September 25, 1997

TO: Malcolm Brenner

RE: Review of Accidents, Incidents, Events, and Research Literature Related to Human Performance Issues Arising out of USAir Flight 427

This updated Supplementary Human Factors document is part of the Boeing submission on the USAir 427 accident to the NTSB. The purpose of this document is to provide background and historical information relevant to the human performance issues arising out of USAir Flight 427. This document consists of two parts and is submitted to the NTSB for its consideration:

- Part (1) of this document provides a list of data sources and the corresponding tabbed references.

- Part (2) of this document contains a review of events and research data that relate to several topics associated with this investigation. The events and data referenced in this review are numbered and enclosed.

CC: Human Performance Group Team Members

PART (1)

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* Previous additions (Rev. 2-28-1996)

** New additions (Rev. 9-25-1997)

PART (2)

This part contains a summary of seven topics listed below. Each topic contains a summary of relevant events and references.

A. Encounters with wake turbulence can surprise or startle experienced flight crews.

- The effect of startle on flight crew performance

B. Crews typically over-perceive the magnitude of unexpected rolls by factor of two or three, and may react accordingly.

C. Flight crews have reported that the duration of a wake turbulence encounter can be as long as 7 to 40 seconds.

D. There have been reported instances of flight crews hearing a "thump," "thud," or "muffled bang" when encountering upsets.

E. There are occasions when both flight crew members independently provide control inputs during the recovery from unexpected upsets.

F. Flight crews typically respond to unexpected upsets by immediately manipulating the flight controls. Both wheel and rudder inputs are often used during recovery.

- Airline training for recovery from unusual attitudes
- What we are learning about a flight crew's ability to recover from unusual attitudes

G. Flight crews have on occasion misapplied the rudder, used the wrong rudder altogether, or have failed to remove rudder inputs when they are no longer necessary.

- The "Unintended Acceleration" and pedal persistence incidents and accidents

A. ENCOUNTERS WITH WAKE TURBULENCE CAN SURPRISE OR STARTLE EXPERIENCED FLIGHT CREWS.

The NASA ASRS Multi-Engine Turbojet Uncommanded Upsets Structural Callback Summary, dated November 8, 1995, contains a compilation of loss of control factors in multi-engine turbojet upsets from January 1987 to May 1995. (93) This compilation shows that encounters with wake turbulence is far and away the leading cause of events that involve loss of control. (94)

Encounters with wake turbulence can surprise flight crews. This is true even when flight crews are aware of the potential for encounters near airports. Flight crews have reported that wake turbulence is capable of causing dramatic consequences, such as "violent," "sudden," and "severe" maneuvers, as well as "uncontrollable" airplane roll oscillations.

1. ASRS 293944 (Jan. 1995). A 737-200 encountered wake turbulence from another 737 at 4,000 ft AGL. The pilot flying reported that upon encountering the turbulence, "the nose abruptly pitched up 5 – 10 degrees and the aircraft rolled 40 degrees to the left." The pilot disconnected the autopilot. "The severity of this encounter surprised me.... Had I been distracted by looking at a chart or checking engine instruments, etc., I could have very easily ended up on my back, and this was from another 737!" (60)

2. June of 1995 737 event. Crew reported uncommanded upset that produced aircraft roll of "at least 45" degrees. FDR showed actual roll to be 18 degrees. Upon landing crew was observed to be "visibly shaken." According to crew, "AC felt out of control, very mushy" and "She didn't think she could control the AC." (5), (55), (56) and (57)

3. ASRS 286702 (October of 1994). Crew of a B-737-300 encountered wake turbulence from a B-727 during approach. Crew reported that while in a 12 degree left bank, wake turbulence from the B-727 "rolled the a[ircraft] to the r[ight] about 12 deg[rees], requiring 30 deg[rees] of yoke travel, and pitched and yawed the a[ircraft] an unstated amount. These perturbations lasted about 8 seconds." Crew was "surprised" by the severity of turbulence. (9)

4. ASRS 49794 (January of 1986). Crew of a medium large transport encountered wake turbulence from another medium large transport during take-off and climb. "We were rolled into an approx[imately] 45-50 deg[ree] bank from wake turbulence and attempted recovery." Crew reported that "[s]uch encounters with wake turbulence are highly distracting and require immediate attention." (16)

5. ASRS 188899 (September of 1991). Captain of a medium large transport experienced more wake turbulence from a preceding large aircraft than was usual during a visual approach with about 3.5 miles separation. He elected to fly about 1 dot high on GS to stay out of his wake. At about 50 ft AGL the "a[ircraft] rolled rapidly r[ight] then violently l[eft]." He countered with full right aileron. Aircraft continued left roll and captain initiated a Go-Around. Pilot stated that "Never in 27 y[ears] have I experienced such wake turb[ulence]." (10)

6. August of 1995 737-300 event. Crew reported that during descent while autopilot was engaged the aircraft "shuddered and shook similar to wake turbulence," and rolled left 30 degrees. FDR showed actual roll to be 19 degrees. "Both crew [were] startled by rate of roll." (91)

7. August of 1995 737-300 event. Crew reported uncommanded upset that produced two rolls of 30 degrees. FDR showed actual rolls to be 3, 9, and 9 degrees. Upset "threw flight attendant to the floor and scared flight crew." The upset was perceived by the flight crew to be "more like a barrel roll." In response to the initial left roll, the crew "countered with right aileron-may have hit stops-Airplane responded sluggishly, but did respond and went wings level, at which time it snapped right. Had to go wheel left to recover wings level." In post flight comments the crew stated: "wings level when all of sudden a sharp left roll turned yoke full right. Airplane responded slowly to wings level then snapped right. Airplane rolled right with control wheel at level position. Saw yaw damper at full left indication. Did manual input a little left rudder." NTSB later, investigated this incident and a report was issued by Office of Research and Engineering on February 12, 1996. This report indicates the subject airplane encountered wake vortices from a preceding airplane. (51)

8. ASRS 107506 (December of 1988). Crew of a medium large transport encountered wake turbulence from a large transport during take-off. "It took almost full aileron input to keep from rolling past 45 deg[rees]." "The wake I encountered was considerably more than normal." (11)

9. ASRS 298642 (February of 1995). A medium large transport encountered wake turbulence from a wide body aircraft while in trail during a visual approach to landing. While hand flying on second encounter with wake, crew "held it to a 45-50 deg[ree] r[ight] bank" by using rudder input. Pilot claimed that during his seven second encounter with wake, he "had no aileron control and the aircraft was not responding to the rudder input." Crew reported that he "was amazed at the strength of the wake." (13)

10. ASRS 216232 (July of 1992). Crew of a medium large transport encountered wake turbulence from another transport at about 9000 ft MSL. Crew reported that during the descent ". . .we hit wake turb[ulence] which rolled us to the r[ight] past 30 deg[rees] of bank." "This was the worst wake turb[ulence] I have experienced, and it lasted longer than expected." (72)

