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NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

McDONNELL DOUGLAS CORPORATION,
DC-9-80, N1002G,
YUMA, ARIZONA,
JUNE 19, 1980.

NTSB-AAR-81-16

UNITED STATES GOVERNMENT

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16. Abstract About 1349 m.s.t., June 19, 1980, a McDonnell Douglas DC-9-80, N1002G, skidded off the right side of runway 21R while attempting a simulated hydraulic-systems-inoperative landing at the Yuma International Airport, Yuma, Arizona. The aircraft came to rest about 6,700 feet beyond the landing threshold of the runway. The aircraft was damaged substantially, however the three flightcrew members were not injured. There were no passengers. The weather was clear.

The aircraft was on a certification test flight. The purpose of the flight was to show that the aircraft could be controlled adequately and landed safely with a complete failure of its hydraulic systems. The aircraft landed about 1,735 feet beyond the threshold of runway 21R, and the pilot deployed the thrust reversers and applied reverse thrust before the nosewheel touched down. The aircraft began to yaw, continued to yaw after the nosewheel touched down, and then ground looped to the right and slid off the right side of the runway.

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate procedure established for the certification test flight, and the pilot's mismanagement of thrust following the initial loss of directional control.

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AIRCRAFT ACCIDENT REPORT

Adopted: September 15, 1981

McDONNELL DOUGLAS CORPORATION
DC-9-80, N1002G
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SYNOPSIS

About 1849 mountain standard time, June 19, 1980, a McDonnell Douglas DC-9-80, N1002G, skidded off the right side of runway 21R while attempting a simulated hydraulic-systems-inoperative landing at the Yuma International Airport, Yuma, Arizona. The aircraft came to rest about 8,700 feet beyond the landing threshold of the runway. Although the aircraft was damaged substantially the three flightcrew members were not injured. There were no passengers. The weather was clear, and the runway was dry.

The aircraft was on an FAA certification test flight to demonstrate compliance with a special condition to 14 CFR Part 25. The purpose of the flight was to show that the aircraft could be controlled adequately and landed safely with a complete failure of its hydraulic systems. The aircraft landed about 1,735 feet beyond the threshold of runway 21R, and the pilot deployed the thrust reversers and applied reverse thrust before the nosewheel touched down. The aircraft began to yaw, continued to yaw after the nosewheel touched down, it then ground looped to the right, and slid off the right side of the runway.

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate procedure established for the certification test flight, and the pilot's mismanagement of thrust following the initial loss of directional control.

1. FACTUAL INFORMATION

1.1 History of the Flight

About 1820 m.s.t., 1/ June 19, 1980, a McDonnell Douglas Corporation, DC-9-80, N1002G, took off from the Yuma International Airport, Yuma, Arizona, on an FAA certification test flight required by a special condition to 14 CFR Part 25. The purpose of the flight was to demonstrate that the aircraft could be flown and landed safely with a complete failure of its hydraulic systems. The flightcrew consisted of a Federal Aviation Administration (FAA) project pilot, referred to herein as the pilot, who occupied the cockpit's left seat and flew the aircraft; a McDonnell Douglas engineering test pilot, referred to herein as the copilot, who occupied the right seat and performed the copilot's duties but was designated as pilot-in-command by McDonnell Douglas; and a McDonnell Douglas flight test engineer assigned to monitor the aircraft's flight test instrumentation.

The certification test flight profile required the flightcrew to perform a low approach and go-around followed by another approach and full-stop landing. Both maneuvers were to be flown without hydraulic pressure. The purpose of the go-around

1/ All times herein are mountain standard time based on the 24-hour clock.

was to verify that the aircraft was controllable and stable in ground effect with the landing gear doors open.

According to the flightcrew, a standard preflight briefing was conducted. In addition to the flightcrew, the briefing was attended by McDonnell Douglas' chief engineering test pilot, various McDonnell Douglas maintenance personnel, and FAA and McDonnell Douglas engineering personnel. The purpose of the flight and the maneuvers to be performed were briefed from the applicable flight card. According to the pilots, since the aircraft was to be landed with its rudder hydraulic boost, antiskid, and nosewheel steering systems deactivated, their principal areas of concern during the landing were: (1) to insure that reverse thrust was applied symmetrically; (2) to obtain good nosewheel tracking since only the manual rudder would be available for directional control; and (3) to apply wheel brakes gently since there would be no locked-wheel protection. The copilot also stated that, if an overrun appeared imminent, he was prepared to turn on the electric auxiliary hydraulic pump ". . .for use in the brakes if we were to run out of accumulator pressure." The cockpit voice recorder (CVR) transcript showed that the copilot told the pilot that he would turn the auxiliary hydraulic pump on anytime the pilot wanted it or anytime he (the copilot) felt it was needed.

The engine thrust reversers were checked and found to be operable before the engines were started. The nosewheel steering and centering systems were checked during taxi and all systems operated satisfactorily. The takeoff was uneventful.

The low approach and go-around were flown, the hydraulic systems were turned off, pressure was bled down, the rudder power switch was turned off, and the landing gear was extended using the alternate extension system. According to the pilots, the flight characteristics of the aircraft with the landing gear doors open during these maneuvers were "excellent" and flightpath control was accomplished "easily." A missed approach was then made during which the hydraulic systems were turned on and the landing gear was retracted. After the missed approach was completed, the landing gear was extended, the aircraft was reconfigured for the hydraulic systems inoperative landing, the hydraulic systems were turned off, and the pressure bled down. The first attempt to land without hydraulic pressure was rejected about 800 feet above the ground (AGL) because the warning light for "parking brakes set" was lit. The flightcrew asked the company's chief engineering test pilot about this indication and were told that this is a normal indication when the antiskid system is turned off. The test flight was continued.

A normal traffic pattern was flown, and the aircraft was aligned with runway 21R for the approach and landing. The aircraft was configured as follows: the landing gear was down and locked and the landing gear doors were closed; the leading edge slats and trailing edge flaps were retracted; the rudder power selector lever was in the manual position; the automatic spoiler extension system was disarmed; the left and right engine hydraulic pumps were off; the auxiliary hydraulic pump and hydraulic power transfer unit switches were off; the left and right hydraulic systems had been depressurized and their pressure gauges read zero; and the left and right brake pressure gauges indicated brake accumulator pressure--2,900 psi. Based on this configuration, the aircraft's hydraulic systems were inoperative for the approach and landing. The landing would be made without trailing edge flaps and leading edge slats; the spoilers would not extend automatically at touchdown nor could they be extended manually. With the rudder in the manual operation mode, rudder movement would be generated by aerodynamic forces on the rudder control tab. However, brakes and thrust reversers could be operated through each system's accumulator pressures.

The aircraft's estimated landing gross weight was 113,700 pounds; the estimated center of gravity was 33.4 percent mean aerodynamic chord; and the reference indicated airspeed (V_{ref}) for the approach was 183 knots (KIAS). The final approach was flown on the ILS glidepath. According to the pilot, about 20 feet AGL, he retarded the thrust levers to the flight-idle position and a "soft touchdown" was made just past the arresting cable, 1,831 feet beyond the landing threshold of the runway. The copilot confirmed the estimate of the landing point and also said that the aircraft landed at 175 KIAS.

According to the pilot, he selected reverse thrust at touchdown by rotating the piggyback reverse thrust levers to their "10 or 11 o'clock position." He said he "noted symmetric deployment of the reversers and lowered the nose to the runway." The pilot said that he did not notice any asymmetrical reverse thrust tendencies or any directional deviation of the aircraft until the nosewheel had touched down. When the nosewheel touched down, the aircraft began an immediate deflection to the left.

During an interview after the accident, the copilot stated that reverse thrust was selected when the main landing gear touched down, and the aircraft began to drift to the left when the nosewheel touched down. However, during a later interview, he said that in retrospect he "sort of decided that it (the aircraft's leftward drift) happened between main gear and nose gear touchdown. . . ."

The pilot said that, as the nosewheel touched down and the aircraft began to drift toward the left side of the runway, he depressed the right rudder pedal fully to correct the drift. He said that within a few seconds it became obvious that the use of just the rudder was not going to prevent the aircraft from running off the left side of the runway. He then tapped the right brake pedal, the right tires failed, and the aircraft began to yaw to the right "strongly."

The copilot said that when he saw that the left drift was not being corrected, he placed the auxiliary hydraulic pump switch to the "on" position and notified the pilot of his action. Shortly thereafter, he "heard a right main wheel tire blow out and the aircraft began to turn to the right."

The pilot said that he tried to stop the right turn and yaw with left rudder and then left brake, but ". . .the airplane continued to yaw and track to the right." He said that he tried to stow the reverse thrust levers at the first indication that the use of the left rudder and left wheel brake "was now insufficient to counteract the right yawing action."

According to the copilot, after the right tire blew out, the aircraft turned to the right, began a left skid, and with the nose pointing about 15° to the right of the runway heading, it began to drift toward the right edge of the runway. He heard a left tire blow out as the skid and yaw continued. The aircraft continued to rotate to the right and ran off the right side of the runway with its nose pointed about 90° to the right of the runway heading. The copilot said that to his knowledge he did not ". . .touch the rudder pedals, brakes, or control wheel during the accident."

After the aircraft left the pavement, the left main gear collapsed and the right main gear and the nose gear separated from the aircraft. The aircraft came to rest on its lower fuselage about 50 feet beyond the right edge of the runway and on a magnetic heading of 19°. The wreckage site was about 6,700 feet beyond the landing threshold of runway 21R; the coordinates of the site were 32°39'N, and 114°37'W.

Witnesses to the accident confirmed the pilots' description of the landing. The consensus of their statements indicated that the thrust reversers began to deploy when the main landing gear touched down, and they deployed fully before the nosewheel was lowered to the runway.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	0	0
Minor/None	3	0	0
Total	3	0	0

1.3 Damage to Aircraft

The aircraft was damaged substantially.

1.4 Other Damages

Not applicable.

1.5 Personnel Information

Both pilots were qualified in accordance with existing regulations. (See appendix B.) Both pilots stated that this was the first time they had ever attempted this test flight maneuver. This was the first flight of the day for the copilot; the pilot had flown earlier on the day of the accident, and the flight was made in the accident aircraft. Both pilots had been off duty more than 12 hours before reporting for duty on the day of the accident.

1.6 Aircraft Information

The aircraft, a McDonnell Douglas DC-9-80, was owned and operated by the company, and was an experimental certificated aircraft. The aircraft was maintained in accordance with prescribed maintenance regulations and procedures and had flown 6 hrs 16 min at the time of the accident.

The aircraft was powered by two Pratt & Whitney JT8D-209 engines which have a normal static takeoff thrust rating of 18,500 pounds and a maximum takeoff thrust rating of 19,250 pounds. The aircraft was within the prescribed weight and balance limitations for the flight.

