National Transportation Safety Board
Office of Research and Engineering
Washington, D.C. 20594

Performance Study

Specialist Report
Marie Moler

A. ACCIDENT

Location:	New York, New York
Date:	March 5, 2015
Time:	1102 EST, 1602 UTC
Airplane:	MD-88, N909DL, Delta Flight 1086
NTSB Number:	DCA15FA085

B. GROUP

The Vehicle Performance group members were:

Chairman: Marie Moler
             National Transportation Safety Board
             Washington, DC

Member: David Yingling
             Boeing Commercial Aircraft
             Long Beach, California

Member: Joe Hashemi
             Federal Aviation Administration
             Long Beach, California

Member: Cory White
             Delta Air Lines
             Atlanta, Georgia

Member: Chris Heck
             Air Line Pilots Association, International
             Washington, DC

C. SUMMARY

On March 5, 2015, about 1102 Eastern Standard Time (EST), a Boeing MD-88, N909DL, operating as Delta Air Lines flight 1086, landed on runway 13 at LaGuardia Airport (LGA), New York, New York, and exited the left side of the runway, contacted the airport perimeter fence, and came to rest with the airplane nose on an embankment next to Flushing Bay. The 129 passengers received either minor injuries or were not injured, and the 3 flight attendants and 2 flight crew members were not injured. The airplane was substantially damaged. Flight 1086 was a regularly scheduled passenger flight from Hartsfield-Jackson Atlanta International Airport (ATL) operating under the provisions of 14 Code of Federal Regulations (CFR) Part 121. Instrument meteorological conditions (IMC) prevailed, and an instrument flight rules (IFR) flight plan was filed.

The objective of this study is to determine and analyze the motion of the aircraft and the physical forces that produced that motion.   In particular, the study attempts to define the aircraft's position and orientation during the relevant portion of the flight and landing roll and determine the aircraft's response to control inputs, external disturbances, ground forces, and other factors that could affect its trajectory. In addition, the landing of another MD-88 three minutes prior to the accident is analyzed and compared to the accident event.

The study also discusses historical McDonnell Douglas data on aircraft directional control, specifically in terms of high engine pressure ratios (EPR) in reverse thrust causing loss of rudder authority, crosswind yawing moment, and yawing moment due to differential EPR. Runway performance was extracted from the FDR data using thrust and aerodynamic performance computer simulations. The stopping performance for the accident aircraft and the prior aircraft are compared.

Finally, 78 additional landings, stored on the quick access recorder (QAR) cards on the accident aircraft and the prior MD-88, are analyzed and presented. The purpose of this portion of the study is to investigate how often landing procedures do not match stated guidelines and to what effect.

D. PERFORMANCE STUDY

The aircraft was equipped with a flight data recorder (FDR) and cockpit voice recorder (CVR). The FDR recorded acceleration, speed, altitude, attitude, engine, and control parameters, but did not record accurate universal time, latitude, or longitude [1].

Two sets of radar data were used in this study: airport surveillance radar (ASR) and surface movement radar (SMR). The ASR radar was from the ASR-9 at John F. Kennedy International Airport (JFK), about 10 nautical miles (NM) away from the accident aircraft's final location. ASR-9 data updates every 4.5 seconds and has an inherent uncertainty of ± 2 Azimuth Change Pulses (ACP) = $\pm$ (2 ACP) x (360º/4096 ACP) = $\pm 0.176°$ in azimuth, ± 50 ft in altitude, and $\pm 1/16$ NM in range. SMR data was from LGA and updated every second. SMR data records the motion of all aircraft and surface vehicles on aircraft property. Within the airport, the uncertainty of the SMR radar data is estimated to be 25 feet or less.

The aircraft left a series of witness marks as it departed the runway and went across the soft ground between runway 13 and the access road along the sea wall. The witness marks started 3200 ft from the threshold and were surveyed by the Port Authority. Detailed diagrams of the marks are included in this report and on the docket.

Weather Observations

The official weather prior to the accident reported by the Automatic Terminal Information Service (ATIS) at 1551 UTC (1051 EST, 11 minutes prior to the accident) at LaGuardia was wind from 30° at 11 kts. Visibility was 1/4 mile, vertical visibility 900 ft, and precipitation was snow and freezing fog. The temperature was -3°C (26°F), dew point -5°C (23°F), and the altimeter setting was 30.12 inHg [2]. METARS indicated 0.06 inches of precipitation had accumulated during the last hour. Snow was reported to be falling at a rate of ¾ inch per hour at the time of the accident.

The ATIS reported that braking action advisories were in effect. The runways were reported wet and sanded and de-iced but had 1/4 inch of wet snow. It was noted that all runways and taxiways had a three foot snowbank along their edges.

Approach and Landing of Accident Aircraft

Time Correlation of Radar and FDR Data

The last available ASR-9 return was about 1500 ft before the runway threshold and at an altitude of 100 ft. The first SMR return was about 6500 ft before the runway threshold at an altitude of 400 ft. Figure 1 shows the aircraft's descent and approach into LGA. The aircraft flew north along the Hudson River before turning west and circling onto the heading for runway 13 at LGA.


**Figure 1.** Aircraft radar track with selected UTC times and altitudes marked.

The ASR and SMR data overlap for about 5000 ft and are shown in Figure 2 with the JFK ASR track in white and the LGA SMR track in blue. Four of the early SMR returns are offset about 250 ft to the right of the ASR track. The other returns were within 50 ft of each other. The SMR and ASR data were time synchronized using their latitude and longitude tracks.
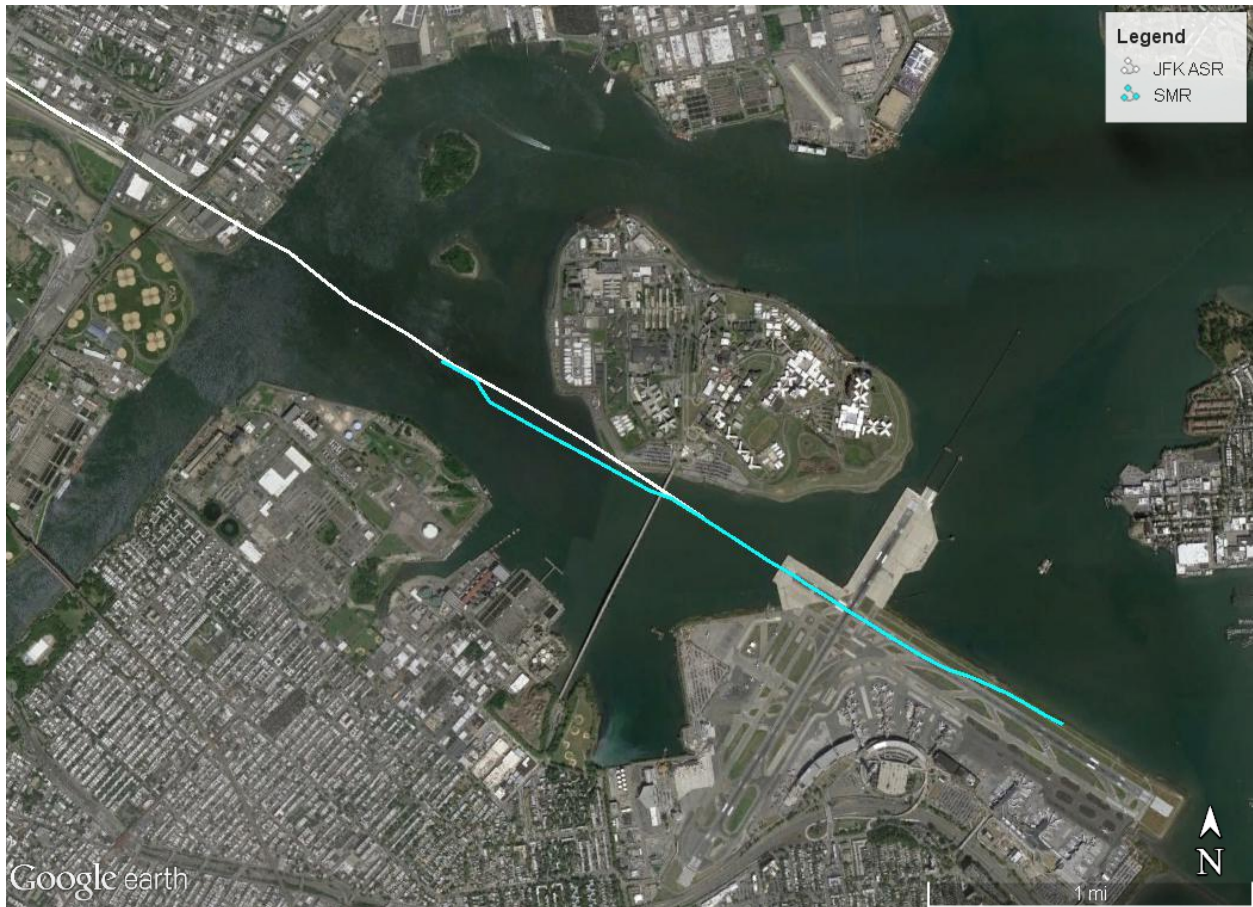

Figure 2. JFK ASR (white line) and LGA SMR (blue line).

The aircraft left a series of witness marks on the tarmac and through the soft ground between runway 13 and the access road along the sea wall. The witness marks were surveyed and are shown in Figure 3. Figure 4 overlays the SMR path with the ground marks and the aircraft's final resting point. The SMR ground track, the ground marks, and the aircraft location showed good agreement.
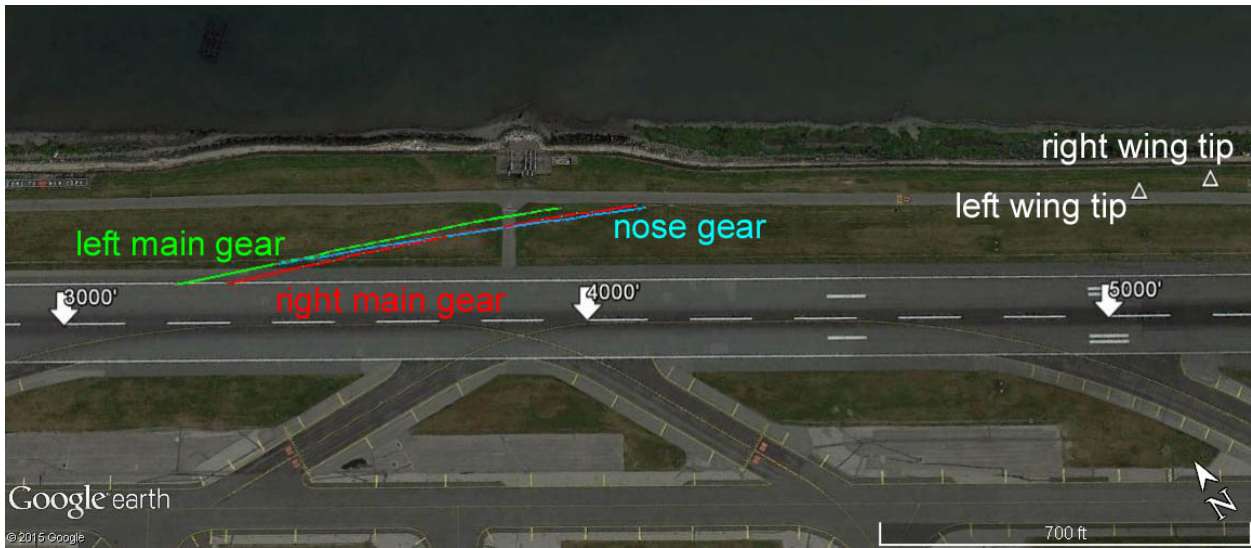
Figure 3. Ground marks from left main gear (green), right main gear (red), and nose gear (blue). The 3000, 4000, and 5000 ft points on the runway are shown by white arrows.
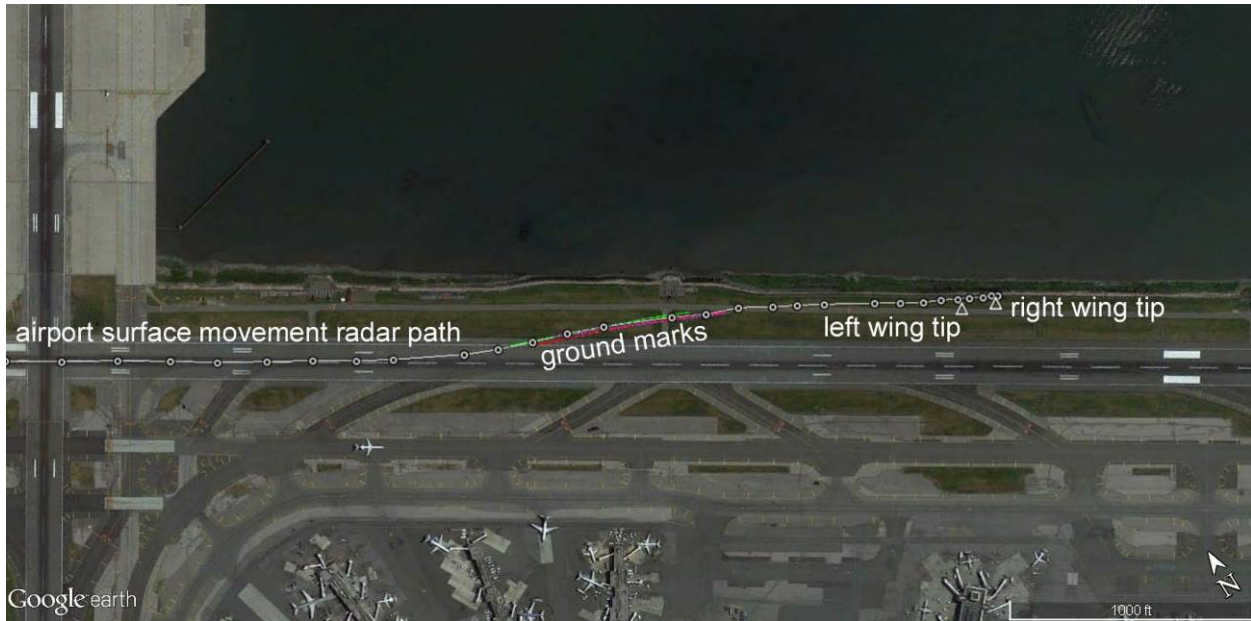
Figure 4. Airport surface movement radar path, recorded ground marks (pink and green), and final location of aircraft.

The FDR data was time synchronized with the radar data using FDR and ASR altitude and by comparing the SMR track with the ILS (instrument landing system) information recorded by the FDR. ASR and SMR times were converted to seconds past midnight to compare to the FDR's elapsed seconds parameter. The FDR's pressure altitude parameter was corrected using the reported barometric pressure of 30.12 inHg. The time difference between the ASR seconds past midnight and the FDR elapsed seconds was determined by comparing ASR and FDR altitude data (Figure 5); the ASR, FDR, and SMR track data (Figure 6); and input from the Cockpit

Voice Recorder Specialist group who time correlated the CVR elapsed seconds with the air traffic control (ATC) information [3]. The difference between the ASR seconds past midnight and FDR elapsed seconds was 44026.4 seconds as shown below:

$$\text{ASR time (UTC)} = \text{FDR elapsed seconds} + 44026.4 \text{ s}$$
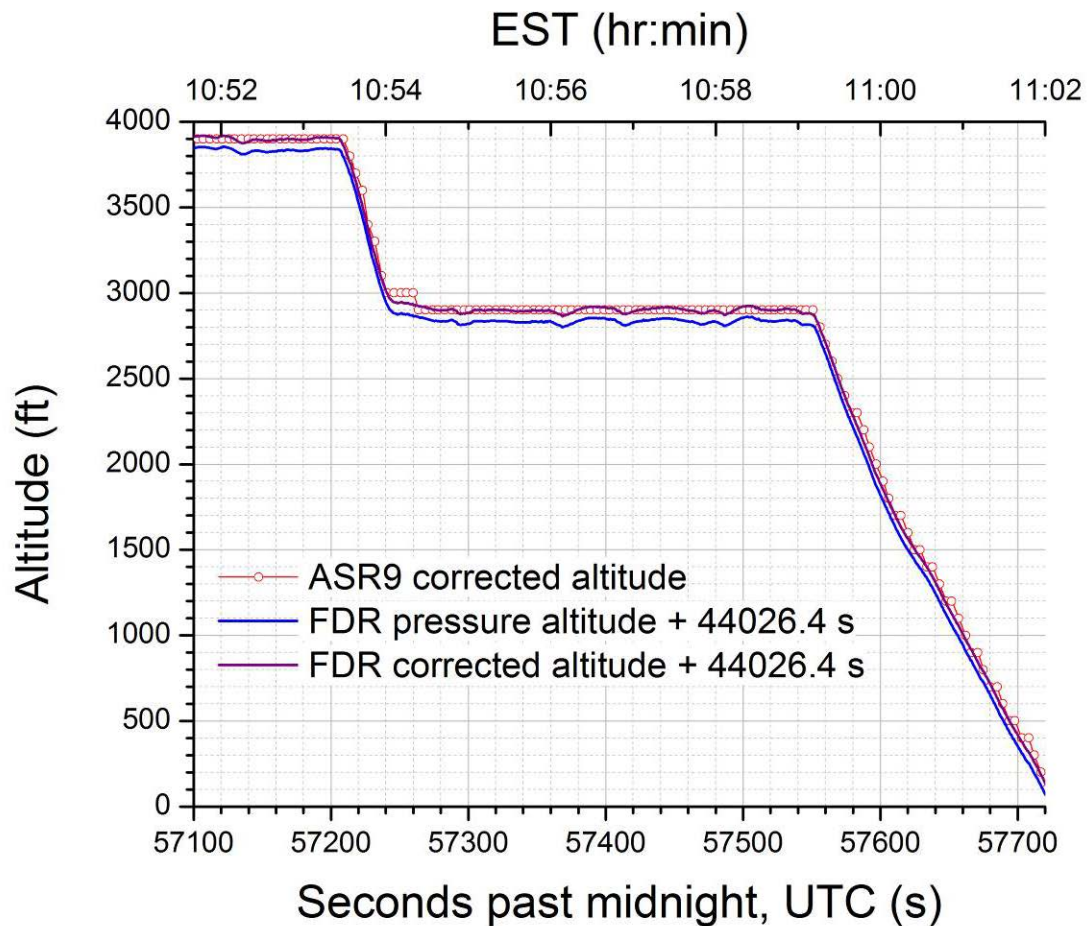
Figure 5. Altitude from JFK ASR and the aircraft FDR versus time.

The aircraft's FDR recorded glide slope and localizer data on approach into LGA. Using Federal Aviation Administration (FAA) data for the ILS for runway 13 the aircraft's approach path and altitude were calculated from FDR data. The ILS position calculations fell between the ASR and SMR tracks (shown in Figure 6). The data showed good position agreement and the 44026.4 second time sync matched.
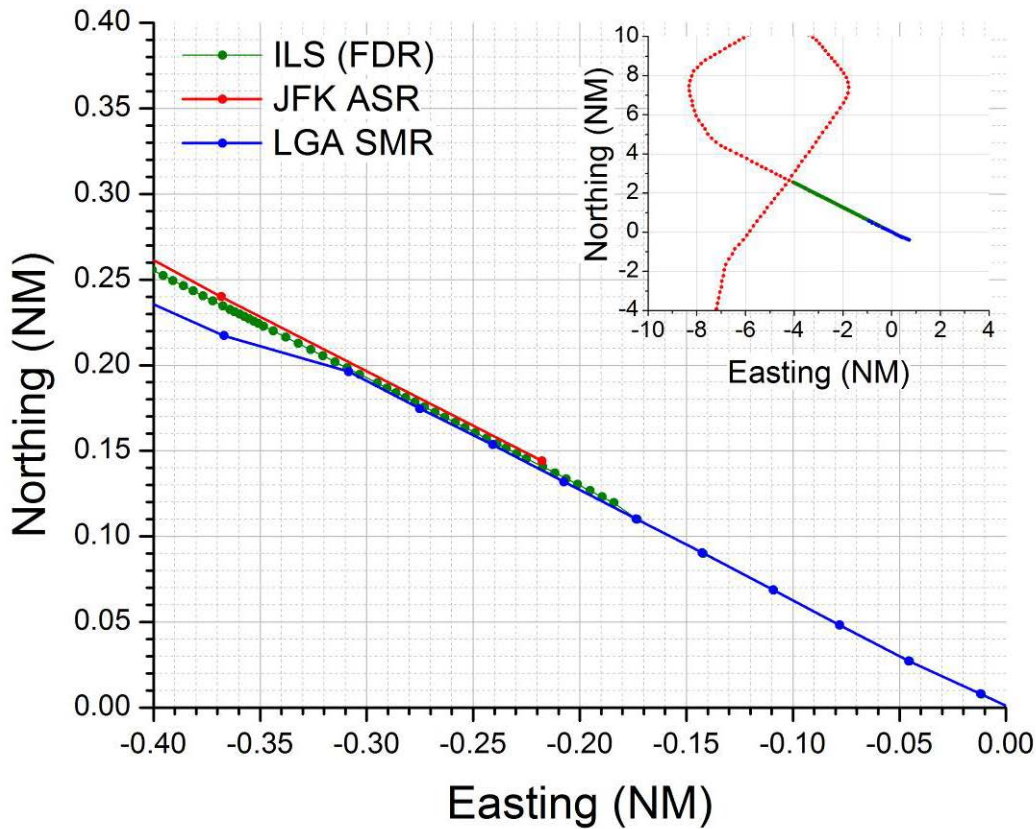
Figure 6. Position data for ILS calculations, ASR and SMR. Location 0,0 is the threshold of runway 13.