11. ASRS 285274 (October of 1994). Crew of a medium large transport encountered wake turbulence from a heavy transport (B-707) during visual operation. "As we ap[proached] the glide path, we encountered a sudden roll to approx[imately] 30 deg[rees] l[eft] bank. I diseng[aged] the autop[ilot] to recover." "We encountered the vortex 2 or 3 more times on final, including a moderate one in transition to l[anding]." (73)

12. ASRS 72048 (July of 1987). Crew of a medium large transport encountered wake turbulence from a large transport during a visual approach at 2000 ft. Crew reported that the "aircraft began roll to right, full opposite aileron was applied, with both p[ilots] on controls. Aircraft continued to roll to a bank angle exceeding 75 deg[rees] of bank, stick shaker and g[round] prox[imity] warning system sounded." (12)

13. ASRS 213928 (June of 1992). A large transport was following a wide body on approach with a spacing of at least 5 miles. Passing over threshold "the a[ircraft] unexpectedly rolled hard first one direction and then another while the nose pitched up and down. Extreme c[ontrol] movements were required to level the wings and keep them level. In this situation, everything happened so quickly that everything was reaction." (14)

14. ASRS 280652 (August of 1994). A medium large transport encountered wake turbulence from a large transport at FL330. "The possible wake was exceptionally strong, rolling our a[ircraft] into a 20 deg[ree] bank, and disengaged the autopilot. It lasted about 10 seconds at which point we returned to smooth air." Crew stated that "I have never experienced a wake this strong at such a high alt[itude]." (15)

15. ASRS 149927 (June of 1990). Crew of a medium large transport encountered wake turbulence from another large transport after take-off. Crew reported that "we started the turn at 300 ft AGL with 15 de[grees] angle of bank. We were violently increased to 30 de[grees] angle of bank from the apparent wake turb[ulence] of the l[arge] t[ransport]." (67)

16. ASRS 256700 (November of 1993). A medium large transport encountered wake turbulence from a large transport during climb out without any

warning. Crew reported they "encountered a violent roll l[eft] 25 deg[rees] and then a violent roll back to r[ight] into a 25 deg[ree] bank." (68)

17. ASRS 276427 (July of 1994). A medium large transport (B-737) encountered wake turbulence from a large transport during approach. While F/O was flying they were spaced 3 1/2 mile behind the traffic on final approach. Due to haze the traffic was not visible. Crew reported that they "encountered h[eavy] wake turb[ulence] [with] unc[controllable] roll, 30 deg[ree] l[eft] bank accompanied with brief stall shaker warning, stayed in wake turb[ulence]." (69)

18. ASRS 269033 (April of 1994). Crew of a medium large transport encountered wake turbulence from a large transport during a visual approach. Crew reported that "the FO, who was flying the a[ircraft], responded to the brief encounter with timely roll c[ontrol] inputs, added p[ower], and lowered the nose to maintain airspeed and recover to stable fl[ight]. Max uncommanded bank was 15 to 20 deg[rees]." (35)

19. ASRS 271187 (May of 1994). Crew of a medium large transport encountered wake turbulence from a large transport during a coupled approach with approximately 3 miles separation. The crew stated that wake turbulence magnitude was "sufficient to roll my 737 to 40 deg[ree] bank." Crew executed a missed approach at 100 ft. (61)

20. ASRS 279517 (August of 1994). Crew of a medium large transport encountered wake turbulence during landing (at 50 to 75 ft AGL) from a large transport that was taking-off. With captain's instruction the FO executed a go-around. On climb out, in the clouds at 1000-1200 ft AGL, airplane encountered wake turbulence again. "Full c[ontrol] deflection, in each direction, was required (both p[ilots] on the controls) to stop the roll." Maximum bank angle reached was between 15 to 20 degrees. (62)

21. ASRS 251874 (September of 1993). Crew of a medium large transport encountered wake turbulence from a wide body transport during approach at about 1500 ft AGL. Crew was cautioned about wake turbulence while following the wide body. The encounter "banked the airplane 45 deg[rees] (approx[imately]) to the r[ight]." A flight attendant was injured during the encounter. (63)

22. ASRS 280998 (August of 1994). A large transport (B-727) was following approximately 4 1/2 to 5 miles behind another large transport. Crew were informed by tower about the preceding traffic. Although the crew elected to fly 1/2 dot above the glide slope to avoid wake turbulence, at about 120 feet above the threshold, the following aircraft "encountered a severe R[ight] bank of

approximately 20-25 deg[] . . . . A bunch of L[eft] aileron, L[eft] rudder and a fistful of P[ower] righted the A[ircraft]." (4)

23. ASRS 288796 (November of 1994). On a nice day at altitude of 6000-7000 ft and with low flight crew workload, a medium large transport encountered strong wake turbulence. This occurred during a visual approach behind a large transport which "required full aileron to maintain c[ontrol]." Crew reported that with the separation of 5 to 7 miles the "a[ircraft] began a moderate rate roll (cannot recall direction) requiring full aileron input to c[ontrol] a[ircraft] roll. A[ircraft] continued to roll. Large thrust increase applied, some rudder and leveled off." (64)

24. ASRS 190748 (October of 1991). After taking-off and passing 1200 ft MSL, crew of a medium large transport encountered severe wake turbulence from a previously departing large transport. Crew reported that "the PF was struggling to retain a[ircraft] c[ontrol], using full fl[ight] c[ontrol] inputs to counteract the roll rate." (65)

25. ASRS 156250 (August of 1990). A large transport encountered wake turbulence from another large transport right after take-off. The crew stated that they were in wake turbulence from 100 to 2000 FT AGL. "During that time we experienced very rapid roll rates, with the a[ircraft] rolling 45 deg[rees] left and right, and full aileron often required to keep the a[ircraft] right side up." (66)

26. ASRS 145972 (May of 1990). Crew of a medium large transport encountered wake turbulence from a wide body transport during a visual approach. While the F/O was flying, at about 150 ft, the vortices from the wide body transport were encountered and the aircraft began a rapid roll to the right. This rolling moment continued to below 50 ft AGL. Crew reported that "at the first bump, F/O of course applied substantial aileron estimated at 75% of available roll c[ontrol] and added p[ower] to stabilize the fl[ight] path." (70)

27. ASRS 189664 (September of 1991). Crew of a medium large transport encountered wake turbulence from a wide body transport during a visual approach. Crew reported that shortly after rolling wings level on final approach, "we got an uncommanded l[eft] wing down roll of approx[imately] 30 deg[rees] at 1000 ft AGL. I immediately took c[ontrol] of the a[ircraft] and executed a g[o around]." (71)

