II. Description of Accident Flight

USAir Flight 427, a Boeing 737-3B7, crashed while maneuvering to land at Pittsburgh International Airport on September 8, 1994. The 737 was flying at 190 knots, and leveling off at approximately 6,000 feet following a descent from 11,000 feet. The weather was good; sky clear, visibility 15 miles, with the wind from 250 degrees at 7 knots. The flaps were at 1 and the landing gear was retracted. The autopilot and autothrottle systems were engaged. As the accident sequence began, the airplane was rolling out of a 15 degree left turn toward wings level at a roll rate of about 2 deg/sec.

The flight is known to have encountered the wake of a 727 that preceded it by approximately 69 seconds. As a result of this encounter, Flight 427 started to roll to the left. The roll was stopped several times during the accident sequence, but control was eventually lost when the airplane stalled. During the accident sequence, after the initial roll, the rudder deflected from neutral to its blowdown limit,[1] and is believed to have remained at blowdown until impact.

A. Facts from DFDR/CVR and Radar Data

Figure 1 shows the parameters recorded on the digital flight data recorder (DFDR), annotated with the crew comments and other sounds from the cockpit voice recorder (CVR) for the final 30 seconds of the flight. The captain's and the F/O's comments are designated "C" and "F/O" respectively in Figure 1.

The following summarizes facts significant to the investigation that were obtained from the DFDR, CVR, and radar recordings:

1. A Delta 727 passed the area of the accident approximately 69 seconds prior to the start of the accident sequence.
2. Flight 427 encountered the 727's wake, passing directly through the center of the right core.
3. Both crew members made verbal utterances of surprise when startled by the effects of the wake vortex.
4. Prior to any rapid change in yaw rate, Flight 427 rolled to the left, followed by an unusually large roll acceleration[2] to the right.
5. The captain uttered the comment, "Whoa," just as the maximum roll rate to the right was reached.
6. The roll to the left was arrested three times during the accident sequence.
7. The autopilot was disconnected at time 139.4, but the horn continued to sound.
8. The control column had been pulled essentially full aft by time 144, by which time the airplane had reached a 70 degree left bank and a 19 degree nose down pitch attitude.
9. Flight 427 stalled during the accident sequence, which was caused by the aft-column input recorded on the DFDR.
10. The captain commanded, "Pull," several times just prior to impact.
11. The control column remained essentially full aft from time 144 until impact.

[1] Rudder blowdown occurs when the aerodynamic loads on the rudder become equal to the force that the power control unit (PCU) can apply to the rudder. Rudder deflection is then limited to less than its full mechanical range.

[2] Note that roll rates and roll accelerations are calculated directly from bank angle which is recorded on the DFDR.