Accident Aircraft Magnetic Heading

While the FDR ILS position data and the radar track show the aircraft path aligned with runway 13 (magnetic reported heading 134°, true heading 122°), the FDR shows the aircraft approached on a magnetic heading of 129° (shown in Figure 7) and it landed on a magnetic heading of about 132°, which it maintained until diverting to the left off the runway surface. The two aircraft that landed before the accident aircraft (one of which will be discussed in greater depth in *Comparison to Prior MD-88 Landing*) approached the airport on headings of about 129° (A319) and 131° (MD-88). The accident aircraft's heading on approach was 2° left of the prior MD-88. However, upon nose gear touchdown, both of the prior aircraft aligned with to the reported 134° heading of the runway.
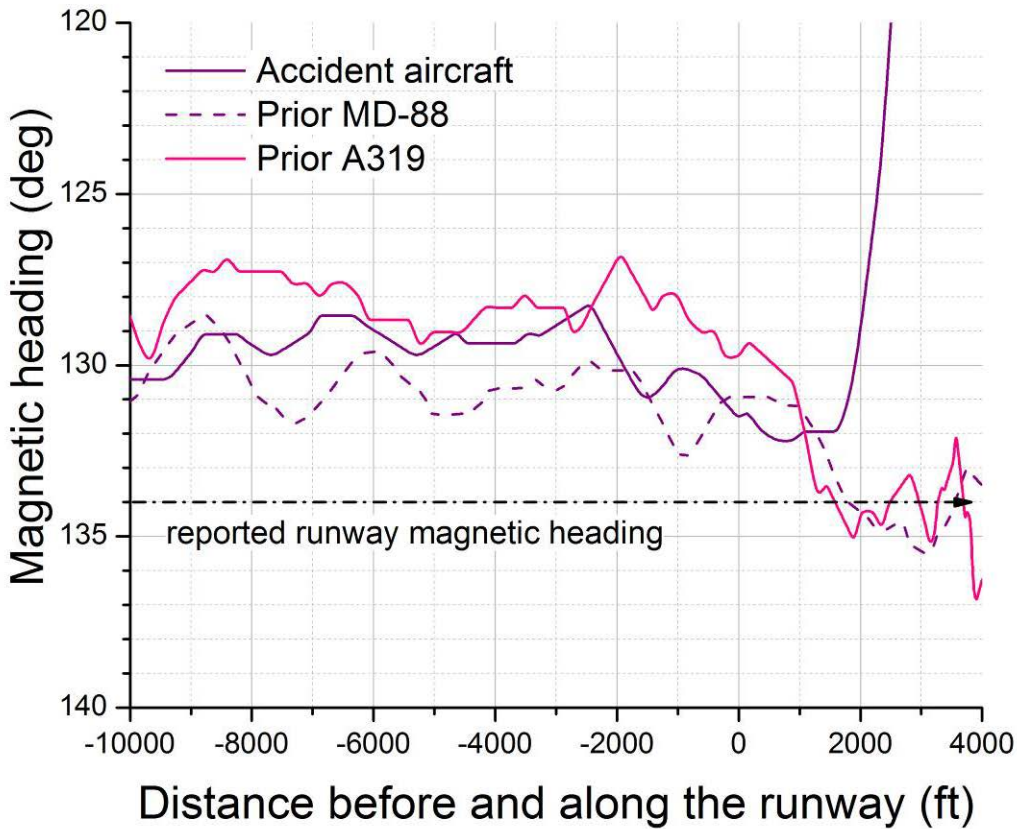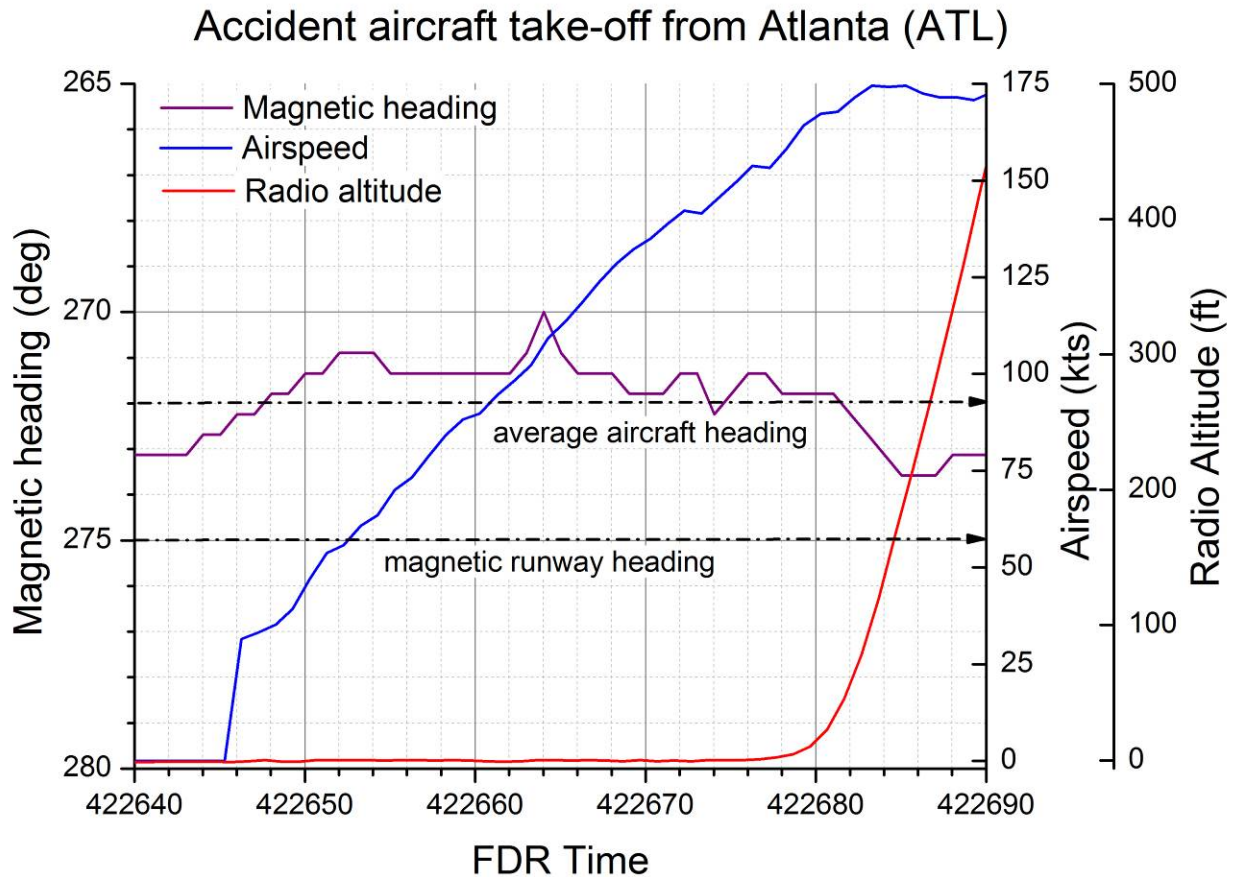
Figure 7. Magnetic headings for accident aircraft and the prior two aircraft to land at LGA.

The data written to the FDR was also saved to a quick access recorder (QAR) onboard for both the accident aircraft and the prior MD-88. A total of 61 previous flights for the accident aircraft and 19 other flights for the prior MD-88 were recorded and will be discussed in greater depth in *Exceedance of EPR Limits on Other Landings*. Figure 8 shows the take-off from Atlanta Hartsfield (ATL) for the accident flight. In 2015 the magnetic headings for the five runways at Atlanta were reported at 275°.[1] The aircraft's heading was 3° to the left of the runway heading for the take-off roll. This implied a bias between the aircraft's internally recorded heading and the heading of the runway.

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[1] Atlanta (ATL) has five runways denoted (from an eastern approach) as 26R, 26L, 27R, 27L, and 28. All five runways are parallel along a magnetic heading of 275° and a true heading of 270°.

Figure 8. Magnetic heading, airspeed, and radio altitude for accident flight take-off from ATL.

However, heading bias could change with time and/or location and cannot be considered to be 2° or 3° nose left for all airports. Forty-one (41) landings of the accident ship (40 prior and accident landing) at 15 different airports were investigated [see APPENDIX]. The aircraft heading was a few degrees nose left compared to the runway heading for all but the five previous LGA headings. When landing at the same airport, the deviation in magnetic heading was relatively consistent (±1°) in its offset. This pattern holds for other landings of the prior MD-88.

LGA's 12° west (12W) magnetic deviation was recorded in 1980. In 1985, the magnetic deviation for Newark (EWR) was reported as 13W. In 2000, Islip (ISP), 40 miles east, and JFK (JFK), 10 miles southeast, reported magnetic deviations of 14W. No newer data was available for airports local to LGA. If LGA's magnetic deviation is actually 14W, consistent with the deviation at JFK, the magnetic heading of runway 13 would be 136°.

All 11 recorded landings at LGA of the accident aircraft and the prior MD-88 lined up well with the magnetic heading for LGA and only LGA, especially when compared to the 2° to 3° offset at JFK, 10 miles to the southeast. When compared to these landings, the accident flight heading is still 2° left. It is unclear whether the nose left bias of the aircraft is an artifact of this particular

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flight, or if the aircraft did remain nose left for the landing roll even after the nose gear touched down. For this report, the aircraft magnetic heading will be presented as recorded by the FDR and the runway magnetic heading as reported by the airport (134°). The possible implications of the aircraft's heading will be discussed later in the *Loss of Directional Control* section of this report.

Final Approach and Touchdown

Using the time synchronization for the FDR, CVR, and radar data calculated above, the FDR data will now be presented in EST. The aircraft's final approach is shown in Figure 9. The glide slope and heading were on path for runway 13's ILS. The aircraft's approach speed was about 140 kts (137 kts crossing the threshold), slowing to 133 kts at touchdown. At a landing weight of 127,500 lbs, the aircraft's V_{ref} for flaps 40 was 131 kts (+ 5 kts).
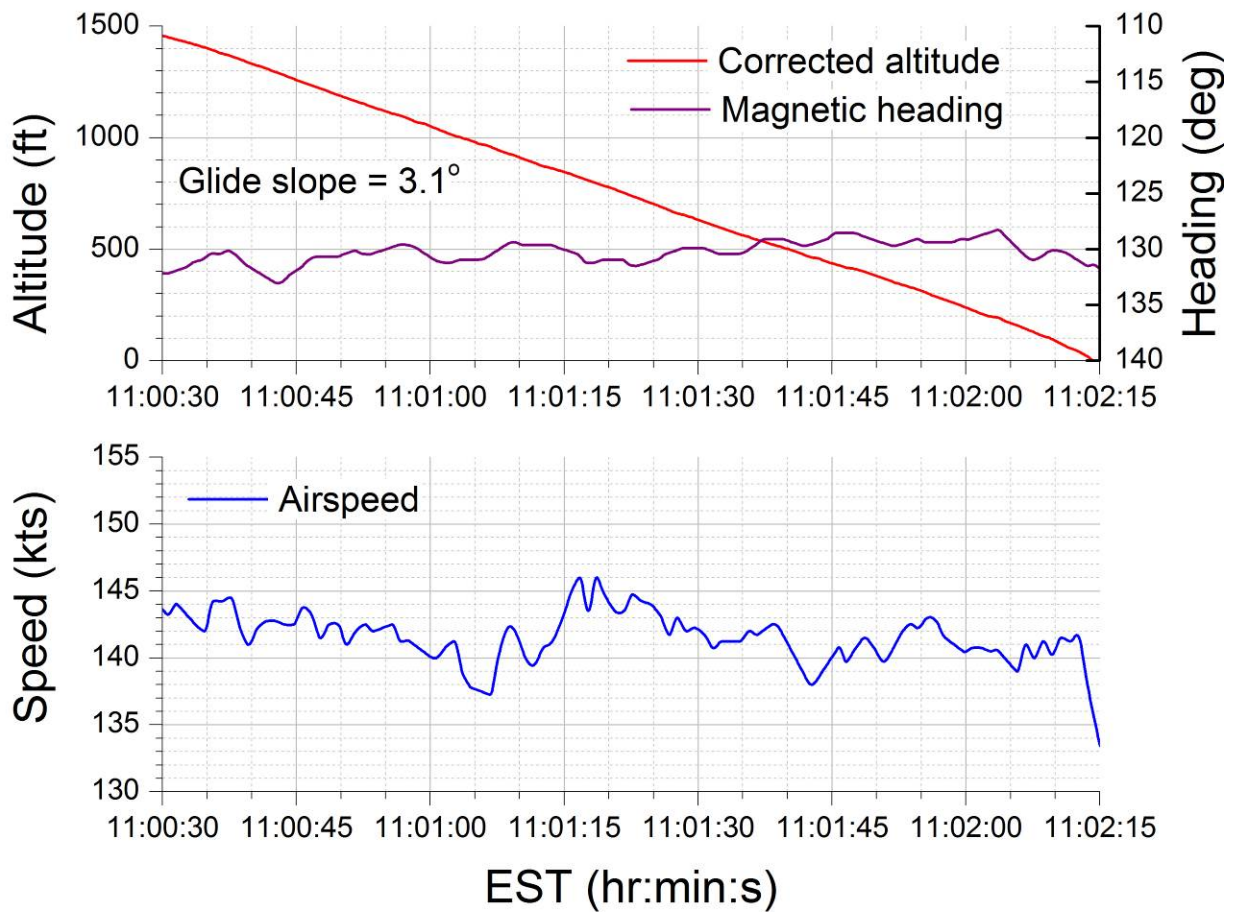

Figure 9. Final approach altitude, magnetic heading, and airspeed.

Figure 10 shows the aircraft vertical acceleration, altitude, and nose gear weight on wheels for the landing. The main gear touchdown corresponded with the initial spike in vertical acceleration at 11:02:16. At about 11:02:28.5, twelve seconds after touchdown, the vertical acceleration parameter begins displaying increasingly unrealistic values. A number of other parameters either hold their last recorded value or begin oscillating between maximum values after this time.
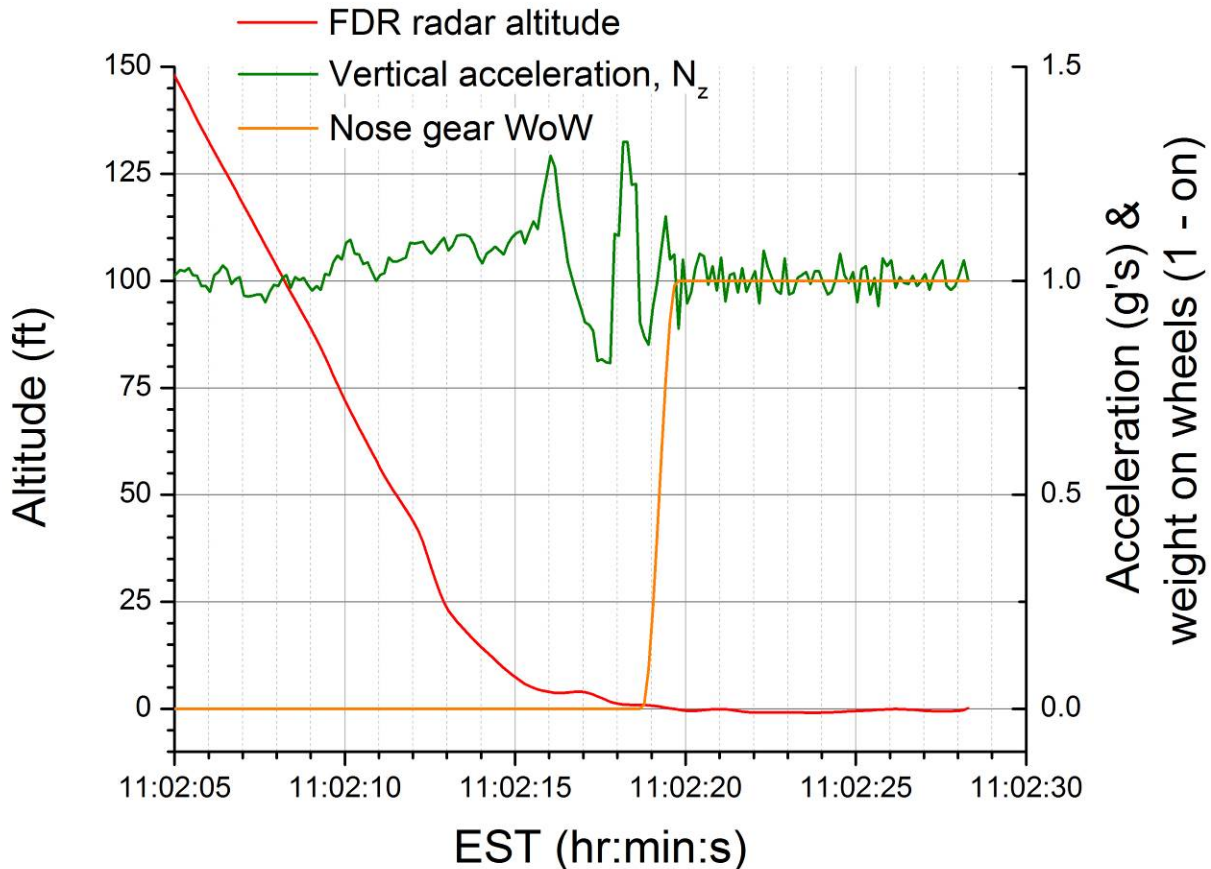
Figure 10. FDR N_z, altitude, and nose gear weight on wheels. After 11:02:27 the acceleration data become unreliable.

The data set was truncated at 11:02:28, just before the vertical acceleration parameter became unreliable. The position of the airplane was determined by integrating the longitudinal, lateral, and vertical load factors from the FDR data. The load factor data suffers from inherent biases that if not accounted for can introduce significant error into the position calculations. These biases drift with time and can be changed by sudden impacts (such as touchdown loads) which limits the usefulness of the integrations to a finite length of time.

The data was therefore integrated in two sets. The first set began at 11:00:15 (altitude of about 1600 ft) and ended one second before touchdown at 11:02:15. ILS position calculations were

used and the integration routine's convergence method was to minimize position error at the end points. The accelerometer biases for the air portion of the integration were calculated as

Longitudinal Load Factor Bias (ΔNx) = -0.00179 g's
Lateral Load Factor Bias (ΔNy) = -0.00654 g's
Vertical Load Factor Bias (ΔNz) = -0.01098 g's

The second integration portion started just at touchdown and continued until 11:02:28.5 when the data became up reliable. SMR data was used to define position as the ILS data was used in the first portion. The acceleration biases for the ground roll were

Longitudinal Load Factor Bias (ΔNx) = -0.00167 g's
Lateral Load Factor Bias (ΔNy) = -0.0051 g's
Vertical Load Factor Bias (ΔNz) = -0.00108 g's

The integration showed good agreement with the radar data as shown in Figure 11. All plots of 'distance along runway' are oriented so that zero is the runway threshold and positive values are moving down the runway. At about 1600 ft down the runway, the aircraft's heading begins going towards the left with the ground path moving left between 500 and 1000 ft later. The loss of reliable FDR data corresponds approximately with the aircraft leaving the runway. As noted earlier, runways and taxiways were reported to have 3 ft snowbanks along their edges.
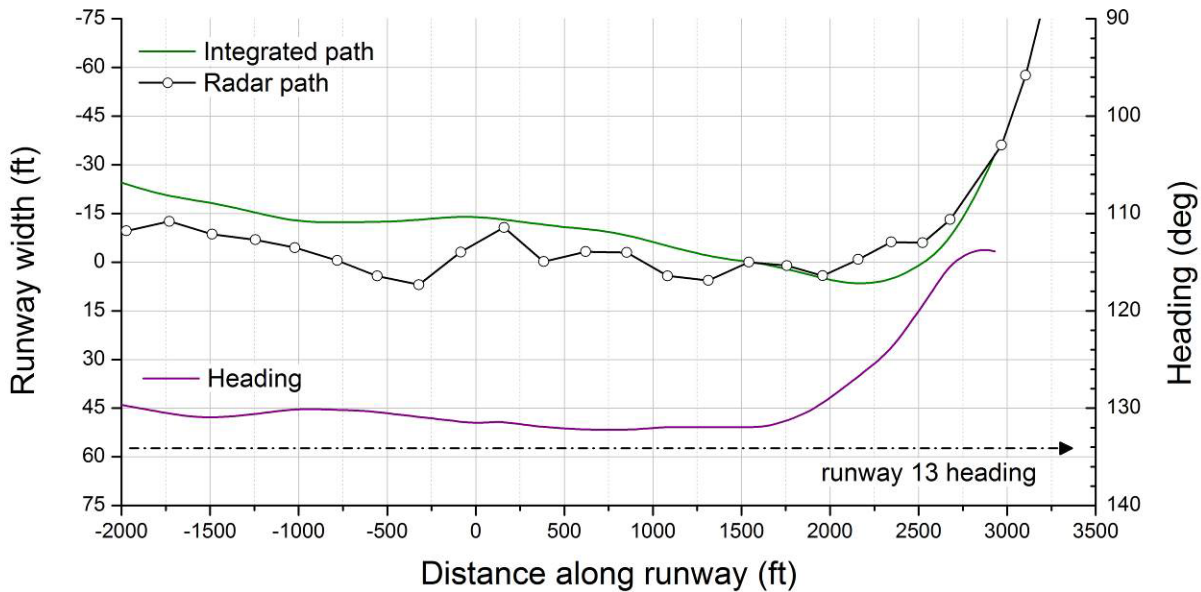

Figure 11. Radar path, integrated path, and heading versus distance along runway. The origin of the runway distance is the threshold of runway 13. The airplane's main gear first touched down about 600 ft past the threshold. The aircraft leaves runway according to SMR data and ground marks at 3200 ft.