28. ASRS 299779 (March of 1995). Crew of a medium large transport encountered wake turbulence from a wide body transport during descent through 8000 ft. Crew reported that the autopilot was engaged and there was 8 miles

separation between airplanes. "We received buffet and roll from previous a[ircraft] that was strong enough at one point to induce 45 deg[rees] bank and disconnect autop[ilot]." Autopilot disengaged as the aircraft approached 45 degrees of bank angle. (74)

29. ASRS 271385 (May of 1994). A wide body transport encountered wake turbulence from a medium large transport during landing. Crew reported that at about 20 ft AGL "we experienced rolls in both directions during the recovery." The captain initiated a go around and assumed control of the aircraft. (75)

30. November of 1995 737-300 event at 7000 feet. Crew reported that the "airplane rolled 20 degrees right. . . ." and ". . . . Airplane felt squirrelly, and [pilot] was afraid that if it banked more than fifteen degrees it would keep going." FDR showed the largest roll to be 2.25 degrees to the right. (95)

31. October of 1995 737-300 event at 6000 feet. Crew reported that while following a 747 with a separation of roughly 10 miles, "the aircraft was suddenly hit by the 747 wake turbulence." "The aircraft rolled violently 30 degrees left [and] the pilot was able to roll the aircraft straight and level." (54)

THE EFFECT OF STARTLE ON FLIGHT CREW PERFORMANCE.

32. Handbook of Military Psychology, 1991 ed. Gal R. and Mangelsdorff A.D., Chichester: Wiley at 185. It is recognized that acute stress (defined as "sudden, novel, or unexpected, and of relatively short duration") can have a negative effect on a crew's performance. "Various stressors have been shown to affect task performance. These include . . . anticipatory. . . dangerous conditions . . . and emergency conditions, such as . . . flight emergencies." Studies include a number of measurable effects of stressors including physiological arousal such as "labored breathing." Motivational losses and stressor after effects include "cue restriction and narrowing of the perceptive field," and "decreased in search behavior," "longer reaction time to peripheral cues," "decreased vigilance," "degraded problem-solving," and "performance rigidity." Data from studies "show that performance stress alone may increase errors on operational procedures threefold." "It has been noted that while performance in a high stress environment may degrade even the best trained . . ., it will eliminate the untrained . . ." (38)

33. J. Orasanu, "Stress and Military Performance," NASA-Ames Research Center. The author identifies the major effects of selected stressors. With the stressor "Danger/Threat/Loss of Control," the major identified effects are: "Subjective anxiety," "Freezing; escape from situation, reduced motivation," and "Performance decrements (sometimes due to haste); memory decrement." (36)

34. J. Chappelow, "Causes of Aircrew Error in the Royal Air Force." Of 149 military flying accidents studied, Chappelow attributes 26% of the accidents to "over arousal" and 17% to "cognitive failure." Over arousal is defined as a non-adaptive response to stressors of an exciting or alarming nature. Cognitive failure is a type of error in which actions fail to meet intentions, usually because an intended action is omitted or because an unintended action is committed. In five accidents that he studied, cognitive failure was an effect of over arousal. Chappelow states that a crew member's personality is thought to be a contributory factor in numerous over arousal accidents. Chappelow finds that the origin of acute over arousal can be a perceived emergency with a sudden onset or operating hazard. (39)

35. R. Thackray, "Performance Recovery Following Startle: A Laboratory Approach to the Study of Behavioral Response to Sudden Aircraft Emergencies." Dr. Thackray of the FAA's Civil Aeromedical Institute summarizes the information available on a person's response to an unexpected and startling event. Dr. Thackray's studies had been conducted, in part, "to estimate pilot response time to potentially critical situations, such as unexpected clear air turbulence."

Dr. Thackray found that the arousal levels experienced in response to a startling event can disrupt perceptual and motor performance for up to ten seconds, and affect tasks involving decision making and information processing for a longer period of time. According to his analysis, "the frequency of incorrect responses (representing errors in information processing) was found to be significantly greater in the startled than the unstartled group during the first minute following stimulation." Dr. Thackray has concluded from all of the research examined in this area, that "more complex perceptual-motor behavior, such as that requiring continuous psychomotor control, is likely to show maximum disruption during . . . [the] 1- to 3- second period [following stimulation] . . . , although significant, but lesser, disruption may still be present for 10 seconds following stimulation," and that "evidence from several studies suggests that the ability to process information may be impaired for 17 to 60 seconds following a startling event." (40)

36. M. Vlasak, "Effect of Startle Stimuli on Performance." "The effects of auditory startle stimulus on the performance of 178 healthy men in various tasks has been studied. The tasks consisted of: mental activity, complex psychomotor

activity, simple sensomotor activity, equilibrium in standing position on one leg, simple visual reaction time, and muscular force of a fatigued muscle. The strong sound of the klaxon-hoot or the sound of the pistol-shot were used as startle stimuli. Performance decreased in all tasks except the force of fatigued muscle, which showed improvement for a period of about 10 seconds. The quantity and quality of the efficiency in mental and complex sensomotor activity decreased very substantially for 20-30 seconds on the average. We suppose that the startle stimulus can cause mistakes in flying." (50)

37. R. Green, "Stress and Accidents." Three types of stress are described by the author. One type, "acute reactive stress," is discussed and the evidence relating the stress to accidents is evaluated. The author indicates that "the conventional wisdom here is that a provocative event, such as an aircraft emergency, will increase the pilot's arousal level and that narrowed attention and disorganized behavior are consequences of this." "Examination of RAF psychologists' reports also suggest that acute stress potentiates further error." Further, the author claims that "the pattern of response [among the pilots] is sufficiently common to provide reasonable evidence that many pilots lose control of their aircraft as a fairly direct result of an increase in arousal or reactive stress." (8)

38. Alan Stokes & Kirsten Kite (1994), "Flight Stress: Stress Fatigue, and Performance in Aviation," Ashgate Publishing Limited, Vermont, U.S.A. In the discussion of the effects of stress on performance, the authors indicate that "A pilot attempting to reach a decision under stress . . . may ignore information about alternative hypotheses and select from a more restricted field of options." "Certainly both cognitive and perceptual tunneling are suggested by accounts of various types of preservation under stress: pilots, for example, may become fixated on or obsessed with one equipment item, one response possibility, or one thought, . . . often despite the operational ineffectiveness of the approach." (78)

39. Daniel Serfaty, Elliot Entien, and Catherine Volpe, "Adaptation to Stress in Team Decision-Making and Coordination." In an experimental study conducted by the authors it is reported that Sales et al point out "that in order to achieve a required level of performance for a task, efficient and reliable teams must: 1) coordinate their resources, information, and actions; 2) adapt continuously their strategies to the demand of the task environment; and 3) use the organizational structure that supports the team process. Any failure to perform these three activities consistently may result in team errors." (85)

