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NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

CONTINENTAL AIR LINES, INC.,
McDONNEL-DOUGLAS DC-10-10, N68045
LOS ANGELES, CALIFORNIA
MARCH 1, 1978

UNITED STATES GOVERNMENT

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16. Abstract About 0925 Pacific standard time on March 1, 1978, Continental Air Lines, Inc., Flight 603 overran the departure end of runway 6R at Los Angeles International Airport, California, following a rejected takeoff. As the aircraft departed the wet, load-bearing surface of the runway, the left main landing gear collapsed and fire erupted from the left wing area. The aircraft slid to a stop about 664 feet from the departure end of the runway. The left side of the aircraft was destroyed. Of the 184 passengers, 2 infants, and 14 crewmembers aboard, 2 passengers were killed and 28 passengers and 3 crewmembers were seriously injured during the evacuation of the aircraft.

The National Transportation Safety Board determined that the probable cause of the accident was the sequential failure of two tires on the left main landing gear and the resultant failure of another tire on the same landing gear at a critical time during the takeoff roll. These failures resulted in the captain's decision to reject the takeoff.

Contributing to the accident was the cumulative effect of the partial loss of aircraft braking because of the failed tires and the reduced braking friction achievable on the wet runway surface which increased the accelerate-stop distance to a value greater than the available runway length. These factors prevented the captain from stopping the aircraft within the runway confines.

The failure of the left main landing gear and the consequent rupture of the left wing fuel tanks resulted in an intense fire which added to the severity of the accident.

17. Key Words
Overrun; departure end; rejected takeoff; V_1 speed; metallic bang; landing gear collapse; accelerate-stop; aircraft performance; tire failure; retread tires; slide/rafts; evacuation; pilot training; simulators; wet runway; runway friction.
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SYNOPSIS

About 0925 Pacific standard time on March 1, 1978, Continental Air Lines, Inc., Flight 603 overran the departure end of runway 6R at Los Angeles International Airport, California, following a rejected takeoff. The takeoff was rejected just before the aircraft attained a V_1 speed of 156 knots, because the flightcrew heard a loud "metallic bang" and the aircraft started to "quiver." As the aircraft departed the wet, load-bearing surface of the runway, the left main landing gear collapsed and fire erupted from the left wing area. The aircraft slid to a stop about 664 feet from the departure end of the runway. The left side of the aircraft was destroyed. Of the 184 passengers, 2 infants, and 14 crewmembers aboard, 2 passengers were killed and 28 passengers and 3 crewmembers were seriously injured during the evacuation of the aircraft.

The National Transportation Safety Board determined that the probable cause of the accident was the sequential failure of two tires on the left main landing gear and the resultant failure of another tire on the same landing gear at a critical time during the takeoff roll. These failures resulted in the captain's decision to reject the takeoff.

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1. FACTUAL INFORMATION

1.1 History of the Flight

On March 1, 1978, Continental Air Lines, Inc., Flight 603, a McDonnell-Douglas DC-10-10 (N68045), was a scheduled flight from Los Angeles International Airport, California, to Honolulu, Hawaii.

At 0857:18 1/, Flight 603 called Los Angeles clearance delivery and was cleared for the route of flight which was to have been flown. About 2 min later, the flight received permission from Los Angeles ground control to push back from the gate. At 0901:37, Flight 603 was cleared by ground control to taxi to runway 6R. The runway was wet, but there was no standing water.

At 0922:29, Los Angeles local control cleared Flight 603 to taxi into position on runway 6R and hold. At 0923:17, local control cleared Flight 603 for takeoff; however, the flightcrew did not acknowledge the instructions and did not comply with them. At 0923:57, local control, again, cleared the flight for takeoff. This time the flightcrew acknowledged the instructions. The captain stated that he delayed acknowledgment of the takeoff clearance because he believed that he had initially been given the clearance too soon after a heavy jet aircraft had made its takeoff.

The flightcrew stated that acceleration was normal and that all engine instruments were in the normal range for takeoff. As the airspeed approached the V_1 speed of 156 kns, the captain heard a loud "metallic bang" which was followed immediately by "a kind of quivering of the plane." The flightcrew noticed that the left wing dropped slightly.

A rejected takeoff was begun immediately; however, according to the digital flight data recorder (DFDR), the airspeed continued to increase to about 159 kns as the rejected takeoff procedures were begun. The captain stated that he applied full brake pressure while simultaneously bringing the thrust levers back to idle power. Reverse thrust levers were actuated and full reverse thrust was used. The flightcrew stated that they noted good reverse thrust.

First, the aircraft moved to the left of the runway centerline and appeared to the flightcrew to be decelerating normally. With about 2,000 ft of runway remaining, the flightcrew became aware that the rate of deceleration had decreased, and they believed that the aircraft would not be able to stop on the runway surface. The captain stated that he maintained maximum brake pedal force and full reverse thrust as he steered the aircraft to the right of the runway centerline in an effort

1/ All times herein are Pacific standard, based on the 24-hour clock.

"to go beside the stanchions holding the runway lights" immediately off of the departure end of runway 6R. 2/ He stated further that he encountered no problems with directional control of the aircraft throughout the rejected takeoff maneuver.

The aircraft departed the right corner of the departure end of runway 6R. About 100 ft beyond the runway, the left main landing gear broke through the nonload-bearing tar-macadam (tarmac) surface and failed rearward. Fire erupted immediately from this area. The aircraft dropped onto the left wing and the No. 1 (left) engine and rotated to the left as it continued its slide along the surface. It stopped between two of the approach light stanchions for runway 24L about 664 ft from the departure end of runway 6R and about 40 ft to the right of the runway 6R extended centerline; it came to rest on a heading of 008°, in an 11° left wing low, 1.3° noseup attitude. When the aircraft came to a stop, the evacuation was begun immediately.

The accident occurred during daylight hours, about 0925, at latitude 33° 56' 30"N and longitude 118° 24' 24"W. The elevation of the accident site was 111 ft m.s.l.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal 3/	0	2	0
Serious	3	28	0
Minor/None	11	156	0

One firefighter was seriously injured and nine firefighters were injured slightly while extinguishing the fire.

1.3 Damage to Aircraft

The left side of the aircraft was destroyed.

1.4 Other Damage

A threshold light and two approach lights for runway 24L were broken. The tarmac surface on the departure end of runway 6R was damaged extensively.

2/ The stanchions were steel supports for the approach lights to runway 24L. These stanchions were not frangible fixtures.

3/ Two passengers died of their injuries about 3 months after the accident. 49 CFR 830.2 stipulates that only those deaths which occur within 7 days following the accident be listed in this section.

1.5 Personnel Information

The flight crewmembers, the flight attendants, and the in-flight supervisor were all properly certificated and trained for the flight. (See Appendix B.)

A Continental Air Lines, Boeing 727 captain was on board the aircraft as a passenger. He was seated in the first-class section of the cabin.

1.6 Aircraft Information

The aircraft was certificated and maintained in accordance with Federal Aviation Administration (FAA) requirements. The gross weight and c.g. were within prescribed limits for takeoff. At the time of the accident, about 120,000 lbs of jet A-1 fuel was on board. (See Appendix C.)

Takeoff computations for the flight showed a takeoff weight of 429,700 lbs--430,000 lbs was the maximum allowable for takeoff. The takeoff c.g. was 21.5 percent mean aerodynamic chord (MAC). The takeoff data also showed a computed V_1 speed of 156 kns, a V_R speed of 161 kns, and a V_2 speed of 170 kns.

The wheel, brake, and tire positions on the DC-10-10 main landing gear are designated by number, from left to right, beginning with the forward tires. (See figure 1.) Nos. 1 and 2 are the forward positions on the left main gear, Nos. 3 and 4 are the forward postions on the right main gear. Nos. 5 and 6 are the aft positions on the left main gear, and Nos. 7 and 8 are the aft positions on the right main gear. The tires in positions 4, 6, and 8 were on their first retread cycle; those in positions 3 and 5 were on their second retread cycle; and those in positions 1, 2, and 7 were on their third retread cycle. It was the company's policy to replace a tire after its third retread cycle.

The tire pressures had been checked immediately after landing from a previous flight on the morning of March 1, about 3 hours before the accident. These pressure readings were: No. 1 - 189 psi, No. 2 - 185 psi, No. 3 - 188 psi, No.4 - 185 psi, No. 5 - 186 psi, No. 6 - 187 psi, No. 7 - 192 psi, and No. 8 - 190 psi. The company required a normal tire pressure of 185 psi; however, their General Maintenance Manual indicates that a normal tire inflation range is between 182 psi to 188 psi.

1.7 Meteorological Information

A large low-pressure system had moved on shore over California with the center of the low pressure located about 70 mi west of the Los Angeles International Airport. The weather associated with this

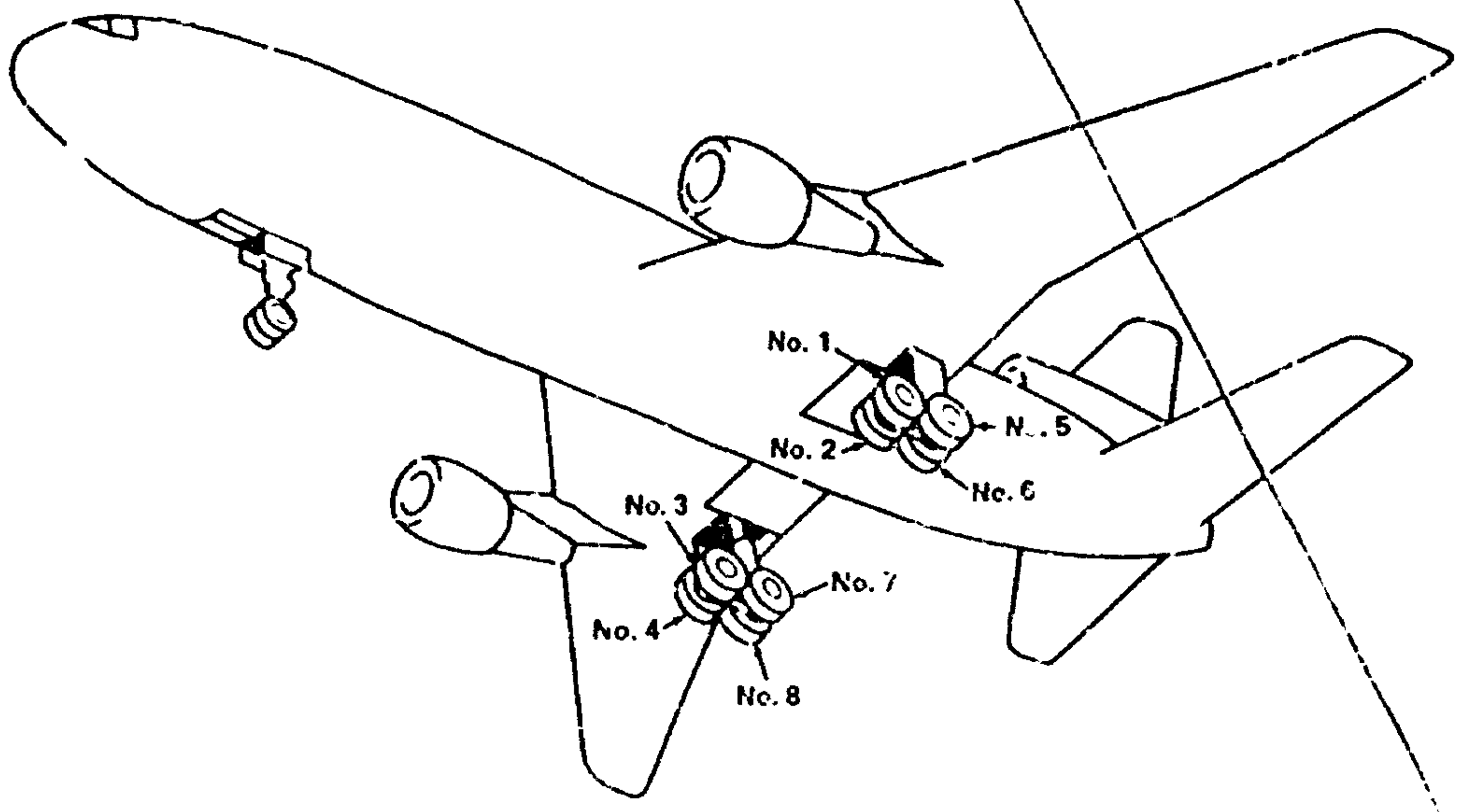

Figure 1. DC-10-10 main landing gear tire/wheel assembly positions.

system was an intermittent, very light or light rain with winds from the southeast at 10 kns. This general pattern was broken by squalls with moderate to heavy rain and winds from the south to 13 kns, gusting to 17 kns and 23 kns.

Pertinent National Weather Service (NWS) observations for the Los Angeles area were:

> <u>0900 Local Record</u> - 6,000 ft scattered; measured ceiling, 10,000 ft; visibility--3 mi in rain; temperature--59°F; dewpoint--58°F; wind--130° at 11 kns, gusting to 20 kns; altimeter--29.51 inHg.; ceiling ragged.
>
> <u>0938 Local</u> - 7,000 ft scattered, measured ceiling 15,000 ft; visibility--3 mi in rain; temperature--59°F; dewpoint--59°F; wind--140° at 11 kns gusting to 20 kns; altimeter--29.58 inHg.; ceiling ragged (aircraft mishap).