The review of the aircraft's maintenance records revealed several Pilot Flight Inspection Report entries (Douglas Form 92-17-1) relating to reverse thrust discrepancies. These entries concerned malfunction of the system's indicator lights and thrust lever alignment problems. The maintenance records disclosed that actions to correct these writeups had been taken.

On June 19, 1980, the Form 92-17-1 for the flight before the accident contained the following writeup: "Item 1, Airplane pulls left during high speed taxi after left steering input." and, "Item 4, Right reverser hangs up going into reverse at the interlock position."

The aircraft's rudder pedal steering mechanism had been disconnected in order to perform a certification demonstration on the previous flight. The Inspection Discrepancy Report--Corrective Action (Douglas Form 92-42) contained the following entry with regard to item No. 1: "Pilot item No. 1, Engn Act (Engineering Action). Reconnected per F4040A, Flight Development Engineering Order." This entry showed that the rudder pedal steering mechanism had been reconnected in accordance with the provisions and procedures of the cited order. The Form 92-42 contained the following entry with regard to item No. 4: "Item 4, NTDF No. 251 (Not to delay flight No. 251)."

After the preflight briefing, the copilot met with the McDonnell Douglas chief engineering test pilot. During this meeting, the nosewheel tracking problem on the previous flight was discussed. The chief engineering pilot asked that an additional check be made to ascertain whether the aircraft would taxi straight ahead without hydraulic power. The copilot said that he informed the pilot of this request; however, the test was not performed. According to the copilot, he forgot about the request until after the aircraft had taxied into the takeoff position. At that time he asked the pilot if he wanted to perform the check, and the pilot said he did not.

The copilot also said that he did not discuss the writeup concerning the right reverser with the pilot. He said that this malfunction was pointed out during the preflight briefing and that the pilot had flown the aircraft on that flight. Therefore, he assumed that the pilot was "as aware of these discrepancies as I was."

1.7 Meteorological Information

The reported weather at the time of the accident was as follows: clear; visibility -- 7 miles; temperature -- 102.8° F; wind -- 280° at 7 kns; altimeter setting -- 29.73 inHg.

1.8 Aids to Navigation

Not relevant.

1.9 Communications

Not relevant.

1.10 Aerodrome Information

Yuma International Airport, elevation 213 feet m.s.l., is located 3 miles southeast of Yuma, Arizona. The airport is served by five runways. Runway 21R is concrete surfaced, 13,300 feet long and 200 feet wide. The pavement was dry at the time of the accident.

1.11 Flight Recorders

The aircraft was equipped with a Sundstrand Data Control digital flight data recorder (DFDR), serial No. 2862, and a Sundstrand Data Control cockpit voice recorder, serial No. 9194. Neither recorder was damaged. Their recording media were read out at the manufacturer's Long Beach, California, facility and the pertinent portions of the media were transcribed, examined, and verified by the Safety Board.

The CVR readout was conducted under the supervision of Safety Board personnel. The shuttle-type CVR records forward for 15 minutes, then reverses and records in reverse for 15 minutes. About 8.5 seconds after landing, the CVR went into the self-test mode. In this mode, a short 400 Hz tone is applied, the recorder reverses, another tone is applied to test the reverse track, and the recorder continues in reverse. The self-test reversal takes place about 2.5 minutes from the recorder's reverse point, thus leaving about 5 minutes of old data on the tape. A complete CVR transcript was made by playing the tape to the first tone, then advancing the tape to the next tone--about a 5-minute interval--which signaled the continuation of the recording.

In addition, the aircraft was equipped with an inertial navigation system (INS) and on-board flight test instrumentation which recorded the following performance parameters: nosewheel and main landing gear wheel touchdown; aircraft yaw rate and yaw acceleration; engine reverser operation; forward and reverse thrust expressed in engine pressure ratios (EPR); wheel brake system operation; flight control deflections; and a time baseline. Because of the availability of additional data, the flight test instrumentation was used instead of the DFDR data to correlate the various performance parameters. However, the DFDR was used to validate the on-board flight test instrumentation data.

The on-board instrumentation data, INS data, and the tire marks on the runway--which began upon application of the right brake--were used to reconstruct the groundtrack and timing of the landing roll. In order to locate the touchdown point, it was necessary to use INS data. The INS velocities were used to obtain a calculated aircraft groundtrack. With some minor adjustments to these velocities, the integration produced a track which closely matched the actual ground track after brake application. Since the known groundtrack was matched so well, the Safety Board assumed that the calculated groundtrack from touchdown time to the time of the right brake application was a valid reconstruction of the actual ground-track. The data showed that between 1848:47.8 and 1848:48, the main landing gear struts compressed slightly, returned to their neutral position, then compressed again. Thereafter, the struts did not return to their neutral position. Simultaneous with the slight initial compression of the main landing gear struts, the aircraft's longitudinal accelerometer depicted a longitudinal deceleration, indicating that a slight skip had occurred. The final compression of the main landing gear struts occurred at 1848:48.9, and this time was used as the time of main landing gear touchdown for the groundtrack calculations. The INS data showed that the aircraft traveled about 4,785 feet along the runway before its center of gravity crossed the right edge of the runway. Since the physical evidence showed that the aircraft center of gravity left the runway about 6,520 feet beyond the landing threshold, main landing gear touchdown occurred about 1,735 feet beyond the landing threshold of runway 21R. The calculated point was within 96 feet of arresting cable and closely approximated the pilot's and copilot's estimate of main landing gear touchdown. (See appendix C.)

During the simulated hydraulic failure established for the test flight, the following aircraft controls and systems were available to the pilot for use during the landing and rollout: manual rudder, main wheel braking (limited by hydraulic accumulator pressure), reverse thrust, and limited nosewheel steering after the auxiliary hydraulic pump was turned on. In addition, the nosewheel was castering during the initial portion of the landing roll, thus providing some directional stability. Therefore, the instrumentation data cited herein reflect either the operation of these systems or the operation of systems which affect these systems. Unless otherwise noted, all times cited hereafter represent the time in seconds after main landing gear touchdown; the distances, in parentheses, represent the distance in feet beyond the runway's landing threshold; and unless otherwise specified, the amount of movement of the rudder and rudder control tab are expressed as hingewise angular deflections. Their direction of movement is depicted by the position of their trailing edges either left or right of the centerlines of the vertical stabilizer and rudder, respectively.

These data showed that the aircraft approached the runway with its nose aligned about 4° right of the runway heading. About [illegible] seconds before touchdown, the rudder was deflected about 2° left and the aircraft began to yaw left about 1°/second toward the runway heading. At 15 feet AGL, the thrust levers were retarded to their forward idle position. The aircraft landed near the runway centerline, about 173 KIAS, and its descent rate was less than 100 fpm. The aircraft's attitude at touchdown was as follows: pitch--5° aircraft noseup; roll--0.5° left wing down; heading--2° right of runway heading correcting back toward runway heading; and sideslip--2° left. Beginning at main landing gear touchdown, a 20-pound push force was exerted on the elevator column, and this force remained relatively constant until 4 seconds after the nosewheel touched down. About 1 second after touchdown, the rudder was returned to neutral as the aircraft continued to correct toward the runway heading.

About 1 second after main landing gear touchdown, reverse thrust began to increase on both engines; however, about 1 second later the thrust on each engine began increasing at different rates. Six seconds after main landing gear touchdown (at 3,470 feet) and coincident with nosewheel touchdown, reverse thrust had reached 1.60 EPR on the left engine and 1.38 EPR on the right engine. These levels created a 2,725-pound thrust differential and a nose left yawing moment of 37,800 foot-pounds. The aircraft had decelerated to 155 KIAS, and about 2 seconds to 2.5 seconds before the nosewheel touched down it had developed a yaw acceleration of 2°/second² to the left. About 1 second after the left yaw began, the pilot applied full right rudder pedal. The rudder control tab was deflected 20° to 22° left, and the rudder was deflected 12° to 13° right.

When the nosewheel touched down, the aircraft's nose was 1° left of the runway heading, the rudder was still deflected 12° to 13° right, and the yaw acceleration had stopped. However, the aircraft continued to yaw left at 2°/ second. The pilot applied the right brake for 0.5 second, released it, and then almost immediately reapplied the brake with continuous 2,350 psi right brake pressure. Since the antiskid had been turned off, the right main gear wheels (Nos. 3 and 4) locked up and began to skid, leaving marks on the runway. Two seconds later, 8 seconds after touchdown (at 4,000 feet), the No. 3 tire blew out.

When the No. 3 tire failed, the rudder was deflected 13° right; the aircraft was yawed about 4° left of the runway heading. About 0.1 second earlier the copilot had turned the auxiliary hydraulic pump on. Almost simultaneously with the tire failure, the right engine's reverse thrust began to increase, and shortly thereafter, the left engine's reverse thrust began to decrease.

At 8.8 seconds after touchdown (at 4,180 feet), the No. 4 tire blew out. The rudder was still 13° right, the reverse thrust on the left engine had decreased to 1.39 EPR while on the right engine it had increased to 1.63 EPR. The aircraft had yawed about 5° left of the runway heading. Within 0.5 seconds after the No. 4 tire failed, forward thrust was restored on the left engine, and the thrust decreased to forward idle.

When the No. 4 tire blew out, the aircraft had decelerated to 139 KIAS. Almost simultaneously, the aircraft began to yaw right, and within 1 second the yaw rate was 7°/second. Shortly after the onset of the right yaw, the rudder began to move left and the reverse thrust on the right engine began to decrease.

At 11 seconds after touchdown (at 4,680 feet), the aircraft had decelerated to 130 KIAS, the rudder control tab was deflected 22° right, and the rudder was deflected about 10° left. The right reverser was out of the engine's exhaust and the engine was producing 1.28 EPR forward thrust. The aircraft's nose was 3° right of the runway heading and it was yawing right about 6°/second. Although the rudder control tab remained at 22° right deflection, as the aircraft continued to yaw right and decelerate the rudder began to move right. About 1.5 second after the right reverser had been removed from the exhaust, the engine's thrust had decreased to forward idle where it remained until the aircraft came to rest.

Shortly after the aircraft started to yaw right, the pilot applied the left brake for about 1 second and then released it. About 12 seconds after touchdown (at 4,920 feet), the pilot reapplied 1,500 psi of left brake pressure. The aircraft had decelerated to about 129 KIAS, the nose was 11° right of the runway heading, and the yaw rate began to decrease. At 14.6 seconds after touchdown (at 5,480 feet and at 118 KIAS), the tires on the two left main gear wheels (Nos. 1 and 2) blew out. The aircraft's nose was about 21° right of the runway heading. The right yaw rate had decreased; however, after the Nos. 1 and 2 tires blew out the right yaw rate began to increase.

Between 12 seconds and 18.6 seconds after touchdown, the aircraft decelerated from 129 KIAS to about 36 KIAS and its nose rotated from 11° right to about 43° right of the runway heading. During this interval, the rudder control tab remained deflected about 24° to 26° right; however, the rudder began to trail in the streamwise direction. At 18 seconds after touchdown, when the aircraft's nose was about 38° right of the runway heading and at 80 KIAS, the rudder had deflected to about 23° right.