B. CREWS TYPICALLY OVER-PERCEIVE THE MAGNITUDE OF UNEXPECTED ROLLS BY FACTOR OF TWO OR THREE, AND MAY REACT ACCORDINGLY.

1. CAA Air Traffic Control Evaluation Unit, ATCEU Memorandum No. 197, "The Vortex Reporting Program: Analysis of Incidents Reported Between January and December 1992." Pilots in 15 of 20 reported events believed the upsets to have been more severe than the FDR showed them in fact to have been. In one case, a pilot believed he encountered a 30 degree roll, when the FDR showed the roll to have been only 7 degrees. (32)

2. FAA Safety Analysis Branch Office of Accident Investigation. Safety Issue Analysis and report on Boeing 737 Uncommanded Rolls, September 1995. The report indicates that "pilots typically overstate the degree of roll in an event." Pilots in 7 out of 7 reported events(US domestic airlines) believed the upsets to have been more severe than the FDR showed them in fact to have been. (86)

3. June of 1995 737-300 event. Crew reported that "at 4000 feet 210 knots, autopilot channel B in heading select - no traffic in area, in the clear - aircraft turned [greater than] 30 degree bank left with pilot response of turning aileron to right." Crew also reported that "felt like being in the wake of a heavy" In another USAir interview report, it was said that the captain, who was "visibly shaken," stated that the aircraft had rolled left "at least 45 degrees." According to crew, "AC felt out of control, very mushy" and "She didn't think she could control the AC." (5), (55), (56) and (57)

4. January of 1995 737-300 event. Crew reported that upon encountering wake turbulence, a right roll to about 20 degrees was followed by a left roll to approximately 30 degrees. The FDR indicates that there was first a left roll to approximately 20 degrees of bank, followed by a right roll of approximately 12 degrees of bank. (20)

5. July of 1995 737 event. Crew reported right bank of approximately 35 degrees. The FDR showed a right bank of 24 degrees. (6)

6. August of 1995 737-300 event. Crew reported that the aircraft "shudder and shook similar to wake turbulence," and rolled left 30 degrees. FDR showed actual roll to be 19 degrees. "Both crew [were] startled by rate of roll." (91)

7. March of 1995 737 event. Crew encountered an upset due to a right yaw damper kick. The captain thought the roll acceleration rate experienced was

sufficient to roll the aircraft "on its back" if left unchecked. The first officer stated that he applied right rudder in response to the kick; the captain said that he applied "1/4 left rudder" with "no effect." (33)

8. August of 1995 737-300 "uncommanded roll" event. The crew said in interviews following the event that rolls of 30 degrees were encountered. These rolls "scared [the] flight crew," which perceived them to be "more like a barrel roll." In fact, the FDR shows a roll of 3 degrees past wings level in one direction, followed by a second roll of 9 degrees past wings level the other direction, followed by a third roll in the opposite direction of 9 degrees past wings level. NTSB later, investigated this incident and a report was issued by Office of Research and Engineering on February 12, 1996. This report indicates the subject airplane encountered wake vortices from a preceding airplane. (51)

9. ASRS 260432 (January of 1994). Crew of a wide body transport possibly encountered wake turbulence from a large transport during the final approach. When passing over the runway threshold lights, the aircraft entered into a series of abrupt and violent roll excursions which the captain estimated to be in the range of "15-20 deg[rees] of bank." Later analysis of FDR readout showed the maximum bank angle was "about 7.5 deg[rees]." (77)

10. November of 1995 737-300 event at 7000 feet. Crew reported that the "airplane rolled 20 degrees right. . . ." and ". . . . Airplane felt squirrelly, and [pilot] was afraid that if it banked more than fifteen degrees it would keep going." FDR showed the largest roll to be 2.25 degrees to the right. (95)

11. October of 1995 737 event. Crew reported that during approach at 4000 feet with autopilot engaged, the airplane "starts suddenly to roll hard to the left." Crew disconnected the autopilot, then approximately 45 seconds later the airplane again rolled to the left, "exceeding 30 [degree] bank." FDR showed the largest roll to be less than 8 degrees. (24)

12. September of 1995 737-300 event. Crew reported that while climbing manually, "aircraft experienced an uncommanded rudder trim input to the full left travel." This occurred in "approximately 1 to 2 seconds." FDR showed the actual rudder trim rate in the event was near the expected rate of 0.5 deg/sec. and the maximum rudder deflection achieved was approximately 1.5 degrees prior to flight crew intervention. The maximum rudder deflection during this event was 7 degrees. (45)

13. February of 1996 737-500 event. Crew reported an uncommanded left roll to 25 degrees which occurred while the autopilot was engaged. FDR showed the largest left roll to be about 10 degrees. (46)

14. September of 1996 737-500 events. Uncommanded rolls were reported to have occurred during consecutive flights on the same airplane. From the first event (-1),the crew reported that during the descent while the autopilot A was engaged the "A/C [aircraft] rolled rapidly, but slowly left to aprox[approximately] 50 degrees". "Both pilots agreed the motion was quite different from wake turbulence." FDR showed a roll attitude of about 30 degrees. From the second event (-2), the log entry stated that the "A/C [aircraft] departed from normal flight on two ocaisions[occasions]." The attached report indicates a 20 degree roll to the right and a 30 degree roll to the left occurred during this event. FDR showed a right roll of less than 2 degrees. No uncommanded left roll occurred during the entire event (-2). (52)

15. April of 1997 737-300 event. Crew reported that the airplane rolled right to approximately 30 degrees in 1 to 2 seconds. FDR showed the maximum bank angle reached was approximately 15 degrees with a role rate of 7 degrees per second. (58)

C. FLIGHT CREWS HAVE REPORTED THAT THE DURATION OF A WAKE TURBULENCE ENCOUNTER IS AS LONG AS 7 TO 40 SECONDS.

1. ASRS 298642 (February of 1995). A medium large transport encountered wake turbulence from a wide body aircraft while in trail during a visual approach to landing. While hand flying on second encounter with wake, crew "held it to a 45-50 deg[ree] r[ight] bank" by using rudder input. Pilot claimed that during his seven second encounter with wake, he "had no aileron control and the aircraft was not responding to the rudder input." Crew reported that he "was amazed at the strength of the wake." (13)

2. ASRS 286702 (October of 1994). Crew of a B-737-300 encountered wake turbulence from a B-727 during approach. Crew reported that while in a 12 degree left bank, the wake turbulence from the B-727 "rolled the a[ircraft] to the r[ight] about 12 deg[rees], requiring 30 deg[rees] of yoke travel, and pitched and yawed the a[ircraft] an unstated amount. These perturbations lasted about 8 seconds." Crew was "surprised" by the severity of turbulence. (9)

3. ASRS 280652 (August of 1994). A medium large transport encountered wake turbulence from a large transport at FL330. "The possible wake was exceptionally strong, rolling our a[ircraft] into a 20 deg[ree] bank, and disengaged the autopilot. It lasted about 10 seconds at which point we returned to smooth air." Crew stated that "I have never experienced a wake this strong at such a high alt[itude]." (15)