Landing Roll and Deployment of Braking Devices

As stated, touchdown for the main gear was marked using the spike in vertical acceleration at 11:02:16. Vertical acceleration was recorded eight times a second, while other parameters were recorded only once a second. The nose gear weight on wheels transitioned to 'on' between 11:02:18.7 and 19.7, between 2.7 and 3.7 seconds after main gear touchdown (seen in Figure 10). Figure 12 shows the vertical, lateral, and longitudinal accelerations of the aircraft. The negative lateral acceleration beginning about 11:02:22 coincides with the aircraft's movement to the left. However, a left yaw rate began about 11:02:20.5, which will be further discussed in the *Loss of Directional Control* section.
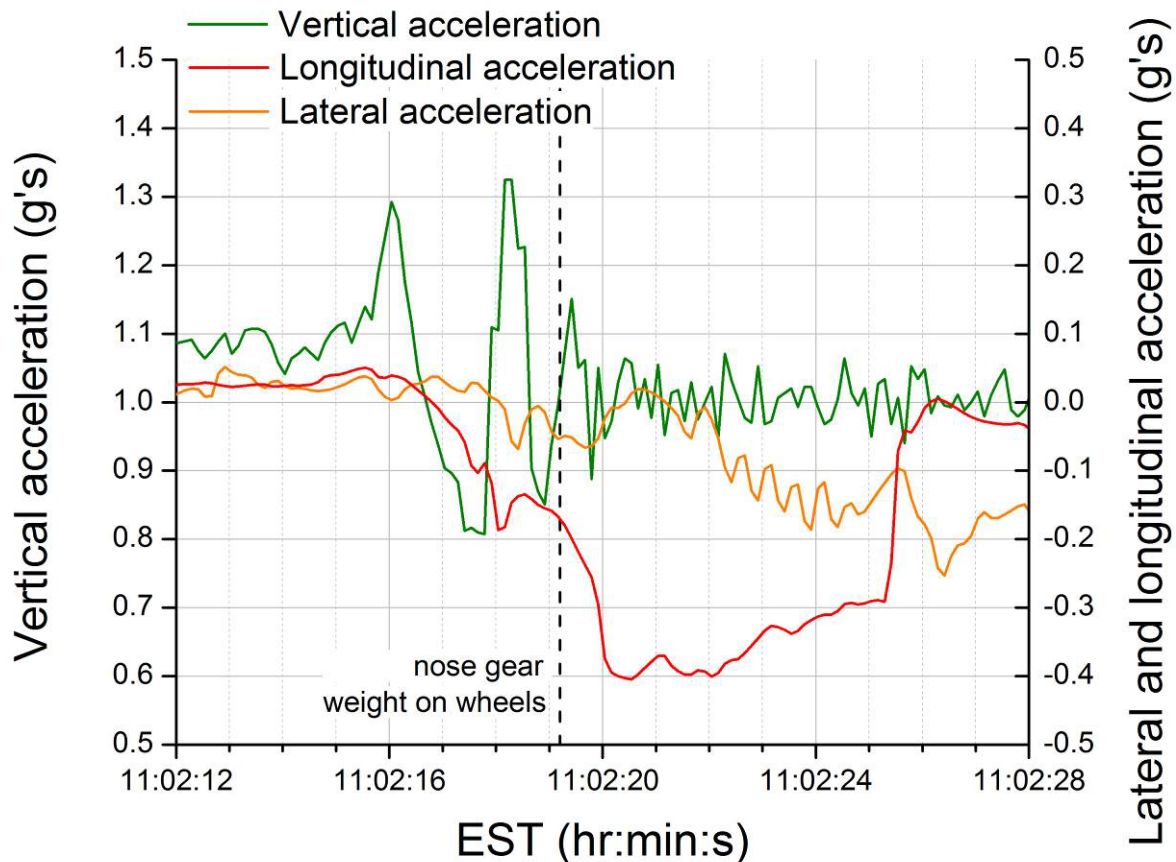

Figure 12. Vertical (left axis), lateral and longitudinal (right axis) accelerations versus time.

Figure 13 shows the as-sampled braking channels versus time. The red line is marked as autobrakes/left brake and the blue as manual brakes/right brake. Autobrake pressure is only recorded on the left channel when autobrakes are deployed. The initial rise in the red channel is consistent with the deployment of autobrakes (the recorded brake pressure is applied on the right and left side equally). Autobrakes were applied between 1.8 and 2.8 seconds after main gear touchdown and reached a maximum value of over 3000 psi by 11:02:23.8. The right manual

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brake was depressed between 11:02:24.9 and 25.9, which is also when the autobrake/left brake pressure begins to fall to zero. On this aircraft, when the brakes are deployed manually, the autobrakes automatically disengage. The zero pressure reading on the left braking channel indicates that the crew manually applied only right brake. Braking only on the right side of the aircraft should cause it to yaw to the right.
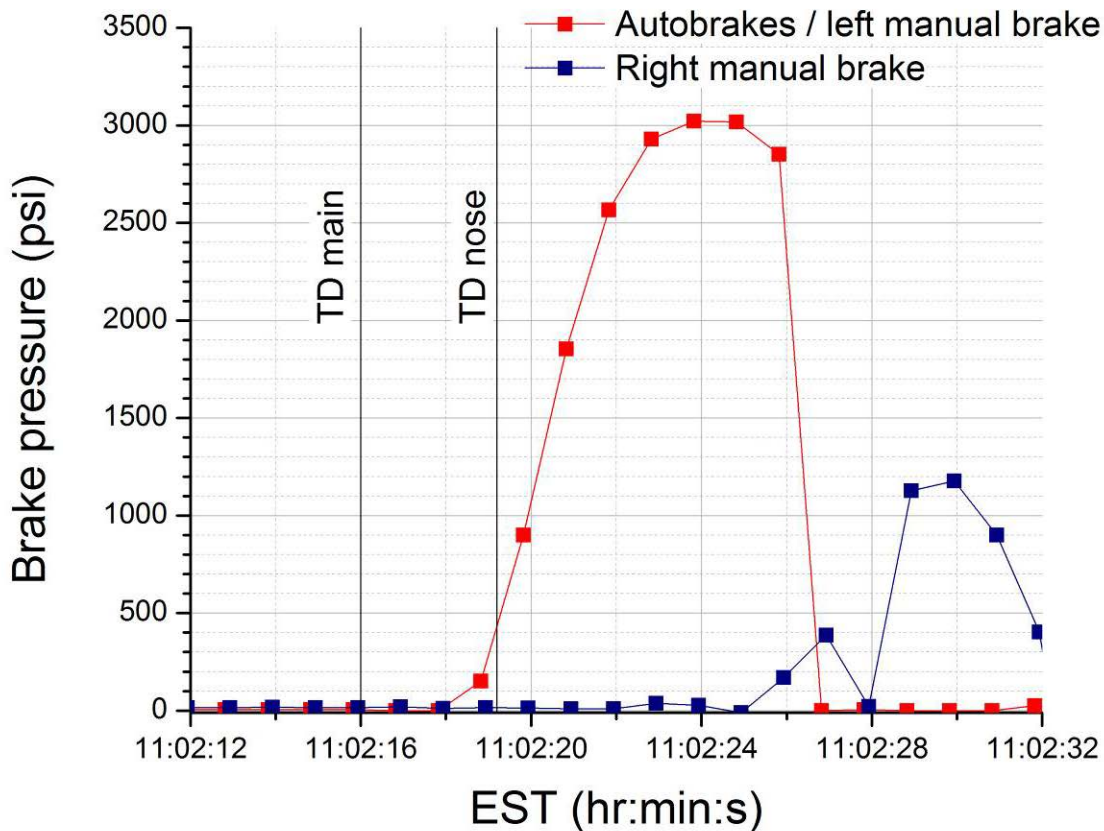
Figure 13. Aircraft brakes versus time.

Figure 14 and Figure 15 show the deployment of braking devices (wheel brakes, spoilers, and thrust reversers) versus time and position on runway. The left outboard spoiler channel first recorded motion at 11:02:17.5 (1.5 seconds after main gear touchdown) and both spoilers were deployed before the nose gear touched down. The left outboard spoiler stowed after 11:02:25, likely in response to a strong right wheel input (not shown) as the aircraft continued to move to the left.
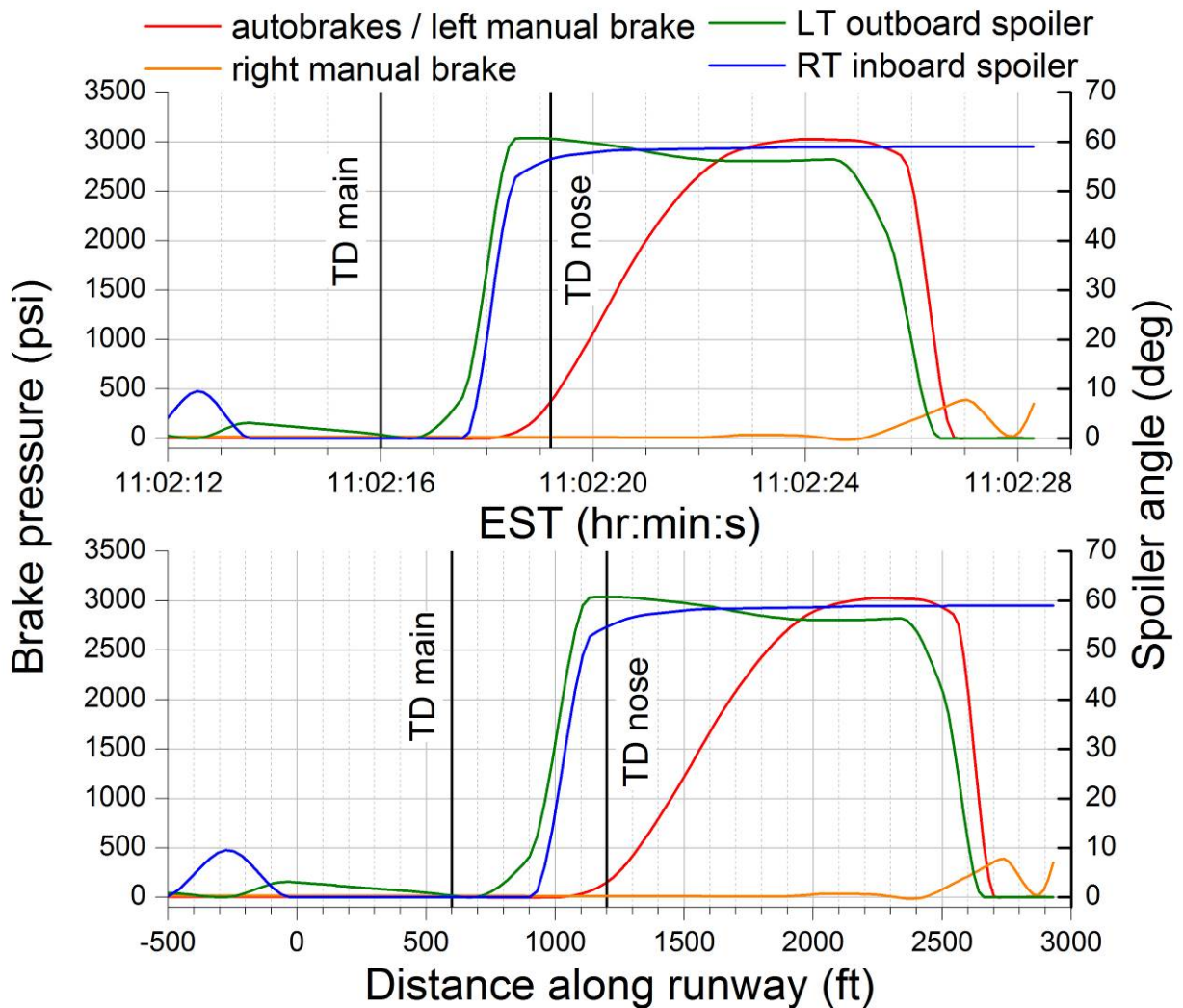
Figure 14. Aircraft brakes and spoilers versus time and distance along runway.

Thrust reversers were also deployed between main gear and nose gear touchdown. The left engine thrust reverser deployment parameter sampled 0.5 seconds before the right engine which may account for the right/left time offset seen in Figure 15. Between 4 and 5 seconds after deployment, the engine pressure ratio (EPR) rose above 2 for the left engine and 1.9 for the right engine. The EPR values for both engines stayed above 1.5 until after the thrust reversers were stowed at 11:02:25.
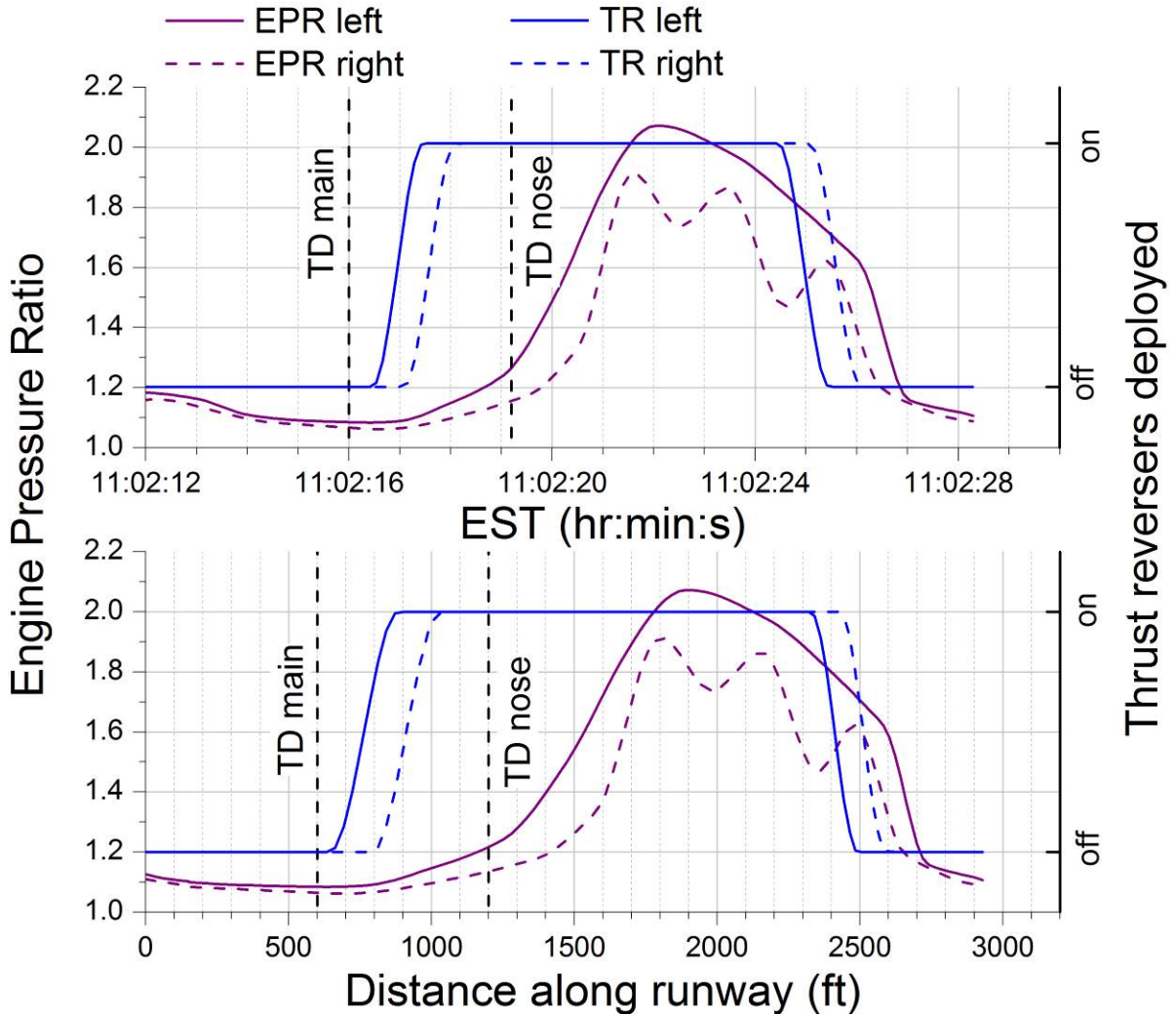
Figure 15. Thrust reverser (TR) deployment and engine pressure ratio (EPR) versus time and distance along runway.

Both autobrakes and thrust reversers were stowed at about 11:02:25. Figure 16 shows information from Figure 14 and Figure 15 overlaid on an image of runway 13. Runway 13 is 7000 ft long. The final 2000 ft of the runway have been cropped from the image.
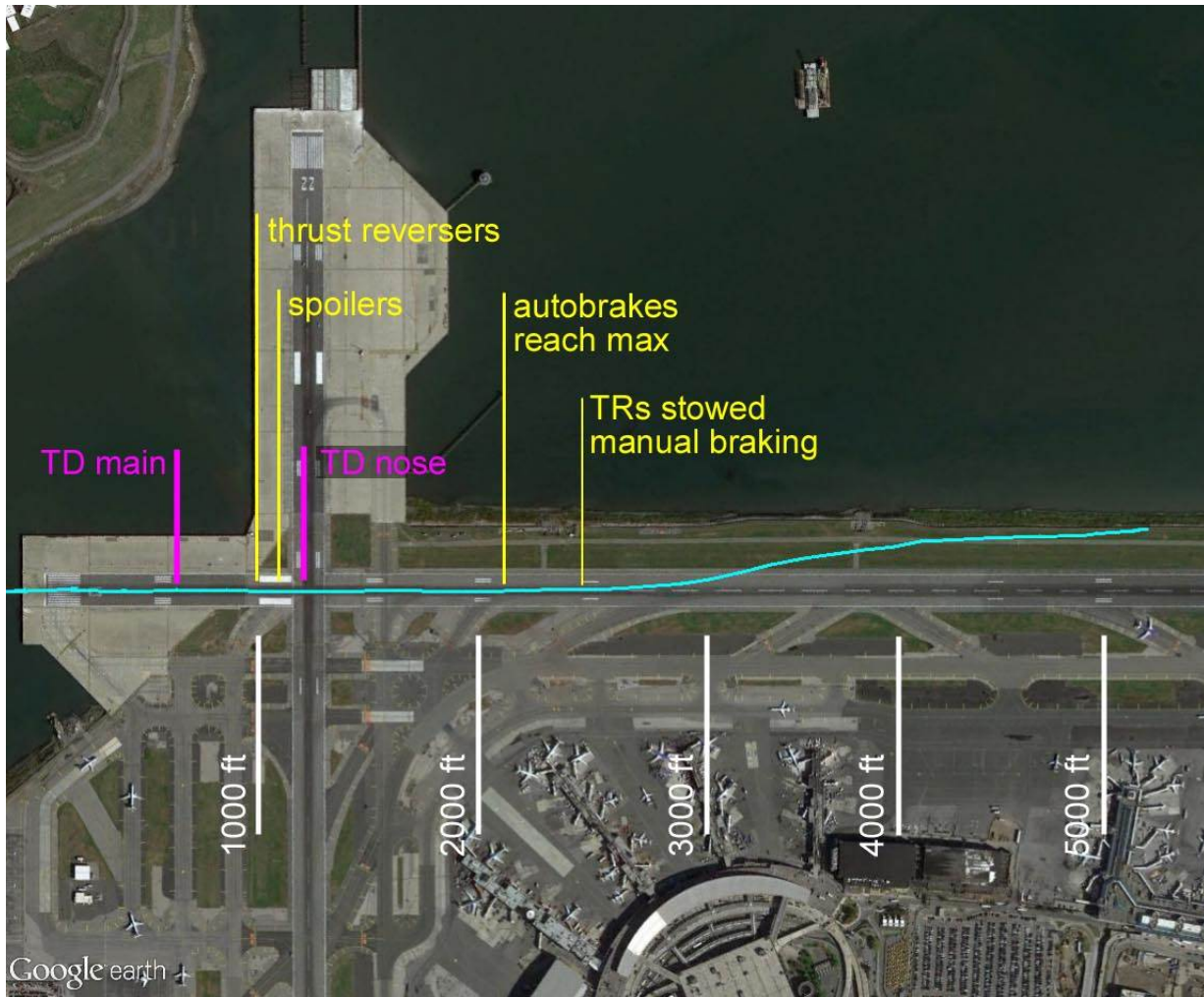
Figure 16. Runway location of touchdown, thrust reverser deployment, spoiler deployment, and when autobrakes reached their maximum pressure.