The aircraft continued down the runway skidding to the left and rotating to the right. At 21 seconds after touchdown (6,565 feet), the aircraft's main landing gear skidded off the right edge of the runway. The aircraft's nose pointed 73° right of the runway heading when the landing gear left the pavement. After it left the runway, the aircraft continued to slide and rotate to the right until it came to rest.

In addition to the data retrieval systems, the aircraft also was equipped with a cockpit camera operating at a film speed of 1 frame per second. The cockpit camera log disclosed that at touchdown the pilot was moving the reverse thrust levers aft and both engine reverser unlock lights were on. One second after touchdown, both engine reverse thrust lights were on and both engine EPR gauges read about 1.05 EPR. At 3 seconds after touchdown, the EPR readings on both engine have increased to 1.13 EPR. At 5 seconds after touchdown, the reverse thrust readings on the left and right engines were 1.58 EPR and 1.35 EPR, respectively. The camera data corroborate the other instrumentation data concerning this part of the flight, and both sources corroborate witness statements concerning the operation of the reversers.

1.12 Wreckage and Impact Information

The first tire marks attributable to the accident aircraft were located about 1,900 feet beyond the landing threshold of runway 21R. (All distances herein are expressed in feet beyond the landing threshold of runway 21R.) Starting at 4,000 feet, the first pieces of tire rubber and carcasses were found along the right side of the runway, and at 5,500 feet, pieces of tire rubber and carcass were found along the left side of the runway. About 3,500 feet, the rubber and wheel markings showed that the aircraft began to drift left of the runway centerline. At 5,500 feet, the centerline of the aircraft's fuselage was displaced about 10 feet left of the runway centerline. Thereafter, the aircraft began to track toward the right side of the runway and its rate of movement to the right increased as the landing roll continued. During this movement, the aircraft began rotating to the right and it entered a left skid.

About 6,310 feet, the nosewheel left the runway pavement with the aircraft's nose pointing about 54° to the right of the runway centerline. About 6,565 feet, the main gear left the pavement. The aircraft continued skidding left and rotating to the right in the sandy soil and came to rest with its nose pointing almost 180° from the direction of landing. During its off-runway movement, the aircraft sank into the soil, the left main landing gear collapsed into its wheel well, the right main gear separated in an outward direction from its main attach points, and the nose gear strut and wheel twisted off the nosewheel assembly.

The main landing gear wheels were damaged by contact with the runway surface after the tires failed. The blown out Nos. 1 and 2 tires remained on their respective wheel rims. Small sections of the outboard rim edges were broken out on both sides of each wheel.

The Nos. 3 and 4 tires separated from the wheel rims. The No. 3 wheel rim was worn flat for about 3 inches. The No. 4 wheel rim was worn flat for about 5 inches, and a 10-inch edge of the rim was broken out on the opposite side of the wheel from the worn spot.

All four brake assemblies were tested on the aircraft's left and right hydraulic systems and were found to function normally; no hydraulic fluid leakage was observed at any of the pistons. The brake assemblies were disassembled and the rotating discs, pressure plates, and back plates examined. Examination revealed no evidence of any preexisting malfunction or failure. The examination revealed evidence of discoloration, grooving, smearing, and the transfer of friction material from the rotating to the stationary discs. Some of the drive links on the rotating discs of the Nos. 3 and 4 brake assemblies had been milled down to the point of failure.

Except for the damage to the landing gear and main gear wheels and tires, the remainder of the damage to the aircraft was inflicted after the landing gear separated from the aircraft. The undersides of the fuselage and wings were damaged as the aircraft slid along the ground and the fuselage skin and longerons had buckled on the lower fuselage between fuselage stations (FS)-434 and -568, and between FS-1174 and -1307.

Examination of the empennage disclosed missing fasteners, skin separation, and minor skin buckles in the area of the vertical stabilizer. The horizontal stabilizers, elevators, and trim surfaces were not damaged; however, there was interference between the surfaces of the upper tailcone and rudder, which was caused by structural damage to the tailcone after the landing gear failed.

The examination of the engines disclosed that the No. 1 engine reverser was stowed, and the No. 2 engine reverser was deployed. The thrust reverser system was examined after both engines were removed from the aircraft, and both thrust levers and reverse thrust levers operated freely from the cockpit. Their continuity to their respective engines was intact. The examination of the linkages and actuators of both thrust reversers did not reveal any evidence of preexisting malfunction or failure. Both thrust reversers were connected to a hydraulic power test panel and they operated normally; there was no evidence of any binding at the interlock position.

Both fuel control units were removed and tested at Hamilton Standard, Inc., Long Beach, California. The tests were conducted under the supervision of the Safety Board and in accordance with the manufacturer's acceptance test procedures. The calibration and operational parameters of both units were found to be within the manufacturer's specifications. The tests did not disclose any evidence of failure or malfunction.

The cockpit controls and instruments were documented after the accident. The following pertinent readings and control positions were noted.

Control/Instrument		Position/Setting
Engine fire handles	--	Both pulled
Landing gear handle	--	Down
Stabilizer trim	--	1° noseup, switch-normal
Spoiler/speed brake lever	--	Retracted position
Rudder power lever	--	Manual
Thrust levers	--	Idle
Reverse thrust levers (Piggybacks)	--	Stowed
Left engine hydraulic pump switch	--	Off
Right engine hydraulic pump switch	--	Low
Hydraulic power transfer unit pump switch	--	Off
Hydraulic auxiliary pump switch	--	On
Hydraulic pressure gauge, left	--	Zero
Hydraulic pressure gauge, right	--	2,700 psi
Antiskid system	--	Off

1.13 Medical and Pathological Information

Not relevant.

1.14 Fire

At 1834, 18 minutes before the accident, there was 28,985 pounds of jet-A fuel on-board the aircraft distributed as follows: left main tank--8,195 pounds; center wing tank--12,760 pounds; and right main tank--8,030 pounds. Despite the damage to the underside of the wings and the bottom of the fuselage, there was no evidence of any spilled fuel and there was no fire. The airport fire department arrived on scene as the flightcrew exited the aircraft.

1.15 Survival Aspects

The integrity of the cockpit and cabin areas was not compromised during the accident sequence. After the aircraft stopped, the pilot shut down the engines and the flight test engineer opened the forward passenger entry door on the left side of the aircraft. All three flightcrew members exited through the open forward passenger door. It was not necessary to use the evacuation slides.

1.16 Tests and Research

During the investigation, test maneuvers were conducted to determine rudder control effectiveness under varying levels of forward and reverse engine thrust. In addition, the capability of the brake accumulator to sustain antiskid on braking operation with all hydraulic systems inoperative was evaluated.

1.16.1 Rudder Effectiveness

The rudder system of the DC-9-80 aircraft has two modes of operation--powered and manual. The right hydraulic system supplies hydraulic pressure to the rudder for the powered operation. If the No. 2 engine driven pump fails, the electric auxiliary hydraulic pump is available to pressurize the right system, and finally, if the pressure in the right system is lost, the left system can pressurize the right system through the operation of the hydraulic power transfer unit pumps.

During powered rudder operation, the rudder control tab is locked hydraulically. Rudder pedal movement activates the rudder and the locked control tab is faired with and moves with the rudder. Hydraulic power to the rudder may be shut off by placing the rudder power control handle on the control pedestal in the manual position. When hydraulic power to the rudder control unit is shut off or when the hydraulic pressure drops to about 950 psi, the rudder automatically reverts to manual operation, unlocking the rudder control tab. A light on the cockpit overhead annunciator panel comes on to indicate manual rudder operation.

During manual rudder operation, rudder pedal movement operates the rudder control tab. Aerodynamic force on the control tab moves the rudder; thus, in order to deflect the trailing edge of the rudder to the left, the control tab's trailing edge is deflected right. Performance data showed that when the rudder pedal is depressed to its full travel position, the control tab is deflected at least 22°.

In order to protect the empennage from overload in case of an inadvertent application of excessive rudder control, a rudder throw limiter is installed. As the aircraft's airspeed increases, the system decreases the amount of rudder travel available from about 22° to about 2.5°. During acceleration, rudder throw is unrestricted to 176 knots then will gradually reduce until reaching 2.5° at 300 knots. On deceleration, the throw will increase until reaching 22° at 157 knots.

The inputs to the rudder system are total air pressure from a pitot tube on the vertical stabilizer and static pressure inside the tailcone. Since the tailcone is vented by side louvers located in an area of ambient pressure during all forward thrust conditions, the static pressure inside the cone is also ambient under these conditions. The difference between the total and ambient air pressures--which is proportional to airspeed--operates the rudder throw limiter.

After the accident, the effectiveness of the rudder systems during ground operations was evaluated. The data herein were obtained either from test flights conducted before and after the accident or extrapolated from the data recorded on these test flights. The control capability of the rudder during both powered and manual operation was evaluated for various symmetric and asymmetric thrust conditions as well as the forward idle thrust condition. Yawing acceleration was derived and correlated with airspeed, rudder deflection angles, and reverse thrust EPR settings.

Directional controllability at various levels of symmetric forward and reverse thrust was determined by performing left and right turns with rudder pedal nosewheel steering rendered inoperative. Heading changes were made by rudder inputs alone. The values recorded during the tests were corrected to represent the yaw acceleration that would have been generated at maximum rudder deflection. The following table shows the yaw accelerations generated by the powered rudder at 140 knots equivalent airspeed 2/(KEAS) and at 90 KEAS:

2/ Calibrated airspeed corrected for compressibility.

Thrust	140 KEAS (degrees/second^2)	90 KEAS (degrees/second^2)
Forward Idle	3.5	1.5
Reverse Idle	2.	1.1
1.3 EPR Reverse	1.7	0.35

The manually operated rudder generated the following yaw accelerations:

Thrust	140 KEAS (degrees/second^2)	90 KEAS (degrees/second^2)
Forward Idle	2.9	1.3
Reverse Idle	2.55	1.1
1.3 EPR Reverse	1.75	0.35

The curves between the 140 KEAS and 90 KEAS points were essentially linear for both modes of rudder operation.

The flight test data showed that at 1.6 EPR symmetric reverse thrust and at 109 KEAS, the powered rudder control effectiveness was zero. Data for this thrust level were not obtained for higher speeds. Tests were not conducted to obtain data for the manual rudder at 1.6 EPR symmetric reverse thrust.