The NWS precipitation record for Los Angeles showed 4/100 ins. of rain between 0800 and 0900 and 4/100 between 0900 and 1000.

The NWS wind-recording device at Los Angeles records velocity only. At 0924, this device recorded a wind velocity of 12 kns. A mean wind direction, as determined from the 0900 and 0938 weather observations and three tower observations, was about 110°.

1.8 Aids to Navigation

Not applicable

1.9 Communications

No communications difficulties were reported.

1.10 Aerodrome Information

Runway 6R at Los Angeles International Airport is hard surfaced and is 10,285 ft long and 150 ft wide. The elevation at the departure end is 111 ft m.s.l. The runway has an average up hill gradient of .12 toward the departure end. Runway 6R is constructed of an asphalt-concrete composition and is grooved for 9,834 ft--about 66 ft on each side of the runway centerline. The last 451 ft of the departure end of the runway is not grooved. There is a displaced threshold of 331 ft on the approach end of the runway. Runways 25L and 25R, which are 12,000 ft long, are restricted from aircraft which exceed 325,000 lbs gross weight because of runway overpass strength limitations. These, therefore, were not available to Flight 603. Testimony at the public hearing revealed that this restriction will apply for several years before improvements can be made to this runway overpass to allow heavy aircraft operations. The Safety Board determined that 19 percent of all aircraft operations at Los Angeles involve wide body aircraft that cannot use runways 25L and 25R. The FAA predicts that this level will reach 30 percent by 1980--a 50-percent increase.

The FAA had a program to modify all approach light stanchions with frangible fittings. In 1977, the Safety Board recommended that the program be expedited so that the modifications would be completed in from 3 to 5 years. The FAA replied that they would do their best to meet the recommended time frame. At the time of this accident, the approach light stanchions for runway 24L, which are located at the departure end of 6R, had not been modified.

The last 1,500 ft of runway 6R had a heavy deposit of rubber on the surface. This deposit was caused by the tires of aircraft landing in the opposite direction (runway 24L). No evidence was found to indicate any rubber removal or friction surveys on runway 6R since its construction and grooving in 1974.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The aircraft was equipped with a Fairchild, Model A-100 cockpit voice recorder (CVR), serial No. 3842. No useable information could be retrieved because the tape had broken. The captain had discovered this malfunction during his preflight check and had called maintenance personnel to correct the malfunction. However, it was not corrected, and the captain did not recheck the equipment. The malfunction was not recorded in the aircraft logbook.

The CVR is a minimum equipment list item and is required by 14 CFR 121.359 to be operational at takeoff. Tests and readout revealed that the CVR was probably inoperative for at least two flights before the day of the accident.

1.11.2 Digital Flight Data Recorder

The aircraft was also equipped with a Sundstrand, Model 573A DFDR, serial No. 2273. The DFDR was not damaged and all parameters had been recorded correctly.

The DFDR data showed that the takeoff roll began from a static position on runway 6R at 0923:54. (See figure 2.) The wing flaps were set at 5°. Takeoff thrust was established at 101-percent N_1 on all engines as the aircraft accelerated through 37 kns. At 152 kns, 46 sec into the takeoff roll and 4 kns below V_1, the longitudinal accelerometer began recording a marked decrease in the aircraft's acceleration although takeoff thrust was being maintained on all engines. No indications of tire failure were evidenced below 152 kns by the DFDR. At 152 kns, the DFDR roll attitude parameter began to record a gradual lowering of the left wing. V_1 speed, 156 kns, was reached 1.2 sec later, or 47.2 sec after the start of the takeoff roll. Engine thrust began to be reduced less than 0.5 sec after V_1 speed. A maximum speed of 159 kns, 2 kns below V_R, was recorded 1.8 sec after V_1 and 0.5 sec after longitudinal acceleration had changed from positive (acceleration) to negative (deceleration) values. Thrust reversers unlocked while the airspeed was decelerating through 157 kns at a peak deceleration rate of -0.23g. About 1.2 sec later, the thrust reversers were deployed at 152 kns as the engines were spooling down for thrust reversal and as the left wing reached its maximum down attitude of 2.1°. The engines began to spool up for thrust reversal 4.8 sec after V_1; maximum reverse thrust values were attained in 3 sec on the center engine, in 6 sec on the left engine, and in 8 sec on the right engine. Aircraft heading began to deviate to the right of the runway centerline as full reverse thrust was being attained. The heading reached 079°, the maximum deviation from the centerline, as the aircraft's speed decelerated through 58 kns.

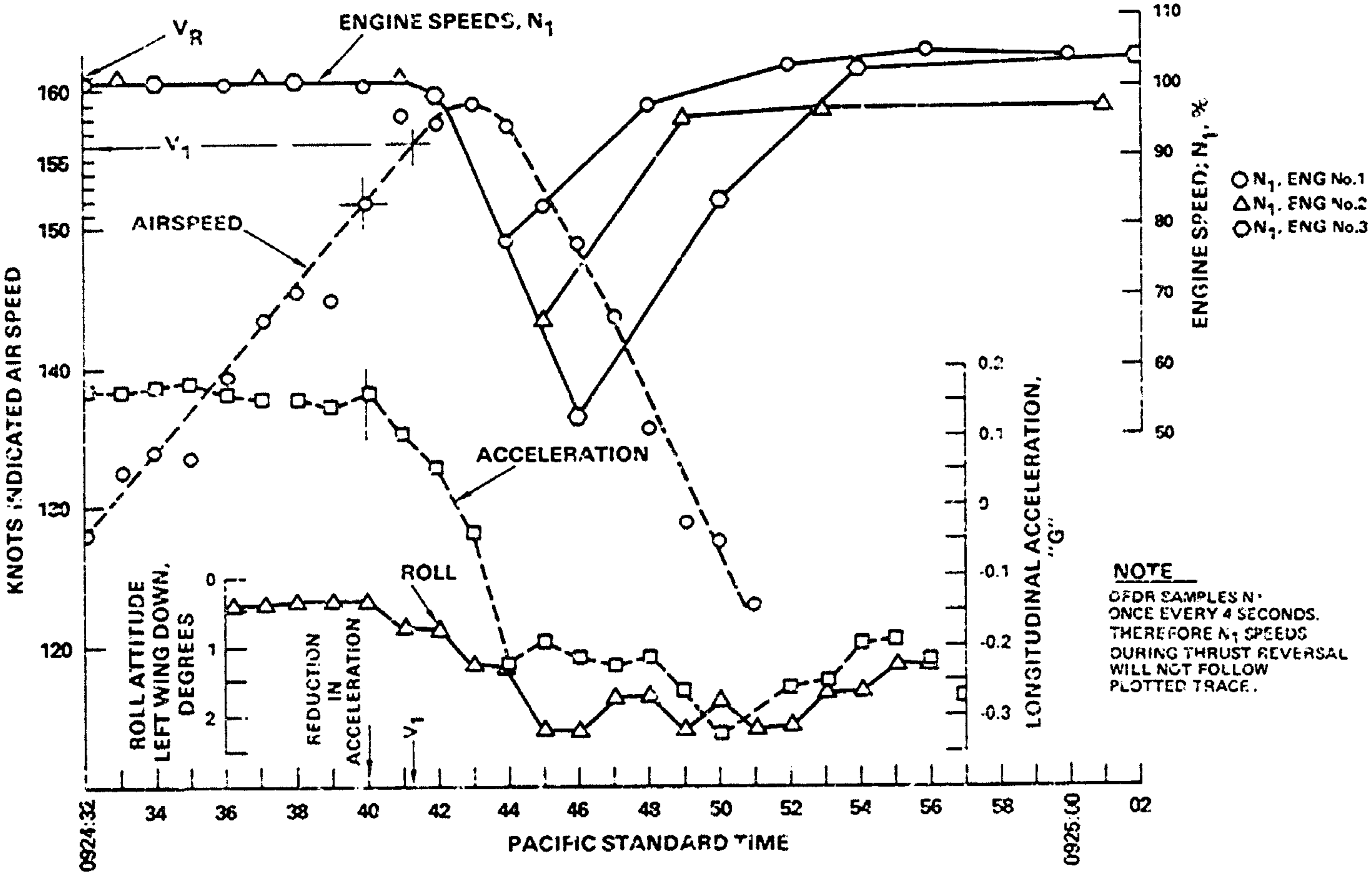

Figure 2. Aircraft performance before, after RTO initiation.

A peak vertical acceleration value of 1.22g was recorded 20.8 sec after V_1 indicating the end of the runway. The airspeed at this time was decelerating through 68 kns with reverse thrust being maintained at 104- to 105-percent N_1 speed on the wing engines and at 100-percent N_1 speed on the center engine. Three sec later, the aircraft heading began a rapid turn to the left simultaneous with a sudden 10° lowering of the left wing. The left engine speed also decreased suddenly. Peak engine speeds for the center and right engines were recorded 1 sec later. Engine speeds began to decrease on the center and right engines at airspeeds of 57 kns and 30 kns, respectively. The last recorded airspeed was 30 kns.

Between 159 kns and 68 kns, the peak longitudinal deceleration values were between -0.20g and -0.30g. The aircraft pitch attitude remained at 0° throughout the ground roll on the runway. The DFDR recording ended at 0925:17 with the aircraft on a heading of 008° and at a left wing-down attitude of 11°.

The DFDR was not equipped, nor was it required to be equipped, to record brake pressure or brake pedal travel.

1.11.3 Time-Distance Correlation

The DFDR data were used to derive correlations between aircraft speed, ground distance, and time for use in analyzing aircraft performance.

The DFDR longitudinal acceleration data were integrated to determine groundspeed and ground distance traveled. Corrections for the effects of density altitude (29.58 inHg. barometric pressure and surface temperature of 59°) were made to obtain true airspeeds so that the headwind component of the wind could be determined from comparisons of true airspeed and groundspeed. The resulting headwind averaged about 5 kns. The total ground distance traveled, determined from the integrated data, was compared to the aircraft's final position 664 ft beyond the runway to determine the location on the runway where the takeoff roll began. The resulting distance, measured from the takeoff end of the runway to the aircraft's center of gravity, was found to be 166 ft. V_1 speed, 156 kns, was reached 6,080 ft from start of the takeoff roll, or 6,250 ft from the end of the runway. At 152 kns and while engine thrust was being maintained at the takeoff setting, the marked decrease in longitudinal acceleration recorded by the DFDR corresponded to 5,560 ft of ground distance. The aircraft overran the departure end of the runway at 68 kns indicated airspeed and had covered 4,560 ft of runway from the time the rejected takeoff was recorded by the DFDR at 152 kns.

1.12 Wreckage and Impact Information

Debris was removed from the runway before investigators arrived, and its location was not documented. A witness, who was seated in the jumpseat of an aircraft which taxied down runway 6R shortly after the accident, reported that pieces of rubber and a tire carcass were strewn on the runway surface beginning about 3,000 ft from the approach end of the runway.

The event sequence was reconstructed based on marks left on the runway by the left main landing gear tire and wheel assemblies. The reconstruction showed that black marks from the No. 2 tire were evident beginning 6,300 ft from the departure end of runway 6R. These marks were spaced from 16 ins. to 20 ins. apart. With about 4,520 ft remaining, 6 in.-wide white squiggle marks from the No.2 tire were evident. With about 4,500 ft remaining, marks from both rims of the No. 2 wheel could be seen. Within the next 20 ft, marks from the inboard wheel rim of the No. 1 wheel appeared on the runway surface, with marks from both rims evident with 4,461 ft remaining. About 260 ft farther down the runway, bits of carcass ply were imbedded into the runway surface in line with the outboard rim of the No. 1 wheel. Marks from the tube well of the No. 1 wheel and from a piece of the No. 5 tire appeared at 3,403 ft and 3,380 ft, respectively. With about 1,575 ft remaining, all of the runway marks from the left main tire and wheel assemblies began to show evidence of shimmy. This characteristic continued until the aircraft left the runway surface. There were no signs of reverted rubber or other indications of hydroplaning on any tire or tire fragment. (See figure 3.)

The tire marks made by the right main landing gear during the last 2,000 ft of the roll indicated that the tires were not hydroplaning. These tracks suggested some degree of braking action when compared to the tracks of the nose gear.

About 100 ft after the aircraft left the runway surface, the remains of the left main landing gear wheel and tire assemblies broke through the tarmac surface of the nonload-bearing area and the landing gear structure failed aft. The left-main landing gear strut was found trailing behind the wing; the lower end of the strut was supported by the No. 1 wheel and two brake assemblies, which were resting on the ground. The upper end of the strut was not deformed and was connected to the main landing gear support fitting. The support fitting was not connected structurally to the wing box. Extensions of the wing upper skin, upper doubler, lower skin, and lower doubler aft of the wing rear spar connecting the gear support fitting to the wing box had failed. The upper skin had torn off along the rear spar. The lower skin had torn off aft of the rear spar. The lower doubler was torn off aft of the skin fracture.

The upper and lower auxiliary spar was torn off at the flap hinge fitting. Major fasteners connecting the support fitting to the wing box failed, except for the lower outboard 1 1/2-in.-diameter bolt connecting the support fitting to the wing box internal bulkhead, directly forward of the support fitting.