Table 1 summarizes the deployment of braking devices in time for the accident landing roll.

Table 1. Timeline and distances for aircraft touchdown and braking device deployment.

	Main gear TD	Thrust reversers	Spoilers	Autobrakes deployed	Nose gear TD	EPR > 1.3
EST (hr:min:s)	11:02:16	11:02:16.5 - 11:02:17.5	11:02:16.5 - 11:02:17.5	11:02:17.8 - 11:02:18.8	11:02:18.7 - 11:02:19.7	11:02:19 – 11:02:20
Elapsed time (s)	0	0.5 - 1.5 s	0.5 – 1.5 s	1.8 – 2.8 s	2.7 – 3.7 s	3 – 4 s

Figure 17 shows the deployment of the braking devices with the longitudinal acceleration (N$\underline{x}$) of the aircraft. Only the left engine EPR and left outboard spoiler angle are shown in an effort to simplify a data-busy figure. After main gear touchdown, there was an initial drop in N_X (blue line) that was consistent with wheels on the ground. The first local minimum in N_X corresponds with the deployment of the thrust reverser buckets (first diamond on violet line). The spoiler deployment (green line) corresponds with another pronounced drop in longitudinal acceleration. The thrust reversers were deployed and EPR increased (violet line) concurrently with the increase in autobrake pressure (red line) showing the greatest drop in N_X to a value of -0.4 g's. The maximum negative N_X value actually precedes peak EPR and autobrake pressure. This maximum deceleration value was held until the peak EPR value on the left engine was reached and then began to decrease as the EPR value falls. As the braking devices were stowed the longitudinal acceleration increases to a value near zero.
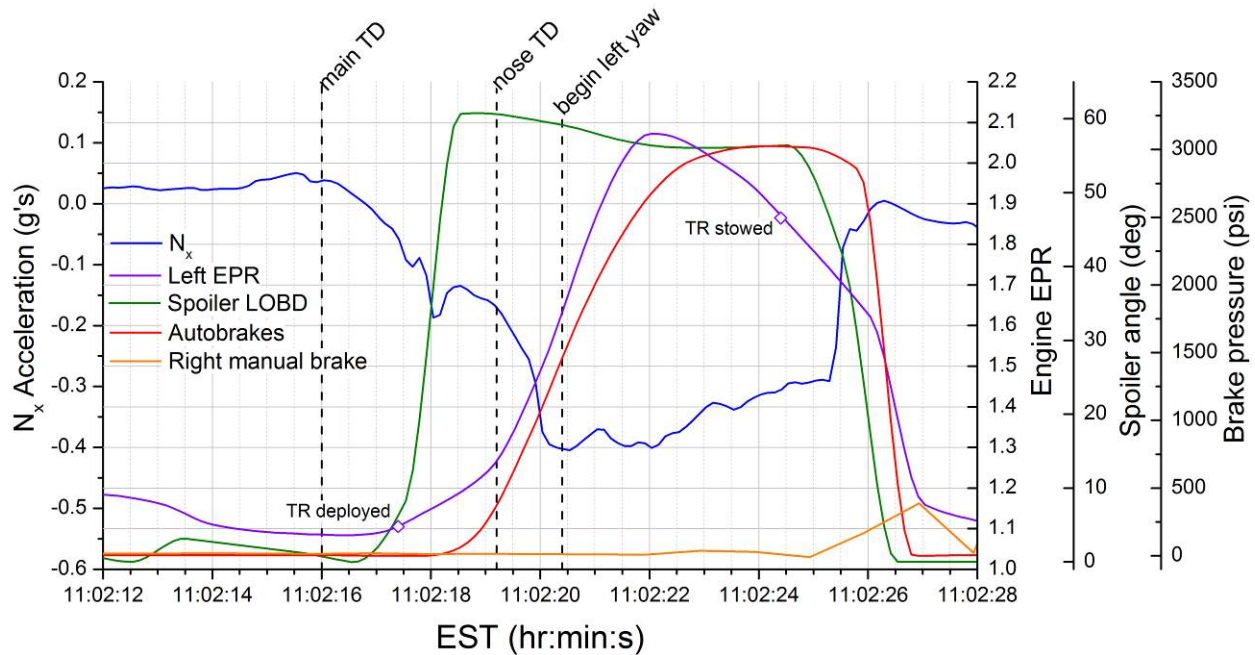

Figure 17. Longitudinal acceleration (N$_X$) and the timing of the braking devices – thrust reversers, spoilers, and brake pressure.

Deviation from Runway Heading

The aircraft touched down within 5 ft of the runway centerline according to SMR shown in Figure 18 and Figure 19. The aircraft did not deviate from the centerline more than ±5 ft until 2300 ft down the runway (1700 ft and 8 seconds after main gear touchdown). At 1600 ft the heading began to move further left, leading the centerline departure by 700 ft and four seconds. The aircraft's ground speed at touchdown was about 140 kts. Its groundspeed at 2500 ft was 93 kts. The aircraft left the runway 3200 ft from the threshold.
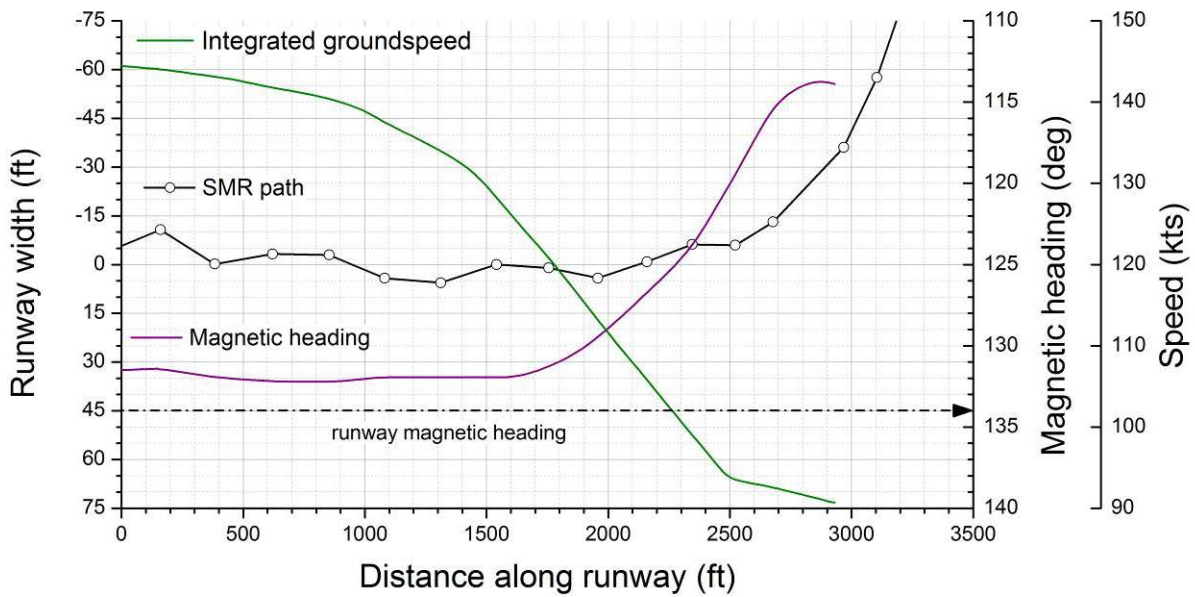
Figure 18. Radar path on runway and magnetic heading versus distance. The aircraft's main gear touched down 600 ft from the threshold.
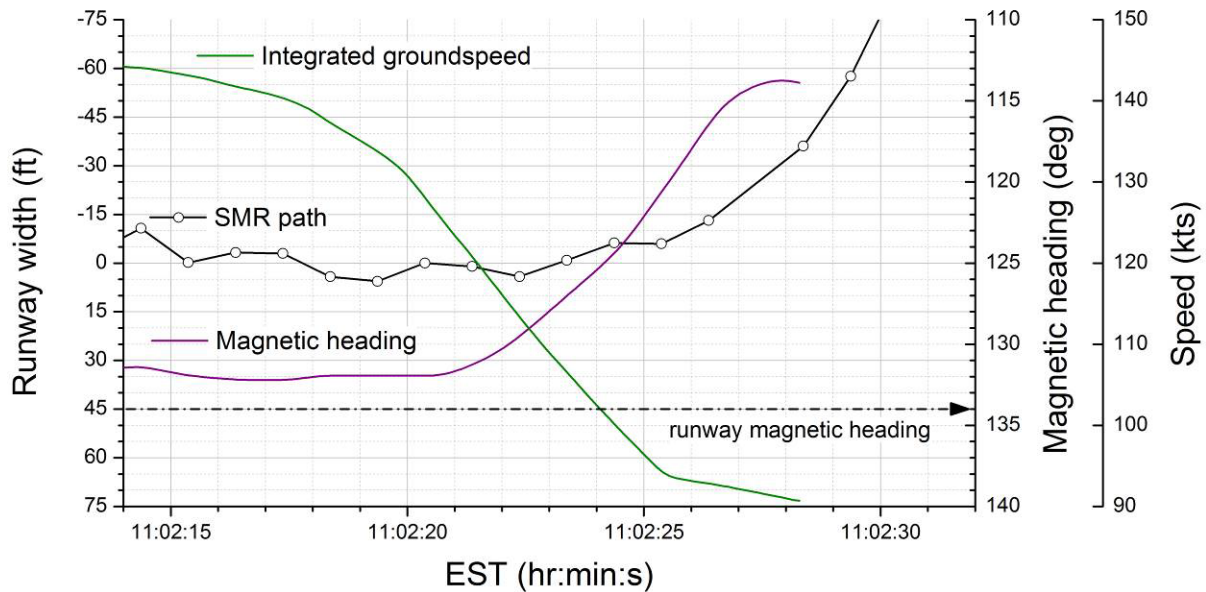
Figure 19. Radar path on runway and magnetic heading versus time. The airplane's main gear touched down at 11:02:16.

The crew began applying right rudder at 1600 ft and 11:02:20.5 as shown in Figure 20. Due to an intermittent electrical issue [1], the rudder deflection parameter on the FDR had numerous drop-outs during the landing roll and had to be corrected. The corrected data is shown in Figure

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20.   The crew applied increasing opposing rudder as the aircraft turned to the left, briefly releasing the rudder at about 11:02:24, before applying maximum rudder deflection (23°).

After nose gear strut compression, the rudder pedals also apply nose wheel steering. This parameter was not recorded, but the relationship between rudder pedal and nose wheel steering was provided by Boeing. If the nose wheel steering was functioning as expected, its angle is shown in Figure 20. In addition to rudder and nose wheel steering, the crew applied right manual brake, which disconnected autobrakes. Differential braking on only the right main gear should increase the aircraft's yaw to the right.
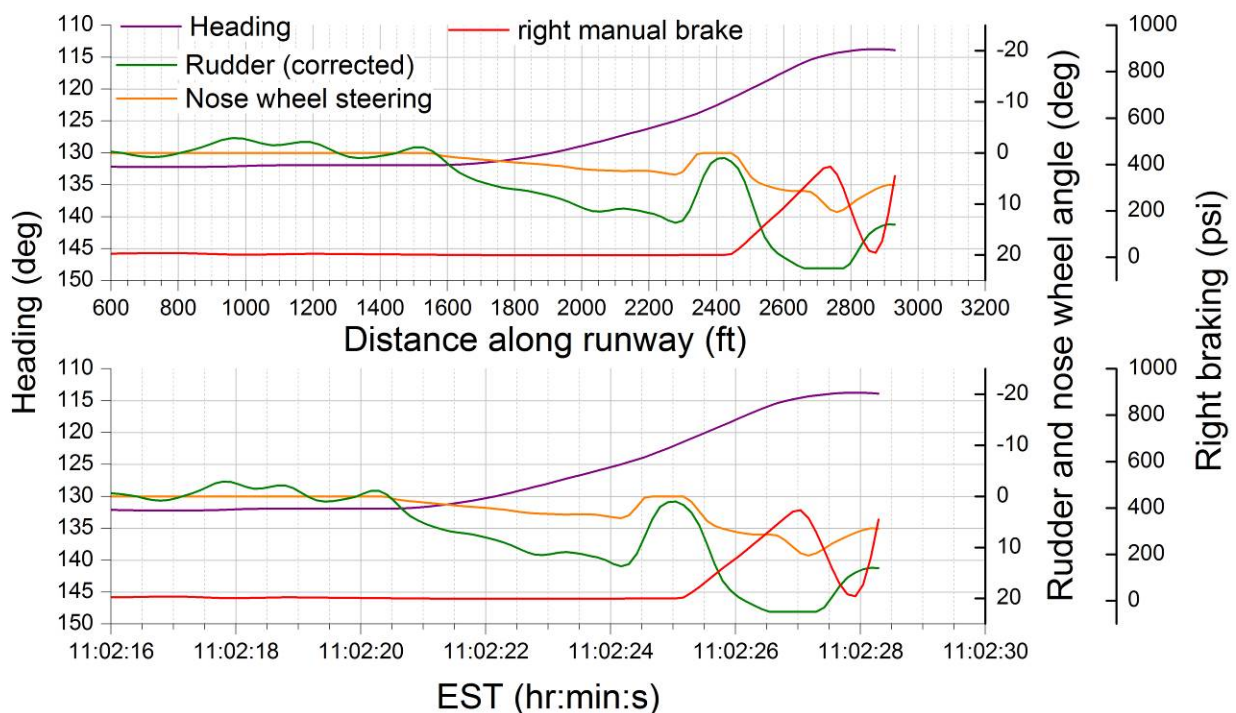
Figure 20. Aircraft rudder application, nose wheel steering, right manual braking, and heading versus distance and time.[2]

In summary, the FDR and radar recordings showed the main gear touching down at 11:02:16, 600 ft from the threshold. The thrust reversers, spoilers, and autobrakes were deployed before the nose gear touched down. The right rudder was engaged beginning about 11:02:20.5 in response to a left yaw rate which will be discussed in the *Loss of Directional Control* section. By 11:02:21 the aircraft's heading began to deviate from the runway heading. At 11:02:25 and 2500 ft thrust reversers were stowed and maximum right rudder and right brakes were manually applied. The aircraft left the paved runway 3200 ft from the threshold.

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[2] Rudder parameter convention is: positive angles for rudder trailing edge right, negative for trailing edge left. Nose wheel steering is: positive degrees to the right, negative to the left. Plots are oriented so that left is to the top of the plots and right to the bottom.

Comparison to Prior MD-88 Landing

Three minutes prior to the accident landing, Flight 1526, another Delta MD-88, landed on runway 13 at LGA. The prior MD-88 touched down its main gear slightly farther down the runway than the accident aircraft. The prior MD-88's nose gear initially touched down at about 1100 ft down the runway, lightened, then came down again at about the 1500 ft mark. Flight 1526's main gear touched down at an airspeed of 125 kts. At a landing weight of 112,500 lbs and flaps 40, the prior aircraft's V_{ref} was 124 kts. The accident flight's weight was 127,500 lbs and its V_{ref} was 131 kts (as referenced earlier). For Figure 21 through Figure 25, solid lines show data from Flight 1086, the accident aircraft, and dotted lines show the same data from Flight 1526, the prior aircraft.
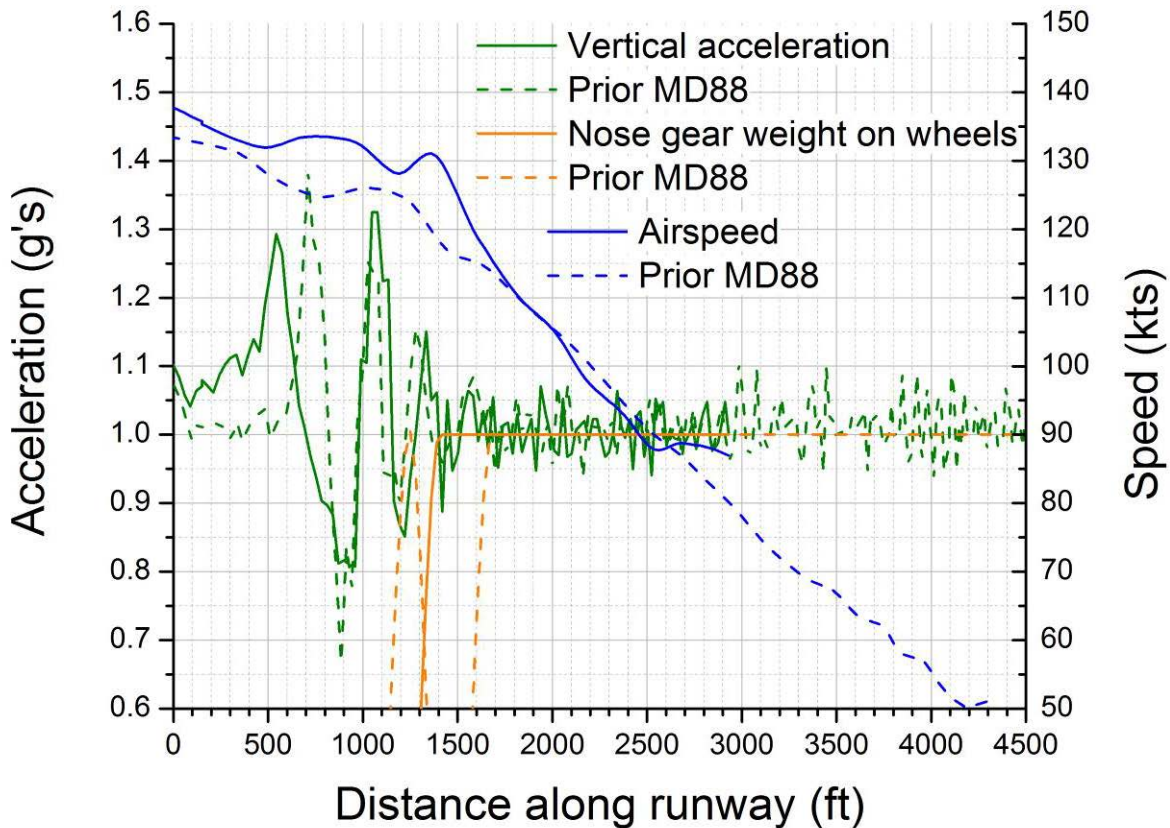
Figure 21. Vertical accelerations, nose gear weight on wheels, and speed for the accident aircraft (solid lines) and prior MD-88 (dotted lines).

Figure 22 and Table 2 compare the application of braking devices for both aircraft. Autobrakes, which are triggered by spoiler handle deflection, initiated at approximately the same time as nose gear touchdown. Manual braking was not used during the landing roll for the prior MD-88 landing. The accident aircraft deployed thrust reversers sooner than the prior MD-88, but the spoilers about a half a second later.
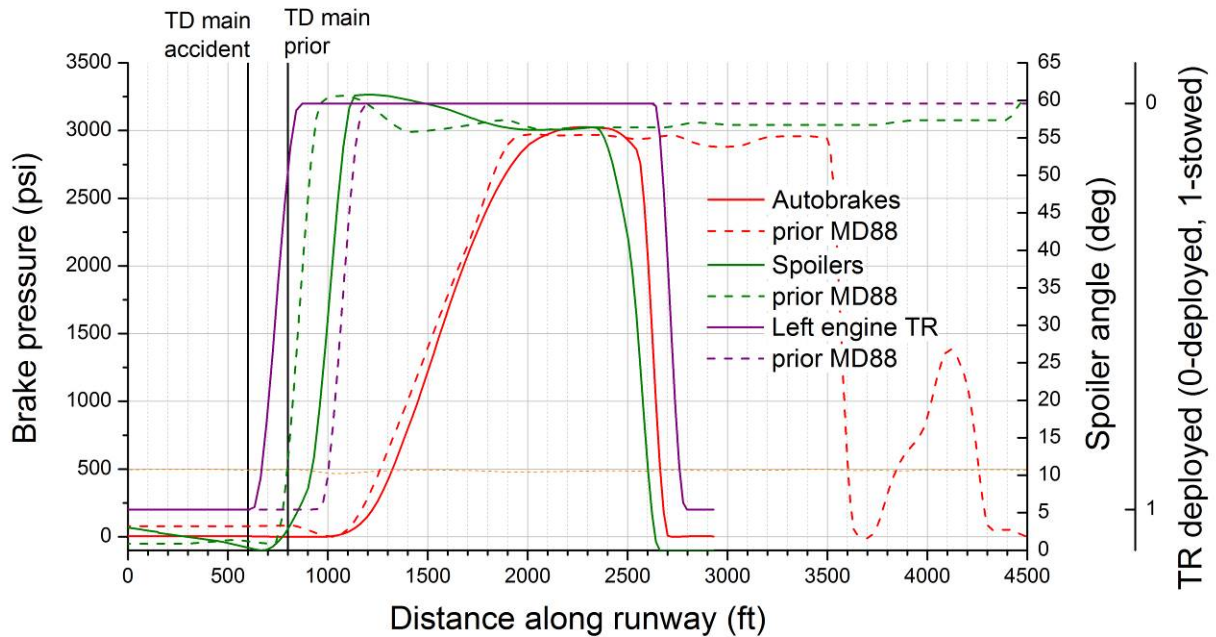
Figure 22. Braking devices versus distance for accident aircraft and prior MD-88.