Directional control capability of the aircraft for the powered and manual modes of rudder operation with asymmetric thrust applied was determined with one engine at forward idle thrust and the other at various reverse thrust EPR settings. Rudder pedal nosewheel steering was rendered inoperative and the airspeed was decreased until full rudder input was required to maintain the aircraft's heading for that particular thrust level. The tests disclosed that in the powered mode at 140 KEAS directional control could be maintained with 1.52 EPR asymmetrical reverse thrust, while at 90 KEAS directional control could be maintained at 1.23 EPR reverse thrust. In the manual mode, directional control at 140 KEAS and 90 KEAS could be maintained at 1.45 EPR and 1.2 EPR reverse thrust, respectively. These tests were conducted to evaluate rudder effectiveness during an engine-out condition and to depict a conservative level of rudder effectiveness since the tests were conducted with the opposite engine at forward idle thrust. However, because of the nature of these asymmetric reverse thrust tests, the rudder was deflected away from the disturbing effects of the reversed engine; this was not true in the case of the accident aircraft, since both engines were delivering reverse thrust during the rollout.

During the powered rudder portion of the symmetric reverse thrust tests, the operation of the rudder limiter was evaluated at the following levels of symmetric reverse thrust: 1.3 EPR, 1.6 EPR, and 1.8 EPR. The test data indicate that as the level of reverse thrust increases, the static pressure inside and outside the tail cone decreases below ambient pressure while total pressure remains essentially the same. Thus, the differential pressure sensed by the rudder throw limiter is increased, since the pressure differential sensed by the limiter is a function of the level of the applied reverse thrust and airspeed. The test data indicate that at speeds between 138 KIAS to 180 KIAS and during symmetrical reverse thrust operation, the rudder limiter system restricted the rudder deflections from 15.4° to 17.4°, or about 2° to 5° less than the design limits.

The rudder limiter affects both the powered and manual modes of the rudder operation. The data retrieved from the accident aircraft showed that with about 1.3 EPR (right engine) and 1.6 EPR (left engine) reverse thrust applied and between 158 KIAS and

140 KIAS, full rudder pedal application produced a right rudder deflection of 11° to 12.5° hingewise. Thus, the data indicate that the manual rudder deflections during the accident were restricted, compared to the deflections of the powered rudder, by about 4.4° to 4.9°. However, based on the available data, the Safety Board cannot determine if this resulted from the operation of the rudder limiter or a degradation in aerodynamic hinge moment caused by the effect of thrust reverser outflow on the rudder control tab.

These data show that vertical stabilizer and rudder effectiveness increase as airspeed increases; thus, yawing acceleration generated by rudder deflection varies directly with airspeed. While interference caused by reverse thrust operation (tail blanking) decreases the effectiveness of the rudder, the magnitude of the interference at a given level of reverse thrust will vary directly with airspeed. The degree of tail blanking is a function of reverse thrust levels and airspeed, and is dependent on thrust reverser geometry and its relative position to the vertical fin and rudder.

In addition, test results also showed the effect of speed on runway directional control. These data were expressed as available control moments derived from the manual rudder, nosewheel steering, and differential wheel braking (antiskid system operative) at various speeds between 0 and 150 knots with no reverse thrust applied. The data showed that the available rudder control moments decreased from about 300,000 foot-pounds at 150 knots to about 36,000 foot-pounds at 50 knots. Differential wheel braking produced a control moment of about 300,000 foot-pounds at 150 knots and this increased to about 290,000 foot-pounds at 10 knots. The nosewheel steering produced a control moment of about 200,000 foot-pounds throughout the cited speed range.

Data also depicted the available control moments with symmetric 1.3 EPR reverse thrust on a wet runway. Since the runway was dry at the time of the accident, the data concerning nosewheel steering and differential braking would not be particularly relevant. However, the available control moment developed by the manual rudder was 150,000 foot-pounds at 150 knots, and this decreased to zero at 70 knots.

1.16.2 Antiskid System and Hydraulic Accumulators

After the accident, the brake accumulator was evaluated to determine if it would permit antiskid system operation during the landing roll with the hydraulic systems inoperative. The test showed that the accumulator's capacity was sufficient to sustain a steady application of the brakes with the antiskid system in operation and that the aircraft could be stopped safely in this configuration.

1.17 Other Information

1.17.1 Engine Thrust Reverser System

The left and right engine thrust reversers operate on pressure supplied by their respective hydraulic systems. Each reverser system is equipped with an accumulator to supply operating pressure in the event of a total loss of hydraulic system pressure. When the thrust reverser levers are moved toward the reverse thrust position, the reversers unlatch and start to extend. As the thrust reverser unlatches, a latch switch allows the engine reverser unlock light to illuminate. An interlock prevents the thrust reverser levers from being moved beyond the idle thrust position while the reversers are in transit. When the reversers are extended, a reverse-extended switch turns on the engine reverse thrust light, the interlock is removed, and reverse thrust can be applied as desired. Thrust reverser actuation time is about 2 seconds.

All DC-9 aircraft have essentially identical empennage configurations, engine locations, and thrust configurations. However, the JT8D-209 engine installations on the series 80 aircraft are larger than those on previous series DC-9 aircraft. Its target reversers are about 1.5 feet farther aft than those on the previous series, and the reversers are rotated 15° inboard. Extrapolation of test flight data showed that at the same levels of symmetrical reverse thrust, the yawing acceleration produced by maximum rudder deflection was similar for the series 80 aircraft and previous DC-9 aircraft. The data showed that the level of reverse thrust was the major variable affecting the effectiveness of the vertical stabilizer and rudder of any DC-9 aircraft.

The JT8D-209 engine produces about 2,000 to 4,500 lbs more thrust than the engines on the earlier DC-9's. Despite the increase in engine thrust for the DC-9-80 aircraft, the total amount of thrust reverser lever travel available to the pilot has remained the same as in the earlier DC-9 series. This has increased the gain or sensitivity of the thrust reverser levers since smaller lever deflections command greater changes in thrust levels.

Flight test data on previous DC-9-80 flights indicated that asymmetric reverse thrust encounters were a problem. After the accident, the thrust reverser rigging procedures (production and maintenance) were modified. Although the modifications do not change the sensitivity of the thrust lever system, they were designed to reduce the likelihood of asymmetry encounters during the application of reverse thrust.

1.17.2 Nosewheel Steering System

The nosewheel steering system consists of two independent control valves and two actuating cylinders--left and right--that are supplied hydraulic pressure from separate sources. The left and right actuating or steering cylinders receive pressure from their respective hydraulic systems. Except for slight reduction in steering angle, the steering system will function normally with one hydraulic system operating. Nosewheel steering is controlled by either the steering wheel or the rudder pedal. The nosewheel can be turned 82° left or right by the steering wheel and 17° left or right by the rudder pedals. When the auxiliary electric hydraulic pump was turned on, the right system was pressurized and both steering wheel and rudder pedal steering became available.

1.17.3 DC-9-80 Certification Procedures

The earlier DC-9 series aircraft were certificated under Part 4b of the Civil Air Regulations (CAR) and Special Conditions thereto issued by the FAA. One of these special conditions required that "The airplane must be shown by test flight to be capable of continued safe flight and landing with a complete failure of the hydraulic system." This demonstration was performed successfully with the DC-9-10 and -30 series aircraft.

With regard to the DC-9-80, McDonnell Douglas elected to show compliance with the later airworthiness standards of 14 CFR Part 25. The FAA then issued Special Conditions No. 25-95-WE-27. One of the special conditions contained therein required that McDonnell Douglas show by flight test that the aircraft was "... capable of continued safe flight and landing with a complete failure of the hydraulic system." This special condition only requires McDonnell Douglas to demonstrate that the aircraft can be flown and landed safely with this malfunction. There is no requirement to stop the aircraft within a specified distance; however, according to the FAA, the aircraft must be stopped within the confines of a runway of reasonable length.

In addition, the certification regulations required McDonnell Douglas to demonstrate "... by analysis or test, or both..." that the aircraft was capable of continued safe flight and landing under any possible condition of the thrust reverser. This was demonstrated on the earlier series aircraft with and without nosewheel steering, and the tests were completed with no reported difficulties. On the DC-9-30 aircraft, the landings were made with the rudder pedal steering mechanism disconnected. Two landings were made with the rudder in powered mode, and one landing was made with the rudder in manual mode. After main gear touchdown, both engines were placed in reverse thrust, takeoff thrust was then applied and the fuel to one engine was cut off. The test flight report stated, "Directional control was applied by the pilot until the aircraft began to deviate with full rudder as the speed decreased. The rate of deviation was not considered excessive and the airplane was controlled by reducing power on the operative engine." All that the regulations required was a subjective judgment by the test pilots that the aircraft could be controlled safely, and they concluded that it was. As a result of these demonstrations, McDonnell Douglas included a caution note in the Airplane Flight Manuals (AFM) of all DC-9's to reduce reverse thrust if directional control difficulties were encountered while operating with reverse thrust applied.

With regard to the DC-9-80, Special Conditions No. 25-95-WE-27 required McDonnell Douglas to establish "... by flight and ground tests ..." that the DC-9-80 could be "... safely landed and stopped with a critical engine reverser deployed." These tests were underway but had not been completed at the time of the accident. However, the tests conducted after the accident showed that the aircraft could maintain directional control with reverse thrust settings ranging from 1.52 EPR to 1.2 EPR on one engine and the other engine in forward idle thrust.

The results of the complete hydraulic system failure demonstrations on the earlier DC-9's were as follows: The DC-9-10 report stated, "The lateral control characteristics during the approach were normal. The touchdown speed was 150 knots. The airplane was controllable during landing with no difficulties experienced during the landing roll-out. There was a slight directional sensitivity experienced which was caused by slight asymmetrical thrust being applied. This was controllable when the pilot concentrated on the EPR (engine pressure ratio). With the brake system on manual (anti-skid off) there was braking available to the end of the landing roll with 6,000 feet of runway used. Under these conditions the airplane controllability was considered satisfactory."

The DC-9-30 comments were as follows: "The airplane touched down at 155 KIAS. Light to moderate braking and reverse thrust were used during the roll-out utilizing approximately 6,800 feet of runway. Controllability during the approach and landing was normal and no unusual characteristics were experienced during the demonstration."

Neither the certification regulations nor the special conditions required a quantitative measurement of the precise amount of yawing acceleration produced by the vertical stabilizer and rudder; all that was required was a subjective evaluation that the aircraft could be controlled safely. According to the test pilots who had flown these engineering certification test flights, the aircraft could be controlled safely.

According to McDonnell Douglas, the data obtained during these certification demonstrations were evaluated before they conducted the DC-9-80's complete hydraulic system failure demonstration. These data did not disclose any problem that indicated a need to conduct a more extensive evaluation of the aircraft's controllability during the landing roll, and they did not consider it to be a high risk factor. Accordingly, the flight cards for the DC-9-80's complete hydraulic system failure demonstration were prepared, based on the same procedures used successfully in the demonstrations conducted with the series -10 and -30 aircraft.

1.17.4 Flightcrew Procedures

At the time of the accident, the aircraft was operating pursuant to an experimental certificate; therefore there was no approved AFM in existence. The procedures to be used on the hydraulic system inoperative landing were contained on the flight card prepared by McDonnell Douglas. This card contained the procedures which would enable the pilots to conduct the flight in a manner that would insure that regulatory compliance would be demonstrated.