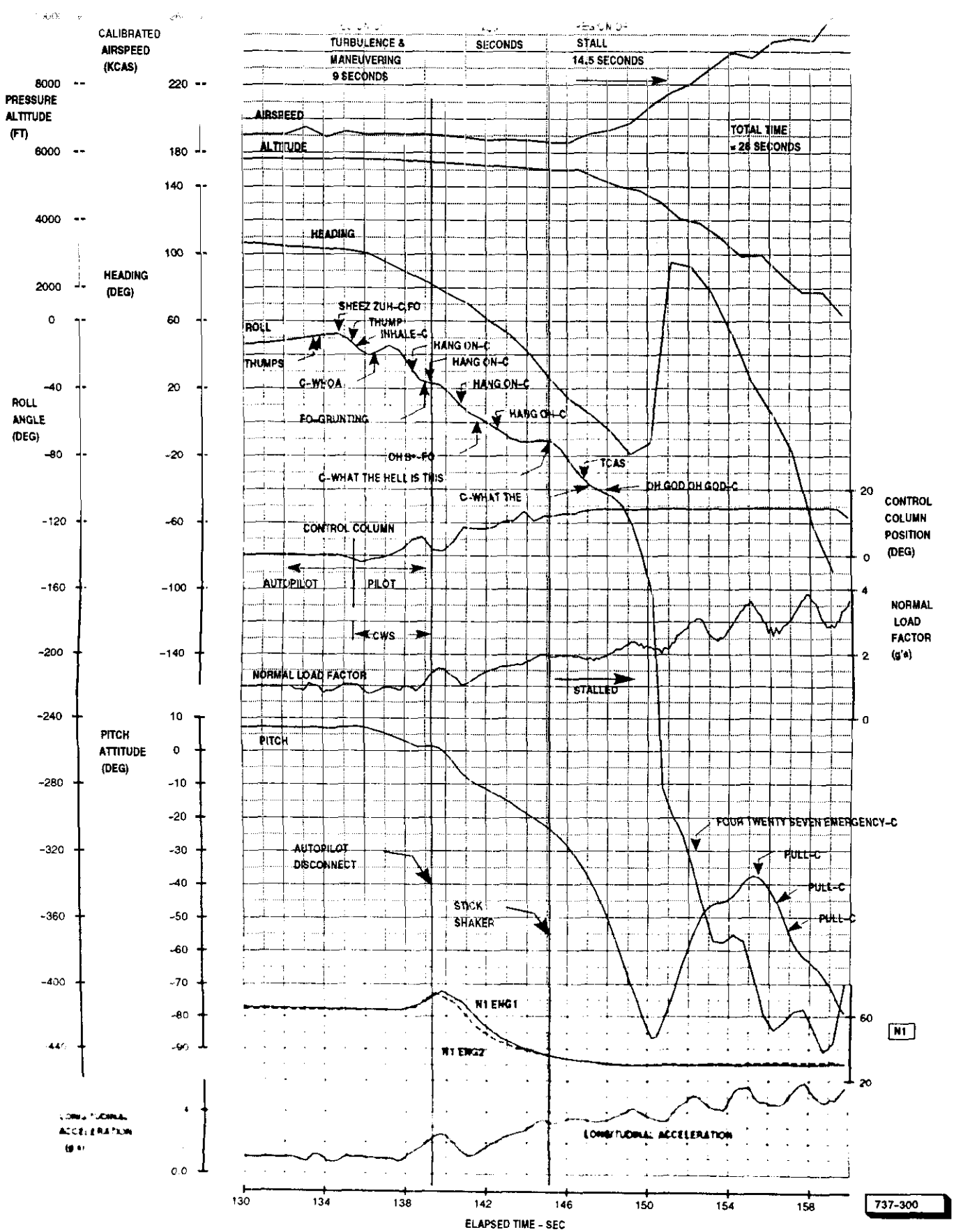


Figure 1: Flight 427 DFDR Annotated Plot

B. Kinematic Analysis of DFDR

In the course of the Flight 427 accident investigation, much effort has been directed at understanding the encounter with the 727 wake, and the flight crew's subsequent response to that encounter. As a part of this effort, an exhaustive kinematic analysis of the DFDR data was conducted to determine as much information as possible about the lateral and directional control positions (which were not recorded on the DFDR) during the accident sequence. Appendix A provides a detailed explanation of this kinematic analysis, which employs a process validated by Dennis Crider of the NTSB.[3]

The kinematic analysis required that the effects of the 727 wake on the 737 first be determined and introduced into the analysis. A flight test program,[4] conducted by the NTSB Performance Group at the FAA Flight Test Center near Atlantic City, used an FAA 727 and a USAir 737-300 to acquire the required information.