Table 2. Comparison of timing for braking devices for accident aircraft and prior MD-88.

	Seconds after main gear touchdown		
	Spoilers deployed	Thrust reversers deployed	Brakes initiate
Accident aircraft	~ 1 s	~ 1 s	~ 2 s
Prior MD-88	< 1 s	> 1.5 s	~ 1 s

Figure 23 compares the engine pressure ratios between the two aircraft landings. The accident aircraft's EPR values were higher, greater than 2.0 and 1.9, as compared to the prior aircraft's maximum EPR values of greater than 1.8 and 1.5. The prior aircraft's left engine EPR stayed above 1.6 for 2.5 seconds longer than the accident aircraft.
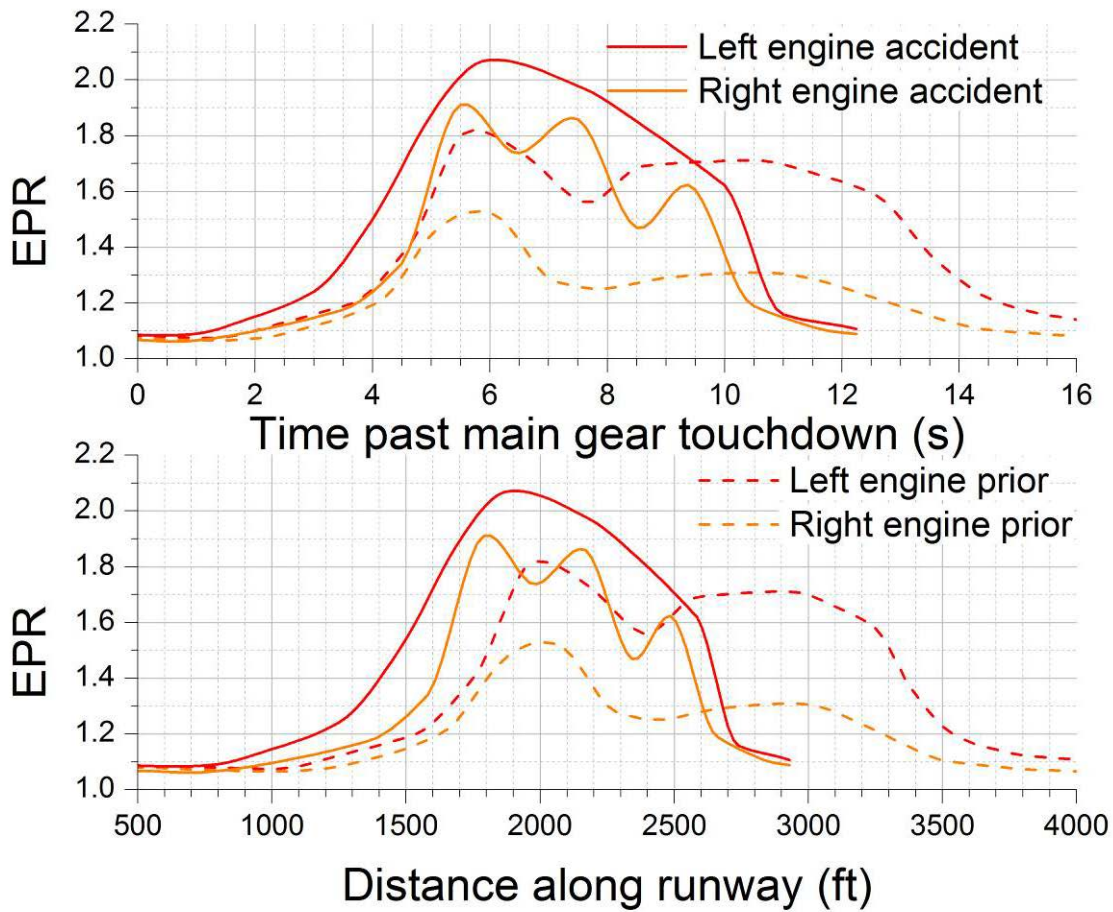
Figure 23. Engine pressure ratios versus time and distance for accident aircraft and prior MD-88.

The prior aircraft did not deviate from the runway heading throughout its landing roll (Figure 24). Until the accident aircraft began heading to the left, the aircrafts' ground tracks were within 10 ft of each other.
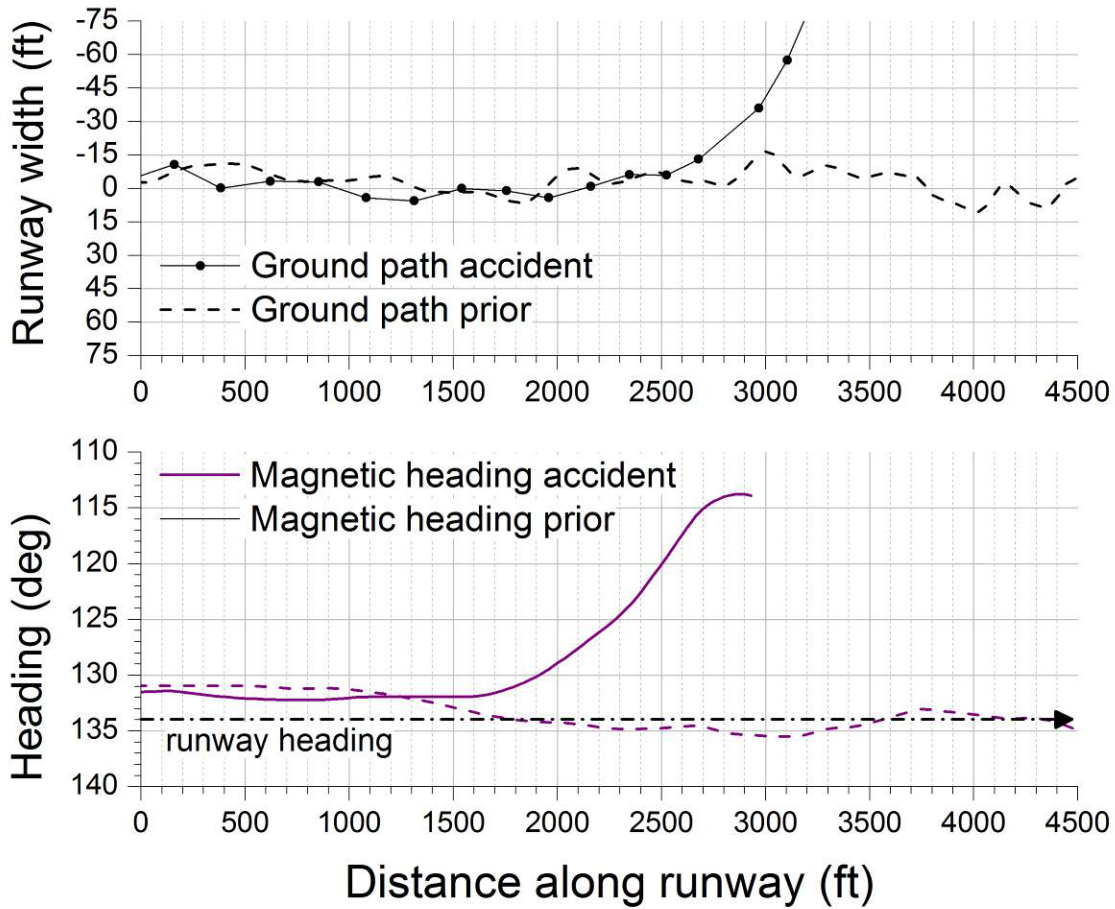
Figure 24. Ground path and heading versus distance for accident aircraft and prior MD-88.

The prior MD-88 crew's maximum rudder input was 10° to the left. The accident crew's maximum rudder input was 23° to the right, as shown in Figure 25. The effectiveness of rudder input at EPRs higher than 1.6 will be discussed in the next section of the report.
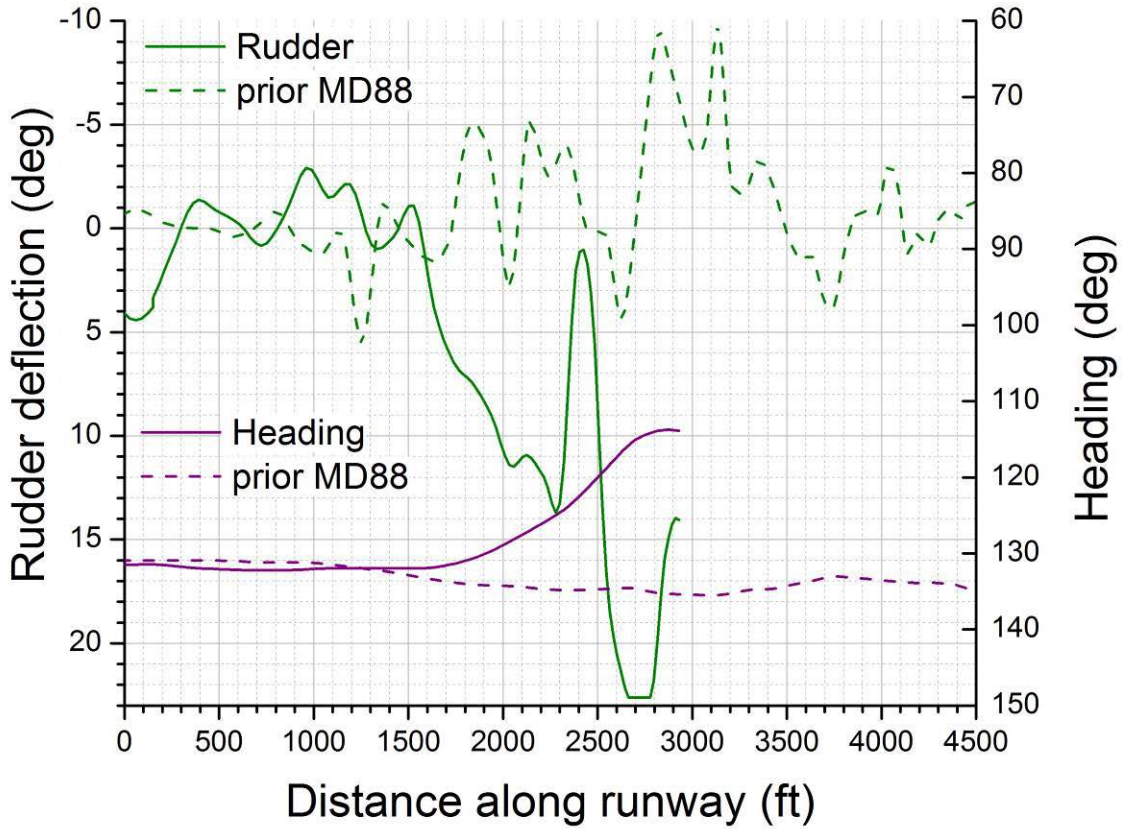
Figure 25. Rudder deflection and heading versus distance for accident aircraft and prior MD-88.

In summary, the accident aircraft and the prior aircraft landing were both Delta MD-88s. For the first 2500 ft of runway, the aircraft followed similar ground paths. The deployment of braking devices occurred along similar time lines for both aircrafts. The prior aircraft was lighter by 15,000 lbs and landed 8 kts slower. The prior aircraft's EPR values did not rise to the same levels (1.82 and 1.53 EPR) as the accident flight (2.07 and 1.91 EPR).

Loss of Directional Control

As discussed in the *Deviation from Runway Heading* section, the FDR recorded the crew inputting right rudder and differential right braking during the heading deviation. Figure 26 shows the calculated aircraft yaw rate during the landing roll. The left yaw rate began at about 11:02:20.5 and the pilot applied right rudder simultaneously. Calculated nose wheel steering increased with the increase in rudder pedal, plateauing at about 3.5° before 11:02:24 when the rudder pedal was released, causing both rudder deflection and calculated nose wheel steering to drop. At approximately the same time, thrust reversers were stowed. At about 11:02:25, right rudder pedal returned and right rudder increased to its maximum deflection by 11:02:26.5. Right manual braking was also applied at 11:02:25. The data was truncated at 11:02:28 in the figure as discussed earlier, but right manual braking continued to increase to about 1100 psi (Figure 13) as the aircraft left the paved runway by about 11:02:30.
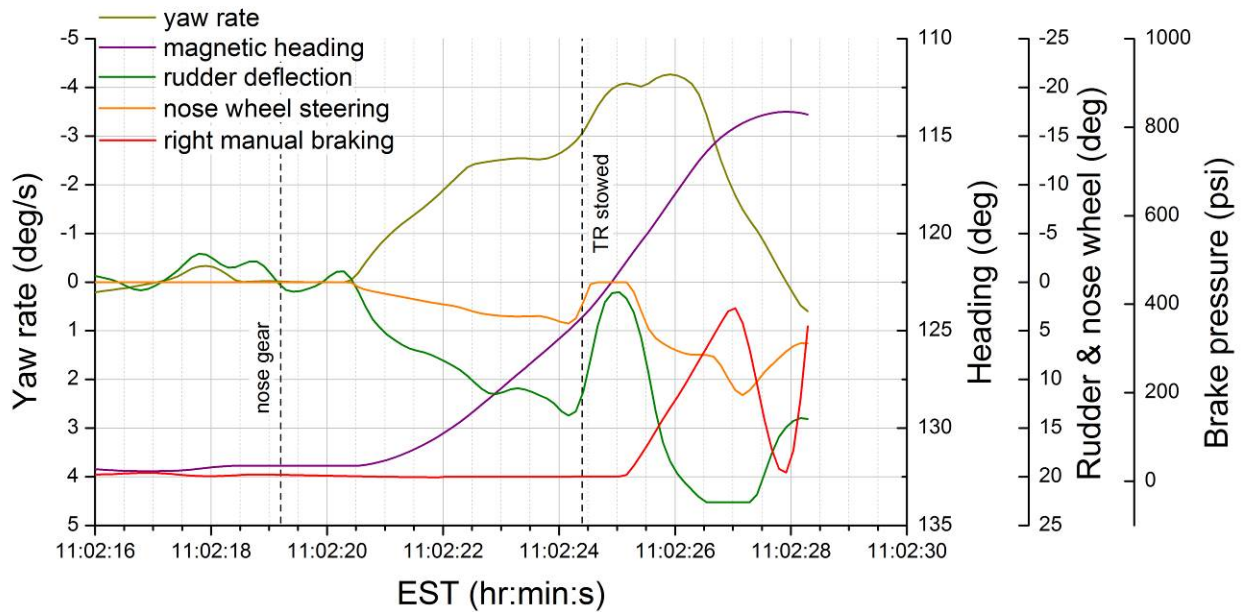
Figure 26. Calculated aircraft yaw rate, heading, rudder and nose wheel steering, and right manual braking during heading deviation.

The yaw rate increased steadily from 11:02:20.5 until 11:02:22.5. For about 1.5 seconds after 11:02:22.5, the yaw rate held steady at about 2.5 deg/s left. The yaw rate began again to increase again as the rudder pedal was released. The increase in yaw rate was finally arrested and then yaw rate decreased as rudder pedal was applied after the thrust reversers were stowed and right manual braking began. The heading stabilized at 113° and began coming back, but the aircraft was not able to recover in time to stay on the runway.

Rudder Blanking Due to High EPR in MD-88s

The MD-80 series of aircraft was developed by McDonnell Douglas in the 1980s and was based on the Douglas DC-9. The aircraft have two rear fuselage-mounted turbofan engines and a T-tail. In 1980, McDonnell Douglas issued a report [4] on the ground handling characteristics of the aircraft, especially the lateral controllability at high reverse thrust engine pressure ratios. Because the engines are mounted alongside the tail, high reverse thrust has the effect of "blanking" the rudder and vertical stabilizer, greatly reducing their directional control authority. The dynamic pressure of the air flowing over the control surface allows the rudder to produce enough lift to guide the aircraft. Therefore, rudder effectiveness is a function of airspeed (less control surface authority at lower speeds) and the reverse thrust EPR. Testing indicated that when in reverse thrust, if the EPR is above 1.3 and the aircraft's speed is below 108 kts, the rudder has limited directional authority. Testing also indicated that when in reverse thrust, if the EPR is above 1.6 and the aircraft's speed is below 146 kts, the rudder has limited directional authority. Boeing released guidance that operators should limit reverse thrust EPR to less than 1.6 during normal landings and less than 1.3 EPR when landing in adverse conditions [5].

Figure 27 shows the left and right EPR versus time and distance along the runway. The aircraft touched down at 133 kts, and its speed was less than 130 kts when the reverse EPR for the left engine was greater than 1.6. Because the EPR exceeded 1.6 in reverse thrust and the aircraft's speed was less than 146 kts, test data showed that the crew could not use rudder to control heading. The aircraft's left engine exceeded 1.6 EPR at 11:02:20.3 and the right engine exceeded 1.6 EPR at 11:02:21. From the time the left yaw began until the thrust reversers were stowed, the rudder was an ineffective means of controlling the aircraft's heading.
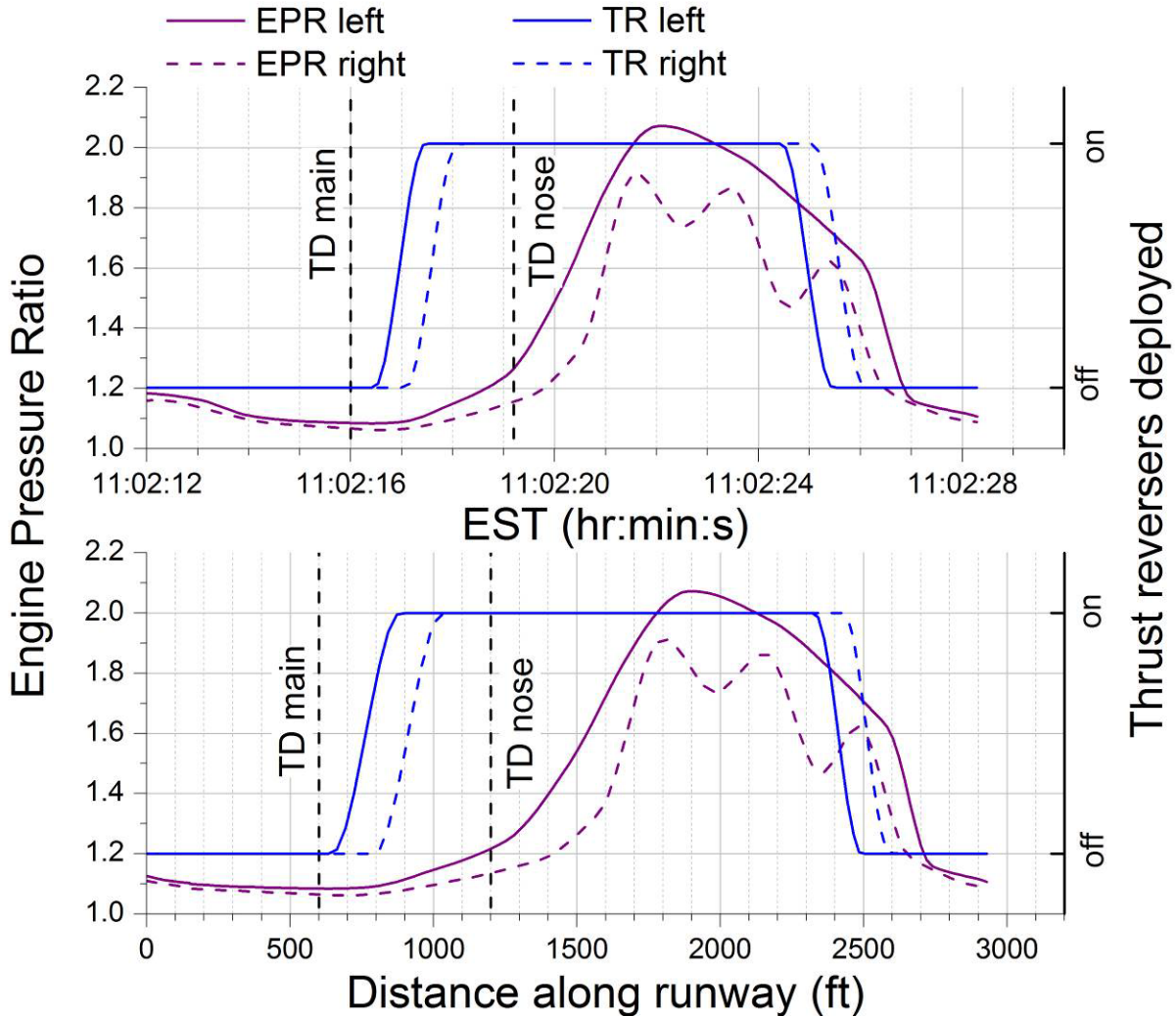
Figure 27. Thrust reverser deployment and EPR along runway.