According to McDonnell Douglas, one of the purposes of the certification program was to determine if the procedures and pilot techniques that were applicable to the DC-9-50 could be used to fly the DC-9-80. While there was no approved DC-9-80 AFM in existence, a preliminary -80 AFM was being developed and evaluated as the certification program progressed. The preliminary AFM contained procedures and pilot techniques for the DC-9-80, as well as FAA-approved DC-9-50 information. McDonnell Douglas stated that the pilots conducting the FAA certification test program were briefed that these -50 pilot techniques applied to the DC-9-80, and that, unless otherwise briefed, the pilot techniques outlined in the preliminary AFM and in previous series DC-9 AFM's should apply. In addition, the pilots were briefed that these procedures were, until shown otherwise, the best guidelines for proper pilot technique. With regard to the technique to reduce reverse thrust if directional control problems were encountered during reverse thrust operation, this cautionary note was contained in the AFM of every DC-9 series aircraft. In addition, two FAA engineering test pilots stated that it was common knowlege that the application of reverse thrust on tail-mounted engines can create directional control problems; therefore, if this occurs, reverse thrust should be reduced.

The flight card prepared for this demonstration contained the airspeeds to be flown, the procedures required to configure the aircraft for the test properly, the system gages and warning lights that were to be monitored, and then directed "Use reverse thrust and minimum braking." The approved procedures in previous DC-9 AFM's concerning the application of reverse thrust after landing stated, in part, "Reverse thrust may be used as soon as practical after touchdown."

At the preflight briefing before the accident flight, the procedures contained on the flight test card were amplified. The briefing covered brake application technique, the necessity to apply reverse thrust symmetrically and to establish nosewheel tracking. During the briefing the copilot also advised the pilot that he would turn the electric auxiliary hydraulic pump on if there was any doubt about stopping the aircraft. However, the briefing did not discuss or establish crew coordination techniques to monitor the engine acceleration during the application of reverse thrust; it did not establish any order of priority for the application of reverse thrust and nosewheel touchdown; and it did not include any review of pilot techniques or crew coordination items to be used in the event they encountered any directional control problems during the landing roll.

With regard to the use of reverse thrust, the pilot stated that he applied it after the main landing gear touchdown, that he ". . .noted symmetric deployment of the reversers and lowered the nose to the runway." He said that, after the Nos. 3 and 4 tires failed and the aircraft began to yaw to the right, he applied left rudder and brakes to counteract the right yaw. "The aircraft continued to yaw to the right and track to the right. I attempted to stow the reverse thrust levers at the first indication that the use of left rudder and brake was now insufficient to counteract the right yawing actio...

1.17.5 Postaccident Actions

On August 21, 1980, the hydraulic-systems-inoperative certification test flight which resulted in the accident was reflown. However, as a result of the investigation conducted after the accident, the flightcrew procedures were revised. Also, since the DC-9-80 has larger wheel brake accumulators and a more advanced antiskid system than the DC-9-10 and DC-9-30, the DC-9-80, with a complete failure of its hydraulic system, could be stopped safely with its antiskid system in operation; therefore the revised procedures required the antiskid system to be on for landing. The procedures used during the second test were as follows:

> Make positive main gear touchdown to minimize float;
>
> Lower the nose immediately after main gear touchdown and after nosewheel touchdown apply the brakes smoothly to full pedal deflection;
>
> Set thrust symmetrically to the idle reverse detent. Do not use asymmetrical reverse thrust to maintain directional control;
>
> Use rudder and differential braking as required for directional control. Maintain the maximum possible steady brake pedal deflection to minimize accumulator pressure loss;
>
> Maintain symmetrical idle reverse thrust until the aircraft is stopped, unless higher symmetrical reverse thrust is required by existing conditions;
>
> Maintain maximum possible braking until the aircraft is stopped. Do not try to taxi the aircraft.

In addition, a card, containing procedures to be used in the event directional controls problems occurred after landing, was developed and inserted in the flight card package. The card contained pilot techniques concerning the activation of the hydraulic systems, the antiskid system, and thrust management. The procedures and pilot techniques were designed to enable the flightcrew to regain directional control and either stop the aircraft or reject the landing, reconfigure the aircraft and then takeoff.

The subsequent certification test flight was conducted without incident and met certification standards. As a result of this test, the hydraulic-systems-inoperative landing procedures for DC-9-80 flightcrews were changed. The new procedures incorporate the techniques used on the second test flight. In addition, the flightcrew procedures concerning the use of reverse thrust on normal landing were amplified. The new procedure reads as follows:

> **REVERSE THRUST - GROUND OPERATION**
>
> Reverse thrust may be applied to the idle reverse thrust detent when the nose gear is firmly on the ground. When reverse thrust is verified, proceed as follows:
>
> > Set thrust symmetrically above 60 knots to 1.6 EPR and below 60 knots to idle reverse thrust detent unless higher thrust is dictated by existing conditions.

During reverse thrust operation, should difficulty be experienced in maintaining directional control, reduce thrust as required. Do not attempt to maintain directional control by using asymmetric reverse thrust.

Reverse thrust operation when operating on wet/slippery runways or with one engine in reverse.

After nose gear contact, apply down elevator and apply reverse thrust to idle reverse thrust detent. After reverse thrust is verified, gradually increase reverse thrust as required.

During reverse thrust operation, should difficulty be experienced in maintaining directional control, reduce reverse thrust as required. Do not attempt to maintain directional control by using asymmetric reverse thrust.

2. ANALYSIS

The aircraft was maintained in accordance with prescribed regulations and procedures. The review of the maintenance records disclosed two pilot discrepancy reports which were relevant to the accident maneuver. One stated that the right engine's reverser "hangs up" at the interlock position when "going into reverse"; the second stated that the aircraft pulled to the left "after left steering input." The camera log disclosed that both engine reverse thrust lights illuminated at the same time and the onboard flight instruments showed that reverse thrust began increasing on both engines simultaneously. Since neither of these actions could have occurred with the right engine interlock in place, the Safety Board concludes that the interlock operated properly when reverse thrust levers were placed in the reverse position.

Although the copilot had been asked to check the aircraft's nosewheel tracking with the hydraulic system turned off, this check was not performed. The postaccident examination of the nosewheel steering system did not disclose any evidence of any preexisting malfunction or failure; however, the nosewheel's tracking capability could not be determined.

The flightcrew was certificated properly and was qualified for the flight; however, neither pilot had performed a hydraulics-systems-inoperative landing.

Investigation revealed that the sequence of events which led to the accident began with the application of reverse thrust on landing. Despite the fact that both pilots understood that two principal areas of concern were to establish good nosewheel tracking and to insure the reverse thrust was applied symmetrically, these objectives were not accomplished. The pilot's statements and the evidence showed that they monitored the reverser system indicator lights and assured themselves that both lights on both engines were lit. However, the evidence showed that they did not monitor the reverse thrust increase after the interlock cleared and reverse thrust was applied to the engines. The asymmetric thrust increase went unnoticed. As a result, the asymmetric reverse thrust produced a left yaw moment of 37,800 foot-pounds and a left yaw acceleration of 2°/second^2.

About 1.5 seconds before the nosewheel touched down, the pilot applied hard right rudder pedal and held this input for 5 seconds. During this time interval, the aircraft decelerated from 160 KIAS to 136 KIAS and the rudder deflection was about 12°

to 13° right. The test data showed that, either due to the action of the rudder limiter or a degradation in aerodynamic hinge moment caused by the effect of reverse efflux on the rudder control tab, the rudder deflections were about 7° to 9° less than the design limits of the rudder. The yaw acceleration stopped after the rudder was applied, but the aircraft continued to yaw to the left at 2°/second.

Although the pilot attempted to correct the yaw with opposite rudder and then wheel braking, the source of the yawing moment was not reduced until the No. 3 tire blew out. At, or just before, the time the No. 3 tire blew out and about 2 seconds after he began to apply differential braking, the pilot began to increase reverse thrust on the right engine. During this period the aircraft was decelerating from about 155 KIAS. The test data showed that at 140 KEAS, manual rudder could produce yaw accelerations of 1.75°/second^2 at 1.3 EPR symmetric reverse thrust; 2.6°/second^2 at reverse idle thrust; and 2.9°/second^2 at forward idle thrust. These yaw accelerations increase with increased speed. Thus, had the reverse thrust been decreased, the potential to restore directional control would have been increased. The data indicated that had the pilot reduced the reverse thrust on both engines to idle there was sufficient rudder control effectiveness to develop a yaw acceleration to the right and, based on the timeliness of this corrective action, directional control of the aircraft might have been regained. Because of the variables involved in this action--the speed at which the thrust levers were retarded, the amount of the thrust reduction, and engine spool down rates--it is difficult to state with certainty that this action would have been successful. However, the data indicated that had the reverse thrust been reduced to idle at the time the pilot first resorted to differential braking it was highly probable that he could have regained directional control and kept the aircraft on the runway. While the data also indicated that this capability existed up to the time the Nos. 3 and 4 tires blew out, the probability of regaining control would have been reduced because the aircraft had yawed farther to the left and was closer to the side of the runway.

Although there were no FAA-approved procedures in existence governing the proper pilot techniques for the management of reverse thrust on the DC-9-80 in this situation, the evidence showed that the procedures and pilot techniques used on the DC-9-50 and earlier DC-9 aircraft unless otherwise briefed, applied to the DC-9-80. The AFM's of the previous series DC-9's cautioned the pilot to reduce reverse thrust if he encountered directional control difficulties while in reverse thrust and the evidence disclosed that this recommended pilot technique had not been countermanded. Considering the pilot's experience in both DC-9 and other aircraft with tail-mounted engines, the onset of the directional control difficulty should have suggested that the reverse thrust be reduced, if not before, then certainly coincident with the application of differential braking.

However, instead of reducing the reverse thrust, the pilot tried to augment his rudder and brake inputs by manipulating reverse thrust. Just before the No. 3 tire blew out, he increased reverse thrust on the right engine, and 1 second later he retarded the left reverse thrust lever and then placed it in the forward thrust position. Therefore, after the No. 3 and 4 tires had failed and the aircraft began to track toward the right side of the runway, the left engine was producing 1.14 EPR forward thrust while the right engine was producing 1.67 EPR reverse thrust and a right yawing moment had been generated. In addition, the copilot turned the auxiliary hydraulic pump switch on and restored full pressure to the right hydraulic system. At that moment, the right rudder pedal was depressed fully and the nosewheel turned to the right. The evidence showed that the copilot inadvertently placed the adjacent engine driven hydraulic pump switch on the right engine to the low position when he activated the auxiliary pump switch; however, since the auxiliary pump restored full pressure to the right system, the activation of the engine driven pump switch had no effect on the system.