4. June of 1995 737 event. Airplane encountered an upset while autopilot was engaged. Crew reported that the aircraft "began an uncommanded roll of up to 30 to 45 deg[ree]s to the l[eft]. Both pilots applied aileron input to correct. FO applied R[ight] rudder . . . ." According to the flight crew this upset lasted as long as 8 seconds. (5)

5. February of 1996 737 event. On final approach the airplane encountered wake turbulence from a preceding 727 airplane. Crew reported that "the a[irplane] then rolled firmly and smoothly into a left bank." Crew countered the roll with full wheel and rudder. "Yet the a[irplane] remained in an approximately 25 degrees l[eft]-h[and] bank." Captain was concerned that the wake turbulence might be strong enough to cause the airplane to go inverted. Crew reported that "after approximately 20-40 sec[onds] the a[irplane] rolled right and the wings were leveled." In interview with NTSB, crew indicated this wake encounter was more violent than previous encounters. (21)

6. January of 1996 737 event. Crew of a 737 airplane encountered a sever wake turbulence from a A-320 during take off departure. Crew reported that encounter required "approx[imately] full left aileron for approx[imately] 30 sec[onds], followed by almost full r[ight]-h[and] aileron." (30)

D. There have been reported incidents of flight crew hearing a "thump," "thud," or "muffled bang" when encountering upsets.

1. ASRS 314668 (August 1995) 737-300 "uncommanded roll" event. The crew said in interviews following the event that "F/O heard a pop or bang before [roll] event happened. Like a loud snapping or thud, muffled bang. Captain did not hear anything." NTSB later, investigated this incident and a report was issued by Office of Research and Engineering on February 12, 1996. This report indicates the subject airplane encountered wake vortices from a preceding airplane. (51)

2. Recent wake vortex flight tests near Atlantic city, New Jersey indicate that "thump" sounds are heard when the fuselage enters the core from a wake vortex. (Jim Cash and Mike Carriker)

E. THERE ARE OCCASIONS WHEN BOTH FLIGHT CREW MEMBERS INDEPENDENTLY PROVIDE CONTROL INPUTS DURING THE RECOVERY FROM UNEXPECTED UPSETS.

1. ASRS 279517 (August of 1994). Crew of a medium large transport encountered wake turbulence during landing (at 50 to 75 ft AGL) from a large transport that was taking-off. With captain's instruction the FO executed a go-around. On climb out, in the clouds at 1000-1200 ft AGL, airplane encountered wake turbulence again. "Full c[ontrol] deflection, in each direction, was required (both p[ilots] on the controls) to stop the roll." Maximum bank angle reached was between 15 to 20 degrees. (62)

2. ASRS 63448 (January of 1987). Crew of a medium large transport encountered difficulty during landing. Crew reported that "the capt[ain] went into reverse thrust at which time the a[ircraft] weathervaned to the left, he immediately came out of reverse, however due to the weathervane the left wing lifted. I immediately noted the application of additional right rudder which was bringing the nose back to the centerline, however at the same time the a[ircraft] experienced a gust and the left wing rose further. Again I checked control inputs and got on the yoke with the capt[ain] to insure full left yoke application." (79)

3. ASRS 92829 (August of 1988). Crew of a light aircraft stated that "during the l[anding] and roll out the a[ircraft] began to veer to the right." "In an

effort to assist the cap[tain] I attempted to apply full left rudder and found that the capt[ain] had already done so." (80)

4. ASRS 72048 (July of 1987). Crew of a medium large transport encountered wake turbulence from a large transport during a visual approach at 2000 ft. Crew reported that the "aircraft began roll to right, full opposite aileron was applied, with both p[ilots] on controls. Aircraft continued to roll to a bank angle exceeding 75 deg[rees] of bank, stick shaker and g[round] prox[imity] warning system sounded." (12)

5. ASRS 276165 (July of 1994). Flight crews of a large transport encountered cross wind and possibly wake turbulence and had control difficulty during landing. Crew reported that the "in the flare the a[ircraft] picked up a l[eft] to r[ight] drift. F/O tried to compensate with rudder and aileron" while captain was flying. (81)

6. March of 1995 737 event. Crew encountered an upset due to a right yaw damper kick. The captain thought the roll acceleration rate experienced was sufficient to roll the aircraft "on its back" if left unchecked. The first officer stated that he applied right rudder in response to the kick; the captain said that he applied "1/4 left rudder" with "no effect." (33)

7. June of 1995 737. Airplane encountered an upset while autopilot was engaged. Crew reported that the aircraft "began an uncommanded roll of up to 30 to 45 deg[ree]s to the l[eft]. Both p[ilots] applied aileron input to correct. FO applied R[ight] rudder . . . ." According to the flight crew this upset lasted as long as 8 seconds. (5)

F. FLIGHT CREWS TYPICALLY RESPOND TO UNEXPECTED UPSETS BY IMMEDIATELY MANIPULATING THE FLIGHT CONTROLS. BOTH WHEEL AND RUDDER INPUTS ARE OFTEN USED DURING RECOVERY.

1. July of 1995 737 event. Crew responded to autopilot commanded right roll of 30 degrees by using left rudder and left wheel. The left rudder was not removed for the remainder of the flight (the crew made left rudder inputs from 5.5 to 1.5 degrees for the remainder of the flight). The crew offset the left rudder inputs by cross-controlling with right wheel and right wheel trim. (6)

2. On December 27, 1968 an Ozark DC-9 crashed on takeoff at Sioux City, Iowa. As the landing gear was being retracted following liftoff, the aircraft "rolled abruptly and violently to the right to an angle of bank estimated by the flight crew to have reached 90 degrees." The captain responded by applying "additional power and left hand rudder to try and level the wings. When no immediate response was noted he then applied left hand aileron." The takeoff deteriorated and the captain put the aircraft down approximately 110 feet beyond the departure threshold. (47)

3. ASRS 144064 (April of 1990). A light transport twice encountered wake turbulence from a wide-body aircraft. During the second encounter, wake rolled the light transport "to 110 deg[ree] bank left." The crew responded with "full scale deflection of the controls (aileron and rudder) to the right . . . until the roll stopped." (3)

4. ASRS 280998 (August of 1994). A large transport (B-727) was following approximately 4 1/2 to 5 miles behind another large transport. Crew was informed by tower about the preceding traffic. Although the crew elected to fly 1/2 dot above the glide slope to avoid wake turbulence, at about 120 feet above the threshold, the following aircraft "encountered a severe R[ight] bank of approximately 20-25 deg[] . . . . A bunch of L[eft] aileron, L[eft] rudder and a fistful of P[ower] righted the A[ircraft]." (4)