This wake flight test program provided the data necessary to locate the 727 wake relative to the 737 during the accident sequence. The flight test data also allowed the mathematical model of the wake to be verified and improved based on actual data. This process is documented in an NTSB report.[5]

The results of the kinematic analysis provide significant information as to the control activity during the accident sequence. Figure 2 provides time histories of the roll angle, rate, and acceleration; and of the yaw angle (heading), rate, and acceleration; along with the estimated wheel and rudder angles. Significant pilot comments and cockpit sounds are superimposed on this plot. In Figure 2, comments by the F/O are designated "HOT2." All other comments are by the captain

Note that the roll accelerations induced by the wake and wheel, before any rudder activity, are dramatically higher than would typically be experienced by a line pilot during normal flight with the autopilot engaged. Normal autopilot roll accelerations are in the region of 2 deg/sec^2. By contrast, the initial left roll acceleration due to the wake was approximately 19 deg/sec^2, followed by a roll acceleration to the right due to pilot commands of approximately 36 deg/sec^2. It is also important to observe that the wheel time history, shown in Figure 2, is consistent with that derived during the NTSB validation of the Boeing kinematic process.

Obtaining the rudder time history is more challenging because airplane heading—the primary parameter for determining rudder position—was recorded on the DFDR only once every second, whereas roll angle—the primary parameter for determining wheel position—was recorded twice a second. The Boeing interpolation of heading resulted in the rudder position shown in Figure 2. The derived wheel and rudder positions are also shown using an expanded time scale in Figure 3, along with the column position from the DFDR and the engine RPM. Pilot comments and cockpit sounds are shown for reference.

The NTSB Performance Group looked at several other methods of interpolating the heading data. All of the results are shown in Figure 4, and are discussed in the NTSB study. Examination of the various resulting rudder traces shows that the derived rudder before time 136.8, and after time 138.8, are essentially the same. The only difference is the rudder position time history as it transitioned from near neutral to its blowdown limit. The rudder time histories that evolved from the various analyses will be used in later analysis to evaluate pilot response and rudder system failure scenarios.

In addition to Figures 1, 2, and 3, the data derived here is shown in Appendix A in a series of animation stills.

[3] *Kinematic Validation Study,* NTSB Study, Feb. 15, 1997.
[4] *Wake Vortex Flight Test*, NTSB Factual Report, to be issued (test conducted Sep. 1995).
[5] *Kinematic Study Update: Derivation of Lateral and Directional Control Surface Positions,* NTSB Study, June 11, 1997.