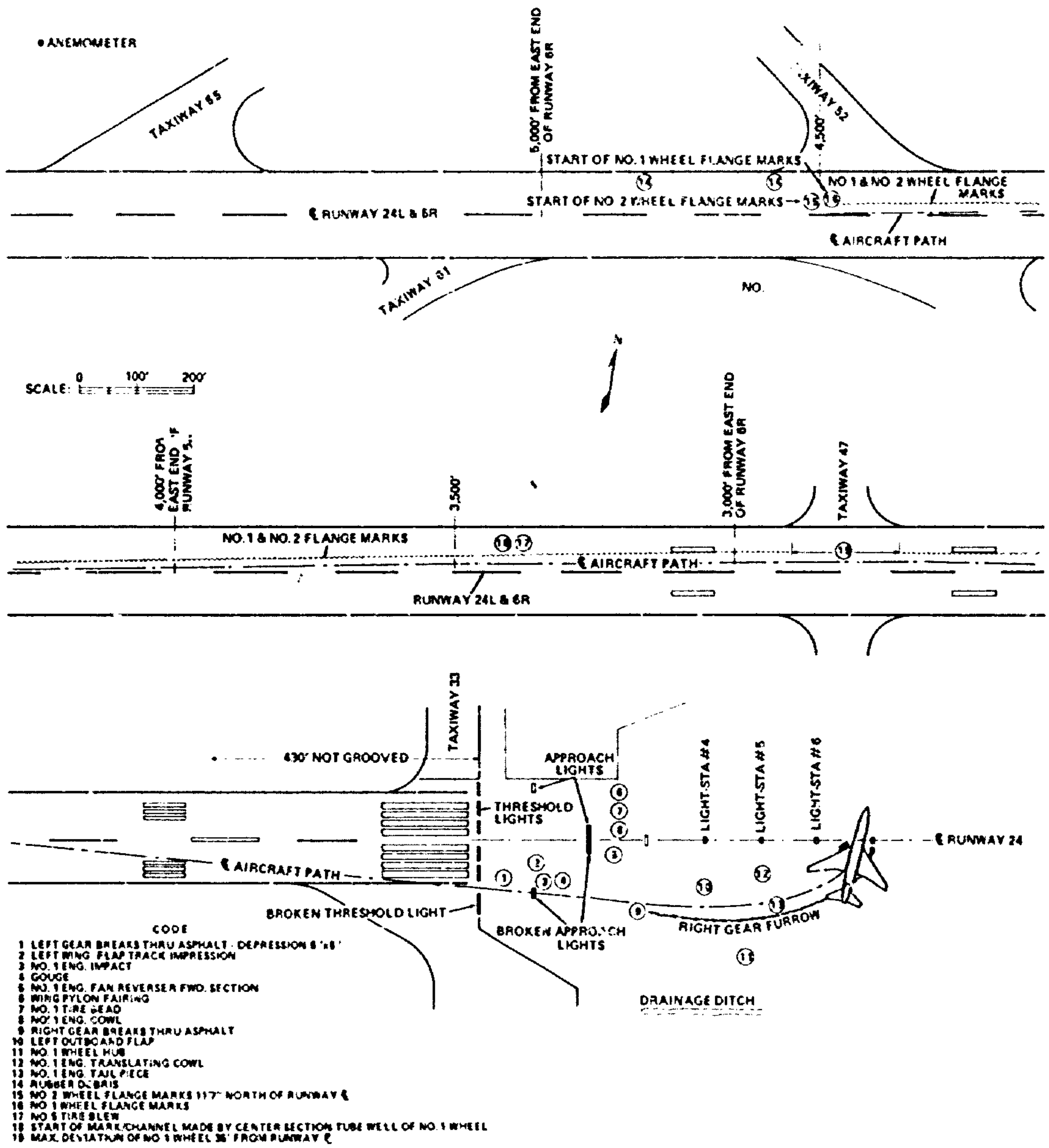

Figure 3. Aircraft wreckage distribution chart.

A trapazoidal portion of the wing rear spar web (about 3 1/2 sq ft) remained attached to the landing support fitting. This opened up the No. 1 fuel tank. The rear spar shear web and doubler had failed. A length of the vertical tang of the rear spar lower cap and a portion of the lower outboard cap of the wing chordwise internal bulkhead also remained attached to the landing gear support fitting. The wing bulkhead upper 1-in. bolts failed 1 in. aft of the rear spar web. The lower inboard 1 1/2-in.-diameter bolt was missing from its hole. A portion of the lower bulkhead cap remained on the lower outboard 1 1/2-in.-diameter bolt. A section of the rear spar web and vertical tang of the lower cap had broken loose at the outboard end of the landing gear fitting, which created a 1-sq-ft hole in the aft wall of the left compartment of the No. 2 fuel tank.

The fuselage, though burned extensively on the left side, remained intact.

The right wing was undamaged except for minor fire damage. The No. 1 and No. 2 right wing leading edge slats had been burned. Slats Nos. 3 through 8 were not damaged. All slats appeared to be extended and attached to the wing. The No. 3 engine pod had been damaged by fire.

The left wing was damaged severely when the left main landing gear collapsed; it was also burned. The wing remained attached to the fuselage but was bent upward. The No. 1 engine and pylon assembly had separated and was located just forward of the wing. The engine pod and pylon assembly was badly burned. The fuel tank had not ruptured when the engine pylon separated. The outboard aileron, inboard aileron, and inboard flap had been burned badly. The outboard flap had separated from the wing and was located a few hundred feet aft and to the left of the aircraft. The left wing leading edge had been damaged by fire. Slats Nos. 5 through 8 were burned on the surface and appeared to be retracted. The slats were still attached to the wing. The lower wingtip skin had broken through, rupturing the fuel tanks near the tip.

When the engines were examined on the scene, all thrust reversers were in the extended position. The Nos. 2 and 3 engines were not damaged. The No. 1 engine was damaged severely when the left main landing gear failed and the left side of the aircraft dropped on the engine and left wing. The investigation revealed no evidence of powerplant failure or malfunction during the acceleration or deceleration sequences until the left main landing gear failed.

1.13 Medical and Pathological Information

The deaths and injuries were incurred during the evacuation. Two passengers died of burns and smoke inhalation; they succumbed to their injuries after deplaning. Of the 71 passengers examined, 28 required hospitalization. Their injuries included various fractures, abrasions, burns, contusions, and rope burns. The injuries of the 43 passengers who were treated and released included various arm, elbow, leg, and ankle contusions and sprains, burns, and rope burns.

The flight attendant's injuries included burns, back and neck injuries, knee and elbow injuries, a fractured heel, smoke inhalation, and rope burns. The flightcrew injuries included bruises, rope burns, and leg injuries.

A review of the flightcrew's medical records disclosed no evidence of preexisting physical problems which could have affected their judgment or performance.

1.14 Fire

According to passenger statements, fire erupted from the left side of the aircraft before it came to a stop. There were conflicting reports from these passengers as to whether fire was visible before the aircraft left the runway surface.

An intense, fuel-fed fire engulfed the left engine, left wing root, and left side of the fuselage after the left main landing gear separated from the aircraft. The fire spread rapidly under the fuselage and damaged the inboard right wing and right engine cowling.

Initially, airport fire station 80N--a satellite station located adjacent to and about equal distance from either end of runway 6R--was notified. An on-duty firefighter outside the station heard two distinct "popping" sounds and turned toward these sounds in time to see some of the tires on Flight 603 disintegrate. The firefighter immediately notified the main airport fire station (station 80) that station 80N was responding. As CB-1, a 3,000-gal crash/fire/rescue (CFR) truck proceeded along a taxiway toward the departure end of runway 6R, the two occupants of the truck saw Flight 603 overrun the runway and saw the fire erupt on the left side of the aircraft. The vehicle was in position to fight the fire about 90 sec after it had responded to the emergency.

As CB-1 approached Flight 603 from the rear, the two firefighters saw the left side of the aircraft being engulfed by flames, and they could see passengers deplaning from the right side. In order to protect the passenger's means of egress, CB-1 was positioned to the right and aft of the tail section, and this position was maintained throughout the evacuation.

The fire chief, who was in a rapid intervention vehicle, and two 3,000 gal crash trucks from fire station 80 arrived on scene about 4 min after the accident and proceeded to fight the fire directly. The fire was extinguished within 2 min after these vehicles arrived.

1.15 Survival Aspects

The accident was survivable. The structural integrity of the cockpit and cabin area was not compromised, since the entire fuselage remained intact and the fire remained outside the fuselage. Some smoke penetrated the cabin area but did not hinder successful evacuation. Passenger and crewmember restraints functioned normally. Five center ceiling panels came loose from their fasteners but were kept from falling into the passenger seats by their restraint straps.

All flight attendants were aware that the takeoff was being rejected. Most of them stated that when aircraft vibration became severe and the rate of deceleration felt inadequate for stopping on the runway, they began to shout commands to the passengers to get their heads down and to assume the braced position. As soon as the aircraft stopped, one of the flight attendants at exit 1F entered the cockpit and reported that the aircraft was on fire. The second officer announced the evacuation. Some flight attendants heard the announcement; others did not. The flight attendants who did not hear the announcement were aware of the fire; therefore, the evacuation procedure started almost simultaneously throughtout the cabin. The crewmembers stated that the evacuation was completed with a minimum of confusion and anxiety. The evacuation was complete in about 5 min. The average age of the passengers was 60 years. Most passengers were with a tour group en route to Hawaii.

All of the slide/rafts on the left side of the aircraft, except that at exit 1L, were deployed; however, because of the intense fire were immediately rendered unusable. The slide/raft at 1L was pulled from its container and fell to the ground after the exit door was opened.

All of the slide/rafts on the right side of the aircraft were deployed and used. However, all eventually became unusable before the evacuation was complete because of the ground fire. The slide/raft at 1R, the forward right exit, was one of the first to be deployed, and it remained in use longer than the other three. This slide/raft failed because of radiant heat and not because of direct contact with flames. About 40 passengers used this slide/raft before it failed.

The slide/raft at 2R, the right mid exit, was deployed and used by about 30 passengers before it burned. It was probably the third usable slide/raft that was deployed.

The slide/raft and overwing ramp at 3R, the overwing exit, did not function properly; it was probably the last slide/raft that was deployed. When the unit extended 6 to 8 ft from the door, the slid/raft inflated and rose to a position vertical to the wing surface because of the upward tilt of the right wing and the gusty surface winds. Two or three passengers were able to force the slide/raft down over the leading edge of the wing inboard of the No. 3 engine. About 10 passengers successfully used the slide/raft before it burned. The 3R slide/raft over the leading edge of the wing was directly above the bodies of the two passengers who were killed. The autopsy reports showed that the male passenger sustained no traumatic injuries, which could indicate that he traversed the slide/raft when it was serviceable. The female passenger sustained a fracture of vertebrae T-5 and fractures of left ribs 4, 5, and 6. She could have fallen from the wing, the slide/raft could have failed immediately after she entered the unit, or she could have been struck by another passenger at the base of the slide.

The 4R, rear exit, slide/raft was probably the first unit to be deployed. About 30 passengers used it before the girt material 4/ tore loose. When the girt fabric failed, the inflated slide/raft fell to the ground.

About 110 passengers and crewmembers evacuated before all of the usable slide/rafts on the right side failed. (See Table 1.) Passenger statements and testimony given at the public hearing indicated that there was some smoke but no fire inside the cabin during the evacuation.

Evacuation data are known for 74-percent of the aircraft's occupants. This percentage represents 132 surviving passengers, the 2 fatalities, and 14 crewmembers.

1.16 Tests and Research

The aircraft's ability to stop on the wet runway under the accident conditions and assumed conditions was analyzed. In order to estimate stopping performance, the drainage, wetness, and slipperiness characteristics of the runway were measured.

The friction values over the total runway length were derived from tests conducted by an engineering consultant to the Safety Board using a Mu meter and associated procedures described in FAA Advisory Circular 150/5320-12, Methods for the Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces. The National Aeronautics and Space Administration (NASA) assisted the Safety Board in determining runway surface friction values along the actual ground track of the aircraft and in evaluating hydroplaning conditions. NASA also estimated the maximum effective braking coefficients available to each tire and wheel along its actual groundpath based on the NASA combined viscous-dynamic hydroplaning theory. NASA braking coefficient data were developed from tests made on runway 6R by engineers from NASA's Langley Research Center using its diagonal-braked vehicle (DBV) and associated prediction theory.

4/ The girt material is attached to a girt bar which connects the slide/raft to the exit sill. It also provides the point of detachment from the aircraft in the event the slide/raft assembly is to be used as a raft after ditching.

Table 1--Evacuation Pattern Through Usable Exits

	Exits 1/					
Slide condition unknown				[2]		[2]
Slide fully inflated		26 (3)	18	7	24	75 (3)
Slide partially inflated		7	5		1	1[illegible]
Slide totally deflated		2	3			5
Slide deflated while exiting		1	1			2
Jumped to ground from exit			2		12 (3)	14 (3)
Jumped to ground from trailing edge of wing				17 (1)		17 (1)
Slid down rope	6 (7)					6 (7)
Totals	6 (7)	36 (3)	29	24 (1) [2]	37 (3)	132 (14) [2]

1/ The numbers in parentheses () denote crewmembers; the numbers in brackets [] denote the fatalities.