Differential Braking and Nose Wheel Steering

While the rudder was rendered ineffective at controlling the aircraft's heading during reverse thrust at high EPR, the aircraft's heading could be affected by nose wheel steering and differential braking. Right differential braking was applied at 11:02:25, 4.5 seconds after the left yaw rate began. Right brake pressure increased to just below 400 psi by 11:02:27, decreased to zero, and then increased to over 1100 psi by 11:02:29. The full pressure available using maximum autobrakes was 3000 psi. Differential braking and effective rudder inputs after the thrust reversers were stowed were applied at the same time, so all of these control systems had some contribution to altering the aircraft heading. The yaw rate was arrested and then reduced after 11:02:25.

Nose wheel steering was calculated to have increased to 3.5° right during the initial input in right rudder pedal and to have increased to over 11° right during the second application of right rudder

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pedal. For the period of time after 11:02:22.5 when the yaw rate held steady at about 2.5 deg/s left, the rudder was rendered ineffective due to high EPR and differential braking had yet to occur, so the arrest in yaw rate might have been due to nose wheel steering input.

In summary, during the landing roll, the aircraft had three mechanisms for directional control: rudder, nose wheel steering, and differential braking. The rudder was made ineffective by EPR values over 1.6. Differential right braking was not used until 11:02:25. Nose wheel steering seemed to have some effect slowing the increase in yaw rate between 11:02:22.5 and 11:02:24.

Deviation from Runway Heading

This section will address the possible forces that may have contributed to the yawing moment to the left.

Yawing Moment Due to Asymmetric Reverse Thrust and Crosswind

The 1980 McDonnell Douglas report [4] also discussed yawing moments due to asymmetric reverse thrust and yawing moments due to crosswind. This section will discuss the possible contributions of the crosswind and reverse thrust asymmetry to the heading deviation.

The McDonnell Douglas report used a yawing moment of inertia of 3.971×10^6 slug-ft^2 for flight test calculations. This number, while not specific to the accident aircraft, was used as a first approximation in this study. Figure 28, below, shows the calculated yaw acceleration and yawing moment of the aircraft using the FDR data and the reported yawing moment of inertia.
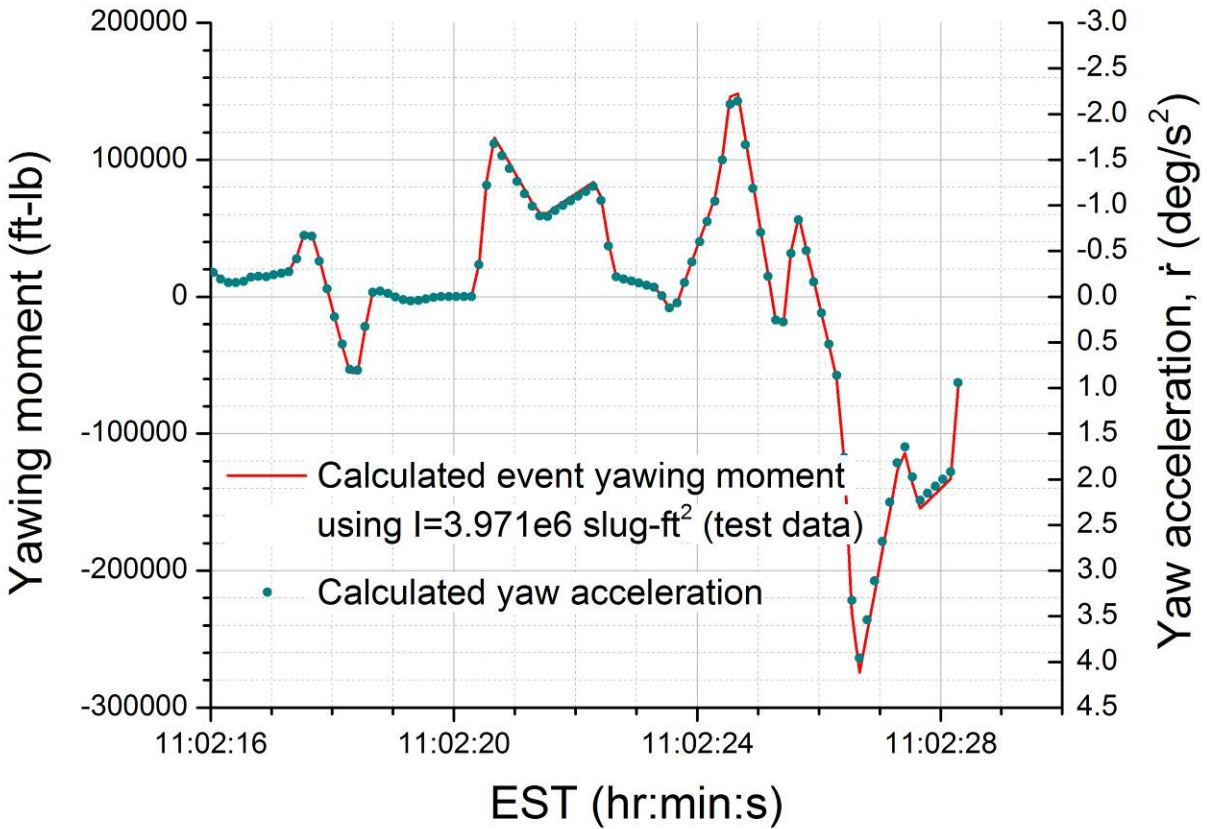
Figure 28. Calculated yawing moment (red line) and yaw acceleration (blue dots) of the accident aircraft.

The report detailed calculations and tests to determine the yawing moment imparted on the aircraft by a 10 kts crosswind and due to asymmetric reverser configuration. The crosswind calculation varied with aircraft equivalent airspeed. The asymmetric thrust data came from wind tunnel tests. For asymmetric thrust, one engine was brought up to a reverse thrust EPR of 1.3 or 1.6 while the other engine remained at idle. For the purpose of this study, the yawing moment imparted by asymmetric reverse thrust was roughly calculated when the left engine was above 1.6 and the right above 1.3. During this time the imparted yawing moment was determined using the McDonnell Douglas report values for 1.6 EPR minus 1.3 EPR yawing moment values (for that equivalent airspeed). Figure 29 shows the calculated yawing moment of the event (red line) from Figure 28 and possible contributions of a 10 kts crosswind from the aircraft's left (blue line) and an EPR split of 0.3 between the left and right engines (green line). Both the crosswind and engine asymmetry were in the correct direction to influence the aircraft's yaw.
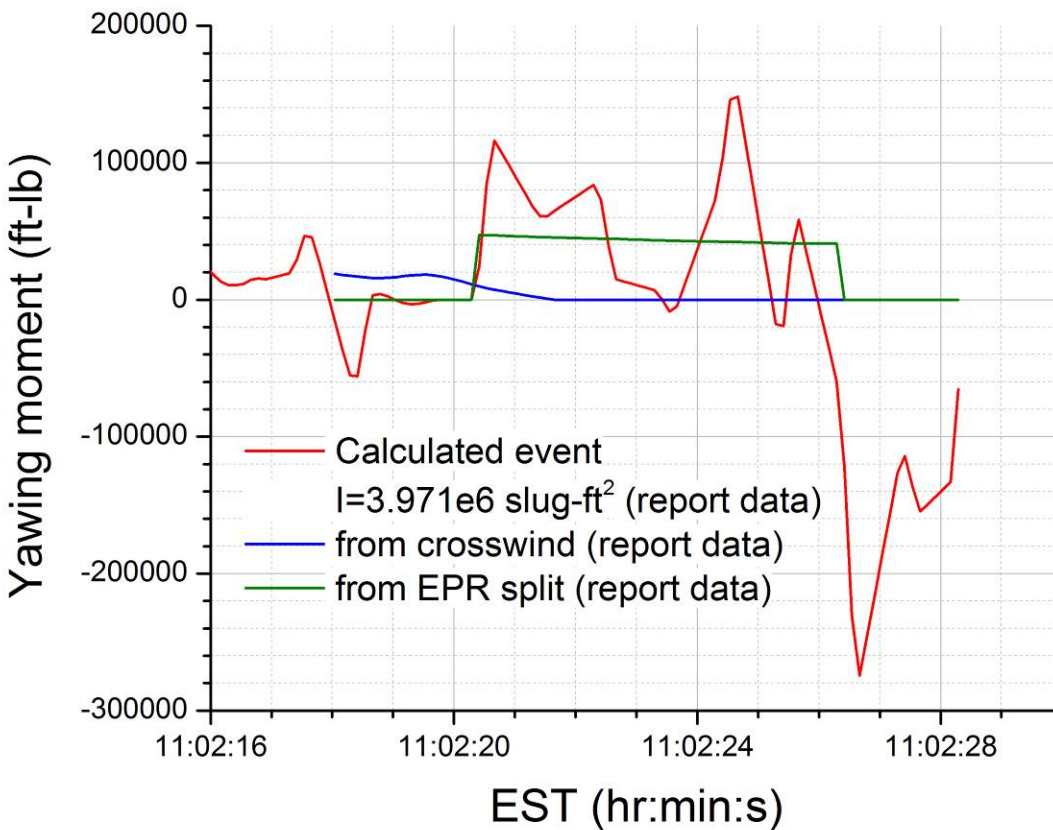
Figure 29. Calculated yawing moment (red line) and possible yaw moments from crosswind (blue) and EPR split (green).

The effect of the EPR split was calculated using data from wind tunnels tests and was approximately half of the total yawing moment necessary to divert the airplane. The EPR split assessed in the Boeing report did not address the total effect of the high EPR (and EPR differential) in reverse thrust in the accident. The left yawing moment was concurrent with the EPR increase above 1.6 on the left engine (Figure 26 and Figure 27).

From the McDonnell Douglas report, a 10 kts crosswind contribution was less than 1/10th of the total yawing moment needed to divert the aircraft. The crosswind data was calculated, not tested, and may not accurately reflect the full effects of wind on the aircraft. Also, thrust reverser induced blanking would have been expected to eliminate aerodynamic forces on the rudder and vertical stabilizer during this portion of the landing roll. If the vertical tail was rendered ineffective as a means of directional control, the turbulence from the thrust reversers could also interfere with the effects of wind on the tail making it less susceptible to crosswinds.

Landing Roll Braking Action

Simulations were performed using Boeing MD-88 aerodynamic, engine and ground interaction models. The simulations were carried out with the engine thrust and controls applied using recorded data from the FDR. For each simulation run, a constant airplane wheel/runway interface performance value was used. A 'wet' condition was simulation with a wheel braking coefficient of 0.307, and an 'icy' condition was simulated with a coefficient of friction between tire and runway of 0.066. An intermediate condition with a coefficient of friction between tire and runway of 0.16[3] was also used in simulations. Wheel braking coefficients assume an anti-skid efficiency of 83%. Simulations were performed for both the accident airplane and the prior MD-88.

Figure 30 shows simulations performed for the prior MD-88, Flight 1526. When the runway performance value was set to a Boeing 'wet' value, the longitudinal deceleration was greater than what was recorded by the FDR. When the runway performance value was set to a Boeing 'icy' value, the aircraft did not decelerate enough. The intermediate value, equivalent to a wheel braking coefficient of 0.16, best correlated the aircraft's deceleration with what was recorded during the actual Flight 1526 landing.
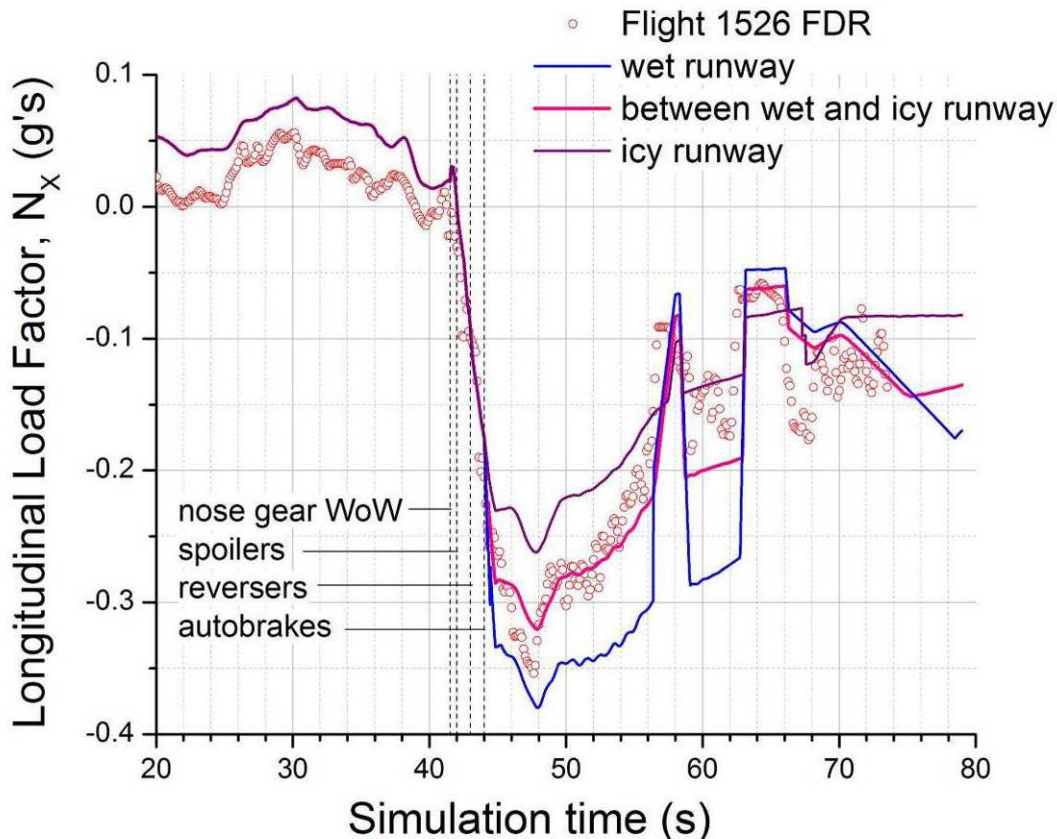
Figure 30. Longitudinal acceleration for Flight 1526 and three landing simulations for different runway frictions. The FDR data has been correlated to the time from each simulation run.

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[3] According to FAA Advisory Circular 25-32 [6], a wheel braking coefficient of 0.16 is equivalent to a pilot-reported braking action of 'medium'.

Figure 31 shows the accident landing with the same three runway conditions. Here, the FDR deceleration is greater than what the simulations predict for any of the three runway conditions (wet, icy, or intermediate) from time 38 s to 40 s, implying better than wet runway performance. After that time, the longitudinal acceleration was approximately consistent with the intermediate runway performance value.
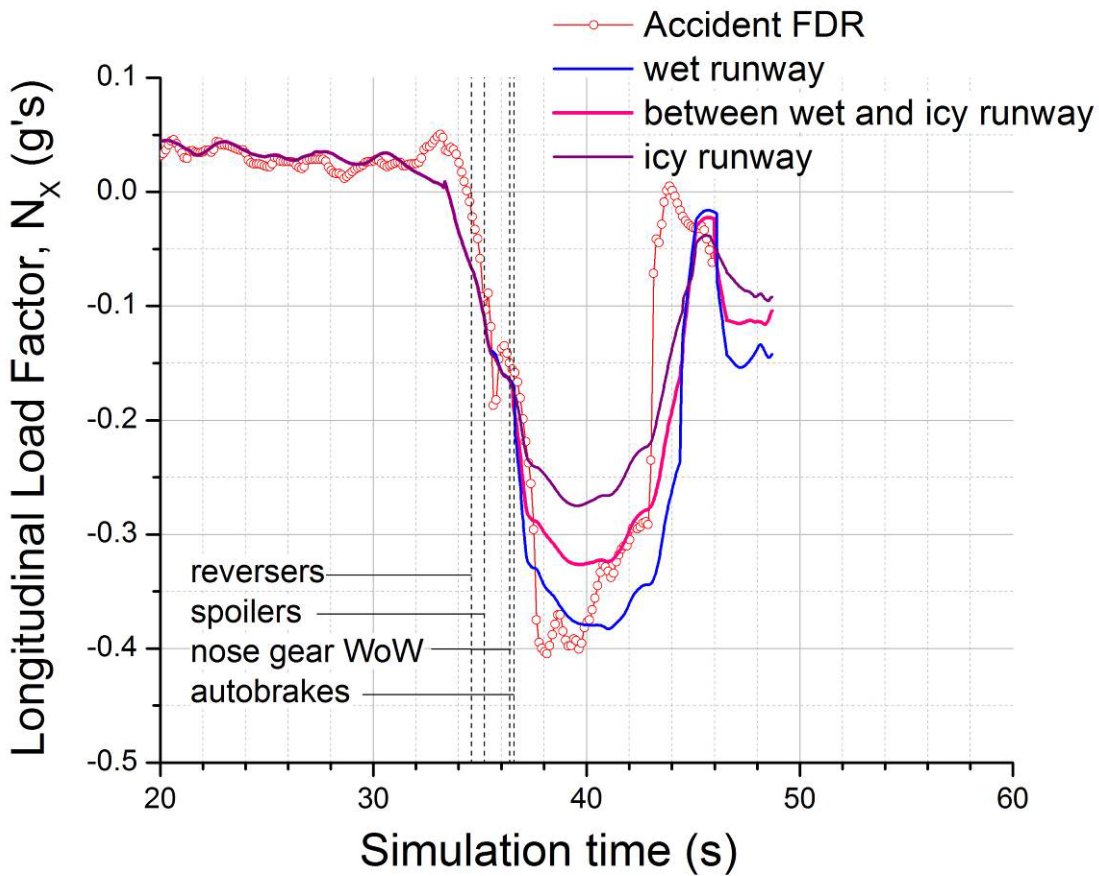
Figure 31. Longitudinal acceleration for accident flight and three landing simulations for different runway frictions.

However, comparing the accident landing and the prior MD-88 in Figure 32 shows that the differing N_x occurs on approximately the same portion runway.
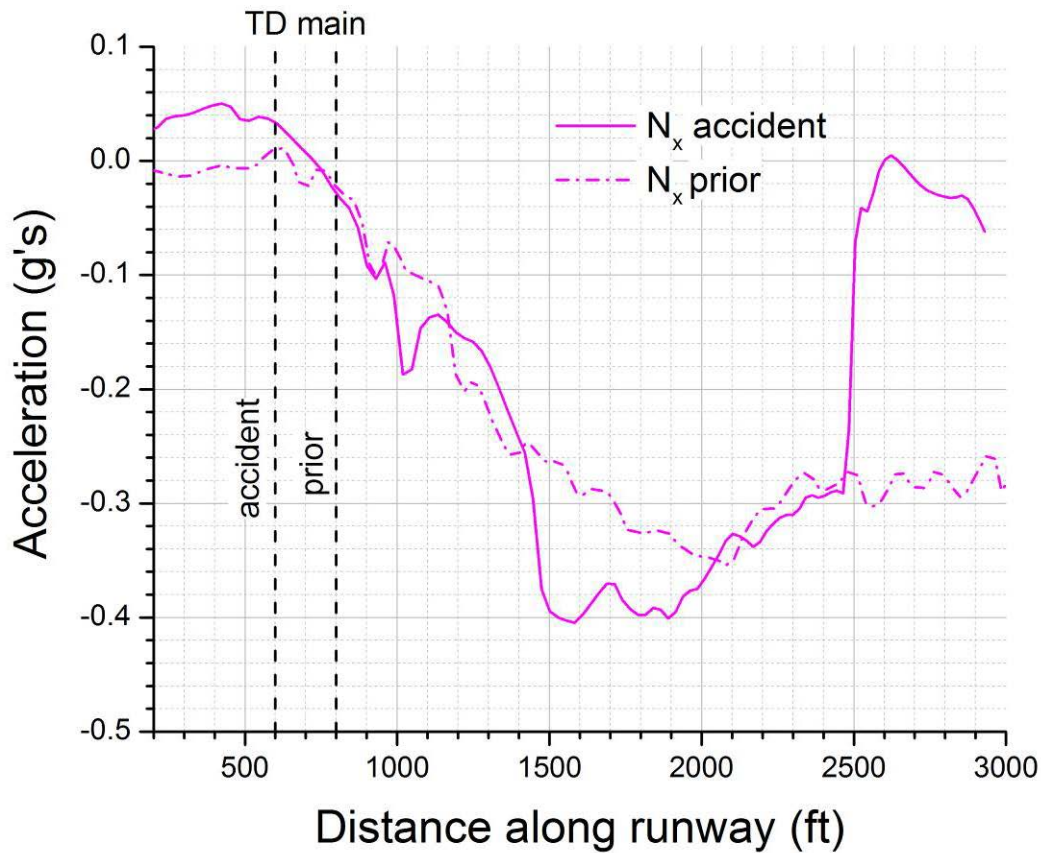
Figure 32. Longitudinal acceleration for the accident aircraft (solid lines) and prior MD-88 (dotted lines).