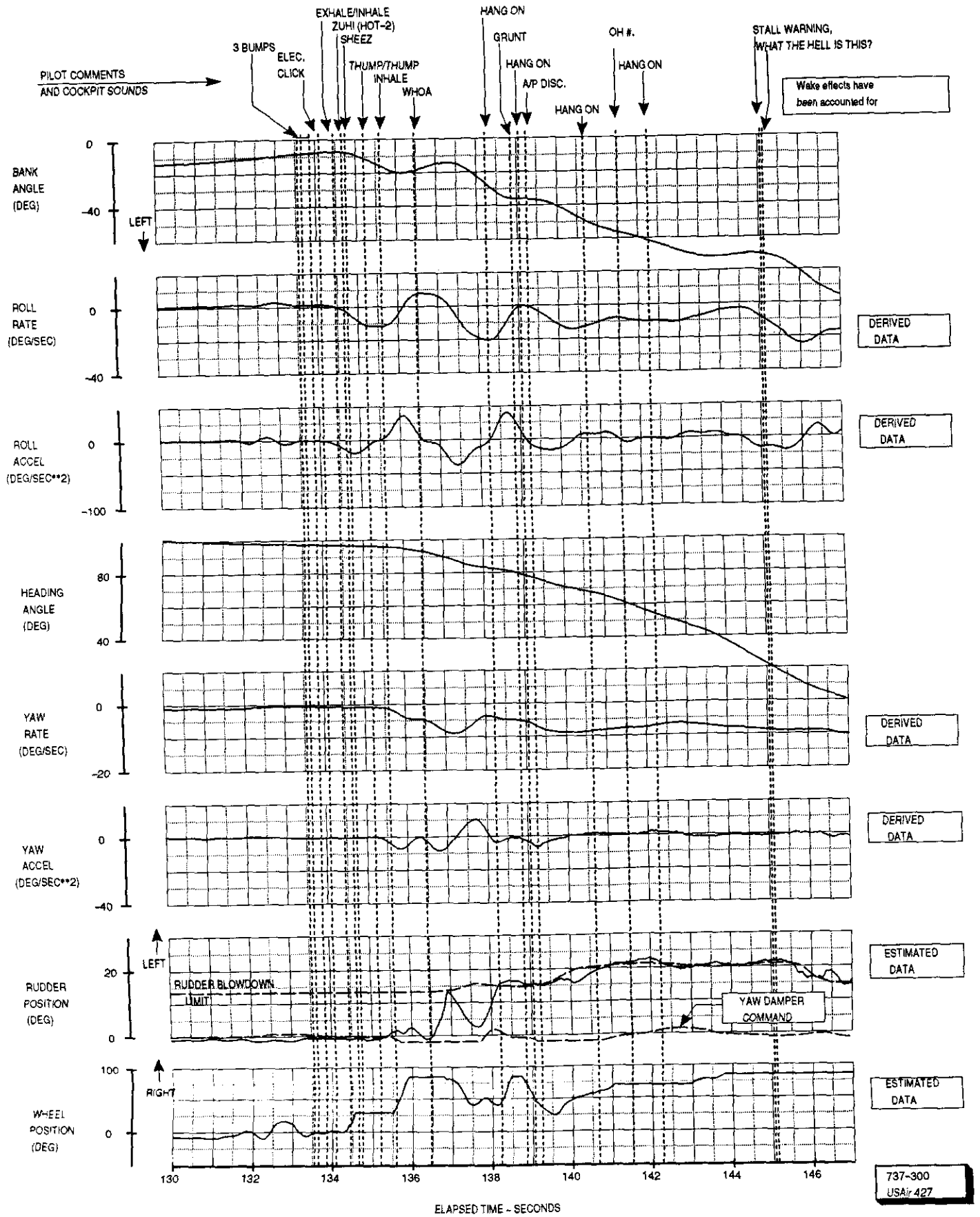