5. January of 1995 737-300 event. The crew reported that upon encountering wake turbulence, the aircraft first rolled to the right. The first officer countered with aileron input and stopped the roll at about 20 degrees of bank, and then the aircraft began a sluggish roll to the left. The first officer applied close to full right aileron, but the aircraft kept rolling left. The captain told the first officer to "use some rudder input" and then personally took control of the aircraft. The captain maintained the aileron input and applied rudder, and stopped the roll at approximately 30 degrees of bank. The captain noted in his written statement that "It . . . occurred to me that since I did not say right rudder that I best take the airplane before the left bank continued." (20)

6. February of 1995 737-400 event occurring during an autopilot approach. The autopilot banked the aircraft to a 30 degree right wing down attitude. As the bank angle approached 30 degrees, the autopilot brought the wheel back to approximately 5 degrees right wheel. The aircraft then experienced a sharp lateral acceleration that drove the bank angle from 30 to 25 degrees right wing down. The source of the lateral acceleration is thought to be wake or atmospheric turbulence. The autopilot system responded to the change in bank angle by commanding a 26 degree wheel input to the right. The turbulence and the right

wheel command pushed the right wing down to a 60 degree bank angle. The autopilot responded by reversing the wheel direction to the left. At this moment, the crew responded to the upset with a left rudder input. The crew also commanded manual left wheel inputs to recover the aircraft. (48)

7. ASRS 220642. A flight crew of a medium weight transport reported in September of 1992 that they encountered turbulence during an autopilot climb. The crew disengaged the autopilot and commanded "considerable left rudder" and left wheel. (42)

8. ASRS 225605. A flight crew of a medium large transport reported in October of 1992 that they rolled right significantly, and "opposite rudder and aileron input was used to counter roll." (43)

9. ASRS 251615. A flight crew of a large transport reported in September of 1993 that their aircraft at cruise altitude rolled violently to the right and then to the left. "The Capt.'s control inputs were full opposite aileron and rudder." (44)

10. ASRS 298642 (February of 1995). A medium large transport encountered wake turbulence from a wide body aircraft while in trail during a visual approach to landing. While hand flying on second encounter with wake, crew "held it to a 45-50 deg[ree] r[ight] bank" by using rudder input. Pilot claimed that during his seven second encounter with wake, he "had no aileron control and the aircraft was not responding to the rudder input." Crew reported that he "was amazed at the strength of the wake." (13)

11. ASRS 288796 (November of 1994). A medium large transport encountered strong wake turbulence from a large transport. Crew reported that "the recovery required full aileron, large thrust increase, and some rudder to control the aircraft." (64)

12. ASRS 92829 (August of 1988). Crew of a light aircraft indicates that during the landing roll out the aircraft began to veer to the right. Crew reported that "in an effort to assist the capt[ain] I attempted to apply full left rudder and found that the capt[ain] had already done so." (80)

13. ASRS 63448 (January of 1987). Flight crew of a medium large transport encountered difficulty during landing. Crew reported that "the capt[ain] went into reverse thrust at which time the a[ircraft] weathervaned to the left, he immediately came out of reverse, however due to the weathervane the left wing lifted. I immediately noted the application of additional right rudder which was bringing the nose back to the centerline, however at the same time the a[ircraft]

experienced a gust and the left wing rose further. Again I checked control inputs and got on the yoke with the capt[ain] to insure full left yoke application." (79)

14. September of 1995 737 event. FO "experienced an abrupt left roll to about 25 degrees" during cruise with autopilot engaged. "The captain took hold of control wheel and applied immediate aileron and input right rudder." First officer reported "it felt like wake turbulence." (90)

15. August of 1995 737-300 event. Crew reported that during descent while autopilot was engaged the aircraft "shudder and shook similar to wake turbulence," and rolled left 30 degrees. "Accomplished coordinated turn, recovered. . . ." "Both crew startled by rate of roll." (91)

16. June of 1995 737 event. Airplane encountered an upset while autopilot was engaged. Crew reported that the aircraft "began an uncommanded roll of up to 30 to 45 deg[ree]s to the l[eft]. Both p[ilots] applied aileron input to correct. FO applied R[ight] rudder . . ." According to the flight crew this upset lasted as long as 8 seconds. (5)

17. April of 1993 737 event. Crew responded to the wake vortex encounter by commanding left wheel and right rudder and then commanding left rudder. (96)

18. August of 1995 737 event. Crew reported uncommanded upset that produced two rolls of 30 degrees. FDR showed actual rolls to be 3, 9, and 9 degrees. Upset "threw flight attendant to the floor and scared flight crew." The upset was perceived by the flight crew to be "more like a barrel roll." In response to the initial left roll, the crew "countered with right aileron-may have hit stops-Airplane responded sluggishly, but did respond and went wings level, at which time it snapped right. Had to go wheel left to recover wings level." In post flight comments the crew stated: "wings level when all of sudden a sharp left roll turned yoke full right. Airplane responded slowly to wings level then snapped right. Airplane rolled right with control wheel at level position. Saw yaw damper at full left indication. Did manual input a little left rudder." NTSB later, investigated this incident and a report was issued by Office of Research and Engineering on February 12, 1996. This report indicates the subject airplane encountered wake vortices from a preceding airplane. (51)

19. October of 1995 737 event. Crew reported that during approach at 4000 feet with autopilot engaged, the airplane "start[ed] suddenly to roll hard to the left." Crew disconnected the autopilot, applied "full aileron and partly rudder". (24)

20. July of 1995 737-300 event. Crew reported that "at an altitude of 3,000 ft the aircraft experienced an uncommanded roll to the right followed by a roll to the left. The use of full opposite aileron did not stop the roll." FDR data show roll attitude changes with opposing control wheel deflections which persisted for approximately 12 seconds. During this event the right bank angle continued to increase towards 35 degrees despite full opposing left wheel deflection that lasted for about one second. During this period, an opposing partial left rudder pedal deflection was sustained for about 3 seconds. (53)

21. 737 event (June 1997). The crew of a 737 encountered wake turbulence from a 747 that was positioned approximately 7 miles away, causing the 737 to roll 20 degrees to the left. The autopilot responded with a right wheel input. The crew overrode the autopilot with an additional right wheel input. The crew also made a right rudder input. While continuing to command right rudder (at times commanding close to the maximum rudder available), the crew made several left and right wheel inputs. The airplane recovered from the left roll, rolled through wings level, and rolled to a 17 degree right wing down configuration. Still the crew commanded right rudder. The airplane was "cross-controlled" for much of the recovery. (59)

22. February of 1996 737 event. On final approach the airplane encountered wake turbulence from a preceding 727 airplane. Crew reported that "the a[irplane] then rolled firmly and smoothly into a left bank." Crew countered the roll with full wheel and rudder. "Yet the a[irplane] remained in an approximately 25 degrees l[eft]-h[and] bank." Captain was concerned that the wake turbulence might be strong enough to cause the airplane to go inverted. In interview with NTSB, crew indicated this wake encounter was more violent than previous encounters. (21)

