminent, this response is understandable and predictable.
- Evidence suggests that the first officer was attempting to operate the flight controls throughout the upset period, and that the captain did not attempt to take over controls until the aircraft was clearly unrecoverable.
- Because the captain was not task saturated in attempting to control the aircraft, it likely allowed more of his cognitive resources to be devoted to trying to decipher the emergency situation and invoke a plan for recovery.
- To better understand the first officer's attempted flight control manipulations ALPA superimposed information from the reports from the experts, the CVR transcripts, the FDR data and data from the Performance Group's Kinematic Study.
- While listening to the Cockpit Voiced Recorder (CVR) the experts noted three grunts or explosive exhalations from the first officer.
- ALPA cross referenced these exhalations with the kinematic study and found that the first one corresponded with the control wheel being rotated sharply to the right. ALPA concluded that this grunt occurred when the first officer exerted force to override the autopilot "command" mode detent.
- The second grunt corresponded to a left rudder input that was denoted by the kinematic study. CVR data indicated that at this point the aircraft rolled rapidly to the left at a rate of approximately 35 to 40 degrees per second.
- In order to counter this abrupt rolling moment, the first officer's response would have likely been to apply considerable control forces to turn the control wheel to the right and attempt to push the right rudder pedal. The forces exerted on these controls likely resulted in the grunting that was heard on the CVR.
- The final grunting sound coincides with the kinematic analysis suggesting that the control wheel was once again being turned through approximately 35 degrees and the increasing rapidly traveling towards a full right direction. One of the experts compared this grunting

to previous grunts by saying that this one was "was louder and more forceful representative of the use of increased muscular force".

- It is likely that this grunting "was louder and more forceful representative of the use of increased muscular force" because the first officer was desperately struggling to press the right rudder pedal, attempting unsuccessfully to oppose the uncommanded left rudder movement.

Pilot Responses to Uncommanded Upsets

- The NTSB's Human Performance Group for this accident turned to the NASA Aviation Safety Reporting System (ASRS) to learn more about how pilots have reacted to uncommanded upsets.
- ASRS conducted a special "structured callback" to assist with this understanding.
- Altogether, information from 589 turbojet loss of control events was analyzed.
- In many cases reporters acknowledged that the events startled them, and many perceived that the events were quite severe.
- Although the events may have startled pilots, and although they may have been severe events, in not one of these cases did the aircraft crash. In every case, regardless of how much the event surprised them, and regardless of how severe they perceived the event, crews were able to recover the aircraft and safely land it.

Unintended Acceleration

- Unintended acceleration has no relevance in explaining this accident scenario.

Rudder Pedal Damage

- Two medical experts formed differing opinions concerning interpretation of rudder pedal damage.
- Due to this conflicting interpretation, information concerning rudder pedal damage is inconclusive and therefore should be disregarded.

Seat Track Damage

- Information concerning seat position could not be determined from seat track damage.
- The lack of seat track damage has no relevancy to this investigation, because due to the first officer's height, he would have had full and unobstructed use of all flight controls, regardless of seat position.

---

Table of Contents

## VII. Recommendations

Since the accident involving USAir 427 the NTSB has issued numerous safety recommendations, all aimed at improving the aviation system and making it safer for the traveling public. ALPA fully supports those recommendations. With regard to the specific event that initiated the USAir 427 accident upset, malfunction of the main rudder PCU which resulted in uncommanded full rudder deflection, ALPA believes that Boeing and Parker should work diligently to replace existing B737 rudder PCU's with improved units as quick as possible without sacrificing quality. In addition, ALPA offers the following recommendations:

- The FAA should eliminate the current practice of derivative certification. Newly developed aircraft should be carefully evaluated against FAR criteria in place at the time of aircraft development.
- For aircraft which were certified as "Derivative" models, the FAA should evaluate those aircraft against existing FAR requirements and those aircraft, to the extent feasible, should be modified in order to be in compliance with the current FAR regulations.
- The FAA should require all FAA certified repair stations to meet all the standards of the original equipment manufacturer.
- In order to increase B737 lateral control margin to an acceptable level, the FAA should mandate the development of additional operational techniques such as increasing B737 minimum maneuvering speeds to Boeing recommended "Block" speeds plus 10 knots.
- The industry should continue with the development and implementation of "Advanced Maneuver" or "Selected Event" training and that the FAA should require the inclusion of this training in every airline's training program.

---

Table of Contents