At the Safety Board's request, these NASA braking coefficient values were used by Douglas Aircraft Company to evaluate the amount of braking actually used and to estimate the aircraft's wet runway stopping capabilities for conditions other than those at the time of the accident. These estimates were based on flight test and aerodynamic data, the Continental aircraft's performance below V_1, actual crew-response times, various calculated braking levels, runway surface conditions, and combinations of failed tires and failed engines.

1.16.1 Runway Characteristics and Friction Tests

The NASA drainage analysis indicated that conditions conducive to dynamic hydroplaning were not present at the time of the accident because of the low rainfall rate and excellent runway drainage, which prevented flooding below rainfall rates of about 1 in. per hour. Also runway 6R had acceptable frictional coefficients along its entire length according to current FAA Mu meter criteria published in Advisory Circular AC 150/5320-12 and U.S. Air Force criteria developed for both the Mu meter and the DBV. The Air Force criteria also confirmed NASA's conclusion concerning dynamic hydroplaning. The DBV predicted a significant loss of effective tire-to-pavement frictional coefficients on the right main landing gear, which experienced no tire failures. This 17- to 38-percent loss was found in the 1,500 ft of runway located in the rubber-coated area in the touchdown zone of runway 24L. The degree of loss depended on the amount of contaminated rubber and was derived by comparing the braking coefficients for the wet, rubber-coated surface with those on a wet, uncontaminated surface.

The effective tire to pavement frictional coefficients available to the failed left main landing gear tires and wheels during deceleration from 156 kns to 74 kns were 42 percent less than those available to the four unfailed right main landing gear tires over the same speed range. Douglas Aircraft Company estimated that the surface contaminants increased the aircraft stopping distance by 300 to 400 ft. By similar analyses, an uncontaminated, wet, and grooved surface was estimated to provide at least a 2,000-ft stopping distance advantage over an ungrooved, clean surface. NASA analysis confirmed these calculations.

1.16.2 Aircraft Stopping Performance

The actual rejected takeoff braking performance for the Continental DC-10 was calculated using DFDR data and aerodynamic data. These calculations produced a relationship between effective tire-to-pavement frictional coefficients and aircraft groundspeed. When these results were compared to the NASA-predicted maximum braking coefficients over the same speed range, substantial differences were found in the 153 kns to 132 kns groundspeed range, during which the aircraft traveled about 1,200 ft in the initial portion of the takeoff. For groundspeeds between 132 kns and 68 kns (the end of runway speed), the Douglas and NASA braking values substantially agreed, indicating that maximum braking was being achieved over the last 2,250 ft of runway. (See figure 4.) Three possible reasons fo the disagreement above 132 kns are: (1) The values predicted by NASA could have been excessive, (2) temporary loss or delay in antiskid system operation, and (3) the crew could have applied less than maximum brake pressure. If the predicted braking levels above 132 kns had been achieved, the aircraft might have stopped intact about 200 ft beyond the departure end of the runway. The Safety Board was not able to quantify the actual amount of braking effort applied by the crew or to accurately determine why the full braking values predicted by the NASA theory were not achieved.

1.16.3 FAA Accelerate-Stop Certification Requirements

14 CFR 25, "Airworthiness Standards: Transport Category Airplanes," defines the certification requirements for normal and rejected takeoffs. The associated takeoff speeds and accelerate-stop distances are predicated on recognition of an engine failure at V_1 on smooth, dry, and hard-surfaced runways. This regulation does not address tire failures on wet, slippery runways--the conditions encountered by Flight 603. Certification tests are the basis for takeoff performance data published in flightcrew flight manuals.

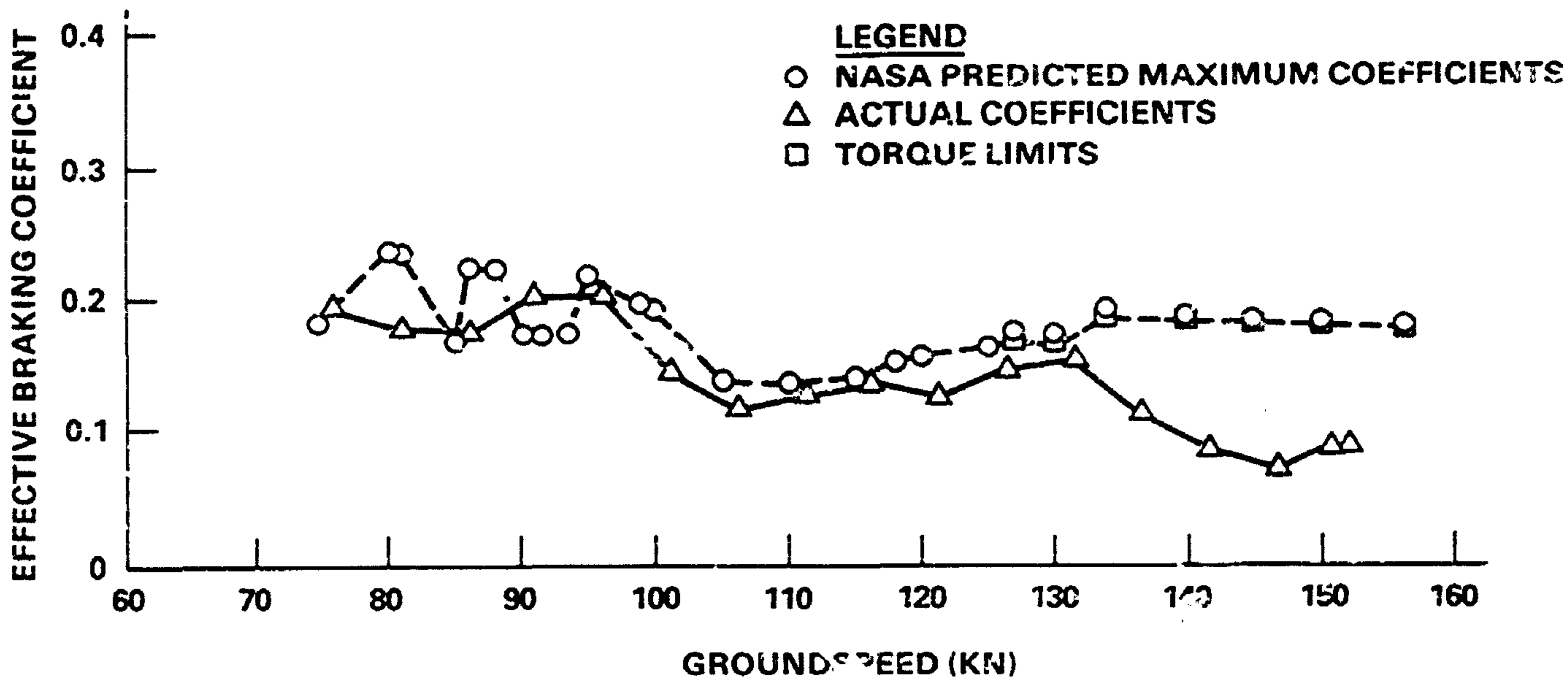

Figure 4. Comparison of actual and predicted maximum braking capabilities.

For the conditions set forth in the airworthiness standards, engine failure on a dry runway, the accelerate-stop distance for Flight 603 was calculated to be 9,450 ft, with 5,980 ft required for acceleration to V_1 and 3,470 ft required to stop the aircraft. These distances were derived from actual rejected takeoff data developed during aircraft certification flight tests. When compared to the total runway length, this distance would provide 835 ft of stopping margin on runway 6R under dry conditions. The calculated accelerate-stop distance for a rejected takeoff with a failed engine on a wet runway was 10,300 ft, 4,320 ft of which would have been required for stopping. Therefore, the estimated stopping distance on a wet runway is 850 ft more than the stopping distance required for the dry runway. Essentially, this means that a DC-10 aircraft could have stopped on the wet runway with one failed engine, with normal tires and maximum braking. Allowing for fan reversers, a 600-ft stopping distance margin would be provided.

14 CFR 25 states further that means other than wheel brakes may be used to determine the accelerate-stop distance if that means: (1) is safe and reliable, (2) is used so that consistent results can be expected under normal operating conditions, and (3) is such that exceptional skill is not required to control the airplane. The engine fan and turbine thrust reversers provide an operational safety margin, because they reduce the dry runway stopping distances determined during certification testing. However, currently FAA disallows reverse thrust credit in determining accelerate-stop distances, because thrust reverser systems have not fully met these criteria. Therefore, many operators of wide body aircraft have disconnected the turbine reversers, a portion of the reverser system, because they have not been reliable and maintenance difficulties have been encountered. The accident aircraft did not have operable turbine reversers to augment the engine fan reversers nor were they required to be operable under current regulations.

The effect of three turbine reversers on the wet stopping distance was calculated. Calculations indicated that these reversers would reduce the fan-reverser-only stopping distance by 600 ft. Applying actual braking coefficients and crew reaction times, turbine reversers could have reduced the actual runway overrun speed in this accident from 68 kns to about 20 kns. This lower overrun speed would have allowed the aircraft to stop 100 ft beyond the end of the runway, which would have drastically reduced the severity of the accident.

The Safety Board recognizes that calculations based on the NASA DBV data are estimates only. However, these estimates have allowed reasonable assessments to be made of the relative value each parameter contributes to stopping performance. No alternative analytical techniques or actual flight test data were available to the Board to otherwise estimate the aircraft's wet runway stopping performance from actual runway friction measurements.

1.16.4 Aircraft Performance in the Continental Training Simulator

The Safety Board observed aircraft performance during rejected takeoffs on runway 6R in Continental's visual "six-degree-of-freedom" DC-10 training simulator. Except for the failed tires, the accident conditions were simulated to the extent possible.

First, we observed a simulated rejected takeoff on a dry runway 6R with a 5-kn headwind and a 430,000-lb takeoff weight; temperature was 59°F. Using maximum braking and full reverse thrust on the three engines, the aircraft stopped with an apparent 2,500 ft of runway remaining. The test was repeated for a wet runway. In this case, an additional distance of 500 ft was necessary.

1.16.5 Tire Service History

The No. 1 tire, serial No. 70750273R3, was manufactured by Goodyear Tire and Rubber Company and retreaded by Air Treads, Inc. The wheel was built up on January 25, 1978, and the wheel and tire assembly was installed on the aircraft on January 26, 1978. This wheel and tire assembly had not been written up. The tire had been retreaded three times. The tire carcass had 695 total landings. Since its last retread, the tire had worn 28 percent and had 125 landings.

The No. 2 tire, serial No. 6059AK0593R3, was manufactured by B.F. Goodrich Tire Company and retreaded to specifications by the Company's facility in City of Industry, California. The tire was installed originally on an American Airlines DC-10, where it had accumulated 216 landings. The wheel was built up on December 23, 1977, and the wheel and tire assembly was installed on the Continental DC-10 on December 24, 1977. The wheel and tire assembly had not been written up since installation. The tire had been retreaded three times. The tire carcass had 961 total landings. Since its last retread, the tire had worn 69 percent and had 233 landings.

The No. 5 tire, serial No. 71390049R2, was fabricated by Goodyear Tire and Rubber Company and retreaded by Air Treads, Inc. The wheel was built up on January 6, 1978, and the tire and wheel assembly was installed on the landing gear assembly the same day. The assembly had not been written up since installation. The tire had been retreaded twice and had 178 landings since its last retread.

The Safety Board inspected the failed tires on scene. In addition, the Safety Board requested that the Department of Transportation's, Transportation Systems Center Tire Laboratory conduct a detailed, independent inspection of the tire pieces in order to specify additional tests on Nos. 1 and 2 tires that might aid in determining the cause and sequence of tire failure. Since the Tire Laboratory's previous experience was with automotive and truck tires, the Safety Board retained a technical advisor, Dr. S. K. Clark of the University of Michigan. to assist in the inspection.

The testing began on March 23 and was completed on April 23, 1978. Results of these tests indicated that both tires had been manufactured to acceptable commercial standards. Tire No. 1 showed catastrophic heat damage in the cords near the beads. Photomicroanalysis showed advanced fatigue in the outer plies of the carcass areas not involved in the latter stages of destruction. Tire No. 2 had excessive heat damage in the sidewalls. There was degradation and excessive working indicated in the outer plies and the breaker ply. Inspection of No. 2 tire revealed that the liner had been repaired in two places. In the repair process, the liner had been buffed and the cords were exposed. These repairs had been made when the tire was originally manufactured. The patches that normally cover such buffed areas were missing. To determine if these buffed areas could have allowed air to leak from the tire between the time the pressure was checked after the previous landing and the tire failure, dynamic leak tests were performed at the B.F. Goodrich Company on both a new tire that had no buffed areas in its liner and on a tire that had buffed areas in its liner. Based on these tests, the Safety Board concluded that if the repair patches were missing before the aircraft departed the airport terminal, the pressure loss during the taxi and takeoff run would have been about 4.5 psi, which would have reduced the tire pressure to about 180 psi.

The March 1 Service Check Work Sheet for the aircraft was reviewed, which was based on the service check performed between the time the aircraft landed as Flight 608 and departed as Flight 603. According to the work sheet, the tires contained the proper pressure. Tire ambient temperature at the time is not known. The aircraft was on the ground for 3 hrs 15 min.