AIRLINE TRAINING FOR RECOVERY FROM UNUSUAL ATTITUDES

23. United Airlines in its Advanced Maneuvers Package is teaching its crews to use both aileron and rudder to recover from banks. L.S. Walters, UAL Standards Captain, says that UAL simulates a sharp roll-off "typically caused by a strong wake vortex," then directs the crews to counter with full aileron and top rudder - what he calls "step and roll" toward the attitude indicator's sky pointer. "We. . . stress the importance of using coordinated controls throughout the roll maneuvers. . . I mean using rudder with aileron to help the roll rate." (1), (23) and (34)

24. American Airlines teaches its crews in its Advanced Aircraft Maneuvering Program that rudder should be used in recovering from high angles of bank. American is also training its crews that rudder should be used in response to high AOA maneuvering encountered during wake turbulence. (17), (18) and (19)

WHAT WE ARE LEARNING ABOUT A FLIGHT CREW'S ABILITY TO RECOVER FROM UNUSUAL ATTITUDES.

1. As reported by L.S. Walters, United Airlines Standards Captain, in March 27, 1995 Aviation Week & Space Technology, pg. 43. When simulating "a sharp roll-off typically caused by a strong wake vortex" in UAL's unusual attitude training, "it was easy to see how a pilot would have an almost irresistible urge to pull on the yoke, not hold full aileron and top rudder." "Walters said getting airline pilots to use full-throw control inputs was difficult. 'Their whole career has [emphasized] not spilling drinks in the back. They're not used to putting it all in, so we have to get them beyond that. " (23)

2. United Airlines Advanced Maneuvers Demonstration instruction materials on rolls and returns, discusses importance of rudder and "stress[es] NOT PULLING BACK ON ELEVATOR BEFORE WINGS LEVEL UPRIGHT." (26)

3. December of 16, 1994 Flight Safety International Pilot Guide: "Unusual Attitude Supplemental Reading Material." To control banks, Flight Safety advises: "If nose low, immediately return to zero degrees of bank by rolling the aircraft. Rolling toward the bank pointer, to place it in the upper half of the case, will correct an inverted attitude. ROLL FIRST - then PULL. DO NOT pull until you have the aircraft right side up." (28)

G. FLIGHT CREWS HAVE ON OCCASION MISAPPLIED THE RUDDER, USED THE WRONG RUDDER ALTOGETHER, OR HAVE FAILED TO REMOVE RUDDER INPUTS WHEN THEY ARE NO LONGER NECESSARY.

1. 737 event (June 1980). First officer was flying a 737-200 on approach. At 800 feet, captain noted and called attention to an increase in airspeed and rate of descent. He expected the F/O to reduce power. Just as the captain touched the power levers intending to initiate a missed approach, the aircraft "slewed" to the left in a wild descending uncoordinated turn. The captain encountered 45 degrees of bank. He pushed the power levers to the forward stops and was able to roll out of the bank, but chose not to because the airplane felt "funny" and "uncoordinated." A male flight attendant then entered the cockpit and discovered that the cause of the steep turn was that the unconscious first officer's leg was holding full left rudder. In the NTSB interview, the captain said he was "startled at the beginning of the incident" and "was surprised he did not realize that the rudder was in." (97; also Witness Interview, Attch. 2, Fourth Addendum, Human Performance Factual Report, Nov. 8, 1996).

2. United Airlines in its Advanced Maneuvers Package recognizes that "the application of incorrect rudder" can occur following a crew's encounter with a surprise engine failure. A "problem" recognized by United in its materials is the "failure [by flight crews] to ascertain and apply the correct rudder." United Airlines states in its training material that "the pilot should be able to unerringly apply the correct rudder to bring the aircraft into coordinated flight." The instructor is to "make sure that the correct rudder is applied . . . ." (2) and (27-A)

3. March of 1995 737 event. According to the NTSB Human Performance Group's interview of the crew, the first officer stated that he added "right rudder," whereas the captain stated that he applied "1/4 left rudder" with "no effect." (33)

4. NTSB Aircraft Accident Report of September 6, 1985 Midwest Express Airlines DC-9-14 at Milwaukee, Wisconsin. During the initial climb following takeoff, there was a loud noise and loss of power from the right engine. The aircraft continued to climb, but then rolled to the right until the wings were observed to be in a near vertical, 90 degree right bank. The aircraft entered an advanced stall and crashed. The NTSB found that "the crew response to the right engine failure was not coordinated" and that "the rudder

was incorrectly deflected to the right 4 to 5 seconds after the failure of the right engine." (37)

The NTSB also noted that "[i]n the course of this investigation, the Safety Board learned of several simulated engine failure incidents in which pilots responded initially with deflection of the incorrect rudder pedal . . . . A Douglas test pilot, who had flight instructor experience in the DC-9, testified to a personal experience where a pilot who was receiving DC-9 instruction commanded rudder deflection in the wrong direction in response to a simulated engine failure. An FAA DC-9 instructor, with extensive training experience, testified that about 1 of every 50 of his students, each of whom held an airline transport pilot certificate, had attempted to deflect the wrong rudder pedal during simulated engine failure on takeoff." (37)

5. July of 1995 737 event. Crew responded to autopilot commanded 30 degree right roll by commanding left rudder and left wheel. The crew then brought the wings level but held in the left rudder command for the remainder of the flight. The crew cross-controlled the wheel and the rudder, using right wheel and right wheel trim commands to offset the left rudder. (6)

6. January of 1979 737 event. Aircraft encountered several sudden roll maneuvers that were reported by airline as being related to suspected lateral control malfunction. Analysis of FDR showed, however, that in coordinating a relatively steep 35 degree right turn for approach, the crew applied and continued to maintain small but excessive amounts of right rudder, approximately 3 to 5 degrees. This, in turn, required excessive left control wheel input, of approximately 30 degrees, to hold the 35 degree right bank. When positioning the airplane for the downwind leg, several rudder control and lateral control oscillations occurred. Control inputs increased in magnitude until 15 degrees of right rudder and 40 to 50 degrees of left wheel were applied. As the airplane turned to final approach, the controls were gradually changed to full left rudder and full right wheel. This cross-control continued to exist until landing. (22)

7. Statement attributed to United Airlines Standards Captain L.S. Walters in March 27, 1995 Aviation Week & Space, pg. 43. In explaining UAL's unusual attitude scenario of failing an engine shortly after takeoff, UAL teaches crews to stay off the rudders. "If you go for a rudder, and it's the wrong one, you've just used up your opportunity." (23)

In another article, Capt. Walters stated:

"In the V2 cut, the greatest danger is loss of airspeed. The second is pushing the wrong rudder pedal - you can get yourself in a situation from which you can't recover.