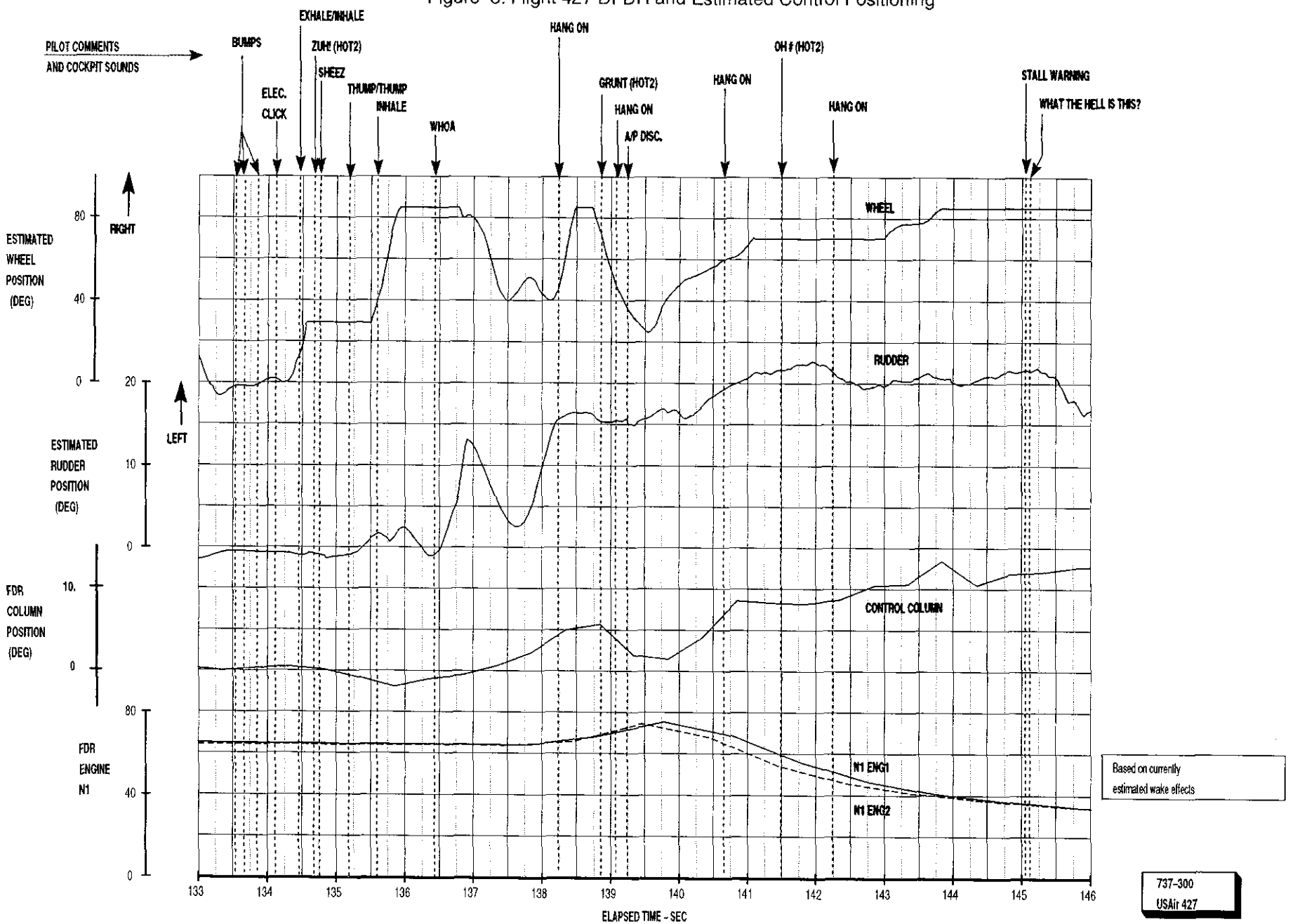