As an alternative evaluation, simplified models of the aerodynamic and thrust components from the simulations were used to calculate a braking coefficient from the FDR data. This method divides the aircraft's deceleration into three parts: the portion due to aerodynamics, the portion due to thrust, and the portion due to wheel/runway interaction. Using models of the aerodynamic and thrust components from the simulations, the changing aircraft braking coefficient could be calculated for the landing roll. For the prior MD-88 the calculated braking coefficient compared to the 0.16 intermediate runway performance value from the simulation is shown in Figure 33. The calculated braking coefficient is a measure of how much friction is requested by the aircraft. There could be more friction available, but the brake pressure and anti-skid system operation might not be high enough to use it. However, both the prior MD-88 and accident aircraft were using maximum autobrakes.
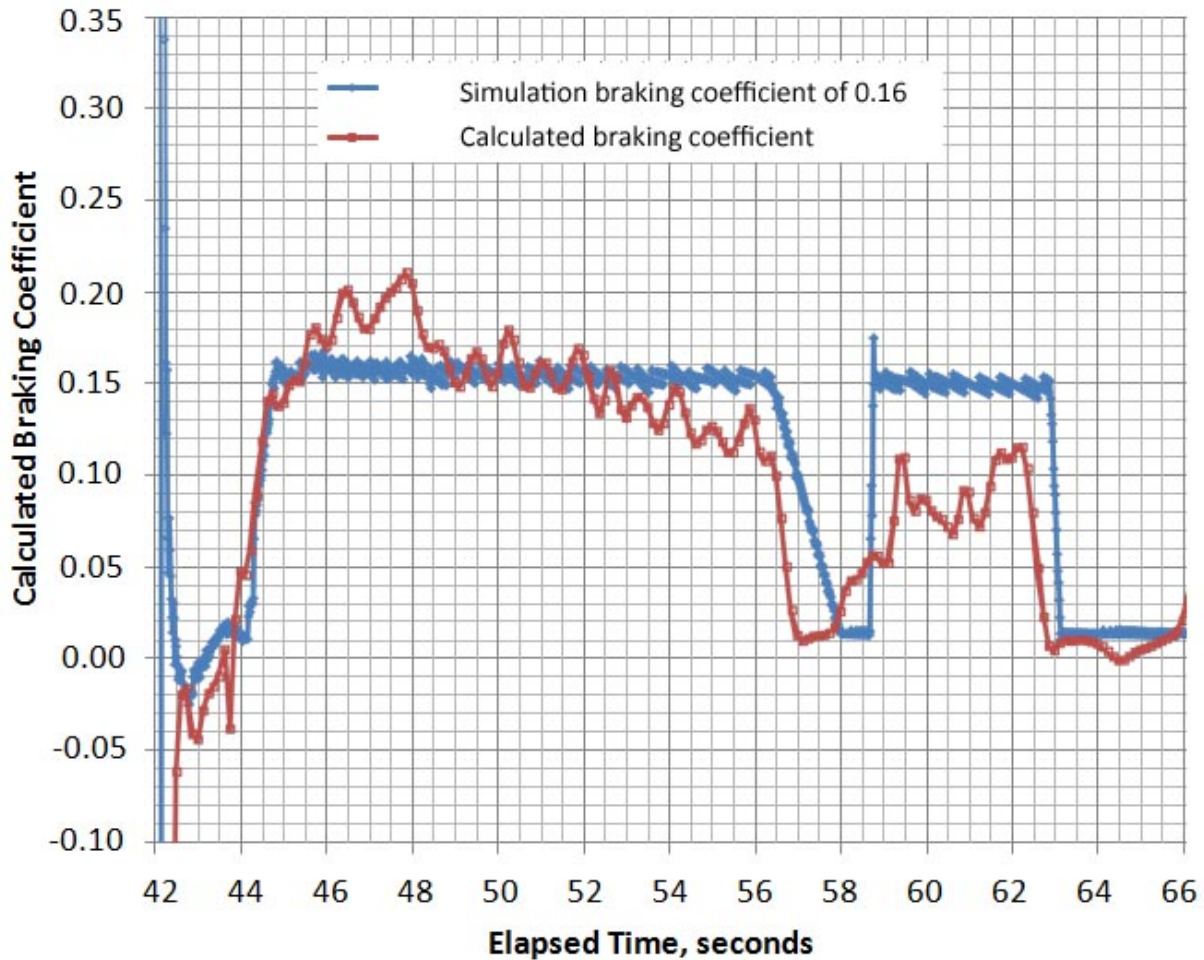
Figure 33. Simulated braking coefficient for intermediate runway friction and the calculated braking coefficient from the prior MD-88 landing.

The braking coefficients in the simulations were constant values while the calculated value changes, but in Figure 33 the areas under the curves for 44 s to 56 s for both evaluations were similar. The braking coefficient values from the two methods were generally in agreement. The accident landing roll was also investigated with the same calculation method. Here, in Figure 34, the braking coefficient was shown to be better than the prior MD-88 for the initial portion of the landing roll after nose gear weight on wheels. After the aircraft's heading turns to the left at about 11:02:21, the tires would experience cornering forces which would split the braking coefficient between longitudinal deceleration forces and lateral cornering forces. This interaction between longitudinal and lateral forces was not explored during this portion of the investigation. Therefore, the braking coefficient calculated in Figure 34 cannot be considered reflective of the event after 11:02:21.
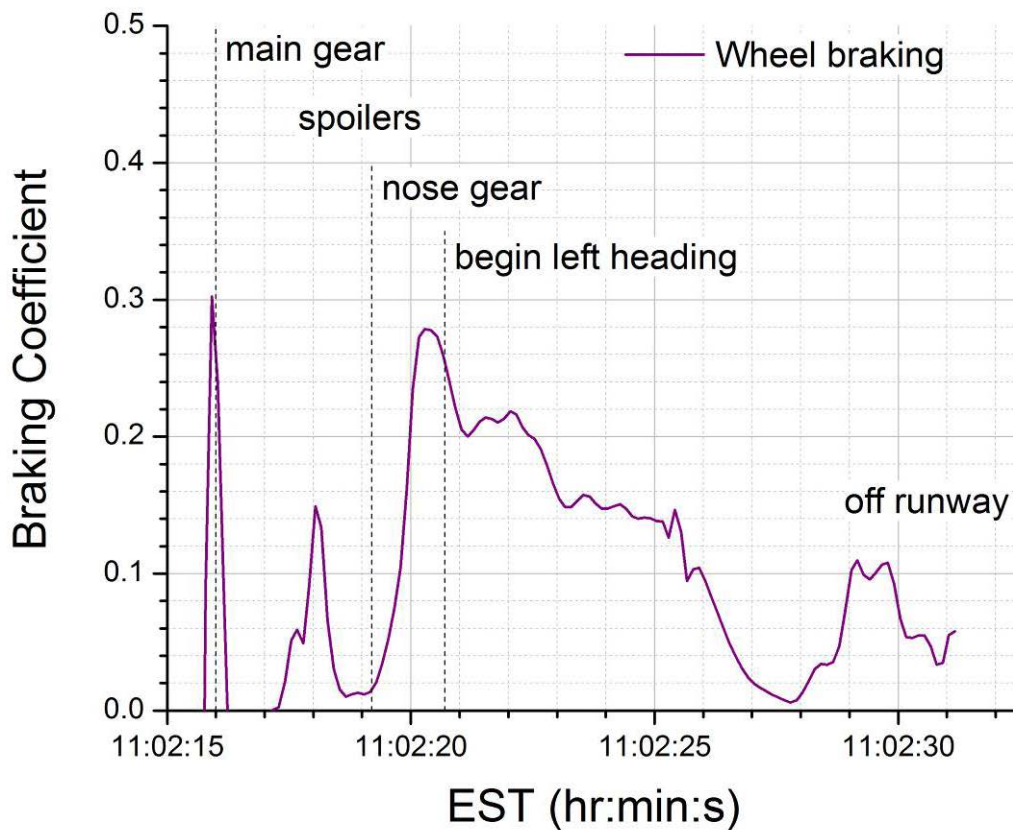
Figure 34. Plot of calculated braking coefficients for accident landing roll.

The accuracy of the ground-aircraft interaction model is dependent upon the accuracy of the engine model in reverse thrust. The maximum measured EPR value for reverse thrust for the MD-88 is 1.6. The engine model used for these results was extrapolated for EPR values above 1.6 and may not accurately reflect the physics of the event. If the engine model under-predicted reverse thrust, it would over-predict braking action and vice versa. However, since both the accident aircraft and the prior MD-88 reach EPR values in excess of 1.6, the model should over or under-predict for both in a similar way. Therefore, it appears that the accident aircraft had similar or slightly improved braking action on the initial portion of the runway when compared to the prior MD-88.

It is possible that the left yawing moment was imparted by the left main gear passing over a patch of pavement with friction that was better than average or the right main gear sliding across a portion of particularly slick runway surface. Two simulations were run with differential friction – one with the right main on ice and the left main and nose gear on wet, and another with the right main and nose on ice and the left main on wet. Both situations caused the simulated aircraft to deviate to the left, but these models could not follow the track of the accident while still maintaining the recorded deceleration.

An accurate simulation of the accident would require validated models and accurate recorded input data. The recorded EPR values in reverse thrust are much higher than the measured test data used to model the effect of the engines, and the effect of an asymmetry at such high EPR values has not been measured. The simulation model assumes that the high EPR values in reverse thrust would blank the vertical stabilizer making it unresponsive to a crosswind in addition to rendering the rudder ineffective. The distribution of the snow or ice on the runway and the associated friction level is unknown and the antiskid behavior of the left and right landing gear was not recorded.

Nose Wheel Steering

As discussed earlier, the accident aircraft's heading on approach matched that of the prior MD-88 and an earlier A319, but upon nose gear touchdown stayed 2° further left than the other two aircraft which aligned along 134°. It was unclear if this difference was due to an error in the magnetic heading recording on the accident aircraft or if the aircraft was indeed nose left even after nose gear touchdown. After the aircraft left the runway, it sustained substantial damage to the nose gear as it traveled off the runway and impacted the sea wall on the edge of Flushing Bay. Additionally, the nose gear was removed from the aircraft to allow its transport from its final resting spot to a hangar at LGA. Post-accident testing of the nose gear steering confirmed that the steering manifold was functional, but determining if the nose gear was otherwise damaged before the accident was not possible.

As noted previously in Figure 26, there was an arrest of the left yaw rate during the landing roll with the right rudder and the right nose wheel steering were applied, but before any differential braking was applied (autobrakes were still active). The rudder would have been considered ineffective because of the high EPR in reverse thrust at the time. The arrest of the yaw rate at that time suggests that the nose wheel was reacting to the rudder pedal input as expected and providing a counteracting yawing moment. It seemed unlikely that the nose wheel steering contributed to the initial left yaw.

Exceedance of EPR Limits on Other Landings

The data written to the FDR was also saved to a quick access recorder (QAR) onboard. The QAR recorded data from 61 previous flights, from February 20th, 2015 until the accident flight on March 5th, 2015. The MD-88 that landed just before the accident aircraft was similarly equipped with a QAR that was provided to the NTSB. The prior aircraft QAR recorded ten flights prior to the LGA landing and nine flights after (from March 2nd through March 7th, 2015) for a total of 19 flights. Each landing was examined (see exemplar landing in Figure 35) and the following data was noted:

Table 3. Parameters recorded for each recorded landing.

Maximum left EPR	Time left EPR >1.6 (s)	Time left EPR >1.3 (s)
Maximum right EPR	Time right EPR >1.6 (s)	Time right EPR >1.3 (s)
Time from TD to left 1.3 (s)	Time from TD to left 1.6 (s)	Time from TD to right 1.3 (s)
Time from TD to right 1.6 (s)	Left/right split at max EPRs	Speed at touchdown (kts)
Speed touchdown + 20 s (kts)	Maximum rudder (deg)	Average heading (deg)
Heading variation (deg)		
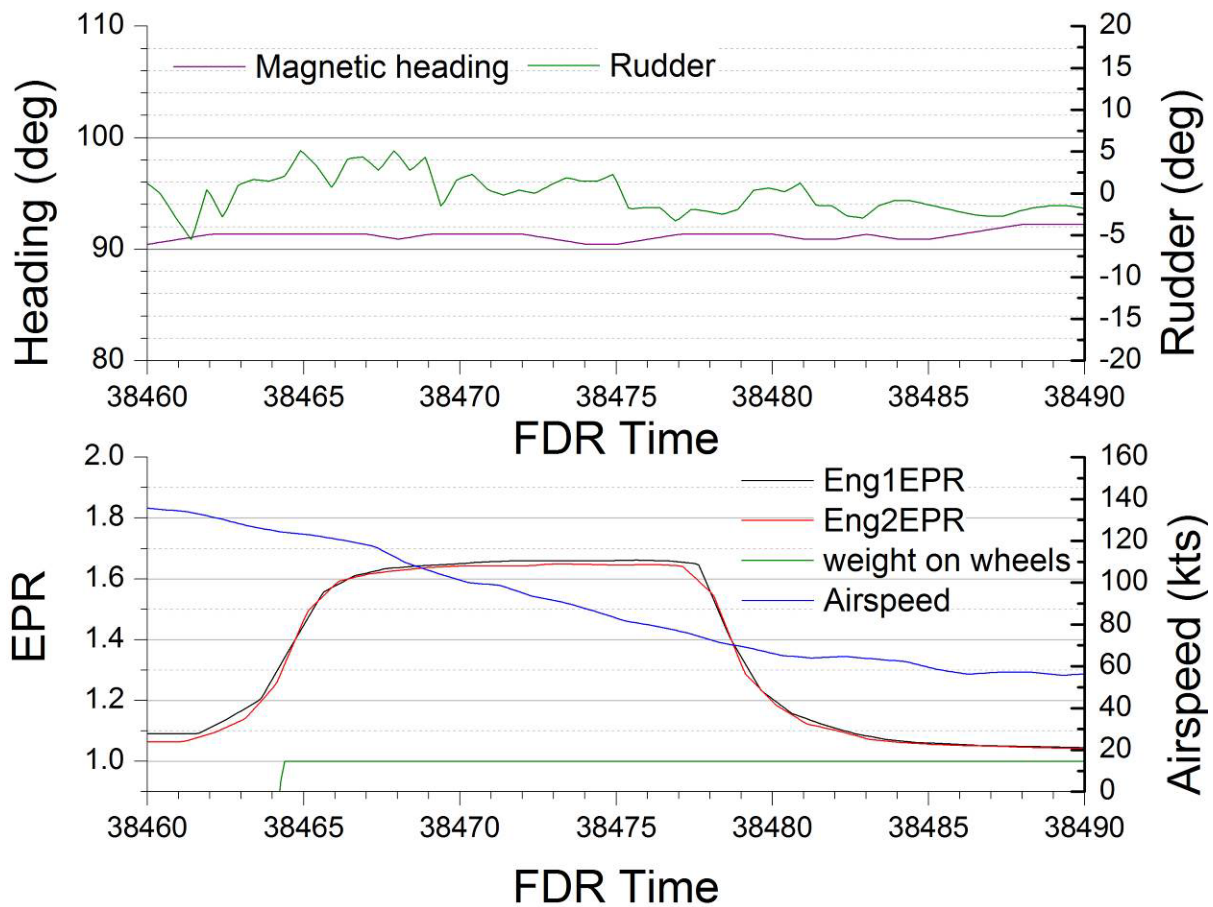
Figure 35. Heading, rudder, EPR, airspeed, and nose gear weight on wheels for an exemplar prior landing of the accident aircraft at ATL on February 21st, 2015.

The landing data was cross referenced with the flight history for the aircraft provided by the Operations group. Using the heading data, the flight was confirmed to have landed at the airport specified by the flight history. The specific runway could not be determined for many of the landings because some airports have multiple parallel runways of differing lengths (such as Atlanta and Dallas-Fort Worth). However, for 34 of the landings the runway length was able to be determined. The recorded time and location from the flight history was then used to reference archived METAR data to determine the recorded weather at the time of landing. The wind data was broken into a headwind and cross wind component using each landing's average heading value. The eight weather parameters recorded for each flight are shown in Table 4.

Table 4. Weather parameters recorded for each prior landing of the accident aircraft.

Temperature (°C)	Pressure (inHg)	Wind (kts)	Wind direction (deg)
Gusts (kts)	Crosswind (calculated)	Head wind (calculated)	Precipitation

Two of the landings of the accident aircraft had unreliable data recorded and are not included in this analysis. The 80 resulting landings were analyzed to look for trends in the magnitude of reverse EPR, the magnitude of rudder applied, variations in heading during the landing roll, and the weather. Nine of the other landings had recorded precipitation, one of them being snow. Figure 36 shows the left and right maximum EPR for each of the previous landings and the accident landing. Twenty-five of the 60 landings by the accident airplane had EPRs for both engines above 1.6 (includes the accident landing). Of the ten landings in precipitation, all of them had maximum EPRs over 1.3, and five had maximum EPRs above 1.6 for at least one engine (includes the accident landing).

For the other MD-88 airplane, only 2 of the 20 landings had both engines above 1.6 EPR, but 8 had the left engine above 1.6 and 1 had the right engine only beyond 1.6 EPR. Three of these landings occurred after the LGA landing of interest.

The left engine tended to have a higher maximum EPR than the right engine (points below the diagonal blue line in Figure 36 have a higher left EPR). For the accident aircraft, 50 of the 60 landings have higher left engine EPR values than right. For the prior MD-88, 19 of the 20 landings have higher left engine EPR values. The accident landing had the highest right and left EPR value of all the recorded landings examined.
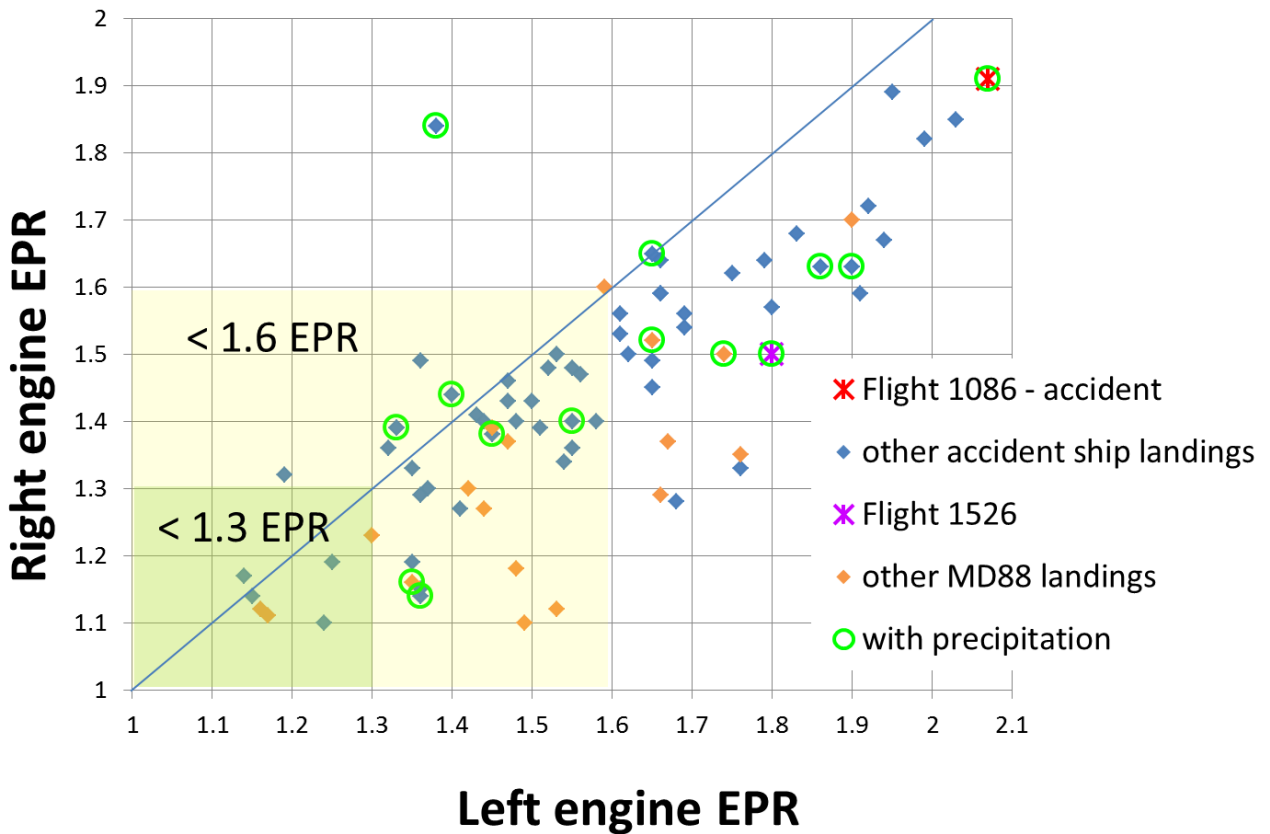
Figure 36. Left and right EPR for 59 previous landings of the accident ship (blue diamonds), the accident landing (red star), Flight 1526 (purple star), and 20 other MD-88 landings (orange diamonds). Landings with precipitation are overlayed with a green circle.