The Safety Board found that these tires were certified for use on the DC-10 aircraft at a 51,060-lb maximum calculated static load, based upon equal load distribution among tires on the main gear. The rated load for the 50 x 20, 32PR tires is 53,800 lbs. However, load distribution was not equal between the two tires mounted on the same axle, because stiffness characteristics of the two tire brands differed under load. The No. 1 tire was stiffer than the No. 2 tire. These differences in deflection characteristics in combination with differences in retread levels, in inflation pressures, in outside diameters, and in wear can cause the load being carried by one of the tires to exceed its rated load. Additionally, no load margin was provided for in the rated load for possible load increases caused by the angle at which the landing gear contacts the taxiway and runway surfaces.

Aircraft tire standard, Technical Standard Order (TSO)-C62b, has not been revised since 1962 in spite of efforts by the industry and FAA. The design strength qualifications outlined in the TSO did not simulate the operational characteristics of wide body aircraft. For example, during tire qualification, prototype tires were tested for 100 landings with decelerations from 90 mph. This speed is too low to compare to the typical wide body aircraft landing speed or rejected takeoff speed. Although new tires provide the wear capacity for about 150 landings, the tire carcasses can be retreaded several times and thus are subjected to several hundred landings. The TSO does not require tests to demonstrate a tire's ability to withstand an overload when a mate tire on the same axle fails. Neither manufacturing tolerences nor variations in operating inflation pressures were considered in the qualification tests.

There is no TSO for retread designs. The Safety Board determined that the retread designs for the accident tires were qualified by limited testing on a voluntary basis. The tire retread design changed the rubber composition in the tread area, the breaker ply, and the skid depth on both tires and added cord in the tread on tire No. 1.

The aircraft tire retreading industry has been using the holographic process on a limited basis for nondestructive inspection of the tread area. The process is used to detect flaws or damage in the carcass before it is retreaded or returned to the users. Other methods of nondestructive inspection, such as ultrasonic and x-ray, have also proved effective for detecting certain flaws in tire parts. The tires on the accident aircraft had not received nondestructive inspection.

Although a nondestructive inspection technique is not currently available to detect cumulative damage, such as that found in the ply structure of the sidewall of a tire on Flight 603, some users are specifying nondestructive inspections of all tires before and after retreading. Rejection rates on these tires are between 3 percent and 4 percent.

There is no data base available to industry on the correlation between tire defects and tire failures. The Safety Board believes that the tire industry and the airline industry should use all available means of nondestructive inspection in order to establish a data base from which a correlation between defects and failures can be established.

An operator's knowledge of and adherence to optimum maintenance practices and operating procedures also affects tire failure rates. For example, these tires were qualified at an inflation pressure of 190 psi, which was optimum for the rated load. However, Continental Air Lines chose to inflate tires to a 182- to 188-psi pressure range. They did so because the wheel's service life is reduced by high tire pressure and because the lower pressure reduces the probability of foreign object damage. The tires may have been overdeflected when the aircraft was operated at maximum weight.

Testimony at the Safety Board's public hearing revealed that the strength of an aircraft tire is degraded by the heat generated by relatively high taxi speeds, long taxi distances, and excessive use of brakes. The most critical circumstance under which the tire must operate is a long taxi on a hot day at maximum gross weight. A flight is assigned a runway and the flightcrew, in most cases, must accept that runway, as in the accident case where runway availability was a factor. Therefore, a crew may have little or no influence on taxi distance. Since not all aircraft are equipped with an inertial navigation system which gives accurate taxi speeds, no groundspeed readout below about 60 kns is available in most cases to the flightcrew and reduced taxi speeds become judgmental. However, the flightcrew does have the responsibility for the judicious use of brakes. Testimony at the public hearing revealed, further, that Douglas Aircraft Company had not determined taxi speed and taxi distance limitations as a function of the DC-10's gross weight. Therefore, users do not have all information required to operate their aircraft properly within the design and qualification limits.

1.16.6 Slide/Raft History

When the combination slide/raft was first considered for use on the DC-10 aircraft, no TSO existed for such a device. Thus, in 1968 or early 1969, when presented with the possibility of having to certify a combination slide/raft as part of the aircraft's type design, the FAA met with industry and decided that the Society of Automotive Engineers' S-9 Cabin Safety Committee would be asked to pursue design objectives.

The Committee published Aerospace Recommended Practice 1145 in July 1970, which detailed slide/raft design objectives. The FAA then adopted the recommended practice as a requirement for certification of the slide/raft devices. In addition, provisions of three existing TSO's--C-12c, Life Rafts; C-69, Emergency Evacuation Slides; and C-70, Life Rafts--were used. The FAA presented additional certification requirements in a commentary paper published in August 1970 and amended in March 1971. The FAA presented these design and test requirements to the aircraft industry as the basic standard for the certification of slide/raft devices. Currently, no separate TSO exists for slide/raft devices.

After the accident, the Safety Board requested the FAA's Civil Aeromedical Institute at Oklahoma City, Oklahoma, to test the tensile strength of girt fabric taken from the exit 4R slide/raft. Three test strips, labeled A, C, and D, were cut from the undamaged area of the girt fabric. Because of the small amount of material available, the test strips were 2 ins. wide. TSO C-69 requires test strips to be at least 4 in. by 6 in. Strips A and D were cut from a section of girt material perpendicular to the girt bar; test strip C was cut from a section parallel to the girt bar. A Dillion tensile test machine with a 5,000-lb capacity was used to conduct the tests. The results of these tests were:

Test Strip	Maximum Tensile Load (lbs)	Free Length 5/ (in.)
A	690	3.6
C	400	5.85
D	725	4.4

At the Safety Board's request, the FAA's National Aviation Facilities Experimental Center at Atlantic City, New Jersey, examined the effects of fire on the slide fabric using both laboratory and outdoor fire test procedures.

Based on these tests, the FAA concluded:

"1. The low resistance of evacuation slide materials to radiant heat produced by a free-burning fuel fire can cause early deflation of the escape slides.

"2. Failure of the yellow uncoated inflated slide sample occurred within 29 to 45 sec when exposed at a distance of 9 ft upwind and to the sides of a free-burning fuel fire where the heat flux varies from 0 95 to 2.07 Btu/ft^2 - sec.

"3. Failure of the yellow uncoated inflated slide sample 18 ft downwind of the free-burning fuel fire occurred in 17 sec as a consequence of conductive and radiative heat flux caused by significant flame bending.

"4. Good correlation was established between the failure time of the slide materials in the laboratory and outdoor fire exposure tests.

"5. A significant improvement in the thermal resistance of a slide fabric was observed when the exposed surface was covered by a reflective coating of aluminum."

1.16.7 Left Main Landing Gear Collapse

The Safety Board investigated the failure of the landing gear-wing structure to determine why the landing gear collapse caused the wing fuel tank to rupture. Metallurgical examination revealed that the structure conformed with the FAA-approved specifications and no abnormal conditions were noted. Failures were due to overload.

5/ Free length is the length of fabric between the clamps.

When the DC-10 aircraft was certificated, the only certification requirement pertaining to landing gear collapse and attendant fuel tank rupture was 14 CFR 25.721 (d). It provides:

> "The main landing gear system must be designed so that if it fails due to overloads during takeoff and landing (assuming that the overloads act up and aft), the failure mode is not likely to puncture any part of the fuel system in the fuselage.
>
> "In addition...the airplane must be designed so that an otherwise survivable emergency landing on a paved runway with any or all wheels retracted may not result in serious injury to occupants or prevent the occupants rapid evacuation if a fire is caused by a rupture of the fuel systems, including tanks."

During the certification program, Douglas Aircraft Company indicated that the DC-10 landing gear was designed so that failure would predictably occur in landing gear structural parts, which were not likely to puncture any part of the fuel system in the fuselage. The Safety Board found four previous DC-10 accidents werein the main landing gear collapsed. In these four accidents, the failure mode was not as Douglas predicted; however, the failures did not rupture the fuel tank in the wing.

Examination of the Continental DC-10's main landing gear discounted any installation anomaly, such as bolt head cocking or misalignment. The failure most probably resulted from a complicated sequence of individual part failures brought about by adverse loading and dynamic effects. (Adverse loading refers to loading other than vertical and aft.) Torque about the vertical axis and sideload were the most likely sources of adverse loading. This torque may have been caused by the differential between the drag forces on the axle on No. 1 tire and the wheel hub on the No. 2 tire. The sideload may have been caused by sluing of the aircraft as it rotated to the left after leaving the paved runway sruface.

The Douglas Aircraft Company has proposed a program to develop special pins which will replace the existing landing gear trunnion pins. When the landing gear collapses, these special pins, called zero margin trunnion pins, would fail and prevent failure of the fuel tank structure. The proposed test program for the special pins includes static and fatigue tests to confirm breakaway loads and to prove that normal gear cycles will not cause the pins to fail.

1.17 Additional Information

1.17.1 Wet Runways and Rejected Takeoffs: Accident History, Certification Requirements, and Industry Awareness

In 1977, an FAA report 6/ covering the 11-year period 1964 through 1975 concluded that, of 171 rejected takeoffs studied, 87 percent were rejected because of some failure or malfunction of tires, wheels, or brakes; tires alone accounted for 74 percent. The data show that the engine failures have not been the dominant cause factor for some time. The report also cites wet or slippery runway involvement in three major accidents 7/ between 1964 and 1975. With respect to rejected takeoffs on wet runways, the FAA report concluded:

> "The increased accelerate-stop distance necessitated by wet or slippery runways is not accounted for in current regulations or airplane flight manuals, allowing potential for further serious accidents.
>
> "In everyday jet transport operations, corrections to takeoff calculations are made for local conditions such as wind, runway slope, etc., yet these can be less significant than a correction for a wet/slippery runway which is needed but not currently required by applicable rules.
>
> "Wet or slippery runways are a significant factor in RTO (rejected takeoffs) accidents. Three of the five RTO accidents with fatalities or total aircraft destruction also involved wet or slippery runways.
>
> "Approximately 3 to 4 percent of air carrier accidents, fatalities, and aircraft losses can be attributed to tire/wheel/brake related RTO's. This includes 21 accidents, 98 fatalities, and 5 aircraft losses in an eleven year period. RTO accidents, fatalities, and aircraft losses of this nature can probably be drastically reduced by applying wet/slippery runway accountability and tire improvements."

The FAA report recommended:

> "...the increased accelerate-stop distance required on wet/slippery runways be taken into account in takeoff calculations

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6/ Jet Transport Rejected Takeoffs, Final Report, February 1977, Flight Standards Service, Federal Aviation Administration.

7/ Boeing 707, N769TW, Trans World Airlines, Inc., Rome, Italy, September 23, 1964.
Douglas DC-8, N4909C, Capitol International Airways, Inc., Anchorage, Alaska, November 27, 1970.
Douglas DC-10, N1032F, Overseas National Airways, Inc., Jamaica, New York, November 12, 1975.

and the necessary changes to airplane flight manuals, procedures, and regulations be incorporated to accommodate this.

"Action be taken to significantly reduce the incidence of tire failures during takeoffs and rejected takeoffs. This may entail improvements in maintenance, quality control, operating procedures, tire strength or design standards, or a combination of these."

In contrast to the dry runway rejected takeoff certification requirement of 14 CFR 25, 14 CFR 121, Air Carriers, Air Travel Clubs and Operators for Compensation or Hire: Certification and Operations, provides an operational safety margin for landings on wet runways. A landing aircraft is required to stop on a dry runway within 60 percent of the effective runway length; the total runway length used for this calculation is increased by 15 percent for wet or slippery conditions. In effect, Part 121 establishes a wet runway stopping distance that is slightly more than twice the dry runway stopping distance. However, even though Part 121 provides for corrections to takeoff weights, distances, and flightpaths required by density altitude, wind, and runway slope during normal and rejected takeoffs, it does not similarly require corrections for the added stopping distance required by rejected takeoffs initiated by engine or tire failures on wet or slippery runways.

On the other hand, FAA Advisory Circular 91-6, Water, Slush, and Snow on the Runway, dated January 1975, discusses the increased runway length and aircraft weight reduction required by jet transport aircraft taking off on runways covered by 1/2 in. of wet slush. The correction data account for the increased drag caused by the slush and are based on the practices of several aircraft operators and on tests conducted by the FAA. In its DC-10-10 Flight Manual, Continental Air Lines published weight and V_1 speed reductions for standing water, wet and dry snow, and slush of different depths. However, the correlation did not consider the damp, well-soaked condition which prevailed at the time of the accident.

In 1962, the British Civil Aviation Authority (CAA) changed the British Civil Airworthiness Requirement (BCAR) to account for the increased accelerate-stop distance necessitated by wet runways under engine-out conditions. Transport aircraft manufactured in the United States under 14 CFR 25 requirements and registered in the United Kingdom are required to be tested on a standard wet runway as specified by the BCAR's. The DC-10, the L-1011, and the B-747 have been certified for BCAR wet runway requirements. The BCAR procedures reduce the dry runway V1 decision speeds so that an aircraft initiating a rejected takeoff at the lower, wet V_1 speed will have more stopping distance on a wet runway. The BCAR reduced the wet runway screen height from 35 ft, the current FAA standard, to 15 ft. The BCAR, however, retained the 35-ft screen height for takeoffs on dry runways. (Screen height is the vertical distance above the runway where the safety airspeed (V_2) is reached with a failed engine.) This reduction in screen height allows the wet runway length to be essentially the same as the dry length and, for the DC-10, imposes no weight penalty. The CAA has stated recently that it has no information to suggest that the lower screen height for wet conditions has degraded the level of safety. They estimate that there have been about 1 million takeoffs on wet runways since the change was adopted.