Figure 2: Flight 427 Accident Sequence Time Histories

Figure 3: Flight 427 DFDR and Estimated Control Positioning



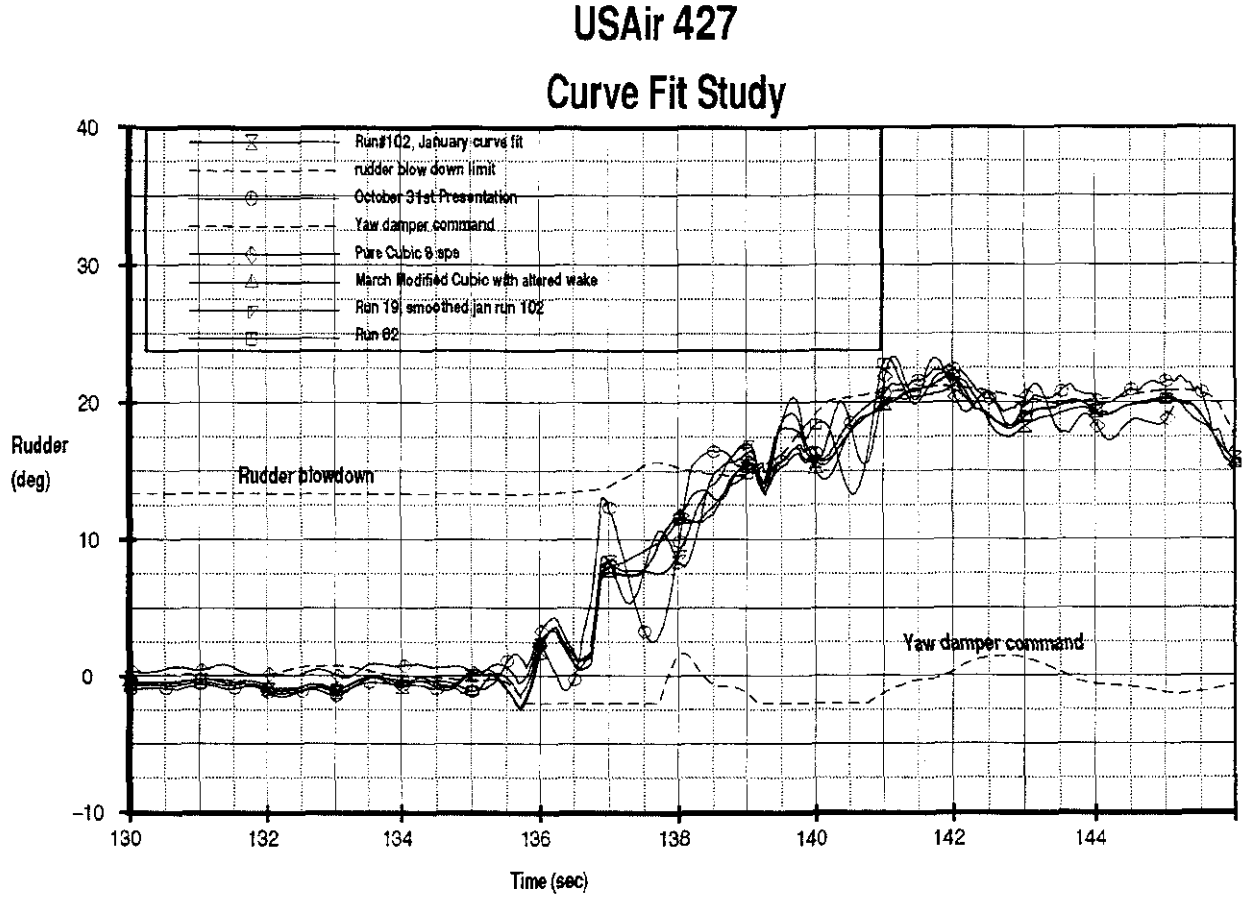


Figure 4: Results of Different Methods of Interpolating Heading Data

The following summarizes the pertinent information obtained from the kinematic analysis:

1. Application of the wheel during the accident sequence caused the roll acceleration to oscillate to values larger than those experienced during the initial upset due to the 727 wake encounter.
2. Before any rudder deflection occurred, the crew experienced two roll accelerations 10 to 18 times larger than would normally be encountered in smooth air with the autopilot engaged, first to the left due to the wake, and then to the right due to manual wheel inputs.
3. The wheel time history determined by Boeing is consistent with that derived during the NTSB validation process.
4. Several rudder traces were derived from the DFDR data by varying the interpolation methods used on the recorded heading.
5. The analysis established a boundary on possible rudder deflection time histories, and there is agreement on rudder activity before time 136.8 and after time 138.8.
6. The aircraft stalled because of the essentially full aft column deflection, as recorded on the DFDR.
7. The stall occurred at approximately 4,300 feet above ground level, 14 seconds before impact.

C. Timeline of Event

As the accident sequence begins, the airplane is rolling out of a 15 degree left bank toward wings level at 6,000 feet with the autopilot and autothrottle systems engaged. The crew had been looking for traffic reported by the Pittsburgh approach controller at "one to two o'clock, six miles, northbound Jetstream climbing out of thirty-three for five thousand." The F/O, who is the pilot flying, comments that he sees the jetstream as the accident sequence begins.

DFDR

time[6]

132.4: At a left bank angle of 11 degrees, rolling right towards wings level, the longitudinal acceleration, normal load factor and airspeed traces on the DFDR show perturbations that are caused by the 737 intercepting the wake of a Delta 727 several miles ahead (as confirmed subsequently by radar data and flight testing).

134.2: As a result of the encounter with the 727 wake, the roll angle begins to deviate from the intended return to wings level. In less than a second, roll acceleration peaks at approximately 19 deg/sec^2 to the left due to the wake, and the pilots utter exclamations of surprise that sound like "sheeez" and "zuh." The wheel moves to approximately 30 degrees right, which is consistent with the autopilot limit.

135.2: A distinct "thump" is heard on the CVR. Subsequent flight testing confirmed this sound to be the fuselage of the 737 encountering the center of the 727's right wake core. By this time, the roll angle—which had reached a minimum of 8 degrees left—moves through 14 degrees left at a maximum roll rate of 12 deg/sec.