So we stress the importance of going through the correct order of immediate inputs for recovery: . . . (3) apply correct rudder - that is, the one on the same side as the low side of the yoke - to maintain wings level while rolling the yoke back to neutral aileron." (34)

8. October of 1986 737-300 event. First officer encountered rapid roll oscillations on first approach. Captain took over and had no difficulty controlling aircraft. On second pass, first officer was again in command and again encountered control difficulties. The captain took over and landed uneventfully. The FDR showed that when the first officer was flying the approaches, right rudder inputs were made, which were countered on both approaches with left wheel. "On both approaches the rudder pedal increased to near full deflection." (25).

9. R. Padfield, "Flying in Adverse Conditions" at 240. In section on "Human Hazards" entitled "Be Suspicious of Yourself," Padfield writes:

"Every pilot who steps into the cockpit of an aircraft carries a psychological flight bag of experience, background, and conditioned responses to outside stimuli. On the surface, we might all look like we're stamped from the same mold, but inside we are all very different. We are human. And despite the concentrated efforts of instructors to standardize our behavior in the cockpit, there will always be that element of unconscious psychological control that might cause us to act in a manner diametrically opposed to what even we know is correct.

A personal example: When I first started flying helicopters, every once in awhile, while hovering, I'd press the wrong pedal when I wanted to turn. Intuitively I knew that I should press the right pedal to turn right and the left pedal to turn left, but sometimes a seat-of-the-pants reaction would cause me to press the opposite pedal first, before I could catch myself doing it. "Why?" I asked myself.

Steering a machine with my feet was an unfamiliar action, especially after I'd driven a car for some years. But it was also vaguely familiar. "Were there other things I had steered with my feet?" I wondered. Then I remembered.

Have you ever gone sledding? If you sit on a sled, you have to steer it with your feet. To turn the sled to the left, you push your right foot forward; to turn it to the right, you push your left foot forward. Being from Pennsylvania, I did a lot of sledding when I was a kid, and in the stress of learning how to hover, every now and then, my unconscious mind would take over and tell my right leg to push the nose of the helicopter around to the left.

. . . .

These are human-factor reactions that most of us overcome with habit and experience during normal operations. But when things start to get stressful, there's no telling what your unconscious might dredge up." (31)

10. On March 8, 1994 Sahara India Airlines conducted a 737-200 training flight in New Delhi. As the aircraft was completing a touch and go, the Instructor Pilot initiated an engine inoperative training exercise in which he retarded the left engine thrust lever at takeoff rotation. The FDR and CVR indicate that the trainee pilot responded to the asymmetric thrust by applying right wheel and left rudder. The Instructor Pilot took over the controls and applied right rudder before the airplane crashed. (29)

11. 1992 Air National Guard C-130 accident near Evansville, Indiana in which the flight crew was returning to its home base. The first officer applied the wrong rudder causing the aircraft to roll excessively and crash.

12. P. Fitts and R. E. Jones, "Analysis of Factors Contributing to 460 'Pilot-Error' Experiences in Operating Aircraft Controls." Authors classify types of pilot error into six classes: substitution errors; adjustment errors; forgetting errors; reversal errors; unintentional activation; and unable to reach a control. A "reversal error" occurs when a control is moved in a direction opposite to that necessary to produce a desired result. This includes: making reversed trim correction; making reversed wing flap adjustment; making reversed movement of an engine or propeller control; and making reversed movement of some other control. 27 instances of pilot "reversal error" experiences were identified by the authors, or 6% of the total experiences studied. (49)

13. April of 1993 737 event. Crew responded to the wake vortex encounter by commanding left wheel and right rudder and then commanding left rudder. (96)

14. On February 22, 1995 a U.S. Airforce T-3A single engine aerobatics training airplane crashed during cadet training. Based on accident investigation findings, "the instructor pilot's academic instruction, flying training and error

analysis experience[inadequately preparing] him to recognize his improper rudder application." According to an Aviation Week & Space Technology report, "apparently, the pilot misapplied rudder controls during a spin, which led to confusion and futile attempts to counter the abnormal stick forces and high rotation rate using elevator controls only" (87)

THE "UNINTENDED ACCELERATION" AND PEDAL PERSISTENCE INCIDENTS AND ACCIDENTS

15. R. Schmidt, "Unintended Acceleration: A Review of Human Factors Contributions." Author reviews driver behavior in automobile incidents/accidents identified as "Unintended Acceleration." A Human Factors analysis of the phenomena is provided by addressing main issues of activation of wrong pedal, lack of awareness of the action/absence of feedback, and the persistence/failure to correct.

According to various investigators and a recent review by Schmidt (1989), the unintended acceleration occurs when driver experience full automobile acceleration lasting as long as 12 seconds with an apparently complete failure of the braking system, often leading to an accident. There is strong support for the review that the right foot contacts the accelerator even though the driver fully intended to press the brake because of inconsistency in foot trajectory generated by spinal-or muscle-level variability. There is considerable evidence that the variable, inconsistent processes that generated muscular forces and their timing are the source of these errors (p.345)."

The reasons why drivers are not aware of such errors and why they can persist for so long have recently been reviewed and summarized by Schmidt (1989, p.363). He points out that the phenomenon of unintended acceleration has not been systematically linked to any known mechanical or design defect in the vehicles. He states that the research literature in human factors, experimental psychology, and kinesiology supports the view that these problems are caused by drivers producing foot placement errors, with some of these errors actually being observed in experimental driving situations. These errors mainly originate at functionally low levels of the central nervous system (CNS) because of force and time variability in the spinal cord and in the muscle that produce the actions. He indicates that errors in conscious choice are therefore rarely involved, which is consistent with the fact that the drivers are frequently not aware of their errors in foot placement.

He points out that once the unintended acceleration is initiated, a serious contributing factor is the failure to detect and correct the pedal errors, mainly because of lack of effective feedback processing from the well-learned, essentially automatic foot movements. He refers to the fact that the onset of the unintended acceleration may produce a startle reaction compounded by severe time stress, placing the individual in a state of hypervigilance in which information-processing activities necessary to take effective action are seriously disrupted. He further

concludes that the literature is reasonably consistent in supporting the hypothesis of foot placement errors as the major cause of the unintended acceleration. (83)

16. W. Reinhart, "The Effect of Countermeasure To Reduce the Incidence of Unintended Acceleration Accidents." Author reviews the data pertaining to the scope of the Unintended Acceleration (UA) problem as defined by the number of accidents and injuries reported annually to NHTSA. Two specific examples of the UA accidents with fatalities are reviewed. Although most drivers who experienced a UA accident claim that the vehicle had some defect, upon close investigation of the vehicle no defects were found. However, the driver often does not believe that explanation, since he or she has correctly applied a brake pedal without error on thousands of previous occasions. (84)