Therefore, the pilot's mismanagement of the reverse thrust application was the precipitating factor which produced the accident; however, the reasons why he did so need to be examined.

The procedures for the hydraulics-systems-inoperative landing for the series 80 aircraft were essentially the same as those used with the series 10 and series 30 aircraft. However, because of the increased thrust capability of the -209 engines, their reverse thrust output at any given EPR setting was higher than that produced at similar EPR settings in the earlier aircraft. The effect of this increased reverse thrust on the directional control capability of the rudder had not been quantitatively determined before the accident; therefore, neither the manufacturer nor the pilots were aware of the decrease in rudder control effectiveness at the higher reverse thrust levels generated by the -209 engine. Once the aircraft had landed, directional control of the landing roll was to be maintained by the rudder and wheel brakes. In addition, some directional stability was afforded by the castering nosewheel after it touched down. The flight card stated that the pilot was to use "reverse thrust and minimum braking," and it did not restrict the amount of reverse thrust he could use. Once reverse thrust was applied, the effectiveness of one of the two main methods of maintaining directional control was decreased in direct proportion to the amount of reverse thrust applied. Since the antiskid system was inoperative, using wheel braking to maintain directional control, particularly at high speeds, would have required a high degree of alertness and skill in order to obtain a change in heading without destroying the tires.

The pilot techniques required to carry out the procedures on the flight card were discussed at the preflight briefing. As a result of the briefing, the pilots stated that they knew that it was important to establish good nosewheel tracking and to insure that the reverse thrust was applied symmetrically. However, the lack of knowledge concerning the effect of reverse thrust on the vertical stabilizer and rudder affected the adequacy of the briefing. The degradation of rudder control effectiveness at high reverse thrust levels made the amount of reverse thrust applied and the manner and timing of the reverse thrust application critical. The briefing did not alert the pilots to this fact nor did it establish techniques to insure that these objectives could be carried out. The briefing did not limit the amount of reverse thrust the pilot could use an[illegible] did not establish an order of priority between the increase of reverse thrust above i[illegible]d nosewheel touchdown. Had the procedure required that the nosewheel be lowered to the runway before reverse thrust was increased above idle, nosewheel tracking would have been established which would have helped counteract the effects of the asymmetric reverse thrust and perhaps limited the yaw acceleration and resultant yaw rate.

The procedures used during this demonstration were essentially the same as those used during the successful DC-9-10 and DC-9-30 demonstrations. These were successful because, except for the slight reverse thrust asymmetry which occurred during the DC-9-10 demonstration, little or no reverse thrust asymmetry was introduced during the landing rolls. Despite the fact that the preflight briefing before this demonstration emphasized the importance of applying reverse thrust symmetrically, this objective was not accomplished. If this had been done and the initial reverse thrust asymmetry had not been introduced, the DC-9-80 demonstration would have been completed successfully.

The tests which identified and quantified the control effectiveness of the vertical stabilizer and rudder at various levels of reverse thrust were not conducted until after the accident. Despite the fact that the applicable certification regulations did not require the manufacturer to conduct this type of testing, the Safety Board was concerned as to whether the data obtained during the certification of the earlier DC-9 series aircraft should have alerted McDonnell Douglas to a need to go beyond the evaluation standards contained in the applicable certification regulations and perform quantitative testing before the accident occurred. The DC-9's certification history contained only one demonstration wherein the effects of reverse thrust on the aircraft's directional control elicited a comment from a test pilot. The test report concerning the DC-9-10's hydraulic-system-inoperative certification test flight noted that a "... slight directional sensitivity ..." was experienced and that it was caused by the application of "... slight asymmetrical reverse thrust." However, the remainder of the report noted that the test pilot did not experience any control difficulties during the landing roll, and he stated that the aircraft's "... controllability was considered satisfactory." The remainder of the certification data, concerning the aircraft's performance with a complete hydraulic system failure and during landings with one engine thrust reverser deployed and the other stowed, showed that the test pilots considered the aircraft to be controllable under those conditions. According to McDonnell Douglas, the certification data did not indicate a problem area; therefore, they did not believe there was any necessity to conduct a more extensive evaluation of the effects of reverse thrust on the control capability of the vertical stabilizer and rudder. Given the evidence available to McDonnell Douglas, the Safety Board does not believe that this decision was imprudent.

In summary, because of the lack of data at the time of the accident concerning the effect of high levels of reverse thrust on the control effectiveness of the rudder, the test flight procedure did not limit the amount of reverse thrust the pilot could use and thereby insure that some degree of rudder effectiveness was retained during the landing roll. In addition, the procedure did not require that the nosewheel be lowered to the runway before the pilot was permitted to increase reverse thrust above reverse idle. With regard to the latter requirement, we believe that even without the data obtained during subsequent testing the procedure should have established this sequence. During the preflight briefing the pilots were apprised of the necessity to establish good nosewheel tracking. Considering the landing configuration of the aircraft, the briefing should have established pilot techniques which insured that the nosewheel was down and tracking before exposing the aircraft to the possibility of an asymmetric thrust occurrence.

The Safety Board also believes that even without the results of the postaccident tests the procedures used for the certification test flight were inadequate in two other areas. Given the earlier encounters with thrust asymmetry during the DC-9-80 certification testing program, flightcrew coordination procedures to monitor the engine acceleration during the application of reverse thrust should have been formulated and incorporated in the procedure to guard against this occurrence. Finally, there was no procedure or briefing which discussed, reviewed, or established pilot techniques to be used in the event directional control was compromised during the landing roll. Since the aircraft was to be landed without nosewheel steering and without the powered rudder, the possibilities of encountering directional control problems during the landing roll were not remote. Procedures and pilot techniques to recognize and then recover from an encounter of this type should have been discussed and established.

The Safety Board, therefore, concludes that the procedures used for the certification flight were not adequate and were causal to the accident. While the failure to limit the amount of reverse thrust to be used after touchdown can be attributed to the lack of quantitative data concerning rudder performance, the other areas discussed above were foreseeable before the accident flight and the procedures developed for the certification test flight should have incorporated pilot techniques to protect the flightcrew and aircraft from their occurrence. Notwithstanding the inadequacy of the procedures, the Safety Board believes that the pilot's attempt to retrieve directional control of the aircraft by using asymmetrical reverse thrust was a causal factor to the accident. Once the yaw developed, despite the fact that the applicable procedures required that reverse thrust be reduced, the pilot did not reduce reverse thrust. Instead he attempted to regain directional control of the aircraft by applying asymmetrical reverse thrust and aggravated the out-of-control condition of the aircraft. This was the final factor that made the accident inevitible.

As a result of the tests conducted after the accident, the procedures for landing without hydraulic system pressure were revised. According to the procedures developed after the accident, the initial action required of the pilot on landing is to "lower the nose immediately after main gear touchdown. . . ." The two major differences between the new procedures and the old involve the use of reverse thrust and main wheel braking. Under the new procedures, the operation of the reversers is prohibited until after the nosewheel contacts the runway, and thereafter reverse thrust will be maintained at idle ". . . unless higher symmetrical reverse thrust is dictated by existing conditions." This change either removes or decreases the possibility of any pilot action adversely affecting the directional stability of the aircraft during the landing roll. It also enhances the rudder effectiveness during the high speed portions of the landing roll since it lessens the reverser efflux in the vicinity of the empennage.

The original procedure required the pilot to use wheel braking without antiskid protection, if necessary, for directional control. However, the revised procedures require the antiskid system to be on. The pilot can now apply full brake pedal deflection to stop the aircraft and, if necessary, to maintain directional control. With the antiskid system operative, the risk of a tire blowout is removed almost completely. On August 20, 1980, the certification test flight was reflown using the new procedures. The test flight was completed successfully.

The Safety Board also notes that as a result of the tests conducted during the investigation of this accident, the procedures concerning the normal landing of the DC-9-80 aircraft have been modified. The revised procedures delay the application of reverse thrust until after the nosewheel is on the ground and specify limits on the amount of reverse thrust to be applied and the indicated airspeed during the landing roll at which reverse thrust must be reduced to idle.

In conclusion, the Safety Board notes that one of the purposes of the certification procedure is to identify aircraft handling characteristics which can cause problems for the flightcrews. In this instance, the certification testing served a good purpose. The accident, though unfortunate, highlighted an aircraft control characteristic which required additional examination and led to appropriate testing. The additional investigation quantified the effect reverse thrust had on the control capability of the vertical stabilizer and rudder. As a result of this additional data, the emergency procedures for landing the DC-9-80 with a complete hydraulic system failure were changed; the DC-9-80's normal landing procedure was changed; and, most important, these positive benefits were accrued before the aircraft entered line operations.

3. CONCLUSIONS

3.1 Findings

1. When the accident occurred, the aircraft was on an certification test flight to demonstrate that the aircraft could be controlled adequately and landed safely with a complete hydraulics system failure.

2. This was the first time either pilot had performed a hydraulics-systems-inoperative landing.

3. The manufacturer had not conducted tests to determine the precise effect the increased level of reverse thrust of the JT8D-209 engine had on rudder control effectiveness; therefore, there was no quantitative information available on the effect this increased thrust would have on the directional control capability of the DC-9-80's rudder.

4. The preflight briefing and flight cards used for the test maneuver were inadequate. They did not include the steps to be taken to insure that good nosewheel tracking was obtained; did not limit the use of reverse thrust; and did not assign the copilot the specific task of monitoring the engines while they were accelerating to their commanded levels of reverse thrust.

5. Reverse thrust was applied within 2 seconds after the main landing gear touched down and before the nosewheel touched down; the engines did not accelerate at the same rate, and neither pilot observed the asymmetric levels of reverse thrust.

6. The aircraft was yawing left at 2°/second before the nosewheel touched down, and this rate continued after the nosewheel touched down even though the pilot applied full right rudder pedal.

7. The pilot used asymmetrical reverse thrust to assist the rudder in an attempt to restore directional control. The use of asymmetrical reverse thrust under the existing conditions was contrary to the prescribed procedures in the preliminary airplane flight manual.

8. The pilot applied the right wheel brakes to regain directional control, and the Nos. 3 and 4 tires blew out.

9. Performance data indicated that directional control of the aircraft might have been recovered if thrust had been reduced to reverse idle before the Nos. 3 and 4 tires blew out.

10. The revised procedures for landing with the hydraulics systems inoperative require the nosewheel to be lowered to the runway before applying reverse thrust, the use of reverse thrust to be limited to reverse idle unless higher is required, and the antiskid system to be left operative.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate procedure established for the certification test flight, and the pilot's mismanagement of thrust following the initial loss of directional control.

4. RECOMMENDATIONS

Accordingly, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Incorporate the following information into the DC-9-80 Aircraft Flight Manual under the abnormal hydraulics-out landing section and the normal landings on wet/slippery runways section:

The maximum rudder effectiveness available is substantially reduced during reverse thrust operation as follows:

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	25
1.6 EPR (Reverse)	minimal

*/Rudder effectiveness also decreases with decreasing airspeed.