135.5: The crew overrides the autopilot roll mode (dropping the autopilot into a control wheel steering [CWS] mode) by making a rapid and large right wheel command, which reaches 85 degrees of right wheel by time 136.1.

135.6: The captain inhales deeply.

136.2: The roll angle has reached 20 degrees left, but as a result of the right wheel inputs the roll rate to the left has stopped and roll acceleration peaks at approximately 36 deg/sec^2 to the right, causing the 737 to begin rolling back toward wings level again.

136.4-136.5: The maximum roll rate toward the right is 8 deg/sec, but the roll angle only reaches a minimum of 14 degrees left (at 137.3). As the maximum roll rate to the right is reached, the captain says "Whoa." The rudder and heading start to move significantly to the left. This is the first significant deflection of the rudder. Up to this time, the column has been moved from neutral to slightly nose down, then back to neutral.

137.0: Half of the right wheel input is removed, and the column begins to move aft in a nose-up command.

137.4: The roll rate then builds to the left again, with roll acceleration peaking at 38 deg/sec^2 to the left.

138.0: The engine rpm starts to increase coincident with an increase in longitudinal acceleration.

138.2: Roll rate reaches a maximum of 20 deg/sec to the left, and the captain comments, "Hang on."

138.2: The wheel is returned quickly to its full right position.

138.7: The roll acceleration peaks at 39 deg/sec^2 to the right, and the right wheel again starts

[6] All times are given as elapsed time in seconds with zero at DFDR relative time 10:30:00 and CVR relative time 1901:42.8. These elapsed times are consistent with all NTSB Performance Group analysis times.

moving left, back toward neutral.

138.2-138.8: The rudder reaches the left blowdown limit and remains at blowdown until impact. The F/O is grunting as the column begins to move back toward neutral and the right wheel input is reduced.

138.9: The load factor starts to increase, peaking at 1.5 g's.

139.2: The roll rate is again brought to zero at a roll angle of 36 degrees to the left. The captain again comments, "Hang on."

139.4: The autopilot disconnect wailing horn sounds and remains on during the remainder of the flight, indicating that the crew had disconnected the autopilot but had not silenced the horn by pushing the disconnect button on the wheel a second time.

139.7: The roll acceleration peaks at 16 deg/sec^2 to the left.

139.8: The engine rpm starts to decrease at the maximum engine deceleration rate to idle, where it remains until impact.

139.8-140.8: The column moves sharply aft to counteract the nose drop caused by the roll, then continues aft until full-nose-up column is being commanded by time 148.

140.9: The captain yet again comments, "Hang on." Pitch attitude by this time is about 8 degrees nose down.

140.9-144.5: The load factor—which had returned to approximately 1g—increases steadily to 2 g's.

141.1: Near full right wheel is applied.

142.5: The captain yet again says, "Hang on."

143.8: Full right wheel is applied and held until impact.

144.0: Roll rate has again nearly stopped, with the roll angle at 72 degrees left bank and pitch attitude 19 degrees nose down. The control column is essentially full aft.

144.8: The onset of stall buffet is heard on the CVR.

145.4: The stick shaker activates. The pilot comments, "What the hell is this?" as the stall begins. Load factor, now 2 g's, starts oscillating, increasing to 3.7 g's at impact.

146.0: Airspeed and altitude remained relatively constant up to this time, with airspeed decreasing just 5 knots and altitude decreasing just 300 feet. Beyond this time, airspeed increases and altitude decreases rapidly.

148.0: Full aft column, is applied and continues until less than a second before impact.

150.2: The greatest nose-down pitch attitude of 86 degrees is reached.

152.3: The captain comments, "Four-twenty-seven, emergency."

155.4: The captain comments, "Pull."

156.4: The captain comments, "Pull."

157.0: The captain comments, "Pull."

160.1: The airplane impacts the ground.