Throughout the investigation it was discussed that crews advance the throttles and then pull them back to rebalance the thrust reverse EPR to the desired level. Figure 37 shows the time spent above 1.6 EPR. Half of the landings where 1.6 EPR was exceeded spent more than 4 seconds above 1.6. The aircraft during the accident did not spend more time at the higher EPR values compared to the other landings. However, the accident aircraft's EPR did rise faster than the other flights. For the 25 flights of the accident aircraft where 1.6 EPR was exceeded, the time between the left engine reaching 1.3 and 1.6 EPR was recorded. Not including the accident flight, the average time from 1.3 to 1.6 EPR was 1.25 seconds and the shortest time between those points was 0.9 seconds. During the accident landing, the EPR in thrust reverse increased from 1.3 to 1.6 in 0.5 seconds.
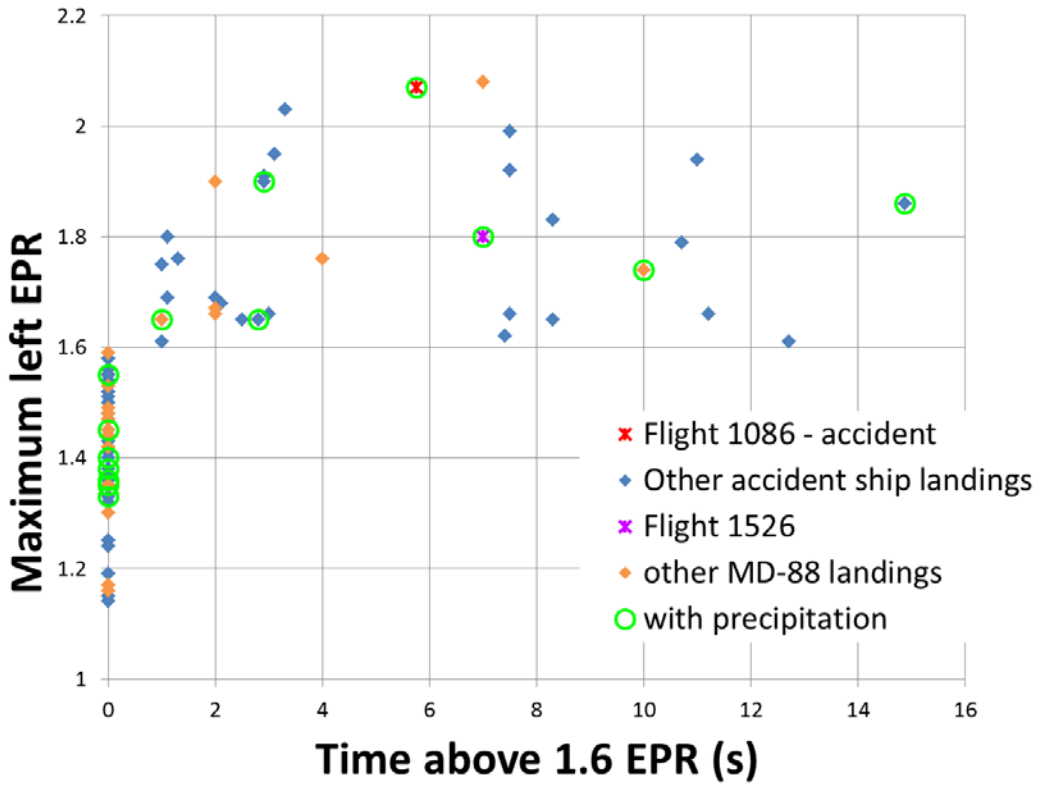
Figure 37. Maximum left EPR and the time spent above 1.6 EPR. The collection of points on time=0 are for EPRs that did not exceed 1.6.

Figure 38 is the maximum left engine EPR versus the crosswinds at landing. Thirty-seven of the 80 landings had crosswinds above 5 kts and nine of those had greater than a 10 kts crosswind. The accident flight and prior MD-88's crosswind components were between 9 and 10 kts. While not an extreme outlier, the accident landing was in the upper quartile for both EPR magnitude and crosswind.
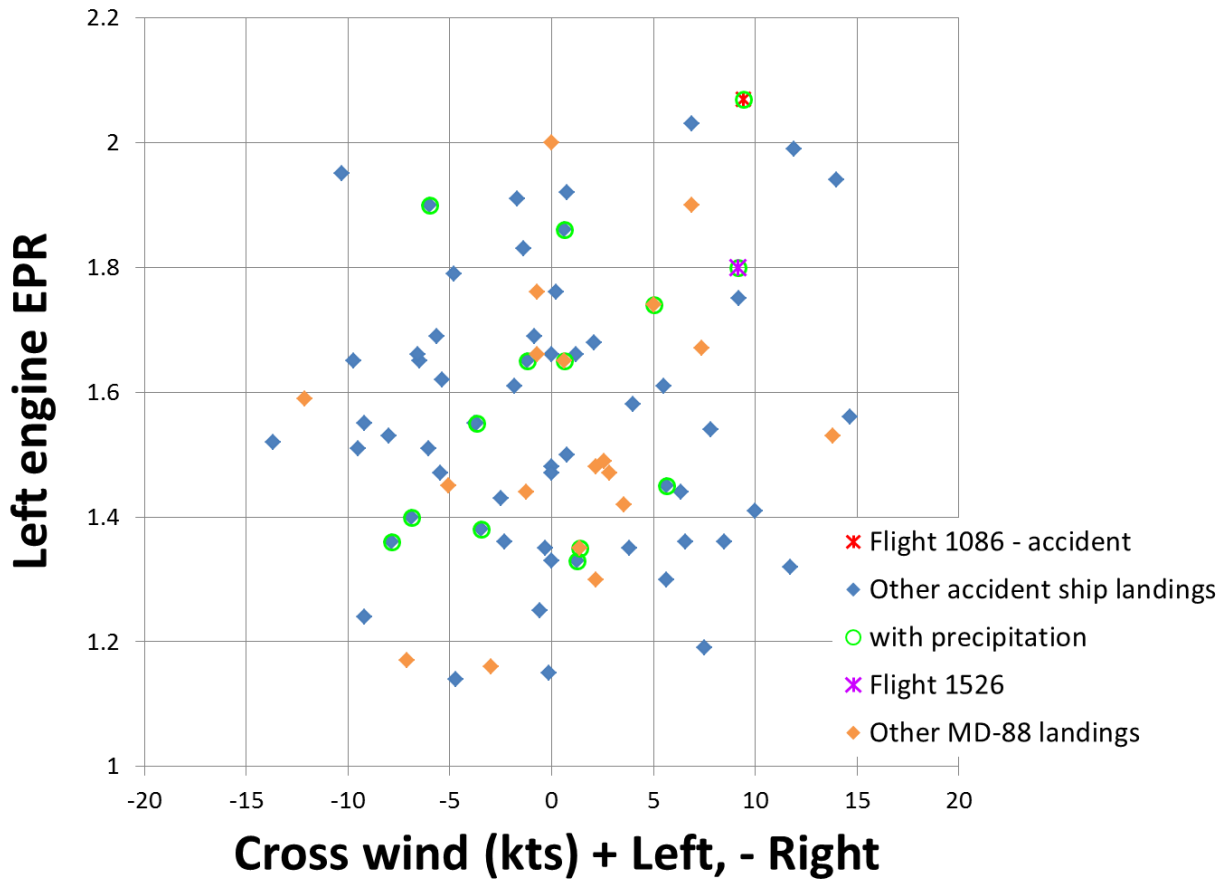
Figure 38. Maximum left EPR versus the crosswind at landing.

All but three of the prior landings had heading variations of less than ±2º in total and generally held the runway heading well. The three outliers were within ±3º of the runway heading. Figure 39 and Figure 40 show the maximum rudder applied during the landing roll versus crosswinds and the EPR split respectively. Figure 39 shows that while landings were equally likely to have a right or left crosswind, 62 of the 80 landings put in more right rudder than left. In Figure 40, the greatest number of points is in the quadrant for higher left engine EPR and counteracting right rudder, though there is little relationship between the magnitudes of the EPR split to the rudder response.

Figure 39. Maximum rudder versus cross wind.

Figure 40. Maximum rudder versus EPR split.

The other landings were also analyzed to try to determine what may influence a crew to input a high thrust reverse EPR. The touchdown airspeed had little effect on the maximum EPR value (see Figure 41). The accident touchdown speed (133 kts) was higher than the mean of all 80 landings (~123 kts), but not the fastest. Figure 42 shows the 34 landings for which the runway length was able to be determined. The length of the available runway does not seem to have a strong effect on the maximum EPR value. Ambient air temperature (not shown) and precipitation (noted for Figure 36 through Figure 42) showed no strong correlation with maximum EPR.
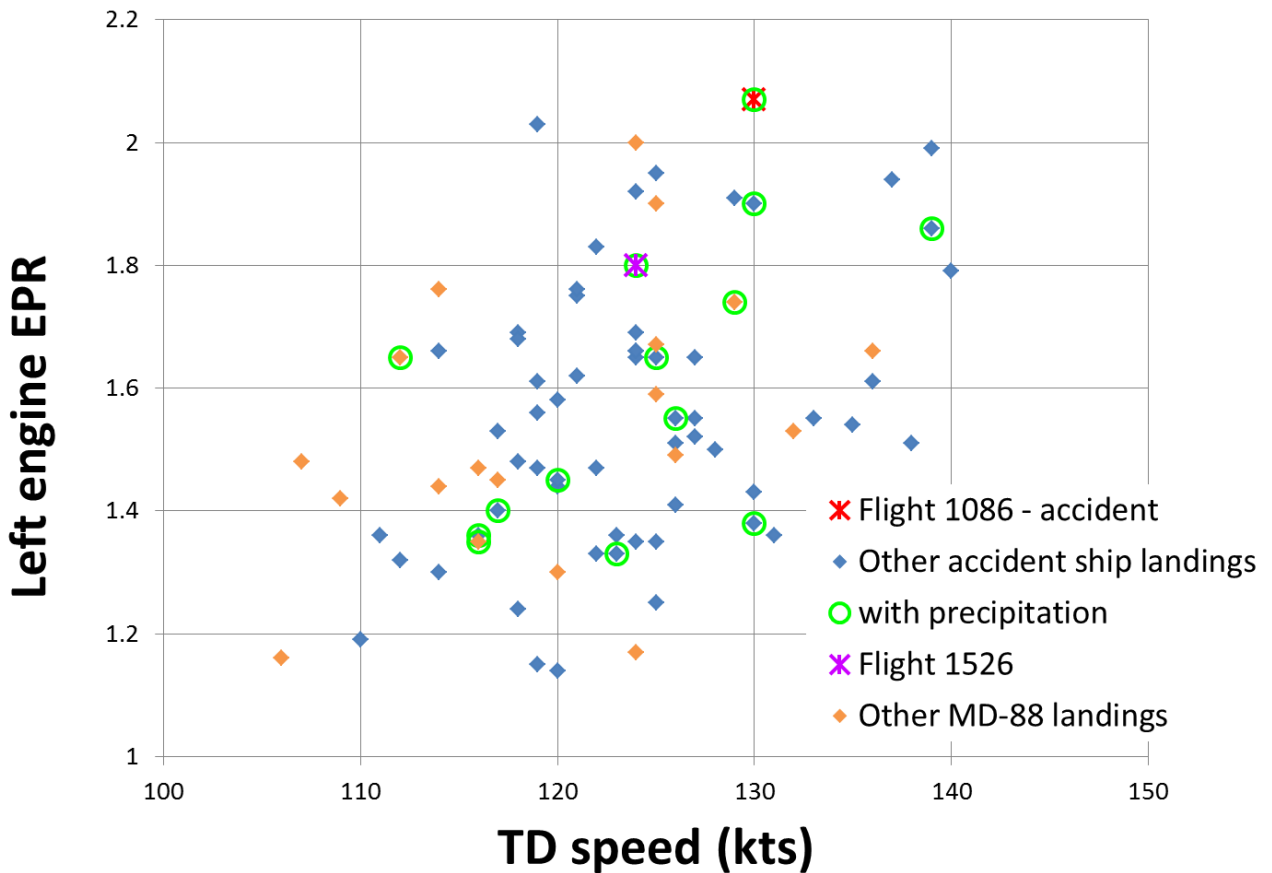
Figure 41. Maximum left EPR versus touchdown speed.
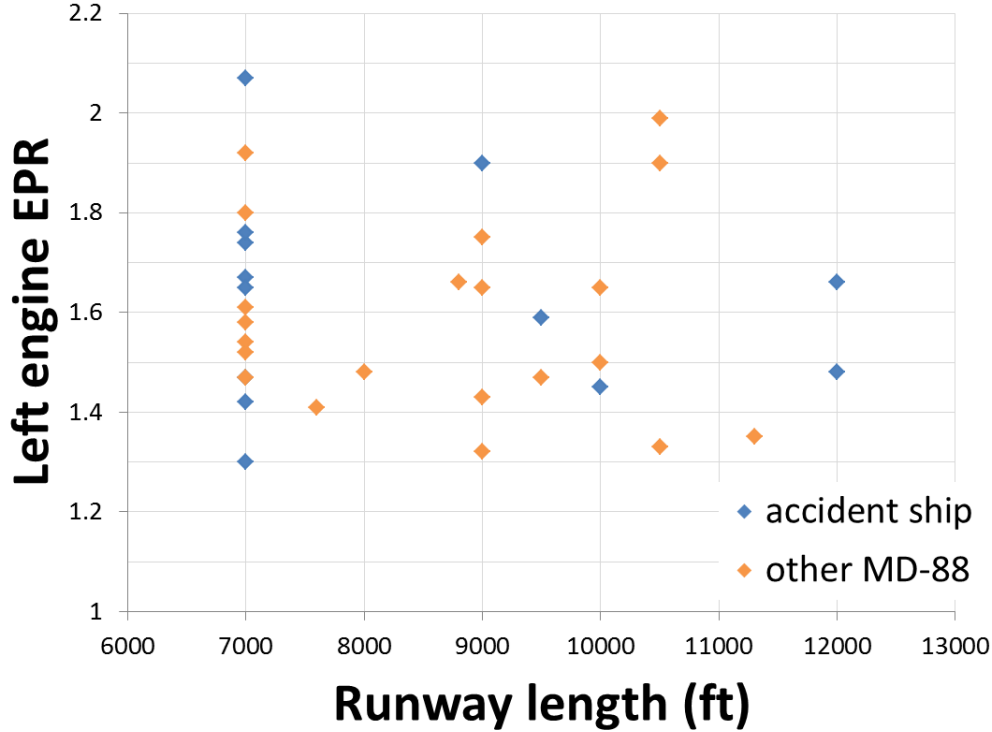
Figure 42. Maximum left EPR versus runway length.

In conclusion, most of the earlier landings of the accident aircraft exceeded the 1.3 and 1.6 EPR thresholds with no discernable detriment to landing performance. Eight other landings had crosswinds from the left greater than or equal to the accident landing, though none with precipitation. The EPR magnitude did not show evidence of being dependent on weather at the time of landing, length of available runway, or touchdown speed. The accident landing thrust reverse application exceeded the other landings in EPR magnitude and the rate of change between 1.3 and 1.6 EPR.

E. CONCLUSIONS

The aircraft was on the appropriate glide slope and heading on approach into LGA. It touched down at 133 kts, consistent with a V_{ref} of 131 kts (+ 5 kts). The aircraft's main gear touched down 600 ft from the runway threshold and nose gear touched down at 1200 ft. Braking devices all deployed in the time between main gear and nose gear touchdown. The aircraft began to experience a left yawing moment about 1600 ft down the runway. The crew applied right rudder, but the aircraft's heading followed the left yaw and the aircraft exited the left side of runway 13 about 3200 ft from the runway threshold.

Boeing released guidance that operators should limit reverse thrust EPR to less than 1.6 during normal landings and less than 1.3 EPR when landing in adverse conditions [5]. This guidance was based on test data that showed that the rudder has limited directional authority for aircraft reverse thrust EPR values above 1.6 and airspeeds below 146 kts, and similarly has limited directional authority for aircraft reverse thrust EPR values above 1.3 and airspeeds below 108 kts [4]. The engine pressure ratios for the engines in reverse thrust exceeded 2.0 for the left engine and 1.9 for the right engine, and the EPR levels exceeded 1.6 for approximately five seconds. The high EPR values had the effect of blanking the rudder during the aircraft's left heading deviation and rendered rudder input ineffective. Once the thrust reversers were stowed and rudder authority was restored, application of left rudder (in conjunction with nose wheel steering and differential braking) was effective in arresting the increase in the left yaw rate. While the rudder was blanked, nose wheel steering input from the rudder pedal likely contributed to slowing the aircraft's yaw rate, but was not sufficient to redirect the airplane until used in conjunction with effective rudder. Differential right manual braking also contributed to controlling the aircraft's heading, but was also applied after the thrust reversers were stowed (4.5 seconds after the initial yaw rate increase).

On the day of the accident, New York was experiencing a winter storm. On landing the aircraft was subject to a 10 kts crosswind from the left and the runway was contaminated with snow. However, the wheel braking coefficients for the accident aircraft and the previous MD-88 were determined to be about 0.16 (which would be considered medium according to Advisory Circular 25-32) or better.

The circumstances at the time of the heading deviation are considered outside the envelope of valid test data for the airplane, so there is substantial uncertainty in evaluating the relative contributions of the different systems or environmental factors. The possible forces that may have precipitated the heading deviation include a yawing moment imparted by asymmetric reverse thrust, a sudden increased crosswind, or differential runway friction. The data was incomplete or the effects of these forces on the aircraft were not measured and/or accurately modeled for the exact contribution of each to be determined. What data was available did not make any single event or environmental factor seem likely on its own to be able to impart the yawing moment experienced by the accident aircraft. It is likely that a combination of asymmetric thrust, crosswind, and runway friction caused the aircraft to deviate from the runway heading.

Analysis of 78 other landings of the accident ship and the prior MD-88 aircraft showed that EPR values in excess of 1.6 were common even when landing in reported precipitation or with a crosswind. None of the other 78 landings showed a significant deviation in heading. Additionally, rudder input direction was more strongly correlated with EPR split direction than crosswind direction. However, of the all the landings examined the accident landing had the highest recorded EPR values and the shortest time between main gear touch down and exceeding 1.6 EPR.

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Marie Moler
Specialist – Airplane Performance
National Transportation Safety Board

F. REFERENCES

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2. Meteorology Factual Report, National Transportation Safety Board

3. Cockpit Voice Recorder Factual Report, National Transportation Safety Board

4. 'Substantiation of Model DC-9-80 Runway Directional Control During Reverse-Thrust Operation' Report number MDC-J9005, McDonnell Douglas Corporation, Issued 13 August 1980, Updated 20 June 1984.

5. Boeing Flight Operations Bulletin, MD-80-02-03. Reverse Thrust EPR Control. November 5, 2002.

6. FAA Advisory Circular 25-32. Landing Performance Data for Time-of-Arrival Landing Performance Assessments. 22 December 2015.

G. APPENDIX

Table G-1. Aircraft recorded magnetic heading on landing roll versus runway magnetic heading for prior MD-88 and accident aircraft at 19 different airports.

	Airport	Runway heading reported in	Runway magnetic heading (deg)	Recorded airplane magnetic heading (deg)	difference
Accident aircraft landings	AGS	1990	352	351	1
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	ATL	2015	95	92	3
	ATL	2015	95	91	4
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	ATL	2015	275	272	3
	ATL	2015	275	271	4
	ATL	2015	275	271	4
	CHS	2010	334	332	2
	CVG	1995	4	2	2
	DAB	2000	70	66	4
	DAY	1990	59	58	1
	DAY	1990	239	238	1
	DFW	2015	356	353	3
	JFK	2000	315	312	3
	JFK	2000	225	222	3
	JFK	2000	225	222	3
	JFK	2000	225	223	2
	MCO	2015	185	182	3
	MCO	2015	185	182	3
	MCO	2015	5	2	3
	MCO	2015	5	1	4
	MCO	2015	185	181	4
	NAS	2010	143	139	4
	PBI	2010	99	96	3
	PIT	1995	280	278	2
	SYR	2000	280	278	2

	TPA	1995	7	3	4
	LGA	1980	224	224	0
	LGA	1980	314	314	0
	LGA	1980	44	44	0
	LGA	1980	224	224	0
	LGA	1980	224	224	0
accident	**LGA**	**1980**	**134**	**132**	**2**
Prior aircraft landings	LGA	1980	224	224	0
	LGA	1980	224	224	0
	LGA	1980	224	224	0
	LGA	1980	224	224	0
	LGA	1980	224	224	0
	LGA	1980	224	224	0
	MEM	2000	358	356	2
	ATL	2015	95	91	4
	ATL	2015	275	270	5
	ATL	2015	275	270	5
	PBI	2010	99	96	3
	RSW	2000	58	54	4
	RSW	2000	58	55	3
	SRQ	2010	139	136	3