When reverse thrust levels above reverse idle are used, carefully monitor and maintain symmetric reverse thrust to avoid adverse yawing moments. (Class II, Priority Action) (A-81-104)

Incorporate the following information into the DC-9-80 training manuals and training programs under the flight control and landing sections:

When thrust reversers (located just forward of the vertical stabilizer) are used during landing rollout, the exhaust gases from the engines are deflected by the thrust reverser buckets in such a manner that the free-stream airflow over the vertical stabilizer and rudder is blocked, reducing the effectiveness of these surfaces. At a nominal airspeed of 100 KIAS, the reduction in rudder effectiveness with increasing symmetric reverse thrust levels is shown below.

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	25
1.6 EPR (Reverse)	minimal

*/Rudder effectiveness also decreases with decreasing airspeed.

On a dry runway, directional control is easily maintained by differential antiskid braking and nosewheel steering. However, under adverse conditions such as a slippery runway with rain, snow, or ice, when crosswinds reduce the braking effectiveness of the gear on the upwind wing, or when a high speed landing is made with both hydraulics systems out (i.e., flaps/slats retracted, ground spoilers, rudder hydraulic boost, nosewheel steering all rendered inoperative, and brake antiskid systems limited by hydraulic accumulator pressure), the vertical stabilizer and rudder will be the primary source of directional stability and control during the high speed portion of the landing rollout. Under these conditions, it is important to make allowance for the adverse effects of reverse thrust on the effectiveness of the vertical stabilizer and rudder.

The cockpit thrust reverser levers in the DC-9-80 are more sensitive (i.e., command increased amounts of thrust per degree of movement) than previous DC-9 models because of the greater thrust range of the engines on the DC-9-80. The higher sensitivity of the cockpit thrust reverser levers make selection of symmetric reverse thrust more difficult than on previous models; therefore, careful attention should be given to selecting and maintaining symmetric reverse thrust levels to avoid adverse yawing moments. (Class II, Priority Action) (A-81-105)

Require that DC-9-80 landing-approved simulators incorporate actual aircraft characteristics including the decrease in vertical stabilizer and rudder control effectiveness as a function of engine reverse thrust levels. The flight test data used should be taken from McDonnell Douglas report MDC-J9005. Figure 14, Yawing Acceleration Due to Maximum Rudder, Power ON, and figure 15, Yawing Acceleration Due to Maximum Rudder, Manual, should be used for symmetric reverser configurations for thrust values from forward idle to 1.3 EPR reverse. Data similar to that in figure 71, Effect of Reverse Thrust on Directional Control, should be derived and used for all speeds and symmetric reverse thrust settings. Control effectiveness from a symmetric 1.3 EPR to a symmetric 1.6 EPR should decrease to zero. For asymmetric reverse thrust conditions, the data in figure 20, Controllability with Asymmetric Reverse Thrust, should be used. (Class II, Priority Action) (A-81-106)

Incorporate the following information in the DC-9 series -10 through -50 Aircraft Flight Manuals under the abnormal hydraulics-out landing section and the normal landings on wet/slippery runways section:

The maximum rudder effectiveness available is substantially reduced during reverse thrust operation as follows.

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	45
1.6 EPR (Reverse)	15

*/ Rudder effectiveness also decreases with decreasing airspeed.

(Class II, Priority Action) (A-81-107)

Incorporate the following information in the DC-9 series -10 through -50 Training Manuals and Programs under the flight control and landing sections:

When thrust reversers (located just forward of the vertical stabilizer) are used during landing rollout, the exhaust gases from the engines are deflected by the thrust reverser buckets in such a manner that the free stream airflow over the vertical stabilizer and rudder is blocked, reducing the effectiveness of these surfaces. At a nominal airspeed of 100 KIAS, the reduction in rudder effectiveness with increasing symmetric reverse thrust levels is shown below.

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	45
1.6 EPR (Reverse)	15

*/ Rudder effectiveness also decreases with decreasing airspeed.

On a dry runway, directional control is easily maintained by differential antiskid braking and nose-wheel steering. However, under adverse conditions such as rain, snow, or ice making the runway slippery, when crosswinds reduce the braking effectiveness of the gear on the upwind wing, or when a high speed landing is made with both hydraulic systems failed (i.e., flaps/slats retracted; ground spoilers, rudder hydraulic boost, nosewheel steering, brake antiskid all rendered inoperative; manual brake system limited by hydraulic accumulator pressure), the vertical stabilizer and rudder will be the primary source of directional stability and control during the high speed portion of the landing rollout. Under these conditions it is important to make allowance for the adverse effects of reverse thrust on the effectiveness of the vertical stabilizer and rudder. (Class II, Priority Action) (A-81-108)

Require that DC-9 series -10 through -50 landing-approved simulators incorporate actual aircraft characteristics including the decrease in vertical stabilizer and rudder control effectiveness as a function of engine reverse thrust levels. The flight test data to be used should be taken from McDonnell Douglas Corporation report MDC-J9005. Data similar to that in figure 71, Effect of Reverse Thrust on Directional Control, should be derived and used for all speeds and symmetric reverse thrust settings. (Class II, Priority Action) (A-81-109)

Conduct an engineering evaluation of the DC-9 series -10 through -50 brake hydraulic accumulators and antiskid systems to determine if the brake antiskid systems can be left on during hydraulics-out landings. Revise where applicable the hydraulics-out landing procedures for the DC-9 series -10 through -50 airplanes to correspond with those developed for the DC-9-80 within the capabilities of the respective brake hydraulic accumulators and antiskid systems. (Class II, Priority Action) (A-81-110)

Examine all aircraft models with aft pod-mounted engine/thrust reversers to determine if vertical stabilizer and rudder effectiveness is lost or reduced when reverse thrust is used during landing rollout. If this adverse characteristic occurs, revise landing procedures, appropriate manuals, and training materials as necessary to assure that maximum directional control is maintained during the landing rollout. (Class II, Priority Action) (A-81-111)

Revise certification requirements for those aircraft for which safe flight and landing following a partial or total hydraulic system failure must be demonstrated to: (a) include a quantified level of directional control following touchdown in terms of yawing moment or yaw acceleration for appropriate rollout speeds; (b) require that the applicant demonstrate that these values can be obtained, using those controls which are available and using the procedures which are to be specified for this condition in the aircraft's approved flight manual; and (c) demonstrate or calculate landing distances for this special condition and include them in the aircraft's flight manual. (Class II, Priority Action) (A-81-112)

Ensure that Phase I, II, and III simulator requirements for other model aircraft as defined in 14 CFR Part 121, Appendix H, specifically include the representative degradation of directional control associated with the effect of reverse thrust on the aerodynamic control surfaces if the simulated aircraft has such characteristics for normal and abnormal configurations or systems condition, and revise Advisory Circular 121-14C accordingly. (Class II, Priority Action) (A-81-122)

Ensure that air carrier training and proficiency check programs required by 14 CFR Part 121 include a demonstration of directional control characteristics during landing rollout when conducted in accordance with the training and checking permitted, using a Phase I, II, or III simulator as provided for in 14 CFR Part 121, Appendix H. (Class II, Priority Action) (A-81-123)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ PATRICIA A. GOLDMAN
Member

/s/ G. H. PATRICK BURSLEY
Member

FRANCIS H. McADAMS, Member, did not participate.

September 15, 1981

APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. **Investigation**

The National Transportation Safety Board was notified of the accident about 1900 on June 19, 1980. The Safety Board dispatched a partial investigation team to the scene. Investigation groups were established for operations, structures, systems, maintenance records, and performance. Parties to the investigation were the Federal Aviation Administration and McDonnell Douglas Corporation.

2. **Public Hearing**

A public hearing was not held, and depositions were not taken.

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APPENDIX B

PERSONNEL INFORMATION

Pilot George H. Lyddane

The pilot, George H. Lyddane, 40, was employed by the FAA, on April 1974, and has been assigned to their Western Region Flight Test Branch since that date. Mr. Lyddane holds an Airline Transport Pilot Certificate No. 1567896, with an airplane multiengine land rating and commercial privileges in airplane single-engine land, sea, and gliders. He has type-ratings in Learjet, Boeing 727, and McDonnell Douglas DC-9 aircraft. His first-class medical certificate was issued August 6, 1979, with no waivers or limitations.

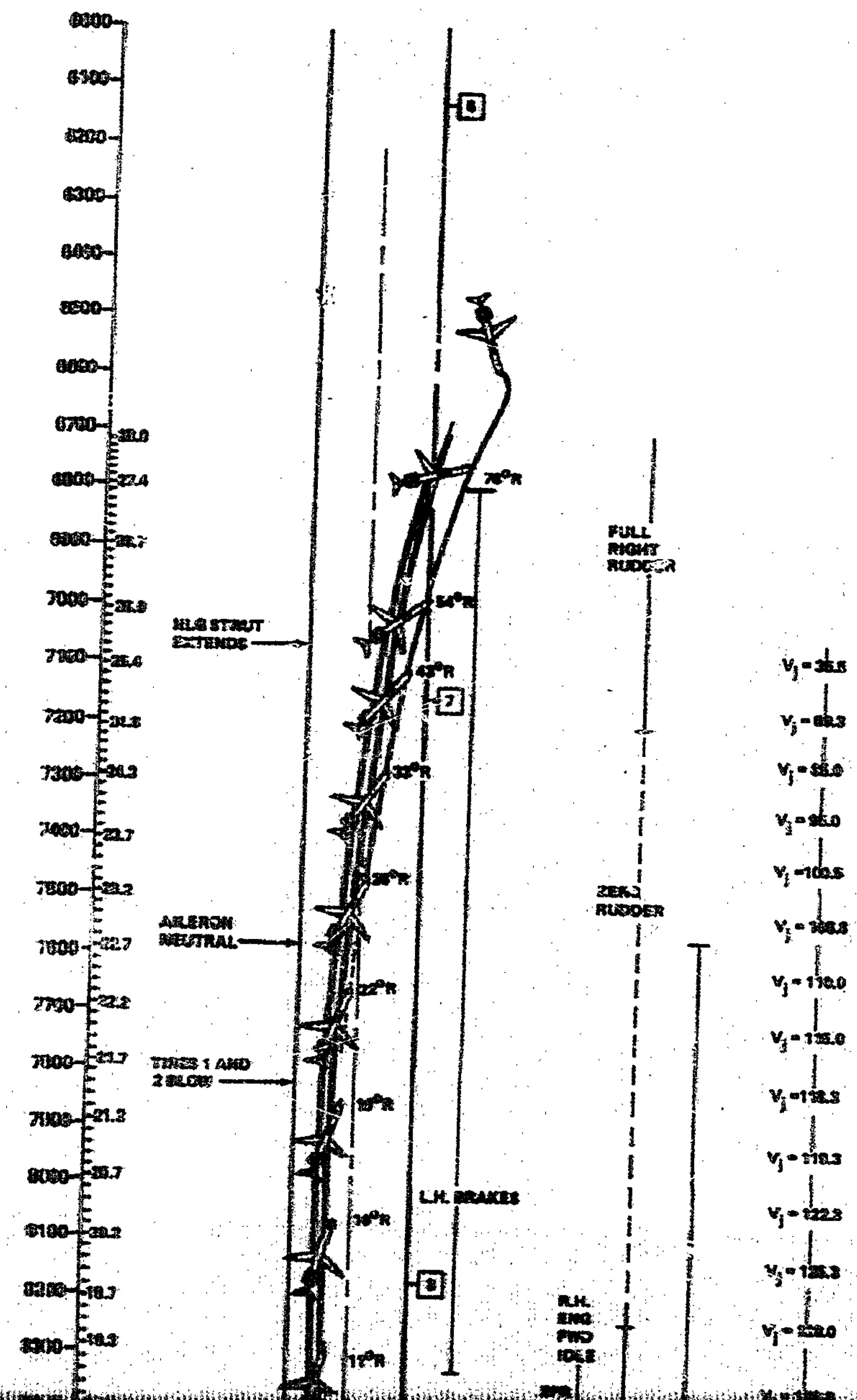
Mr. Lyddane was a graduate of the United States Air Force Test Pilot School, and he has flown 8,200 hours. He has flown 210 hours in DC-9 aircraft, 150 hours of which were in the series 80.