During the investigation of the accident, the Safety Board learned that, for more than 5 years, one DC-10-10 operator at Los Angeles has routinely accounted for the added wet runway stopping distance by reducing V_1 speed and aircraft weight. The reduction in weight is required because of the 35-ft screen height standard set by the FAA. For the accident case, the wet V_1 speed would have been 149 kns, 7 kns lower than the dry V_1 speed (156 kns), and the takeoff weight would have been reduced by 10,300 lbs. Under these conditions, the accident aircraft could have been flown successfully, because the tire failures heard as "bangs" by the flightcrew occurred above the wet V_1 speed. Therefore, the captain would have already made his decision to continue the takeoff.

1.17.2 Pilot Training for Rejected Takeoffs

During recent DC-9 landing and rejected takeoff simulator runs, Douglas Aircraft Company found evidence that pilots may not be adequately trained for the maximum braking effort required to stop from near V_1 speed. 8/ Eight engineering test pilots and three airline pilots were involved in the evaluation of the ground handling characteristics of the simulator. Although each pilot was instructed to apply a maximum braking effort during each run, time-history records of brake pedal deflections showed that some airline pilots required as many as eight runs to achieve maximum braking. On the other hand, the test pilots applied full braking on their first or second run.

FAA Advisory Circular 121-14A, Aircraft Simulator Evaluation and Approval, dated February 9, 1976, set forth acceptance standards for approval of aircraft simulators used in pilot training. It contains accuracy criteria for takeoff performance characteristics (time to V_1 speed) based on the aircraft manufacturer's flight test and certification data for dry runways. The Advisory Circular does not contain deceleration criteria for dry, wet, or slippery runways. The Circular does not provide for the measurement of the amount of braking effort applied by pilots or achieved by the brakes to assess how well pilots are attempting to stop aircraft during high-energy rejected takeoffs on critical length runways.

8/ Kibbee, G. W., Douglas Aircraft Company: Expansion of Flight Simulator Capability for Study and Solution of Aircraft Directional Control Problems on Runways, NASA Contractor Report 2970, April 1978.

Appendix E of 14 CFR 121 prescribes flightcrew rejected takeoff simulator training requirements during initial, transition, and upgrade training. The rejected takeoff requirement for the simulator is based on being "accomplished during a normal takeoff run after reaching a reasonable speed determined by giving due consideration to aircraft characteristics, runway length, surface conditions . . . and any other pertinent factors that may adversely affect safety or the airplane." The requirement does not address the critical nature of rejected takeoffs near V_1 speeds at maximum gross weights on wet or slippery runways.

The rejected takeoff procedures in the Continental DC-10 Flight Manual specify that brakes should be applied "as required" after retarding the throttles to idle. Reverse thrust is to be applied "as required" following brake application. These procedures do not address rejected takeoff initiated at or near V_1 speed and at maximum takeoff gross weights. In contrast to the Continental Air Line procedures, Douglas Aircraft Company DC-10 Newsletter to DC-10 operators, dated August 1977, discussed the emergency nature of a rejected takeoff initiated near V_1 speed. The letter recommended using maximum brake pedal deflection, simultaneously selecting reverse thrust, and applying full reverse thrust as soon as possible. Douglas further emphasized that these procedures are absolutely essential in attaining the calculated rejected takeoff performance.

1.17.3 Runway Surface Standards

14 CFR 139 addresses certification and operation of land airports serving certified air carriers. Subpart E requires the airport operator to promptly, and as completely as practicable, remove from runway pavement areas rubber deposits or other contaminants as required by operational considerations. However, the regulation does not contain specific criteria for acceptable runway surfaces and conditions. FAA Advisory Circular AC 150/5320-12, Methods for the Design, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces, June 1975, presents guidance to airport operators on runway surface testing with respect to texture and friction, a minimum friction standard, and criteria and methods for restoring surfaces. It also suggests sampling intervals for runway friction surveys based on annual aircraft operations. Annual aircraft operations at Los Angeles International Airport have exceeded 460,000 since 1975. In 1977, these operations totaled 495,312. During the same period from 1975, the annual operations on runway 6R have averaged between 50,000 and 60,000. For this level of operations, the FAA Advisory Circular suggests a friction survey once every two weeks. No evidence was found to indicate that the Los Angeles International Airport operator had the equipment suggested by the FAA Advisory Circular or had conducted surveys for runway friction on runway 6R since its construction and grooving in 1974.

1.18 New Investigation Techniques

None

2. ANALYSIS

The flightcrew was properly certificated and each crewmember had received the training and off-duty time prescribed by applicable regulations. There was no evidence of medical or psychological problems that might have affected their performances.

Except for the inoperative CVR, the aircraft was certificated, equipped, and maintained according to applicable regulations. The gross weight and c.g. were within prescribed limits. The aircraft's airframe, systems, and powerplants were not causal to this accident.

The evidence showed that the accident was initiated by the nearly simultaneous carcass failures of the two tires mounted in the No. 1 and No. 2 positions. Since these tires were mounted on the same axle, the 97,920-lb load on the axle was distributed between the two tires.

The analysis of tire and wheel marks on the runway indicated that the failure sequence began when the tread from the No. 2 tire separated from its carcass about 6,300 ft from the departure end of the runway. The tire carcass remained intact until the aircraft was about 4,520 ft from the runway departure end where squiggle marks indicated blowout. The squiggle marks on the runway at that point and postaccident examination of the tire remains indicated that extreme heat had built up in the carcass sidewall and that the carcass had blown out at its upper sidewall. After the tread had separated, the rubber was abraded by direct contact with the runway surface and eventually blew out.

After the No. 2 tire carcass blew out, the entire load on the axle was imposed upon the No. 1 tire. The markings made by the No. 1 rim, which showed contact with the runway surface 4,480 ft from the runway departure end, indicated that the No. 1 tire failed almost immediately (within two wheel revolutions) after the No. 2 tire carcass failed. The No. 1 tire virtually disintegrated while the whole No. 2 tire carcass, except the beads, came off the wheel. Examination of the remains of the No. 1 tire indicated that the tire ultimately blew out in the lower sidewall.

The DFDR showed that the tires failed just before the aircraft accelerated through 152 kns--about 4 kns below the calculated V_1 speed. The DFDR further showed that the captain reacted promptly to the tire failures and began rejected takeoff procedures. However, he was not able to stop the aircraft within the remaining runway.

Thus, to understand this accident sequence, two distinct, but related, issues must be analyzed. First, since the tire failures triggered the sequence of events, tire failures and tire reliability in general must be anaylzed. Second, reasons must be determined for the captain's inability to stop the aircraft on the runway even though the rejected takeoff was initiated before the aircraft reached V_1 speed.

Tire Failures and Tire Reliability

Both the No. 1 and No. 2 tires were on their third retread cycle, a limit which was set by the airline based upon prior experience of unscheduled removal of DC-10-10 tires. The two tires had been manufactured by different companies and had different design characteristics. Both, however, met all specifications set forth in FAA regulation for certification. Tire No. 2 had been subjected to more total landings than tire No. 1 and its tread was worn about 40 percent more. The pressure of both tires had been checked about 3 hours before the accident, and the Safety Board has no evidence to indicate that either tire was inflated below the limits allowed by the operator during the taxi and takeoff roll immediately preceding the accident. However, No. 2 tire had the lower pressure which shifted load to the No. 1 tire.

Tests conducted at DOT's Tire Laboratory did not disclose evidence of defects in the retread manufacturing process which could have explained the separation of tread from the No. 2 tire carcass. Examination of the tire did show that repair patches had been installed on the tire's liner when the tire was originally manufactured. The Safety Board believes that these patches may have lost their sealing capability either just before or during the accident sequence. If so, either of two possibilities could explain the tread separation. First, the leakage of air under the tread was sufficient to cause the tread to separate without being sufficient to detect during checks or second, the tire liner had lost its integrity, and external leakage was causing overdeflected operation during the takeoff roll. This overdeflection could have produced a standing wave 9/ behind the footprint which led to tread separation.

Another possible tire failure sequence might be that the No. 1 tire became underinflated during the taxi/takeoff cycle for some undetermined reason. The selection of tires for an aircraft is based upon the assumption that each tire will carry its share of the load. Further, it is assumed that the load will be equally distributed between the tires mounted on the same axle. The tires' rated loads, as established by the tire manufacturer, must therefore equal half of the maximum calculated static load carried by the axle. Thus, when one of the two tires fails, the remaining tire must support the entire axle load which can be nearly double the tire's rated load. Although the tire is probably capable of supporting this load statically, it will be seriously overdeflected and dynamic operation will cause a rapid temperature rise in the sidewall.

9/ A wave-like fold in the tire which develops behind the portion of the tire deflected against the ground (the footprint) when the tire is not inflated properly. The onset of this wave depends on the ground-speed of the aircraft.

In this instance, tire No. 2 would have then been overloaded and overdeflected which could result in tread loss followed by carcass blowout. Failure of the No. 2 tire alone probably would not have affected the aircraft's accelerate-stop performance to the extent that an accident was inevitable. The Safety Board believes that had the No. 1 tire not suffered previous degradation, it would have been capable of operating for a longer period than evident in this accident. The examination of the tire's carcass disclosed advanced fatigue in the ply structure. In addition, there was evidence of severe cord overheating near the sidewall bead area, and several other areas of the sidewall showed evidence of very high temperatures. Such conditions are typical of those produced by overload or overdeflected operation for a prolonged period of time.

Although the Safety Board cannot determine when such damage was inflicted, it is concerned that airframe and tire design, and operational and maintenance procedures can combine to cause prolonged operation of tires in an overdeflected or overloaded condition. Normal differences between two tires on the same axle, particularly if they are of different designs, could preclude them from carrying equal loads. The Safety Board believes that the preexisting damage in the No. 1 tire was a factor in causing it to ultimately fail almost immediately after the No. 2 tire failed, and thus, the preexisting damage may have been a causal factor.

About 3,400 ft from the departure end of runway 6R, the No. 5 tire failed. This failure was caused by foreign object damage when pieces of either the No. 1 wheel or No. 2 wheel broke off after the wheels contacted the runway surface and hit the No. 5 tire. This failure further reduced the braking capability of the aircraft.

<u>Rejected Takeoffs</u>

Because of its gross weight of about 430,000 lbs, the only runway available to the aircraft at Los Angeles International Airport was 6R, which was 10,285 ft long. Based on current FAA dry runway certification data, an 850-ft stopping margin would be expected if a rejected takeoff was initiated at V_1 because of engine failure. However, when wet runway surface conditions and tire failures are considered, the stopping margin is eliminated. Although other runways at the airport, which are 2,000 ft longer than runway 6R, probably could have contained the rejected takeoff, they were not available to aircraft with gross weights of more than 325,000 lbs because of runway overpass strength limitations. A project to eliminate this limitation is in the planning stages. The Safety Board urges the responsible authorities to expedite this project and make longer, safer runways available to heavier aircraft at Los Angeles International Airport.

Even though the measured wet friction characteristics of runway 6R exceeded minimum standards suggested by the FAA, the Safety

Board believes these characteristics contributed to the partial loss of the aircraft's braking capabilities and, therefore, contributed to the inability to stop the aircraft on the runway. This loss of runway friction was particularly evident in the rubber coated areas on the departure end of the runway, the touchdown area for landings on runway 24L.

The FAA developed the minimum runway friction standards and methods for the measurement of these standards. FAA Advisory Circular AC 150/5320-12, Methods for the Design, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces, made this information available to airport operators. Because the information in this Advisory Circular is not mandatory, airport operators do not routinely use it. At the time of this accident, neither the Los Angeles International Airport operator nor the FAA authorities in the Los Angeles area had the FAA-recommended equipment to make these measurements. Furthermore, no record could be found to show that friction surveys had ever been conducted or that rubber deposits and other contaminents had ever been removed from the surface of runway 6R/24L since the runway was grooved in 1974. When the Safety Board made the results of its runway friction tests available, the affected areas were cleaned. For some time the Safety Board has maintained that the provisions of AC 150/5320-12 should be made mandatory. As a result, the Safety Board issued safety recommendations A-76-136 and 137 on November 18, 1976. The FAA disagrees with the Safety Board, in that it believes the economic burden placed on individual airport operators would be prohibitive and the precision techniques for friction testing are not presently available. However, they are presently studying the matter.

Certification and operations regulations do not take into account the longer stopping distances required by rejected takeoffs on wet or slippery runway surfaces or the reasons for rejected takeoffs other than an engine failure. The FAA reached this same conclusion in its 1977 Jet Transport Rejected Takeoff Study. However, the FAA still has not developed procedures which would allow aircraft manufacturers, airline operators, or flight crewmembers to determine changes in decision speeds or aircraft gross weights, or both, so that successful rejected takeoffs could be accomplished from near V_1 speed on a wet runway following engine or tire failures. The Safety Board concurs with the recommendations in the FAA's study and believes that, unless FAA takes wet or slippery runways and the other reasons for rejected takeoffs into account, accidents and incidents will continue, especially when aircraft are required to operate on dry, wet, or slippery runways of critical length.

Flightcrews, for the most part, are trained for rejected takeoffs in flight simulators, and therefore, training is limited by the capability of the simulator and by the training requirements of 14 CFR 121. Since the simulator's accelerate-stop performance is based on the aircraft manufacturer's dry runway, engine-out certification data, it is impossible to simulate realistic wet runway conditions or malfunctions other than an engine failure. FAA simulator requirements contain performance specifications for the acceleration portion of the rejected takeoff maneuver, but not for the stopping portion of the maneuver. Further, the FAA does not require that the instructor, evaluation pilot, or trainee determine pilot reaction time and the amount of braking effort applied by pilots in the simulator.

The training requirements of 14 CFR 121 do not require rejected takeoffs at the maximum gross weights and decision speeds encountered in normal operations. As revealed in testimony at the public hearing, crewmembers do not typically receive this more demanding training. Although a captain is expected to know that a maximum braking effort would be required when a rejected takeoff is initiated at the higher speeds and gross weights, he cannot be expected to judge whether the aircraft is decelerating at its maximum capability if he has never been trained for that eventuality.

The captain of Flight 603 reacted promptly to the tire failures, and he acted in accordance with Continental procedures. During depositions, he stated that he applied full brake pressure immediately. However, because there was no requirement for the DFDR to record brake pressure at the brake or flight test data available to validate the Douglas/NASA predicted deceleration rates, the Safety Board was not able to verify if maximum brake pressure was achieved during the early portion of the rejected takeoff. Further, the Safety Board could not determine if the antiskid system performed to its maximum capability during the same time period.

After the captain and the other flight crewmembers became aware that they would not be able to stop the aircraft on the runway, the captain steered the aircraft to the right to avoid colliding with the approach light stanchions for runway 24L. The Safety Board believes that this action reduced the severity of this accident. Impact with the nonfrangible stanchions could have caused additional major structural damage.

The Rejected Takeoff Decision

The determination of the minimum length of runway required for takeoff in air carrier operations, or conversely the determination of the maximum weight for the airplane to take off on any given runway, is based upon a balanced field concept. This concept is predicated upon the calculated ability of the aircraft to either stop within the length of the runway or to successfully continue the takeoff after an engine failure during the takeoff roll. Before each takeoff, the flightcrew will use accelerate-stop performance data obtained from the aircraft's certification tests to calculate the maximum allowable takeoff weight and the critical engine failure speed (V_1). The flightcrew has been trained to use the V_1 speed as a decision point during the takeoff roll. If an engine failure is recognized before the V_1 speed is reached, the pilot is trained to reject the takeoff and he, in fact, must reject the takeoff since he cannot be assured of successfully continuing. On the other hand, if the aircraft is beyond the V_1 speed before an engine failure is recognized, the takeoff must be continued since the pilot cannot be assured of stopping the aircraft on the remaining runway.

Although V_1 speed is designed to be the go-no-go decision speed in event of an engine failure, the Safety Board believes that pilots have come to regard V_1 as the go-no-go decision speed for any anomaly during the takeoff roll. However, the calculated V_1 speed, by current definition and certification standards, is valid only for circumstances in which the aircraft has its full braking capability. Furthermore, since the aircraft's performance data were obtained through testing on dry runways, there is no assurance that the current concept is adequate when the braking coefficient of friction is reduced on a wet surface.

Even when full braking capability is available and the runway surface is dry, a rejected takeoff initiated at or just before the aircraft reaches V_1 speed is risky on a minimum length runway. Using maximum braking and optimum procedures, the aircraft is going to use all of the remaining runway length to stop. (Actually, a small margin is provided since the braking effect of thrust reversal is not considered in accelerate-stop performance data.) In this accident, the aircraft had about 800 feet more than the minimum runway provided by the balanced field concept; even so, two significant factors combined to invalidate the use of V_1 speed as a go-no-go decision point: (1) the loss of effective braking on wheels with blown tires, and (2) the reduction in brake friction coefficient on wet surface.

The Safety Board, therefore, views the captain's no-go decision as a key element in the accident sequence. This is in no way intended to imply that the Board faults his decision, but rather that the limited validity of the decision-making process and of the V_1 concept in its entirety justifies further analysis.

As the aircraft approaches the decision speed (V_1) the decision-making time available to the pilot decreases. At V_1 speed he has no time for a decision and must respond immediately to reject the takeoff if he is to be able to stop the aircraft on the runway even under ideal conditions. A failure to act promptly to any problem encountered as the aircraft approaches the V_1 speed can have catastrophic results if the problem is an engine failure, is structural in nature, or is associated with loss of critical systems or flight controls. Certainly, these possibilities are ever present in a pilot's mind when something unusual occurs at a critical time. Therefore, the dominant tendency is most likely to reject the takeoff when any unevaluated anomaly occurs before V_1 speed, particularly if the problem is accompanied by noise and vibration.

In this accident, the captain heard a loud metallic bang and the flight data recorder indicated that this occurred 1.2 seconds before the aircraft reached V_1 speed. The captain was therefore faced with the need for immediate action. He had no time in which to evaluate the significance of the loud bang and vibration if he was to successfully reject the takeoff. However, it became evident during the Board's investigation that the noise and vibration were associated with a tire failure and that the aircraft could undoubtedly have been flown off the runway successfully.

The Boeing Aircraft Company, in its flight manual, and the McDonnell-Douglas Corporation, in a recent flightcrew newsletter, have emphasized the potentially dangerous nature of the rejected takeoff maneuver at or just below V_1 at a critical field length, and have advocated a better pilot understanding and appreciation of the rejected takeoff decision and the abnormal conditions leading to that decision. Based upon its analysis of this accident and others, the Safety Board agrees that pilot preparedness is essential, and concludes that the problem is sufficiently important and complex to warrant a thorough review and revision of the V_1 concept. Ideally, with a more comprehensive V_1 concept the pilot would be provided a decision speed from which he could be assured of the capability to stop the aircraft on the remaining runway regardless of the reason and circumstances for rejecting the takeoff. This would apply to wet runways as well as dry runways and would account for degraded braking capability due to common failures such as blown tires. Admittedly, such comprehensive criteria may not be practically achievable. Nonetheless, the Board believes that some improvements to the present criteria are needed if accidents such as this are to be prevented.

Fuel Tank Rupture and Fire

Shortly after the aircraft departed the right corner of the departure end of the runway, the left main landing gear broke through the macadam surface of the overrun area and failed. The increased footprint pressure exerted by the No. 6 tire and the load from the Nos. 1 and 2 wheels was beyond the macadam's support capability.

When the DC-10 was certificated, the FAA required that the DC-10 landing gear attachment be designed so that, if it failed because of up and aft overload, no part of the landing gear structure could puncture any part of the fuselage fuel system. The manufacturer satisfied this requirement. In four other accidents, DC-10 landing gear have failed with no wing fuel tank rupture; however, in this case the loads imposed upon the left main landing gear exceeded design loads. As a result, some of the landing gear attachment structure failed in an unusual mode and a large hole was torn in the aft web of the left wing rear spar at the juncture of the two left wing main fuel tanks. The fuel that was released through this rupture was the major contributor to the extensive postcrash fire.

The Safety Board was not able to determine conclusively where or when the fire started. Statements of some passengers and flight attendants indicated that fire may have been present in the area of the left main landing gear wheels before the aircraft left the runway surface. The escape of hydraulic fluid under pressure from ruptured brake and antiskid hydraulic lines 10/, and the friction heat developed from rubber and metal contact with the runway surface could have ignited a fire. Fire engulfed the left side of the aircraft immediately after the left main landing gear failed. This fire continued until extinguished by the Los Angeles Airport Fire Department.

The Safety Board believes that the quick response of the Los Angeles Fire Department, particularly fire Station 80N, prevented greater loss of life and lessened injuries to evacuees. This quick response was possible because the authorities at Los Angeles International Airport, unable to meet the required emergency response times, constructed auxiliary fire stations at the midpoint of the airport's 2 major runway complexes. The decision of the firefighters on CB-1 to position themselves so that firefighting agent could be used to keep escape lanes open for the evacuation was exemplary and reduced the number of deaths and serious injuries. The Safety Board believes that authorities at other major airports, who may be having difficulty with their required emergency response times, should follow the example set at Los Angeles International Airport.

Slide/Raft Inadequacies

Because of the intense fire on the left side of the aircraft, passengers exited from the right side. All cabin exit doors were opened, and all slide/rafts, except the left forward (1L) exit, were deployed. Apparently, the door at exit 1L was opened in the emergency mode with the slide deployment mechanism disarmed. When the captain and a male passenger attempted to attach the slide/raft, it was pulled from its door container and fell to the ground.

The slide/rafts which were deployed from the four right side emergency exits were exposed to fire and radiant heat. All of the slide/rafts failed before the evacuation was completed. Passengers and

10/ Tests have shown that the hydraulic fluid used in aircraft systems, Skydrol, is not flammable under noraml circumstances. However, when subjected to heat in a vaporized form under pressure, it will ignite and burn.

crewmembers who were still in the aircraft when all slide/rafts had failed either jumped to the ground or slid down the escape rope from the first officer's side window in the cockpit.

The Board understands that the primary purpose of an emergency evacuation system is to provide for rapid passenger and crew egress from an aircraft under emergency conditions. However, this investigation disclosed that when these slide/rafts were certificated as a part of the DC-10 aircraft, no consideration was given to the slide/rafts serviceability when exposed to radiant heat.

The girt fabric on the 4R slide/raft failed because of an apparent overload when passengers went onto the slide/raft faster than those at the bottom of the slide/raft could leave it. This unusual passenger flow resulted from the combined effects of (1) the shallow deployment angle of the slide/raft, and (2) a design feature inherent with the slide/raft concept.

For the slide/raft to function as a raft, the sides and ends must be raised above the level of the slide/raft floor. Therefore, the unit is constructed with inflatable tubes along both sides and across both ends. The slide surface and raft floor is attached inside this inflatable, rectangular framework. The surface which the evacuee slides on, slopes from atop the inflated tube at the headend (aircraft end) down to the center section of the unit. This center section which serves a dual purpose (raft floor and slide surface) is attached near the bottom of the side wall inflatable tubes. A few feet from the tail end (outboard end) of the unit, the sliding surface slopes upward from this center section to the top of the inflatable tube that crosses the tail end of the unit. Thus, when the slide/raft is deployed from a normal door sill height, the sloped section at the tail end of the slide surface acts to declerate the evacuee. However, when the slide/raft is used from a lower-than-normal sill height, as was the case in this accident, the sloped surface becomes an obstacle that must be climbed over by the evacuee.

The 26-ft slide/rafts were fabricated with side sections which allow increased seating capacity when used as a raft. Passenger's shoes and other personal articles were found in these side sections indicating that some passengers exited the slide/raft via the side. The girt width of the 26-ft-long slide/raft was about 42 in. The slide width was about 172 in. Extreme asymmetrical loading of the girt was therefore possible if passengers attempted to exit via one side of the slide/raft.

The Safety Board believes that the success of the emergency evacuation of the passengers, most of whom were elderly, was the direct result of the efforts of the entire flightcrew and cabincrew and that of a Continental B-727 captain who was onboard as a passenger. Their immediate response and their initiative in seeking alternate escape routes when the normal routes were rendered useless, undoubtedly saved lives and decreased the number of injuries.

3. CONCLUSIONS

3.1 Findings

1. The crewmembers were certificated and qualified for the flight.

2. The aircraft was certificated, equipped, and maintained in accordance with FAA requirements, except for the inoperative CVR.

3. The runway was wet, but there was no standing water.

4. Runway 6R was the only runway available for takeoff. Two 12,000-ft runways, the use of which could have made a successful rejected takeoff possible, were not available to wide body aircraft.

5. Lineup for takeoff began about 166 ft from the approach end of runway 6R. The flightcrew used the minimum lineup distance and established takeoff thrust as required by company procedures.

6. The captain promptly rejected the takeoff at or below 152 kns (V_1 speed was 156 kns) after hearing a loud "metallic bang" and feeling a "quivering" of the aircraft.

7. The captain responded to the emergency by first applying brakes and then applying maximum reverse thrust on all engines. Ground spoilers actuated when thrust levers were moved to the reverse thrust positions.

8. Reverse thrust began about 5.8 sec after V_1 was reached and peaked 3 to 8 sec after the engines began to spool up for reverse thrust. Reverse thrust was maintained above 100 percent N_1 on all three engines during the reversal sequence.

9. Reverse thrust was maintained on the center and the right engine until just before the aircraft stopped beyond the end of the runway. Reverse thrust on the left engine ceased when that engine was torn from the aircraft, 100 ft beyond the end of the runway.

10. The first tire failed at the No. 2 tire position about 6,300 ft from the departure end of runway 6R. The tire failed because of a thrown tread. The carcass blew about 4,520 ft from the departure end of the runway.