Copilot Fred W. Hamilton

The copilot, Fred W. Hamilton, 42, was employed by McDonnell Douglas on March 1970, and is assigned as an engineering test pilot. Mr. Hamilton holds an Airline Transport Pilot Certificate No. 1525987 with an airplane multiengine land rating and commercial privileges in airplane single-engine land. He has a type-rating in the McDonnell Douglas DC-9 aircraft. His first-class medical certificate was issued August 14, 1979, with the following limitation: The airman ". . .shall wear correcting glasses while exercising the privileges of his airman's certificate."

Mr. Hamilton has flown 3,199 hours. He has flown 509 hours in DC-9 type aircraft, 223 hours of which were in the series 80.

Both pilots' medical certificates had been issued more than 6 months before the accident flight, therefore they were exercising the commercial privileges of their Airline Transport Pilot Certificates.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AILERON NEUTRAL
TIRES 1 AND 2 BLOW
L.H. BRAKES
FULL RIGHT
R.H. ENG FWD IDLE
76°R
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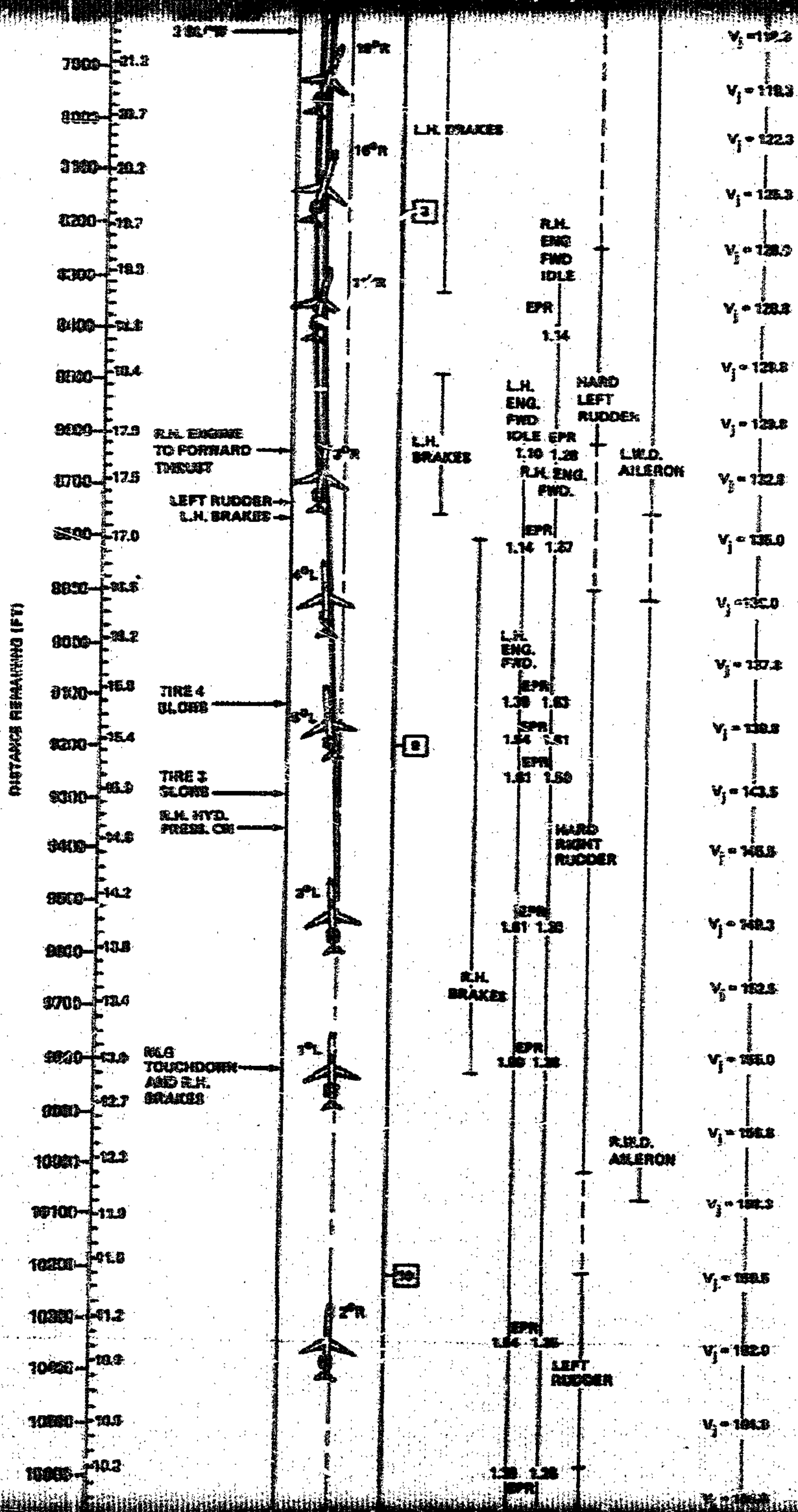
33°R
26°R
22°R
18°R
14°R
11°R


DISTANCE REMAINING (FT)
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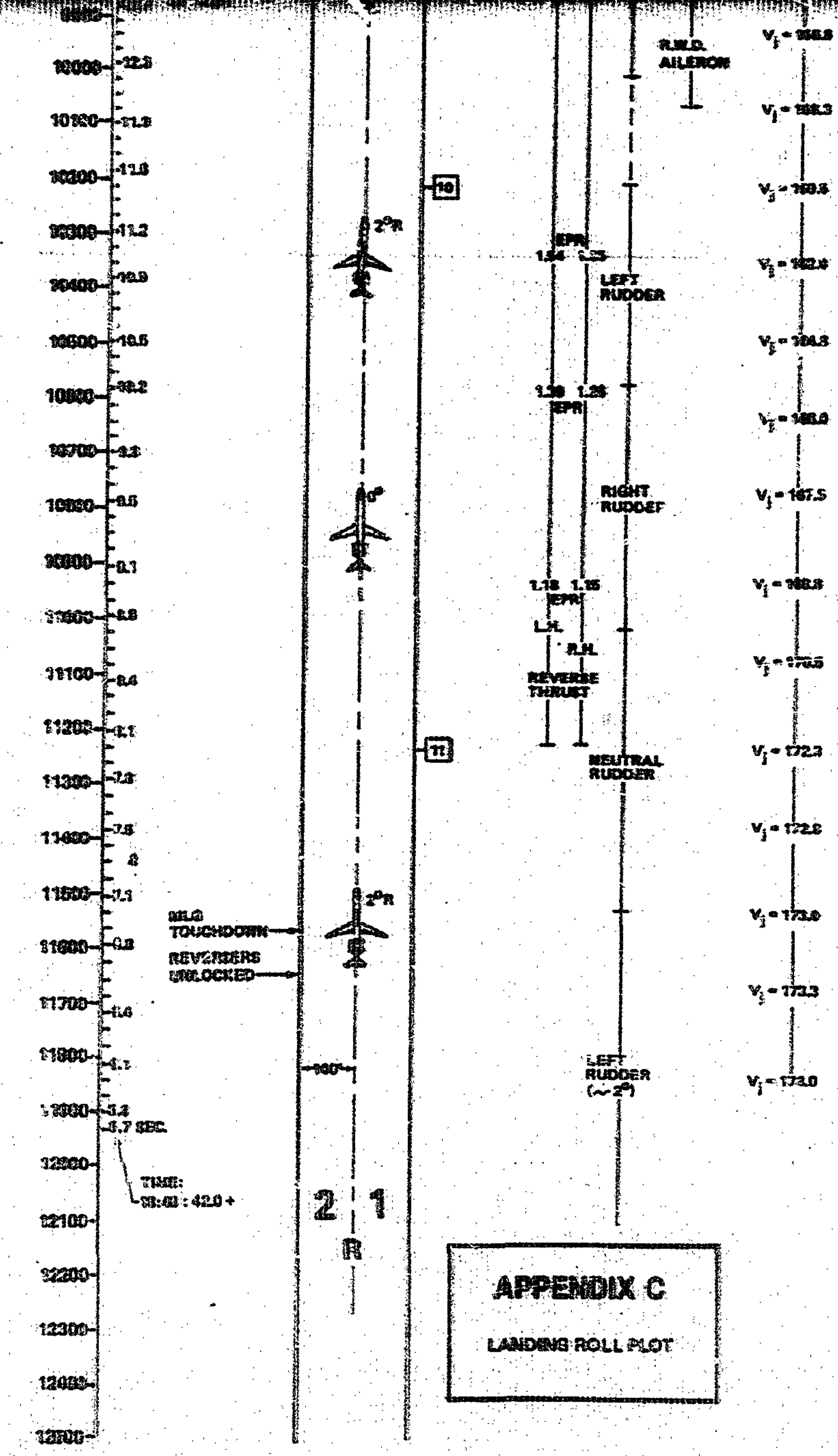
R.H. ENG FWD IDLE
EPR 1.14
HARD LEFT RUDDER
L.H. ENG. FWD IDLE
L.W.D. AILERON
R.H. ENGINE TO FORWARD THRUST
LEFT RUDDER
L.H. BRAKES
R.H. ENG. FWD.
L.H. ENG. FWD.
TIRE 4 SLOWS
TIRE 3 SLOWS
R.H. HYD. PRESS. ON
HARD RIGHT RUDDER
R.H. BRAKES
M.G TOUCHDOWN AND R.H. BRAKES
R.W.D. AILERON
LEFT RUDDER
EPR



APPENDIX C

LANDING ROLL PLOT