11. The second tire failed at the No. 1 tire position about 4,480 ft from the departure end of runway 6R. Fatigue in the ply structure may have been caused by long-term overload since the tire was mounted on an axle with a tire of a different brand which had less sidewall stiffness. The tire blew out because of an overload.

12. The third tire failed at No. 5 tire position about 3,400 ft from the departure end of runway 6R. Pieces of the wheel rim from either the No. 1 or the No. 2 wheel hit the tire and caused it to blow out. This blow out affected further the aircraft's braking capability. Also, the left main landing gear might not have collapsed if No. 5 tire had been available to distribute load on the overrun area.

13. The tires on the aircraft may have been operated in the over-deflected condition, since the average inflation pressure was less than the optimum pressure for maximum gross weight.

14. The aircraft left the departure end of runway 6R at a speed of about 68 kns.

15. The aircraft slid to a stop about 83 sec after the start of the takeoff. It came to rest about 664 ft beyond the departure end of runway 6R on a heading of 008°.

16. The aircraft could not be stopped on the available runway because of the partial loss of braking effectiveness attributed to failed tires and a wet runway surface.

17. Dynamic hydroplaning conditions were not present.

18. Runway 6R had acceptable friction characteristics according to current FAA suggested criteria for the Mu meter; however, the Mu meter data could not be used to estimate aircraft stopping performance.

19. During the 4-year period between the grooving of runway 6R/24L and the day of the accident, the airport operator did not make the friction surveys suggested by the FAA. The FAA and the airport operators did not have ready access to equipment or trained personnel required to conduct periodic friction surveys.

20. No FAA procedures or data are available to aircraft operators or flightcrew to relate degraded runway friction conditions to changes in allowable aircraft takeoff weights, decision speeds, and stopping distance.

21. The current FAA rejected takeoff requirements for aircraft certification, aircraft operations, and pilot training do not address wet runway, slippery runway, or tire failure conditions.

22. It was not possible to determine accurately from performance analyses if the full braking capability of the aircraft was achieved during the initial phase of the rejected takeoff.

23. In its 1977 report on rejected takeoffs, the FAA concluded that aircraft safety could be improved by accounting for wet/slippery runway conditions and tire improvements.

24. Flightcrew simulator training for rejected takeoffs is inadequate because of the lack of FAA requirements for wet runway considerations in those simulators and for rejected takeoff training at the maximum takeoff gross weights and decision speeds encountered in normal operations.

25. The landing gear attachment structure failed and caused the left wing fuel tank to rupture.

26. Fire may have started before the aircraft left the runway surface.

27. The evacuation was started promptly and almost simultaneously throughout the cabin.

28. The 1L exit was opened with the slide/raft handle in the disarm position.

29. Slide/rafts at exits 2L, 3L, and 4L burned immediately after they were deployed.

30. All slide/rafts on the right side were deployed and used.

31. The overwing ramp for the 3R slide/raft malfunctioned.

32. The slide/raft at 1R failed from radiant heat damage; the girt bar supporting fabric failed at 4R because of overload or uneven load; all other slide/rafts burned.

33. The evacuation was completed using the emergency rope which hung from the first officer's side window.

34. The first crash-fire-rescue unit was on the scene fighting the fire in about 90 sec from the initiation of the rejected takeoff.

35. Two passengers died of burns and smoke inhaltion after exiting through the 3R exit.

36. Evacuation time was approximately 5 minutes.

3.2 Probable Cause

The National Transportation Safety Board determined that the probable cause of the accident was the sequential failure of two tires on the left main landing gear and the resultant failure of another tire on the same landing gear at a critical time during the takeoff roll. These failures resulted in the captain's decision to reject the takeoff.

Contributing to the accident was the cumulative effect of the partial loss of aircraft braking because of the failed tires and the reduced braking friction achievable on the wet runway surface which increased the accelerate-stop distance to a value greater than the available runway length. These factors prevented the captain from stopping the aircraft within the runway confines.

The failure of the left main landing gear and the consequent rupture of the left wing fuel tanks resulted in an intense fire which added to the severity of the accident.

4. SAFETY RECOMMENDATIONS

As a result of this accident, the Safety Board, on September 6, 1978, recommended that the Federal Aviaiton Administration:

"Assess current tire rating criteria, as used by the Tire & Rim Association and as interpreted by airframe designers and Federal Standards, in terms of compatibility of tire, airframe, and intended operation to assure that adequate margins are provided for all normal conditions. (Class II, Priority Action) (A-78-67)

"Upgrade Technical Standard Order C-62b to reflect current engineering practices and operational conditions in both the specifications for performance standards and certification test requirements. (Class II, Priority Action) (A-78-68)

"Insure that the tire is compatible with the airframe by considering this compatibility during the airplane certification. Tire loads which result from design peculiarities and normal variations in maintenance and operational practices must be considered. (Class II, Priority Action) (A-78-69)

"Issue a new Technical Standard Order to specify performance standards and qualification test requirements for retreaded tires. (Class II, Priority Action) (A-78-70)

"Prohibit different model tires or tires manufactured by different manufacturers from being mounted on the same axle where different characteristics between such tires can affect tire loading under normal operating conditions. (Class I, Urgent Action) (A-78-71)

"Require that operator maintenance and operational practices regarding tire usage, such as taxi speeds and distances and inflation pressures, are in accordance with the tire manufacturers' recommendations. (Class II, Priority Action) (A-78-72)

"Expedite the development of a nondestructive inspection technique which would detect flaws in tire carcasses. Require nondestructive inspection for new and retreaded tires and develop criteria based upon such inspection to withdraw a faulty tire from service. (Class II, Priority Action) (A-78-73)

"In the interim, establish a safe upper limit for the number of retread cycles allowed each model tire. (Class II, Priority Action) (A-78-74)"

On November 17, 1978, also as a result of this accident, the Safety Board recommended that the Federal Aviation Administration:

"Review and revise the accelerate-stop criteria required to be demonstrated during aircraft certification and used during operations to insure that they consider the effects of wet runway conditions and the most frequent and critical causes of rejected takeoffs. (Class II, Priority Action) (A-78-84)

"Evaluate, with industry, the British CAA wet runway normal and rejected takeoff requirements for applicability as a U.S. standard. (Class II, Priority Action) (A-78-85)

"Revise Advisory Circular 121-14 to provide guidance on (1) programming aircraft simulators to account for the degradation of aircraft deceleration performance on wet runways during landings and rejected takeoffs and (2) installing instrumentation to enable evaluation of pilot performance during RTO's on critical length runways, particularly the response times in activating stopping devices and the level of brake application to insure that such performance is compatible with a minimum-distance stop. (Class II, Priority Action) (A-78-86)

"Insure that pilot training programs include appropriate information regarding optimum rejected takeoff procedures at maximum weights, on wet and dry runways, and at speeds at or near V_1, and for rejected takeoffs which must be initiated as a result of engine or tire failures. (Class II, Priority Action) (A-78-87)

"Encourage operators of turbine engine-powered aircraft to include in flight manuals the maximum use of aircraft deceleration devices when an RTO is initiated at or near decision speed (V_1) on wet or dry runways of critical length. (Class II, Priority Action) (A-78-88)

"Develop and publish an Advisory Circular, or include in other appropriate documents available to air carrier and other pilots, general accelerate-stop performance data for RTO's on wet runways necessitated by engine and tire failures. Emphasize the need for maximum braking procedures when an RTO is required at high gross weights and speeds. (Class II, Priority Action) (A-78-89)"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PHILIP A. HOGUE
Member

January 25, 1979

5. APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. Investigation

The Safety Board was notified of the accident about 1240 e.s.t. on March 1, 1978. The investigation team went immediately to the scene. Working groups were established for operations, systems, powerplants, structures, weather, performance, witnesses, flight data recorder, human factors, cockpit voice recorder, and maintenance records.

Participants in the on-scene investigation included representatives of the Federal Aviation Administration, Continental Air Lines, Inc., the Air Line Pilots Association, Douglas Aircraft Company, The Goodyear Tire and Rubber Company, the B.F. Goodrich Company, PICO Division of Sargent Industries, Inc., the Union of Flight Attendants, the International Association of Machinists, and the General Electric Company.

2. Depositions

Depositions of the crewmembers were held following the accident. The flightcrew was deposed on March 2, 1978. Counsel for the Air Line Pilots Association and for Continental Air Lines, Inc were present at these depositions.

The flight attendants and the in-flight supervisor were deposed on March 4-6, 1978. Counsels for the Union of Flight Attendants and Continental Air Lines, Inc. were present at these depositions. Also present at these depositions were other representatives of the Union of Flight Attendants and Continental Air Lines, Inc., and representatives of the Air Line Pilots Association.

3. Public Hearing

A 4-day public hearing at Los Angeles began on May 30, 1978. Parties represented at the hearing were: The Federal Aviation Administration, Continental Air Lines, Inc., the Air Lines Pilots Association, Douglas Aircraft Company, The Goodyear Tire and Rubber Company, the B.F. Goodrich Company, Air Treads, Inc., PICO Division of Sargent Industries, Inc., and the Union of Flight Attendants.

APPENDIX B

PERSONNEL INFORMATION

Captain Charles E. Hersche

Captain Charles E. Hersche, 59, was hired by Continental Air Lines, February 11, 1946. He holds Airline Transport Pilot Certificate No. 383338 with type ratings in Douglas DC-3 and -10, Convair 340 and 440, Boeing 707 and 720, and Viscount 700 and 800 aircraft. He has a First Class Medical Certificate dated February 22, 1978, with the limitation, "Holder shall possess correcting glasses for near vision while exercising the privileges of his airman certificate."

Captain Hersche passed his last proficiency check on October 13, 1977. His last recurrent training was accomplished on September 19-20, 1977, and his last recurrent training to include emergency door training was accomplished on September 27-28, 1976. He had accumulated about 29,000 total flight-hours, 2,911 hours of which were in the DC-10 aircraft. His flying time during the last 90 days was 111 hours 30 minutes of which none had been flown in the 24-hour period before the accident.

First Officer Michael J. Provan

First Officer Michael J. Provan, 40, was hired by Continental Air Lines, May 23, 1966. He holds Airline Transport Pilot Certificate No. 1672725 with a type rating in the Boeing 727 and commercial privileges in the Lockheed 382. He has a First Class Medical Certificate dated December 22, 1977, with no limitations.

First Officer Provan passed his last proficiency check on December 7, 1977. His last recurrent training was accomplished on February 8-9, 1978. This training included emergency door training. He had accumulated about 10,000 total flight-hours, 1,149 hours of which were in the DC-10 aircraft. His flying time during the last 90 days was 95 hours 46 minutes. In the last 24 hours, he had 6 hours 16 minutes duty time, of which 4 hours 45 minutes were flying time, followed by 17 hours 19 minutes rest time.

Second Officer John K. Olsen

Second Officer John K. Olsen, 39, was hired by Continental Air Lines, July 1, 1968. He holds Commerical Pilots License No. 1731161 and a First Class Medical Certificate dated September 11, 1977, with no limitations. He also holds Flight Engineer Certificate No. 1865562 with a turbo-jet powered rating.

Second Officer Olsen passed his last proficiency check on September 13, 1977. His last recurrent training was on August 8-9, 1977, and his last recurrent training to include emergency door training was on August 23-24, 1976. He had accumulated about 5,000 total flight-hours as a pilot and about 8,000 total flight-hours as a flight engineer, 1,520 hours of which were in the DC-10 aircraft. His flying time (flight engineer) during the last 90 days was 168 hours 57 minutes. In the last 24 hours, he had 8 hours 50 minutes duty time, of which 5 hours 24 minutes were flying time, followed by 14 hours 40 minutes rest time.

Flight Attendants

	Date of Hire	Last Recurrent Training	Last Hands-on DC-10 Training
Judy Blair	12/28/64	1/23/78	2/27/77
Louise Buchanan	9/18/60	1/13/78	2/11/77
Mary Dahse	2/23/60	1/13/78	1/10/77
Janna Harkrider	7/1/65	1/27/78	1/23/77
Norma Heape	6/3/57	1/12/78	1/22/77
Bett Lietz	4/18/60	1/13/78	1/29/77
Carole Mason	12/20/60	1/12/78	1/28/77
Marcia Wagner	5/13/74	1/10/78	2/25/77
John Woodman	2/20/73	1/17/78	2/17/77
Lori Yang	4/1/69	1/27/78	2/12/77
In-flight supervisor			
J. Fred Winkler	9/16/66	2/28/78	2/4/77

Passenger/B-727 Captain

A Continental Air Lines Boeing 727 captain was riding in the first-class section of the cabin. He assisted the crew of Flight 603 during the evacuation.

APPENDIX C

AIRCRAFT INFORMATION

McDonnell-Douglas DC-10-10, serial No. 46904, N68045, was manufactured on May 19, 1972. It was certificated and maintained according to procedures approved by the FAA. At the time of the accident, the aircraft had accumulated 21,358 flight-hours; 65 hours 15 minutes had been flown since the last major phase check. The "A" check, the "B" check, and the first phase of the "C" check were accomplished on February 23, 1977.

Engines: Three General Electric CF6-6D

	Serial No.	Date of Installation	Total Time	Hours Since Last Overhaul
No. 1	451405	6/10/77	11,590	2,948
No. 2	451244	12/5/77	13,808	941
No. 3	451327	7/18/77	10,362	2,511